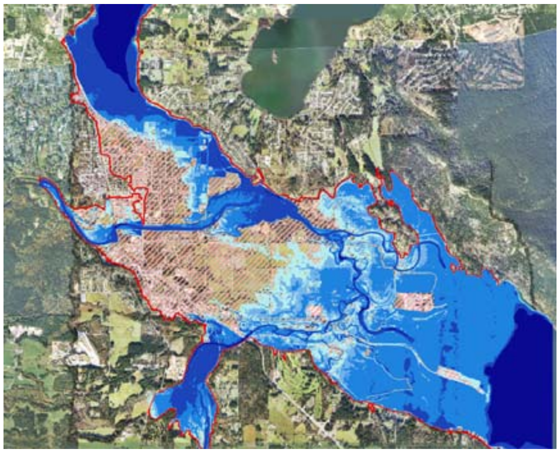
FLOOD ASSESSMENT STUDY NORTH VANCOUVER

(Solicitation No. 23254-103674/A)

FINAL REPORT



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Natural Resources Canada

March 31st, 2010

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EXECUTIVE SUMMARY

This study provides a broad-scale assessment of riparian flood hazard for select streams in North Vancouver through the development of a spatial database containing depths and extents of floodwaters. This database has been developed following the standards outlined for the HAZUS-MH Flood Model and will ultimately be used within this data model to help assess potential disaster loss due to riparian flooding in North Vancouver.

Initially 24 creeks and rivers were selected for assessment. A comprehensive data search looking for existing hydrologic and hydraulic data was completed, and ultimately portions of five watercourses were mapped: Capilano River, MacKay Creek, Mosquito Creek, Lynn Creek and the Seymour River.

Flood depth maps for various inflows between the 10-year and 200-year flow events in combination with two tidal conditions were created. The maps show that the 200-year flows are generally confined within the main channels of the rivers. Floodplain inundation is observed on MacKay Creek in the vicinity of 1st Avenue and on the Seymour River.

CREDITS AND ACKNOWLEDGEMENTS

The project was conducted under the guidance of Nicky Hastings, GIS Specialist with Natural Resources Canada, who throughout the project provided information, direction and advice. Ms. Fiona Dercole, Section Manager of the Public Safety Group at the District of North Vancouver coordinated the information provided by the District. Additional client review was provided by Bert Struik and Murray Journeay of NRCanada, and from Ariel Estrada, P.Eng of the District of North Vancouver.

Tami Nicoll, GIT with help from technicians collected and compiled the data, ran hydraulic models, produced mapping products in GIS and prepared this report. Project Management and primary review was conducted by Tamsin Lyle, P.Eng. Principal review was provided by Monica Mannerström, P.Eng.

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1 INTRODUCTION

Natural Resources Canada (NRCAN), in collaboration with the District of North Vancouver (DNV) has retained Northwest Hydraulic Consultants (NHC) to develop a spatial database of flood hazard for flood-prone watercourses in North Vancouver, British Columbia. The database will ultimately be used to help assess disaster loss using the HAZUS-MH model. This report outlines the results of the database development.

1.1 BACKGROUND

In 2006, the DNV initiated a Natural Hazards Management Program to examine risk assessment and mitigation and to provide public access to hazard and risk information. In November 2009, the District adopted a new policy for risk tolerance in the municipality, one that approaches the management of natural hazards by considering both the consequence and the likelihood of natural hazard events such as landslides, debris flows, wildland-urban interface fires, earthquakes and flooding. A significant body of work has already been completed with regards to debris flows; however no broad-scale assessment has been completed for riparian flood hazard. The current project and reporting aims to close this data gap.

HAZUS-MH is a software program used to perform potential loss estimates from floods, hurricane winds and earthquakes including physical damage to infrastructure; economic loss from business interruptions and reconstruction costs; and, social impacts to the population at risk such as displaced households and shelter requirements. HAZUS-MH applies engineering knowledge and geographic information systems (GIS) technology to identify the potential size of an event and an inventory of the population and environment that will be affected.

The HAZUS-MH Flood Model can be used to assess both riverine and coastal flooding. Hydrologic computations, hydraulic calculations, and the results of stream-specific hydraulic models must be provided to the model as input data. This user-supplied flood hazard data includes a digital elevation model (DEM), cross-sections attributed with flood elevations, and floodplain boundary information.

1.2 SCOPE OF REPORT

The objective of this project is to provide a spatial database detailing the initial assessment of riparian flood hazard for key watercourses in North Vancouver. Given the compressed schedule and budgetary constraints this work has focused on the compilation and analysis of available data sources. This project represents a scoping level exercise; completed to identify data gaps and areas requiring more detailed analyses. The results presented within this report are therefore preliminary in nature and should be used with full understanding of their limitations.

2 METHODOLOGY

A series of steps are required to develop the inputs for the riparian flooding component of the HAZUS-MH program. The following four steps used to produce the flood hazard mapping are described within the methodology section of this report:

1. Identification of Key Watercourses
2. Data Collection and Gap Identification
3. Hydraulic Modelling
4. Flood Hazard Mapping

2.1 KEY WATERCOURSE IDENTIFICATION

There are several dozen identified watercourses within the DNV. Many of these watercourses and small creeks lie in well-defined, incised channels that would not generally be associated with a flood hazard, although they may pose a debris-flood hazard; debris hazards have been assessed as a separate project. In concert with NRCAN and the DNV, 24 streams and associated tributaries which could pose flood hazard to public or private infrastructure were initially selected for assessment. Many of the smaller creeks within this subset are subject to very localised flooding issues and were considered not relevant to this broad scale assessment. Also, restrictions in data availability limited the number of creeks we were able to assess. Therefore, we have focussed efforts in this initial assessment on 10 of the largest watercourses where potential flood hazard may be widespread:

1. Capilano River
2. MacKay Creek
3. Mosquito Creek
4. Mission Creek
5. Hastings Creek
6. Lynn Creek
7. Seymour River
8. Blueridge Creek
9. McCartney Creek
10. Gallant Creek

The locations of all watercourses are shown on Figure 1.

2.2 DATA COLLECTION AND DATA GAP IDENTIFICATION

Available data and reports relating to flood hazard and estimations of peak flows on the identified key watercourses have been collected and documented by NHC. Special effort was made to identify projects involving topographic and bathymetric surveying, as well as past hydraulic modelling. Data sources include the NHC project database and library, the provincial government's ECOCAT database, and the DNV Hazards Database. The results of this search are summarised in Section 3.1. Where no data was available, or if data was insufficient to create scoping level flood mapping a data gap was identified.

2.3 HYDRAULIC MODELLING

Several 1-D hydraulic models currently exist for the major watercourses within the DNV that have been developed by NHC and other consultant engineers as components of design and flood mapping projects for third party clients. Some of these models are available and have been used for the present study to develop flood profiles for various return period events. All available models were originally developed using the USACE Hydraulic Engineering Centres River Analysis System (HEC-RAS). HEC-RAS is a one dimensional (1-D) model that uses a standard-step computational hydraulic method suitable for the calculation of water surface profiles and average channel hydraulics. All models, with the exception of Mosquito Creek, were run in steady, sub-critical flow conditions to calculate flood levels over a range of discharge. Due to relatively steep gradients, the model for Mosquito Creek at William Griffin Park was run in steady, mixed flow conditions.

2.3.1 HYDROLOGIC ANALYSIS

In consultation with the NRCAN and DNV, the 10, 25, 50, 100, and 200-year events were determined to be the appropriate return periods for hydrologic hazards on the key watercourses. Available hydrologic analyses providing estimates of discharge for these return periods were used for model input (see Section 3.1.1).

2.3.2 TIDAL INFLUENCE

Although tidal flooding was not within the scope of this project, ocean levels have a significant impact on water levels in many north shore rivers and creeks, and therefore some basic assumptions around water levels are required.

The highest flood levels likely occur during high tides in combination with large storm surges. For the hydraulic analyses, the model was run for two tidal scenarios and the corresponding flow depth at each model cross-section tabulated. The tidal boundary conditions were based on the Canadian Hydrographic Services (CHS) gauge at Point Atkinson and previous work by NHC & Triton (2006) which included a long-term historic probabilistic analysis of tide and storm surge frequencies. Where NHC had access to the HEC-RAS model files the following tidal levels were included in the model runs:

- 200-year tide and surge level[1] = 2.88 m (GSC)
- 2-year tide and surge level = 2.09 m (GSC)

While combining the 200-year flow event with a 200-year ocean level (tide + surge) would correspond to a much higher return period than 200 years since the events are statistically partly independent, this model run was included to present a type of 'worst-case' scenario. The lower tidal run will reflect the flood hazard associated with riparian flooding.

For comparison the District and City of North Vancouver use 3.6 m (GSC) and 3.5 m (GSC) as flood construction levels for development areas near the ocean. Flood construction levels include freeboard elevations to account for local variations in height, wind and wave setup and uncertainty in the estimation of water levels.

2.3.3 FREEBOARD

In general when developing floodplain maps or flood construction levels, freeboard elevations are added to calculated water levels to account for localised variations in the levels as a result of local topography, wind or wave set-up, and uncertainty in the calculation of water levels. Current BC guidelines suggest freeboard elevations of 0.6 m be added to any modelling conducted using daily peak flows, and 0.3 m for instantaneous peak flows.

For this project, given that we were collating diverse sets of data and models, which were developed using inconsistent criteria, NO freeboard has been added to any of the models or to the mapping. If detailed floodplain mapping is completed in future on any of these rivers or creeks, freeboard should be added to models and mapping. The magnitude of the selected freeboard should also be reviewed.

2.3.4 LIMITATIONS TO MODELLING AND MAPPING

Hydraulic modelling and flood map generation have inherent limitations. The accuracy of hydraulic models is limited by the spatial resolution of the available topographic and bathymetric information as well as the data available for calibration and verification. In some instances (MacKay Creek, Mosquito Creek) the original section data was unavailable, and it was not possible to assess whether the data was adequate forflood modelling. General limitations are discussed below:

- Hydraulic models assume the river bed and banks are fixed. However, bank erosion, sedimentation and log jam formation can all occur during major floods and these processes affect the local hydraulic conditions considerably.

[1] Upper 95% confidence limit

- The computed flood extents represent riparian flooding generated from the main river channels. The models are 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. Additionally, localised flooding that results as from poorly designed bridge or culverts or as a result of blocked bridge or culvert openings requires detailed survey data and focussed modelling; the models used in this mapping exercise were not originally developed to look at this type of problem.
- Most of the models used to develop the flood mapping in this report were not originally conceived as flood models and may not be entirely suitable for this purpose. In some instances, existing hydraulic models were discounted because they were constructed to look at localised hydraulic features and not flood extents. Other models were used regardless, however their limitations should be considered. This information is detailed in Section 3. In particular, flood extent mapping requires that the model boundaries be set well outside the expected wetted area, otherwise the model will unrealistically confine flow within the model bounds, artificially raising water levels.
- Models used to analyse large flow events should ideally be calibrated to high flows, however, for the most part, no high flow and water level data is available for the models presented in this report. We have assumed that the original model calibration/validation is acceptable for the purposes of this report.
- Channels and floodplains change over time and flood extent and depth mapping reflect conditions at the time of surveys.
- Modelling and survey techniques have evolved over time and the material reviewed as part of this project may not reflect present day standards. Effort was not made to assess the quality of the original modelling work.

2.4 FLOOD HAZARD MAPPING

2.4.1 *PRELIMINARY DATA PROCESSING*

To enable the generation of inundation levels and extents, a digital elevation model (DEM) was first developed of the floodplain areas. TIN surface representations were created in ArcGIS 9.3 software using 2009 'bare-earth' LiDAR data at 1 m resolution provided by the DNV, with the exception of the area surrounding the lower Capilano River where LiDAR data was provided by Metro Vancouver.

The cross-sections used in the 1-D modelling were imported into GIS using tools developed by NHC and attributed with the flood levels calculated in the model results.

For the reach of Lynn Creek upstream of Cotton Road, lower Mackay Creek, and lower Mosquito Creek, where NHC did not have access to the HEC-RAS model files, planimetric maps showing the location of each cross-section were georeferenced in ArcGIS and the cross-section lines were digitized and subsequently coded with the calculated flood levels from the accompanying hard copy reports.

2.4.2 Flood Extent Generation

Flood extents were generated based on the 200-year flood level without freeboard for both tidal scenarios. TIN surface representations of the 200-year flood water surface elevation were created in GIS using the model cross-sections. This surface was then converted to ESRI grid format and intersected with the floodplain topography DEM to obtain a grid representation of the wetted area of the 200-year event. This resultant grid is converted to polygon coverage and smoothed using tools in ArcGIS. As this method of polygon creation allows for the creation of non-contiguous wetted areas, polygons that were not contiguous with the main wetted area (i.e. connected to the main channel) were eliminated. Dry areas within the preliminary floodplain polygon that were less than 100 m^2 in area were incorporated into the floodplain as this implied level of resolution is not realistic given the data sources and methodology followed.

