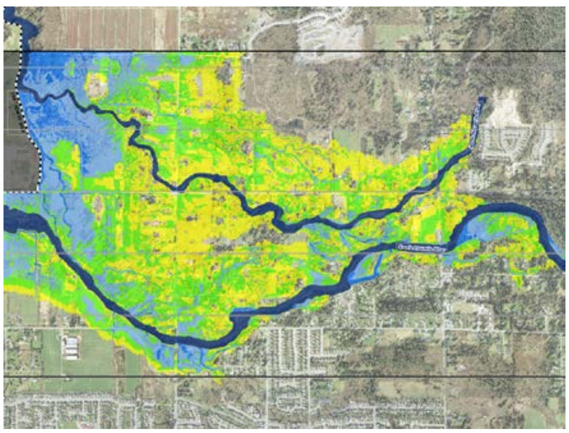
NORTH ALOUETTE AND SOUTH ALOUETTE RIVERS ADDITIONAL FLOODPLAIN ANALYSIS (FILE NO. 11_5255-20-60)

PHASE 2 – TECHNICAL INVESTIGATIONS COMPLETION
FINAL REPORT



MAPLE RIDGE
British Columbia

City of Maple Ridge, British Columbia

24 February 2016

NHC Ref. No. 300349

nhc
northwest hydraulic consultants
water resource specialists

NORTH ALOUETTE AND SOUTH ALOUETTE RIVERS
ADDITIONAL FLOODPLAIN ANALYSIS
PHASE 2 – TECHNICAL INVESTIGATIONS COMPLETION

FINAL REPORT

Prepared for:

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24 February 2016

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CREDITS AND ACKNOWLEDGEMENTS

The NHC team would like to thank the City of Maple Ridge for initiating this study, making available extensive background information and providing advice and support throughout the study. Key City representatives were:

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EXECUTIVE SUMMARY

In January 2010, the City of Maple Ridge (the City) retained Northwest Hydraulic Consultants (NHC) to complete a hydraulic assessment and prepare floodplain maps for the North and South Alouette Rivers. This assessment focussed on the floodplain area bounded by Park Lane, 236th Street, 127th Avenue and 136th Avenue (Figure 1).

Flooding along the Alouette Rivers has become a source of increasing concern for Maple Ridge residents in recent years. In 2007, extensive flooding prompted the creation of a multi-stakeholder task force. Its objectives were to identify and compile information on flood issues and to develop a strategy to manage/reduce the flood risk along the North Alouette and South Alouette Rivers.

In order to complete a comprehensive plan that can guide future flood management actions and adapt to community needs, the City of Maple Ridge has adopted a phased project which allows for the adjustment of project goals and objectives as findings are summarised and tools are developed. The project is to be completed in three phases:

Phase 1 – Data Review and Scoping: Review of flood hazard problems and available information. Scoping of technical investigations. (Report issued in January 2011.)

Phase 2 – Technical Investigations Completion: Geomorphic assessments, climate and hydrologic analyses, hydraulic modelling of rivers and floodplain, and hazard mapping. (Described in this report, January 2016.)

Phase 3 - Results Assessment and Reporting: Assessment of modelling results for the development of flood management strategies and flood damage mitigation options. (Completion of additional tasks recommended in this report.)

Channel cross-section surveys completed in 2014, high-quality LiDAR data also from 2014, and the collection of calibration data during the winter of 2014-2015, allowed for development of a sophisticated 2-dimensional MIKEFlood numerical model. The hydraulic model was used for simulating the flood levels corresponding to the 2, 5, 10, 25, 50, 100 and 200-year events and the subsequent generation of flood extent and flood hazard mapping for these flows. The updated and improved mapping, based on current topographic information, recent flow estimates and much improved hydraulic modelling methods, is more accurate than the 1990 floodplain maps and should replace these.

This report presents the updated 200-year floodplain maps for the North and South Alouette River study reaches and describes their development. The 200-year flood limit includes 0.6 m of freeboard and determines the updated flood construction levels (FCLs). Also included are the 25-year flood levels, with 0.6 m freeboard. Flood estimates incorporate a 10% increase in flows on all unregulated basins for projected climate change impacts to year 2100. Downstream boundary conditions were set to a large winter flow on the Fraser River, which includes an allowance for sea level rise.

The City's investment in floodplain mapping products is of significant value and facilitates: 1) the identification of present flood hazards; 2) evaluation of any planned future changes in the floodplain/river channels; and, 3) development of flood management tools. It is recommended that the City adopts the revised floodplain maps.

Recommendations for future tasks to be completed under Phase 3 include:

- Development of flood bylaws.
- Development of an early warning system for severe flooding.
- Development of an emergency preparedness plan.
- Development of a flood recovery program.
- Completion of a vulnerability assessment to identify high risk areas.
- Development and assessment of different flood mitigation options.

The report also includes recommendations for maintaining and updating the hydraulic model and mapping over time.

Section 9 provides a study summary, conclusions and a description of long term benefits of the project. Specific recommendations are available in Section 10.

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1 INTRODUCTION

1.1 Background

The City of Maple Ridge (City) retained Northwest Hydraulic Consultants (NHC) in January 2010 to complete a hydraulic assessment and prepare floodplain maps for the North and South Alouette Rivers. This assessment focussed on the floodplain area bounded by Park Lane, 236th Street, 127th Avenue and 136th Avenue (Figure 1). Current land use within the floodplain is shown in Figure 2.

Flooding along the Alouette Rivers has become a source of increasing concern for Maple Ridge residents in recent years. In 2007, extensive flooding prompted the creation of a multi-stakeholder task force. This task force included representatives from the municipality, relevant provincial and federal agencies, universities and the community at large. Its objectives were to identify and compile information on flood issues and to develop a strategy to manage / reduce the flood risk along the North Alouette and South Alouette Rivers.

In order to complete a comprehensive plan that could guide future flood management actions and adapt to community needs, the City of Maple Ridge has adopted a phased project approach recommended by NHC. This approach allows for the adjustment of project goals and objectives as findings are summarised and tools are developed. The project is to be completed in three phases:

Phase 1 – Data Review and Scoping: Review of flood hazard problems and available information. Scoping of technical investigations. (Report issued in January 2011.)

Phase 2 – Technical Investigations Completion: Geomorphic assessments, climate and hydrologic analyses, hydraulic modelling of rivers and floodplain, and flood events and hazard mapping. (This report, issued January 2016.)

Phase 3 - Results Assessment and Reporting: Assessment of modelling results for the development of flood management strategies and flood damage mitigation options.

Phase 1 provided a summary of the geomorphology, climate and hydrology of the Alouette Rivers. For completion, some of this material is included here. The geomorphology and the climate information has not been updated. However, some of the hydrology has been reviewed to reflect recent trends.

1.1.1 Initial Phase 2 Work in 2011

An initial version of the Phase 2 – Technical Investigations Report and Executive Summary were submitted to the City of Maple Ridge in June 2011.

As part of the technical investigations in the initial Phase 2 work, a hydraulic model was developed for the North and South Alouette rivers (1D flow) and floodplain (2D flow). The modelling was undertaken to simulate a range of flood flows up to the 200-year design flood and to develop corresponding inundation mapping for the rivers. Geometric data input to the model included river cross-sections surveyed by BC Hydro and partial Digital Elevation Model (DEM) data of the floodplain.

The BC Hydro river surveys, completed in 2008, were collected to carry out dam breach modelling for the Alouette Dam as part of a broader safety review of dams in BC. For consistency with the BC Hydro study, the same river cross-sections surveyed by BC Hydro were initially provided to NHC for flood modelling. However, dam breach modelling is significantly different from flood modelling in that extreme flow volumes are simulated and water levels are assessed to a lesser degree of accuracy.

The resulting initial Phase 2 model was useful for general demonstration of flood hazards and assessing impacts of major floodplain alterations, which were summarised in the 2011 Executive Summary. However, due to the simplified portrayal of the river channels, the model accuracy was low and the model was not considered suitable for establishing Flood Construction Levels (FCLs) or detailed inundation mapping.

The initial Phase 2 modelling was also limited by a lack of suitable calibration data. Ideally, a hydraulic model should be calibrated to the highest possible historic flood if 200-year flood simulations are to be performed. Both flow measurements and surveyed high water marks are needed for the calibration event. Although both rivers have Water Survey Canada (WSC) hydrometric gauges, the gauges often fail during peak flows and observed high water marks are limited.

1.1.2 Finalization of Phase 2 in 2015

On 31 May 2013, the City of Maple Ridge and NHC met to discuss the status of work completed to date, what would be required to complete Phase 2 and finalize the study and how the City could best move forward with flood management of the rivers. As a result of the meeting discussions, NHC recommended a new scope of work to enhance and expand on findings from the initial project work.

It was agreed that NHC would resurvey the channels in more detail and at a reduced spacing. The new (2014) survey focused on the previously defined project area (roughly 5 km long reaches of both rivers) and was carefully laid out to capture the constricted channel locations that have the greatest impact on water surface profiles. In addition, the City collected up-to-date LiDAR data for the entire floodplain to be modeled.

A program was also initiated allowing for the collection of more calibration data over the winter of 2014 - 2015. This program monitored peak flows, quickly mobilizing a field crew during high floods to measure flows and map high water levels. The data collected from this program has been used to recalibrate and validate the Phase 2 model.

This report summarizes the finalized results of Phase 2 – Technical investigations Completion, including the updated hydraulic model, flood profiles and inundation mapping.

1.2 Terminology

To distinguish clearly between the two Alouette Rivers, the Alouette River is referred to as the South Alouette River in this report; the North Alouette River keeps its official name.

1.3 Scope of Work

As per the City of Maple Ridge terms of reference, the scope of services for the Phase 2 Completion Work comprised:

- Review of past work and new data available,
- Collection of calibration data,
- New survey of channel cross-sections,
- Update of existing MIKEFlood model,
- Floodplain mapping, and
- Enhancement and reissue of the Phase 2 report.

1.4 Report Organization

In addition to the introduction, background information and scope of work included in Section 1, Section 2 provides a review of the North and South Alouette River geomorphology. The climate and hydrology of the system are included in Sections 3 and 4, respectively. Calibration data collection is outlined in Section 5, the channel surveys in Section 6 and the hydraulic modelling of the system is discussed in Section 7. Section 8 summarizes the floodplain mapping for the study area, followed by summary and conclusions in Section 9 and recommendations in Section 10.

2 GEOMORPHOLOGY

The geomorphic setting and a summary of the fluvial geomorphology of both the North and South Alouette Rivers was presented in the Phase 1 reporting. This section summarizes previous analyses completed to meet the evaluation objective:

> *Assess if morphology of rivers has changed over time. If so, examine the impact of these changes on the flood hazard.*

Given the above objective, historical changes to the rivers' morphology was examined by looking at historical air photos and mapping (planform changes), and by looking at changes to bed levels (section changes). Changes to the land use of the surrounding watersheds were also reviewed. The results of these analyses are presented below. It should be noted that the Section 2 geomorphic assessment was completed during initial Phase 2 work in 2011 and has not been updated to include the cross sections collected by NHC in 2014.

2.1 Historical Planform Changes

Available air photographs were scaled and rectified using geo-referencing tools. Subsequently, bank lines for all the years of photography were digitized based on the edge of vegetation. Overlaying these layers in GIS allowed for the evaluation of planform changes over time.

On the North Alouette River system, there has been significant channel change, particularly between the 232nd St. Bridge and the 132nd Ave. Bridge (Figure 3). Although anecdotal evidence suggests greater recent in-channel deposition observed through the growth and expansion of bar features, these sediment accumulations are transient and are likely to be mobilized in the next high flow event. A possible exception occurs near the constriction in the North Alouette channel downstream of the 224th St Bridge: sediment accumulating upstream of the bridge may be slower to flush downstream. Bedform changes are now expected at the 232nd Street bridge crossing as a new single span bridge was constructed in 2013. As the bridge clearance was increased and the old piers were removed, conveyance at this location has been substantially increased, lowering water levels for some distance upstream of the bridge.

Since 1959, the South Alouette River channel has experienced some lateral migration, mainly at meander bends. At the large bend at Maple Ridge Park, field observations verify that significant erosion of wide sections along the right (north) bank has occurred. Conversely, point bar features along inner banks of the South Alouette – one at the first large bend downstream of 232nd St and another, immediately upstream of the 224th St Bridge – became increasingly vegetated and established between 1959 and 1974.

2.1.1 Impacts of Planform Changes

In general, a meandering planform involves channel shifting through erosion on the outside of bends and deposition on the inside. Bank retreat as a result of this erosion has been observed both on the North and South Alouette River systems. The property on the north bank of the North Alouette just upstream of the 224th St Bridge is affected by this process. On the South Alouette, this has been occurring on the north bank along Maple Ridge Park.

Land loss is balanced by the development of bar forms along the opposite bank. The in-channel deposition has been a concern locally on the North Alouette River system. The aggradation of the channel bed - even if temporary - can contribute to higher water levels, and increase the severity of flooding during high flow events.

In contrast, the establishment of vegetation on point bars on the South Alouette River suggests that the channel bed has become more stable presumably because of reduced sediment input from upstream related to river regulation by BC Hydro's Alouette Dam.

2.2 Historical Cross-Sections

The Province surveyed 68 sections of the North Alouette and South Alouette Rivers in 1981, which were used in the 1991 floodplain mapping study. Horizontal positions for 1981 cross-sections were recorded to a less precise local datum. In 2008, BC Hydro conducted extensive surveys of both rivers as part of their Alouette Dam Flood Simulation and Mapping project; 109 sections were surveyed from the dam to the mouth of the rivers to geodetic datum. Figure 4 shows the locations of the 1981 and 2008 cross-sections in the study area.

There were limitations to the precise quantitative analysis of cross-sections. As sections were surveyed at different locations in 1981 and in 2008, direct comparison of cross-sections was limited. Although cross-sections at bridge locations were consistently surveyed, bridge replacements in the intervening period may have altered some sections. For instance, the 132nd Ave. Bridge across the North Alouette River was replaced in 1995 and the 232nd Street bridge was replaced in 2013. On the South Alouette River, the 232nd St. Bridge was built in 2004 and the 224th St. Bridge in 1995. At two locations on the South Alouette, cross-sections that do not lie at bridge crossings were surveyed at the identical locations but with different orientations across the channel, complicating direct comparison.

2.2.1 Cross-Section Analysis

Figure 5 and Figure 6 show historical comparison of cross-sections collected on the North and South Alouette Rivers respectively.

The North Alouette River shows greater change within cross-sections than the South Alouette River. The river has the potential to move large quantities of relatively unconsolidated, glaciofluvial till, which forms the region’s surficial geology, because of the erodibility of the material and the gradient of the channel headwaters. This sediment is carried downstream and deposited on the floodplain; it is typically re-mobilized in subsequent high flow events. As a result, channel geometry varies as sediment is deposited and later transported further downstream. At both the 224th St. and the 132nd Ave. bridges across the North Alouette, the cross-sections clearly show that the river bed has aggraded between 1981 and 2008, with deposition on the order of 1 m. The reach between 232nd St and 224th St is expected to be a depositional one owing to its low gradient, although the new 2013 232nd Street bridge should greatly increase conveyance. The amount of deposition is primarily influenced by the availability of sediment from upstream. Sediment accumulated along the right bank at the 224th St crossing may have been removed by dredging (August 6, 1997) thereby explaining the retreated right bank profile in 2008.

In comparison to the North Alouette, cross-sections on the larger South Alouette River (Figure 6) show less variation in bed topography. There is a slight lowering of the channel bed at cross-sections in the upper reach, particularly upstream of the 232nd St Bridge; the two lower reach cross-sections exhibit some deposition, mainly at the thalweg. This is expected as there is a marked change in channel gradient from 0.7% to 0.3%, and consequently, in stream energy, between the two reaches.

2.2.2 Specific Gauge Analysis

A specific gauge analysis was conducted for the two Water Survey Canada (WSC) hydrometric gauges available in the study area; one on each of the North and South Alouette Rivers. Specific gauge analyses are conducted by looking at measured flows and water levels at the gauge site to check for trends over time. Over 600 records of site visits by WSC were examined and compiled to complete this analysis. On the North Alouette River over 450 records from 1911 through 2003 were examined; only 7 records are available for the period from 1911 to 1959. Fewer records are available from the South Alouette gauge, 180 plus records were examined starting in 1977. The records were grouped by discharge, and water levels over time were plotted.

Results of specific gauge analyses carried out on the two WSC gauges show some trends in water levels over time. At WSC gauge 08MH006 on the North Alouette River, water levels for a specific discharge have decreased between 1961 and 2003 (Figure 7). This implies degradation of the channel bed at the 232nd St. crossing, where the gauge is located, or in the downstream reach controlling levels at this point. The 232nd St. Bridge likely acted as a channel constriction resulting in high flow velocities scouring the bed at the gauge section, particularly at high flows. A possible secondary explanation is that high flows travelling down the steep valley slope are able to mobilize any sediment temporarily deposited at this section, transporting it downstream towards the 132nd St and 224th St bridges where aggradation has been noted. It should be noted that the newest replacement of the bridge in 2013 may have changed the rating relationship post this analysis.

The South Alouette gauge 08MH005 is located on the right bank at 232nd St. To some extent, the bridge replacement in 2004 could have affected the rating relationship. A specific gauge analysis suggests that the channel has partly aggraded as water levels have increased between 1977 and 2003 for flows less than the mean annual flow of 3.5 m^3/s (Figure 8). At flows in the mean flow range the channel is relatively stable (i.e. the trendlines are effectively flat). This suggests that outside the low-flow channel, the river is not changing significantly. However, at higher discharges, the channel may be degrading as suggested by the cross-section comparison. Unfortunately, there are too few discharge measurements taken at high flows to allow for accurate comparison. Also, the 2008 cross-section does not extend fully to the right bank to provide complete evidence. Prior to dam construction, much larger flows shaped the river channel and for the current, reduced flows, the channel is oversized. Upstream tributaries may have contributed some sediment to raising the bed locally, despite the overall reduced sediment supply past the dam.

2.2.3 Instability Summary

Both rivers are dynamic and have changed over the course of the last century; these changes are more apparent on the smaller, unregulated North Alouette system. The regulation of the South Alouette system, which decreases peak flows downstream of the dam, has altered the natural expected changes to the system. Unfortunately, the lack of consistent historic survey data and high flow discharge measurements mean that drawing conclusions regarding the overall pattern of aggradation or degradation is difficult. Bridge sites generally constrict flow and can consequently cause degradation at flood flows, which appears to be the case at the two gauge sites. Although the cross-section comparison is quite limited, there is reasonable evidence that some aggradation may be taking place in the lower North Alouette study reach.

2.3 Changes in Land Use

Changes to land use within the watershed can have a large impact on river morphology. For example, an urbanised area will generally create more runoff and stream power, which can change the river structure. Lands within the study area in the City of Maple Ridge have been converted from primarily forest to a mix of agricultural, commercial and residential land use since incorporation (Figure 2). Much of this area also lies within the Agricultural Land Reserve (ALR), and as such is protected from major changes assuming the regulatory regime remains in effect.

Historical air photos from 1959, 1974, and 1989 were reviewed to identify past changes in land use within the watershed and the resulting impacts. Additional historical imagery was available from Google Earth for the years 2004 and 2008 and provided a more comprehensive analysis of change. Figure 9 shows the historical air photo images in sequence.

- In the 1959 air photo, land has been cleared for farming and some low density residential development northeast of 224th St. and 136th Ave. intersection. Land has been cleared north of 132nd Ave., between 232nd St. and 224th St., for housing. Clearing of land in the Silver Valley area has also begun.

- The 1974 air photo shows no significant increase in land cleared since 1959. The density of residential development is increasing south of 128th Ave.

- The 1989 air photo shows significant clearing of the land between North and South Alouette Rivers, including loss of riparian vegetation along the north bank of the North Alouette and along the south bank of the South Alouette. Land has been further cleared in Silver Valley to accommodate new houses.

In the 2004 air photo, clearings in the Silver Valley area have expanded and this is accompanied by the start of construction of a new residential subdivision. A farm operation has also been built along 232nd St. between North and South Alouette Rivers. As well, there is more dense residential development south of 124th Ave. between 232nd St. and 224th St. Cranberry bogs have been created, adjacent to the North Alouette River and downstream of 224th St., through the construction of dikes (beyond the image extents on Figure 9).

The 2008 air photo shows the continued construction of houses as part of the development of a residential subdivision in Silver Valley.

2.3.1 Impacts of Land Use Changes on Hydro-Geomorphology

Large-scale land conversion from forest to medium-density residential development in the Silver Valley area has likely impacted the North Alouette river system downstream of 232nd St. to some extent.

Increased sediment availability and increased runoff are two typical effects of land development. There is a significant break in channel slope approximately 500 m upstream of the 232nd St. crossing where the river leaves the mountain valley and enters the broad, alluvial plain. Available sediment is transported down the steep hill slope, and subsequently deposited in the low-gradient channel below. Along the South Alouette River, the urbanization of land south of 124th Ave. may have resulted in somewhat increased streamflows in the tributaries due to reduced infiltration, and potentially increased sediment conveyed to the main channel from the tributaries as a result of ground disturbance and increased runoff. However, a detailed assessment of stormwater runoff was not carried out.

Tributaries to the North Alouette River have likely also been impacted. Development of the area between 224th St. and 232nd St., north of 136th Ave., has altered the natural drainage pattern and path of Cattell Brook tributary. Its flow has been directed through culverts and ditches excavated along 224th St., which appear to be inadequately sized to accommodate flow from the North Alouette River when it overtops its banks.

The hydraulics of the North Alouette system has been altered by large wetlands partially being converted to bogs to accommodate cranberry production. The related construction of dikes has reduced the floodplain water storage area available to the North Alouette River during flood periods.

3 CLIMATE

Characterization of the climate of the North and South Alouette watersheds plays an important role in the development of flood mapping and flood management plans. Maple Ridge, in the lower reaches of the North and South Alouette watersheds enjoys a mild, temperate coastal climate. Mean daily temperatures vary from 2°C in the winter months to just over 17°C at the height of summer. The region has a significant annual precipitation of approximately 2,200 mm, with most of the precipitation falling as rain between October and March; the summers are relatively dry.

The South Alouette watershed includes a large mountainous region, with peaks extending up to 1,800 m elevation. The climate in this part of the watershed differs significantly from the lower reaches. The coastal mountains receive significant precipitation, much of which falls as snow. This can result in large flows in the spring, when snow in the middle and upper elevations melts. In the fall and winter when warm coastal fronts (sometimes referred to as a “pineapple express”) bring warm moist air to the region, rivers swell with stormwater in addition to meltwater from these rain-on-snow events. Many of the North and South Alouette Rivers’ major flood events have been as a result of this type of storm.

It should be noted that the Section 3 climate assessment was completed during initial Phase 2 work in 2011. No record breaking precipitation events have taken place since 2011.

3.1.1 Available Data

Environment Canada maintains four active climate data gauges in and near the Alouette watershed basins (Figure 10):

1) Pitt Polder (CI 1106180), Elevation 5 m
2) Haney UBC RF Admin (CI 1103332), Elevation 147 m
3) Haney East (CI 1103326), Elevation 30.5 m
4) Kanaka Creek (CI 1104R02), Elevation 70 m

Data from these sites has been used to establish general climate indicators for the watersheds.

Historic temperature and precipitation records for each of the four gauges in the vicinity of the watersheds were analysed. After initial assessments, the two most easterly gauges (Haney East and Kanaka Creek) were eliminated from further analysis. These two gauges lie outside the watersheds, and show significantly different annual precipitation volumes than the gauges inside the watersheds. The analysis is therefore focused on data from the Pitt Polder and Haney UBC RF Admin gauges; these provide excellent insight into the climate of the lower and mid elevation watersheds, but provide limited information as to the climate of the upper watersheds. Precipitation and temperature records for the two gauges date back to 1951.

3.1.2 Current Climate

The Pitt Polder and Haney UBC gauges show similar patterns of temperature and precipitation (Figure 11 and Figure 12). Mean monthly temperatures range from just over 2°C in the winter to around 18°C in the summer. Precipitation patterns follow general temperate coastal patterns, with the greatest precipitation amounts falling between October and March; average monthly precipitation is around 300 mm for this period. The summers are relatively dry, with monthly precipitation volumes of around 75 mm. The majority of precipitation falls as rain in the lower watershed; small amounts of snow are observed once or twice a year. Total average annual precipitation at the Pitt Polder gauge is 2,230 mm and 2,150 mm at the Haney UBC RF gauge.

In the upper watershed a general pattern of high precipitation, cold winters and low precipitation, and higher temperature summers is expected. However, temperatures are generally lower by as much as 15 degrees, and precipitation volumes are higher than at lower elevations. Much of the winter precipitation falls as snow, and is stored in the upper watershed until the air heats up in the spring and summer. This gives rise to the nival hydrologic regime on the South Alouette River; where flows peak in the spring during the snowmelt period. The North Alouette River watershed is overall much lower in elevation, and does not have high volumes of snow stored in the mountains.

3.1.3 Historic Trends

According to some observers, the hydrology of the Alouette Rivers has changed over time, particularly in recent years. To investigate potential changes in the hydrology, long term trends in precipitation records were assessed. Flooding on the Alouette Rivers can result from an intense single day precipitation event, but is more commonly attributable to longer periods of precipitation. Therefore, short duration (1-day), medium duration (3-day) and long duration (5-day) precipitation events were calculated for the Pitt Polder and Haney UBC RF gauges. The results are presented in Table 1, Table 2, Figures 13 and 14.

Table 1. Largest recorded precipitation events at Pitt Polder.

Rank	1-Day		3-Day		5-Day	
	Precip	Date	Precip (mm)	Date	Precip (mm)	Date
1	143.8	November 2, 1955	258.0	January 17-19, 1968	336.4	January 15-19, 2005
2	142.6	October 16, 2003	253.6	January 15-17, 2005	287.0	January 16-20, 1968
3	134.1	January 18, 1968	248.5	November 7-9, 1989	280.2	October 16-20, 2003
4	131.0	February 23, 1986	248.4	October 15-17, 2003	278.0	November 5-9, 1989
5	126.0	December 8, 1956	231.4	December 7-9, 1956	271.6	December 13-17,
6	117.9	December 22, 1963	226.1	April 27-29, 1959	271.5	November 8-12, 1990
7	115.0	January 3, 1984	221.5	November 8-10, 1990	258.0	February 12-16, 1982
8	115.0	November 9, 1989	211.1	November 1-3, 1955	253.0	Dec 27-Jan 1, 1963
9	109.6	July 11, 1983	206.5	February 22-24, 1986	249.0	December 14-18,
10	106.0	October 9, 1995	205.0	December 15-17, 1966	247.9	April 24-29, 1959

Table 2. Largest recorded precipitation events at Haney UBC RF.

Rank	1-Day		3-Day		5-Day	
	Precip	Date	Precip (mm)	Date	Precip (mm)	Date
1	145.8	October 16, 2003	256.8	March 17-19, 1997	287.1	October 16-20, 2003
2	127.2	March 17, 1997	249.5	October 15-17, 2003	286.1	December 13-17,
3	125.2	January 18, 1968	238.2	January 18-20, 1968	283.8	March 15-19, 1997
4	119.2	December 13, 1979	227.2	January 17-19, 2005	279.6	January 16-20, 2005
5	115.0	February 23, 1986	220.0	November 8-10, 1990	263.0	January16-20, 1968
6	106.7	December 25, 1972	190.2	December 15-17, 1966	263.0	November 8-12, 1990
7	104.0	January 17, 2005	187.0	November 7-9, 1989	259.0	December 21-25,
8	101.0	January 1, 2007	186.7	November 12-14, 1998	241.1	February 12-16, 1982
9	98.4	January 3, 1984	182.6	February 12-14, 1982	229.8	December 14-18,
10	98.0	July 11, 1983	180.7	February 22-24, 1986	227.5	November 11-15,

The two gauges show varied results, with typically inconsistent ranking of the large events. The consistent large events include January 2005, October 2003 and January 1968.

The largest events in each year were analysed to see if there was any observable increase in rain volumes and number of events per year over the course of the gauge record. Figure 13 and Figure 14 show peak annual precipitation events; no increase in event volume is observed. This was corroborated by checking for the number of heavy rain days per year since the 1950s; a typical heavy precipitation event that might result in flooding. A threshold rainy-day was established to be the 2-year, 1-day event, which is 82 mm and 78 mm for the Pitt Polder and Haney UBC RF gauges respectively. The total number of days with rain in excess of this is presented in Figure 15. The chart shows no observable trend over time, though it does clearly show that the rainiest years at both gauges were 1968, 1997 and 2007. Furthermore, long-term trends were examined by looking at the deviation from normal annual and winter precipitation (Figure 16 and Figure 17). In line with the earlier analyses, there are no detectable trends over the period of record.

In summary, there have been a number of significant precipitation events in Maple Ridge over the years. However, the data available to date does not conclusively show that there has been an increase in either the intensity or frequency of precipitation events. This conclusion is in general agreement with the hydrologic analysis presented in Section 4.

3.1.4 Future Climate

General climate trends were identified by using the ClimateBC downscaling tool developed by UBC and the BC MOF (ClimateBC 2006). Using location and elevation as input, NHC collected and analysed general temperature and precipitation trends for Maple Ridge under three climate change scenarios. (It should be noted that updating these climate trends was not included in the project scope).

Using the ClimateBC tool, key long-term climate values were estimated for three commonly used global circulation models defined in the software. The global circulation models predict different outcomes over time. Results from the three presented models can provide an idea of the variation in possible future climate outcomes. Mean annual temperatures for the City are expected to rise between 2.5°C and 3.5°C over the course of the next 60 years; summer maximum daily temperatures could rise to well over 30°C from the present day mid-twenties (Figure 18). Overall annual precipitation is expected to rise minimally; however, seasonal volumes will change considerably (Figures 19a and 19b). A higher proportion of the annual precipitation will fall during the autumn and winter, which has significant implications for rain driven flood events in the Alouette system. Under the most extreme scenario (GCM_A2x) this yields a 10% increase in winter precipitation volumes, a value recommended in the Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC by APEGBC for year 2100 conditions . This increase is applied to the climate change scenarios in the numerical modelling.

4 HYDROLOGY

The hydrologic regimes of the North and South Alouette Rivers are distinct. The North Alouette, being smaller (drainage area of 37.3 km^2) and unregulated, responds quickly to storm events, particularly large rain events. The much larger watershed of the South Alouette (total drainage area of 234 km^2) includes significant mountainous terrain and the regulated Alouette Lake. The hydrologic regime is dominated by spring freshet type events, which are dampened by the lake storage. The hydrology of both river systems is examined in this section.

4.1 Available Data

Approved long-term peak and daily discharge records up to 2011 were obtained for the Water Survey Canada (WSC) gauges on the South Alouette River near Haney and the North Alouette River at 232nd Street (Figure 1). Preliminary data from 2011 to February 2015 was also collected and reviewed.

Table 3. Summary of WSC hydrometric gauges.

Station Number	Station Name	Gross Drainage Area	Period of Record	Hydrometric Measurement Type	Operational Schedule
08MH005	(SOUTH) ALOUETTE RIVER NEAR HANEY	234 km^2 *	1911 – 1915	Flow	Continuous
			1960 – 1964	Flow	Continuous
			1971 – 1973	Flow	Continuous
			1974 – 1974	Flow	Miscellaneous
			1975 – 2015	Flow	Continuous
08MH006	NORTH ALOUETTE RIVER AT 232ND STREET MAPLE RIDGE	37.3 km^2	1911 – 1913	Flow	Continuous
			1960 – 1968	Flow	Continuous
			1969 – 2015	Flow	Continuous

Note:

1. The South Alouette Watershed includes 24 km^2 between the Alouette Dam and the WSC gauge.

Survey notes from technicians conducting flow estimates and maintenance on the two WSC gauges were also examined. Over the years, the stations have been visited between three and six times per year and the gauge datum checked during these visits. No anomalies were noted and no adjustments were made to the approved record provided by WSC. Historic rating curves for the gauges were also analysed for any changes over time.

Continuous water level and flow data for the two WSC gauges was also reviewed for 2011 to February 2015. However, this data is considered to be preliminary and is not yet approved by WSC. As such, while this data was reviewed for model calibration, it was not included in the statistical flood frequency analysis.

Three other continuous water level gauges have also been installed on the North Alouette River (Figure 1). The City of Maple Ridge has installed a continuous water level gauge on the North Alouette River at 224th Street. Data is available from February 2009 to the present. Similarly, the Alouette Valley Association (AVA) has installed a water level gauge at a pedestrian bridge on the North Alouette near 232nd Street; this too has continuous data available from February 2009 onwards. NHC surveyed both of these gauge locations on April 16th, 2010 in order to tie the gauges in to geodetic datum. Datums were confirmed during follow up site visits in January 2015. Lastly, the City of Pitt Meadows maintains a water level gauge at the confluence of the North and South Alouette Rivers and provides hourly data on its website.

Additional South Alouette River hydrometric information is available from BC Hydro, which monitors outflows from the reservoir at Alouette Lake. BC Hydro has provided partial dam outflow records from 1984, with complete records from 2003 onwards. BC Hydro has also provided information on estimated inflows to the Alouette system and diversion flows to Stave Lake.

WSC also maintains the water level gauge Pitt River Near Port Coquitlam (08MH035), located at the downstream end of the North and South Alouette River system. This gauge is approximately 2km downstream of the confluence of the South Alouette River and Pitt River. This water gauge level data set extends from 1948 to the present.

4.2 General Hydrology

4.2.1 North Alouette River

The North Alouette River has a typical pacific coastal hydrologic regime with the largest flows occurring in the winter as a result of heavy precipitation (Figure 20). Mean monthly flows vary from 0.7 m^3/s in August to 4.9 m^3/s in November. The mean annual discharge is 2.8 m^3/s. These mean flows are relatively small; however peak flows well in excess of 80 m^3/s have been observed (Figure 21). Figure 21 also shows that large flow events can occur in both the summer and winter, though larger flows are more commonly seen in the winter. The largest recorded flows on the North Alouette are presented in Table 4.

Table 4. Largest recorded flow events on the North Alouette River (1969 – Present).

Rank	Instantaneous Flow (m^3/s)	Date
1	245[1]	March 11, 2007
2	162	February 24, 1986
3	157	January 18, 2005
4	154	November 6, 2006
5	147	October 16, 2003
6	140	November 11, 1990
7	132	November 13, 1998
8	126	January 4, 1984
9	124	July 11, 1983
10	118	December 26, 1980

Note:

1. WSC estimate. Large slide that blocked the channel at approximately 11.5 km from the mouth may have caused a flow spike when water broke through the slide dam.

A comparison was made between the extreme flows and extreme precipitation events. Although the large flow events sometimes follow large precipitation events, this is not always the case. There are other factors such as temperature and antecedent conditions that play a role in the hydrology of the most extreme flow events on the North Alouette River.

4.2.2 South Alouette River

The hydrology of the South Alouette River within Maple Ridge is dominated by the control of the Alouette Dam; very little information is available regarding its unregulated regime prior to the construction of the dam in 1926. Modifications made to the dam in 1984 have also impacted the flow regime. Mean annual discharge after 1984 is 3.5 m^3/s. Prior to the modifications it was 2.5 m^3/s. The hydrology information for the post-modification regime is presented in this report, as it reflects the current degree of regulation. Summary information for the South Alouette WSC gauge at 232nd Street is presented in Figure 22 and Figure 23. Peak mean monthly flows occur in the winter, averaging 6.7 m^3/s. Low flows are observed in August, averaging 2.3 m^3/s. Mean annual discharge at the gauge is 3.5 m^3/s. Although the largest events of the year often occur in the winter months (Figure 23), some large events occur in the summer. These large summer event are flushing/pulse flows released by BCHydro for fisheries (BC Hydro 2009) or large freshet releases, such as in 1997. Table 5 summarises the largest recorded flows on the South Alouette since dam modification.

Table 5. Largest recorded flow events on the South Alouette River (1984 – Present)[1].

Rank	Instantaneous Flow (m^3/s)	Date
1	121	March 11, 2007
2	81.1	January 18, 2005
3	76.7	November 23, 1986
4	75.7	November 9, 1989
5	64.3	November 6, 2006
6	50.2	January 12, 1987
7	47.3	October 17, 2003
8	45.8	December 10, 2004
9	41.2	March 19, 1997
10	40.5	December 15, 1999

Note:

1. Only includes events which model the current regime (events since regulation by dam).

Upstream of the lake, the Alouette River watershed is generally untouched and in a natural state. General hydrologic characteristics are presented in Figure 24 and Figure 25. The regime is slightly different from either the North Alouette or the South Alouette downstream of the dam. Large flows are seen both in the winter as a result of rain-on-snow events and in the spring during the freshet. Flows are at their lowest in August and September, when inflows to the lake are around 6 m^3/s.

All outlets from Alouette Lake are regulated through two major routes. First, flows for power generation are diverted from the system into Stave Lake through a diversion tunnel, which has a maximum discharge capacity of 56.6 m^3/s. Second, flows are released into the South Alouette River either through a low level outlet, or over the spillway (overflow weir and crest gate). Minimum flow releases into Alouette River are governed by the 2009 Water Use Plan, and vary between 1.52 m^3/s and 2.97 m^3/s depending on the elevation of the Lake and time of year. In the spring, a 7-day pulse release of at least 9 m^3/s is used to provide a migration cue for the Kokanee. Otherwise, flow is released to the South Alouette River based on BC Hydro operational procedures that maximize storage for power flows while maintaining enough live storage to provide some flood control in the winter. Flood mitigation provisions in the 2009 Water Use Plan require active regulation of the lake storage when the reservoir reaches 122.6 m elevation in the winter months; the free overflow weir is not activated until the lake reaches an elevation of 125.51 m.

The maximum flow released from the dam since 1984 was 143 m^3/s (hourly peak) on 29 November 1995. The next two largest releases are half this flow (76 m^3/s in 1990 and 71 m^3/s in 1986). General patterns are shown in Figure 22.

4.3 Historic Trends

One of the defined objectives of the initial study were to examine any trends in hydrology and climate. There is concern amongst some stakeholders that flows and flood events have increased over the last couple of decades. Trends in the hydrologic regime are assessed in this section.

Figure 26 shows observed daily flows on both rivers from 1911 to 2008. Significant events are seen on both rivers throughout the record. The largest events on the graph occur on the South Alouette River in 1912 and 1913; this is prior to the construction of the Alouette dam, when the river was unregulated.

4.3.1 North Alouette River

Annual peak daily and instantaneous flows for the North Alouette are presented in Figure 27. Although the largest recorded event was in the recent past (2007), no statistically significant patterns show a distinct trend of increasing peak flows. The 2007 event may have been a result of a log jam outburst flow and likely does not represent true flow volumes in the river.

In addition to the peak flow analysis, the data was separated into winter and summer series to review observable trends in peak seasonal events (Figure 28). No significant trends are observed.

Finally, the number of large flow events per year at the gauge were calculated, where a large flow event was considered to be 40 m^3/s or more, which is the estimated bankfull flow (NHC 1990). No clear trends were observed (Figure 29). However, it should be noted that the period from 2002 to 2007 had a larger number of flood flows than typical.

Although no clear trends are detectable at this time, they may become apparent in the future as more data is collected. A reassessment of the climate and hydrologic data should be made in a decade.

4.3.2 South Alouette River

As noted in Section 4.2, the regime of the South Alouette River has changed as a result of the construction of the Alouette dam in 1926 and subsequent dam modifications. A trend analysis using post 1984 modification lake inflows was completed but showed no significant changes. The morphology of the South Alouette River generally shows that the river channel is oversized for the current flow regime, as the channel conveyed significantly higher flows prior to regulation. The South Alouette River is therefore less prone to riparian flooding than the North Alouette.

4.4 Frequency Analysis and Design Flow Hydrographs

4.4.1 North Alouette River

To determine design flows for floodplain mapping, a frequency analysis of available North Alouette flow data was completed. Peak annual flows (both daily and instantaneous) were used to estimate flows for various return periods. In both cases, a Lognormal distribution was determined to be the best fit to the available data points. Maximum annual daily flow data was analysed for the years 1960 to 2011. Peak annual instantaneous flow data was analysed for the period from 1969 to 2011. Flows for various return periods are presented in Table 6.

Table 6. Summary of annual flow frequency analysis for the North Alouette River at 232nd Street.

Return Period (years)	Daily Flow (m^3/s)	Instantaneous Flow (m^3/s)
2	42	78
5	60	115
10	71	141
25	81	174
50	98	201
100	110	228
200	122	256

The 1990 BC Environment report used for the previous Alouette floodplain mapping included a 200-year peak daily flow of 140 m^3/s and a peak instantaneous flow of 300 m^3/s, values 15% and 17% higher than the present analysis, respectively. This is due to the increased period of record, which is double the record that was available in 1990.

The values from the frequency analysis were used to create design inflow hydrographs for the Maple Ridge floodplain mapping (Figure 30). These dynamic hydrographs incorporate a 48 hour flooding event, with a peak instantaneous flow incorporating a 10% increase to allow for climate change projections to year 2100 as recommended by APEGBC (2012). The central 24 hour period of the event also has an average daily flow equal to the corresponding peak daily flow with a 10% climate change increase (Table 7).

Table 7. North Alouette design discharge hydrographs with climate change impacts.

Return Period (years)	Daily Flow (m^3/s)	Instantaneous Flow (m^3/s)
2	46	86
5	66	127
10	78	155
25	89	180
50	108	221
100	121	251
200	134	282

Using the design hydrographs with a climate change allowance, 200-year daily and peak instantaneous flow values are within 6% of the previous 1990 study. For reference, the 200-year design flow is 15% larger than the historical maximum flow of 245 m^3/s experienced in 2007.

4.4.2 South Alouette River

A simple flood frequency analysis was not possible for South Alouette River, as the river is regulated and flood flows could not be directly based on the gauge records. For the purposes of this project and future planning, it assumed that the dam remains in place and operational conditions in the 2009 BC Hydro Water Use Plan remain in effect.

Design inflows into Alouette Lake were established using records provided by BC Hydro, dating from 1984. These include observed releases from the dam, lake elevations and calculated inflows to Alouette Lake. A frequency analysis of peak annual daily inflows to the lake was carried out and results are presented in Table 8; no instantaneous data was available. However, BC Hydro reports the top four hourly peak events in their FloodSIMM report. These are 781 m^3/s in March 2007, 759 m^3/s in October 2003, 710 m^3/s in November 1995 and 703 m^3/s in November 1990. Peak hourly flows are significantly larger than peak daily flows, with instantaneous/daily (I/D) ratios ranging from 1.7 to 2.3 and averaging 1.9 for these four events.

Table 8. Summary of frequency analysis for the South Alouette River above Alouette Lake.

Return Period (years)	Daily Flow (m^3/s)
2	275
5	357
10	401
25	448
50	479
100	507
200	533

To calculate outflow from the lake and into the South Alouette downstream, NHC developed a STELLA flow routing model, where inflow hydrographs based on the peak daily flow (Table 8) were routed through the Lake and out the overflow weir. Several assumptions and simplifications were made to complete this analysis; these were based on BC Hydro's operational guidelines for the dam:

- Dynamic hydrographs were developed assuming a 48-hour storm event with a triangular shape, where the middle 24 hours had a daily flow equal to that presented in Table 8; peak instantaneous flow is 1.3 times the daily flow. Base flows were assumed to be 10% of the peak daily flow. The shape and length of the storm were developed based on observing historic records and finding a common representative storm shape. Alternate storm lengths and shapes were tested as part of a sensitivity exercise.

- The lake elevation was assumed to be at the Maximum Normal Operating Level of 125.51 m elevation. This is a conservative assumption, as the lake would be actively operated (i.e. flows would be released slowly), once the lake has reached an elevation of 122.6 m.

- The free crest weir was assumed to be fully operational, with no flow being diverted to the crest gate. Outflow from the low level outlet gate was assumed to be negligible.

- The Stave diversion system was assumed to be non-operational; all flow was routed into the South Alouette River. This is a conservative assumption, as the Stave diversion system has an actual maximum capacity of 56.6 m^3/s.

Outflows from the dam into the South Alouette River were calculated by routing inflows through Alouette Lake. Design outflows are summarised in Table 9 and Figure 32.

Table 9. Summary of Alouette Lake inflows and design discharge outflows to the South Alouette River.

Return Period (years)	Peak Daily Inflow (m^3/s)	Peak Instantaneous Inflow (m^3/s)	Peak Daily Discharge (m^3/s)	Peak Instantaneous Discharge(m^3/s)
2	275	359	200	227
5	357	466	276	315
10	401	523	314	362
25	448	584	362	412
50	479	625	389	444
100	507	661	415	473
200	533	695	440	500

Alouette Lake significantly attenuates the reservoir inflows, even when conservative assumptions are used in terms of outflow scenarios. The peak instantaneous flow of 500 m^3/s is comparable to the 558 m^3/s used in the 1990 MOE study. The dam modifications in 1984 account for the decrease in the expected flow. No extra allowance was made for climate change, as the system is controlled by the Alouette Dam and it is assumed that compensation in operating procedures will be made by BC Hydro. This assumption should be confirmed with BC Hydro in the future.

Some sensitivity tests were performed on the synthesized storm length and storm shapes. The sensitivity of the synthesized flow to storm length was tested using the STELLA Model. Both 72-hour and 120-hour storms, with the identical peak daily flow as the 48-hour storm were routed through the lake (Figure 33). The assumed length of the storm has an impact on the peak outflow, and consequently on the total volume of flow discharged into the South Alouette system. The change is more marked for the frequent events, with a 15.9% increase in peak flows for the 2-year event, when a 120-hour storm is considered rather than a 48-hour storm. For the 200-year event there is only a 4.8% increase in flows.

The sensitivity of the synthesized flow to storm shape was tested using the STELLA Model. A 48 hour storm with a peak flow equal to 1.9 times the daily flow was developed. The 1.9 Q_i/Q_d (peak instantaneous flow to daily flow ratio) was assumed based on the average calculated ratio value for the four extreme events in the upper South Alouette for which both daily and hourly inflow estimates are available. The storm produces the same volume of water as the base triangular 48-hour event; a comparison is presented in Figure 33. The assumed shape of the storm has a small impact on the peak outflow. The change is more marked for the largest events, with a 4.6% increase in peak flows for the 200-year event, when a peaky storm is considered rather than a triangular storm. For the 2-year event there is a 2.2% decrease in peak flows. The change in storm volume (i.e. total flow out of the lake over a 10-day period) is almost unchanged for all events.

4.4.3 Tributary Inflows

Inflow hydrographs for major North and South Alouette tributaries identified in Phase 1 of this project are summarized in Table 10. These were calculated based on the design discharge hydrographs for the North Alouette River (Table 7), as the tributary watershed characteristics (size, elevation, aspect) were considered to be similar to the North Alouette system (Figure 10). A simple area watershed transfer was used to generate scaled hydrographs and is based on the watershed areas presented in Table 11. Hypsometric curves for each of the tributaries are presented in Figure 34 for comparison.

Table 10. Tributary design hydrograph peak instantaneous discharges.

Return Period (years)	Blaney Creek Peak Instantaneous Flow (m^3/s)	Fenton Road Peak Instantaneous Flow (m^3/s)	McKenny Creek Peak Instantaneous Flow (m^3/s)	Additional[1] North Alouette Peak Instantaneous Flow (m^3/s)	Additional[2] South Alouette Peak Instantaneous Flow (m3/s)
2	64	15	14	14	43
5	94	22	21	20	64
10	115	27	25	25	78
25	133	32	29	29	91
50	164	39	36	35	112
100	186	44	41	40	127
200	209	50	46	45	142

Notes:

1. Flows contributed by the North Alouette watershed area downstream of the North Alouette WSC Gauge.
2. Flows contributed by the South Alouette watershed area downstream of the South Alouette WSC Gauge.

Table 11. Summary of tributary watershed areas and elevations.

Location	Watershed Area (km²)	Mean Elevation (m)
North Alouette WSC (08MH006)	37.3	448
Blaney Creek	26.8	216
Fenton Road	5.4	13
McKenny Creek	5.0	17
Confluence of North and South Alouette Rivers	42.1	-
South Alouette WSC (08MH005)	234.0	568
Confluence of Alouette River and Pitt River	251.5	-
Additional[1] North Alouette Tributary Area	4.8	-
Additional[2] South Alouette Tributary Area	17.5	-

Notes:

1. North Alouette tributary watershed area downstream of the North Alouette WSC Gauge.
2. South Alouette tributary watershed area downstream of the South Alouette WSC Gauge.

4.4.4 Coordination of Hydrographs

For the purposes of floodplain mapping and model design runs, it is assumed that the flow event peaks simultaneously in all unregulated watersheds. Inflow hydrographs peak simultaneously on the North Alouette River, the five smaller tributary watersheds and the South Alouette River upstream of the Alouette Reservoir. Due to the routing that takes place through the Alouette Reservoir, there is a 7.5 hour delay between the peaking of the North Alouette River and the peaking of the South Alouette River downstream of the reservoir. Actual combinations may vary but this assumption is considered representative of actual conditions and somewhat conservative.

4.5 Data Limitations

All hydrometric information suffers from inherent limitations; these are particularly relevant in a highly dynamic system such as the North Alouette River. Throughout the course of the hydrologic and hydraulic modelling investigations, NHC identified possible failings in the published flow data for the North Alouette gauge. These include general errors associated with high flow estimates from rating curves, and errors in lower and medium flows resulting from morphodynamic changes to the river in the vicinity of the gauge.