2.4.3 Flood Depths

Grids representing the modelled depth of floodwater for the 10, 25, 50, 100, and 200-year events were created following similar methodology as the generation of the floodplain polygons. Surfaces representing the water surface elevations at each flood return period for both tidal scenarios were created using the elevations attributed to each model cross-section. The floodplain topography DEM was then subtracted from the water elevation surface to create a new surface representing water depth at each flood return period. As this method creates areas of non-contiguous wetted area, wetted areas of the grid (i.e. depth >0 m) that did not intersect the main flooded area were calculated to equal a depth of 0. The LiDAR data used to create the floodplain topography DEM does not penetrate waterbodies; therefore, the resultant topography DEM and subsequently calculated flood depth grid will not be accurate for areas that were wet at the time of LiDAR data acquisition. As the LiDAR data was collected during relatively low flow conditions, this inaccuracy will be confined to the low-flow channel boundaries. Detailed bathymetric data would be required to prepare accurate depth grids within the generally wetted channel; this type of information was not available in a suitable format for the studied creeks.

3 RESULTS

3.1 AVAILABLE DATA

3.1.1 HYDRAULICS

Considerable data, including hydraulic modelling, is available for the larger watercourses (Capilano River, Lynn Creek and Seymour River) selected as the initial key watercourses for flood hazard mapping. Significantly less data is available for many of the smaller watercourses, with hydraulic modelling available at the time of writing for Mackay Creek and Mosquito Creek only.

Table 1 summarizes the data sources identified as potentially useful for flood hazard mapping for eight of the ten prioritized creeks in North Vancouver; Map label numbers correspond to those on Figure 2. No reference to survey data or hydraulic modelling was found for Blueridge Creek and McCartney Creek. As indicated in Table 1, not all identified potential data sources could be used for this initial flood hazard mapping. Much of the identified survey data on the ten prioritized watercourses originates from small local surveys, predominantly located in the upper reaches of the watersheds. Channels are generally steep and incised in these locations, and the predominant hazard originates from debris flows and floods rather than riparian flood processes.

Table 1: Summary of available data potentially useful for flood mapping.

Map Label	Creek	Data Type	Date	Consultant	Flood Mapping Completed/Reason
1	MacKay	survey	2009	NHC	no/ upper reaches, local survey only
2	MacKay	survey, HEC-RAS	2009	NHC	no/ upper reaches, local survey only
3	MacKay	survey, HEC-RAS	2008	NHC	no/ local survey only
4	MacKay	survey	2008	NHC	no/ upper reaches, local survey only
5	Mosquito	survey (DNV), HEC-RAS	2008	NHC	yes
6	Mosquito	survey (KWL), HEC-2	1997	NHC	yes
7	Mission	survey (DNV)	2009	NHC	no/ local survey only
8	Mission	survey, HEC-RAS	2002	NHC	no/ upper reaches, local survey only
9	Hastings	survey, HEC-RAS	2005	NHC	no/ local survey only

Map Label	Creek	Data Type	Date	Consultant	Flood Mapping Completed/Reason
10	Gallant	survey	2003	NHC	no available model, local survey only
11	Seymour	survey, HEC-RAS	2004	NHC	yes
12	Lynn	survey, River2D	2004	NHC	more recent modelling used (see 13)
13	Lynn	survey, River2D, HEC-RAS	2010	NHC	yes
14	Capilano	survey, River2D, HEC-RAS	2010	NHC	yes
15	Seymour	survey, HEC-RAS	Feb. 2003	KWL	no/ model files unavailable
16	Capilano	survey, HEC-RAS	Jul. 1991	KWL	more recent modelling used (see 14)
17	Lynn	survey	Apr. 1998	KWL	more recent survey used (see 23)
18	Lynn	survey	Jan. 1996	KWL	used in creation of recent modelling (see 23)
19	Lynn	survey	Jan. 1985	KWL	more recent survey used (see 23)
20	MacKay	survey	Feb. 1998	KWL	no/ upper reaches only
21	MacKay	survey, HEC-RAS	Dec. 1998	KWL	yes
22	Mosquito	survey	Jan. 1985	KWL	no/ upper reaches only
23	Lynn	survey, HEC-RAS	Dec. 2004	KWL	yes

Figure 2 displays the location and spatial extent of past hydraulic projects on the selected watercourses. As this study was limited by the extent of available modelling results, calculations of flood depth were completed for reaches along the following subset of watercourses: Capilano River, Lynn Creek, Mackay Creek, Mosquito Creek and Seymour River; Table 2 identifies the specific project responsible for the original development of the hydraulic models used in this study. Flood hazard mapping for the remaining watercourses would require additional channel cross-sectional surveys and the development of numerical models. The complete list of available data for the initial ten subject watercourses is presented in Appendix A.

Table 2: Original numerical model development for this study.

Stream	Year of Model Development	Author	Project Name	Client
Capilano River	2009	NHC	Capilano River Bridge No. 0367 Replacement	BC Ministry of Transportation
Lynn Creek	2009	NHC	Lynn Creek Bridge Assessment	MMM Group
Lynn Creek	2004	KWL	Lynn Creek Management Plan	DNV
MacKay Creek	1998	KWL	Lower MacKay Creek Management Plan	DNV
Mosquito Creek (Hwy 1)	2007	NHC	Mosquito Creek Bank Protection	DNV
Mosquito Creek (lower)	1997	NHC	Mosquito Creek Bridge Crossing	Earth Tech
Seymour River	1995	Ministry of Environment, Lands and Parks	Floodplain mapping for the Seymour River in North Vancouver	

3.1.2 HYDROLOGY

As part of the data collection task, NHC compiled available hydrologic analyses recently completed for North Vancouver (Appendix B). The 200-year flood has been estimated for most of the major watercourses on the North Shore, however, the period of record for these streams is limited and therefore the 200-year estimates are subject to uncertainty. A complete range of return period flows were generally available for the five streams where flood depth mapping could be completed (Table 3). For Mackay Creek, only the model results for the 10-year and 200-year flows were available. On lower Mosquito Creek, model results for the 200-year flow were available while the 10, 100 and 200-year flood results were available for the small section upstream. The 1995 Seymour River model results were available for the 200-year instantaneous and 200-year maximum daily flow estimates. The 200-year daily flow of 550 m^3/s (MELP, 1995) is very similar to the 20-year instantaneous discharge estimated in both the MELP (1995) and KWL (2003) reports for the lower Seymour River. The model results for the 200-year maximum daily flow have therefore been used in this study to estimate flood depths at the 20-year instantaneous flood discharge. The model results for each stream reach are presented in Appendix C.

Table 3: Instantaneous peak discharge estimates used in the 1-D model runs.

Stream	Watershed Area (km^2)	Peak Instantaneous Discharge (m^3/s)								Method	Author
		2-yr	5-yr	10-yr	20-yr	25-yr	50-yr	100-yr	200-yr		
Capilano at mouth	216	378	495	561	619	636	685	731	773	Flood frequency analysis	NHC (2010)
Lynn at mouth	59	105	125	142	157		178	194	209	Flood frequency analysis and area transfer	KWL (2004)
Seymour at mouth	188				530		650 (64-yr)		808	Flood frequency analysis	MELP (1995)
Seymour at mouth	188	276	377	450	525		631	718	808	Flood frequency analysis	KWL (2003)
MacKay at Marine Drive	7	12		22			33	39.1	45	Rainfall-runoff analysis	KWL (1998)
Mosquito at William Griffin	9	16	22	26				40	46	Flood frequency analysis/Creager	NHC (2008)
Mosquito at mouth	15								72	n/a	KWL (1992)

3.2 DATA GAPS

For the largest watercourses on the north shore, the available hydraulic modelling tends to be concentrated near the river mouths, with very little information available for the middle reaches of these streams (Figure 2). On smaller watercourses, such as Mission Creek and Hastings Creek, the very little survey data that exists tends to be highly localized and unsuitable for flood hazard mapping at the scale required. A summary of gaps for each of the ten initial priority watercourses is presented in Table 4. The table shows the gaps prior to the completion of this report; the mapping prepared as part of this reporting should be considered preliminary and has therefore not been included in the table.

Table 4: Data gaps for mapping of ten prioritised watercourses

Stream	Reach	Data Availability					Comments
		Instream Bathymetry	Floodplain Topography	Hydrology	Hydraulic Modelling	Floodplain Mapping*	
Capilano River	Below Upper Levels Hwy	✓	✓	✓	✓	×	
	Above Upper Levels Hwy	×	✓	✓	×	×	
MacKay Creek	Below Marine Drive	✓	✓	P	✓	×	Hydrology – some return periods missing from analysis
	Above Marine Drive	×	✓	P	×	×	Hydrology – some return periods missing from analysis
Mosquito Creek	At Marine Drive	✓	✓	P	✓	×	Hydrology – some return periods missing from analysis
	Above Marine Drive	×	×	P	×	×	Hydrology – some return periods missing from analysis
Mission Creek	All	×	✓	×	×	×	
Hastings Creek	All	×	✓	×	×	×	
Lynn Creek	Lower River	✓	✓	✓	✓	×	Mapping prepared, not designated
	Upper River	×	✓	✓	×	×	
Seymour River	Lower River	✓	✓	✓	✓	✓	
	Upper River	×	✓	✓	×	×	
Blueridge Creek	All	×	✓	×	×	×	
McCartney Creek	All	×	✓	×	×	×	
Gallant Creek	All	×	✓	×	×	×	

P – Partial data available. More information on what is available in Section 3.1 and Appendices
* - Official designated floodplain mapping available

Further to the specific gaps identified above, it is important to reiterate that the modelling and mapping presented in this report is scoping level information. For the development of floodplain maps that would be used for detailed analysis or for the development of flood construction levels additional quality checks and likely additional modelling and mapping should be completed.

3.3 FLOOD HAZARD MAPPING

As the present study is limited by available data for the key watercourses on the North Shore, the following sections describe the development of flood extent mapping and flood depth grids for flows of various return periods where data was available. This includes reaches of Seymour River, Capilano River, Lynn Creek, Mackay Creek, and Mosquito Creek. Floodwater extents and flood depth grids are presented for each watercourse in Figures 3 to 10. Flood profiles used in the generation of the flood depth grids are listed in Appendix C while data files in GIS format containing the gridded datasets, floodwater extents and model cross-sections are included as a separate attachment to this report.

3.3.1 CAPILANO RIVER

Model Details

The 1-D numerical model of the lower Capilano River spans a 1.65 km reach from Fullerton Bridge to the CN Bridge downstream, and was developed by NHC using 14 surveyed cross-sections (see NHC, 2010). Based on field observations the average Manning's roughness coefficient was estimated to be 0.040 for the model runs. Calibration data was unavailable for the modelling. The model was initially developed to assess hydraulic conditions for a replacement bridge at Marine Drive; the model was not constructed specifically for flood modelling or mapping and therefore results should be considered only for scoping level studies. Additional modelling should be completed to refine the flood extents for future planning and development.

Flood Hazard Mapping

HEC-RAS results for the 10, 25, 50, 100 and 200-year peak instantaneous flows were used to create flood depth grids along the modelled reach (Figure 3, 4). In general, the 200-year flood (without freeboard) is contained within the channel boundaries, with the exception of minor areas south of the Park Royal Mall parking lot (Figure 4). Flood depths in this area range up to 1 m. Significant flooding due to storm surge is evident within the area south of Park Royal Mall when the model is run with the 200-year tide and surge level, resulting in standing water of up to 1.5 m depth in this area (Figure 4). The increase in flood depths due to the higher tide surge ends approximately 600 m upstream of the CN Bridge. The mobile home park on the left bank of the river is not mapped as being within the wetted area; however the mapping does not include freeboard, which if added would inundate some portions of the park.

3.3.2 LYNN CREEK

Model Details

The Lynn Creek flood depth mapping combines 1-D numerical modelling results from two separate sources. The model describing the reach extending 200 m upstream of the Upper Levels Highway downstream to the Cotton Road Bridge was developed by KWL as part of the Lynn Creek Management Plan (see KWL, 2004). Flood depths for the lower reach of Lynn Creek downstream of Cotton Road were calculated using the model developed by NHC in 2009 (see NHC, 2010b).

The 1-D hydraulic model for the lower reach was developed by NHC using 11 surveyed cross-sections covering 700 m of channel downstream of the Cotton Road Bridge. The Manning's roughness coefficient was estimated to be 0.040 based on observed bed materials and channel pattern. Calibration data was unavailable for the modelling. The NHC model was re-run at both tidal scenarios (2-year and 200-year tide and surge level) using the peak hydrology estimates calculated by KWL. As the 25-year return period was not provided in the KWL reporting, the 20-year flood was substituted in the model runs. The NHC model was initially developed to assess hydraulic conditions for a new rail bridge at the Port; the model was not constructed specifically for flood modelling or mapping and therefore results should be considered only for scoping level studies. Additional modelling should be completed to refine the flood extents for future planning and development.