Published flows for most gauges are calculated from observed water levels and an assumed rating curve. Rating curves are developed based on river surveys where both the water level and total flow across a section are measured. The majority of these measurements are taken when the flows are low or at medium flow events; it is rare to capture a high flow event. Thus, curves are extrapolated well beyond the highest measured flow-water level pair and there is a great deal of uncertainty in the curve at high water levels and flows. For example, the highest measured flow at the North Alouette gauge was 41.3 m^3/s in January 1966. However, WSC has reported flows as high as 245 m^3/s based on an extrapolated curve.

The uncertainty in the high flow estimates is further increased by completing a regional hydrologic analysis. Nearby gauged watersheds that have similar characteristics (median elevation, size, aspect, non-regulated, more than 15 years of record) to the North Alouette River were examined. A comparison of maximum instantaneous flows per area are presented in Table 12. The flow-area ratios for the North Alouette River are significantly higher than for other nearby gauges.

Table 12. Summary of flows by area for nearby gauges.

Return Period (years)	North Alouette (08MH006) Instantaneous Peak Flow/ Area ($m^3/s/km^2$)	Kanaka Creek (08MH076) Instantaneous Peak Flow/ Area ($m^3/s/km^2$)	Jacobs Creek (08MH108) Instantaneous Peak Flow/ Area ($m^3/s/km^2$)
2	2.1	1.3	1.5
5	3.1	2.0	1.8
10	3.7	2.5	2.0
25	4.5	3.1	2.1
50	5.1	3.9	2.2
100	5.7	4.7	2.2
200	6.2	5.5	N/C

At lower water levels there remains uncertainty in the published flows; primarily because the North Alouette River is a dynamic system and the channel in the vicinity of the gauge changes frequently (see Section 2). In an attempt to deal with the rapidly changing channel, WSC updates the rating curves for the North Alouette gauge regularly; it has been updated six times since 2007. Over this period, for the same water level, reported flows vary by as much as 20%.

Given the above, it is important to consider limitations of the hydrologic analyses and subsequent hydraulic modelling when looking at project results.

A further limitation to the high flow data on the North Alouette River is the known history of outburst floods resulting from the sudden release of a log jam; this is a well-known process in the Pacific Northwest. For example, a large log jam was observed in the upper watershed in March 2007. There is reason to believe that an outburst flood through this jam was the cause of the flooding in the Alouette Valley on 11 March 2007. Unfortunately, the WSC gauge on the North Alouette that might have recorded this type of peaky flow event was not functioning; the reported hydrograph was estimated by WSC.

5 COLLECTION OF CALIBRATION AND VALIDATION DATA

In October 2014, NHC initiated a program for the collection of hydraulic model calibration data along the North Alouette River. This program was instated due to the limited peak flow data and flooding extent information available for large events. During the duration of the program, NHC monitored peak flows so that field crews could be quickly mobilized during high floods to measure flows, mark high water levels and note flooded areas. This program was undertaken between October 2014 and February 2015. Data was collected for flow events on 3 November 2014 and 23 January 2015 and used for calibration and verification, respectively.

5.1 November 2014 Flood Event

On the night of 03 November 2014, NHC staff members measured flows on the North Alouette River approximately 100 m downstream of the WSC 08MH006 gauge (Figure 1). High flow measurements were taken, however, the actual peak was not captured. The staff also collected several water level measurements at the major North Alouette River Bridges at 132nd Avenue, 224th Street and 232nd Street. Lastly, high water levels and flood extents were marked along 132nd Avenue, 224th Street and 136th Avenue. This information was georeferenced and incorporated into to project GIS data.

A request for flood information and photographs was made to the Alouette Valley Association (AVA), which provided a compiled report of local residents' comments and observations. Resident responses were collected from 132nd Avenue, 136th Avenue and 224th Street. Flood water surface levels, extents and debris information provided by the AVA was also georeferenced and incorporated into project GIS data.

5.1.1 Review of November 2014 Data

In addition to the information collected by NHC on site, data on the November 2014 flood event was collected from all available gauges applicable to the project study area. The data collected included:

- Maple Ridge Gauge at 224th Street – Water Surface Elevation Data (5 min Interval)
- AVA Gauge at the pedestrian bridge - Water Surface Elevation Data (5 min Interval)
- Pitt Meadows Gauge at Alouette Confluence - Water Surface Elevation Data (1 hr Interval)
- South Alouette WSC (08MH005) – Preliminary Water Surface Elevation Data (5 min Interval)
- South Alouette WSC (08MH005) – Preliminary Flow Data (5 min Interval)
- Pitt River WSC (08MH035) – Preliminary Water Surface Elevation Data (5 min Interval)

Unfortunately, it was not possible to use data from the North Alouette WSC gauge (08MH006). There have been several major bed form changes at this location since the last WSC stage rating curve was developed. WSC has also reported difficulties with the existing water level gauge, which is currently undertaking repairs/recalibration.

The only sources of continuous gauge data along the North Alouette River during the November 2014 event came from the two water level gauges at 224th Street (property of the City of Maple Ridge) and the pedestrian bridge downstream of 232nd Street (property of the AVA).

5.1.2 November 2014 North Alouette Hydrograph

To determine the November 2014 event North Alouette inflow hydrograph, NHC developed stage-discharge rating curves for both the Maple Ridge and AVA gauges. These rating curves were developed in Aquarius Time-Series software by Aquatic Informatics and are shown in Figures 35 and 36. Using these rating curves, the peak instantaneous flow for the North Alouette November 2014 event is estimated to be 69 m^3/s. Maximum flow was reached at approximately 1:30 AM on 04 November 2014. The hydrograph from the AVA gauge was selected for modelling use, as it is furthest upstream and less of a damping effect is observed on the peak (Figure 37). The event has an estimated return period of less than two years.

5.2 January 2015 Event

A smaller event took place from 23 to 26 January 2015 and was recorded for model validation. NHC staff measured a peak flow of 59 m^3/s at the North Alouette River 232nd Street Bridge as well as high water marks at multiple points along the river. This information was georeferenced and incorporated into to project GIS data. Flood extents data was not collected by staff, as this event was considered too small.

5.2.1 Review of January 2015 Data

In addition to the information collected by NHC onsite, data for the January 2015 event was also collected from all available gauges applicable to the project study area. The data collected included:

- Maple Ridge Gauge at 224th Street – Water Surface Elevation Data (5 min Interval)
- AVA Gauge at the pedestrian bridge - Water Surface Elevation Data (5 min Interval)
- Pitt Meadows Gauge at Alouette Confluence - Water Surface Elevation Data (1 hr Interval)
- South Alouette WSC (08MH005) – Preliminary Water Surface Elevation Data (5min Interval)
- South Alouette WSC (08MH005) – Preliminary Flow Data (5min Interval)
- Pitt River WSC (08MH035) – Preliminary Water Surface Elevation Data (5min Interval)

As in November, it was not possible to use data from the North Alouette WSC gauge (08MH006) as the gauge was not recording.

5.2.2 January 2015 North Alouette Hydrograph

As with the November event, the North Alouette January 2015 inflow hydrograph was determined using the NHC stage - discharge rating curves for the Maple Ridge and AVA gauges (Figure 38). As the AVA gauge showed the best agreement with onsite measurements completed by NHC, the AVA hydrograph was selected for modelling use. Maximum flow was reached at approximately 7:30 PM on 23 January 2015.

6 SURVEY OF CHANNEL CROSS SECTIONS

In 1981, the BC Ministry of Environment surveyed a total of 68 sections of the Alouette Rivers to produce the original floodplain mapping. The sections were not geo-registered and are now out-of-date, considering the channel changes that have taken place over time. The BC Hydro survey included a total of 109 cross-sections. In addition to providing only fairly schematic outlines of the channels, the sections are also widely spaced. These cross-sections were used in the initial Phase 2 modelling completed in 2011.

Following this initial Phase 2 modelling, it was agreed that more detailed river cross-section survey was required to produce detailed hydraulic model results. NHC resurveyed the North and South Alouette river channels in more detail and at a reduced spacing in 2014. This survey focused on the previously defined project area (roughly 5 km long reaches of both rivers) and was carefully laid out to capture constricted channel locations that have the greatest impact on water surface profiles. This information was combined with previous surveys carried out by NHC in 2010 and incorporated into the hydraulic model. A total of 77 new surveyed cross sections (Figure 39) were added to the model. Spot survey data collected at the river bridges was also incorporated.

7 HYDRAULIC MODELLING

As a component of this project, a comprehensive hydraulic model was developed of the two Alouette Rivers and Maple Ridge floodplain using DHI MIKE hydrodynamic software. A 1D model is suitable for simulating discharges, water levels and other hydraulic parameters while flows remain within the river banks. For this project, 1D in-bank river modelling was completed using MIKE11. However, it is difficult to realistically simulate complex overbank flooding and bank breaching in one-dimensional modelling. Instead, these floodplain processes were modelled with a more accurate two-dimensional model using MIKE21 FM (Flexible Mesh) software. The two models were then connected using the overarching MIKEFLOOD software.

This chapter outlines the general methodology used to develop the MIKE11, MIKE21 and MIKEFlood models.

7.1 DEM Development

The City of Maple Ridge supplied an updated DEM dataset in 2014 which covers the entire study area. It was supplied to NHC as a 2 m resolution grid. The DEM does not include in-channel bathymetric data; bathymetry was derived directly from cross-section surveys. The DEM was used to guide development of the stream network, bank lines and cross-sections, as well as the dikes and high land that define the boundary between the MIKE11 and MIKE21 model areas. Elevation data was extracted from the DEM via cross-sections for input to the MIKE11 model, and the DEM surface was resampled based on the model mesh for input to the MIKE21 model. Processing was done using ESRI ArcGIS 10.1 software, including the 3D Analyst and Spatial Analyst extensions.

7.2 MIKE11

The MIKE11 model covers the in-channel sections of the North and South Alouette Rivers from their headwaters to the confluence with the Pitt River (Figure 39). Some of the key inputs for the MIKE11 model were developed using ArcGIS. These include the stream network, cross-sections and watershed areas.

Stream centrelines for the North and South Alouette Rivers were digitized based on BC 1:20,000 scale Corporate Watershed Base (CWB) stream data. Features were modified with reference to the DEM, survey and recent orthophotography. Vertices were added to represent key features such as cross-section locations, bridges and tributary confluence points. The stream features were calibrated to determine river chainage. The stream network shapefile was input directly to MIKE11 as the basis for the MIKE11 geometry file.

Cross-section lines were drawn based on the locations of the 2010 and 2014 surveys. Additional cross-section lines were added as required at bridge locations and cross-section elevation values were extracted from an interpolated surface generated in GIS. Left and right bank lines were digitized based on the DEM and orthophotos, and were used, along with the stream centreline, to tag cross-section data points as left bank, right bank or thalweg. Cross-section elevations and tags were extracted from a combination of the DEM (for overbank areas) and the bathymetric survey data, using custom GIS tools developed by NHC. The cross-section line location and elevation point data were exported from the GIS to MIKE11.

Preparation of model data in the GIS was an iterative process. As preliminary modelling results highlighted areas that required refinement, revisions were made in the GIS and data was re-exported for the model.

Mainstem and tributary watershed areas are required as inputs to the model. These were determined in the GIS using BC Corporate Watershed Base (CWB) stream and watershed boundary data as a base.

Additional data was used as reference when developing the GIS data layers for the model.

- Dike crest mapping was obtained from the BC online Land and Resource Data Warehouse (LRDW).

- The City provided 25 cm resolution orthophotos of the study area taken in April 2009; these were supplemented by recent orthophotos from Google Maps.

7.2.1 Network

A single model network that includes both the North and South Alouette Rivers was developed (Figure 39). The network was designed using common North American practice, where the chainage increases moving upstream. Therefore, the networks and associated structures are set up to run with negative flow.

The network includes two branches:

1. North Alouette River – from the km 13.0 in UBC research forest to the confluence with the South Alouette River.

2. South Alouette River – from km 19.6 at the Alouette Dam to the confluence with the Pitt River.

7.2.2 Cross Sections

The cross-section file was created by updating the 2008 cross section file with cross sections imported directly from the GIS DEM using in-house tools; interpolated sections were added as necessary. A total of 327 sections are used to describe the North Alouette River, and 478 sections make up the South Alouette River. The total number of cross sections used to describe each river in the model greatly exceeds the number of surveyed cross sections due to interpolation between surveyed sections. Interpolated cross sections were added to the model to increase model stability by allowing for a smooth transition from one bedform to the next.

Where the MIKE11 model is bound by the MIKE21 model, cross-sections extents (markers 1 and 3) were located at high points as noted in the GIS analysis. Some adjustments to the marker locations and elevations were made once the MIKE11 and MIKE21 models were linked in MIKEFlood; the elevations of the two models should match as closely as possible.

All sections are modelled using a resistance radius; this method is applicable to the relatively small channel sections found on the Alouette Rivers. All sections are georeferenced and are therefore easily viewed in the MIKE11 Network. Relative, transversal roughness was applied to all sections.

Marker points for the low flow boundaries were placed from a combination of the orthophotos and normal water level edges noted on available mapping and from visual inspection of the section shape. Roughness values were determined based on orthophotography, site observation and literature values.

7.2.3 Hydraulic Structures

Bridge structures were included in the network file. A total of 7 bridges were included as shown in Table 13. All major road crossings were included in the model, as well as one private crossing on the North Alouette River, which has a significant pier in the main channel.

Bridges were modelled using either basic energy equations or the Federal Highway Administration (FHWA) WSPRO method, depending on whether or not the bridges are skewed from the direction of flow. All bridges were assumed to be prone to submergence and overflow. Basic geometric parameters, including bridge width and skew for each of the bridges were derived from available information as described in the Phase 1 reporting. The North Alouette River bridge at 232nd Street is an exception, as it was replaced in 2014. As-built dimensions for this bridge were provided by the City.

Table 13. Summary of bridge crossings.

Bridge	Chainage (m)	Comments
NORTH ALOUETTE		
224th Street Bridge	8315	Geometry from 1981 MOE Study and LiDAR
132nd Avenue	8770	Bridge as-built information from 1997
232nd Street	10240	Bridge as-built information from 2014
Private Access	10408	Significant structure with large concrete pier in channel
SOUTH ALOUETTE		
216th Street Bridge	8772	Geometry from 1981 MOE Study
224th Street Bridge	10720	Bridge as-built information from 1981
232nd Street	12610	Bridge as-built information from 2006

It should be noted that two additional private crossings between 132nd Avenue and 232nd Street on the North Alouette River were not modelled; these are single span narrow structures that would not impact the hydraulics significantly. They may however accumulate debris during a flood event which would result in localized hydraulic impacts; these types of impacts were not modelled directly.

7.2.4 Model Inflows and Water Level Boundaries

A total of 8 boundaries are used in the MIKE11 model: two open inflow boundaries, five point source inflow boundaries and one open water level boundary. The open inflow boundaries are located at the upstream most limits of the North and South Alouette Rivers. Point source inflow boundaries are used to add flow to the system at the confluence of major tributaries to the Alouette Rivers. The location of the boundaries is described in more detail in Table 14. There is only one downstream water level boundary, which is located at the confluence of the South Alouette River with the Pitt River.

Table 14. Summary of MIKE11 model boundaries.

Boundary Type	Branch	Chainage	Comments
Open Inflow	North Alouette	12773	Primary inflow to North Alouette
Open Inflow	South Alouette	19025	Primary inflow to South Alouette
Point Source Inflow	North Alouette	2192	Blaney Creek
Point Source Inflow	North Alouette	136	Local inflows direct to North Alouette
Point Source Inflow	South Alouette	7907	McKenny Creek
Point Source Inflow	South Alouette	3078	Fenton Slough
Point Source Inflow	South Alouette	8000	Local inflows direct to South Alouette
Open Water Level	South Alouette	0	Downstream boundary at Pitt River

7.2.5 MIKE11 Model Calibration

Model calibration forms an important step in hydraulic model development. In the case of the 1D MIKE11 model, it involves the fine tuning of initially selected channel Manning's roughness coefficients and the energy loss coefficients associated with the various hydraulic structures along the rivers. Coefficients were adjusted to match results to the November 2014 flood event described in Section 5.1.

The November 2014 was simulated from November 3rd to 5th, with peak flows occurring at 1:30 AM on the 4th. The North and South Alouette Rivers were set to the AVA Gauge North Alouette November 2014 hydrograph and the South Alouette WSC (08MH005) hydrograph, respectively. The point source tributary inflows were set as scaled hydrographs of the North Alouette. Last, the downstream water level boundary at Pitt River was set using a time series from the Pitt River WSC (08MH035) gauge. A summary of model calibration boundary flow inputs is shown in Figure 40 and downstream water level inputs in Figure 41. Further details on these inputs are available in Section 5 above.

A comparison of modelled to observed water levels are presented Figures 42 to Figure 46. The modelled water levels on both the South and North Alouette Rivers match relatively well with the observed water levels. Agreement between maximum observed and modelled peak river water levels is summarized in Table 15.

Table 15. MIKE11 calibration peak river water level agreement.

Gauge Name	River	MIKE11 Chainage (m)	Peak WLs (m GSC)		
			Observed	Modelled	Difference
232nd Street HWM	North Alouette	10265	14.68	14.57	0.11
AVA Gauge	North Alouette	9937	12.76	12.71	0.05
Maple Ridge Gauge	North Alouette	8340	7.07	7.18	0.11
Pitt Meadows Gauge	Alouette Confluence	31	1.84	1.82	0.02
South Alouette WSC	South Alouette	18973	12.47	12.52	0.05

Agreement is very good throughout the study area. Agreement at the Maple Ridge gauge at peak flows is approximately 11 cm; this is due in part to the presence of a small depression and ditch system along the edge of the bridge which connects to the 224th Street ditch system. These features were considered to be part of the local minor stormwater system and were not included in this large scale flood model. More variation is also seen at the Pitt Meadows gauge located at the confluence of the North and South Alouette Rivers, which sees three tidal peaks during the duration of the flooding event.

The roughness values required to best match the model results to the calibration event are well within normal limits. The final roughness values used in the MIKE11 model are shown in Table 16.

Table 16. Summary of MIKE11 roughness values.

River	Downstream Chainage	Upstream Chainage	Resistance (Manning's Roughness)
North Alouette	32	8207	0.035
North Alouette	8207	8956	0.045
North Alouette	8956	127773	0.050
South Alouette	6	7899	0.030
South Alouette	7899	13000	0.035
South Alouette	13000	18973	0.040

7.2.6 MIKE11 Model Validation

Model validation allows for a secondary proof of the completed calibration. The January 2015 event was simulated from January 23rd to 25th and reach peak flows at approximately 7:30 PM on the 23rd.

The North and South Alouette Rivers were set to the AVA Gauge North Alouette January 2015 hydrograph and the South Alouette WSC (08MH005) hydrograph, respectively. The point source tributary inflows were set as scaled hydrographs of the North Alouette. Lastly, the downstream water level boundary at the Pitt River was set using a time series from the Pitt River WSC (08MH035) gauge.

A summary of model validation boundary flow inputs is shown in Figure 47 and downstream water level inputs in Figure 48. Further details on these inputs are available in Section 5.

A comparison of modelled to observed water levels are presented Figures 49 to Figure 53. The modelled water levels on both the South and North Alouette Rivers match relatively well with the observed water levels. Agreement between maximum observed and modelled peak river water levels is summarized in Table 17.

Table 17. MIKE11 validation peak river water level agreement.

Gauge Name	River	MIKE11 Chainage (m)	Peak WLs (m GSC)		
			Observed	Modelled	Difference
232nd Street HWM	North Alouette	10265	14.50	14.42	0.08
AVA Gauge	North Alouette	9937	12.59	12.58	0.01
Maple Ridge Gauge	North Alouette	8340	7.00	7.06	0.06
Pitt Meadows Gauge	Alouette Confluence	31	1.81	1.70	0.11
South Alouette WSC	South Alouette	18973	12.66	12.57	0.09

Agreement is very good throughout the study area, validating the November 2014 calibration.

7.3 MIKE21

A two-dimensional hydraulic model, MIKE21, was used to simulate overland flow and to determine flood depths on the floodplain. The following section provides information on the general assumptions, set-up and application of the MIKE21 model.

7.3.1 Model Development

As with the MIKE11 model, GIS was used to develop some of the key inputs to the MIKE21 model. These included the DEM described above, the definition of the boundary between the MIKE11 and MIKE21 models and surface roughness data.

In order to input the DEM to the MIKE21 model, the MIKE21 mesh points were imported to the GIS, elevation values were extracted from the DEM surface at each mesh point location, and the results returned to the MIKE21 model. The mesh was developed such that the floodplain topography would be adequately represented while being mindful of long run times associated with meshes that are too detailed; the final mesh is presented in Figure 54. The triangular mesh elements on the main Maple Ridge floodplain and adjacent to the river channels have a width of 20 m. Those elements in the cranberry fields and the most northern section of the study area have a width of 35 m.

It should be noted that the flow path observed during the November 2014 flooding, which follows 224th Street, was refined to improve the representation of the road and various ditches. Similar refinements were made on the right bank of the North Alouette north of 132nd Avenue and west of 224th Street to improve the representation of the various ditches that drain into the North Alouette. The model has a total of 45,856 elements.

The boundary between the MIKE11 and MIKE21 models along the river should follow the high point along each bank, such as the dike crest. GIS was used to map this boundary, and to refine it based on requirements relating to mesh element size and shape in the hydraulic model. Once the boundary was finalized in the model, the GIS was also used to determine MIKE11 chainage values for each node in the boundary. This facilitated linkage between the MIKE11 and MIKE21 models.

Resistance values are defined in MIKE21 as a Manning's M value, which is equivalent to the inverse of Manning's N. A surface roughness data layer was developed in the GIS based on a simplified version of land use data supplied by the City and general roughness values shown in Table 18 and Figure 55. Roughness values were extracted at each MIKE21 mesh point location, and imported to the MIKE21 model.

Table 18. Floodplain resistance values.

Land Use	Manning's N
Urban	0.08
Rural (residential, small farms)	0.05
Agricultural	0.04
Forest	0.06
Water	0.01
Other (mine pits, significant roadways)	0.03

In order to limit the number of elements, internal structures (weirs) were used to represent the agricultural dikes as opposed to refining the element size near the dikes. Weir elevations were set based on average LiDAR elevations. This is a slight simplification of the system, as the weirs were given a constant elevation, whereas there is some variation in dike elevation along their lengths. However, for the purposes of modelling flood levels, this is assumed to be a robust assumption.

In addition to the major inputs of boundaries and roughness some general assumptions were made including:

- In MIKE21, wetting, flooding and drying depths were selected based on NHC's experience with previous similar models. The model was assigned a wetting depth of 0.2 m, a flooding depth of 0.15 m and drying depth of 0.02 m; very small tolerances can cause model instabilities as cells 'switch' on and off too frequently, while large tolerances may cause model inaccuracies through a loss or gain of water volume. A small evaporation volume was included in the model to approximate losses to groundwater (groundwater losses are not possible in the basic MIKE21 set-up).

- Based on the mesh size, the water velocities and a series of trials, a timestep of 5 seconds was selected for the model runs.

- The initial water surface elevation was set at a constant value of zero, representing a dry starting condition.

7.3.2 MIKE21 Model Calibration

The MIKE21model has no inflow boundaries, as it is designed to run in tandem with the MIKE11 model. And therefore, it is not possible to calibrate or validate this model by itself. The model was calibrated and verified along with the MIKE11 model using MIKEFlood.

7.4 MIKEFlood

MIKEFlood provides the linkage between the one-dimensional flow in MIKE11 and the two-dimensional overland flow in MIKE21. The links are established through a series of weir equations that connect a MIKE21 cell with the nearest MIKE11 channel section. Once a link is established, MIKEFlood tracks the water surface elevations in both MIKE11 and MIKE21. If either model overtops the elevation of the connection point, water is transferred from one domain to the other via source/sink terms in MIKE21 and lateral inflows in MIKE11. This allows water to overtop the channel banks and flow onto the adjacent floodplain or drain from the floodplain back into the channel.

Lateral links were developed in GIS based on the DEM. Links were drawn at high points along the boundary between the channel and floodplain on dikes or natural high points. The development of links is an iterative process, where adjustments are made to either the MIKE21 domain or the MIKE11 marker locations so that the elevations in the two models match. Ultimately, the links were set to be equal to the MIKE21 elevation; no other changes to the default values were made.

7.4.1 MIKEFlood and MIKE21 Model Calibration

The MIKEFlood model was also calibrated to the November 2014 flood event. Information collected by NHC and the AVA was used to estimate the observed flood extents and check depths. Adjustments were made to the MIKE11, MIKE21 and links such that the model extents approximate the observed extents. Some of the adjustments are listed below:

- The mesh was refined along the flow path noted during the November 2014 flooding, which follows 224th Street, to improve the representation of the road and various ditches.

- The main Maple Ridge floodplain mesh was refined to a 20 m width to allow the model to include the impacts of local high points along the river channel.

During the calibration event, flooding began at the lower reaches of the North Alouette River in the early evening of 03 November 2014 and flow-ins from ditches along the right bank of the North Alouette at a chainage of 5199 m. Water then infilled the low-lying lands on either side of 136th Street between 7PM and 10PM. During this time, water also started to overflow the left bank of the North Alouette at the downstream boundary of the MIKEFlood model, flooding the land located between the two Alouette rivers.

Flooding at the North Alouette 224th Street bridge began just past midnight, approximately an hour before the peak of the storm. Water then flowed up 224th Street, north of the bridge. During the peak of the storm, water also extended along 136th Street.

Table 19. MIKEFlood high water mark water level agreement.

High Water Mark Location	Peak WLs (m GSC)		
	Observed	**Modelled**	**Difference**
224th Street, North of North Alouette Bridge	6.99	6.98	0.01
	6.96	6.96	0.00
	6.46	6.44	0.02
	5.90	5.90	0.00
	6.08	5.90	0.18
136th Avenue, West of 224th Street	4.45	4.07	0.38
	4.18	4.03	0.15
	4.02	3.70	0.32
	3.79	3.35	0.44
	3.91	3.30	0.61

It should be noted that the model did not accurately capture the flooding alongside the intersection of 224th Street and 136th Avenue. Observations suggest that most of this water was carried in the adjacent ditch, part of the local minor stormwater system that was not included in this large scale flood model. The relatively large difference in peak water levels modelled west of 224th St. may be caused in part by the fact that the model did not capture the routing water through this ditch. This should be confirmed using flood extents data collected during future flood events.

7.4.2 MIKEFlood and MIKE21 Model Verification

It was not possible to complete a detailed verification of the MIKEFlood and MIKE21 model with the January 2015 event, as the event was lower and no flooding extents were recorded. The model results were simply reviewed to confirm that no flooding extents were generated.

7.5 Model Limitations

The simulation of the November 2014 flood confirms that the model is capable of predicting flood extents and water levels, and provides insights into the progression of flooding in Maple Ridge. The model performed well, with modelled and observed lateral extents and high water levels matching closely. The model should be seen as a valid and useful tool for flood management planning for the region.

However, the model does have limitations that need to be recognized. It assumes the river bed and banks are fixed. However, bank erosion, sedimentation and log jam formation can all occur during major floods, especially in the more dynamic North Alouette River. These processes can affect the local hydraulic conditions considerably. It should also be noted that the computed flood extents represent riparian flooding from the main river channels. The model is not intended for representing localised ponding on isolated, low-lying portions of the floodplain caused by the accumulation of rainwater or melting snow. Localised ponding is controlled by rainfall intensity, local topography, drainage characteristics of the soil and the capacity of drainage structures such as culverts and ditches.

7.6 Model Results

7.6.1 Sensitivity Testing

Part of the process of developing hydraulic models is conceiving a set of reasonable assumptions that define the model structure and its inputs. Some of the assumptions made during the model development relate to model boundaries and channel and floodplain roughness. Sensitivity analyses on these assumptions were conducted by re-running the model with slight variations on the assumptions. The results of the sensitivity analyses are presented in this section.

Model Inflows

Water levels and inundation area are a function of the inflows used for the modelling. To test the sensitivity of this, the model was run with some simple changes to the 5-year design inflows. All 5-year design inflows to the model (mainstem and tributary) were increased and decreased by 10%. This variation in peak flows corresponded to an average variation in water levels of approximately 15 cm along the length of the river, with a total range of 10 cm to 20 cm, depending on location.

The impact on water levels and inundation areas are presented in Table 20.

Table 20. Peak river water levels for flow sensitivity analysis.

Gauge Name	River	Chainage (m)	Peak WLs (m GSC)		
			5yr Results	+10% Flow	-10% Flow
232nd Street HWM	North Alouette	10265	15.09	15.17	15.06
AVA Gauge	North Alouette	9937	13.11	13.18	13.08
Maple Ridge Gauge	North Alouette	8340	7.61	7.62	7.42
Pitt Meadows Gauge	Alouette Confluence	31	3.53	3.60	3.49
South Alouette WSC	South Alouette	18973	14.20	14.30	14.11

Roughness Coefficients (Channel and Floodplain)

A key parameter in any hydraulic model is the roughness coefficient. For a coupled MIKEFlood model, roughness parameters are estimated for both the channel (in MIKE11) and for the floodplain (in MIKE21). For the Alouette flood model, the November 2014 calibration event was used to select roughness values in both model domains. To test the sensitivity of these inputs, two additional model runs were completed where the channel and floodplain roughness were all adjusted up and then down by 10%. As with the other sensitivity runs, the 5-year event was used as a base case. Results of this analysis suggest a range of 9 cm to 21 cm in total water level variation, with an average variation of 13 cm (Table 21).

Table 21. Peak river water levels for roughness sensitivity analysis.

Gauge Name	River	Chainage (m)	Peak WLs (m GSC)		
			Calibration	+10% M	-10% M
232nd Street HWM	North Alouette	10265	15.09	15.16	15.03
AVA Gauge	North Alouette	9937	13.11	13.18	13.05
Maple Ridge Gauge	North Alouette	8340	7.61	7.40	7.66
Pitt Meadows Gauge	Alouette Confluence	31	3.53	3.58	3.49
South Alouette WSC	South Alouette	18973	14.20	14.29	14.12

7.6.2 Design Flood Modelling

The model has been run for seven design scenarios from the 2-year event through the 200-year event. Design inflow hydrographs correspond to those developed in Section 4.4 and include a 10% flow increase on the North Alouette and all tributaries as an allowance for climate change (Table 7). All unregulated inflows were timed to peak simultaneously. Outflows from the Alouette Reservoir to the downstream South Alouette River include a 7.5 hour delay due to reservoir routing.

Downstream boundary conditions were set to a large winter flow on the Fraser River and incorporate a year 2100 sea level rise allowance of 1 m, which yields a high water level of 3.1 m GSC at the confluence of the Pitt and Alouette Rivers. This downstream water level was held constant througout the design events, as the rise and fall of water levels due to large events on the Fraser is much slower than that of the Alouette Rivers system. The sea level rise allowance only affects water levels at the very downstream ends of the rivers.

It should be noted that the Tretheway Dike is located near the western edge of the study area. This dike is known to be substandard and the area which it protects would be inundated at flows less than the 200-year event on the Alouette Rivers. As no breach analysis or detailed review of this dike was completed as part of this work, the corresponding flood levels in this area are not known. For the purposes of flood modelling, extent maps and hazard maps, this area is shaded in grey.

Flood extent maps for each of the seven design scenarios are available in Map 1 to Map 7. Three flood scenarios; the 2-year, 25-year and 200-year floods are compared to provide an overview of inundation:

2-Year Flood Depths

The 2-year flood extents mapping shows more extensive flooding than the 2014 calibration event, suggesting the calibration flood had a return period under 2 years. While the 2014 event had only localized flooding at low points adjacent to the river, the 2-year extents show an interconnectivity between low points. Water is shown flowing freely along lower sections of the floodplain, including areas north of the North Alouette Rivers and in between the North and South Alouette Rivers.

It is important to note that there are several areas adjacent to the South Alouette River that show water depths of 1 m or higher. The largest of these areas are located between 224th Street and the Abernethy Way and upstream of the 232nd Street bridge. Both of these areas include residential development leading to potential evacuation of residents.

25-Year Flood Depths

By the 25-year event, a majority of the study area experiences some inundation. Although most of the inundated area remains below 0.5 m of depth, walking or driving become potentially dangerous activities. The same areas adjacent to the South Alouette River (between 224th Street and the Abernethy Way and upstream of the 232nd Street bridge) require residential evacuation and have localized depths of above 2 m. Agricultural and undeveloped land near the North Alouette Greenway is also inundated to a depth great than 1 m.

The 25-year event also shows the formation of deep channel flow crossing the flood plain. Narrow channels with depths of water greater than 1m are observed crossing between the two rivers and following local ditch systems north of the North Alouette River. This channelized flow is especially dangerous and is better highlighted in the hazard mapping in the following section.

200-Year Flood Depths

During the 200-year flood event, water levels are high enough to cover most of the local high points within the floodplain. Much of the floodplain experiences water levels above 0.5 m, flooding the ground floor of buildings and causing electrical failures. This is also deep enough to cause vehicles to be carried off roadways. Under these conditions, safe ground transport is not possible. For historical reference, this event is larger than the flood event experienced on the North Alouette River in 2007.

Residential development along the South Alouette and portions of the North Alouette experience flood depths in excess of 1 m and should be evacuated. Evacuation is also recommended for residents within the floodplain between the two rivers where water depths exceed 1m and flow may become channelized. Inundation of the agricultural and undeveloped land near the North Alouette Greenway is expected to exceed 2 m of depth.

7.6.3 Flood Hazard Mapping

Flood hazard maps for planning and emergency management are included in Maps 8 to Map 14 and are based on the results of the design flood modelling. Hazard rating is a function of water depth and velocity (m*m/s). Hazard ratings are based on the 'Hazard to People flood thresholds' determined in the UK, which are summarized in Table 22 below (UK DEFRA/EA 2006):

Table 22. 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** (e.g. 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."

2-Year Flood Hazard Rating

The 2-year flood hazard mapping shows relatively low hazard ratings across the inundated extents. There is some interconnectivity between low points and water flows freely along lower sections of the floodplain. However, moderate and significant hazards are present only in small creeks and ditches.

Exceptions are found adjacent to the South Alouette River between 224th Street and the Abernethy Way and upstream of the 232nd Street bridge. In these locations, water depths and velocities reach moderate to significant ratings. Significant hazards are dangerous for most people; these areas are within the flood zone and contain deep, fast flowing water. As noted in the previous section, both of these areas contain residential development and would likely need to be evacuated.

25-Year Flood Hazard Rating

By the 25-year event, a majority of the study area has a hazard rating and caution is recommended. Moderate to significant hazard ratings are assigned to the lands adjacent to the South Alouette River and the agricultural and undeveloped land near the North Alouette Greenway. Moderate to significant hazard ratings also apply to areas adjacent to the North Alouette River near the 232nd Street bridge, 132nd Avenue bridge and 224th Street bridge. These areas become flood zones with deep, fast flowing water and are dangerous for most people.

Significant to extreme hazard ratings are applied to the deep channels crossing the floodplain and along the South Alouette between 224th Street and the Abernethy Way and upstream of the 232nd Street bridge. These areas should be associated with an extreme danger rating.

200-Year Flood Hazard Rating

During the 200-year flood event, most of the local high points within the floodplain are no longer dry and caution is recommended throughout the floodplain. The floodplain is interlaced with low lying sections and channelized flow with significant hazard ratings, dangerous for most people. Under these conditions, safe ground transport is not possible.

Significant to extreme hazard ratings are also applied to much of the flood plain along the South Alouette River and to the land near the North Alouette Greenway. Along the North Alouette, significant hazard ratings are noted in areas adjacent to the North Alouette River near the 232nd Street bridge, 132nd Avenue bridge and 224th Street bridge. Full evacuation should be completed from these areas prior to peak inundation. This requires a large and highly organizaed evacuation plan and the implementation of a hazard warning system.

8 FLOODPLAIN MAPPING

The 200-year floodplain mapping is included under the Floodplain Mapping tab. The 200-year flood construction levels (FCLs) shown incorporate a freeboard of 0.6 m. Also included is the 25-year flood level with a freeboard allowance of 0.6 m. This 0.6 m freeboard allowance acts as a margin of safety to account for various sources of uncertainty in the model as well as local variations in topography and corresponds to the provincial standard. Mapping was completed using the 200-year and 25-year results described in Section 7.6 and include a 10% increase in flows on all unregulated flow sources to allow for climate change impacts as recommended by APEGBC (2012). All unregulated inflows were timed to peak simultaneously. Outflows from the Alouette Reservoir to the downstream South Alouette River include a 7.5 hour delay due to reservoir routing. Downstream boundary conditions were set to a large winter flow on the Fraser River and incorporate a 1 m sea level rise allowance for year 2100 conditions, also as recommended by APEGBC (2012).

LiDAR data surveyed in 2014 was used to create a digital elevation model (DEM) for the study area. The DEM was modified to include ground survey data for the 132nd Avenue bridge on the North Alouette River, the 224th Street bridge on the North Alouette River and channel surveys for the North and South Alouette Rivers. The map depicts flood levels based on ground conditions represented in the 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.

Although the model geometry was kept fixed, variations (erosion, degradation or aggradation) may occur during a flood event and/or over time. The map does not provide information on site-specific hazards such as land erosion or sudden shifts in watercourses. Channel obstructions, local stormwater 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.

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. A qualified professional must be consulted for site-specific engineering analysis.

It should be noted that the Trethewey Dike at the downstream end of the study area does not meet provincial diking standards and would likely breach at some flow less than the 200-year flood. The area behind the dike is considered part of the floodplain although not specifically mapped due to the absence of breach modelling.

The 200-year flood extent map shows both the 2016 extents recommended by NHC and the currently approved flood extents, which were published in 1990. For the most part, extents from the two studies are very similar. However, there are some locations where the 1990 extents exceed the recommended 2016 extents. The largest variations can be observed at the north edge of the flood extents near 232nd Street as a result of the bridge replacement. Also, some variation is expected, as the 1990 mapping was completed using 1m topographic data, which is far less detailed than the LiDAR obtained in 2014. The design flows used for the 1990 mapping are also slightly more conservative. Yet, there are areas where the 2016 inundation boundaries exceed the 1990 limits, slightly increasing the floodplain.

The finalized inundation boundaries included in the map were verified during a field visit by NHC staff on 1 December 2015. Locations and local topography were reviewed based on variations between model 200 year FCL results and the 1990 mapping.

9 PROJECT SUMMARY, CONCLUSIONS AND BENEFITS

9.1 Summary and Conclusions

1. The hydrologic regimes of the North and South Alouette Rivers are distinctly different. The North Alouette, being smaller (drainage area of 37.3 km^2) and unregulated, responds quickly to storm events, particularly large rain or rain-on-snow events. The much larger watershed of the South Alouette (total drainage area of 234 km^2) includes the regulated Alouette Lake which is dominated by spring freshet type events. However, downstream of the dam, peak flows occur during the winter.

2. Both rivers are dynamic and their channel geometry has changed over the past century; these changes are more apparent on the smaller, unregulated North Alouette system. There is evidence that some aggradation may be taking place in the lower North Alouette study reach. The regulation of the South Alouette River, which decreases peak flows downstream of the dam, has altered the natural geomorphology of this system, with some corresponding reduction in channel size. Due to the channel changes and extensive development within the floodplain, the City identified a need to update the floodplain mapping from 1990.

3. Channel cross-section surveys from 2014, high-quality LiDAR data also from 2014, and the collection of calibration data during the winter of 2014-2015, allowed for development of a sophisticated 2-dimensional MIKEFlood numerical model. The hydraulic model was used for simulating the flood levels corresponding to the 2, 5, 10, 25, 50, 100 and 200-year events and subsequent generation of flood extent and flood hazard mapping for these flows. The updated and improved mapping, based on current topographic information, recent flow estimates and much improved hydraulic modelling methods, is more accurate than the 1990 floodplain maps and replaces these.

4. The 200-year updated peak flows on the North Alouette River include a 10% increase to account for projected approximate climate change impacts to the year 2100, as recommended in the APEGBC (2012) guidelines. No extra allowance was made for climate change on the South Alouette River for outflows at the dam, as it is assumed that BC Hydro will adjust their operating procedures over time to compensate for climate change. Compared to the previous hydraulic modelling boundary conditions used for the 1990 floodplain mapping, the updated North Alouette River maximum instantaneous flow is 6% lower and the updated South Alouette

maximum instantaneous flow is 11% lower, implying the previous values were conservative in view of presently available records.

5. A sea level increase of 1 m at the mouth of the Fraser River was assumed but was found to only affect the very downstream reaches of the rivers within the study area. Assuming a high winter tide, including sea level rise, and a large winter flow on the Fraser River yielded a water level estimate of 3.1 m GSC at the confluence of the Pitt and Alouette Rivers.

   The updated downstream starting level is 1.6 m lower than the starting level used in 1990 and reflects winter conditions, when the Alouette Rivers peak, rather than the freshet level as previously used. (The current freshet design level at Pitt River confluence is 5.5 m and does not affect design levels in the study area.

6. Flood extent mapping for the 200-year flood suggests water levels will cover most of the local higher-elevation areas within the floodplain. Much of the floodplain will experience water depths above 0.5 m, typically flooding the ground floor of buildings and causing electrical failures. This depth will cause vehicles to be carried off roadways and safe ground transport will generally not be possible. For historical reference, this event is larger than the flood event experienced on the North Alouette River in 2007.

7. Flood hazard mapping for the 200-year flood shows that the floodplain is interlaced with low lying sections which experience extensive flooding and semi-channelized flow, causing significant hazard ratings. 'Significant' to 'Extreme' hazard ratings are applicable to much of the flood plain along the South Alouette River, land near the North Alouette Greenway and along the North Alouette River near the 232nd Street, 132nd Avenue and 224th Street bridges.

8. Floodplain mapping corresponding to the 200-year flood was prepared for the North and South Alouette Rivers' study area. The 200-year flood construction levels (FCLs) include a freeboard allowance of 0.6 m. The mapping also shows levels corresponding to the 25-year flood level including 0.6 m freeboard. Isolines are based on the 2D model output. The inundation boundaries were verified in the field by NHC staff and are similar to those prepared in 1990 by the provincial government. Compared to the previous mapping, the floodplain is reduced somewhat in a few areas and slightly increased in others.

9.2 Project Benefits

Over the past decades flooding along the Alouette Rivers, especially the North Alouette, has become a source of increasing concern for the residents of the floodplains. In 2007, extensive flooding prompted the creation of a multi-stakeholder Task Force which had as its objectives to compile information on flood issues and develop a strategy to manage and/or reduce the flood risk of the area. Six focus areas were: 1) River hydrology, hydraulics and floodplain mapping; 2) River operation and maintenance; 3) Flood response; 4) Flood proofing and protection; 5) Data collection and information sharing; and 6) Floodplain management roles and responsibilities.

The information compiled and floodplain maps developed as part of the present project forms a key tool in meeting the Task Force objectives and aiding the City in moving forward to reduce potential future flood losses. Key benefits of the project are:

- Areas prone to flooding during different return period events are now identified and up-to-date FCLs estimated. Over time, appropriate flood protection measures (structural and non-structural) can be developed for affected housing and long-range improvements to infrastructure be planned.

- The hydraulic model forms a tool for evaluating the impact on flood levels caused by changes within the floodplain and the river channels. The effects on flood levels resulting from fill placement, new diking or development on the floodplain can be evaluated using the model. The benefits of enlarging bridge openings/ culverts or removing gravel depositions and debris can be assessed.

- The hazard mapping can be used for issuing flood warnings to areas likely to be affected during particular events and for developing emergency response procedures. The maps indicate which roads will be most severely affected at a particular flow and safe access/egress routes can be identified.

- The mapping forms a public educational tool to inform residents regarding flood hazards and to provide guidance on improving residents' safety.

- An important component of flood preparedness is flood recovery. (This was clearly demonstrated after the Calgary 2013 flooding, where recovery plans had been developed in advance.) The present mapping products will aid in developing flood recovery procedures.

The City's investment in floodplain mapping products is of significant value and facilitates: 1) the identification of present flood hazards; 2) evaluation of any planned future changes in the floodplain/river channels; and, 3) development of flood management tools as outlined in Section 10.2.

10 RECOMMENDATIONS

10.1 Technical Recommendations

1. It is recommended that the City adopt the updated 200-year floodplain maps and incorporate the revised FCLs into flood bylaws. Flood bylaws serve to clarify future development guidelines and provide regulations regarding building renovations and any modification to the floodplain. Typically, bylaws have the added benefit of reducing the City's liability. They are generally developed in two phases, the first phase requiring engineering input and application of the available floodplain mapping and the second phase involving legal review.

2. It is recommended that a flood early-warning system be developed for the North Alouette. NHC previously reviewed the practicality of installing real-time flow gauges in the upper watershed but concluded that these would not provide a beneficial increase in advance flood warning. Similarly, hydrologic runoff modelling is not a practical option since insufficient model calibration data is available. As an alternative, real-time precipitation data could be used in conjunction with existing water level gauges to obtain valuable information during flood events. At the very least, one real-time precipitation gauge would provide an indication of anticipated changes in water levels downstream or potentially allow the detection of a debris blockage on the upper North Alouette. The work would involve reviewing historic peak flows and precipitation records to explore if a reasonable relationship can be developed between the two, incorporating antecedent ground conditions.

3. The hydraulic model provides a snap-shot in time of river conditions corresponding to the estimated flood flows and the surveyed cross-sections/floodplain. The model and corresponding mapping need to be updated over time, typically at least every ten years or following a large flood. The following specifics are recommended:

   a) Record peak flows, high water marks and flood extent information during future floods (return period of 5-10 years or more) to fine-tune the present model calibration and increase the floodplain mapping accuracy.

   b) Encourage WSC to maintain their gauges on the Alouette River systems and ensure that rating tables are kept current. The AVA and Maple Ridge gauges are also valuable and need to be maintained. Make all information available in real-time.

   c) Over time, monitor temperature, precipitation and flows in the study area to identify potential climate change impacts.

   d) Confirm with BC Hydro the assumptions made regarding future operating procedures of the Alouette Dam.

   e) Monitor channel changes and any changes within the floodplain and resurvey as deemed necessary. Update the hydraulic model and floodplain maps.

10.2 Flood Management Recommendations

Considering the frequency and severity of flooding within the Alouette River watersheds, it is recommended that an integrated flood management plan be developed, incorporating both structural and non-structural measures. The plan should incorporate the following components:

1. Develop a flood emergency preparedness and response plan. Utilizing the floodplain and hazard mapping, the plan should be prepared jointly between the City and its First Responders. High priority should be given to safe access/egress to reduce the risk of loss of life during large floods. This is of particular concern within the low-lying land between the two rivers, where pre-planning is critical to the safe transport and possible evacuation of residents.
2. Develop guidelines for a flood recovery program. The program needs to clarify the impacts of flooding, likely inundation durations, the potential extent of damages and procedures for recovery.
3. Carry out a vulnerability assessment to identify the potential for loss-of-life, economic losses, social and environmental losses resulting from a particular flood or a range of floods. The purpose of the assessment is to identify critical areas where potential losses are highest and flood mitigation most urgently needed. The work can be completed at either an overview level or as a more detailed evaluation.
4. Based on identified high risk areas, develop suitable flood mitigation options and associated approximate costs for initial evaluation. Improvements in one area must not negatively affect flood hazards in another area.

REFERENCES

APEGBC 2012. *Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC.* Professional Practice Guidelines.

BC Environment 1990. *A Design Brief on the Floodplain Mapping Study Alouette and North Alouette Rivers.* Floodplain Mapping Design Brief.

City of Maple Ridge 2010. Discussion with Operations Staff (Russ Carmichael, Wayne Hardy, Ed Mitchell, Bernie Serne and Ralph Kivi), December 1st, 2010.

NHC 2006. *Lower Fraser River Hydraulic Model*. Final Report. Prepared for Fraser Basin Council, December 2006.

NHC 2010. *North Alouette and South Alouette Rivers' Assessment and Floodplain Analysis: Phase 1-Scoping*. Final Report.

UK DEFRA/Environment Agency 2006. *R&D Outputs: Flood Risks to People, Phase 2.* FD2321/TR2 Guidance Document.