The hydraulic model developed by KWL in 2004 is based on the combination of a detailed 2001 topographic survey of the Lynn Creek bed combined with overbank geometry derived from 1995 and 1997 surveys. Manning's roughness coefficient varied along the modelled reach from 0.04 at the upstream end to 0.075 at the downstream boundary, as determined through model calibration. It should be noted, that a theoretical roughness coefficient for a gravel bed river like Lynn Creek would generally be around 0.04; the value used in this model appears to be high. Model results for this upper reach are available for the 200-year flow only.

Flood Hazard Mapping

Flood depth grids for the 200-year flow and the 200-year flood extent represent the combined results from the two separate 1-D models. Flood depths for the 10, 25, 50, and 100-year floods were developed for the extent of the lower modelled reach (Figure 5). In general, the 200-year flow (without freeboard) is confined within the channel boundaries, with minor areas of overbank flow at localized areas along the modelled sections (Figure 6). Although floodwater depths in these areas are generally below 0.5m, estimated flood depths of up to 1.5 m are located directly upstream of the CN bridge crossing. Some additional overbank flooding downstream of the CN rail bridge due to storm surge is evident when the model is run with the 200-year tide and surge level, resulting in standing water of up to 1 m depth in this area and impacting infrastructure on the west bank as well as the greenway along the east bank (Figure 6). The increase in flood depths due to the higher tide surge ends upstream of the Cotton Road Bridge.

3.3.3 MACKAY CREEK

Model Details

The 1-D numerical modelling results used in this study are from the 1998 model developed by KWL (see KWL, 1998) for the reach extending from Roosevelt Crescent downstream to the CN bridge crossing. The model was developed using 19 surveyed cross-sections and Manning's roughness coefficient was estimated to be 0.040 for all model runs. The model files were unavailable at the time of writing and available model results were limited to the 10-year and 200-year flood levels. These results describe modelling scenarios for 1998 conditions at both return period flows as well as an additional high tide scenario for the 200-year flood. Downstream tidal boundaries vary slightly from those used for the other three streams in this study. The lower boundary for the existing (1988) conditions model run scenario was based on critical depth, which was calculated to be 2.6 m GSC immediately downstream of the 1st Avenue Bridge at the 200-year flow. This is 0.5 m higher than the 2.09 m GSC lower tidal boundary used for other streams in this study. The high tide model scenario on Mackay Creek used a downstream water surface elevation of 3.1 m GSC compared to 2.88 m for the other streams. No LiDAR data was available or used for the initial development of this model, and the model boundaries were limited by available surveyed sections. The HEC-RAS model confines the flow to the section widths as if there are walls at the ends of the sections, which may lead to artificially higher water levels in the channel. Results should be considered only for scoping level studies. Additional modelling should be completed to refine the flood extents for future planning and development.

Flood Hazard Mapping

Estimated 200-year flood extents were similar for both the high and lower tidal scenarios. Banks were overtopped along the length of the modelled reach at the 200-year flood, with flood depths over 2 m in the marshy area directly upstream of 1st Avenue (Figure 7). Some buildings along the west bank of Mackay Creek north of 3rd Street are within the floodwater extents at both the modelled 10 and 200-year flows (Figure 7). However, the flood extents and flood depths presented in this study must be regarded as preliminary. To undertake the flood depth mapping the calculated flood profiles at the model cross-sections were extended horizontally until the water surface elevation intersected with the floodplain topography. 1-D numerical models place vertical walls at the boundaries of each cross-section. This may result in artificially higher water levels outside of channel boundaries as the model cannot account for flood attenuation once flow leaves the main stream channel.

In this case, the large spatial extent of the wetted area may be unrealistic and the development of 2-D modelling is recommended to improve accuracy of the modelled flood depths and extents. 2-D modelling allows for greater refinement of flow paths within the channel and overbank areas; realistically modelling the attenuation of overbank flow. Given the availability of detailed overbank topography and relatively recent channel cross-sectional surveys, this exercise would be quite cost-effective and ultimately provide a greatly improved estimate of flood hazard risk for these problem areas.

3.3.4 MOSQUITO CREEK

Lower Mosquito Creek Model Details

The 1-D numerical modelling results available for the 200-year flood on lower Mosquito Creek extend from Larson Road to the Bewicke Avenue crossing. The survey data used for the modelling was originally collected by the City of North Vancouver prior to the construction of the 1st Avenue bridge crossing. KWL developed a HEC-2 model using this cross-section data to determine the 200-year flood profile and velocities along this reach (see KWL, 1996). NHC was later retained in 1997 to design bank protection at the bridge crossing (see NHC, 1997). NHC did not have access to the KWL model files and therefore created a duplicate HEC-2 model of the 200-year flood profile with the same cross-sectional data to assess potential bank erosion; no calibration data was available.The lower boundary for the model run was based on critical depth, which was calculated to be 2.74 m GSC immediately downstream of the Bewicke Avenue crossing at the 200-year flow. The results presented within the current project utilize the NHC (1997) model results (Appendix C). Manning's roughness coefficient was estimated to be 0.040 at all 11 cross-sections in the model.

Lower Mosquito Creek Flood Hazard Mapping

LiDAR data provided by the District of North Vancouver does not cover lower Mosquito Creek and therefore could not be used to generate the flood extents. DEM data based on the 1:20,000 BC TRIM mapping is freely available online, Unfortunately, the resolution of this data set (horizontal accuracy = 10 m, vertical accuracy = 5 m) does not allow for completion of the flood hazard mapping..

Mosquito Creek at William Griffin Park Model Details

This 1-D numerical model was originally developed by NHC in 2007 using 15 cross-sections along a short 100 m segment of Mosquito Creek in William Griffin Park, directly upstream of the Mission Creek confluence. This section of Mosquito Creek has a relatively steep gradient (4 - 7%); consequently, the model was run in mixed flow conditions to allow for potential supercritical flow. Based on field observations the average Manning's roughness coefficient was estimated to be 0.055 for the model runs. The model was initially developed to assess hydraulic conditions for future bank protection works, not specifically for flood modelling or mapping, therefore results should be considered only for scoping level studies.

Mosquito Creek at William Griffin Park Flood Hazard Mapping

HEC-RAS results for the 10, 100 and 200-year peak instantaneous flows were used to create flood depth grids along the modelled reach (Figure 8). This section of the creek flows through a well-vegetated floodplain within a greenway area of William Griffin Park. At the 200-year flood, flow depths up to 1.5 m are calculated in the channel and up to 0.8 m in small areas on the floodplain (Figure 8). The pedestrian path, along the west bank through this section, is located above the 200-year flood profile.

3.3.5 SEYMOUR RIVER

Floodplain mapping developed in 1995 under the Canada-British Columbia Floodplain Mapping Agreement is available for the lower Seymour River; however, the data and tools used to develop the flood mapping for this project are likely out-of-date (see MELP, 1995). For this reason, the lower Seymour River floodplain has been regenerated using the 200-year flood level results within the 1995 report and the new floodplain topography DEM. An update of the original 1995 model of this reach was developed by KWL as part of the Lower Seymour Management Plan in 2003; however, the model files were unavailable at the time of writing.

Model Details

The 1995 1-D numerical model of the lower Seymour River covers a 4 km reach extending from Burrard Inlet to the start of the bedrock canyon upstream. The model was developed with HEC-2 software, an earlier version of HEC-RAS, using a total of 26 surveyed cross-sections along the reach (see MELP, 1995). The Manning's roughness coefficient was estimated to range between 0.022 and 0.050 for flood flow conditions. Model results for the 200-year instantaneous and daily flood flows are available. As discussed in Section 3.1.1, the model results for the 200-year daily flood have been used to approximate the conditions at the 20-year instantaneous flood. Downstream tidal boundaries were 1.9 m GSC for the low tide scenario and 3.4 m GSC for the high tide with storm surge scenario, up to 0.5 m higher than that used for the other models.

Flood Hazard Mapping

The calculated flood extent for the 200-year flood varies somewhat from the 1995 extent, particularly in the area between Mount Seymour Parkway and the Dollarton Highway, due to the improved accuracy of the topography data available for this study (Figure 9). Overbank flood depths up to 2 m along the Seymour Boulevard and up to 2.5 m downstream of the Mount Seymour Parkway were estimated for the 200-year flood. The 20-year flood is generally contained within the channel banks, with the exception of areas along Seymour Boulevard and within parkland south of Mount Seymour Boulevard (Figure 10). The Seymour River is tidally influenced downstream of the Dollarton Highway bridge. Model results for the 200-year high tide scenario show numerous areas would be affected by coastal flooding (Figure 10), although the estimate of 3.4 m GSC for the downstream boundary is conservatively high according to more recent analyses of the Point Atkinson tidal gauge (NHC and Triton, 2006).

Similar to the case in Mackay Creek, the floodwater extents and depths presented in Figures 9 and 10 are potentially misleading. Water elevations outside of the main stream channel may be artificially high due to the model inability to account for flood attenuation and the extensive wetted area extending east along Old Dollarton Road. In this case, the large spatial extent of the wetted area may be unrealistic and the development of 2-D modelling is recommended to improve accuracy of the modelled flood depths and extents. 2-D modelling allows for greater refinement of flow paths within the channel and overbank areas; realistically modelling the attenuation of overbank flow. Given the availability of detailed overbank topography and relatively recent channel cross-sectional surveys, this exercise would be quite cost-effective and ultimately provide a greatly improved estimate of flood hazard risk for these problem areas.

4 SUMMARY AND RECOMMENDATIONS

This study provides a broad-scale assessment of riparian flood hazard for select streams in North Vancouver through the development of a spatial database containing depths and extents of floodwaters. This database has been developed following the standards outlined for the HAZUS-MH Flood Model and will ultimately be used within this data model to help assess potential disaster loss due to riparian flooding in North Vancouver.

As a first step within the process of developing a comprehensive spatial database of riparian flood hazard, this overview study provides a compilation of available hydrologic data for ten key watercourses within North Vancouver. While the availability of hydraulic modelling for five of these watercourses has allowed for a preliminary update of floodwater extents and depths along the lower stream reaches, the remaining prioritized streams will require additional data for inclusion into the database (Table 4 and Table 5). For these streams, analyses of peak hydrology should be updated, particularly where estimates date prior to 2000. This will allow for inclusion of recent gauging records and an update of the methodology to be in line with changing regulations and current best practices. Many of these smaller streams will have to be surveyed to allow for the development of numerical models. Re-surveys are recommended for streams such as Mosquito Creek, where significant time has passed since previous surveying and an additional bridge has been constructed that may have altered cross-sectional characteristics.

Table 5: Summary of available data for the ten prioritized watercourses

Stream	Most Recent Peak Hydrology Analysis[1]	Channel Surveys (lower reaches)[2]	Hydraulic Modelling (lower reaches)[2]	Area of watercourse with no data
Capilano River	2009	2009, 1991	2009	Upstream of Fullerton Bridge
MacKay Creek	1998	1998	1998	Upstream of Roosevelt Crescent
Mosquito Creek (upper)	2008	2007	2007	Upstream of William Griffin Park
Mosquito Creek (lower)	1992	1996	1996	Upstream of Larson Road to William Griffin Park
Mission Creek	1982	2009 (minor)	none available	Only very localized surveys available
Hastings Creek	1982	none available	none available	Only 1 small local survey available
Lynn Creek	2009	2009, 2001, 1995, 1984	2009, 2004	From 200 m upstream of Hwy 1 crossing
Seymour River	2003	2001, 1992, 1984	2003	Complete, upper reaches last surveyed in 1992

Stream	Most Recent Peak Hydrology Analysis[1]	Channel Surveys (lower reaches)[2]	Hydraulic Modelling (lower reaches)[2]	Area of watercourse with no data
Blueridge Creek	1982	none available	none available	No surveys available
McCartney Creek	1982	none available	none available	No surveys available
Gallant Creek	2003	2003 (minor)	none available	Only 1 very local survey available

[1] For channel at mouth, including 200-year flood
[2] Spatial extents of channel surveys and hydraulic models vary

The accuracy of the flood depth grids and floodwater extents developed within this study will be restricted by the limitations inherent in the underlying data sources used in their creation. This mapping exercise did not include any quality checks of the models used to great the depth grids. Nor, was there any consideration of freeboard and it was not added to any of the flood depth grids.

4.1 Next Steps

This project has identified numerous data gaps in available survey data and hydraulic modelling on the 10 largest watercourses on the North Shore. A number of steps are required to complete flood hazard mapping of all identified key watercourses in North Vancouver.

1. Prioritize the stream reaches within the 24 identified key watercourses where survey data and hydraulic modelling is currently lacking based on local knowledge and perceived hazard.
2. Consider what design event is suitable given the vulnerability of the different watercourses. Update or complete hydrologic analyses as necessary (see Tables 4 and 5); frequency analyses for all watercourses should be updated after any major flow event.
3. Complete cross-sectional surveys in areas prone to flood hazard where data is currently unavailable (see Tables 4 and 5) and develop 1-D numerical modelling for areas covered by the new survey data.
4. Develop 2-D modelling for Mackay Creek and Seymour River where 1-D modelling results many not provide realistic flood hazard extents.
5. Acquire LiDAR data for lower Mosquito Creek to allow completion of flood hazard mapping in this area (as with the area around lower Capilano River, this data may already be available through the City of North Vancouver).