Figures

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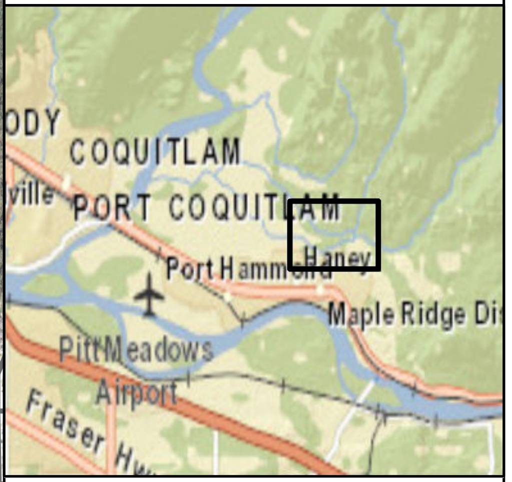

- Project Limits
- Bridge
- WSC Hydrometric Station
- AVA Hydrometric Station
- CMR Hydrometric Station
- River
- Dike
- Road

DATA SOURCES:
- City of Maple Ridge, 2011 Orthophoto
- GeoBase National Roads Network
- BC Freshwater Atlas
- Esri World Street Map

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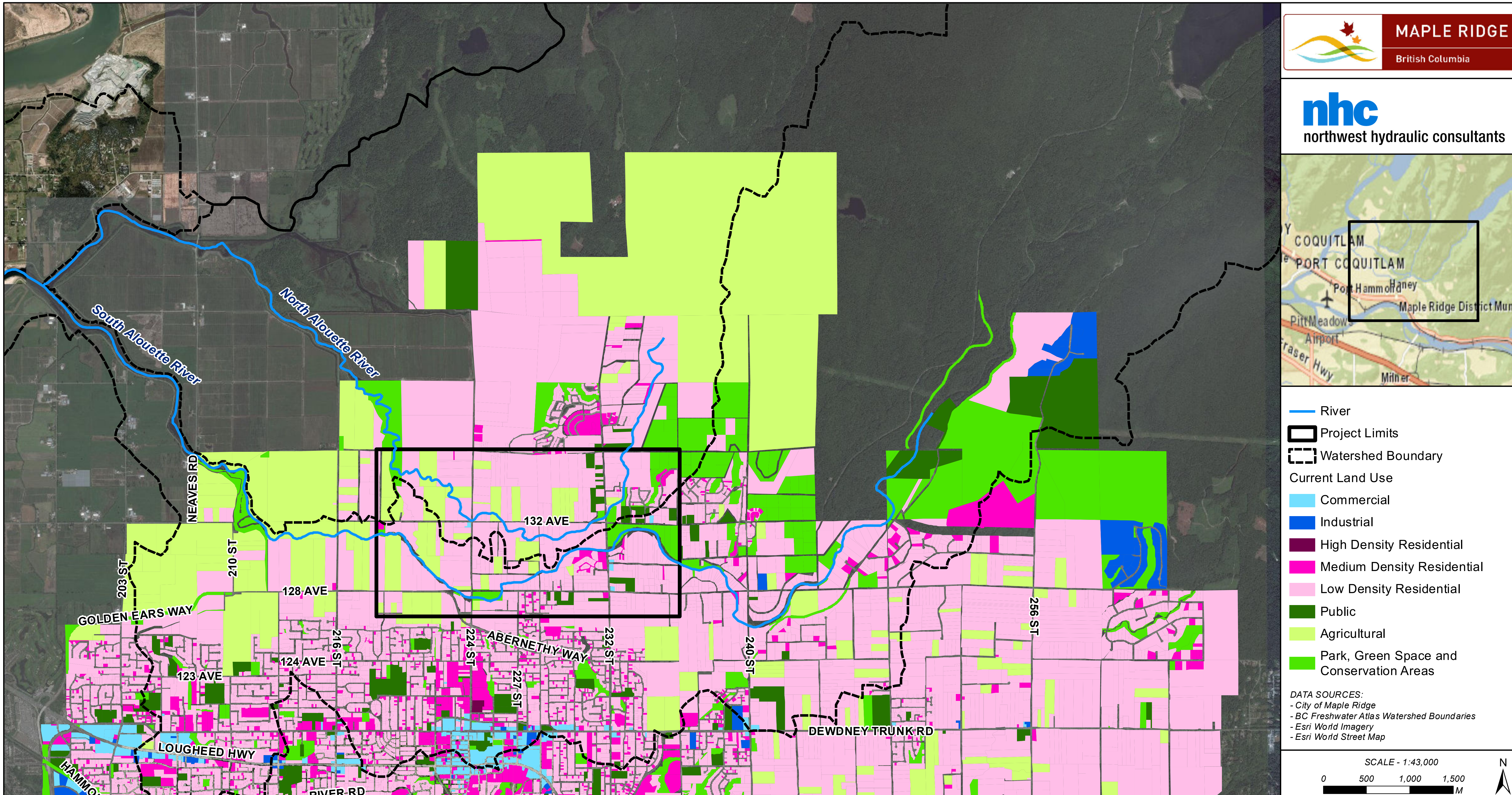
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES

Job: 300349	Date: 08-DEC-2015

ALOUETTE RIVERS ADDITIONAL FLOODPLAIN ANALYSIS

Study Area

FIGURE 1



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DATA SOURCES:
- City of Maple Ridge
- BC Freshwater Atlas Watershed Boundaries
- Esri World Imagery
- Esri World Street Map

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

Job:300349 | Date: 30-NOV-2015

ALOUETTE RIVERS
ADDITIONAL
FLOODPLAIN ANALYSIS

Current Land Use

FIGURE 2

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Bridge

Erosion Site

Deposition Site

DATA SOURCES:
- 2011 orthoimagery supplied by City of Maple Ridge.

SCALE - 1:6,000

0 50 100 150 200 250 M

N

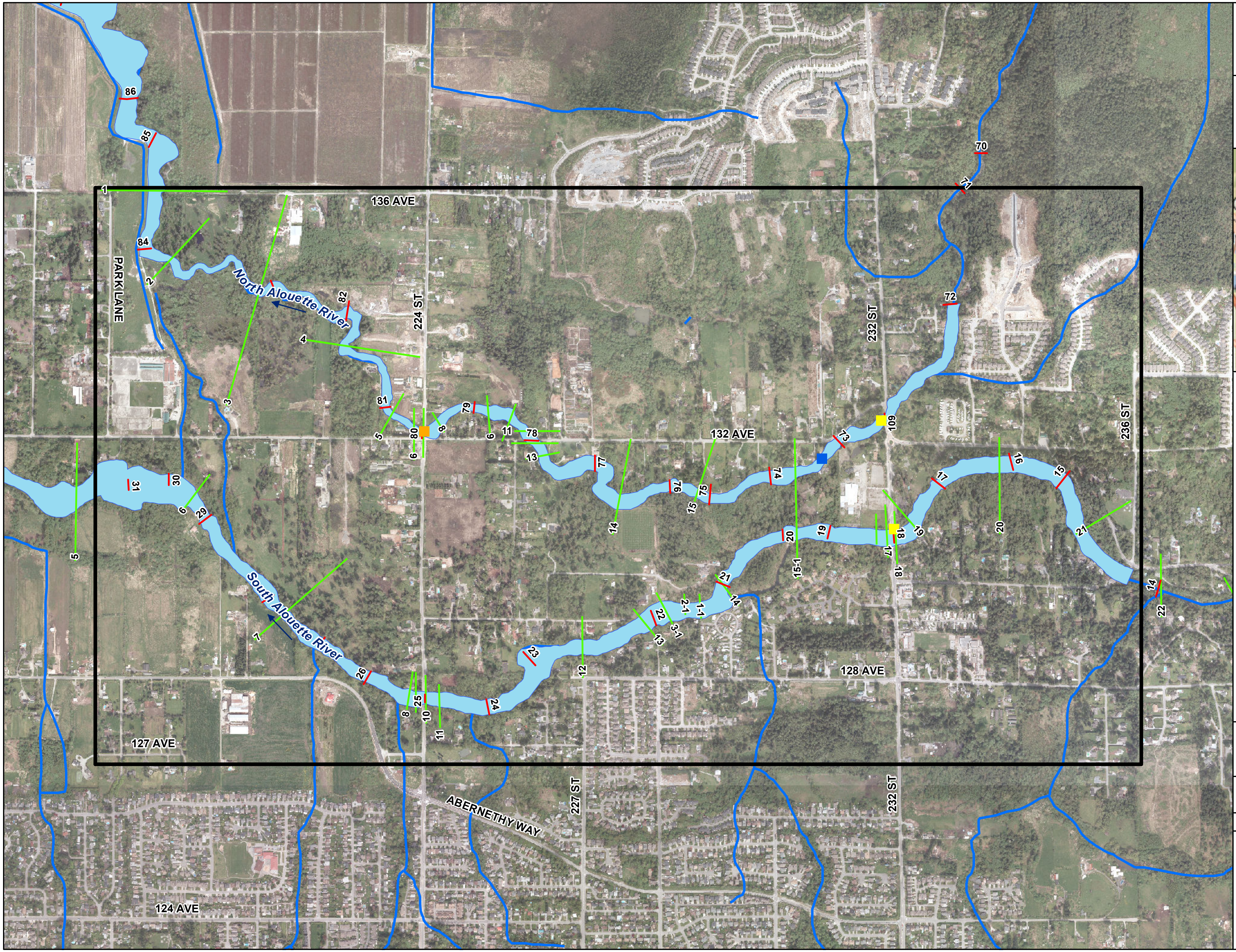
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES

Job:300349	*Date: 08-DEC-2015*

ALOUETTE RIVERS
ADDITIONAL
FLOODPLAIN ANALYSIS

North Alouette River
Overview of Geomorphic Features

FIGURE 3



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- Project Limits
- WSC Hydrometric Station
- AVA Hydrometric Station
- CMR Hydrometric Station
- 2008 Survey
- 1981 Survey
- River
- Stream

DATA SOURCES:
- City of Maple Ridge, 2011 Orthophoto
- BC Freshwater Atlas
- Esri World Street Map

SCALE - 1:12,000

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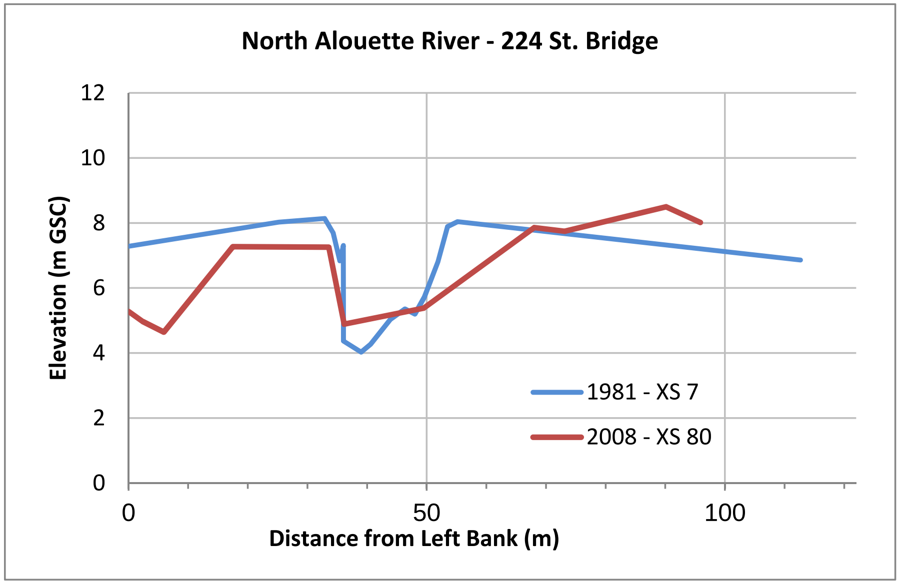
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES

Job: 300349	Date: 08-DEC-2015

ALOUETTE RIVERS ADDITIONAL FLOODPLAIN ANALYSIS
Historical Cross Section Locations

FIGURE 4

Historic Cross Section Comparison on North Alouette River



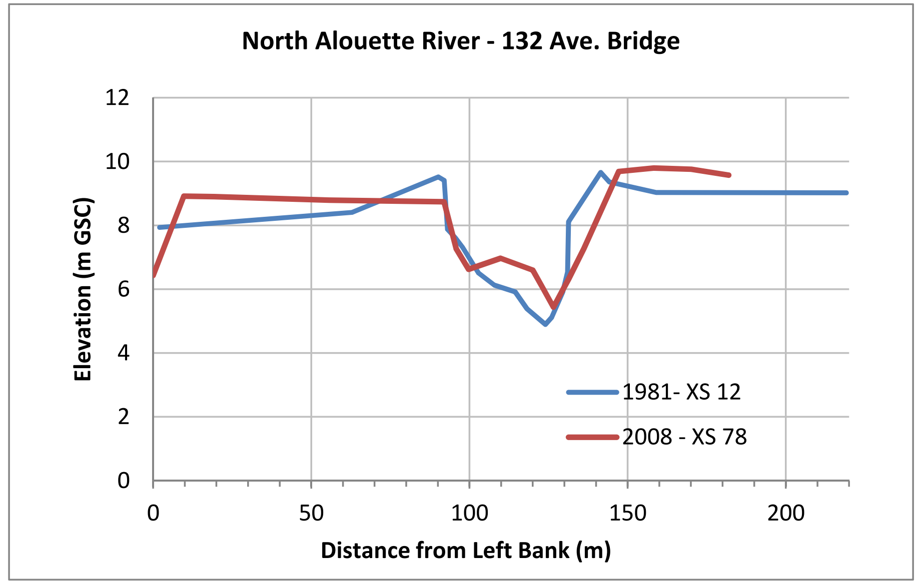
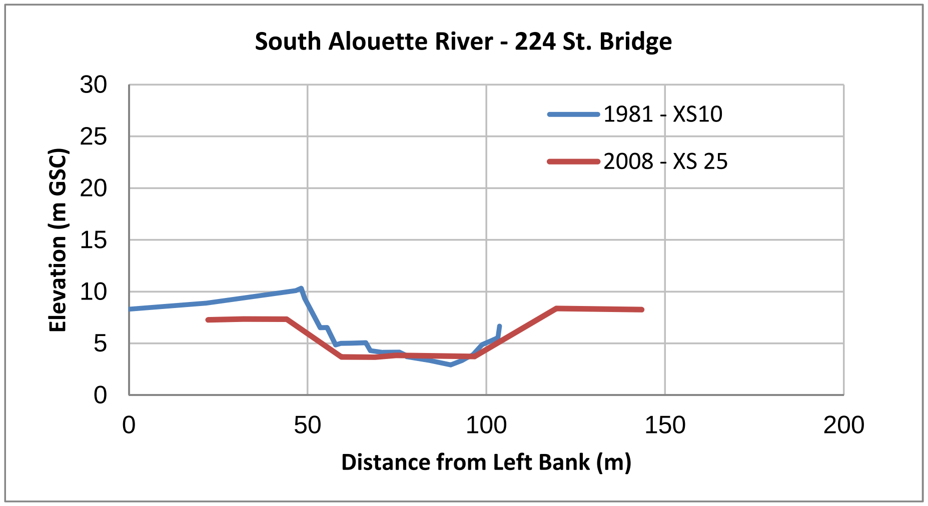
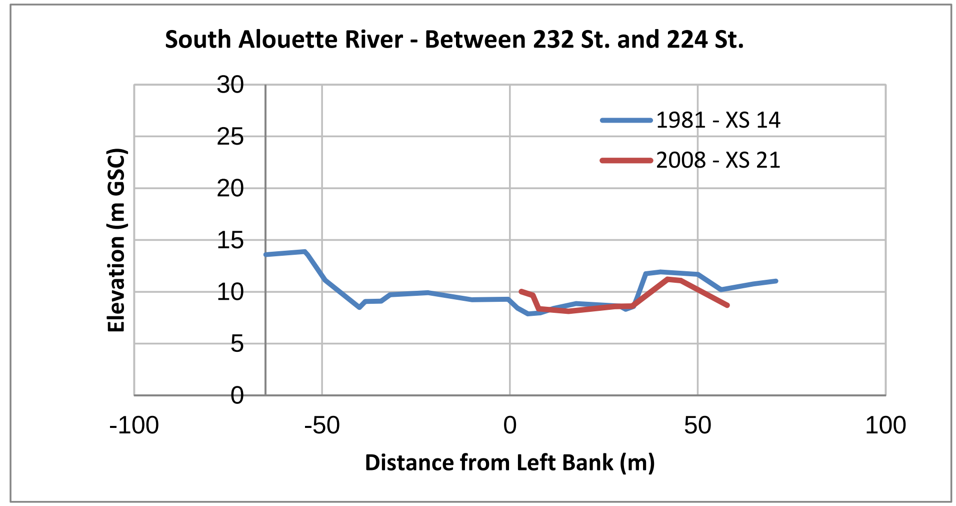
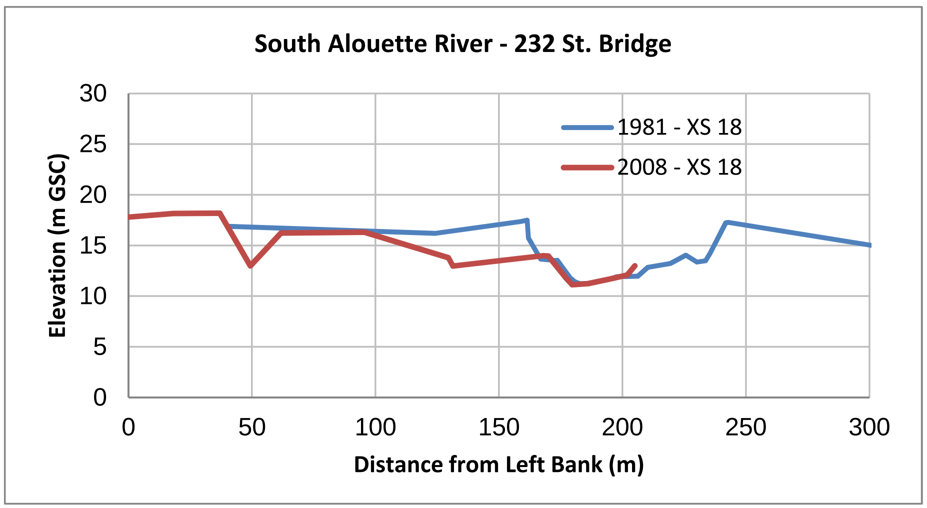


Figure 5

Historic Cross Section Comparison on South Alouette River







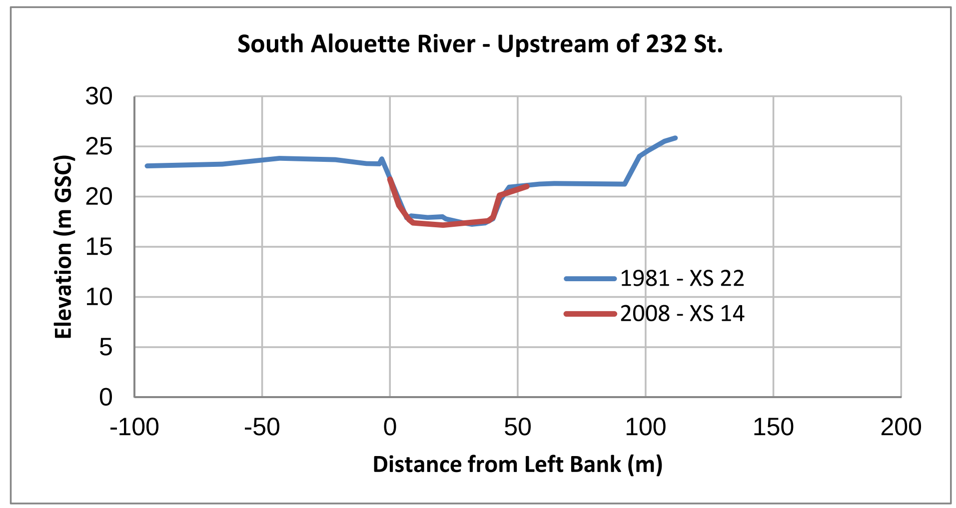


Figure 6

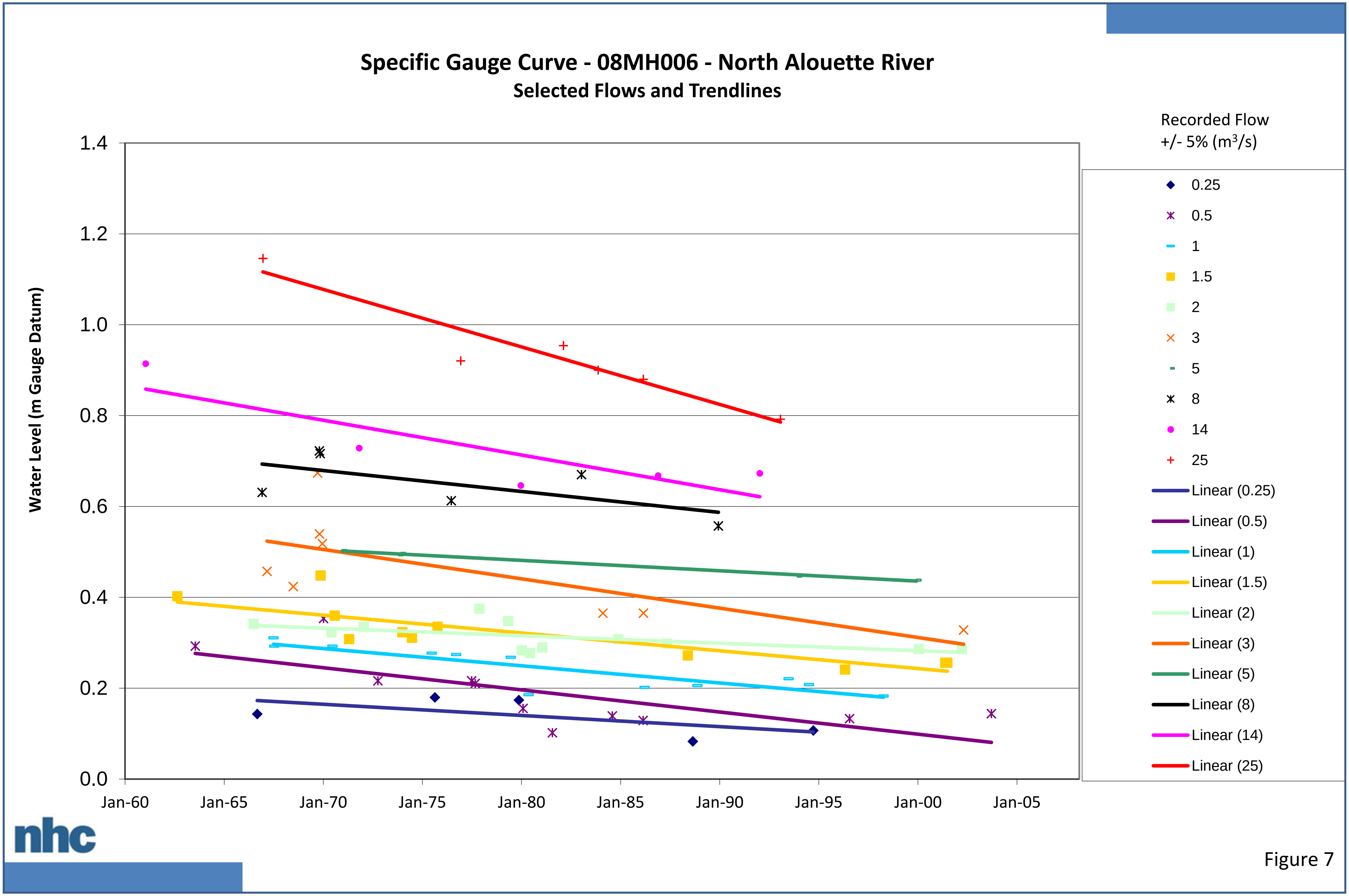

Specific Gauge Curve - 08MH006 - North Alouette River
Selected Flows and Trendlines
Water Level (m Gauge Datum)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Jan-60
Jan-65
Jan-70
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
Jan-00
Jan-05
Recorded Flow +/- 5% (m³/s)
0.25
0.5
1
1.5
2
3
5
8
14
25
Linear (0.25)
Linear (0.5)
Linear (1)
Linear (1.5)
Linear (2)
Linear (3)
Linear (5)
Linear (8)
Linear (14)
Linear (25)
nhc

Figure 7

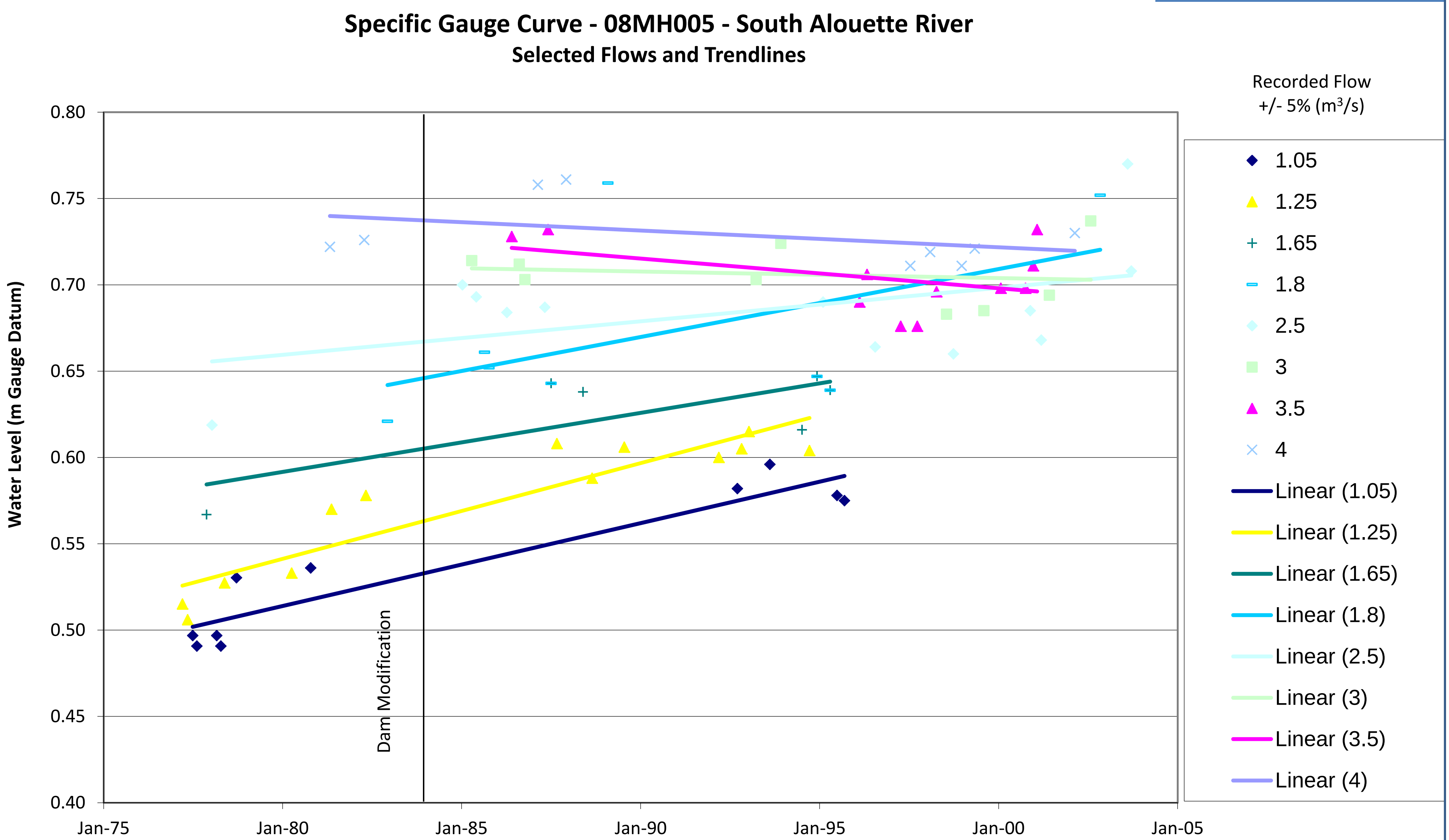

Specific Gauge Curve - 08MH005 - South Alouette River
Selected Flows and Trendlines
Recorded Flow +/- 5% (m³/s)
Water Level (m Gauge Datum)
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
Jan-75
Jan-80
Jan-85
Jan-90
Jan-95
Jan-00
Jan-05
Dam Modification
1.05
1.25
1.65
1.8
2.5
3
3.5
4
Linear (1.05)
Linear (1.25)
Linear (1.65)
Linear (1.8)
Linear (2.5)
Linear (3)
Linear (3.5)
Linear (4)

Figure 8

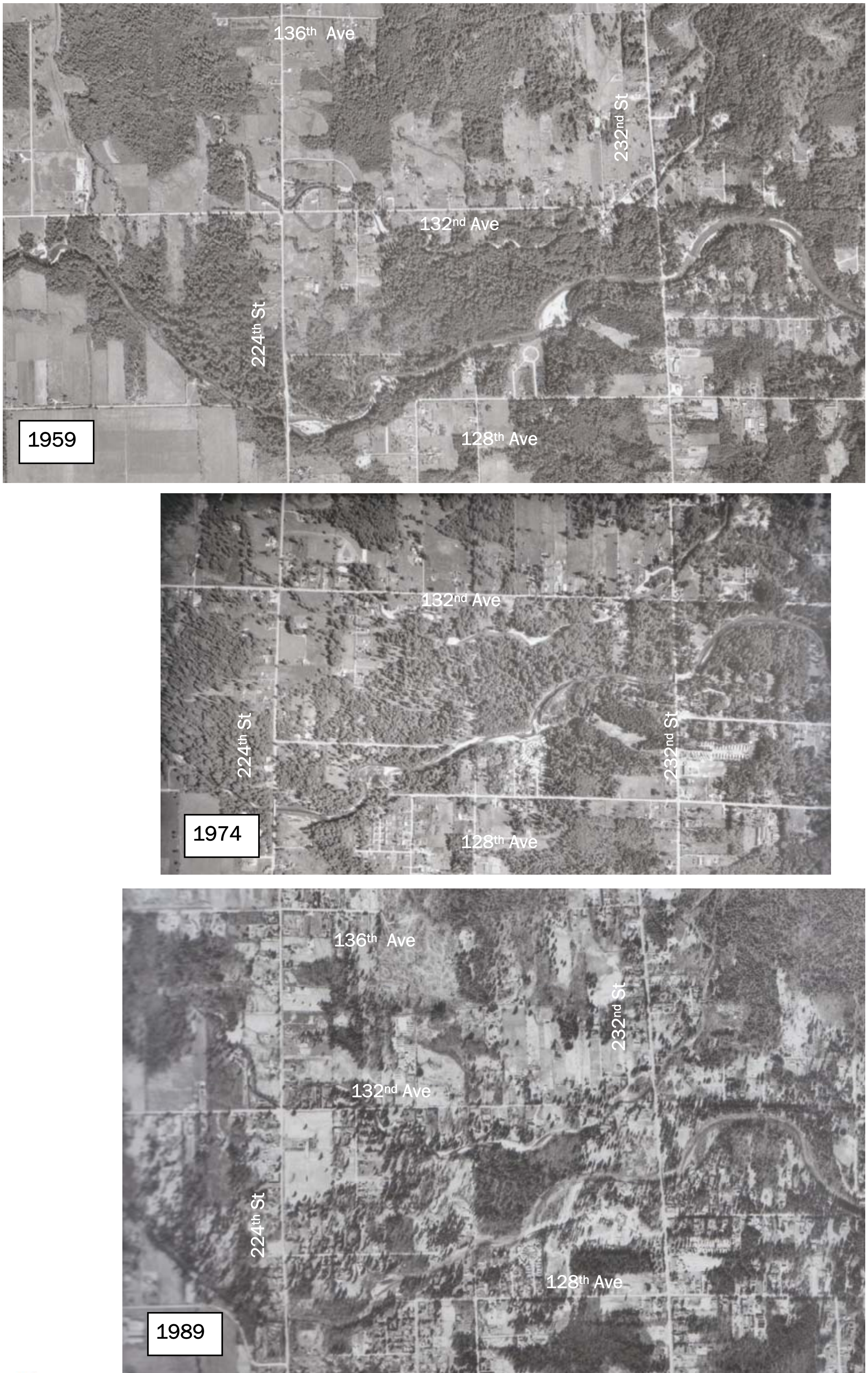
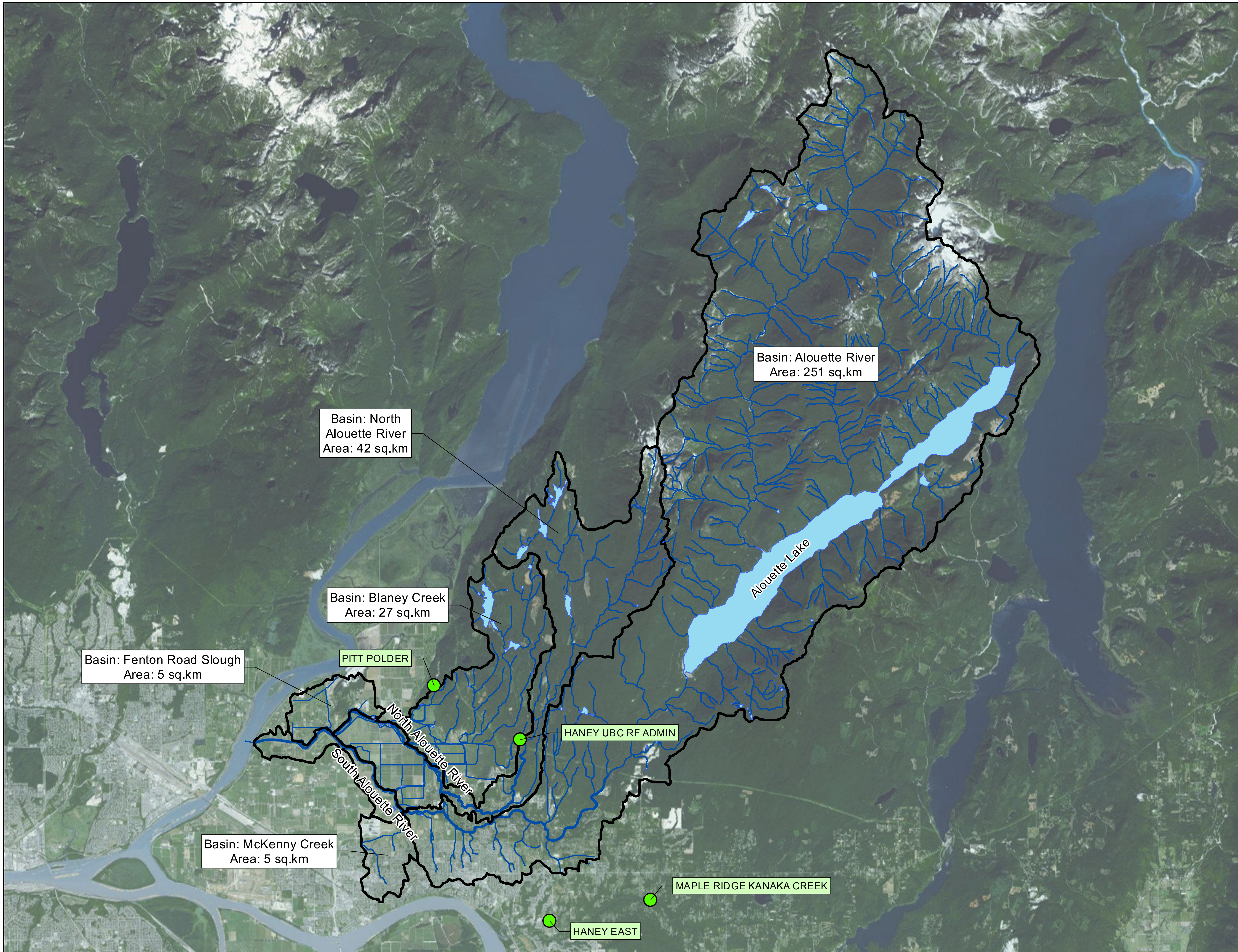


Figure 9a: Historical Airphotos of Study Area in Sequence

Figure 9b: Historical Airphotos of Study Area in Sequence



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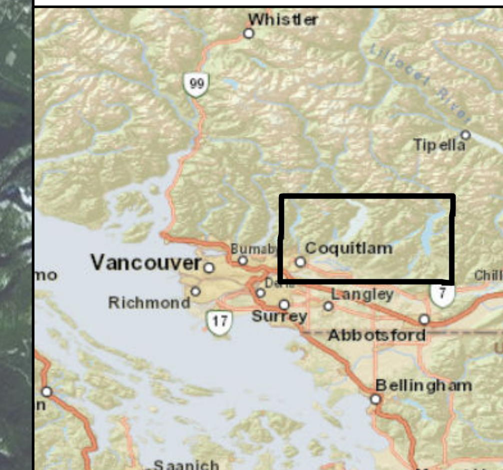

ClimateGauges
Lake
Watershed Boundary
Stream

DATA SOURCES:
- Streams and watershed polygons: BC Freshwater Atlas
- Orthophotos: ArcGIS Map Service, World_Imagery
- Inset map background: ArcGIS Map Service, Streetmap

SCALE - 1:135,000

0 1 2 3 4 5 KM

N

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

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ALOUETTE RIVERS ADDITIONAL FLOODPLAIN ANALYSIS

Alouette Rivers Watersheds

FIGURE 10

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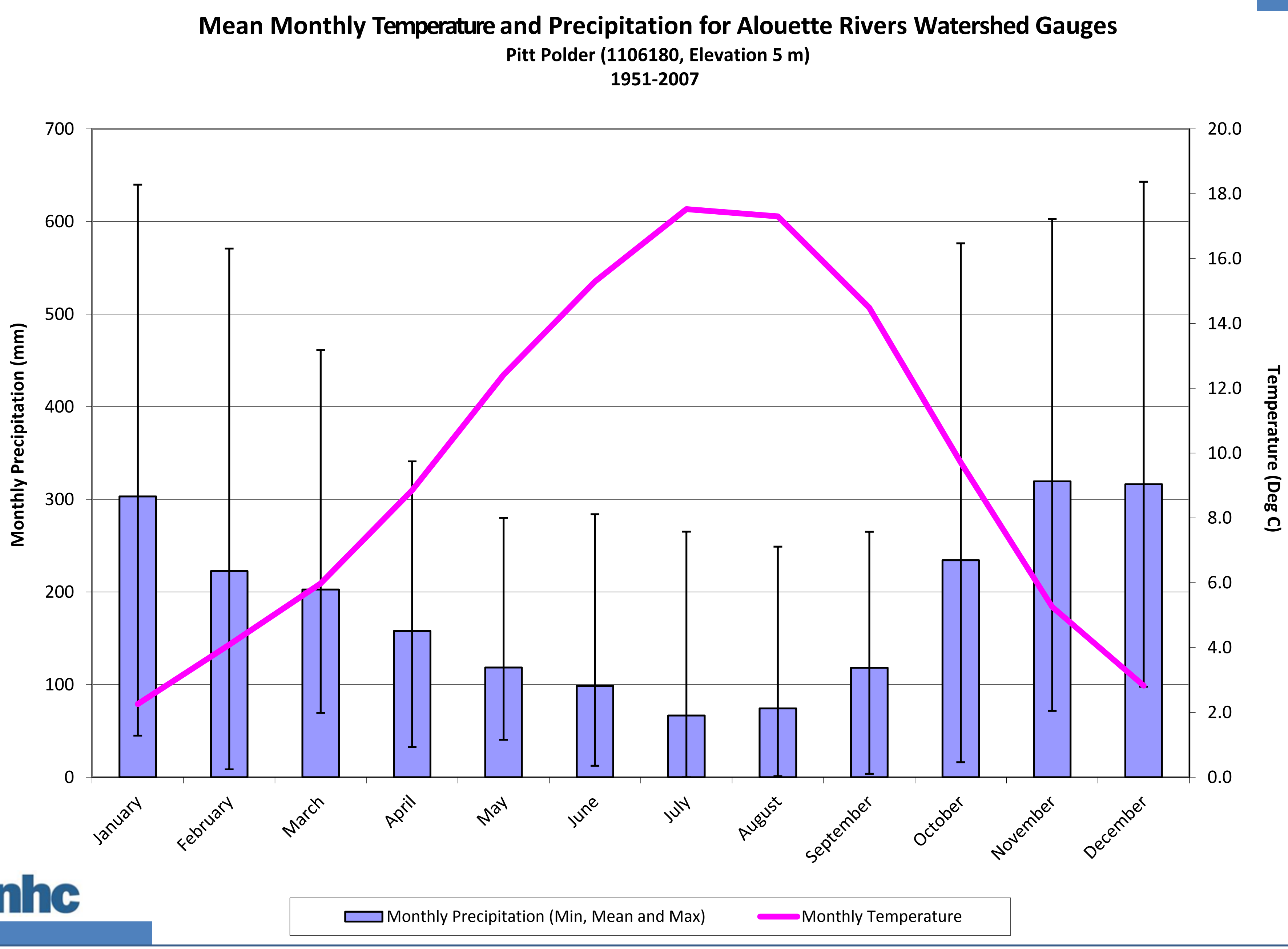
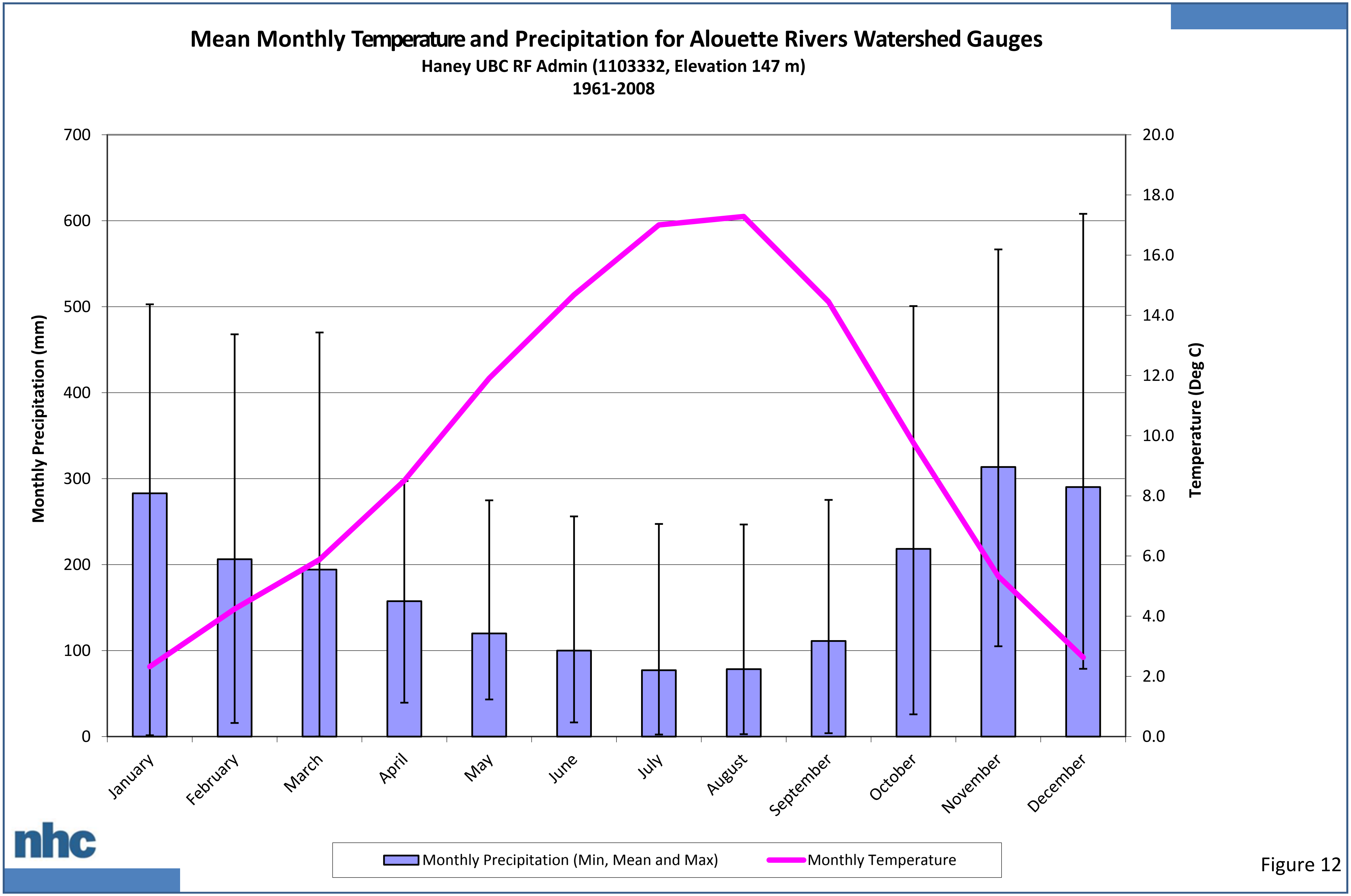


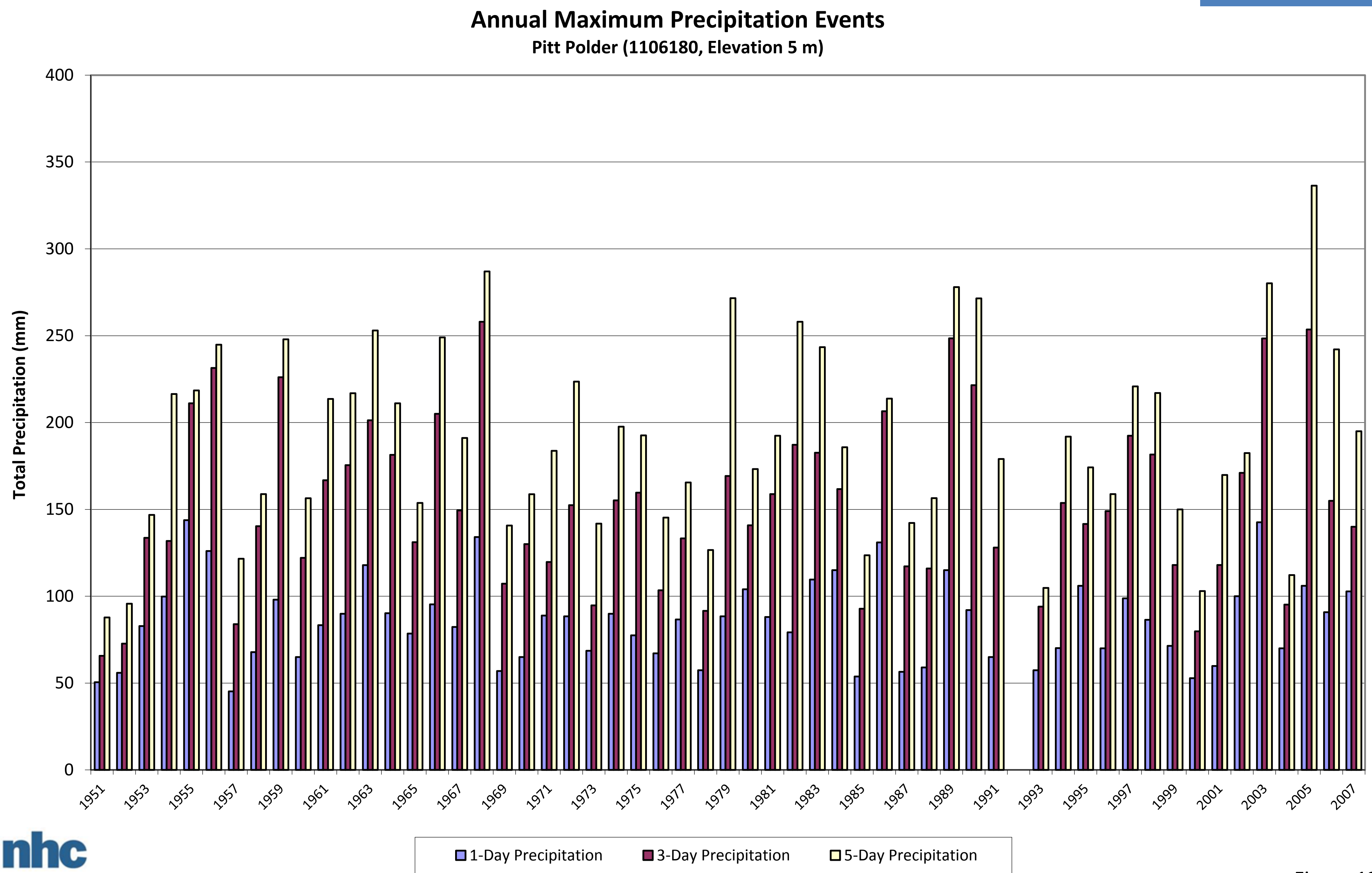
Mean Monthly Temperature and Precipitation for Alouette Rivers Watershed Gauges
Pitt Polder (1106180, Elevation 5 m)
1951-2007
Monthly Precipitation (mm)
Temperature (Deg C)
0
100
200
300
400
500
600
700
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
January
February
March
April
May
June
July
August
September
October
November
December
Monthly Precipitation (Min, Mean and Max)
Monthly Temperature

Figure 11



Mean Monthly Temperature and Precipitation for Alouette Rivers Watershed Gauges
Haney UBC RF Admin (1103332, Elevation 147 m)
1961-2008
Monthly Precipitation (mm)
Temperature (Deg C)
0
100
200
300
400
500
600
700
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
January
February
March
April
May
June
July
August
September
October
November
December
Monthly Precipitation (Min, Mean and Max)
Monthly Temperature

Figure 12



Annual Maximum Precipitation Events
Pitt Polder (1106180, Elevation 5 m)
Total Precipitation (mm)
0
50
100
150
200
250
300
350
400
1951
1953
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
1-Day Precipitation
3-Day Precipitation
5-Day Precipitation