6. Refine DEM surface with the addition of breaklines and improved interpretation between cross-sections in channel areas to improve flood hazard mapping.

Some general recommendations relating to water resources and flood mapping that should be considered by the local governments include:

1. Continue to collect streamflow information at gauged creeks (Water Survey of Canada, Regional and District gauges). Ideally, the network of gauges should be expanded.
2. Record high water marks on the floodplain during high flows. This data is extremely valuable for model calibration.
3. Most floodplain maps prepared under the federal/provincial floodplain mapping agreement are now about 20 years old and likely no longer accurate. Updating the maps is strongly recommended throughout BC.
4. Considering climate change effects on sea levels and regional hydrology, previous freeboard standards should be reviewed and revised as necessary.

4.2 CONCLUSIONS

This study instigated by Natural Resources Canada is unique in British Columbia. It will provide very valuable information to the local governments and citizens of the North Shore that will ultimately help reduce the risk of flood damages. It is hoped that this pilot study is applied more broadly to other BC and Canadian municipalities.

5 REFERENCES

KWL (Kerr Wood Leidal Associates Ltd.). 2004. Lynn Creek Management Plan. Final report prepared for the District of North Vancouver (DNV). December, 2004.

KWL. 2003. Seymour River Management Plan. Draft report prepared for the District of North Vancouver (DNV). February 2003.

KWL. 1998. Lower Mackay Creek Management Plan. Prepared for the District of North Vancouver (DNV). December, 1998.

KWL. 1996. Lower Mosquito Creek Flood Profile. Prepared for the City of North Vancouver. April, 1996.

MELP. 1995. Design Brief on the Floodplain Mapping Study. Prepared by the Ministry of Environment, Lands and Parks (MELP), Water Management Division. January, 1995.

NHC. 2010. Capilano River Bridge No. 0367 Replacement. Report prepared for the BC Ministry of Transportation and Infrastructure, January 2010.

NHC. 2010b. Lynn Creek Bridge Assessment Hydrotechnical Detailed Design. Draft Report prepared for MMM Group, February 2010.

NHC. 2008. Mosquito Creek Bank Protection (William Griffin Park). Report prepared for the District of North Vancouver, April 2008.

NHC. 2004. Seymour River Crossing Flow Diversion Assessment. Draft Report prepared for JJM Construction Ltd., August 2004.

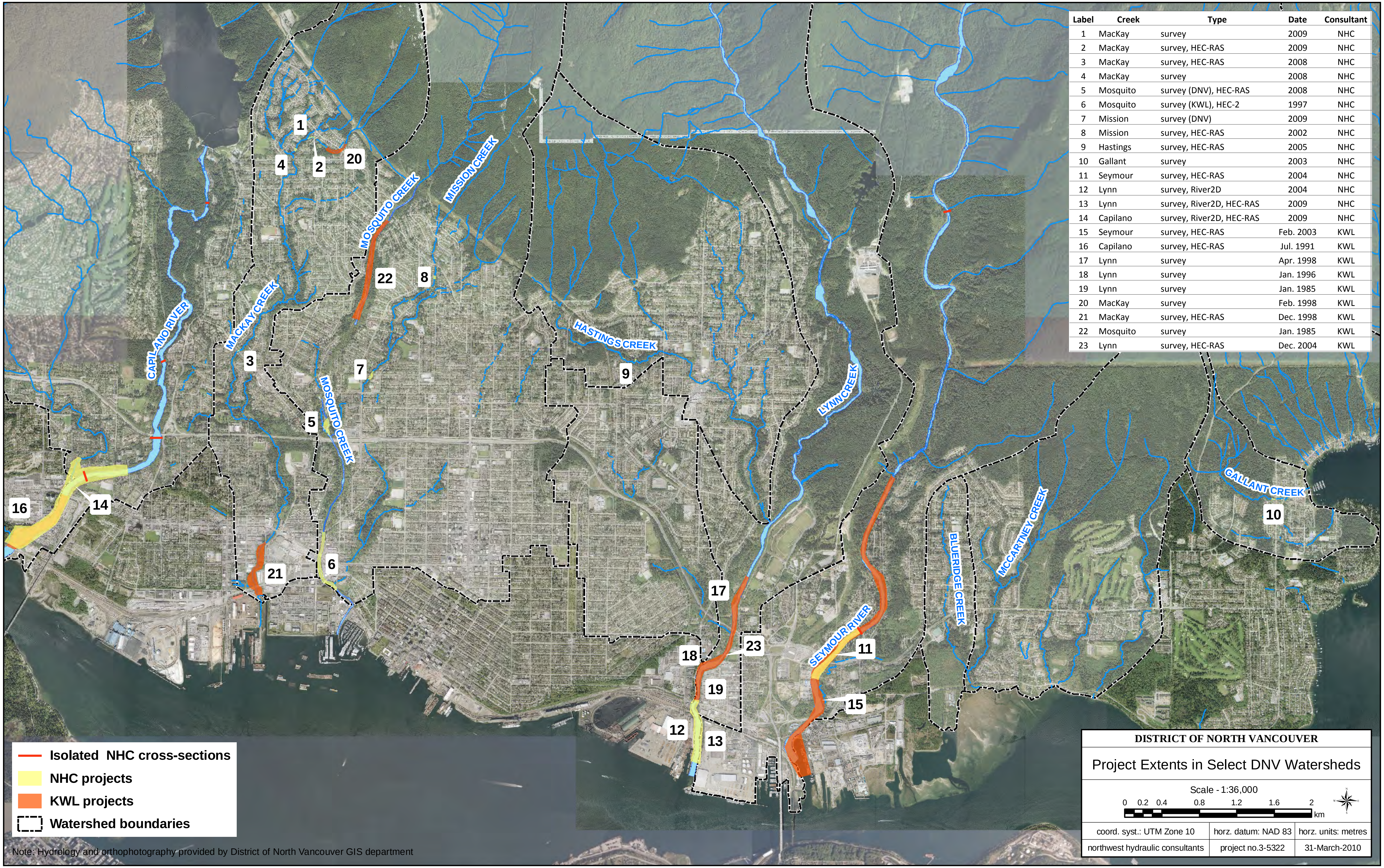
NHC. 1997. Mosquito Creek Bridge Crossing. Prepared for Earth Tech Inc. April 1997.

NHC and Triton. 2006. Lower Fraser River Hydraulic Model. Report prepared for Fraser Basin Council.

FIGURES

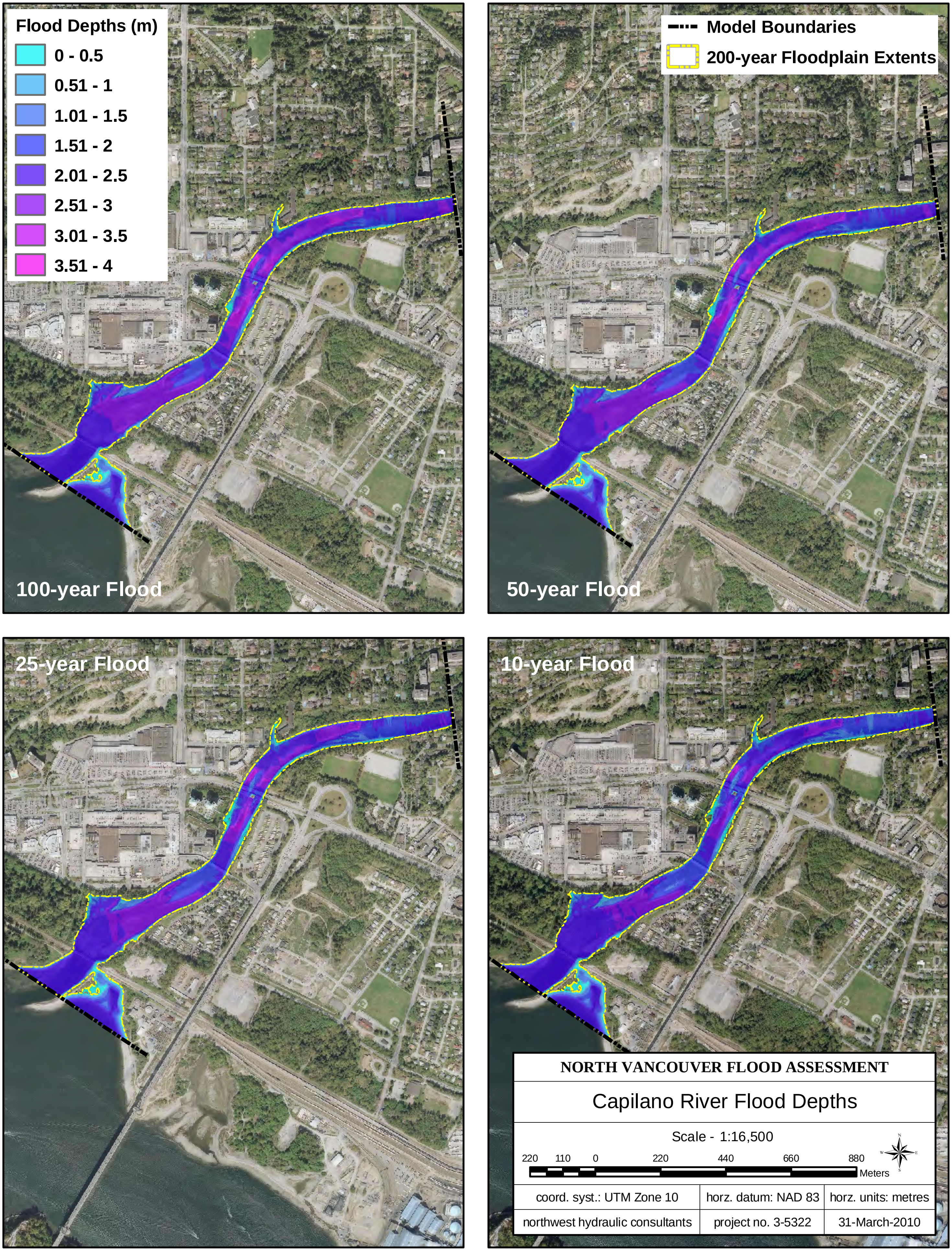

CAPILANO RIVER
MACKAY CREEK
MOSQUITO CREEK
MOSQUITO CREEK
MISSION CREEK
THAIN CREEK
DUNELL CREEK
DYER CREEK
KILMER CREEK
THAMES CREEK
HASTINGS CREEK
COLEMAN CREEK
PIERARD CREEK
HOSKINS CREEK
LYNN CREEK
KEITH CREEK
SEYMOUR RIVER
MAPLEWOOD
CREEK
BLUERIDGE CREEK
TRILLIUM CREEK
MCCARTNEY CREEK
MOUNTAIN CREEK
GALLANT CREEK
PARKSIDE CREEK
OSTLER CREEK
STREAM
Priority watercourse
Major DNV watershed boundaries
Note: Hydrology and orthophotography provided by District of North Vancouver GIS department
DISTRICT OF NORTH VANCOUVER
Flood Hazard Mapping Prioritized Streams
Scale - 1:40,000
0 0.2 0.4 0.8 1.2 1.6 2
km
coord. syst.: UTM Zone 10
horz. datum: NAD 83
horz. units: metres
northwest hydraulic consultants
project no.3-5322
31-March-2010

Figure 1



Label	Creek	Type	Date	Consultant
1	MacKay	survey	2009	NHC
2	MacKay	survey, HEC-RAS	2009	NHC
3	MacKay	survey, HEC-RAS	2008	NHC
4	MacKay	survey	2008	NHC
5	Mosquito	survey (DNV), HEC-RAS	2008	NHC
6	Mosquito	survey (KWL), HEC-2	1997	NHC
7	Mission	survey (DNV)	2009	NHC
8	Mission	survey, HEC-RAS	2002	NHC
9	Hastings	survey, HEC-RAS	2005	NHC
10	Gallant	survey	2003	NHC
11	Seymour	survey, HEC-RAS	2004	NHC
12	Lynn	survey, River2D	2004	NHC
13	Lynn	survey, River2D, HEC-RAS	2009	NHC
14	Capilano	survey, River2D, HEC-RAS	2009	NHC
15	Seymour	survey, HEC-RAS	Feb. 2003	KWL
16	Capilano	survey, HEC-RAS	Jul. 1991	KWL
17	Lynn	survey	Apr. 1998	KWL
18	Lynn	survey	Jan. 1996	KWL
19	Lynn	survey	Jan. 1985	KWL
20	MacKay	survey	Feb. 1998	KWL
21	MacKay	survey, HEC-RAS	Dec. 1998	KWL
22	Mosquito	survey	Jan. 1985	KWL
23	Lynn	survey, HEC-RAS	Dec. 2004	KWL

Figure 2



Flood Depths (m)
0 - 0.5
0.51 - 1
1.01 - 1.5
1.51 - 2
2.01 - 2.5
2.51 - 3
3.01 - 3.5
3.51 - 4
Model Boundaries
200-year Floodplain Extents
100-year Flood
50-year Flood
25-year Flood
10-year Flood
NORTH VANCOUVER FLOOD ASSESSMENT
Capilano River Flood Depths
Scale - 1:16,500
220 110 0 220 440 660 880
Meters
coord. syst.: UTM Zone 10
horz. datum: NAD 83
horz. units: metres
northwest hydraulic consultants
project no. 3-5322
31-March-2010

Figure 3

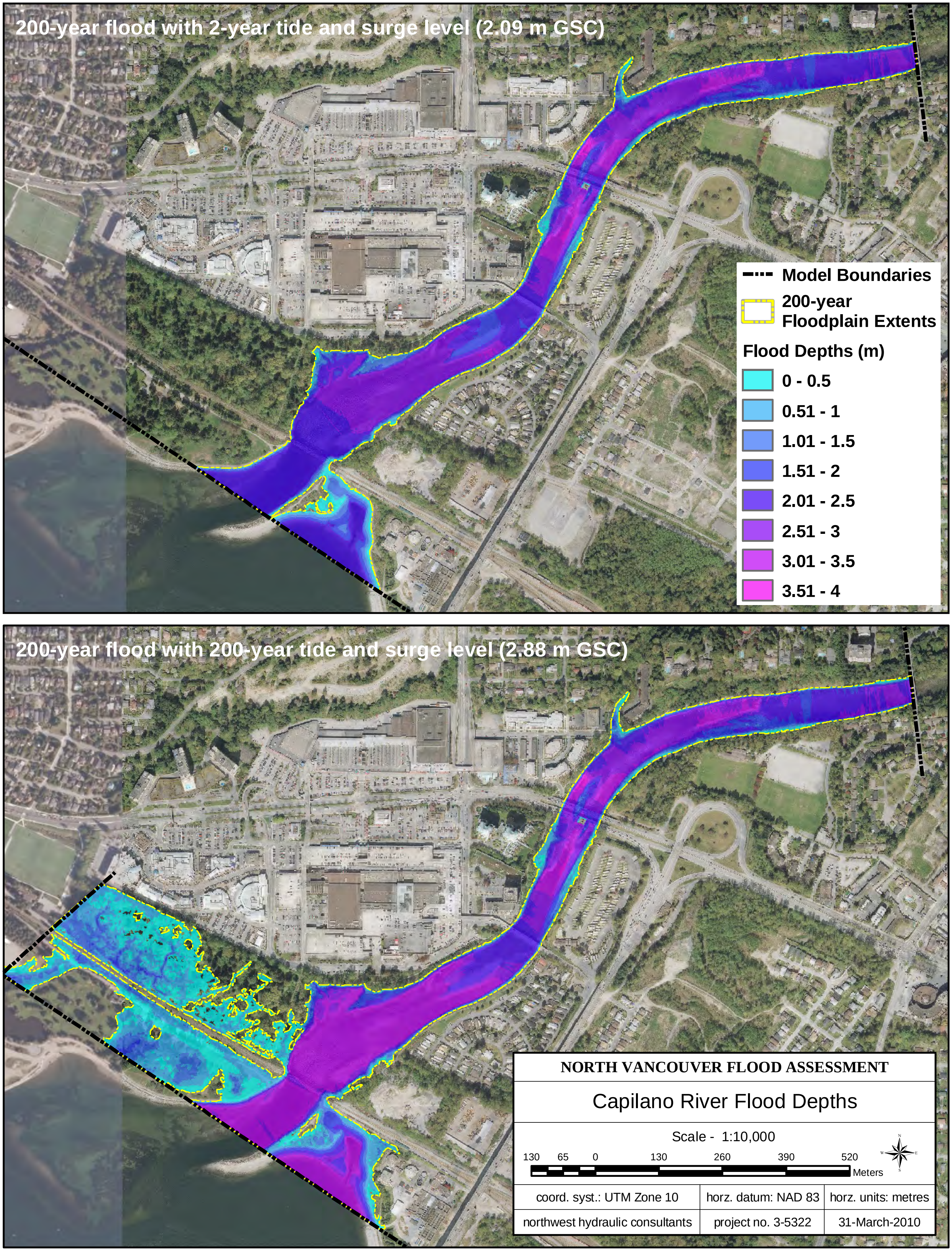
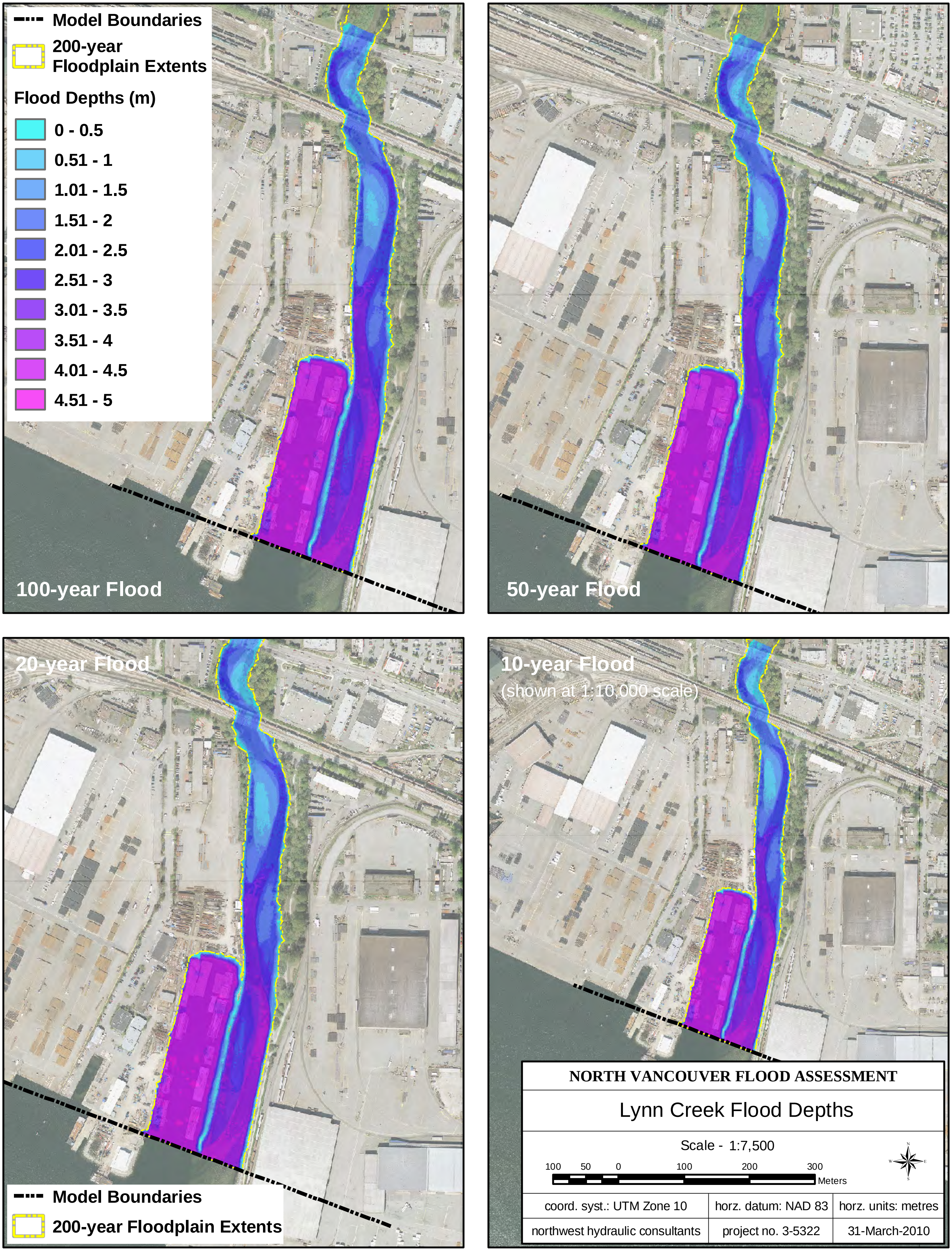

200-year flood with 2-year tide and surge level (2.09 m GSC)
Model Boundaries
200-year Floodplain Extents
Flood Depths (m)
0 - 0.5
0.51 - 1
1.01 - 1.5
1.51 - 2
2.01 - 2.5
2.51 - 3
3.01 - 3.5
3.51 - 4
200-year flood with 200-year tide and surge level (2.88 m GSC)
NORTH VANCOUVER FLOOD ASSESSMENT
Capilano River Flood Depths
Scale - 1:10,000
130 65 0 130 260 390 520
Meters
coord. syst.: UTM Zone 10
horz. datum: NAD 83
horz. units: metres
northwest hydraulic consultants
project no. 3-5322
31-March-2010

Figure 4



Model Boundaries
200-year Floodplain Extents
Flood Depths (m)
0 - 0.5
0.51 - 1
1.01 - 1.5
1.51 - 2
2.01 - 2.5
2.51 - 3
3.01 - 3.5
3.51 - 4
4.01 - 4.5
4.51 - 5
100-year Flood
50-year Flood
20-year Flood
10-year Flood
(shown at 1:10,000 scale)
Model Boundaries
200-year Floodplain Extents
NORTH VANCOUVER FLOOD ASSESSMENT
Lynn Creek Flood Depths
Scale - 1:7,500
100 50 0 100 200 300
Meters
coord. syst.: UTM Zone 10
horz. datum: NAD 83
horz. units: metres
northwest hydraulic consultants
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Figure 5