Figure 13

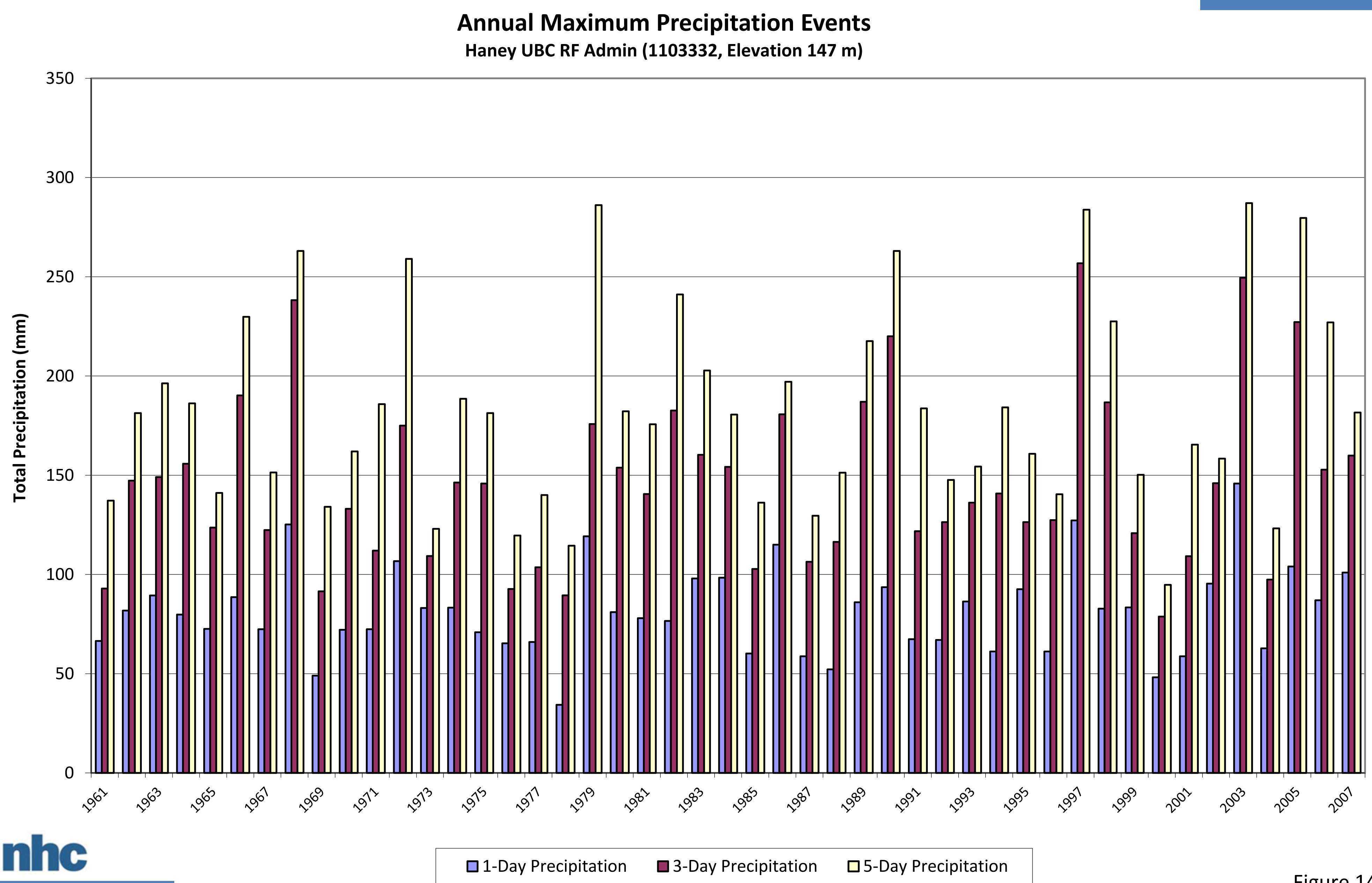
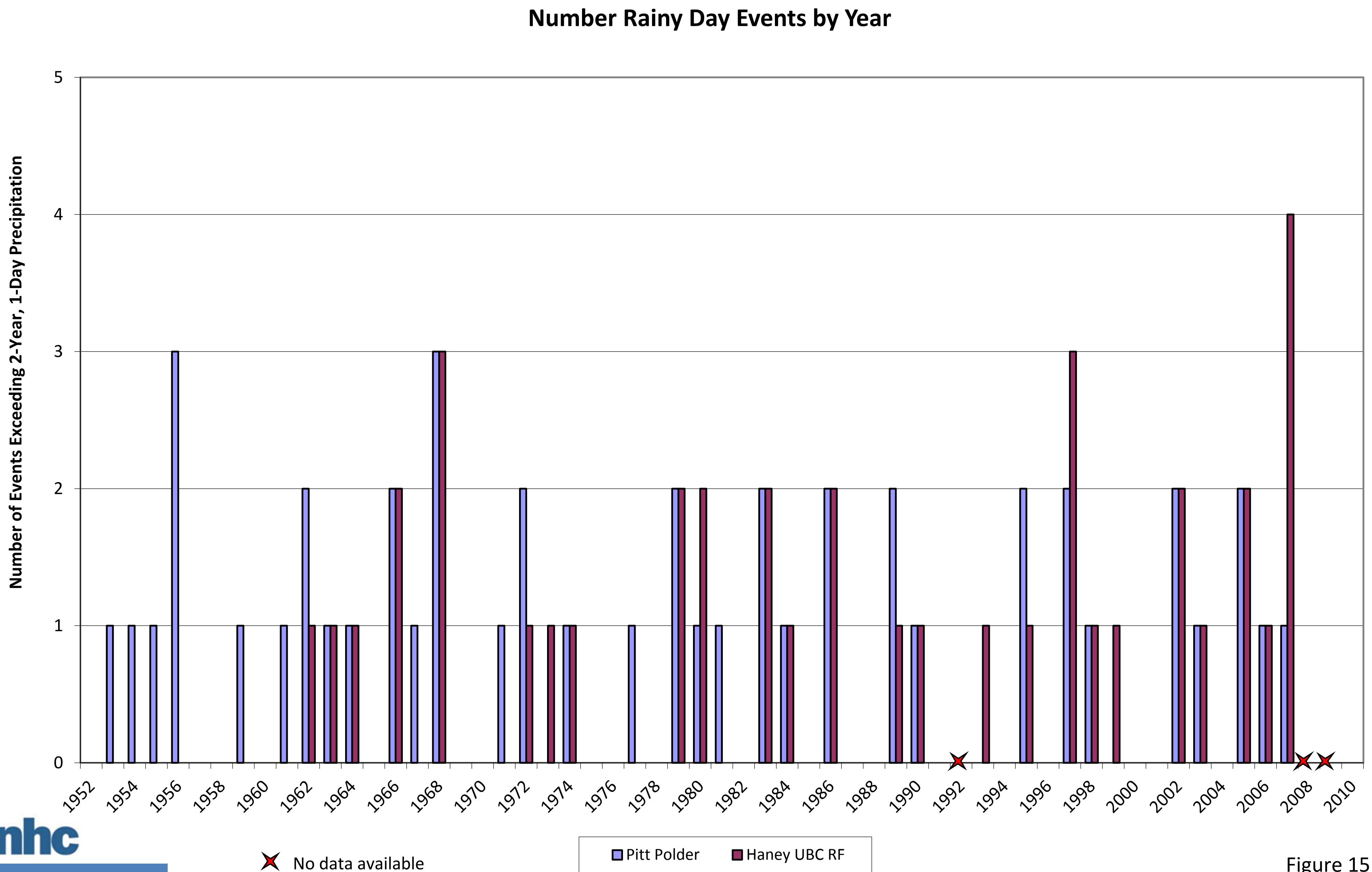

Annual Maximum Precipitation Events
Haney UBC RF Admin (1103332, Elevation 147 m)
Total Precipitation (mm)
350
300
250
200
150
100
50
0
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
1-Day Precipitation
3-Day Precipitation
5-Day Precipitation

Figure 14



Number Rainy Day Events by Year
Number of Events Exceeding 2-Year, 1-Day Precipitation
0
1
2
3
4
5
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
No data available
Pitt Polder
Haney UBC RF

Figure 15

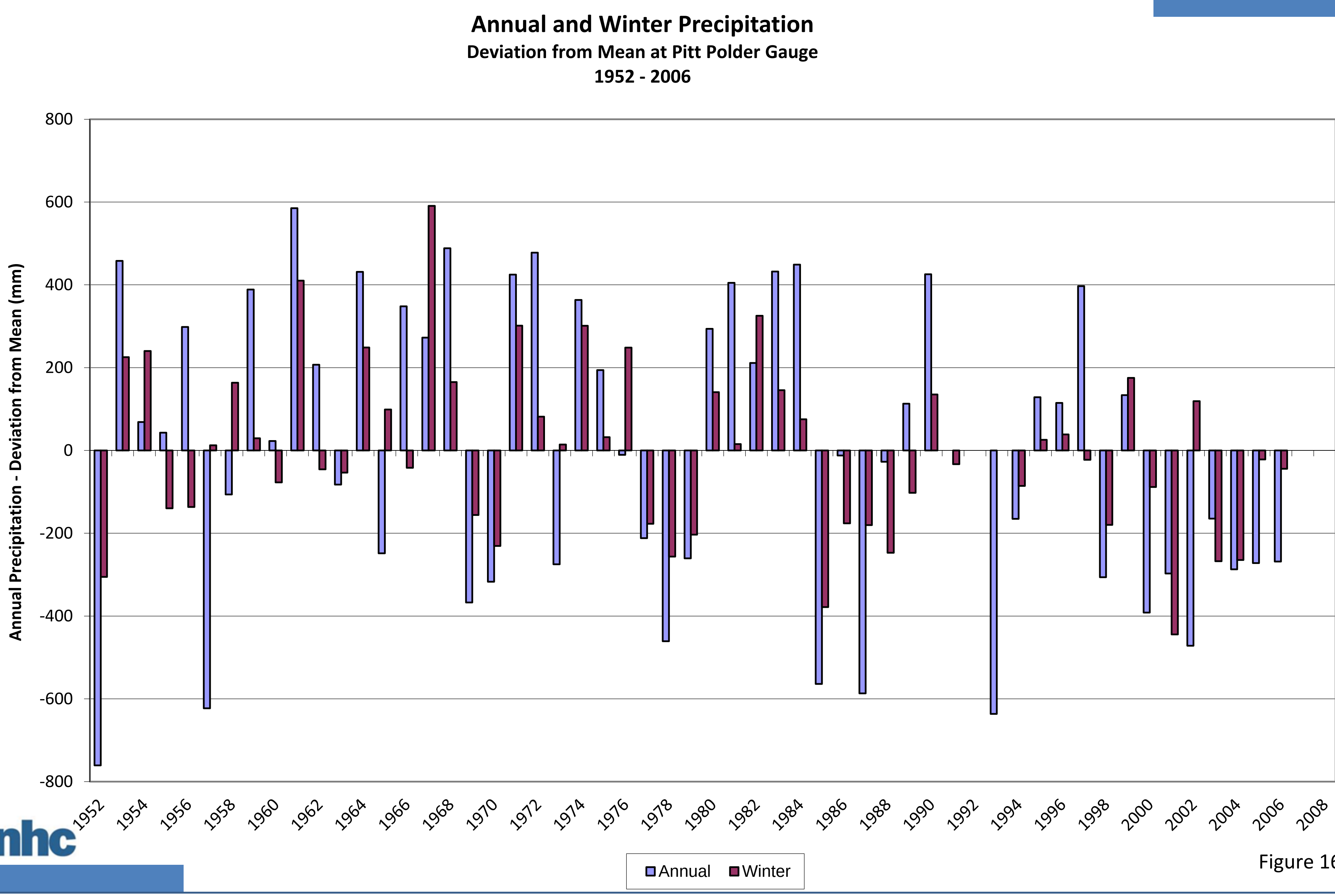
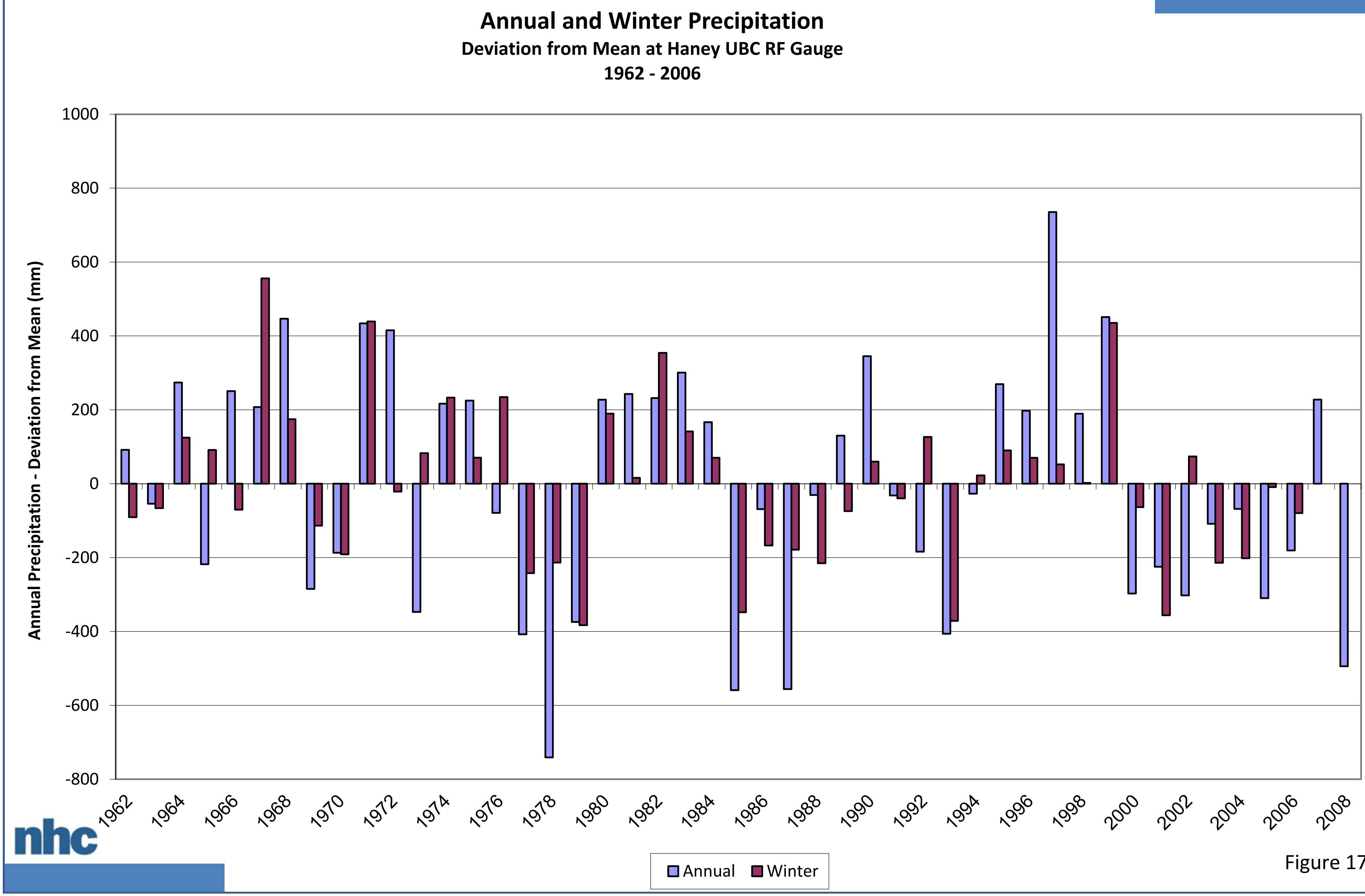
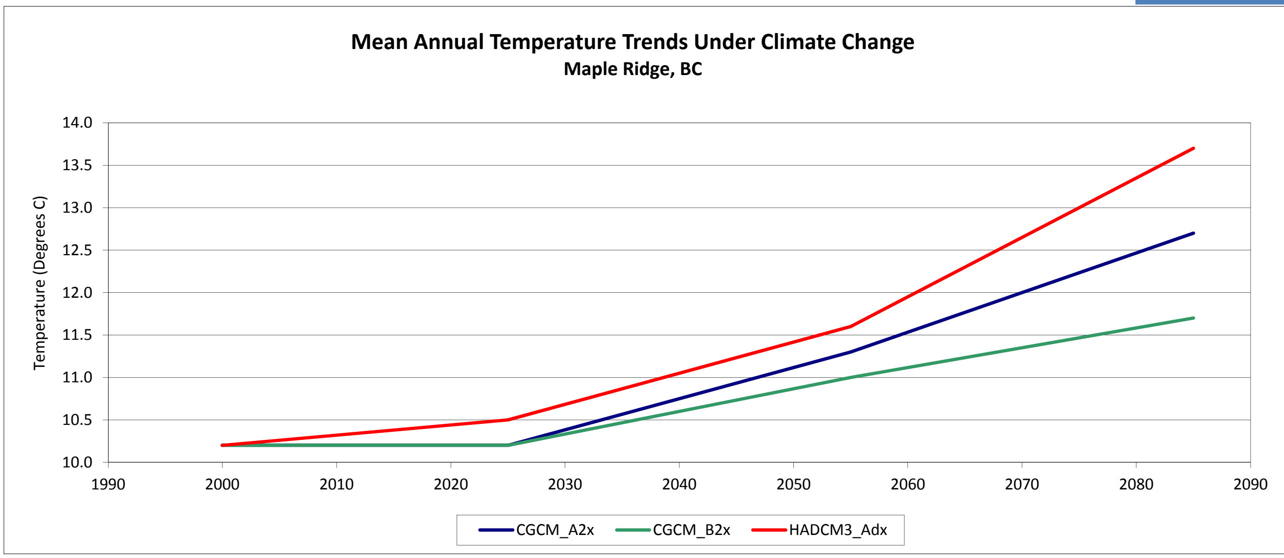

Annual and Winter Precipitation
Deviation from Mean at Pitt Polder Gauge
1952 - 2006
Annual Precipitation - Deviation from Mean (mm)
800
600
400
200
0
-200
-400
-600
-800
1952
1954
1956
1958
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
Annual
Winter

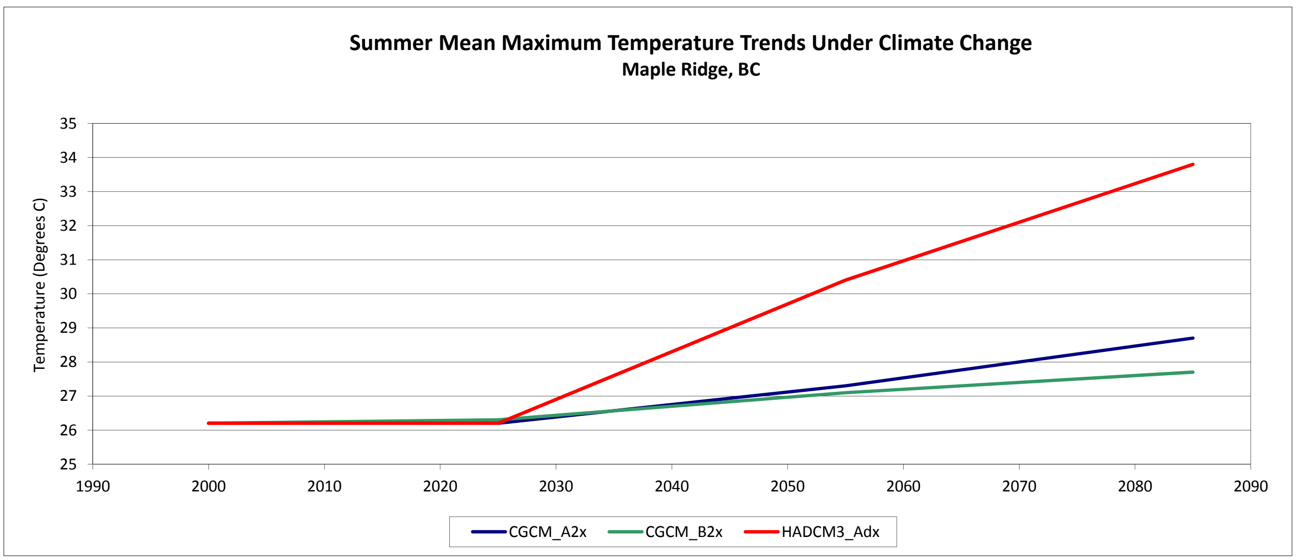
Figure 16



Annual and Winter Precipitation
Deviation from Mean at Haney UBC RF Gauge
1962 - 2006
Annual Precipitation - Deviation from Mean (mm)
1000
800
600
400
200
0
-200
-400
-600
-800
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
Annual
Winter

Figure 17





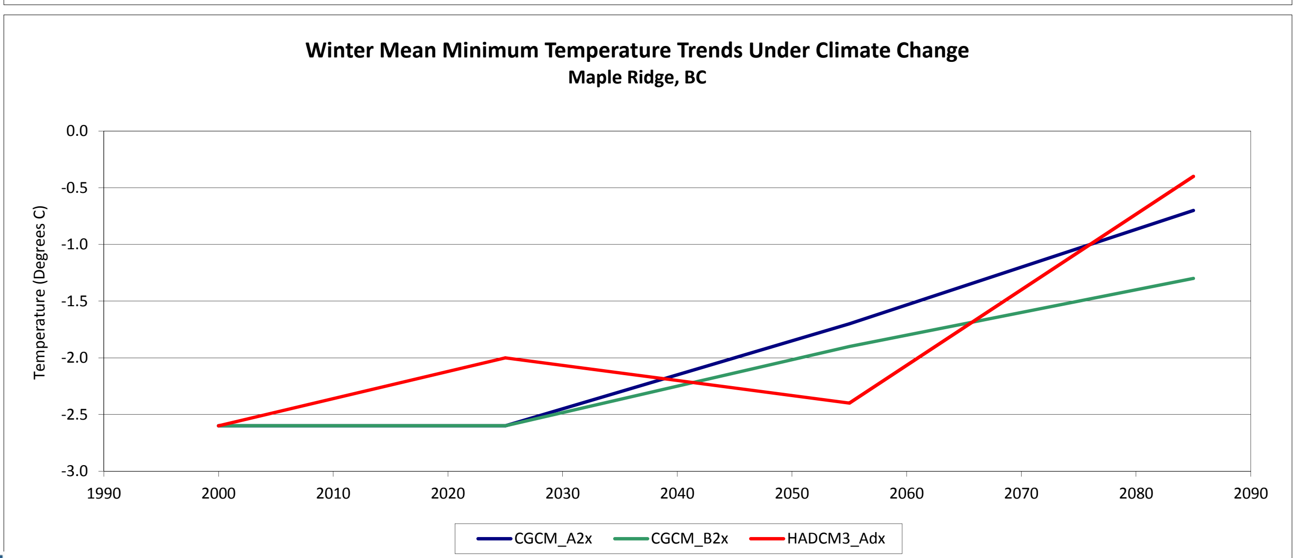
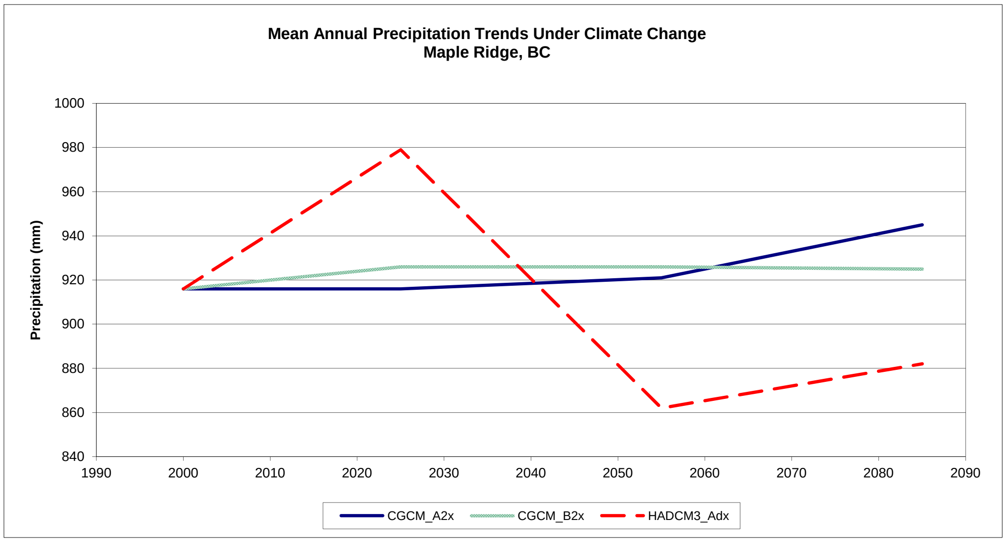
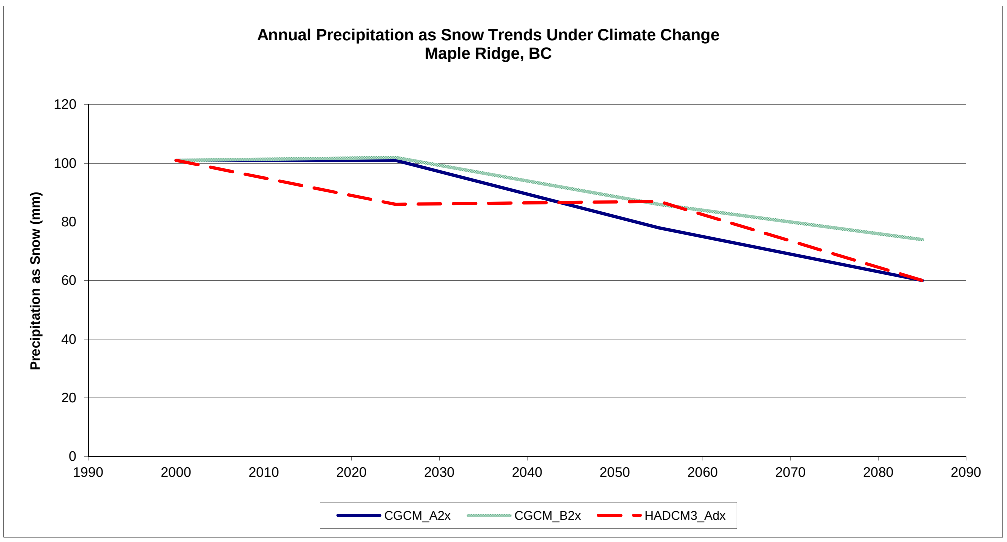


Figure 18: Temperature Trends under Climate Change





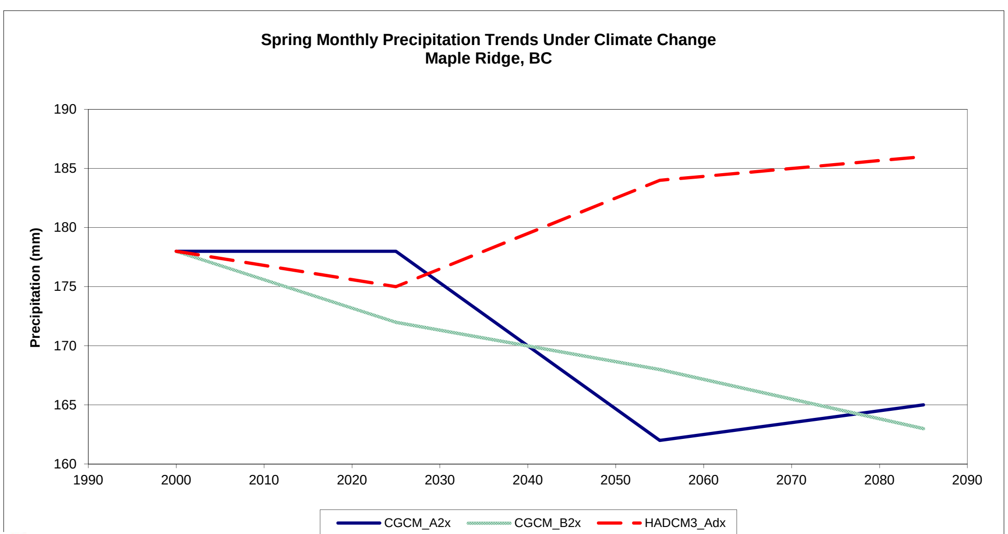
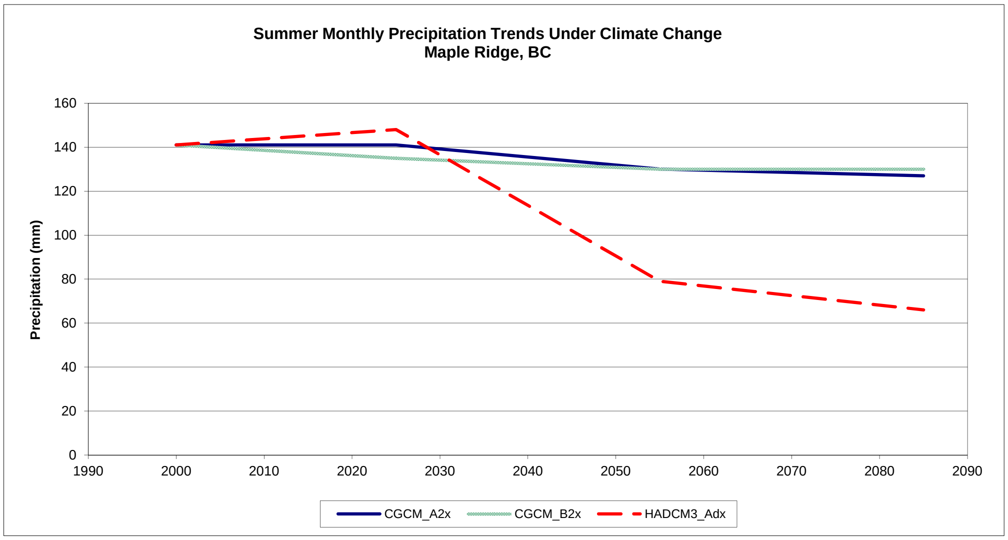
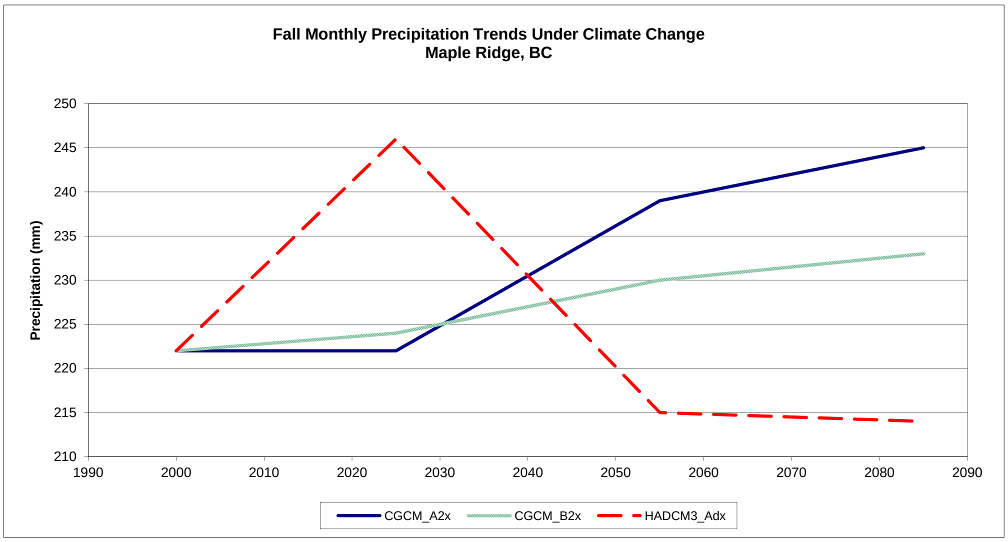
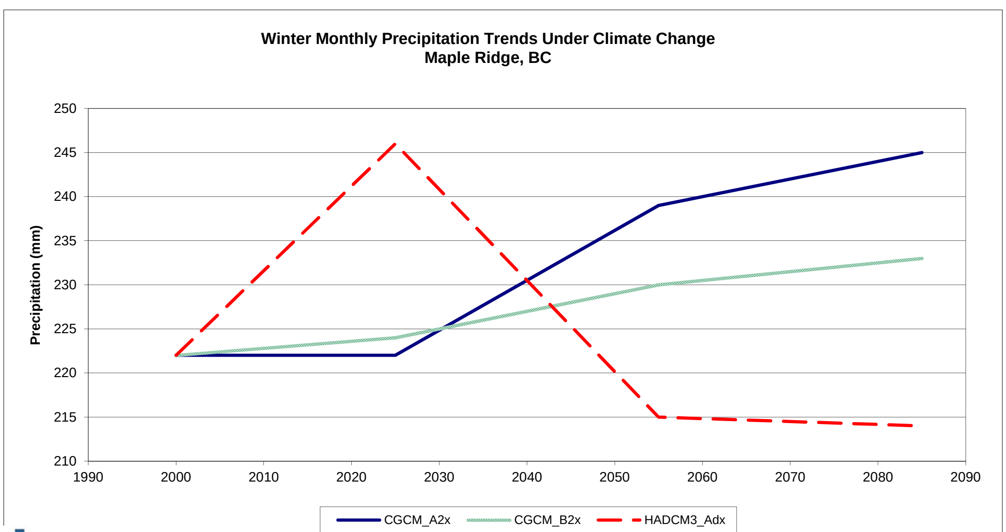


Figure 19a: Precipitation Trends under Climate Change







nhc

Figure 19b: Precipitation Trends under Climate Change

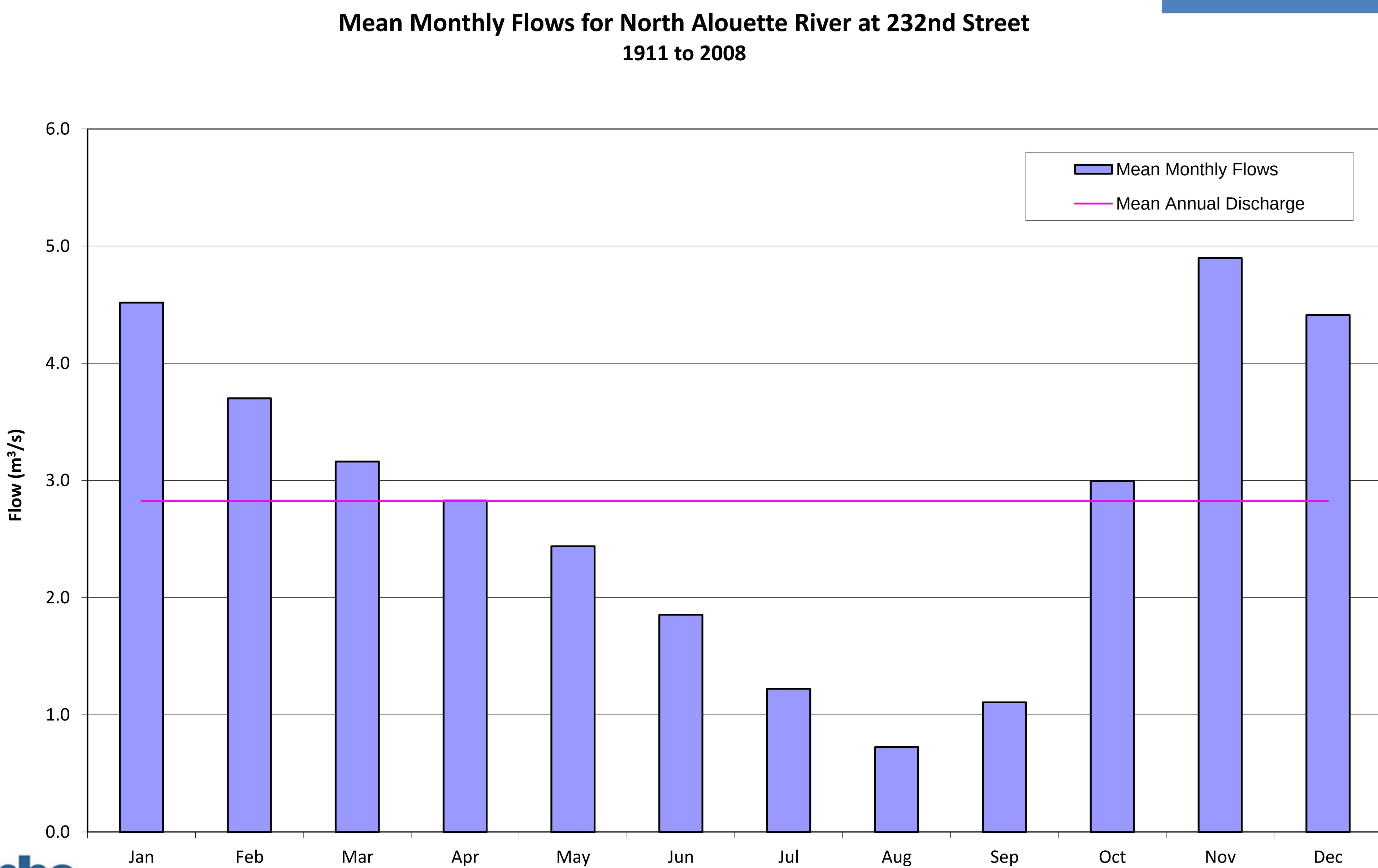

Mean Monthly Flows for North Alouette River at 232nd Street
1911 to 2008
Flow (m³/s)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Mean Monthly Flows
Mean Annual Discharge
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Figure 20

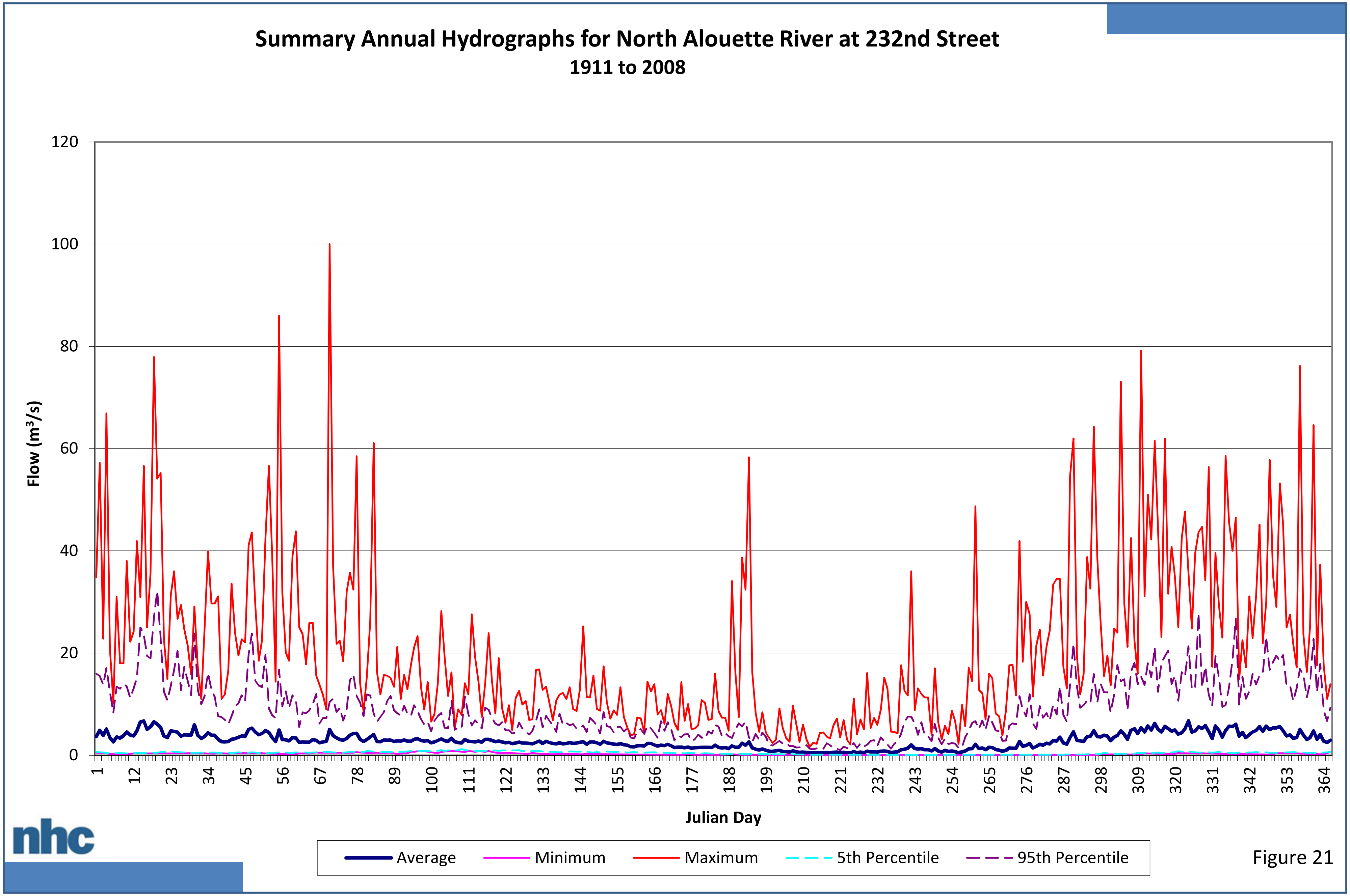

Summary Annual Hydrographs for North Alouette River at 232nd Street
1911 to 2008
Flow (m³/s)
Julian Day
Average
Minimum
Maximum
5th Percentile
95th Percentile
nhc

Figure 21

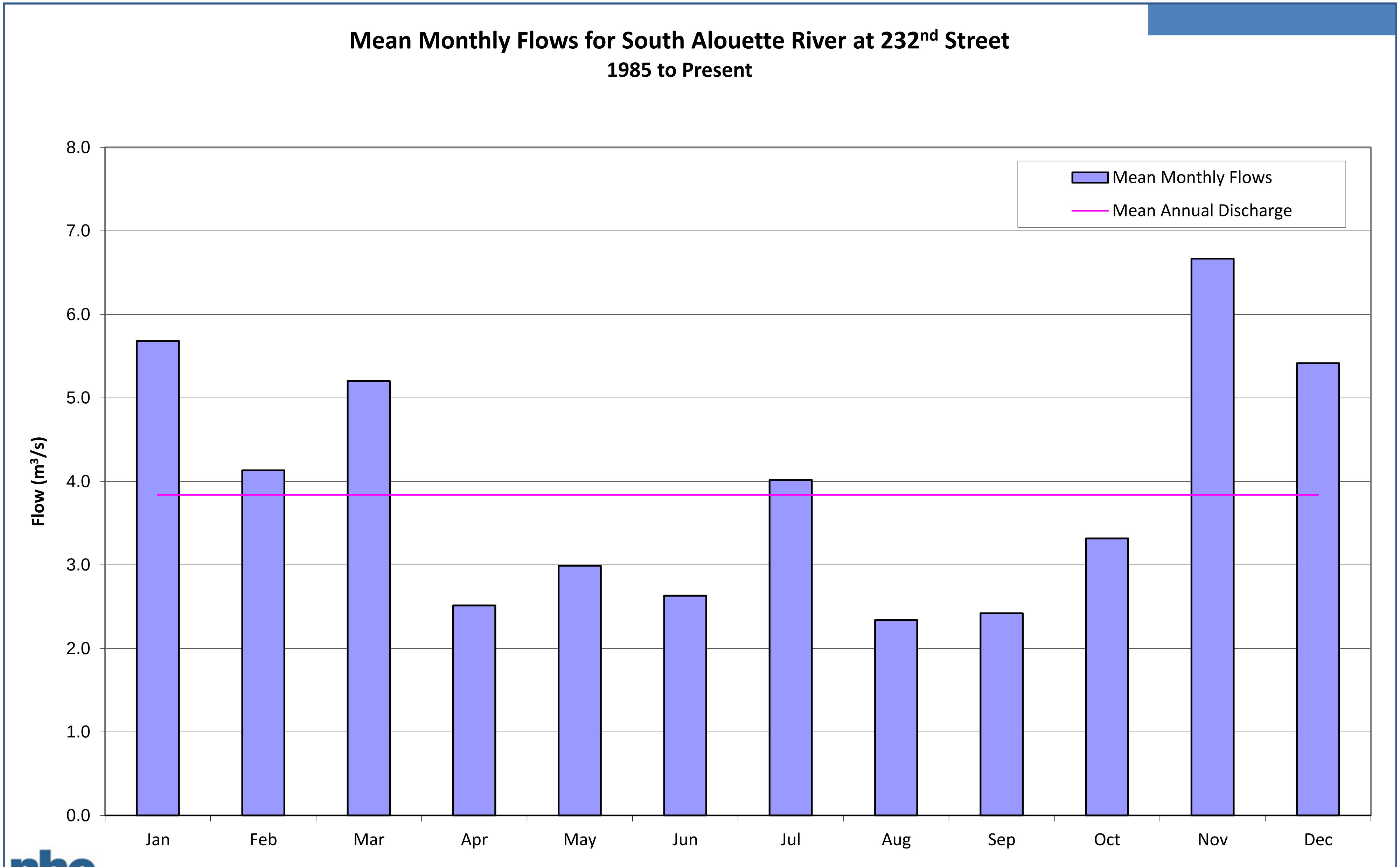

Mean Monthly Flows for South Alouette River at 232nd Street
1985 to Present
Mean Monthly Flows
Mean Annual Discharge
Flow (m3/s)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
nhc

Figure 22

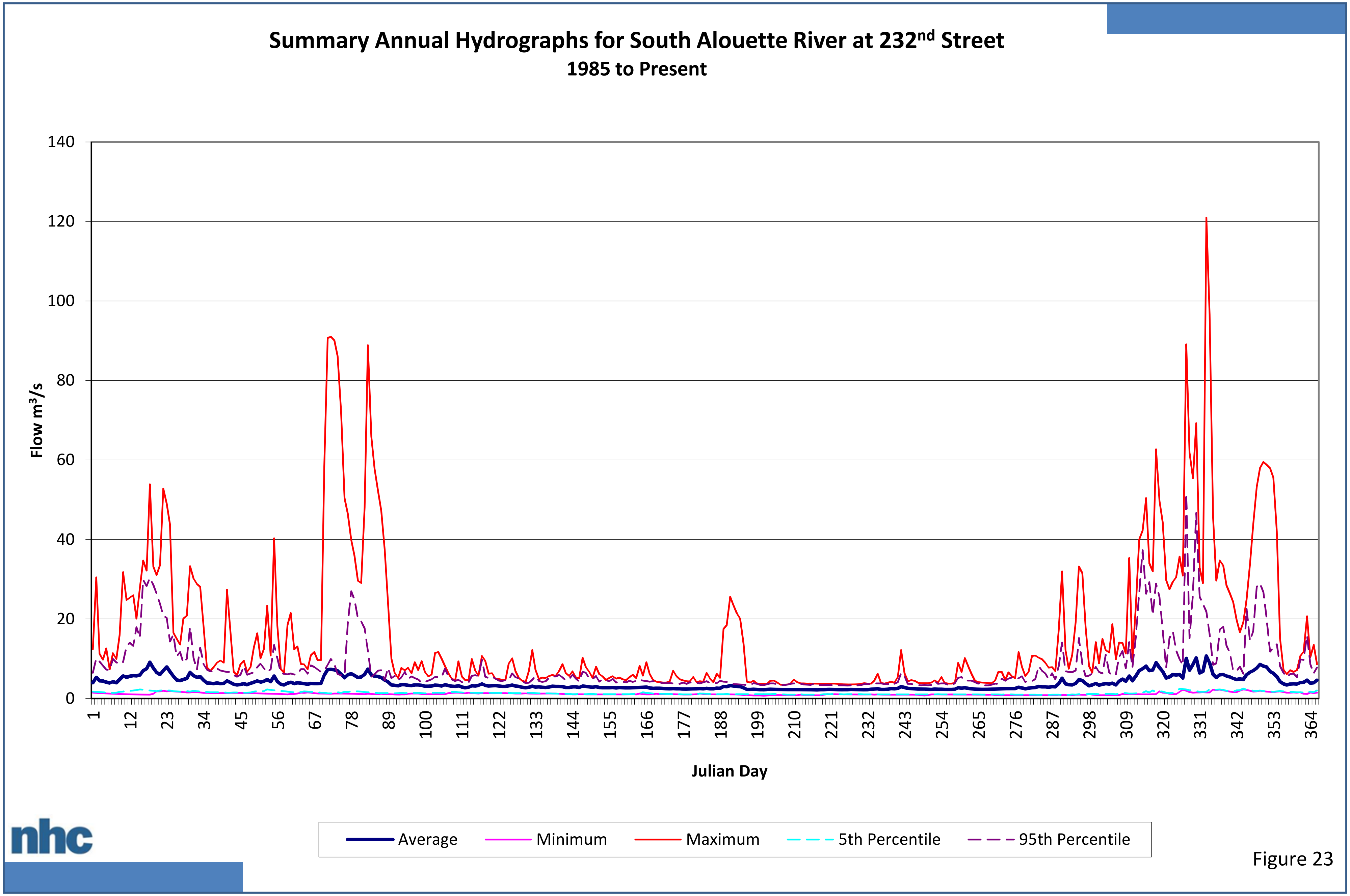

Summary Annual Hydrographs for South Alouette River at 232nd Street
1985 to Present
Flow m³/s
140
120
100
80
60
40
20
0
1
12
23
34
45
56
67
78
89
100
111
122
133
144
155
166
177
188
199
210
221
232
243
254
265
276
287
298
309
320
331
342
353
364
Julian Day
Average
Minimum
Maximum
5th Percentile
95th Percentile
nhc