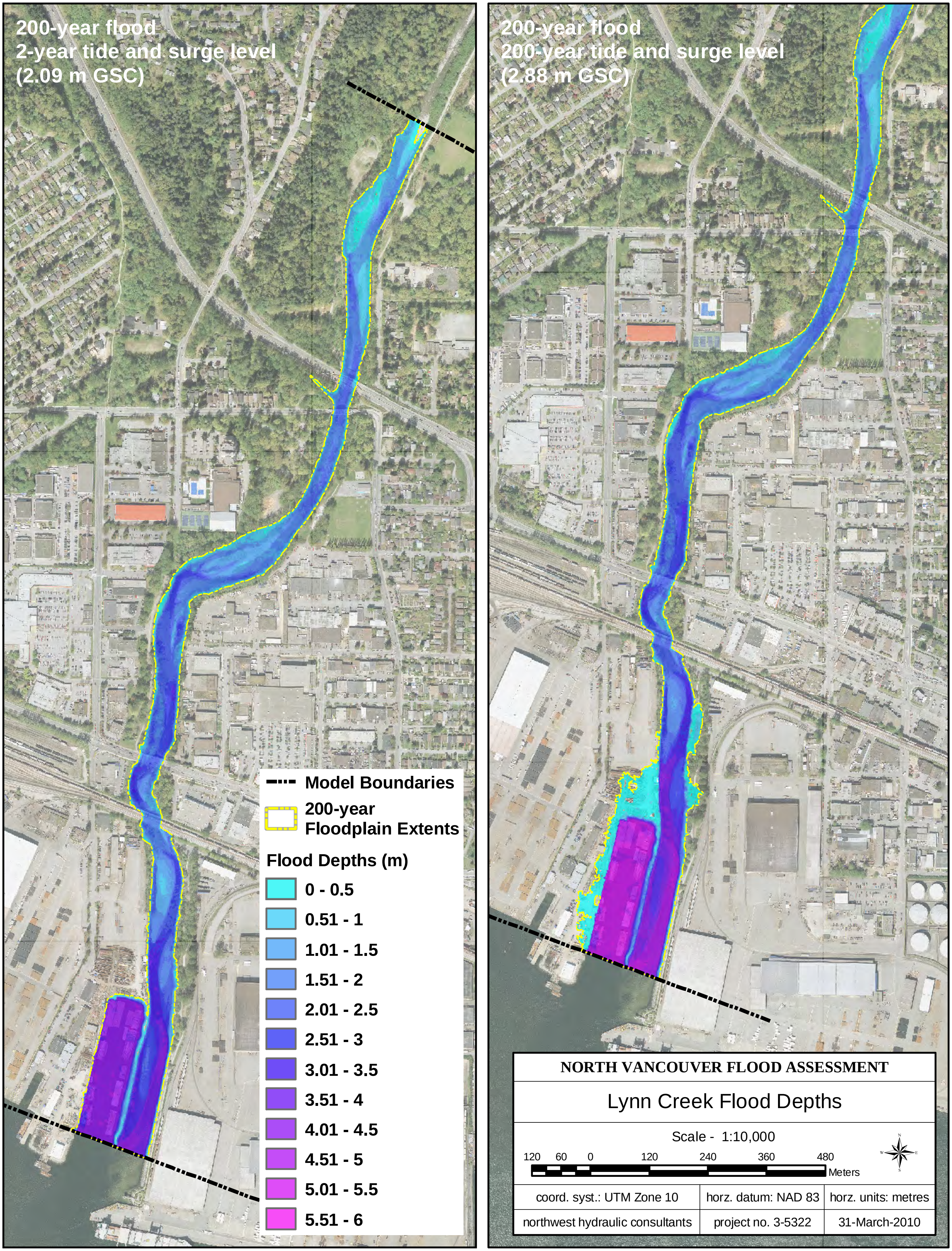
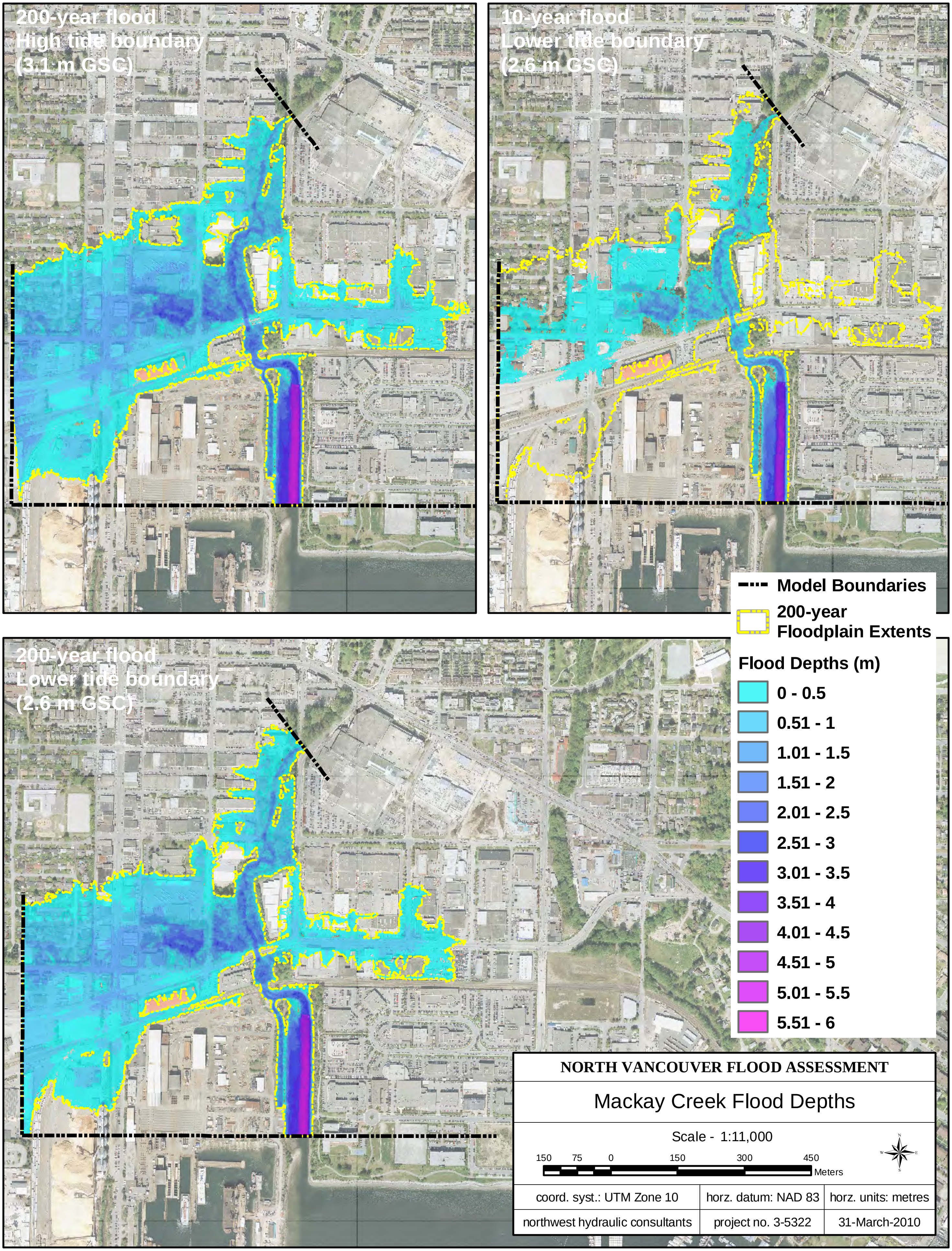

200-year flood
2-year tide and surge level
(2.09 m GSC)
200-year flood
200-year tide and surge level
(2.88 m GSC)
Model Boundaries
200-year Floodplain Extents
Flood Depths (m)
0 - 0.5
0.51 - 1
1.01 - 1.5
1.51 - 2
2.01 - 2.5
2.51 - 3
3.01 - 3.5
3.51 - 4
4.01 - 4.5
4.51 - 5
5.01 - 5.5
5.51 - 6
NORTH VANCOUVER FLOOD ASSESSMENT
Lynn Creek Flood Depths
Scale - 1:10,000
120 60 0 120 240 360 480
Meters
coord. syst.: UTM Zone 10
horz. datum: NAD 83
horz. units: metres
northwest hydraulic consultants
project no. 3-5322
31-March-2010

Figure 6


200-year flood
High tide boundary
(3.1 m GSC)
10-year flood
Lower tide boundary
(2.6 m GSC)
200-year flood
Lower tide boundary
(2.6 m GSC)
Model Boundaries
200-year Floodplain Extents
Flood Depths (m)
0 - 0.5
0.51 - 1
1.01 - 1.5
1.51 - 2
2.01 - 2.5
2.51 - 3
3.01 - 3.5
3.51 - 4
4.01 - 4.5
4.51 - 5
5.01 - 5.5
5.51 - 6
NORTH VANCOUVER FLOOD ASSESSMENT
Mackay Creek Flood Depths
Scale - 1:11,000
150 75 0 150 300 450
Meters
coord. syst.: UTM Zone 10
horz. datum: NAD 83
horz. units: metres
northwest hydraulic consultants
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31-March-2010

Figure 7

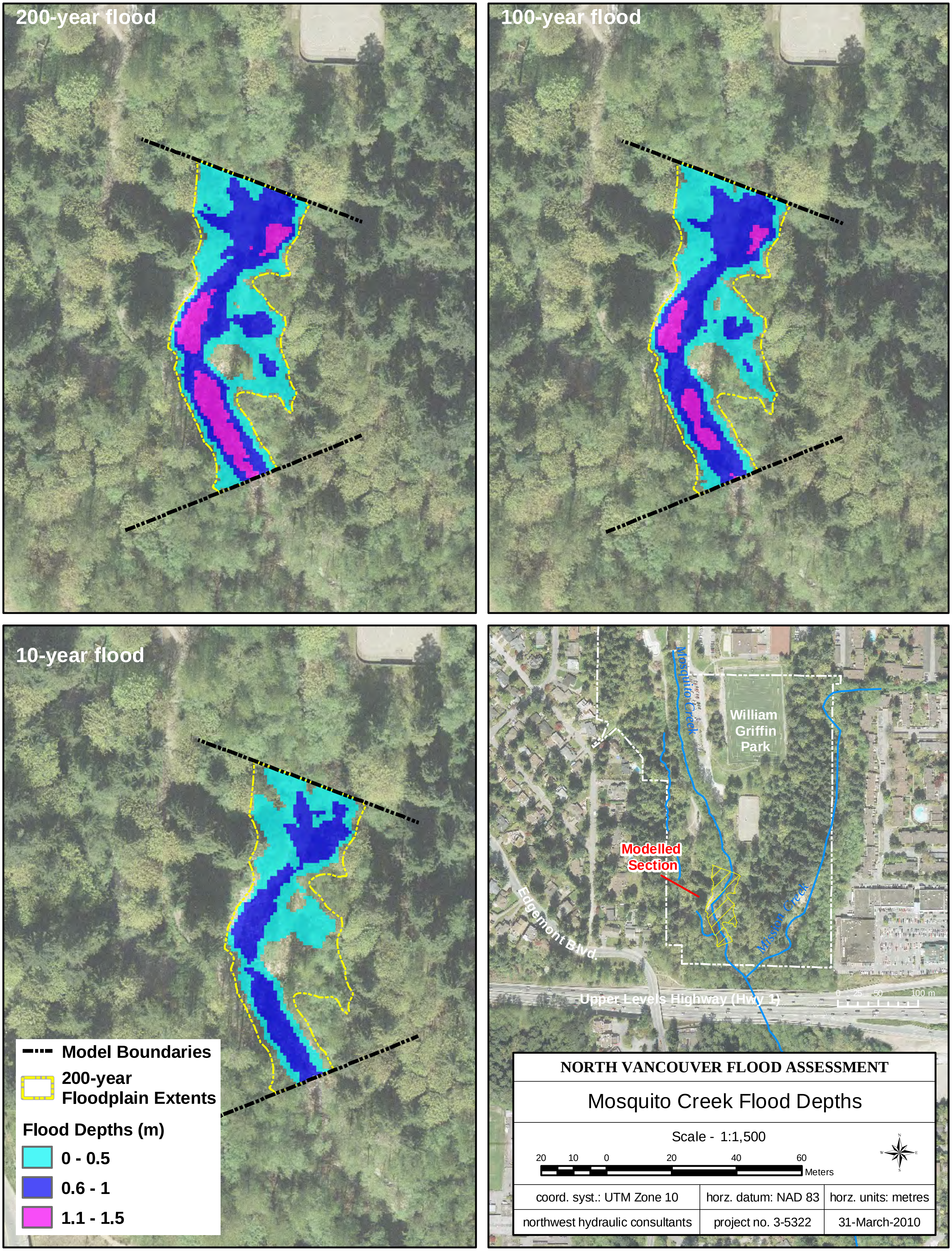
200-year flood
100-year flood
10-year flood
Model Boundaries
200-year Floodplain Extents
Flood Depths (m)
0 - 0.5
0.6 - 1
1.1 - 1.5
Mosquito Creek
William Griffin Park
Modelled Section
Edgemont Blvd
Mission Creek
Upper Levels Highway (Hwy 1)
NORTH VANCOUVER FLOOD ASSESSMENT
Mosquito Creek Flood Depths
Scale - 1:1,500
20 10 0 20 40 60
Meters
coord. syst.: UTM Zone 10
horz. datum: NAD 83
horz. units: metres
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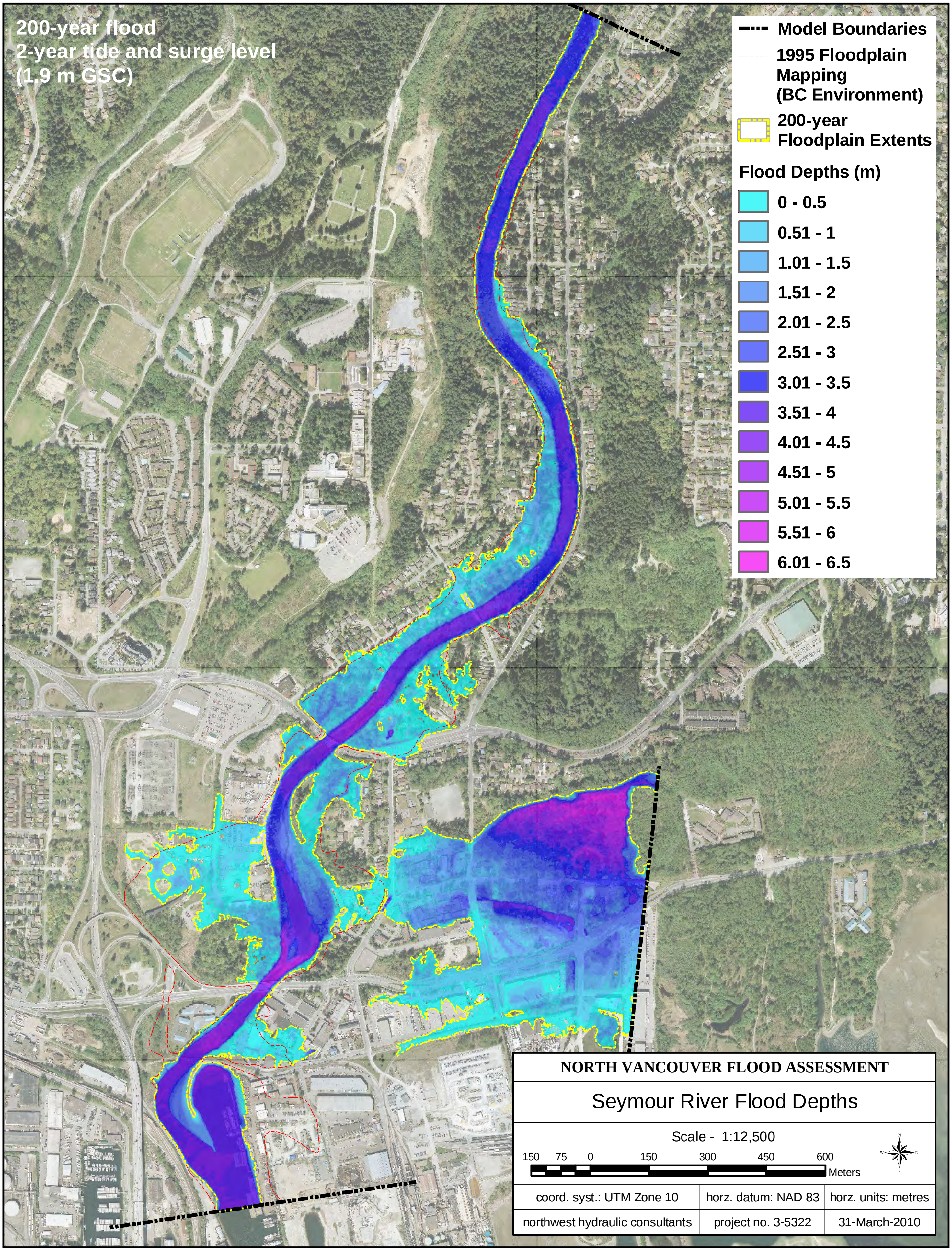
Figure 8