Figure 23

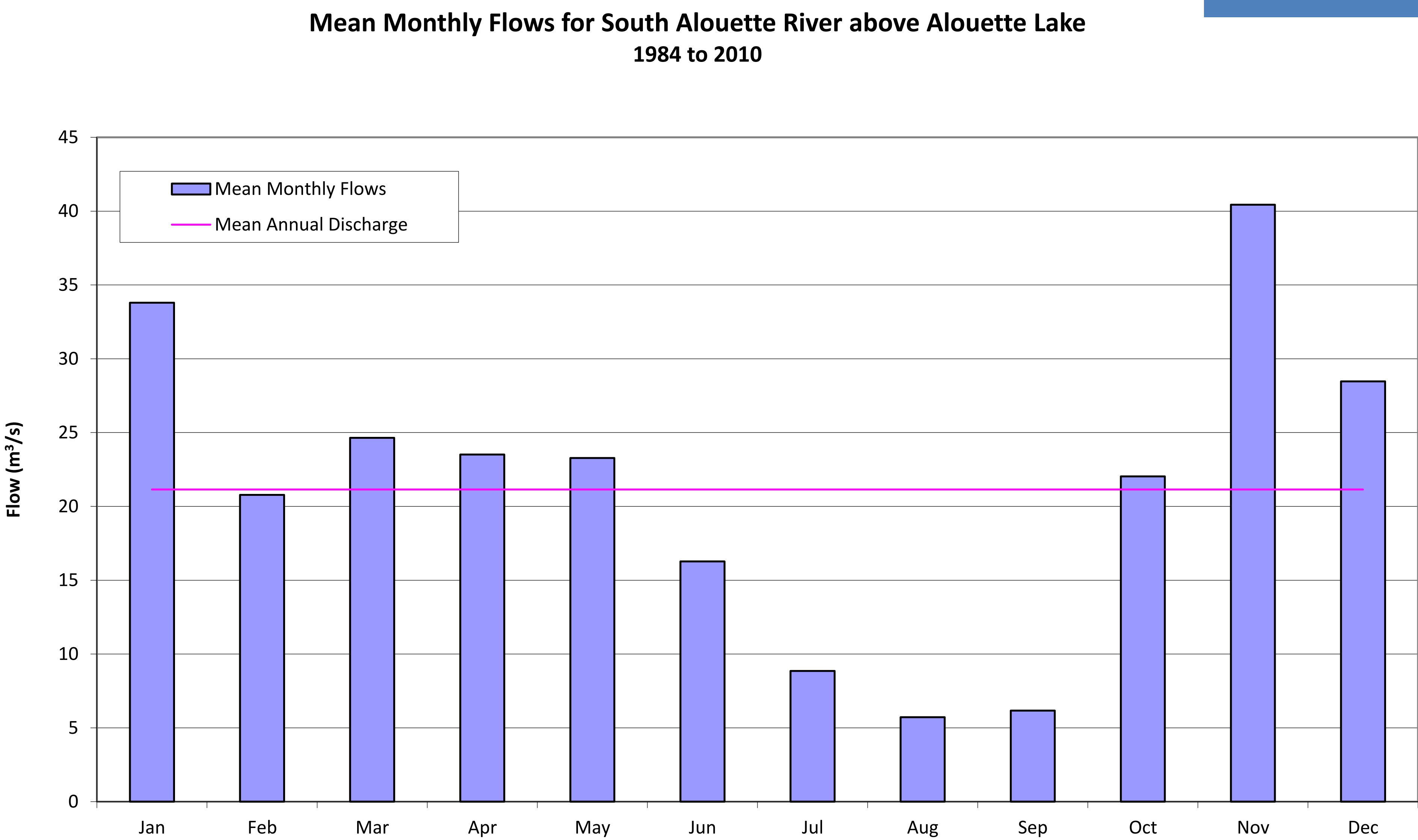

Mean Monthly Flows for South Alouette River above Alouette Lake
1984 to 2010
Flow (m³/s)
45
40
35
30
25
20
15
10
5
0
Mean Monthly Flows
Mean Annual Discharge
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Figure 24

Summary Annual Hydrographs for South Alouette River above Alouette Lake
1984 to 2010

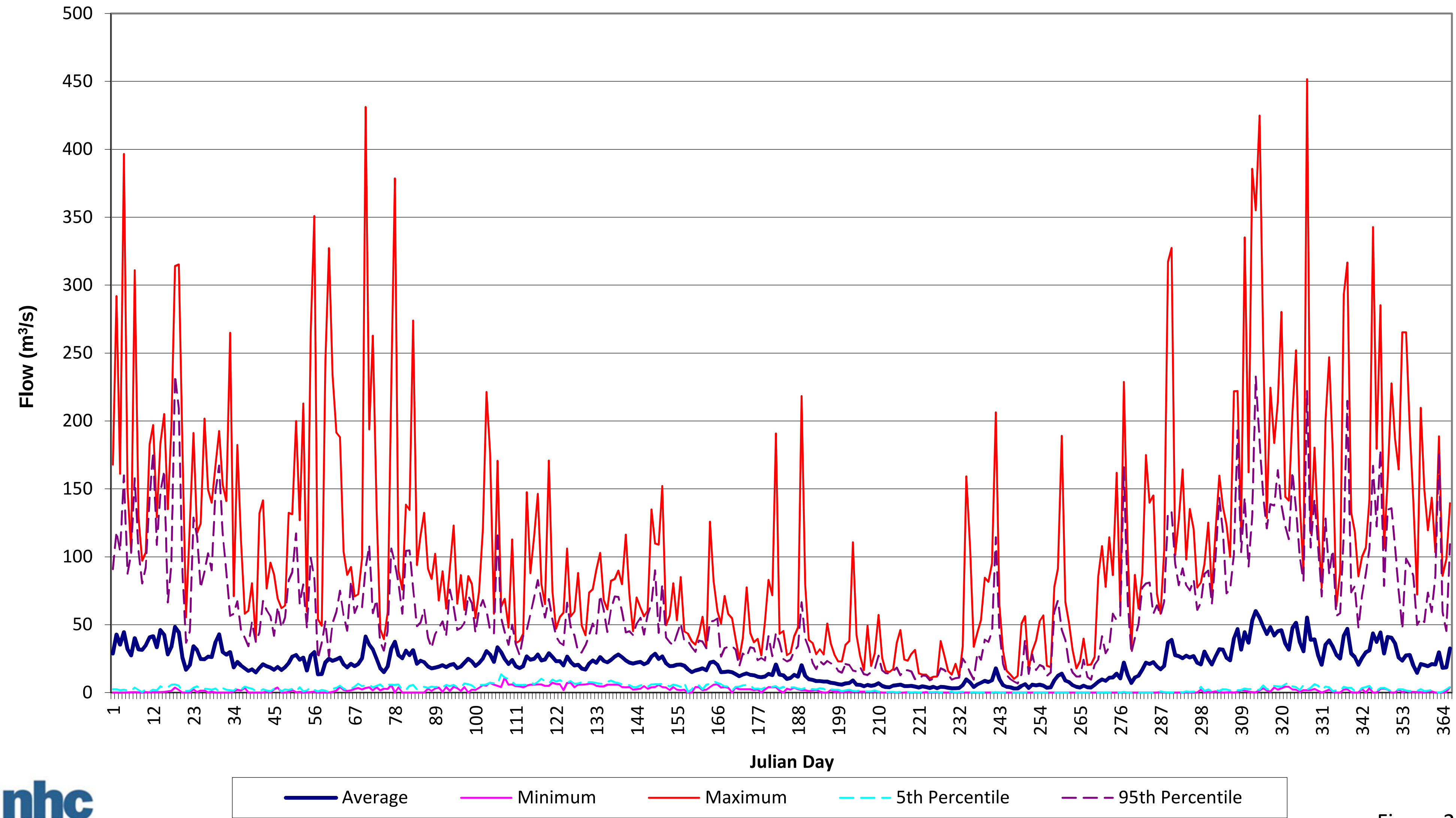
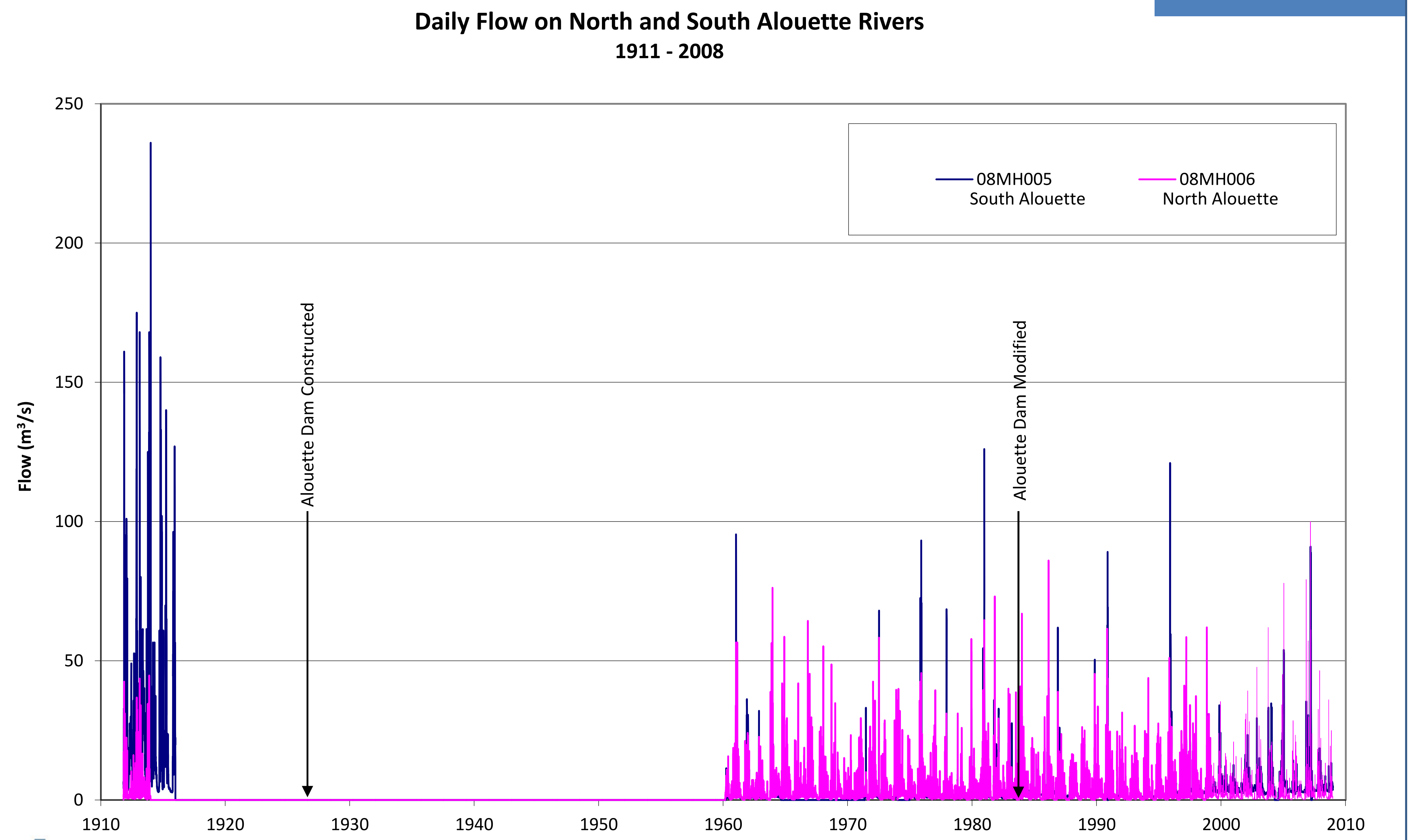


Figure 25



Daily Flow on North and South Alouette Rivers
1911 - 2008
Flow (m³/s)
250
200
150
100
50
0
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
08MH005
South Alouette
08MH006
North Alouette
Alouette Dam Constructed
Alouette Dam Modified

Figure 26

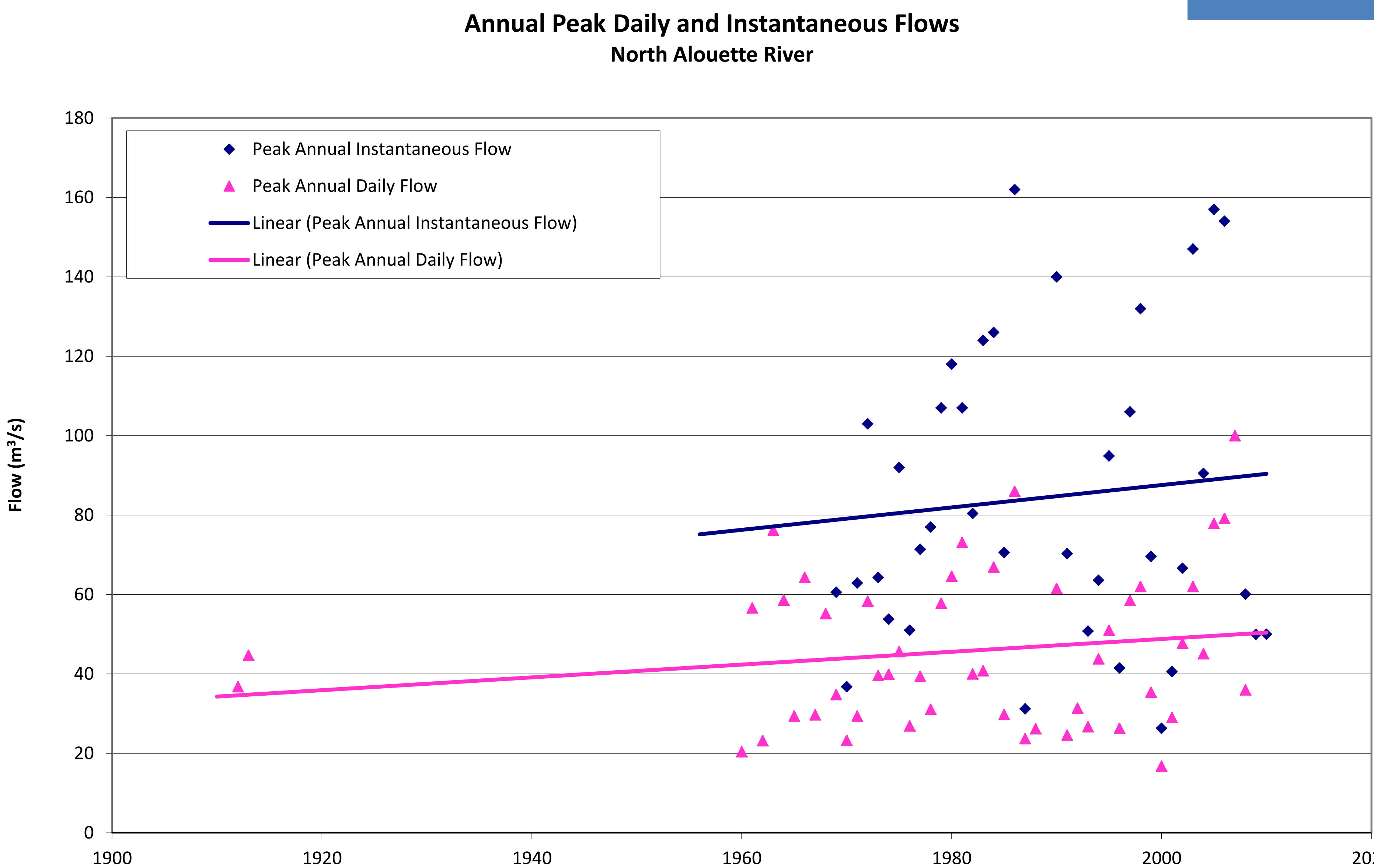

Annual Peak Daily and Instantaneous Flows
North Alouette River
Peak Annual Instantaneous Flow
Peak Annual Daily Flow
Linear (Peak Annual Instantaneous Flow)
Linear (Peak Annual Daily Flow)
Flow (m³/s)
180
160
140
120
100
80
60
40
20
0
1900
1920
1940
1960
1980
2000
2020

Figure 27

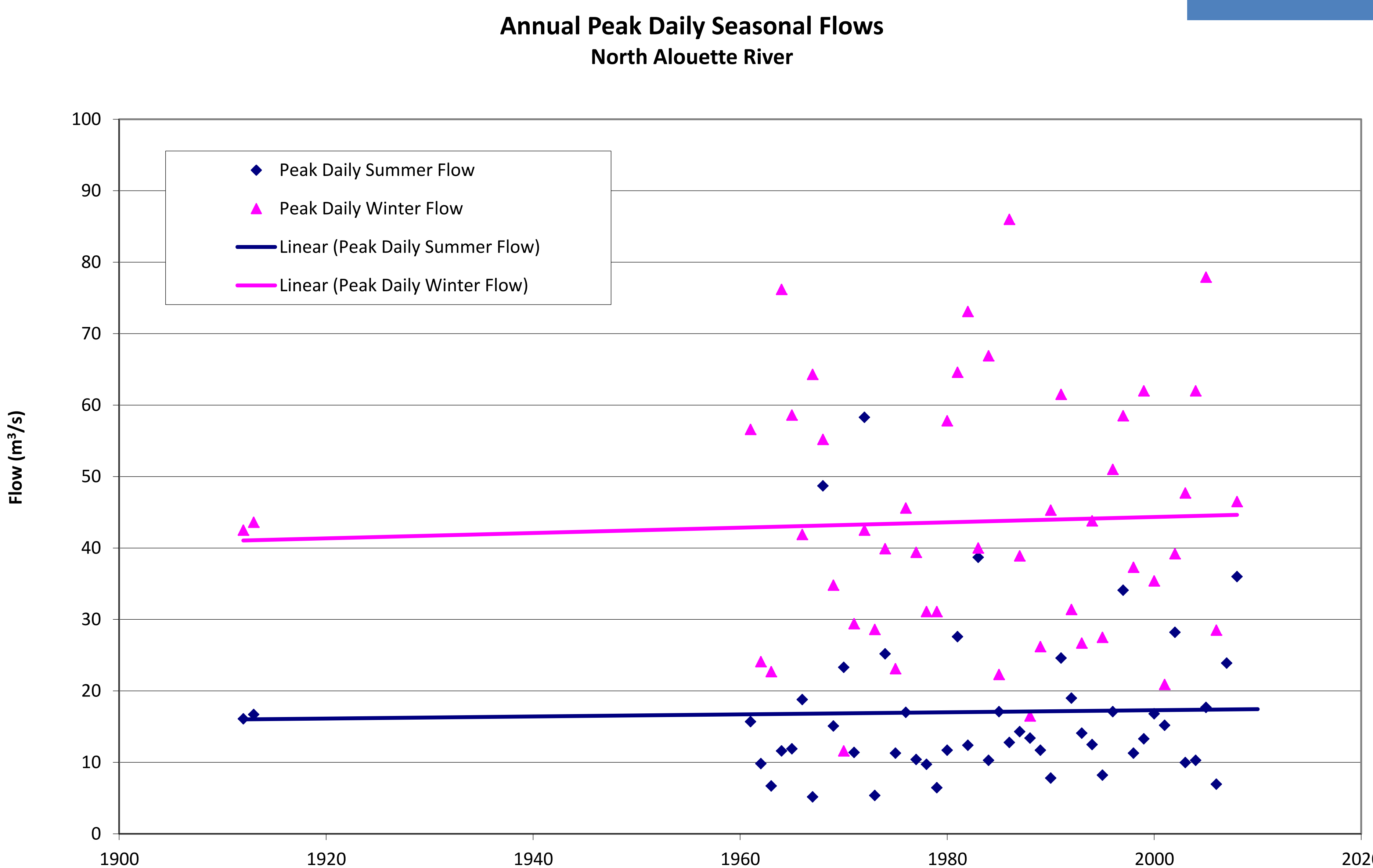
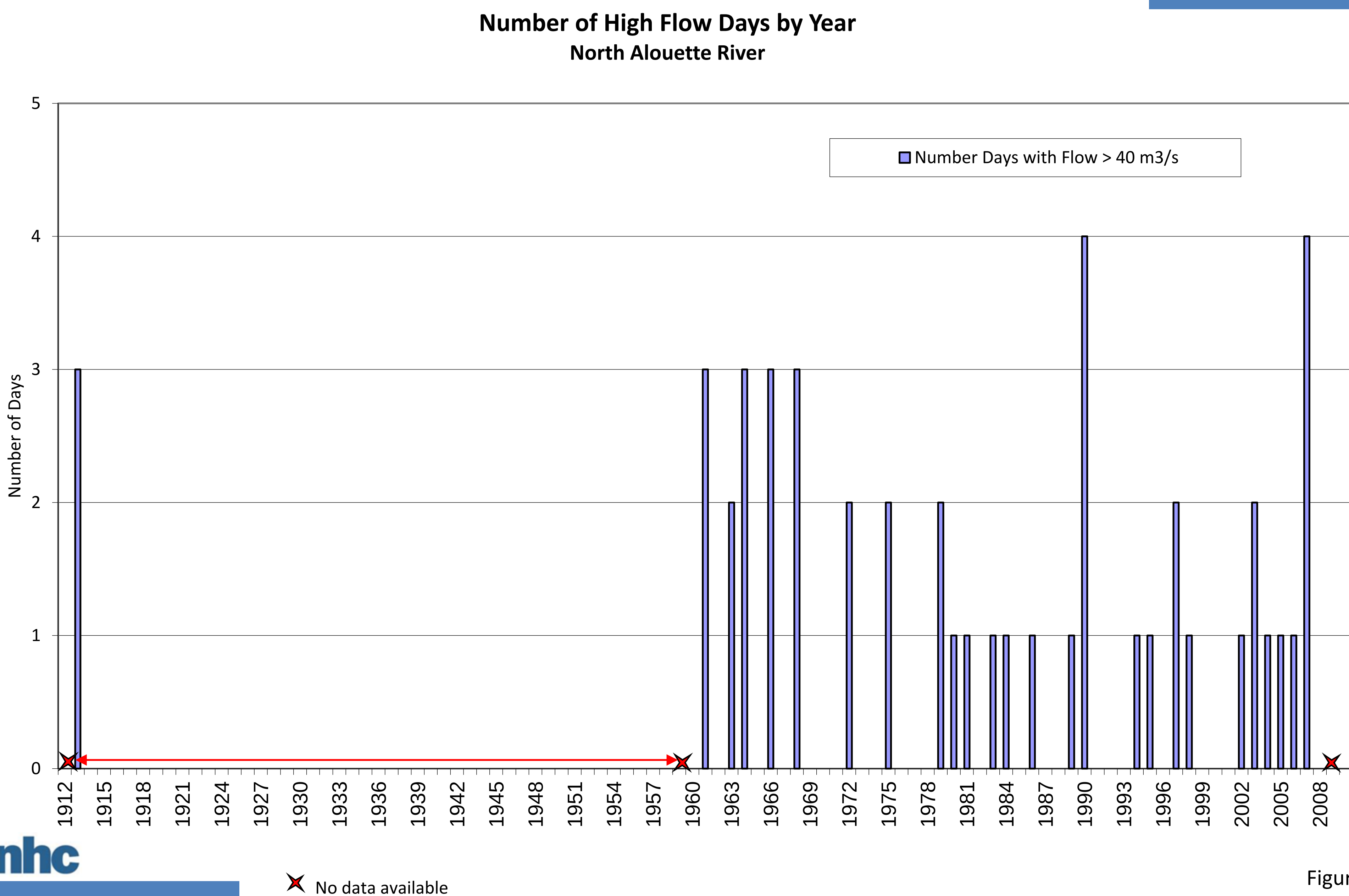

Annual Peak Daily Seasonal Flows
North Alouette River
Peak Daily Summer Flow
Peak Daily Winter Flow
Linear (Peak Daily Summer Flow)
Linear (Peak Daily Winter Flow)
Flow (m³/s)
100
90
80
70
60
50
40
30
20
10
0
1900
1920
1940
1960
1980
2000
2020

Figure 28



Number of High Flow Days by Year
North Alouette River
Number Days with Flow > 40 m3/s
Number of Days
0
1
2
3
4
5
1912
1915
1918
1921
1924
1927
1930
1933
1936
1939
1942
1945
1948
1951
1954
1957
1960
1963
1966
1969
1972
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005
2008
No data available

Figure 29

North Alouette Design Discharge Hydrographs with Climate Change Impacts

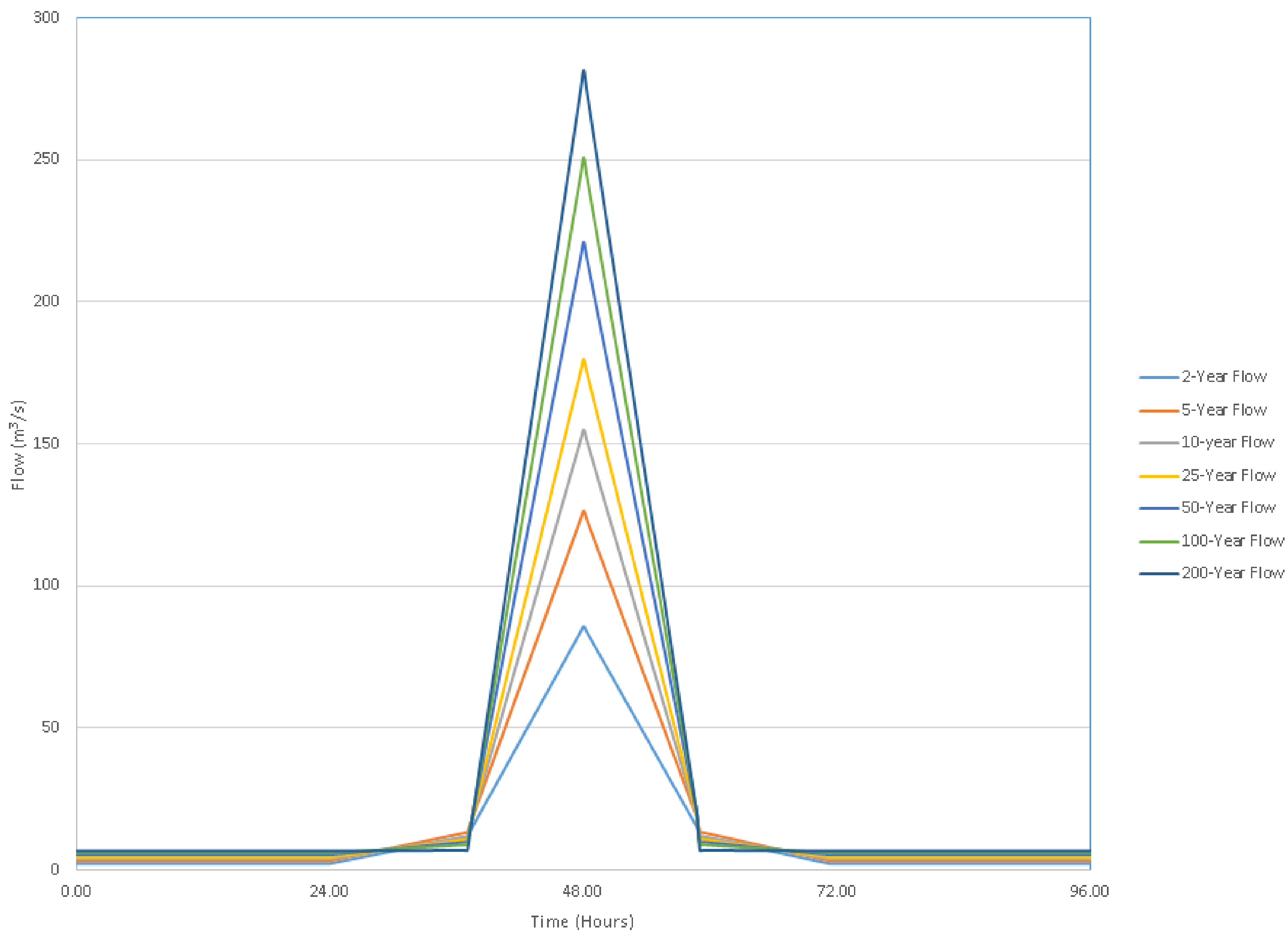


Figure 30

STELLA Systems Model of Alouette Reservoir and Dam – Overview

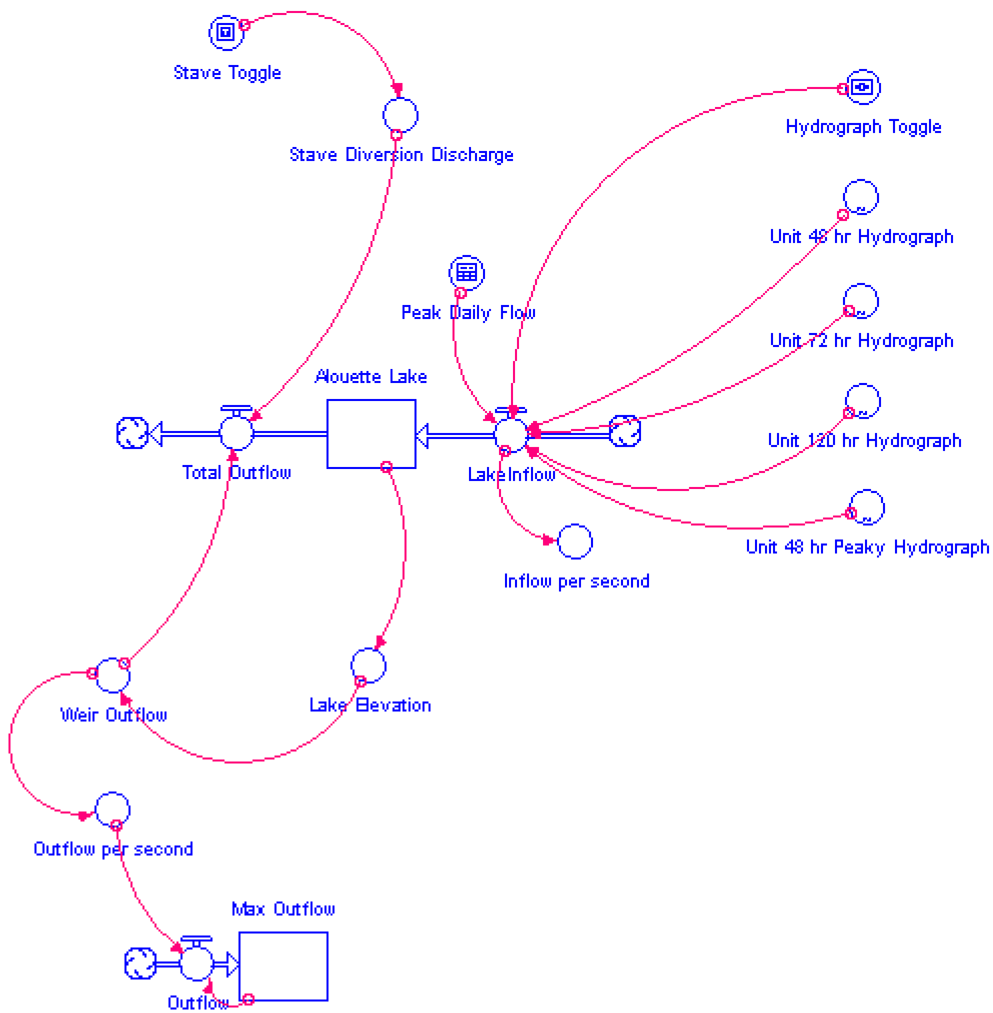


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Figure 31

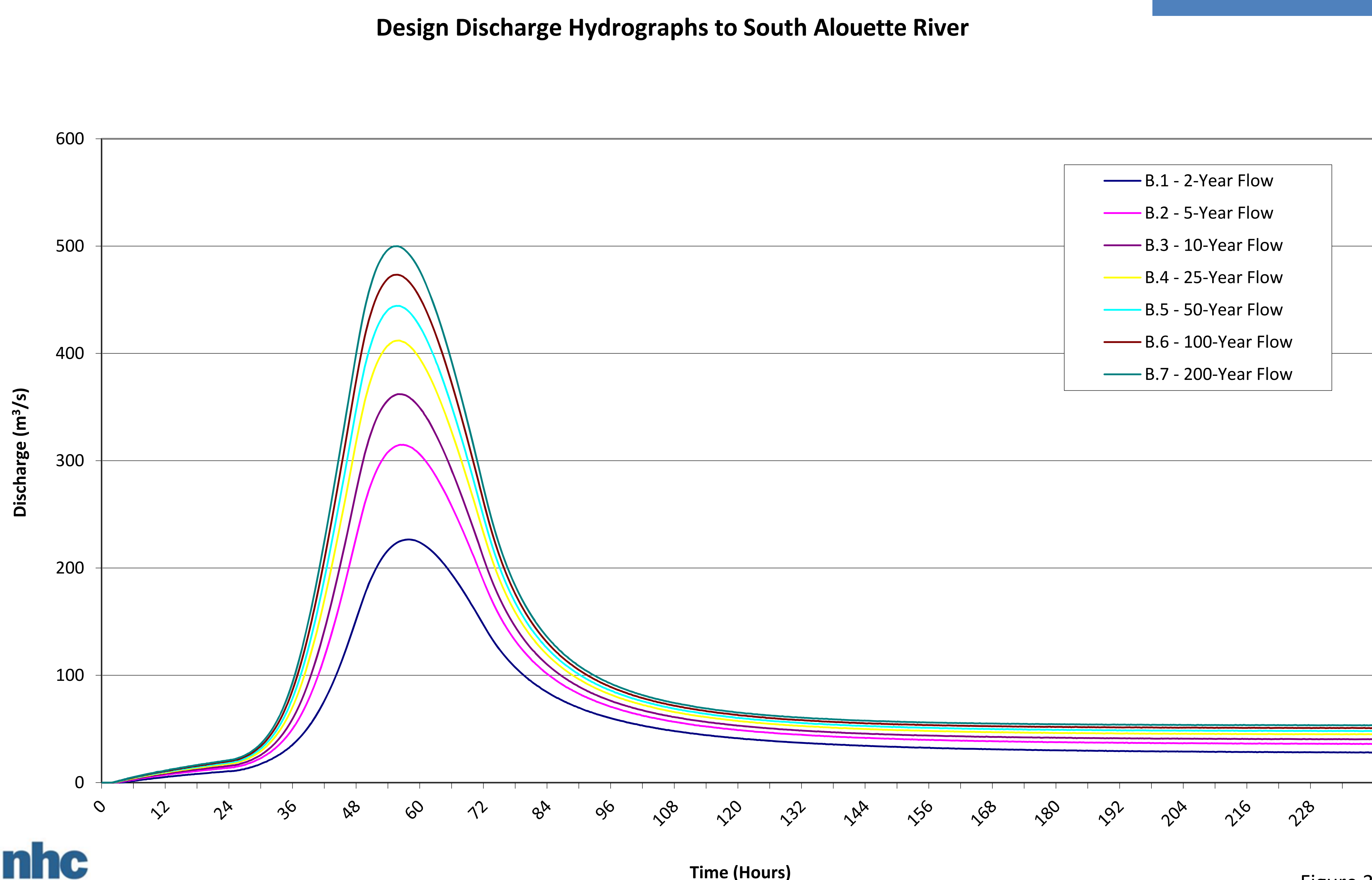
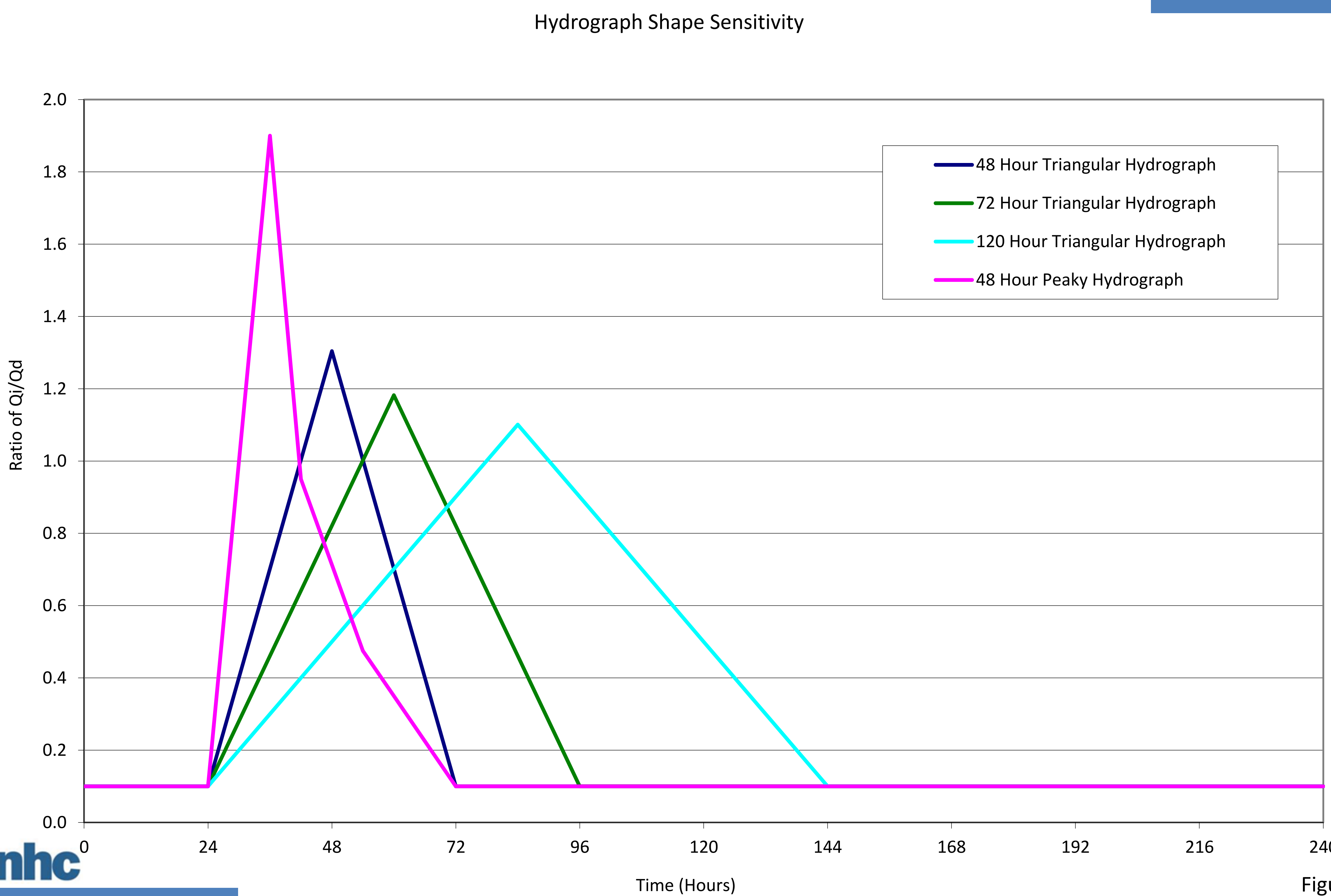
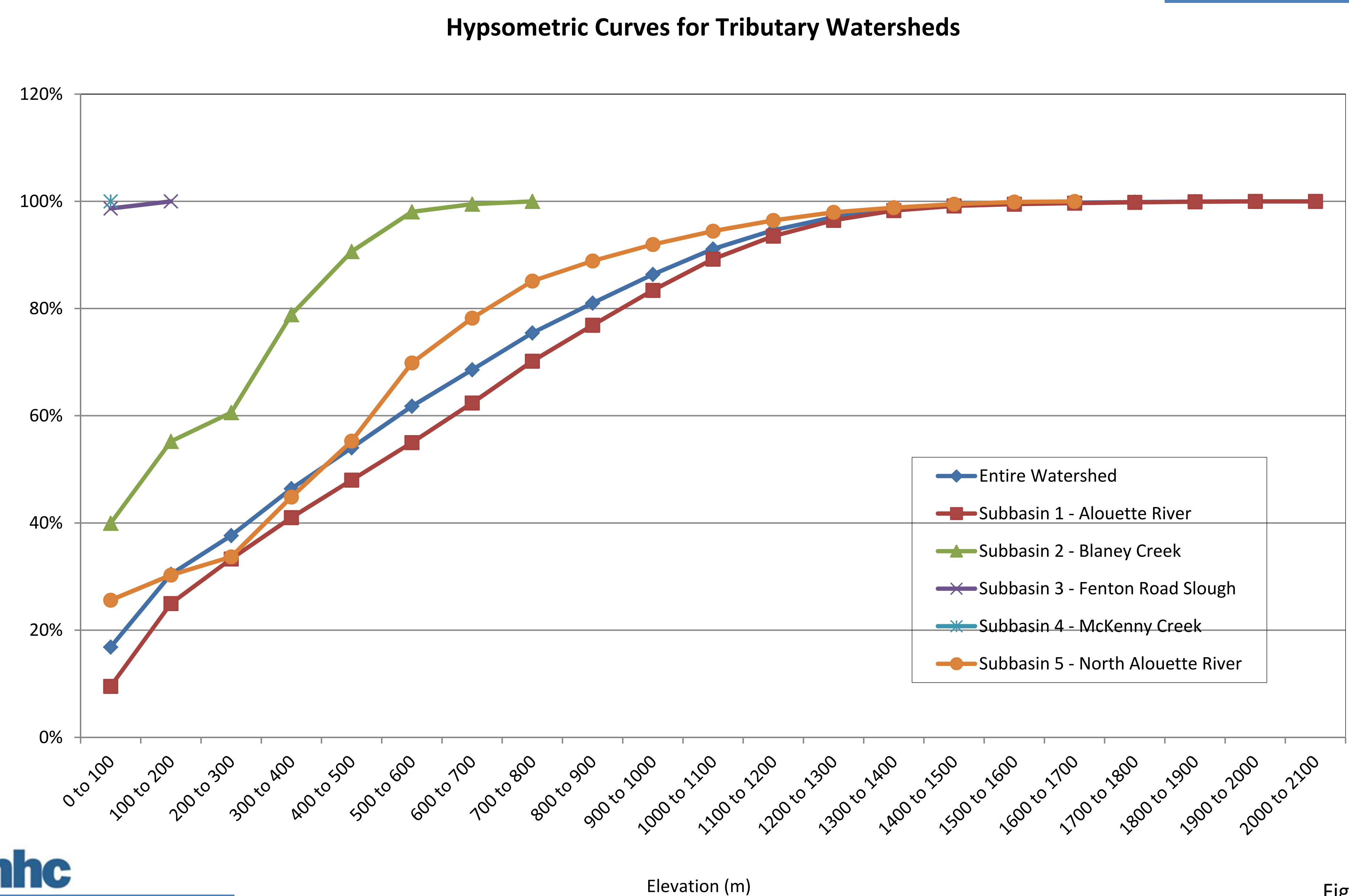

Design Discharge Hydrographs to South Alouette River
Discharge (m³/s)
600
500
400
300
200
100
0
Time (Hours)
0
12
24
36
48
60
72
84
96
108
120
132
144
156
168
180
192
204
216
228
B.1 - 2-Year Flow
B.2 - 5-Year Flow
B.3 - 10-Year Flow
B.4 - 25-Year Flow
B.5 - 50-Year Flow
B.6 - 100-Year Flow
B.7 - 200-Year Flow

Figure 32



Hydrograph Shape Sensitivity
48 Hour Triangular Hydrograph
72 Hour Triangular Hydrograph
120 Hour Triangular Hydrograph
48 Hour Peaky Hydrograph
Ratio of Qi/Qd
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
24
48
72
96
120
144
168
192
216
240
Time (Hours)

Figure 33



nhc

Figure 34

Stage-Discharge Rating Curve for AVA Gauge at Pedestrian Bridge
North Alouette River

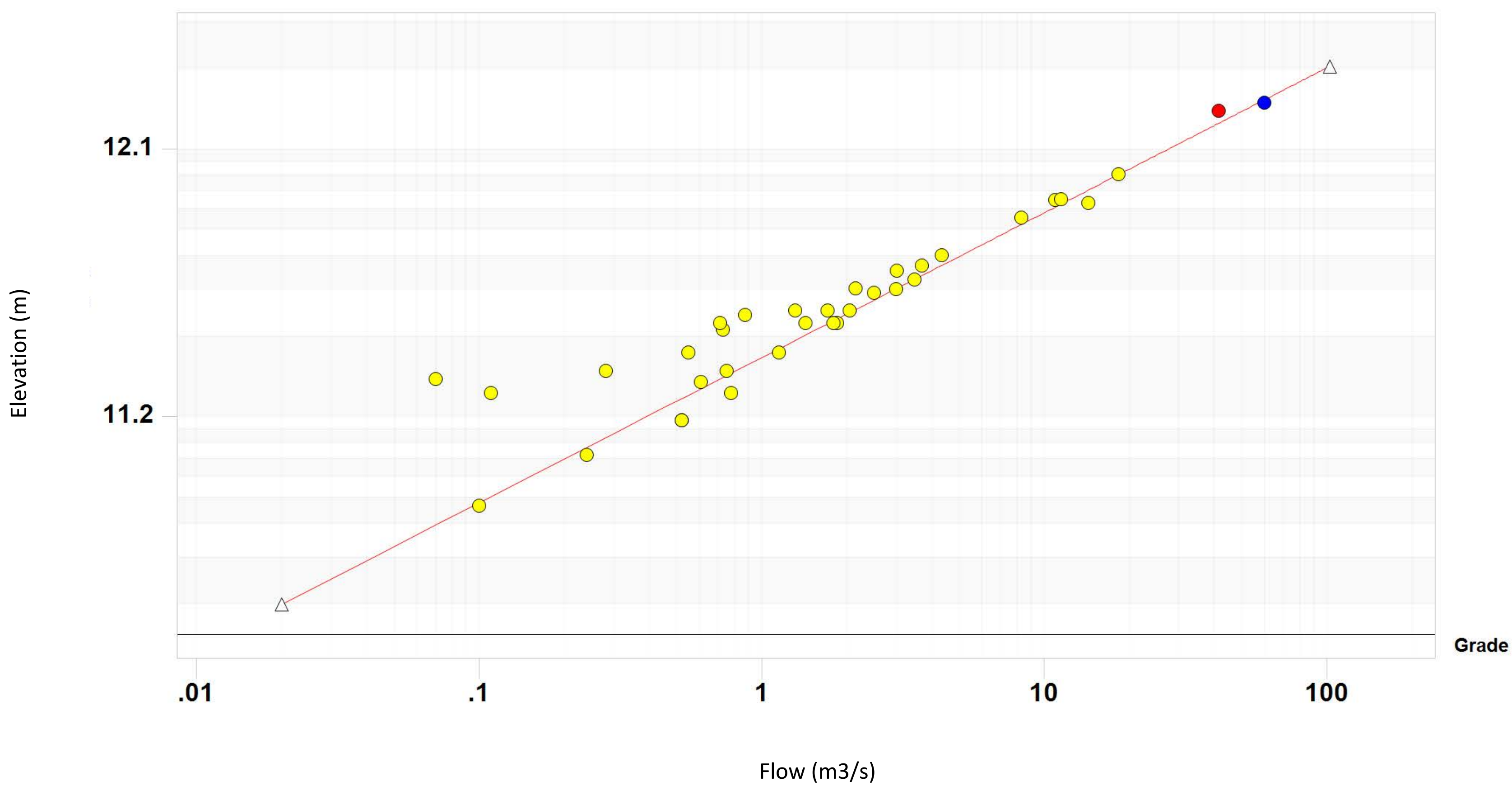
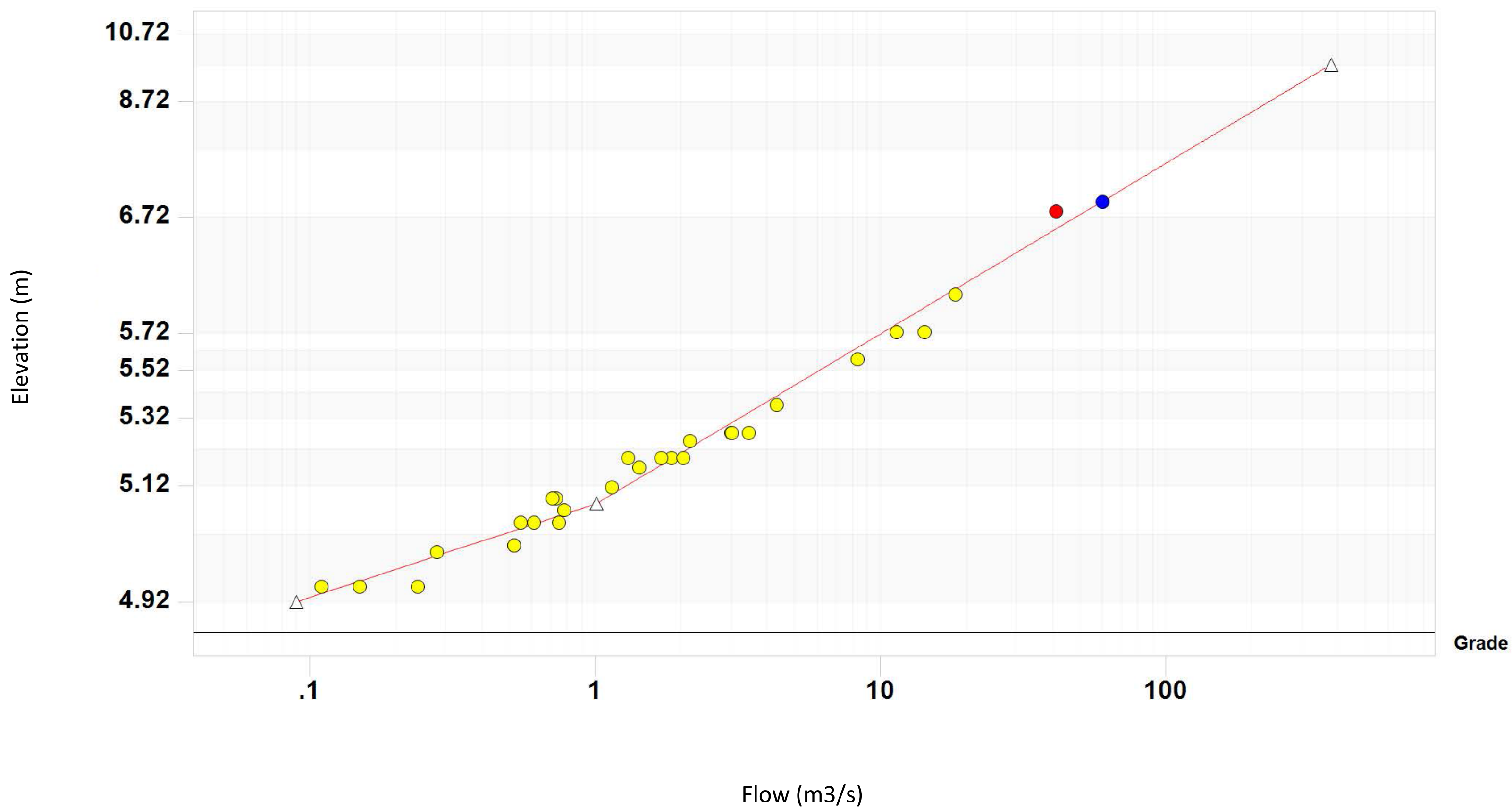


Figure 35

Stage-Discharge Rating Curve for Maple Ridge Gauge at 224th Street
North Alouette River