200-year flood
2-year tide and surge level
(1.9 m GSC)
Model Boundaries
1995 Floodplain Mapping (BC Environment)
200-year Floodplain Extents
Flood Depths (m)
0 - 0.5
0.51 - 1
1.01 - 1.5
1.51 - 2
2.01 - 2.5
2.51 - 3
3.01 - 3.5
3.51 - 4
4.01 - 4.5
4.51 - 5
5.01 - 5.5
5.51 - 6
6.01 - 6.5
NORTH VANCOUVER FLOOD ASSESSMENT
Seymour River Flood Depths
Scale - 1:12,500
150 75 0 150 300 450 600
Meters
coord. syst.: UTM Zone 10
horz. datum: NAD 83
horz. units: metres
northwest hydraulic consultants
project no. 3-5322
31-March-2010

Figure 9

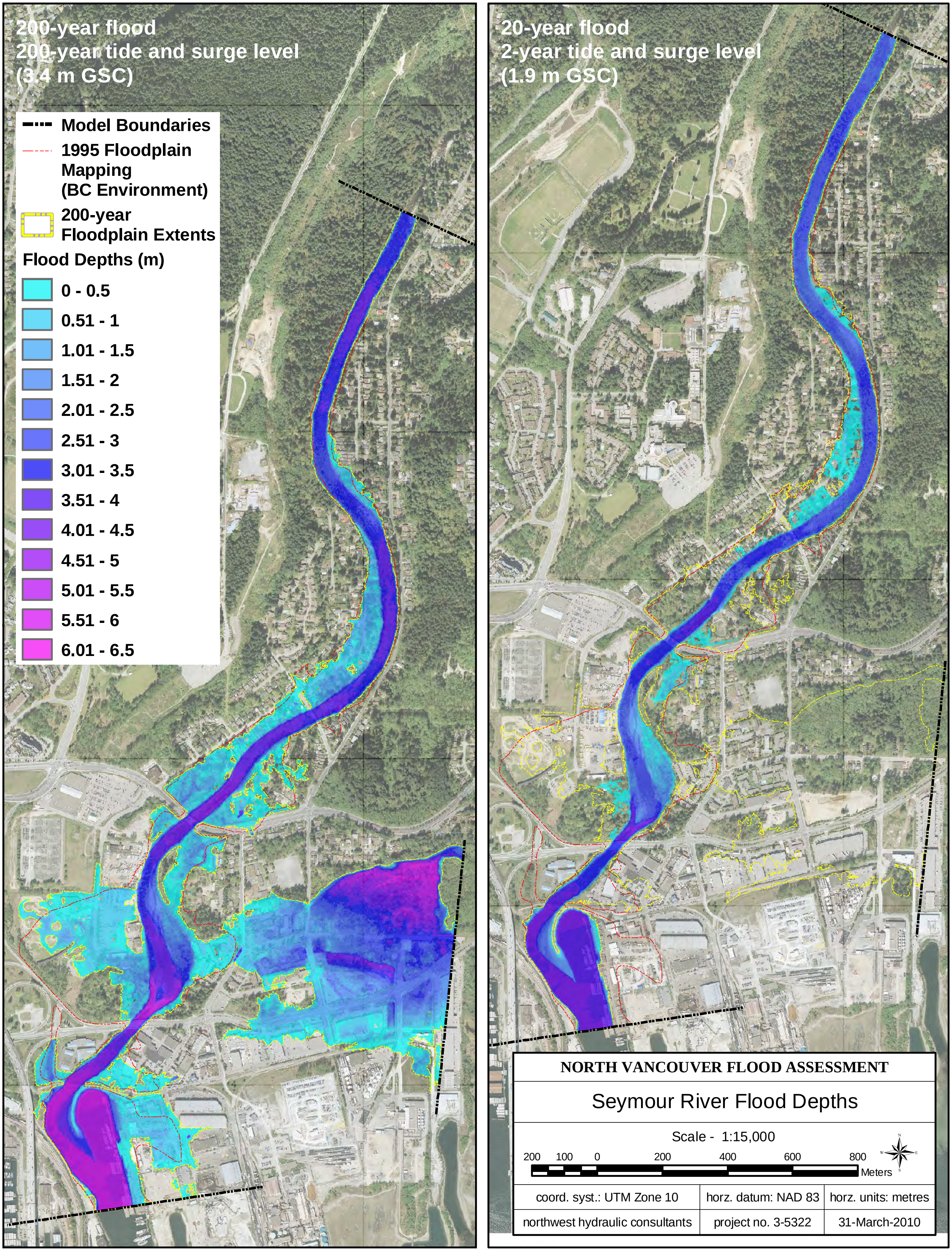

200-year flood
200-year tide and surge level
(3.4 m GSC)
Model Boundaries
1995 Floodplain Mapping (BC Environment)
200-year Floodplain Extents
Flood Depths (m)
0 - 0.5
0.51 - 1
1.01 - 1.5
1.51 - 2
2.01 - 2.5
2.51 - 3
3.01 - 3.5
3.51 - 4
4.01 - 4.5
4.51 - 5
5.01 - 5.5
5.51 - 6
6.01 - 6.5
20-year flood
2-year tide and surge level
(1.9 m GSC)
NORTH VANCOUVER FLOOD ASSESSMENT
Seymour River Flood Depths
Scale - 1:15,000
200 100 0 200 400 600 800
Meters
coord. syst.: UTM Zone 10
horz. datum: NAD 83
horz. units: metres
northwest hydraulic consultants
project no. 3-5322
31-March-2010

Figure 10

APPENDIX A

DATA COMPILATION

Creek	Date	Author	Project/Report Name	Description	Notes	Client
Capilano River	2010	NHC	Capilano River Bridge No. 0367 Replacement	hydraulic design	HEC-RAS, River2D, survey	Ministry of Transportation
Capilano River	Jul-91	KWL	Report on lower Capilano river flood protection	report has peak flow analysis and flood construction levels, survey completed and model created of lower cap		Squamish Indian Band
Capilano River	27-Mar-73	BC water resources	Hydrology Division Report on the Capilano River			
Gallant Creek	2003	NHC	Gallant Creek Flood Hazard	flood hazard assess for private owner	references Bennett Surveys, design flood analysis	DNV
Gallant Creek	1-May-96	KWL	Review of November 23, 1995 Flood Event at Deep Cove - North Vancouver	flood event on Gallant ck - assessment of damage	pdf not available in database	
Gallant Creek	28-Nov-95	KWL	Report on November 23, 1995 Flood Event, Second Draft for Review	description of creek and map where flood had impact in watershed - no surveys		
Gallant Creek	Jul-82	KWL	Report on Creek Systems and Stormwater Control, District of North Vancouver - Working paper No. 12 - report on deep Cover- Dollarton Area	100-yr flood estimate for culverts completed in 1982 report (Rational method)		
Gallant/Parkside Creek	Apr-87	KWL	Report on Indian River Drive - deep cove drainage system	update on the 1982 report that has hydrology for Parkside		
Gavles Creek	Jan-10	LaCas Consultants Inc.	Gavles Creek Flood Control Engineering Report	Flood hazard assessment for private property including creek surveys and hydraulic modelling		Private Resident
Hastings Creek	2005	NHC	Deltalok performance testing	bank protection	HEC-RAS, small survey	Deltalok Inc.
Hastings Creek	Jun-82	KWL	Report on Creek Systems and Stormwater Control, District of North Vancouver - Working paper No. 7 - report on Hastings Creek	overall assessment of creek - has hydrology (100 & 200yr)		
Lynn Creek	1-Dec-04	KWL	Lynn Creek Management Plan	Hydrological Report, Floods/Debris Flow	pdf not available in database - file no. 31.171	DNV
Lynn Creek	2010	NHC	Lynn Creek Bridge Assessment	Hydraulic assessment of proposed 6 lane track crossing of Lynn Creek at Metro Vancouver Port	River 2D, hydrology	MMM Group
Lynn Creek	2004	NHC	Lynnterm Hydraulic assessment	assess impact of adding bridges to lower Lynn Creek	River 2D, hydrology	Vancouver Port Authority
Lynn Creek	1-Apr-98	KWL	Completion Report for 1997 Channel Improvements on Lynn Creek	Report documents the implementation of the 1997 Lynn Creek Bank Protection Repair Project. DNV Contract No. 9-97.	pdf not available in database - file no. 31.172	DNV
Lynn Creek	Jan-96	KWL	Completion report for Lynn Creek 1995 gravel removal	gravel extraction in lower Lynn Creek, survey was completed		DNV
Lynn Creek	Jan-85	KWL	Lynn Creek Stabilization project - status report on implementation program	has survey for area by upper levels highway		DNV

Creek	Date	Author	Project/Report Name	Description	Notes	Client
Lynn Creek	Jul-82	KWL	Report on Creek Systems and Stormwater Control, District of North Vancouver - Working paper no. 8 - Report on Lynn Creek			
MacKay Creek	2009	NHC	5237 Sarita Road Mackay Creek	assess bank failure	references KWL 1974 survey	DNV
MacKay Creek	2009	NHC	5263 Sarita Ave, Mckay Creek assessment	flood hazard assess for private owner	HEC-RAS, small survey	Private Resident
MacKay Creek	2008	NHC	Mackay Creek Bridge	Provide a preliminary assessment of the channel condition at the bridge	HEC-RAS, flood frequency analysis	DNV
MacKay Creek	2008	NHC	Sarita Place Storm Outfall Improvement/Bank Erosion protection	Bank protection at outfall and pedestrian bridge abutment	small survey	DNV
MacKay Creek	Dec-03	KWL	Debris flow study and risk mitigation alternatives for Mackay creek	model created for debris flow on Mackay Creek plus hec-1 model for precipitation in upper Mackay, has peak flow hydrology for mont royal blvd station		
MacKay Creek	May-01	KWL	Upper Mackay Creek Debris Basin	construction of debris basin		
MacKay Creek	Dec-98	KWL	Lower MacKay Creek Management Plan	hydrology and detailed survey along lower Mackay Creek downstream of Maine Drive, backwater analysis hec-ras model	From BC Gov ECOCat database - not currently in DNV Hazards database	DNV
MacKay Creek	Feb-98	KWL	Completion report for 1997 channel improvements on Mackay Creek at Ranger Ave.	channel survey but for upper area only		DNV
MacKay Creek	Jun-82	KWL	Report on Creek Systems and Stormwater Control, District of North Vancouver - Working paper no. 5 - Report on MacKay Creek			
Major Creeks	Apr-99	KWL	Overview report on debris flow hazards, north van	for upper watersheds		
Major Creeks	Aug-96	KWL	DNV Creek and River projects	status report on engineering work program for most north shore creeks		
Major Creeks	Jul-82	KWL	Report on Creek Systems and Stormwater Control, District of North Vancouver	Peak flow hydrology for most streams - no surveys		
McCartney Creek/Blueridge Creek	Aug-09	EBA Engineering Consultants Ltd.	Preliminary Hydrogeomorphic Hazard Assessment of the McCartney Creek Watershed, North Vancouver, BC	Assessment of debris flows/floods/landslide dam within watershed for subject property located on alluvial fan at watershed terminus; creek reconnaissance but no survey	Copy of report forwarded to DNV for inclusion in Hazards database	Private Resident
McCartney Creek	Jun-82	KWL	Report on Creek Systems and Stormwater Control, District of North Vancouver - Working paper no. 9 - Report on McCartney Creek			
Mission Creek	2009	NHC	Mission Creek Culvert	assessment	small survey	DNV
Mission Creek	2002	NHC	Mission Creek	hazard assess for private owner	HEC-RAS, small survey, flood frequency analysis	Private Resident