North Alouette River November 2014 Inflow Hydrograph

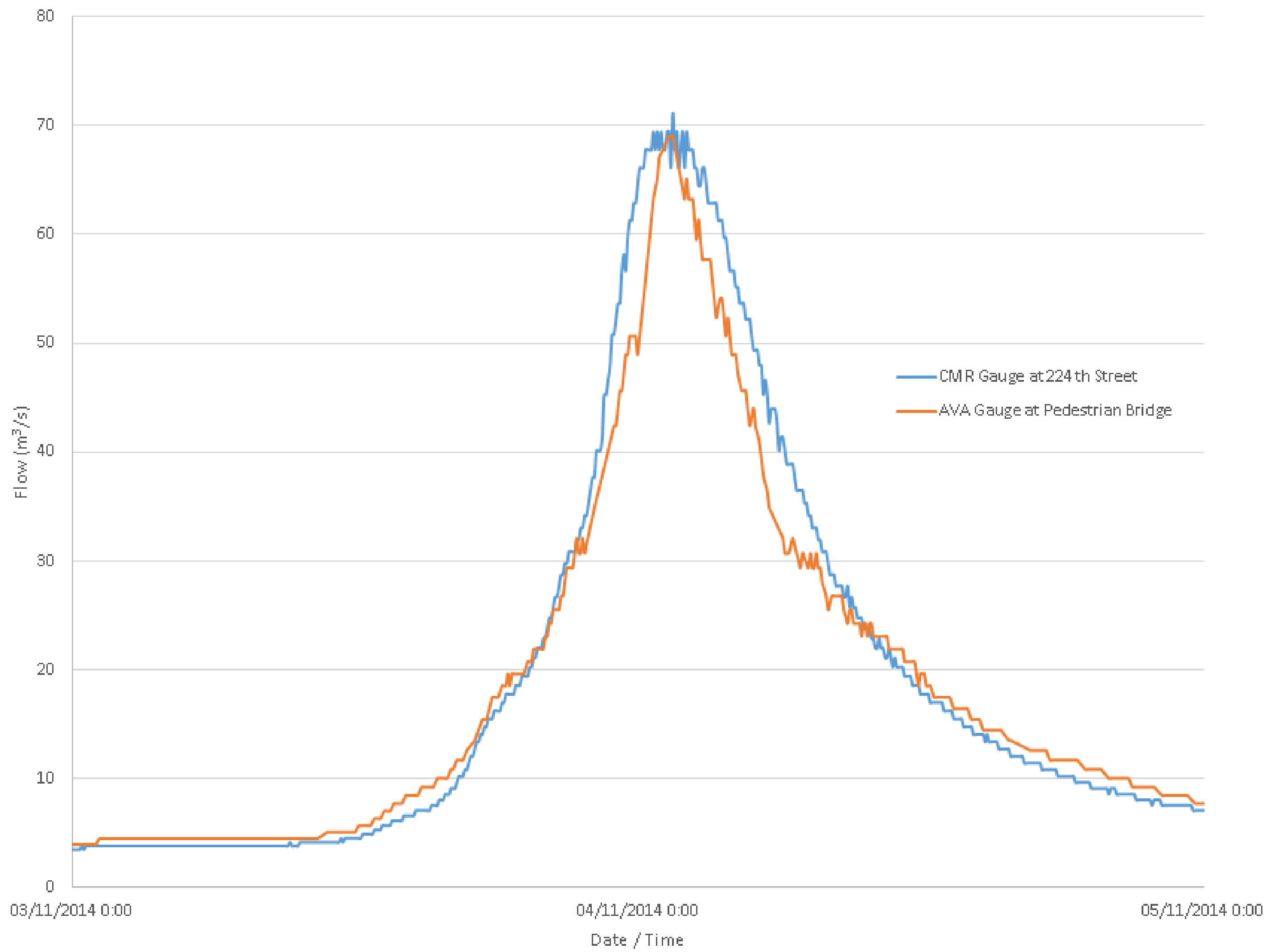
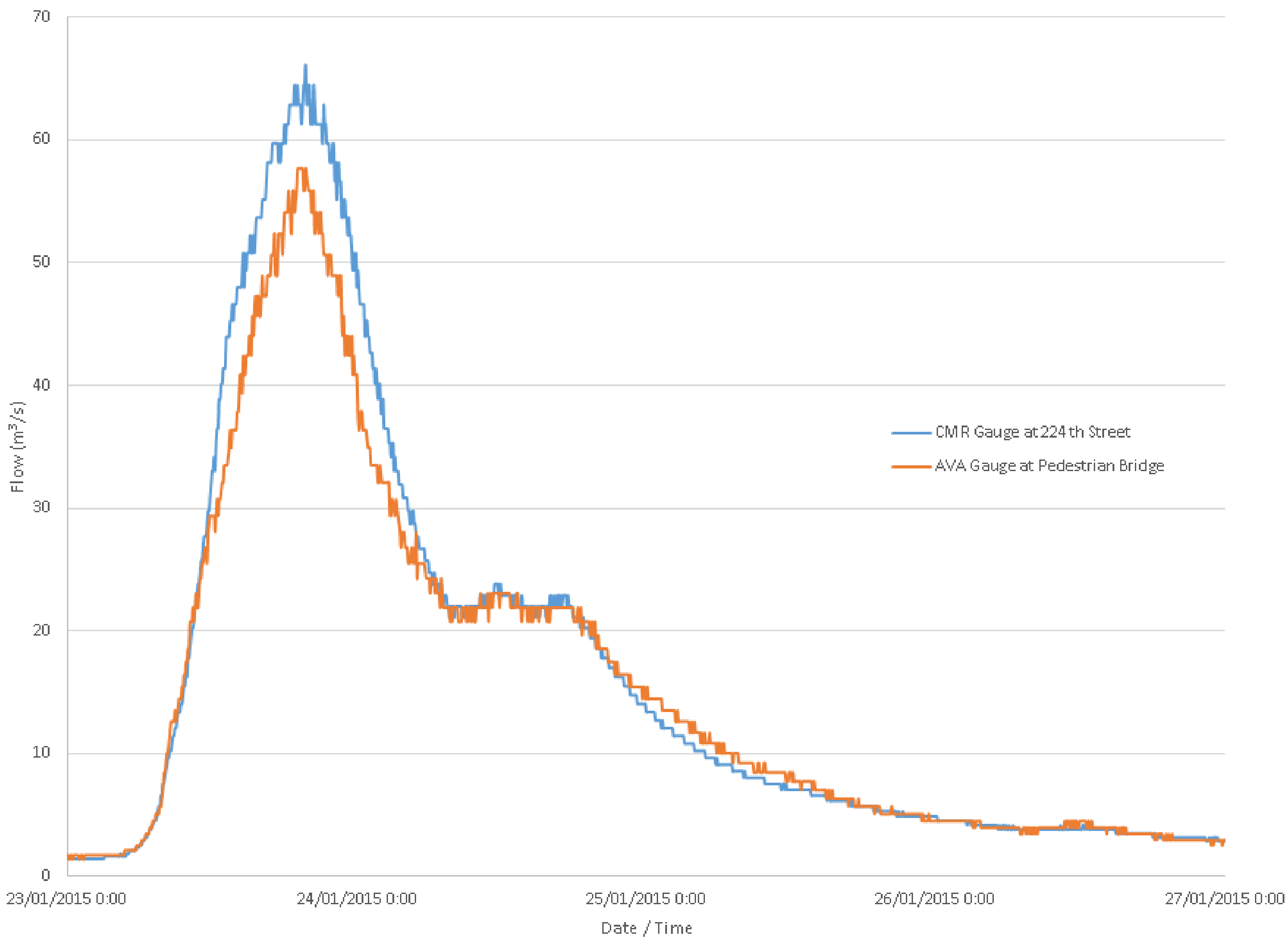


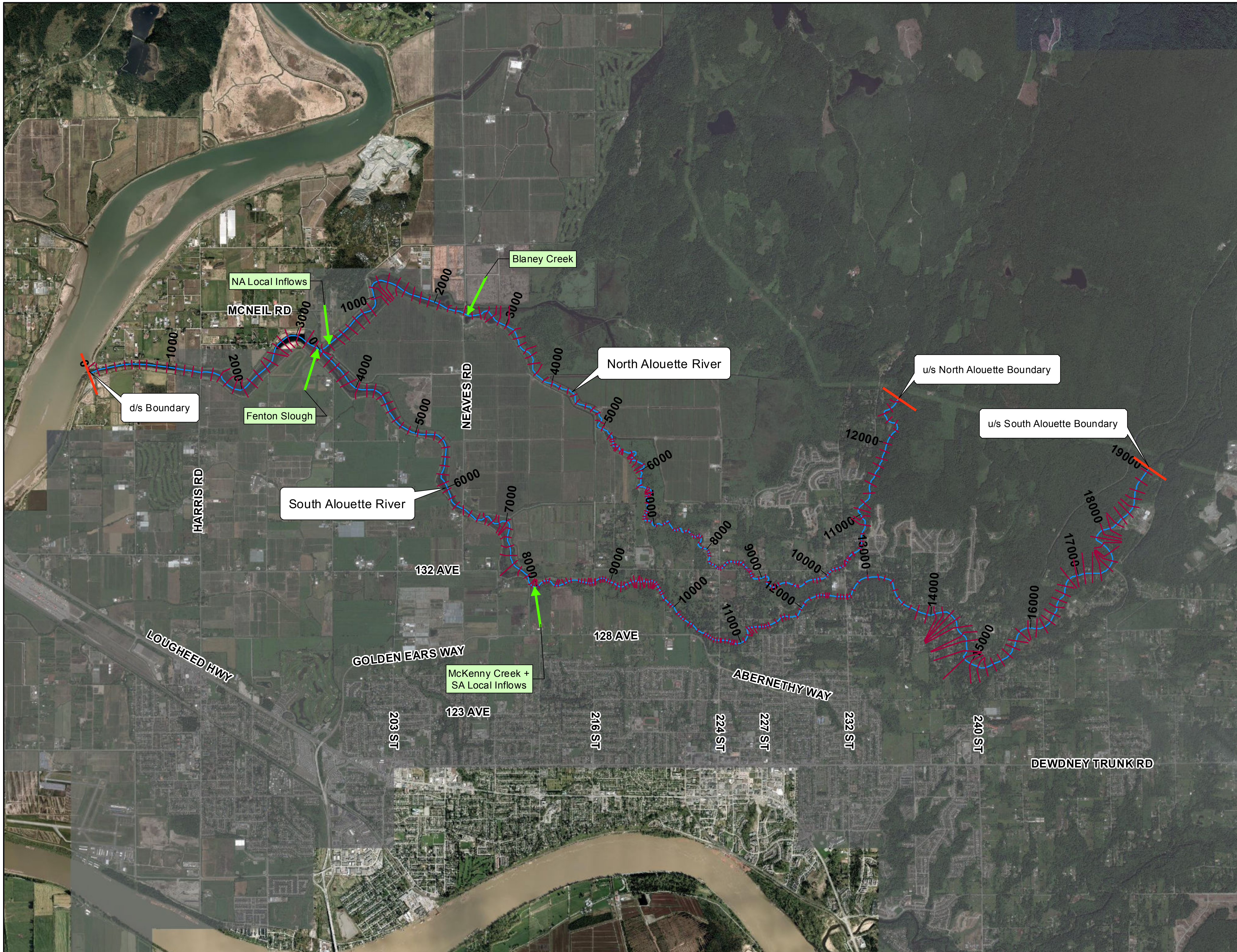
Figure 37

North Alouette River January 2015 Inflow Hydrograph



nhc

Figure 38



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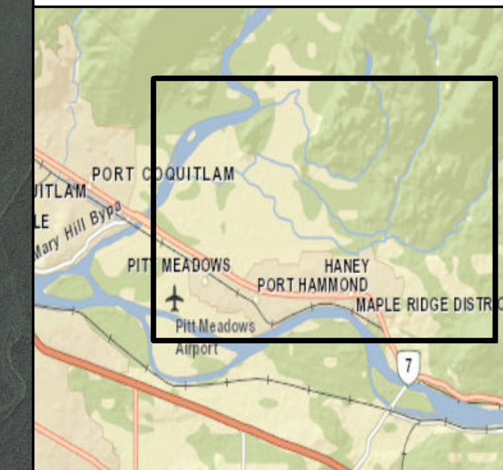

Point Source
MIKE11 Boundary
Cross Section
MIKE11 Model Network

DATA SOURCES:
- Esri World Imagery
- Esri World Street Map

SCALE - 1:45,000
0 500 1,000 1,500 M
N

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

Job: 300349 | Date: 30-NOV-2015

ALOUETTE RIVERS
ADDITIONAL
FLOODPLAIN ANALYSIS
MIKE11 Model Network

FIGURE 39

AM & GDL \\nhanfile-van\Projects\Active\300349 Maple Ridge\GIS\300349_AM_Fig39_MIKE11 Model Network.mxd

November 2014 Calibration Event Model Inflow Boundary Conditions

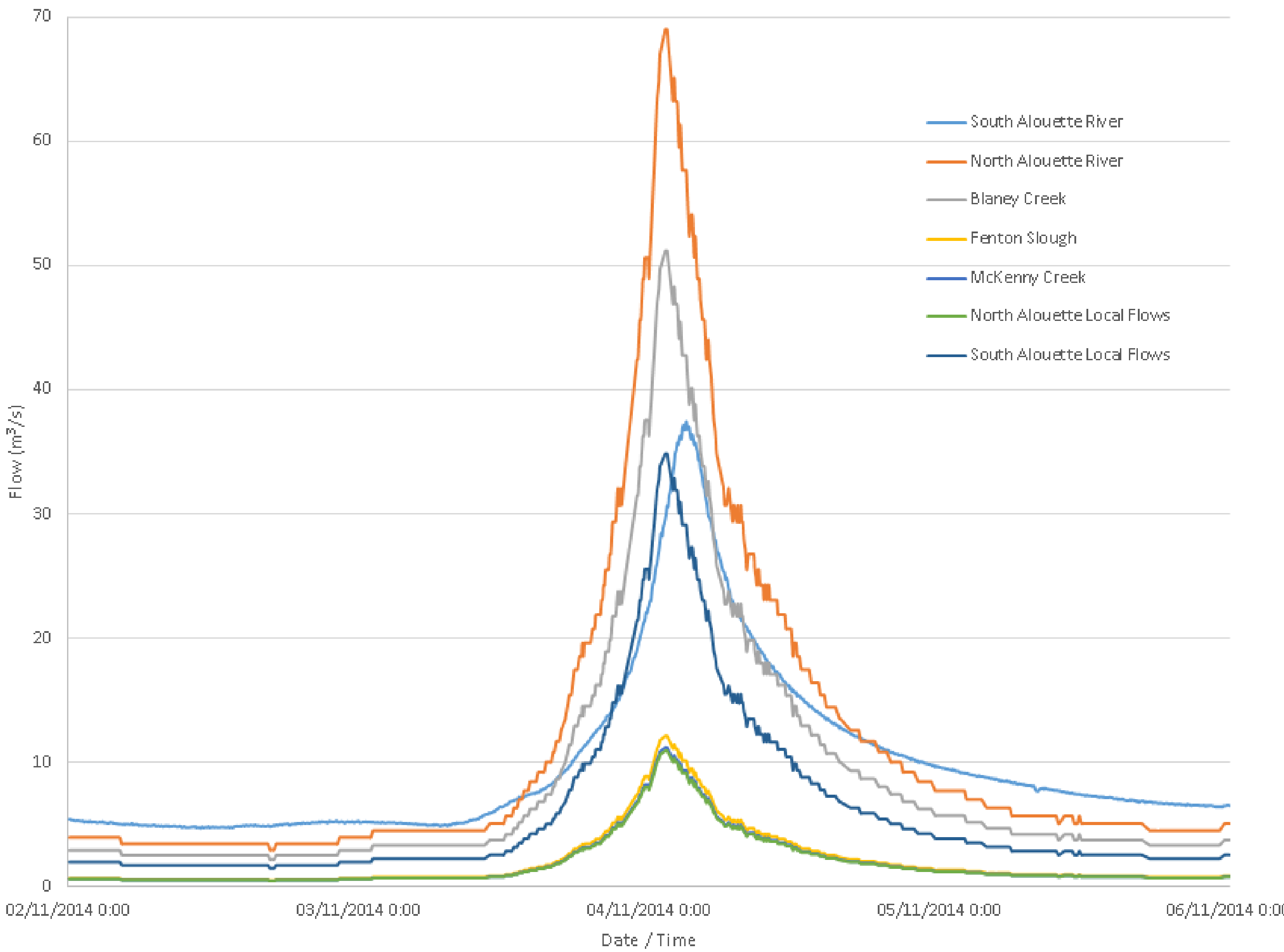

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Figure 40

November 2014 Calibration Event Model Water Level Boundary Conditions

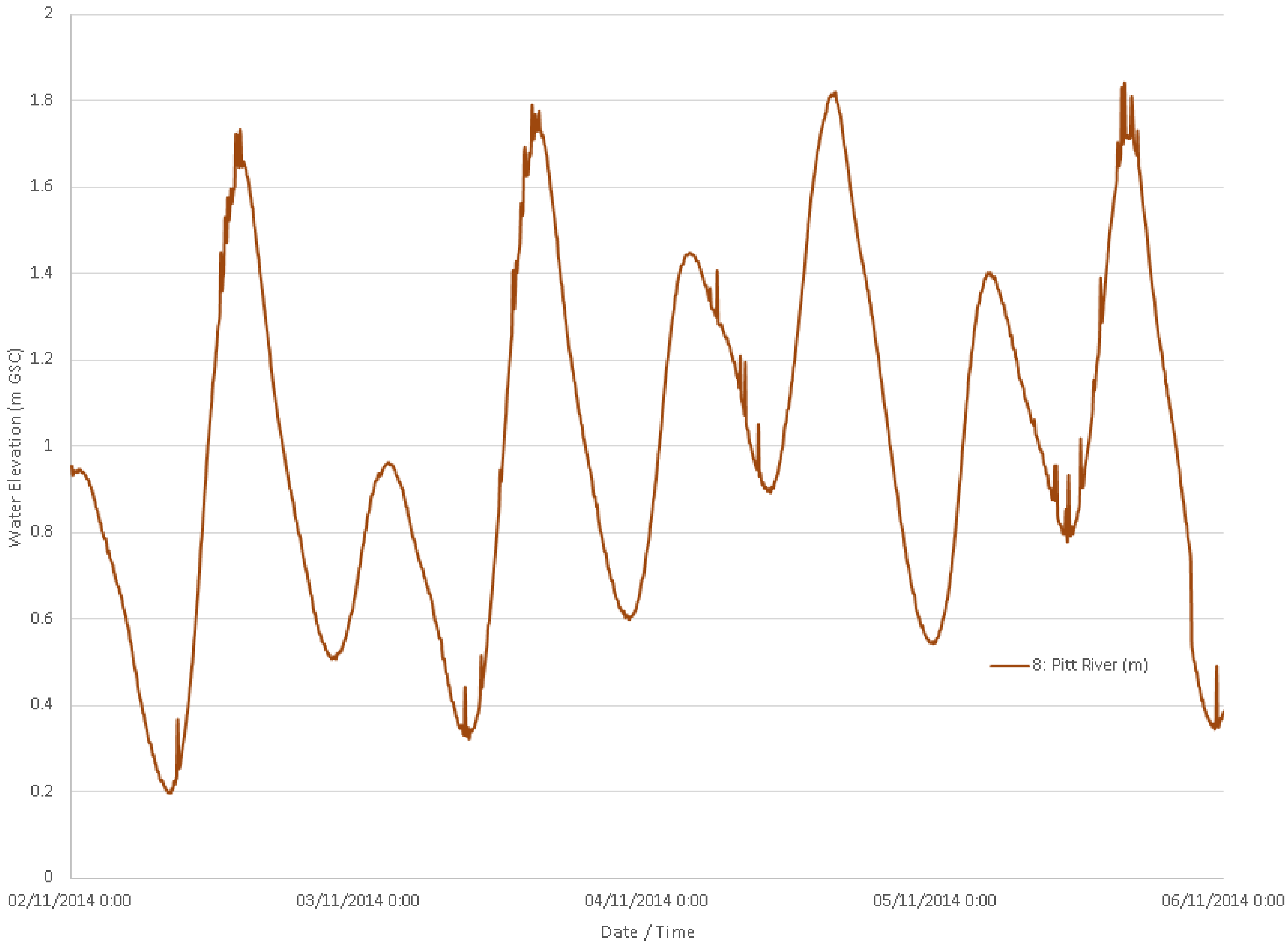

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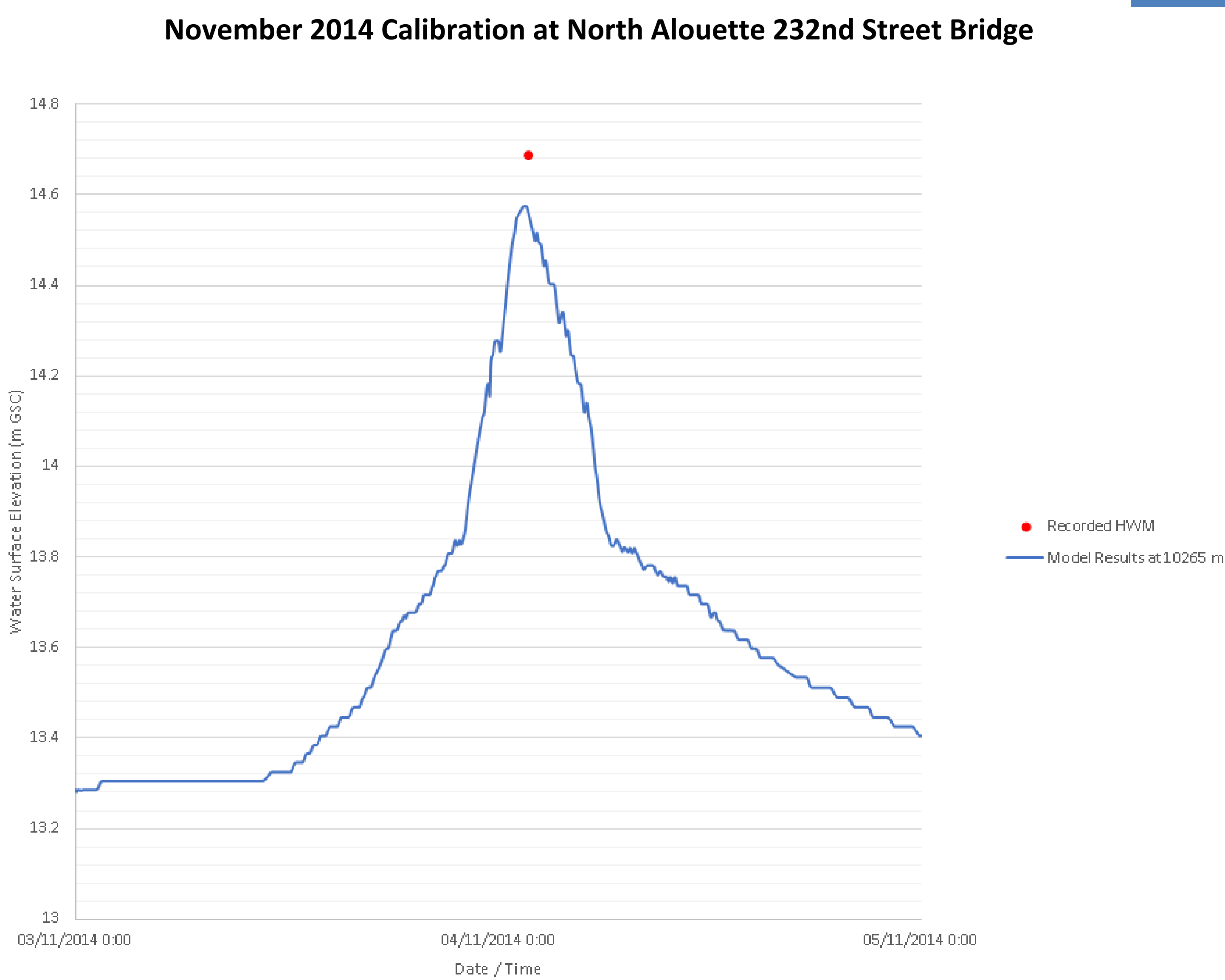
Figure 41



nhc

Figure 42

November 2014 Calibration at North Alouette AVA Gauge

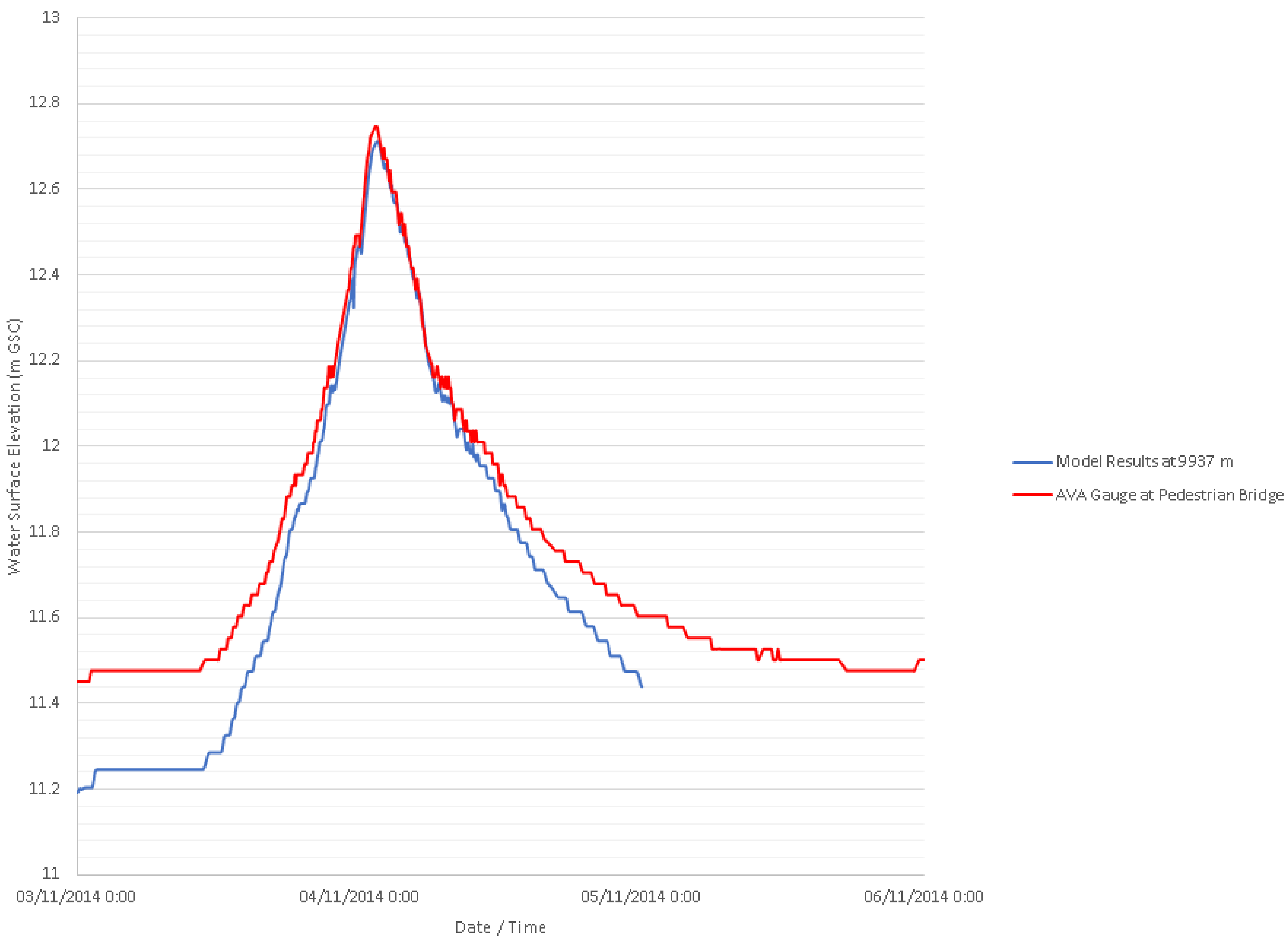


Figure 43

November 2014 Calibration at North Alouette at 224th Street Bridge (Maple Ridge Gauge)

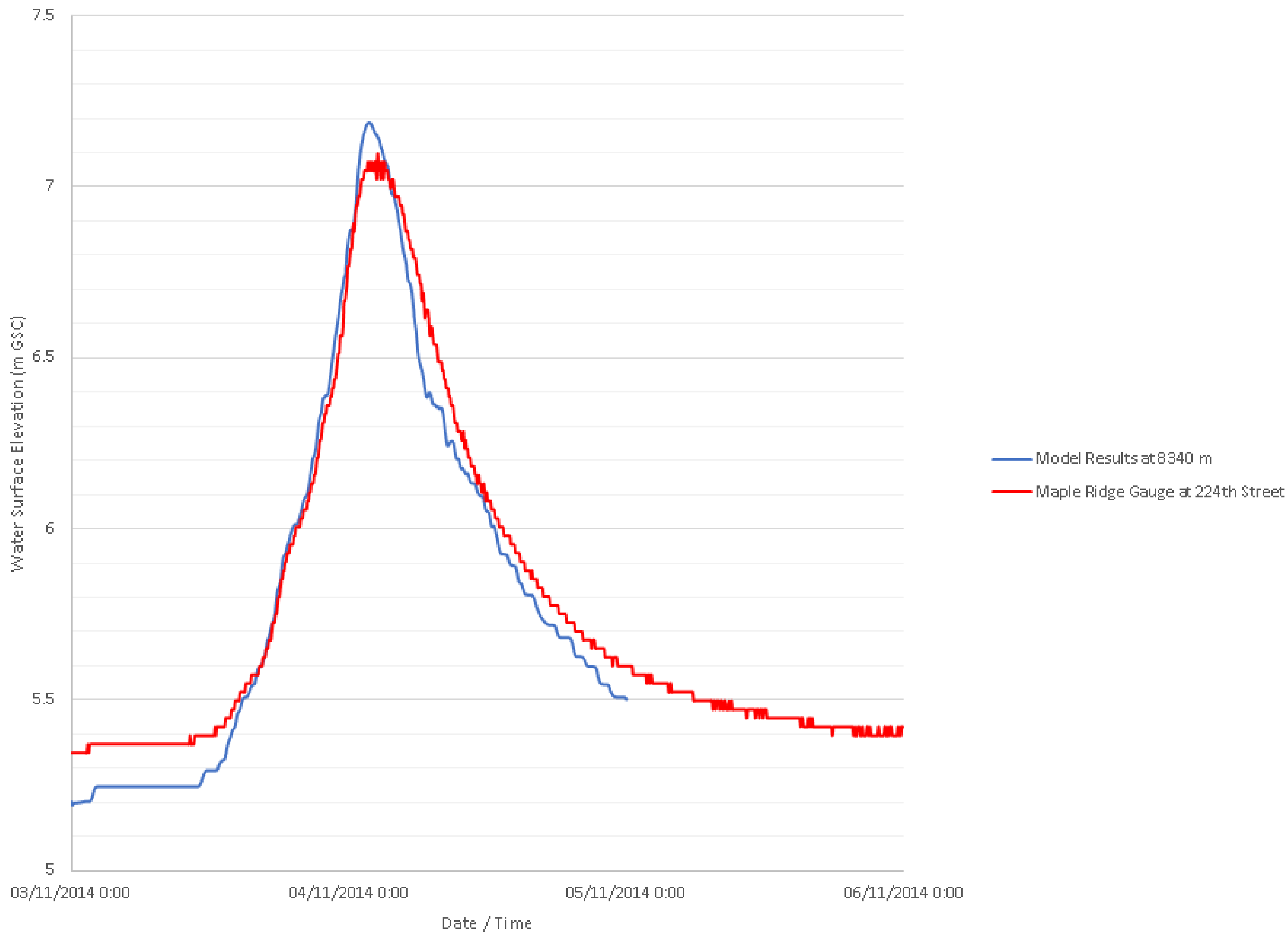
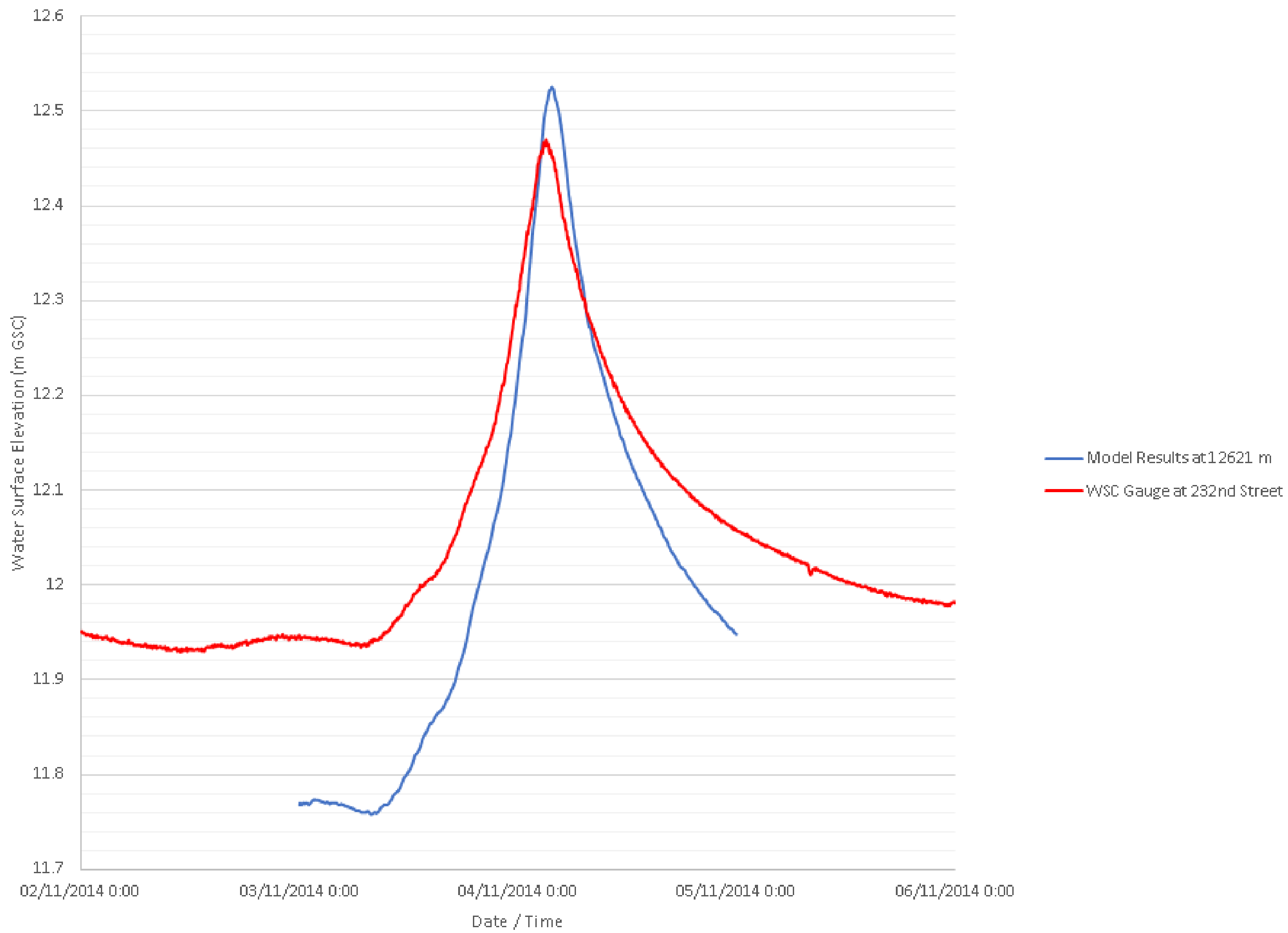


Figure 44

November 2014 Calibration at South Alouette at 232nd Street Bridge (WSC Gauge)

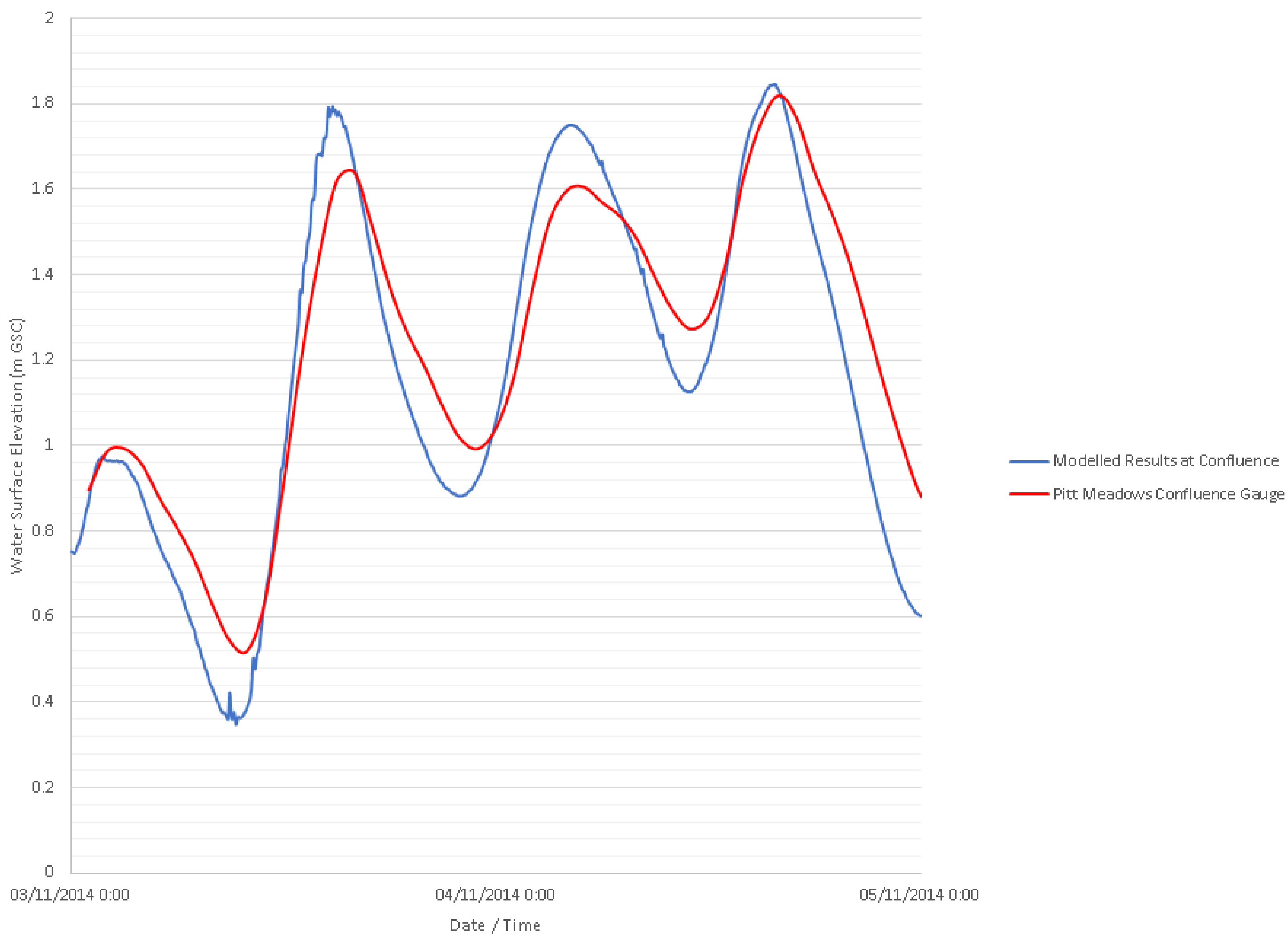


nhc

Figure 45

November 2014 Calibration at Alouette Rivers Confluence

(Pitt Meadows Gauge)



nhc

Figure 46

Janaury 2015 Validation Event Model Inflow Boundary Conditions

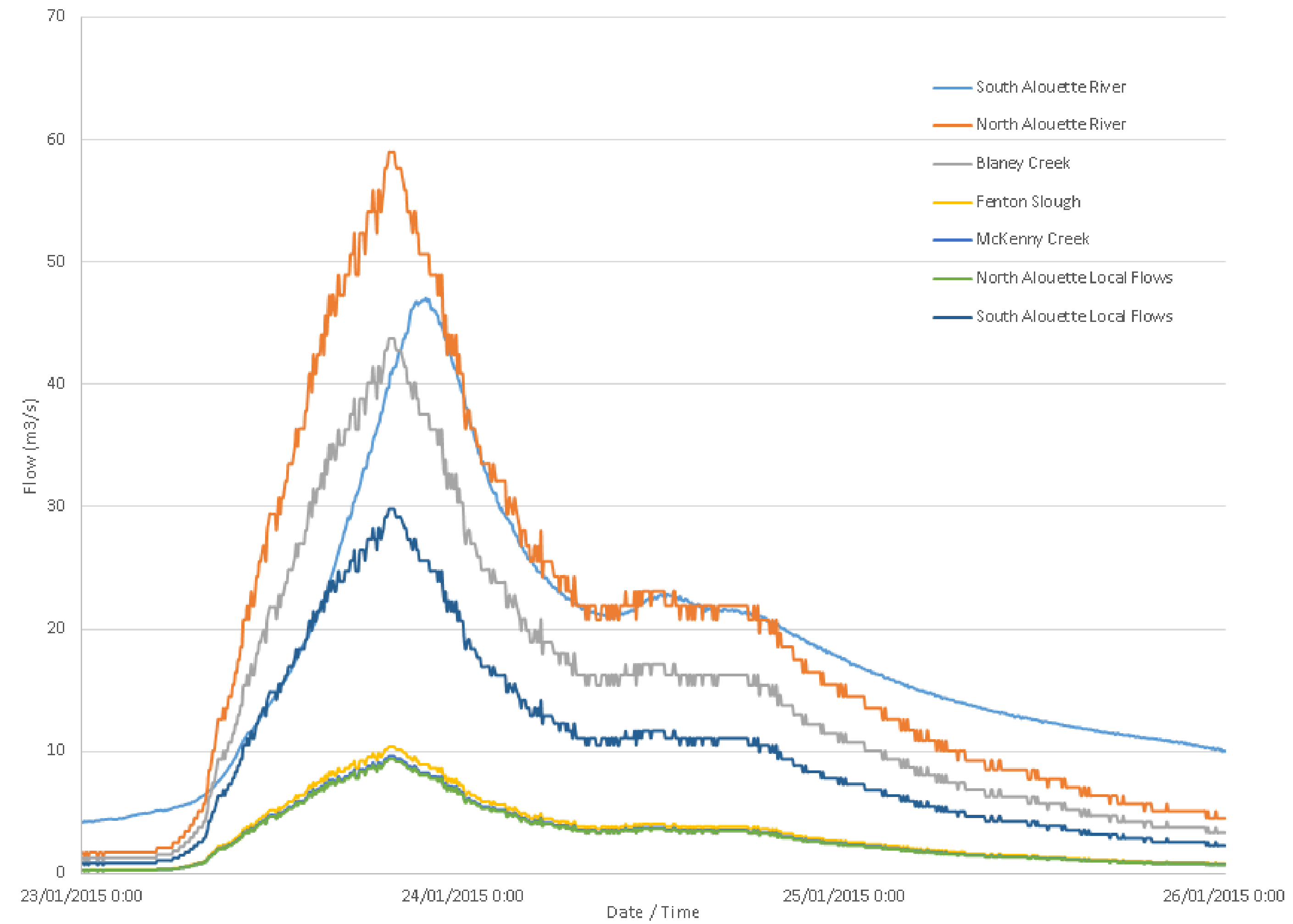
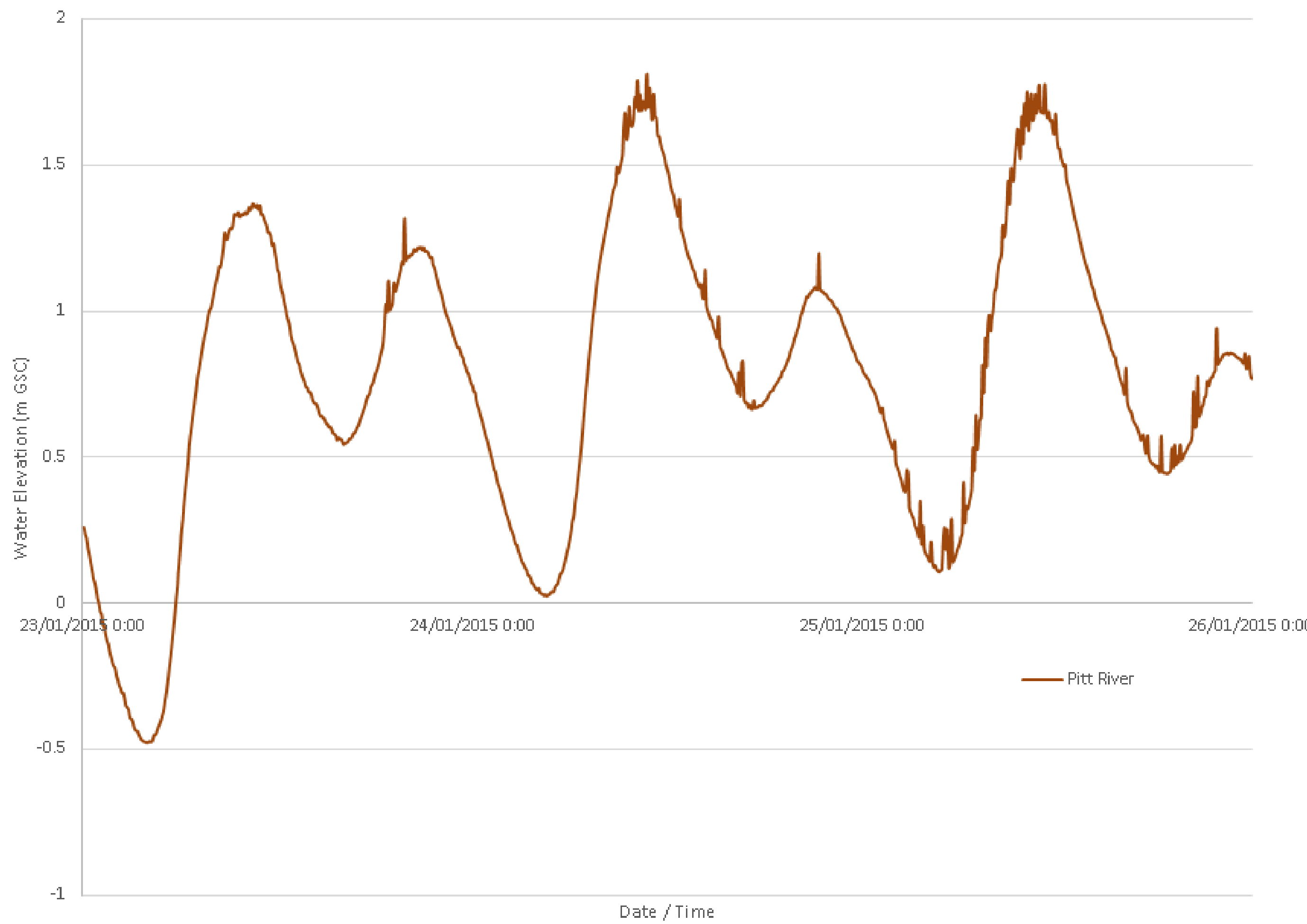


Figure 47

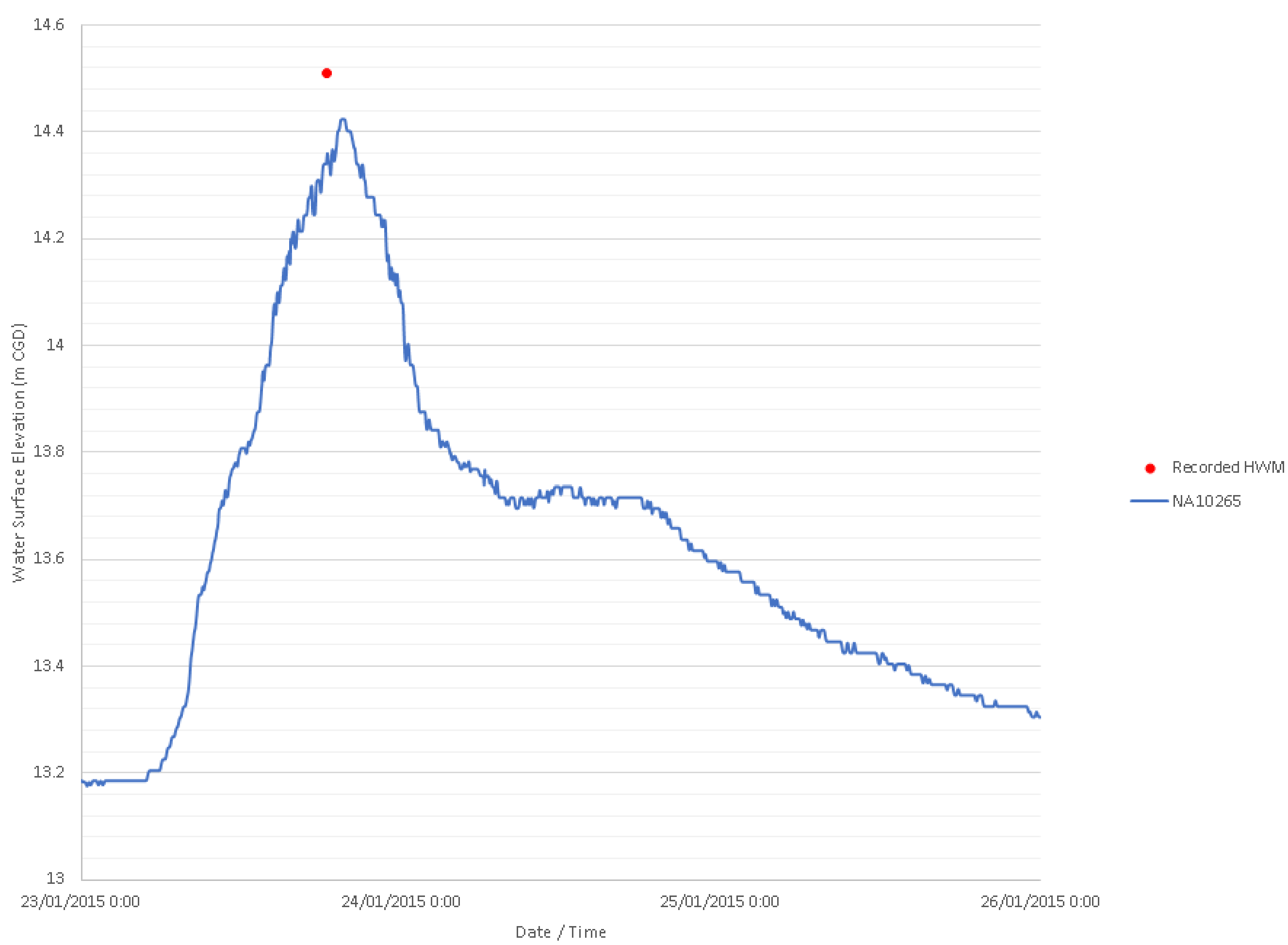
January 2015 Validation Event Water Level Boundary Conditions



nhc

Figure 48

January 2015 Validation at North Alouette 232nd Street Bridge



nhc

Figure 49

January 2015 Validation at North Alouette AVA Gauge

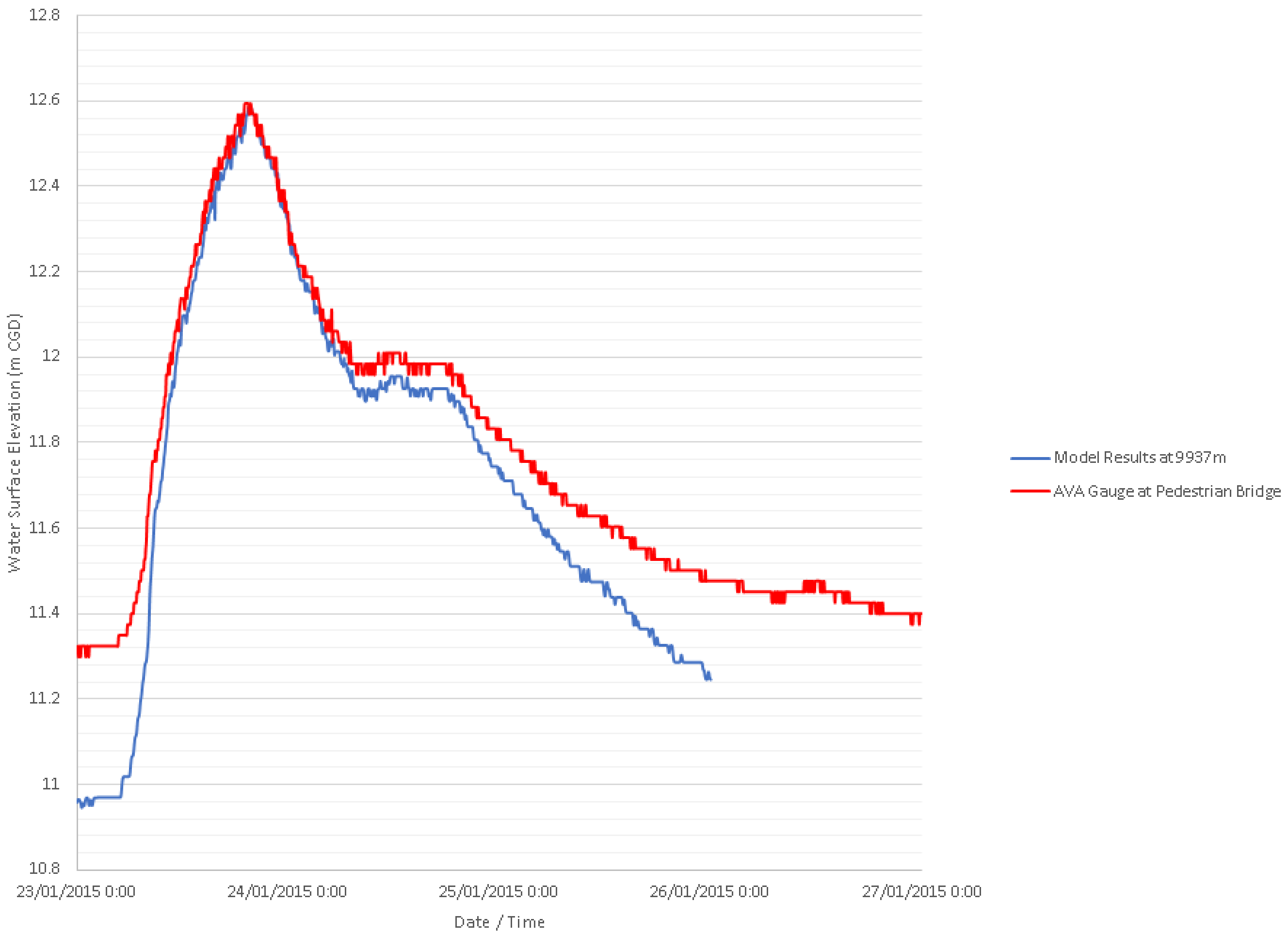
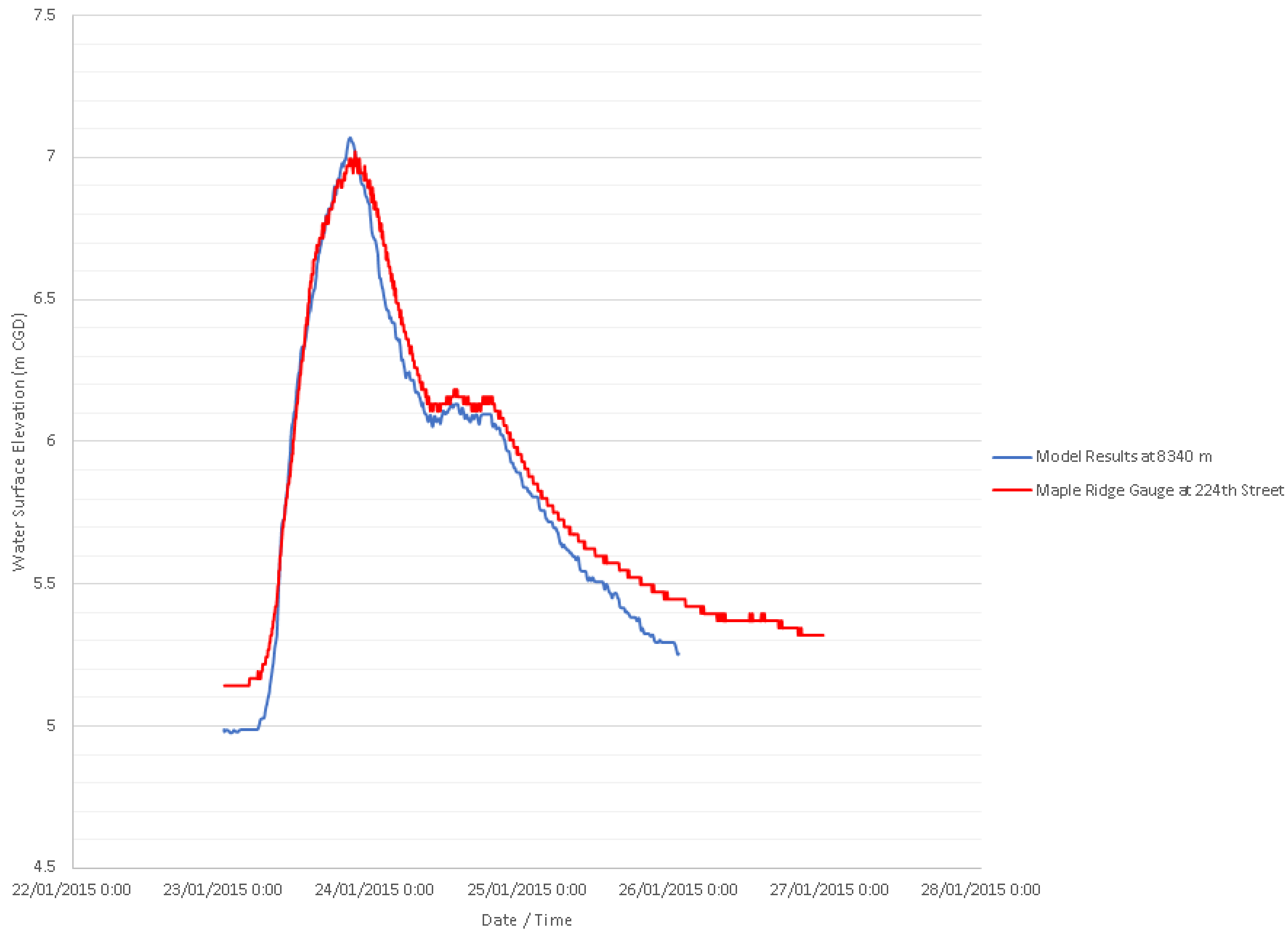


Figure 50

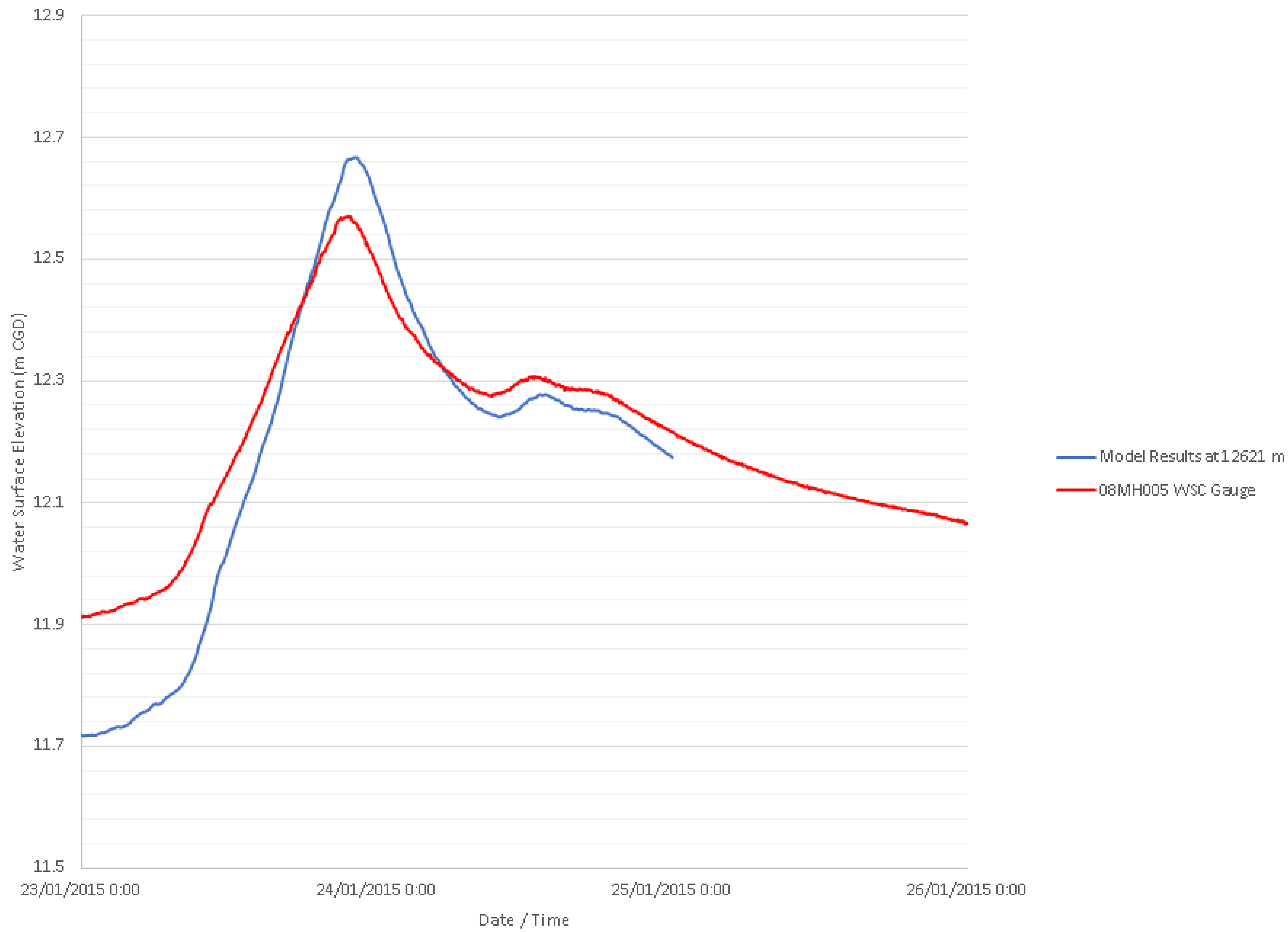
January 2015 Validation at North Alouette at 224th Street Bridge (Maple Ridge Gauge)



nhc

Figure 51

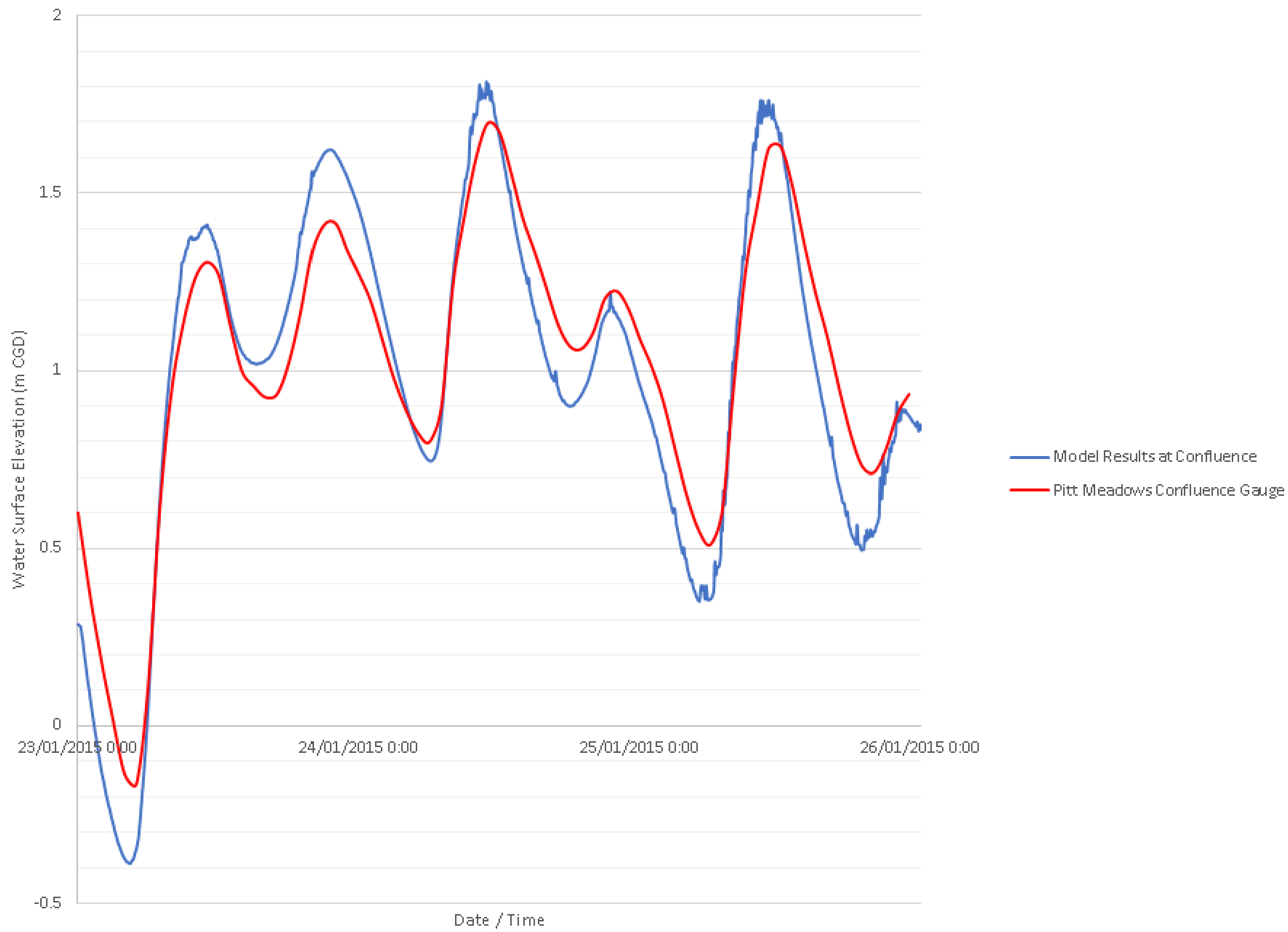
January 2015 Validation at South Alouette at 232nd Street Bridge (WSC Gauge)



nhc

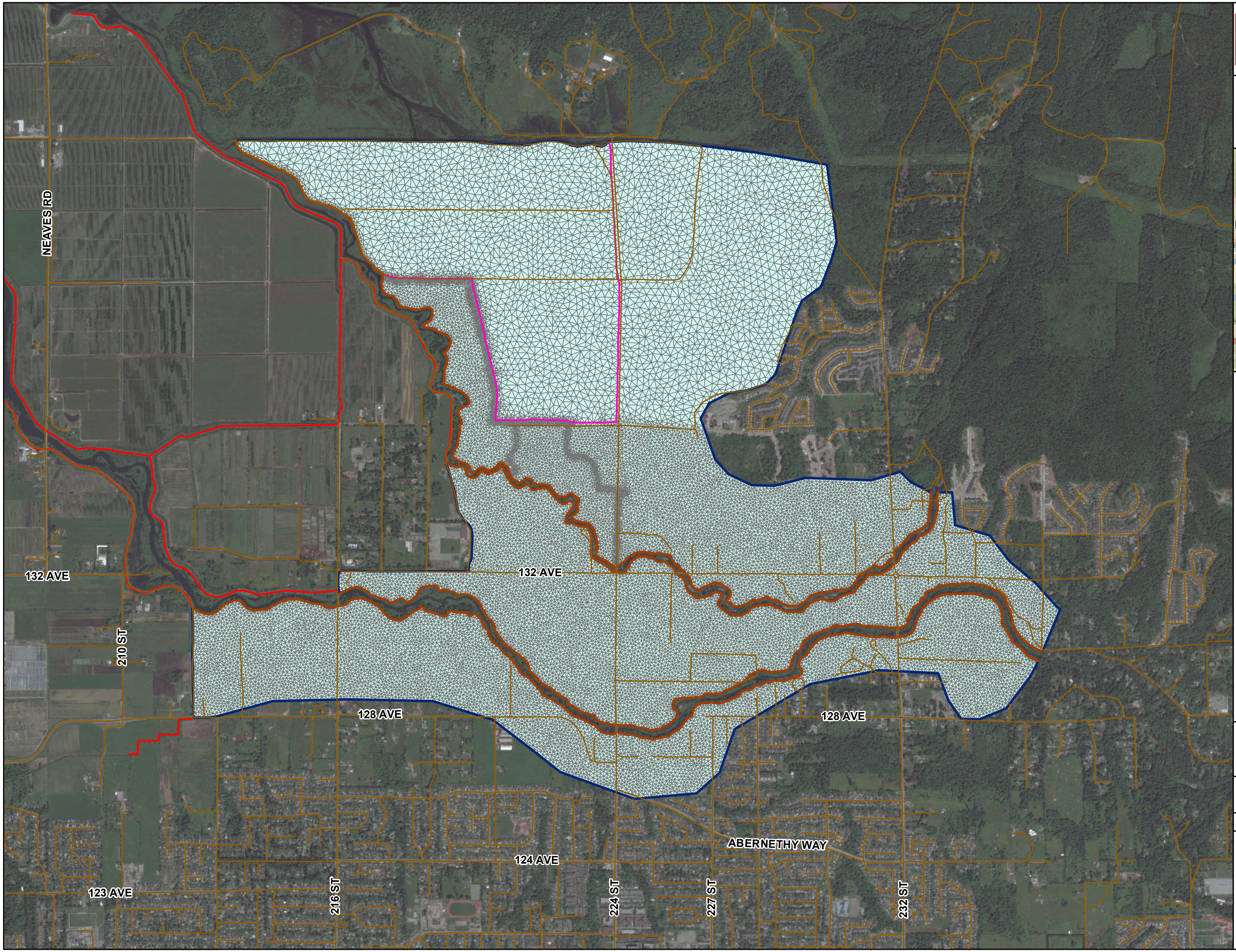
Figure 52

January 2015 Validation at Alouette Rivers' Confluence (Pitt Meadows Gauge)



nhc

Figure 53



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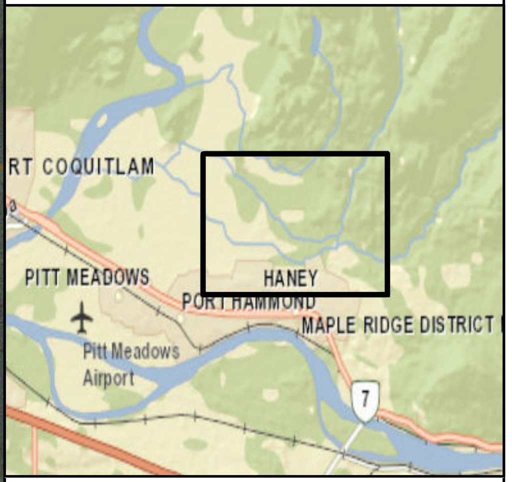


- Roads
- Link (MIKE21/MIKE11)
- MIKE21 Boundary
- Internal Weir
- Dike
- Mesh

DATA SOURCES:
- Esri World Imagery
- Esri World Street Map

SCALE - 1:20,000

0 200 400 600 800 M

N

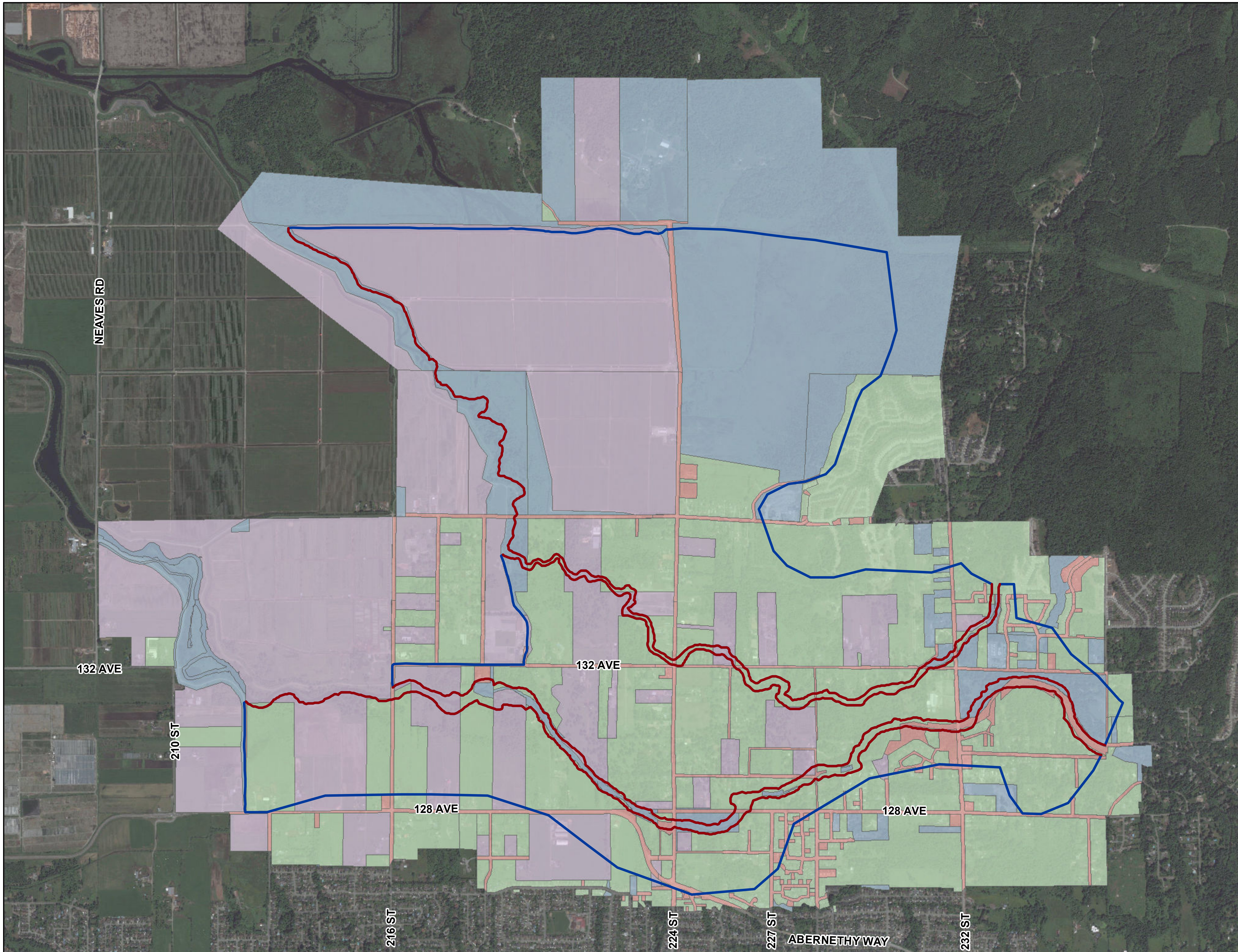
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES

Job: 300349 | Date: 30-NOV-2015

ALOUETTE RIVERS
ADDITIONAL
FLOODPLAIN ANALYSIS

MIKE21 Mesh Surface

FIGURE 54



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Link (MIKE21/MIKE11)
MIKE21 Boundary
Model Roughness
12.5
16.7
20.0
25.0

DATA SOURCES:
- Esri World Imagery
- Esri World Street Map

SCALE - 1:20,000
0 200 400 600 800 M
N

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

Job: 300349 | *Date: 30-NOV-2015*

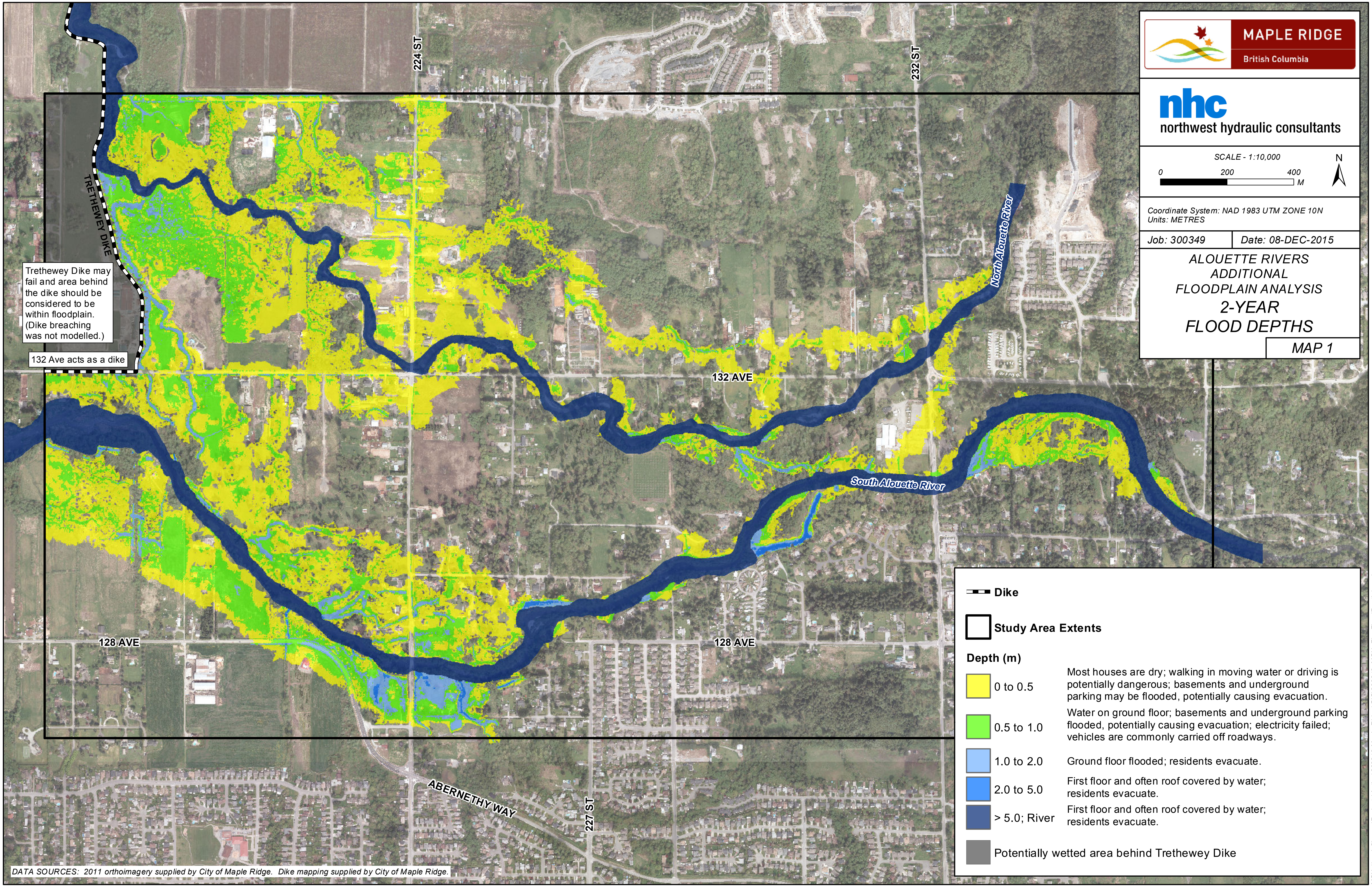
ALOUETTE RIVERS ADDITIONAL FLOODPLAIN ANALYSIS

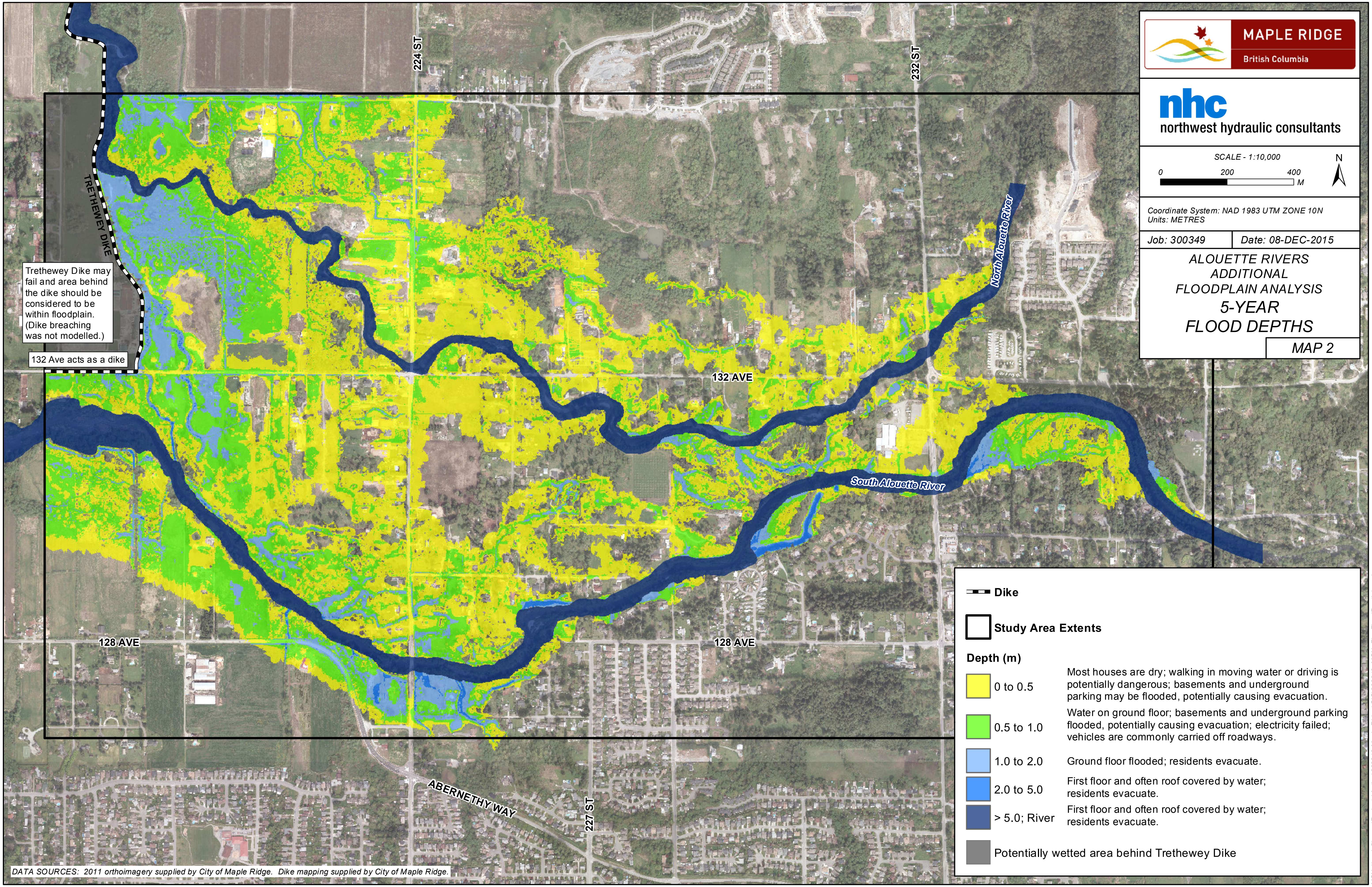
MIKE21 Model Roughness

FIGURE 55

AM & GDL, \\mainfile-van\Projects\Active\300349 Maple Ridge\GIS\300349_AM_Fig55_MIKE21 Model Roughness.mxd nhc

Maps


MAPLE RIDGE
British Columbia
nhc
northwest hydraulic consultants
SCALE - 1:10,000
0 200 400 M
N
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES
Job: 300349
Date: 08-DEC-2015
ALOUETTE RIVERS ADDITIONAL FLOODPLAIN ANALYSIS
2-YEAR FLOOD DEPTHS
MAP 1
224 ST
232 ST
227 ST
132 AVE
128 AVE
128 AVE
ABERNETHY WAY
TRETHEWEY DIKE
North Alouette River
South Alouette River
Trethewey Dike may fail and area behind the dike should be considered to be within floodplain. (Dike breaching was not modelled.)
132 Ave acts as a dike
Dike
Study Area Extents
Depth (m)
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; River
First floor and often roof covered by water; residents evacuate.
Potentially wetted area behind Trethewey Dike
DATA SOURCES: 2011 orthoimagery supplied by City of Maple Ridge. Dike mapping supplied by City of Maple Ridge.



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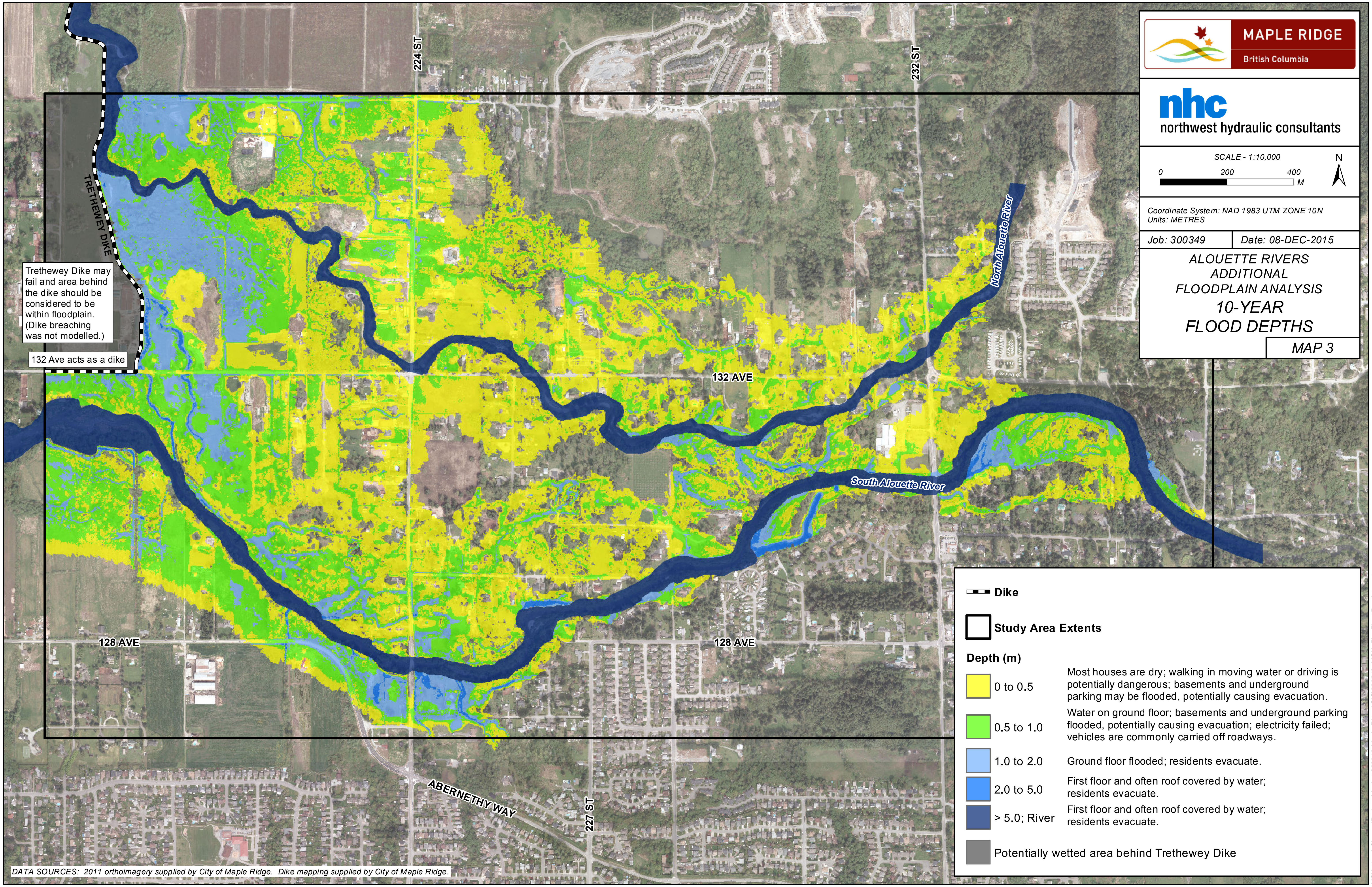

MAPLE RIDGE
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SCALE - 1:10,000
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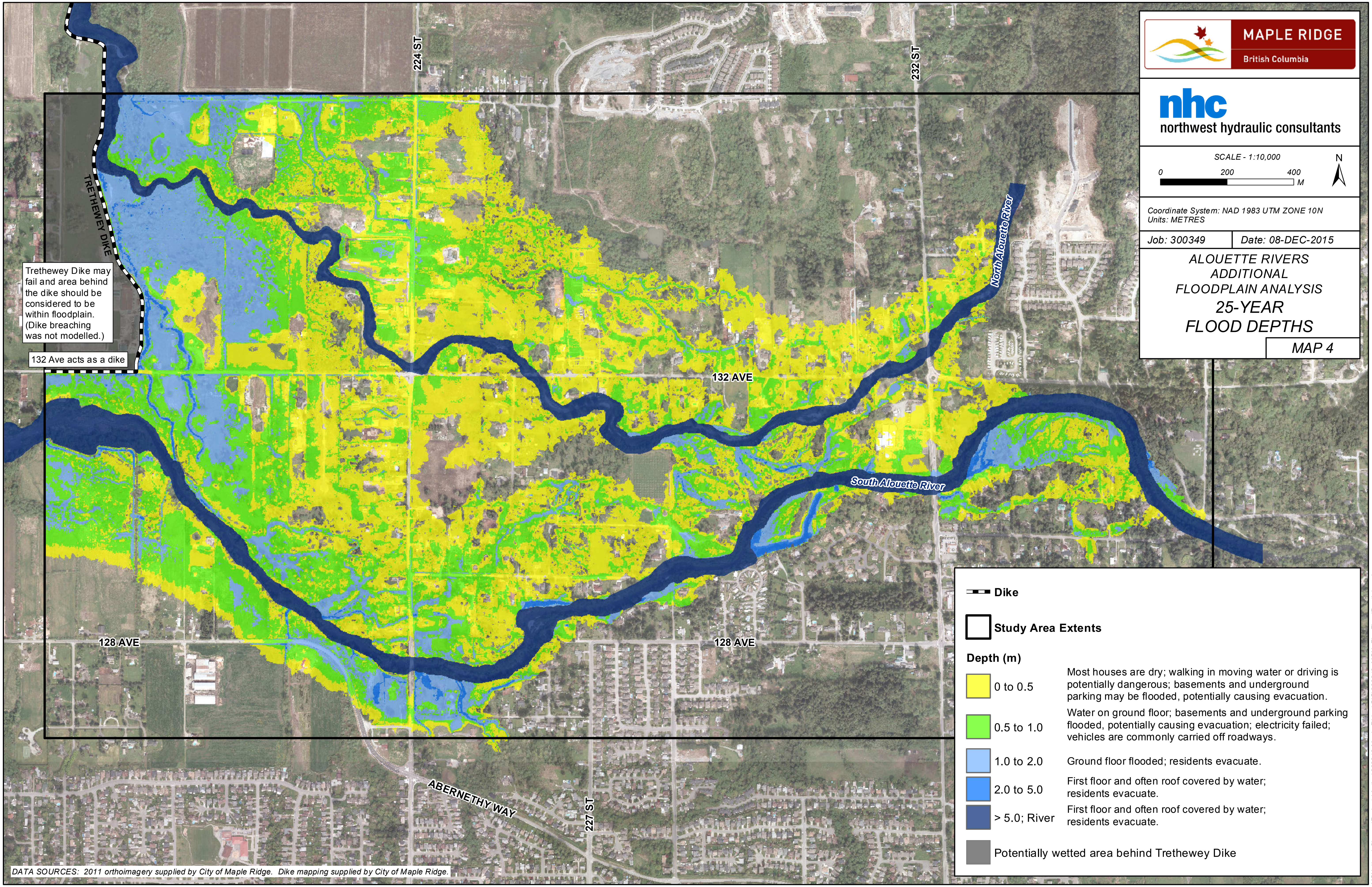
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES
Job: 300349
Date: 08-DEC-2015
ALOUETTE RIVERS
ADDITIONAL
FLOODPLAIN ANALYSIS
10-YEAR
FLOOD DEPTHS
MAP 3
224 ST
232 ST
TRETHEWEY DIKE
Trethewey Dike may fail and area behind the dike should be considered to be within floodplain. (Dike breaching was not modelled.)
132 Ave acts as a dike
132 AVE
North Alouette River
South Alouette River
128 AVE
128 AVE
ABERNETHY WAY
227 ST
Dike
Study Area Extents
Depth (m)
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; River
First floor and often roof covered by water; residents evacuate.
Potentially wetted area behind Trethewey Dike
DATA SOURCES: 2011 orthoimagery supplied by City of Maple Ridge. Dike mapping supplied by City of Maple Ridge.



MAPLE RIDGE
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northwest hydraulic consultants
SCALE - 1:10,000
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Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES
Job: 300349
Date: 08-DEC-2015
ALOUETTE RIVERS
ADDITIONAL
FLOODPLAIN ANALYSIS
25-YEAR
FLOOD DEPTHS
MAP 4
224 ST
232 ST
227 ST
132 AVE
128 AVE
128 AVE
ABERNETHY WAY
TRETHEWEY DIKE
North Alouette River
South Alouette River
Trethewey Dike may fail and area behind the dike should be considered to be within floodplain. (Dike breaching was not modelled.)
132 Ave acts as a dike
Dike
Study Area Extents
Depth (m)
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.
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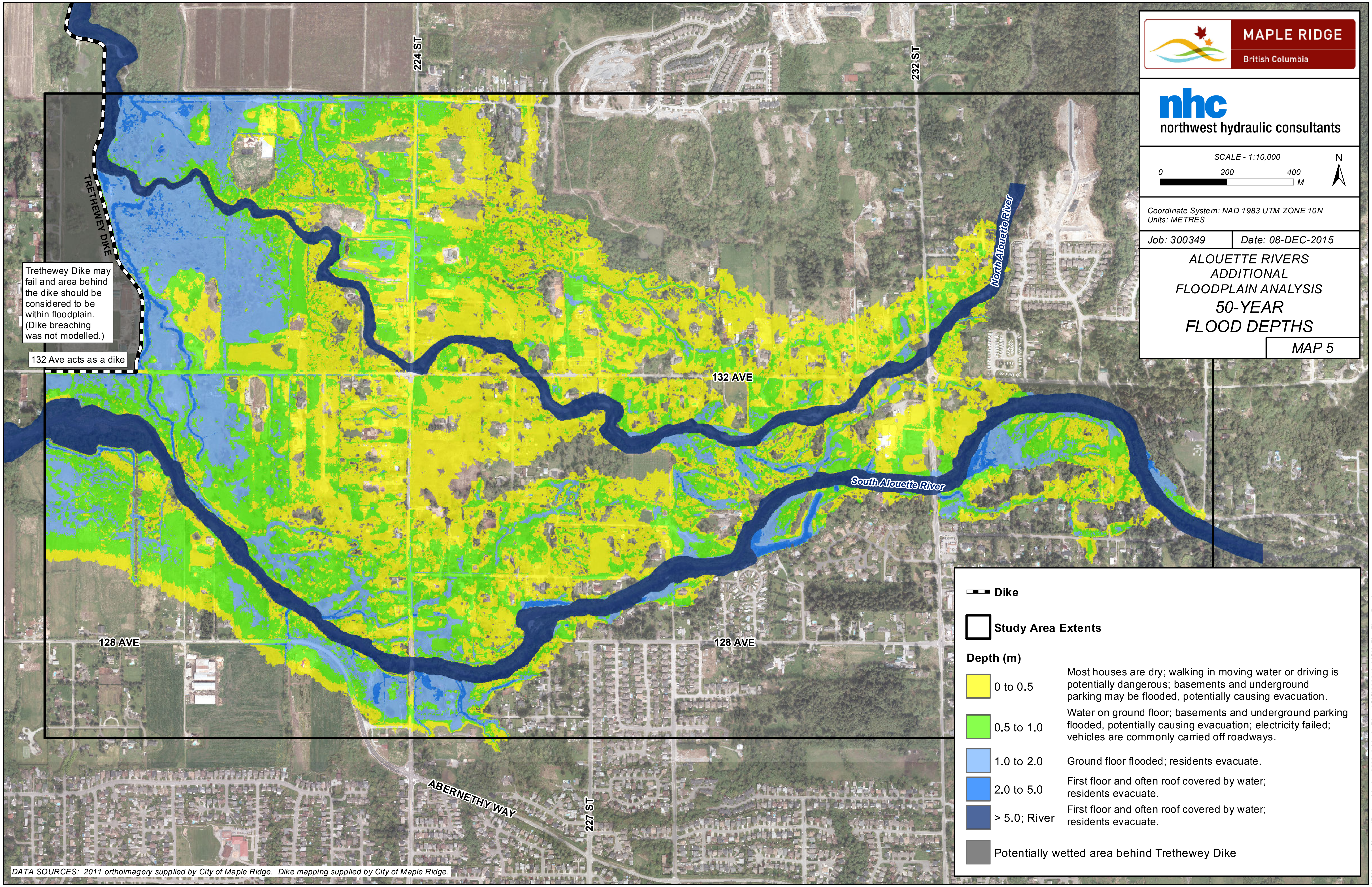
Ground floor flooded; residents evacuate.
2.0 to 5.0
First floor and often roof covered by water; residents evacuate.
> 5.0; River
First floor and often roof covered by water; residents evacuate.
Potentially wetted area behind Trethewey Dike
DATA SOURCES: 2011 orthoimagery supplied by City of Maple Ridge. Dike mapping supplied by City of Maple Ridge.


MAPLE RIDGE
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northwest hydraulic consultants
SCALE - 1:10,000
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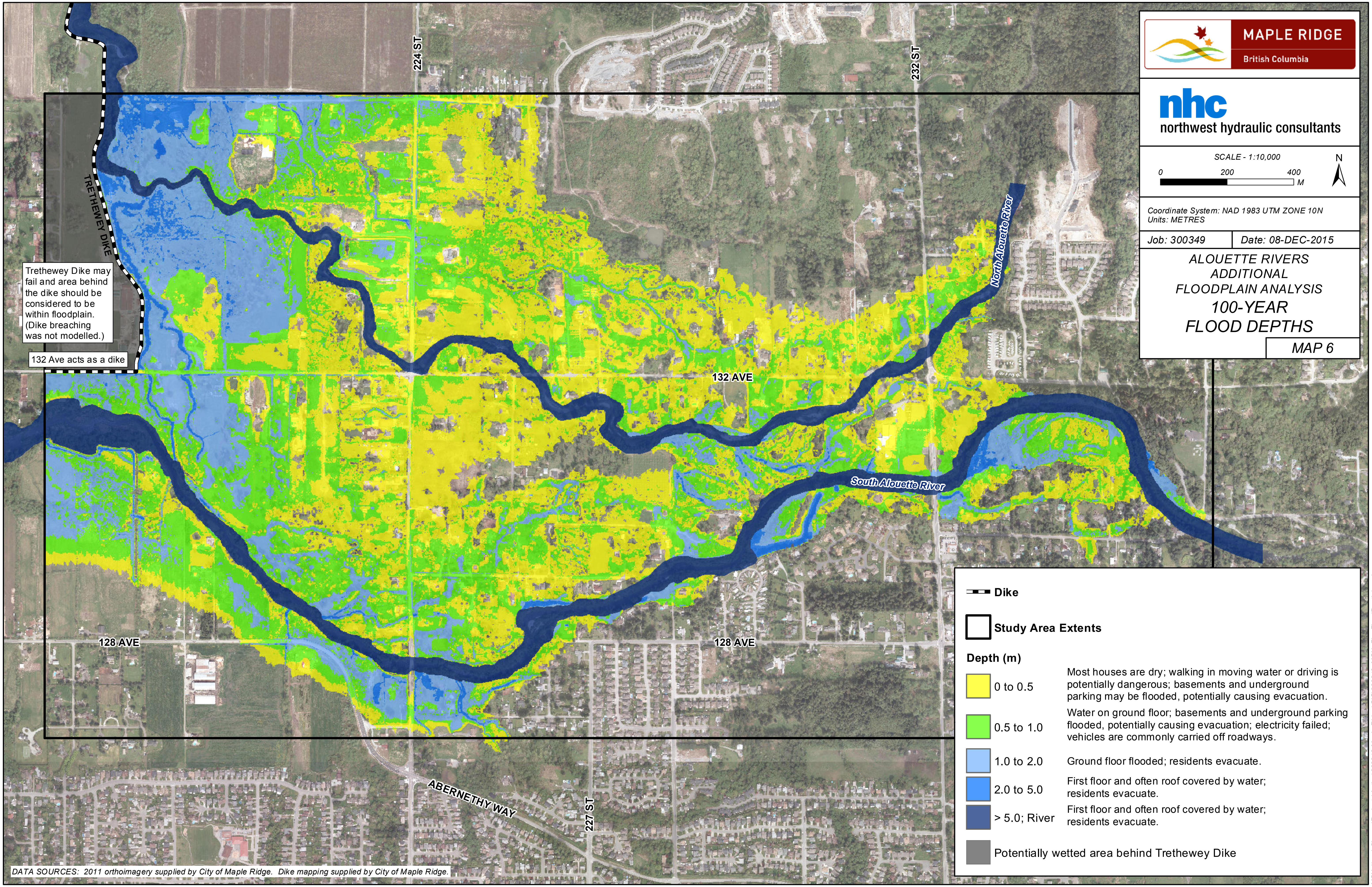
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES
Job: 300349
Date: 08-DEC-2015
ALOUETTE RIVERS
ADDITIONAL
FLOODPLAIN ANALYSIS
50-YEAR
FLOOD DEPTHS
MAP 5
224 ST
232 ST
TRETHEWEY DIKE
Trethewey Dike may fail and area behind the dike should be considered to be within floodplain. (Dike breaching was not modelled.)
132 Ave acts as a dike
North Alouette River
132 AVE
South Alouette River
128 AVE
128 AVE
ABERNETHY WAY
227 ST
Dike
Study Area Extents
Depth (m)
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; River
First floor and often roof covered by water; residents evacuate.
Potentially wetted area behind Trethewey Dike
DATA SOURCES: 2011 orthoimagery supplied by City of Maple Ridge. Dike mapping supplied by City of Maple Ridge.



MAPLE RIDGE
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northwest hydraulic consultants
SCALE - 1:10,000
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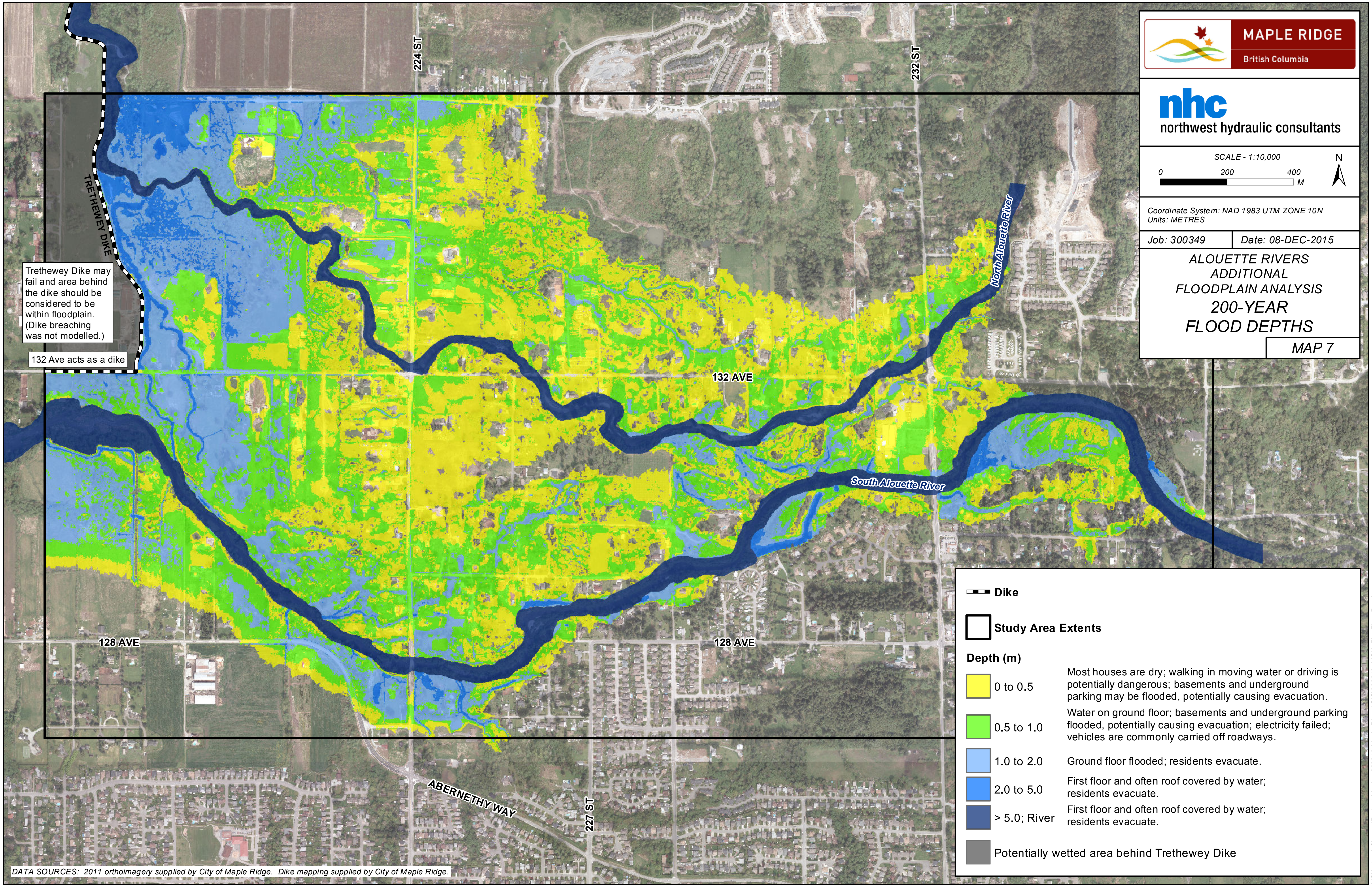
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES
Job: 300349
Date: 08-DEC-2015
ALOUETTE RIVERS
ADDITIONAL
FLOODPLAIN ANALYSIS
100-YEAR
FLOOD DEPTHS
MAP 6
224 ST
232 ST
227 ST
132 AVE
128 AVE
128 AVE
ABERNETHY WAY
TRETHEWEY DIKE
North Alouette River
South Alouette River
Trethewey Dike may fail and area behind the dike should be considered to be within floodplain. (Dike breaching was not modelled.)
132 Ave acts as a dike
Dike
Study Area Extents
Depth (m)
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; River
First floor and often roof covered by water; residents evacuate.
Potentially wetted area behind Trethewey Dike
DATA SOURCES: 2011 orthoimagery supplied by City of Maple Ridge. Dike mapping supplied by City of Maple Ridge.


MAPLE RIDGE
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northwest hydraulic consultants
SCALE - 1:10,000
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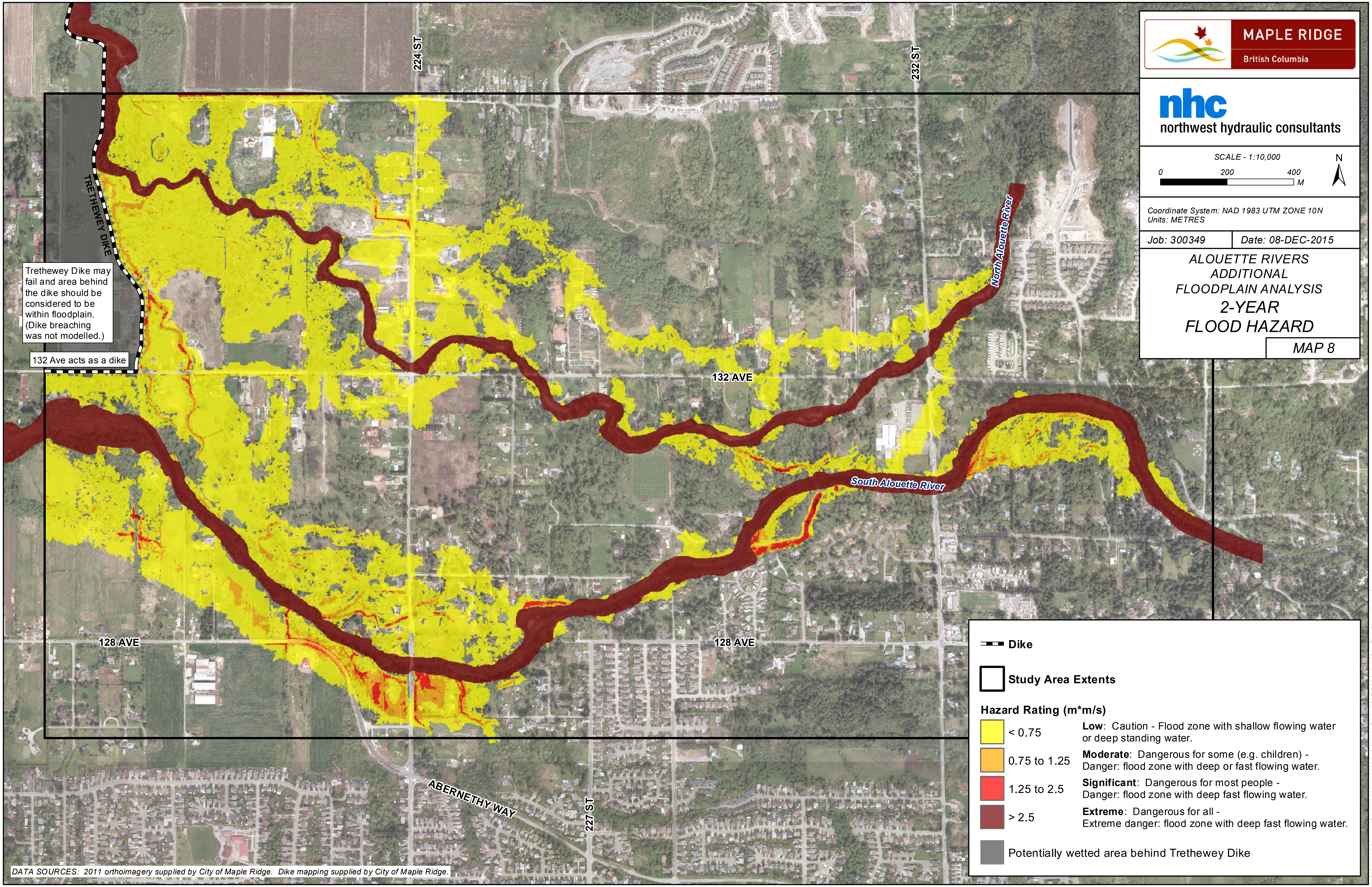
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES
Job: 300349
Date: 08-DEC-2015
ALOUETTE RIVERS
ADDITIONAL
FLOODPLAIN ANALYSIS
200-YEAR
FLOOD DEPTHS
MAP 7
224 ST
232 ST
TRETHEWEY DIKE
Trethewey Dike may fail and area behind the dike should be considered to be within floodplain. (Dike breaching was not modelled.)
132 Ave acts as a dike
132 AVE
North Alouette River
South Alouette River
128 AVE
128 AVE
ABERNETHY WAY
227 ST
Dike
Study Area Extents
Depth (m)
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; River
First floor and often roof covered by water; residents evacuate.
Potentially wetted area behind Trethewey Dike
DATA SOURCES: 2011 orthoimagery supplied by City of Maple Ridge. Dike mapping supplied by City of Maple Ridge.


MAPLE RIDGE
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northwest hydraulic consultants
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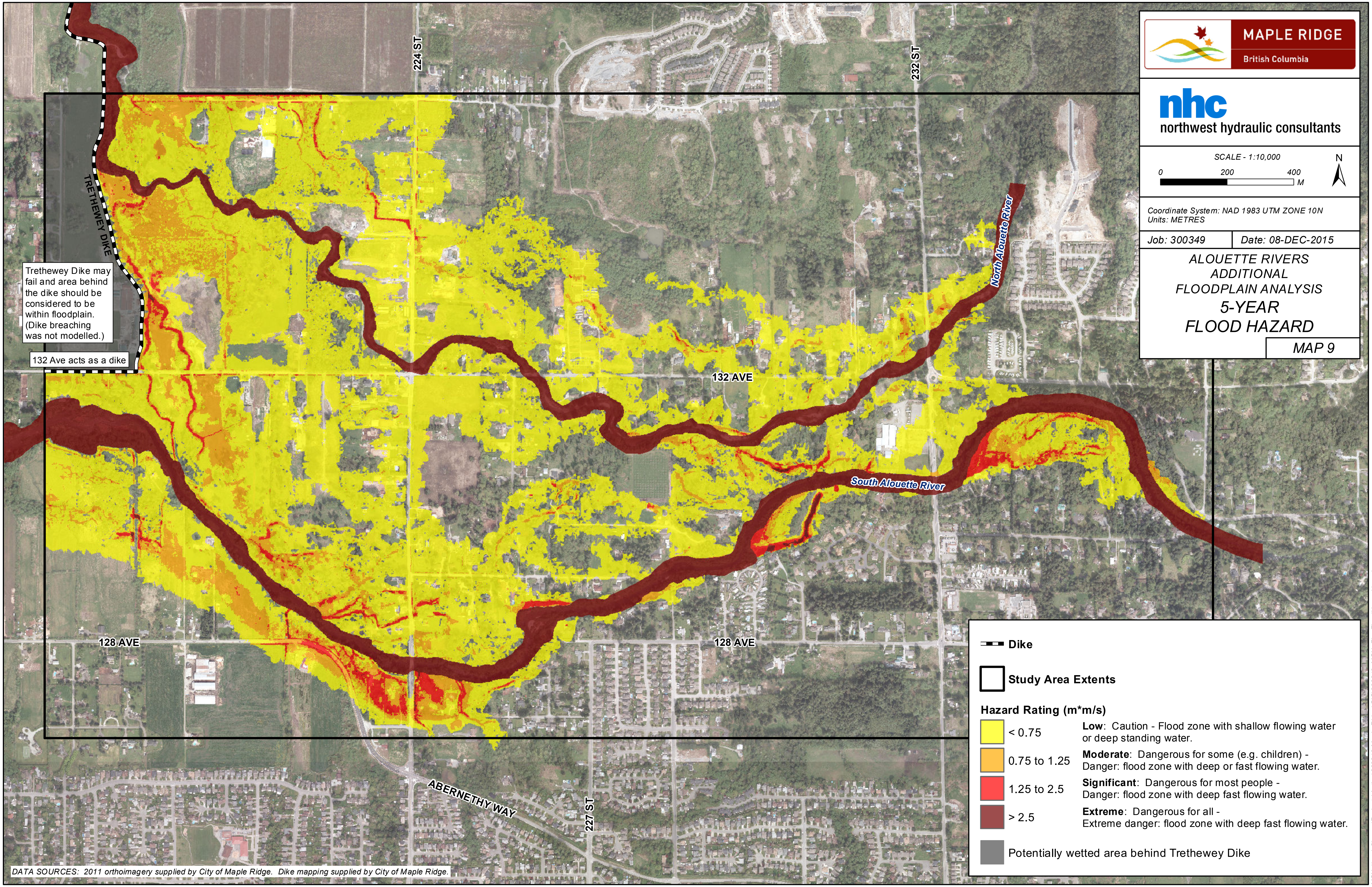
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES
Job: 300349
Date: 08-DEC-2015
ALOUETTE RIVERS
ADDITIONAL
FLOODPLAIN ANALYSIS
2-YEAR
FLOOD HAZARD
MAP 8
224 ST
232 ST
227 ST
132 AVE
128 AVE
128 AVE
ABERNETHY WAY
TRETHEWEY DIKE
North Alouette River
South Alouette River
Trethewey Dike may fail and area behind the dike should be considered to be within floodplain. (Dike breaching was not modelled.)
132 Ave acts as a dike
Dike
Study Area Extents
Hazard Rating (m*m/s)
< 0.75
Low: Caution - Flood zone with shallow flowing water or deep standing water.
0.75 to 1.25
Moderate: Dangerous for some (e.g. 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.
Potentially wetted area behind Trethewey Dike
DATA SOURCES: 2011 orthoimagery supplied by City of Maple Ridge. Dike mapping supplied by City of Maple Ridge.



MAPLE RIDGE
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northwest hydraulic consultants
SCALE - 1:10,000
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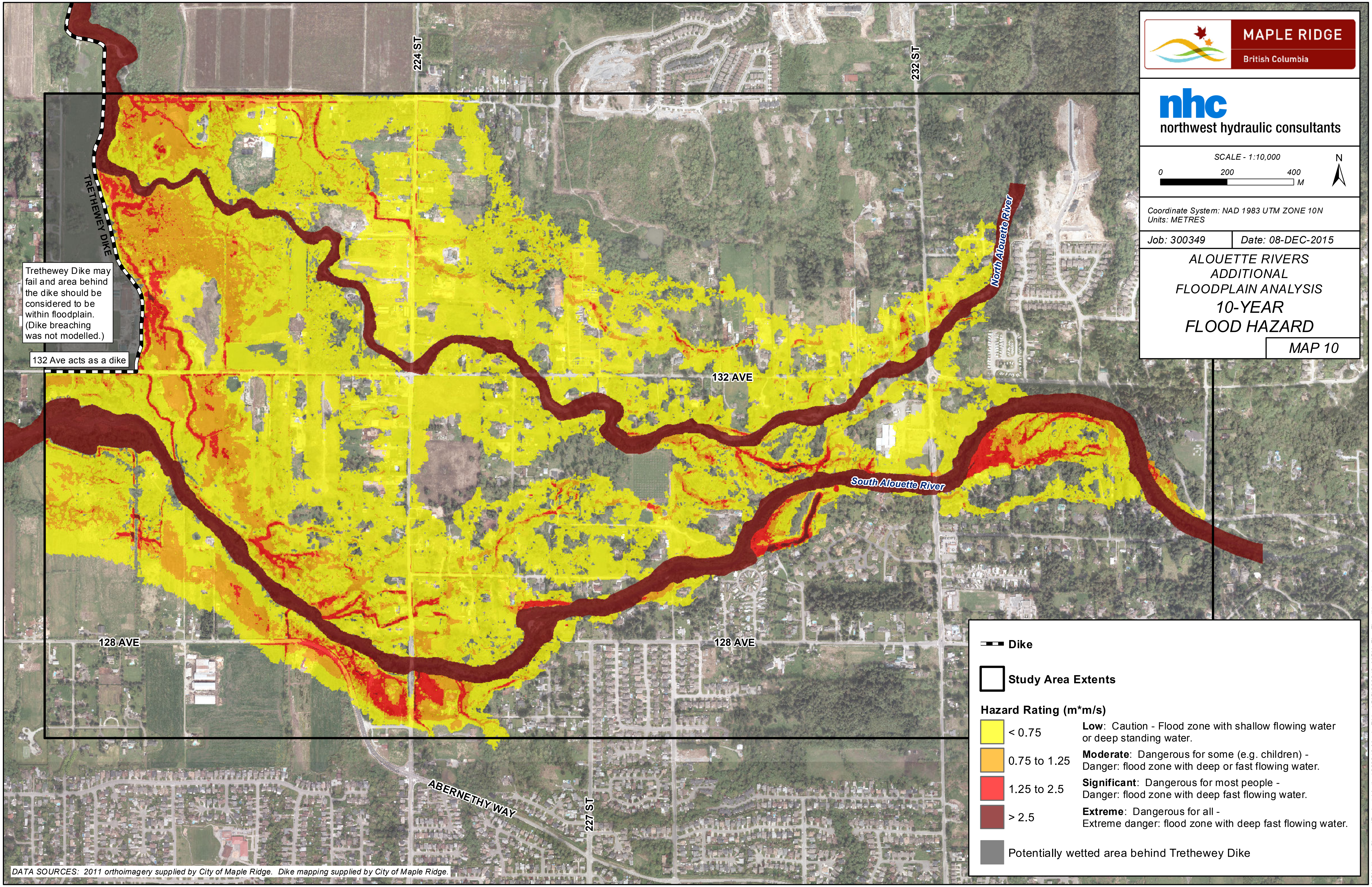
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES
Job: 300349
Date: 08-DEC-2015
ALOUETTE RIVERS
ADDITIONAL
FLOODPLAIN ANALYSIS
5-YEAR
FLOOD HAZARD
MAP 9
224 ST
232 ST
TRETHEWEY DIKE
Trethewey Dike may fail and area behind the dike should be considered to be within floodplain. (Dike breaching was not modelled.)
132 Ave acts as a dike
132 AVE
North Alouette River
South Alouette River
128 AVE
128 AVE
ABERNETHY WAY
227 ST
Dike
Study Area Extents
Hazard Rating (m*m/s)
< 0.75
Low: Caution - Flood zone with shallow flowing water or deep standing water.
0.75 to 1.25
Moderate: Dangerous for some (e.g. 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.
Potentially wetted area behind Trethewey Dike
DATA SOURCES: 2011 orthoimagery supplied by City of Maple Ridge. Dike mapping supplied by City of Maple Ridge.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northwest hydraulic consultants
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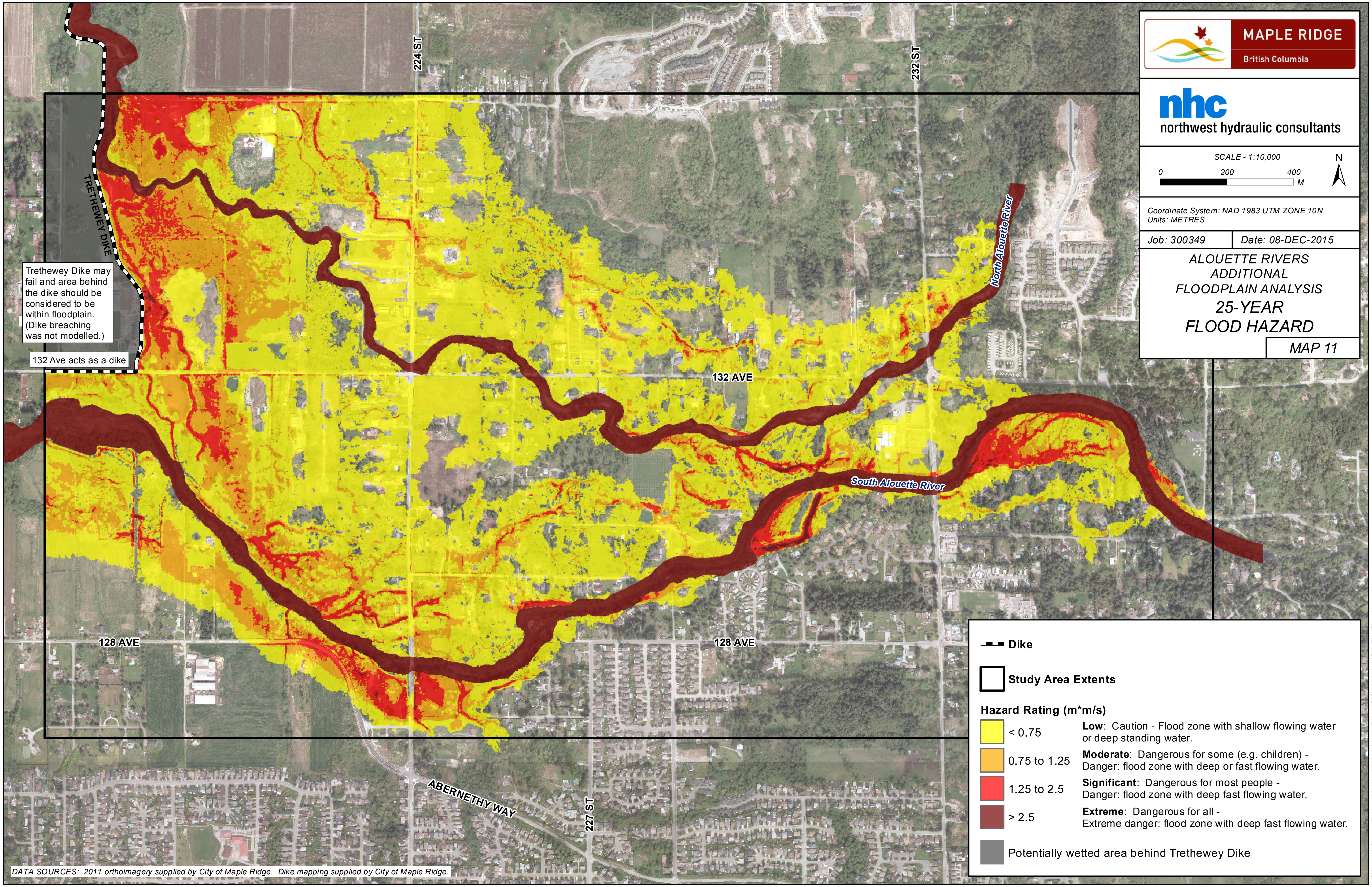
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES
Job: 300349
Date: 08-DEC-2015
ALOUETTE RIVERS
ADDITIONAL
FLOODPLAIN ANALYSIS
10-YEAR
FLOOD HAZARD
MAP 10
224 ST
232 ST
TRETHEWEY DIKE
Trethewey Dike may fail and area behind the dike should be considered to be within floodplain. (Dike breaching was not modelled.)
132 Ave acts as a dike
132 AVE
North Alouette River
South Alouette River
128 AVE
128 AVE
ABERNETHY WAY
227 ST
Dike
Study Area Extents
Hazard Rating (m*m/s)
< 0.75
Low: Caution - Flood zone with shallow flowing water or deep standing water.
0.75 to 1.25
Moderate: Dangerous for some (e.g. 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.
Potentially wetted area behind Trethewey Dike
DATA SOURCES: 2011 orthoimagery supplied by City of Maple Ridge. Dike mapping supplied by City of Maple Ridge.



MAPLE RIDGE
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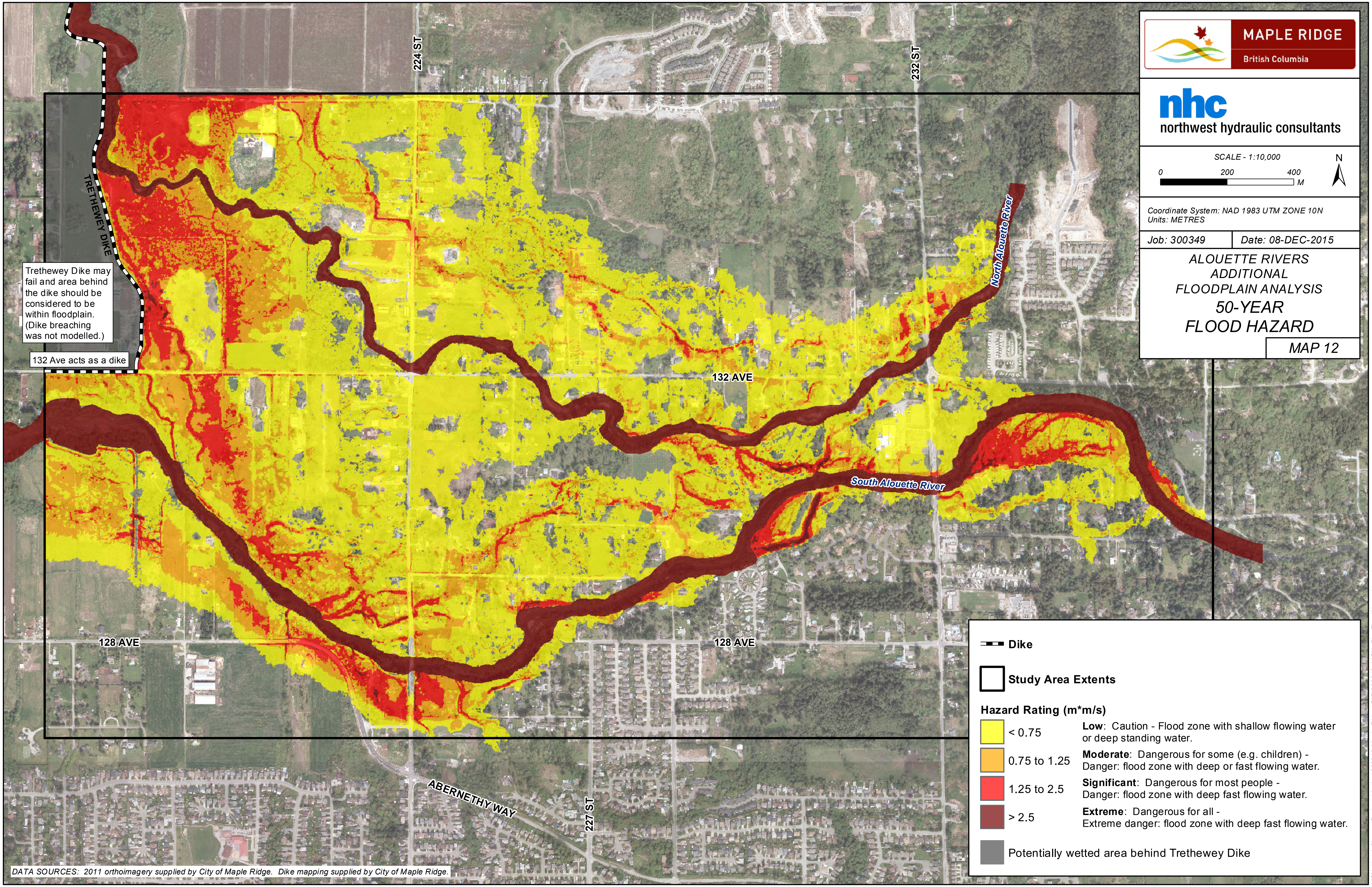
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES
Job: 300349
Date: 08-DEC-2015
ALOUETTE RIVERS
ADDITIONAL
FLOODPLAIN ANALYSIS
25-YEAR
FLOOD HAZARD
MAP 11
224 ST
232 ST
TRETHEWEY DIKE
Trethewey Dike may fail and area behind the dike should be considered to be within floodplain. (Dike breaching was not modelled.)
132 Ave acts as a dike
132 AVE
North Alouette River
South Alouette River
128 AVE
128 AVE
ABERNETHY WAY
227 ST
Dike
Study Area Extents
Hazard Rating (m*m/s)
< 0.75
Low: Caution - Flood zone with shallow flowing water or deep standing water.
0.75 to 1.25
Moderate: Dangerous for some (e.g. 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.
Potentially wetted area behind Trethewey Dike
DATA SOURCES: 2011 orthoimagery supplied by City of Maple Ridge. Dike mapping supplied by City of Maple Ridge.


MAPLE RIDGE
British Columbia
nhc
northwest hydraulic consultants
SCALE - 1:10,000
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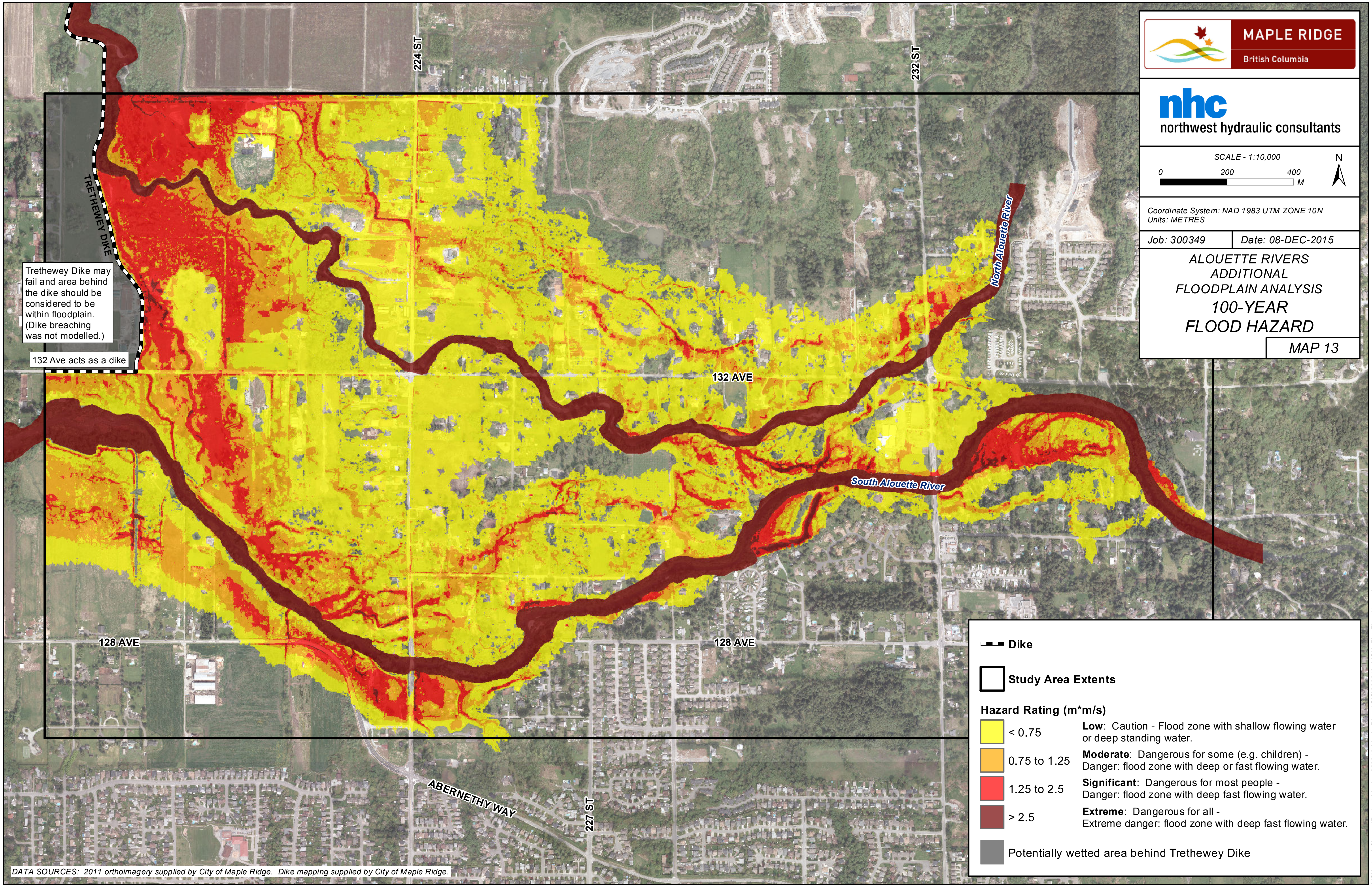
Coordinate System: NAD 1983 UTM ZONE 10N
Units: METRES
Job: 300349
Date: 08-DEC-2015
ALOUETTE RIVERS
ADDITIONAL
FLOODPLAIN ANALYSIS
50-YEAR
FLOOD HAZARD
MAP 12
224 ST
232 ST
TRETHEWEY DIKE
Trethewey Dike may fail and area behind the dike should be considered to be within floodplain. (Dike breaching was not modelled.)
132 Ave acts as a dike
132 AVE
North Alouette River
South Alouette River
128 AVE
128 AVE
ABERNETHY WAY
227 ST
Dike
Study Area Extents
Hazard Rating (m*m/s)
< 0.75
Low: Caution - Flood zone with shallow flowing water or deep standing water.
0.75 to 1.25
Moderate: Dangerous for some (e.g. 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.
Potentially wetted area behind Trethewey Dike
DATA SOURCES: 2011 orthoimagery supplied by City of Maple Ridge. Dike mapping supplied by City of Maple Ridge.


MAPLE RIDGE
British Columbia
nhc
northwest hydraulic consultants
SCALE - 1:10,000
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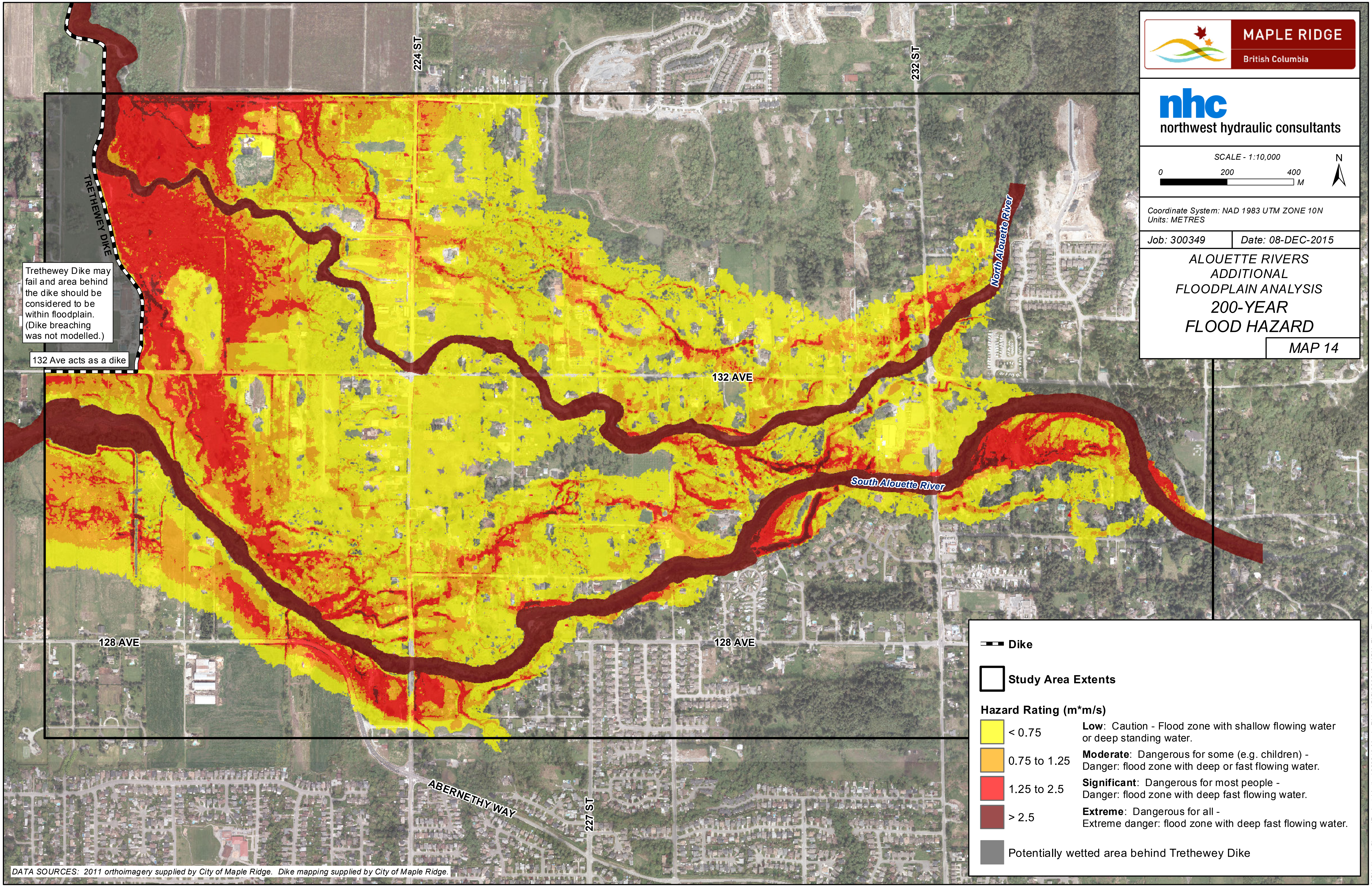
Units: METRES
Job: 300349
Date: 08-DEC-2015
ALOUETTE RIVERS
ADDITIONAL
FLOODPLAIN ANALYSIS
100-YEAR
FLOOD HAZARD
MAP 13
224 ST
232 ST
TRETHEWEY DIKE
Trethewey Dike may fail and area behind the dike should be considered to be within floodplain. (Dike breaching was not modelled.)
132 Ave acts as a dike
132 AVE
North Alouette River
South Alouette River
128 AVE
128 AVE
ABERNETHY WAY
227 ST
Dike
Study Area Extents
Hazard Rating (m*m/s)
< 0.75
Low: Caution - Flood zone with shallow flowing water or deep standing water.
0.75 to 1.25
Moderate: Dangerous for some (e.g. 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.
Potentially wetted area behind Trethewey Dike
DATA SOURCES: 2011 orthoimagery supplied by City of Maple Ridge. Dike mapping supplied by City of Maple Ridge.



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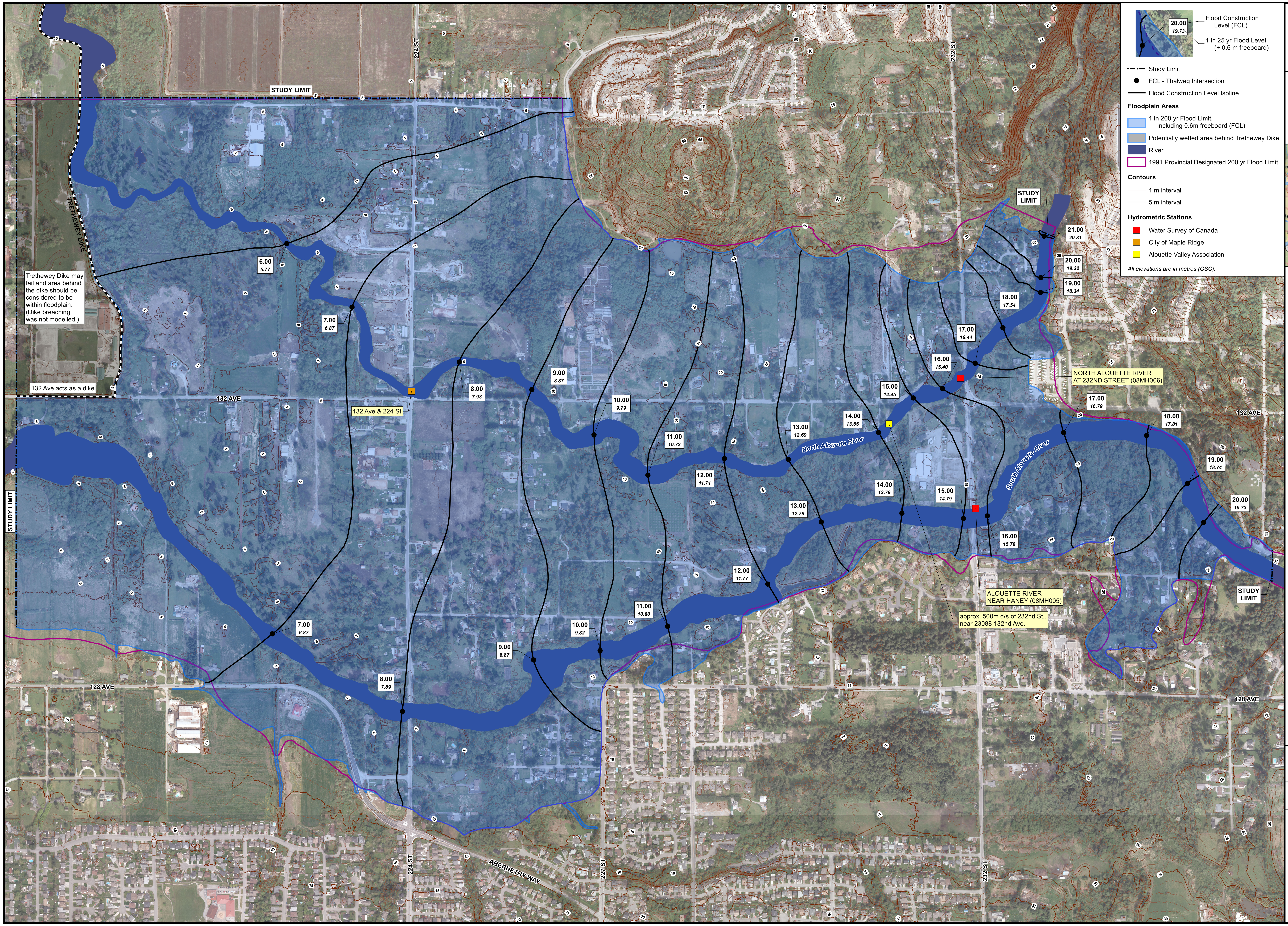
Flood Plain Map



20.00 / 19.73 — Flood Construction Level (FCL); 1 in 25 yr Flood Level (+ 0.6 m freeboard)

- Study Limit
- FCL - Thalweg Intersection
- Flood Construction Level Isoline

Floodplain Areas

- 1 in 200 yr Flood Limit, including 0.6m freeboard (FCL)
- Potentially wetted area behind Tretheway Dike
- River
- 1991 Provincial Designated 200 yr Flood Limit

Contours

- 1 m interval
- 5 m interval

Hydrometric Stations

- Water Survey of Canada
- City of Maple Ridge
- Alouette Valley Association

All elevations are in metres (GSC).

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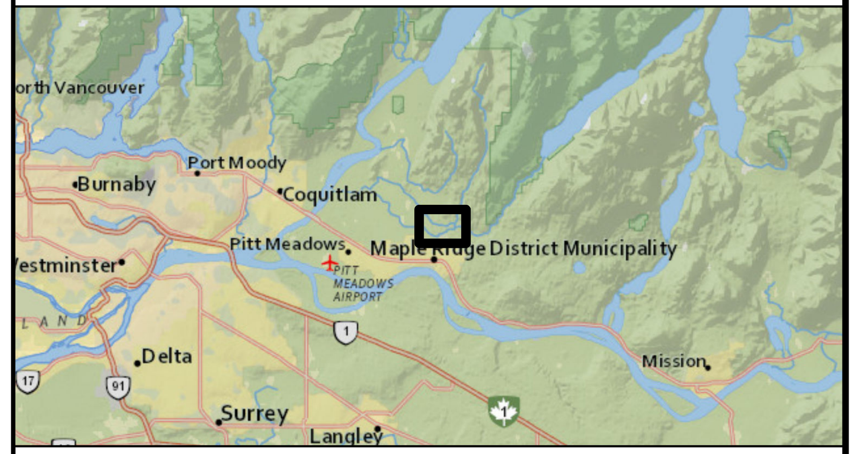

Notes:

1. This map delineates the potential for flooding under conditions caused by a 200-year return period event as described in NHC (2016). To account for future climate change impacts, the 200-year peak flow based on historic analysis was increased by 10% on all unregulated flow sources. No climate change allowance was made for flows released from the Alouette Reservoir, as these are controlled by BC Hydro instead of natural processes.
2. A freeboard allowance (margin of safety) of 0.6 m is included in the flood levels shown to account for various sources of uncertainty in the model inputs and parameters.
3. LiDAR data surveyed in 2014 was used to create a Digital Elevation Model (DEM) for the study area. The DEM surface was modified to include ground survey data for (1) the 132 Avenue bridge on the North Alouette River, (2) the 224 Street bridge on the North Alouette River, and (3) in channel surveys for the North and South Alouette Rivers. 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.
4. 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.
5. The flood levels are based on water surface profiles simulated using an integrated one- and two-dimensional hydrodynamic model developed by NHC (2016) using the MIKE Flood software. Model roughness values were initially assigned based on typical channel and overbank resistance values; then calibrated to a flood event in 2014 and validated to a flood in 2015.
6. The Tretheway Dike does not meet provincial diking standards and would likely breach at some flow less than the 200-year flood. The area behind the dike is considered part of the floodplain although not specifically mapped due to the absence of breach modelling.
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.
8. 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.
9. A Qualified Professional must be consulted for site-specific engineering analysis.
10. 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) does not assume any liability for such variations.

Data Sources:

1. Dike mapping supplied by City of Maple Ridge.
2. Hydrometric station locations acquired from Water Survey of Canada and City of Maple Ridge.
3. 1991 provincial floodplain boundary acquired from Data BC, digitized by BC Ministry of Environment from 1:5,000 scale floodplain maps of the Alouette and North Alouette Rivers (file 00-0200-S.2).
4. Contours created by NHC based on 2014 Lidar data supplied by City of Maple Ridge.
5. 2011 orthophoto supplied by City of Maple Ridge.
6. Index basemap from National Geographic and Esri.

References:

1. NHC (2016). North Alouette and South Alouette Rivers Assessment and Floodplain Analysis, Phase 2 – Technical Investigations (Final Report). Report prepared for the City of Maple Ridge.

Disclaimer:

SCALE - 1:5,000

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Coordinate System: NAD 1983 UTM ZONE 10N Units: METRES	Date 19-JAN-2016

Engineer	GIS	Reviewer	Job Number
ACM	MSN	MM	300349

ALOUETTE RIVERS
ADDITIONAL FLOODPLAIN ANALYSIS

200-YEAR FLOOD EXTENTS INCLUDING FREEBOARD