Creek	Date	Author	Project/Report Name	Description	Notes	Client
Mission Creek	Jun-82	KWL	Report on Creek Systems and Stormwater Control, District of North Vancouver - Working paper no. 3 - Report on Mission Creek			
Mosquito Creek	2008	NHC	Mosquito Creek Bank Protection	erosion assessment and protection design	2007 DNV survey, HEC-RAS	DNV
Mosquito Creek	Dec-03	KWL	Debris flood study and risk mitigation alternatives for Mosquito creek	is Hec-1 model for creek plus hydrology summary in appendix D		
Mosquito Creek	1997	NHC	Mosquito Creek Bridge crossing	flood hazard and bridge design	HEC-2, references KWL survey of lower Mosquito Creek	Earth Tech
Mosquito Creek	Nov-91	KWL	Overview report on Mosquito Creek flood and debris flow protection	recon surveys, overall watershed description		
Mosquito Creek	Jan-85	KWL	Mosquito Creek Stabilization project - completion report on implementation program	would be surveys of the area around the evergreen place debris basin		DNV
Mosquito Creek	Jun-82	KWL	Report on Creek Systems and Stormwater Control, District of North Vancouver - Working paper no. 4 - Report on Mosquito Creek			
Seymour/Capilano	2009/10	NHC	Seymour Capilano Flow Monitoring	flow gauging	isolated cross-sections	Greater Vancouver Regional District
Seymour River	2008	NHC	Seymour River Art	assess hydraulic implications of art	uses MOE floodplain model survey	DNV
Seymour River	2007	NHC	876 Seymour Blvd.	flood hazard assess for private owner	small survey	Private Resident
Seymour River	2004	NHC	Seymour River	gauging during September	HEC-RAS, survey	Greater Vancouver Regional District
Seymour River	2004	NHC	Seymour River Crossing	design of diversion channel	HEC-RAS, survey, flood frequency analysis	JJM Construction
Seymour River	1-Feb-03	KWL	Seymour River Management Plan	Draft. Outlines characteristics of lower Seymour River and identifies some hydrotechnical hazards.	pdf not available in database - file no. 31.309	DNV
Seymour River	1981,1992,1995	MELP	Floodplain mapping for the Seymour River in North Vancouver	floodplain maps plus supporting data – HEC-RAS sections, high water marks		
Seymour River	Dec-91	KWL	Engineering Work Program for Seymour River Management Plan	proposal that id's main flood issues, map with approximate 1981 flood extent on lower Seymour		

APPENDIX B

HYDROLOGY COMPILATION

Stream	Watershed Area (km²)	Instantaneous Peak Hydrology (m^3/s) 2-yr	5-yr	10-yr	20-yr	25-yr	50-yr	100-yr	200-yr	500-yr	Method	Source	Year	Notes
Blueridge at Mt. Seymour Parkway				2				3			Regional analysis (UBC Flood Estimation Program)	KWL	1982	from ' Report on McCartney Creek (Working Paper No. 9); original values in cfs
Capilano at mouth	216.34	378	495	561	619	636	685	731	773	824	flood frequency analysis (FFA)	NHC	2010	from 'Capilano River Bridge No. 0367 Replacement'; instantaneous; I/D = 1.5 as per report; flows adjusted using drainage area from gauge at Cleveland dam; no dam break modelled
Gallant at mouth	2.14								13		Rational Method	NHC	2003	from '2111 Badger Road Flood Hazard Assessment'; runoff coefficient of 0.95 used
Hastings at Hendecourt Road	3.1	5	8	10	12		16				FFA/Area relations	NHC	2005	from 'Design of an Application of the Deltalok System for Hastings Creek'; transferred flows from Mackay Creek gauge (08GA061) using watershed areas
Hastings at Ross Road	3	3		14				23	25		Regional analysis (UBC Flood Estimation Program)			from ' Report on Hastings Creek (Working Paper No. 7); original values in cfs
Lynn at mouth	59.19 (at mouth)	105	125	142	157		178	194	209		FFA/Area relations	KWL	2004	from Lynn Creek Management Plan; FFA then estimation of MAF to drainage area and MAF to various return period flows
Lynn at railway bridge	59.19 (at mouth)	148	195	225	253	262	290	317	345	382	FFA	NHC	2010	from 'Lynn Creek Bridge Assessment Hydrotechnical Design'; Instantaneous; flows at Capilano gauge (08GA010) transferred to Lynn; design flow based on Log Pearson 3 distribution
MacKay at Edgemont Bridge		9		16			22	24	27		FFA (Wiebull)	NHC	2008	from '5011 McKay Creek Bridge at Edgemont Boulevard Scour Assessment'; used upstream MontRoyal Blvd station (08GA061) and transferred using drainage area
Mackay at Marine Drive	6.89 (at mouth)	12		22			33	39	45		rainfall-runoff analysis	KWL	1998	from Lower Mackay Creek Management Plan; 10-yr & 100-yr estimated by rainfall-runoff then 200-yr obtained by scaling 100-yr by 1.13
Mackay at Marine Drive		6		23				37	41		Regional analysis (UBC Flood Estimation Program)	KWL	1982	from 'Estimating Peak Discharges'; original values in cfs; flood frequency curve on pg 45 of report
McCartney at Dollarton Hwy	4.65	2		12				18	20		Regional analysis (UBC Flood Estimation Program)	KWL	1982	from ' Report on McCartney Creek (Working Paper No. 9); original values in cfs
Mission at Queens Road	3	3		7				13	15		Regional analysis (UBC Flood Estimation Program)	KWL	1982	from ' Report on Mission Creek (Working Paper No. 3); original values in cfs

Stream	Watershed Area (km^2)	Instantaneous Peak Hydrology (m^3/s)									Method	Source	Year	Notes
		2-yr	5-yr	10-yr	20-yr	25-yr	50-yr	100-yr	200-yr	500-yr				
Mosquito at Evergreen basin		10	12	13				18	22		rainfall-runoff analysis	KWL	2003	from 'Debris Flood Study and Risk Mitigation Alternatives for Mosquito Creek'; rounded 20-yr estimate up from 20.5 for design flood
Mosquito at Evergreen basin		12						64	71		Regional analysis (UBC Flood Estimation Program)	KWL	1982	from 'Estimating Peak Discharges'; original values in cfs
Mosquito at Evergreen basin?		7		41				64	71		Regional analysis (UBC Flood Estimation Program)	KWL	1982	from ' Report on Mosquito Creek (working paper no. 4)'; original values in cfs
Mosquito at Marine Drive		23						142	159		Regional analysis (UBC Flood Estimation Program)	KWL	1982	from 'Estimating Peak Discharges'; original values in cfs; flood frequency curve on pg 47 of report (values for flow chart on pg 76 of report contradict values presented here)
Mosquito at Marine Drive		20		40				65	74		Regional analysis (UBC Flood Estimation Program)	KWL	1982	from 'Estimating Peak Discharges'; original values in cfs; values from flow chart on pg 76 of report (values for flood frequency curve on pg 47 contradict values presented here)
Mosquito at mouth	14.77								72		n/a	KWL	1996	value listed in 'Lower Mosquito Creek Flood Profile, April 1996' hardcopy report found in nhc archives (32515); report states 200-yr flow estimate is from 'Draft Report on North Shore Regional Hydrology and Computer Modelling, prepared by KWL, November 1992'
Mosquito downstream of William Griffin		16	22	26				40	46		Avg of Creager and Regional Analysis	NHC	2007	from Mosquito Creek Bank Protection project
Seymour at highway bridge	182.18 (at mouth)	299	414	489	560	581	648	713	776		FFA	NHC	2004	from 'Seymour River Crossing'; I/D ratio = 1.56 (average on record); flows transferred from upstream gauge (08GA030) based on area
Seymour at mouth					530		650 (64-yr)		808		FFA	Province of BC	1995	from Appendix 3 MELP 'Design Brief on the Floodplain mapping Study, Seymour River'; FFA transferred from upstream gauge
Seymour at mouth	188	276	377	450	525		631	718	808		FFA	KWL	2003	from Seymour River Management Plan; transferred from upstream gauge using a peaking factor of 1.03 (is less than the 1.07 derived from scaling off watershed area)

APPENDIX C

FLOOD PROFILES

Capilano River downstream of Fullerton Bridge, Original Source: NHC (2010)[1]

High Tide Run (200-year tide and surge level = 2.88 GSC at downstream boundary)

	Water Surface Elevation (m GSC)				
Section[2]	**200-year flood ($773\ m^3/s$)**	**100-year flood ($731\ m^3/s$)**	**50-year flood ($685\ m^3/s$)**	**25-year flood ($636\ m^3/s$)**	**10-year flood ($561\ m^3/s$)**
1	2.88	2.88	2.88	2.88	2.88
2	2.93	2.93	2.92	2.92	2.91
3	3.11	3.08	3.06	3.04	3
4	3.16	3.14	3.1	3.07	3.03
5	3.33	3.29	3.24	3.19	3.13
6	3.82	3.75	3.68	3.6	3.48
7	4.78	4.68	4.58	4.45	4.26
8	5.59	5.56	5.36	5.23	5
9	6.81	6.8	6.61	6.49	6.3
10	7.98	7.89	7.79	7.68	7.5
11	8.94	8.85	8.76	8.65	8.47
12	10.78	10.69	10.6	10.49	10.33
13	12.65	12.55	12.45	12.33	12.15
14	13.79	13.7	13.59	13.47	13.28

Lower Tide Run (2-year tide and surge level = 2.09 GSC at downstream boundary)

Section[2]	**200-year flood ($773\ m^3/s$)**	**100-year flood ($731\ m^3/s$)**	**50-year flood ($685\ m^3/s$)**	**25-year flood ($636\ m^3/s$)**	**10-year flood ($561\ m^3/s$)**
1	2.09	2.09	2.09	2.09	2.09
2	2.2	2.19	2.17	2.16	2.15
3	2.5	2.46	2.42	2.38	2.31
4	2.64	2.6	2.55	2.49	2.42
5	2.98	2.91	2.84	2.76	2.65
6	3.79	3.72	3.63	3.53	3.37
7	4.81	4.7	4.57	4.44	4.24
8	5.58	5.48	5.36	5.23	4.99
9	6.81	6.71	6.61	6.49	6.3
10	7.99	7.9	7.79	7.68	7.5
11	8.96	8.87	8.76	8.65	8.47
12	10.78	10.69	10.6	10.49	10.33
13	12.64	12.55	12.45	12.33	12.15
14	13.79	13.7	13.59	13.47	13.28

[1]NHC. 2010. Capilano River Bridge No. 0367 Replacement. Report prepared for the BC Ministry of Transportation and Infrastructure, January 2010.

[2]Section numbering is from original report

Lynn Creek downstream of Cotton Road Bridge, Original Source: NHC (2010)[1]

High Tide Run (200-year tide and surge level = 2.88 GSC at downstream boundary)

	Water Surface Elevation (m GSC)				
Section[2]	**200-year flood ($209\ m^3/s$)**	**100-year flood ($194\ m^3/s$)**	**50-year flood ($178\ m^3/s$)**	**20-year flood ($157\ m^3/s$)**	**10-year flood ($142\ m^3/s$)**
9	3.81	3.73	3.63	3.52	3.44
8	3.57	3.50	3.42	3.33	3.26
7.5	3.41	3.36	3.30	3.22	3.17
7	3.27	3.23	3.18	3.13	3.09
6	3.16	3.13	3.09	3.05	3.02
5	3.08	3.06	3.03	3.00	2.98
4	3.04	3.02	3.00	2.98	2.96
3	2.98	2.97	2.95	2.94	2.93
2	2.95	2.94	2.93	2.92	2.92
1	2.91	2.90	2.90	2.90	2.90
0	2.89	2.89	2.89	2.89	2.89

Lower Tide Run (2-year tide and surge level = 2.09 GSC at downstream boundary)

Section[2]	**200-year flood ($209\ m^3/s$)**	**100-year flood ($194\ m^3/s$)**	**50-year flood ($178\ m^3/s$)**	**20-year flood ($157\ m^3/s$)**	**10-year flood ($142\ m^3/s$)**
9	3.73	3.63	3.53	3.40	3.30
8	3.43	3.34	3.24	3.11	3.01
7.5	3.22	3.14	3.05	2.93	2.84
7	3.00	2.93	2.86	2.75	2.68
6	2.77	2.71	2.64	2.56	2.49
5	2.58	2.53	2.47	2.40	2.35
4	2.45	2.40	2.36	2.31	2.27
3	2.30	2.27	2.24	2.21	2.19
2	2.24	2.22	2.20	2.17	2.16
1	2.14	2.13	2.13	2.12	2.12
0	2.09	2.09	2.09	2.09	2.09

[1]NHC. 2010. Lynn Creek Bridge Assessment Hydrotechnical Detailed Design. Draft Report prepared for MMM Group, February 2010.

[2]Section numbering is from original report

Lynn Creek upstream of Cotton Road Bridge, Original Source: KWL (2004)[1]

	Water Surface Elevation (m GSC)
Section[2]	200-year flood ($209\ m^3/s$)
2+400	4.25
2+300	5
2+200	5.5
2+100	6.2
2+000	6.7
1+900	7.4
1+800	8
1+700	8.8
1+600	9.6
1+500	10.1
1+400	11.1
1+300	11.5
1+200	12.5
1+100	13.5
1+000	14.5

[1]KWL (Kerr Wood Leidal Associates Ltd.). 2004. Lynn Creek Management Plan. Final report prepared for the District of North Vancouver (DNV). December, 2004.
[2]Section numbering is from original report

Mackay Creek downstream of Roosevelt Crescent, Original Source: KWL (1998)[1]

	Water Surface Elevation (m GSC)		
Section[2]	200-year flood (45 m^3/s, high tide scenario)	200-year flood (45 m^3/s, lower tide scenario)	10-year flood (22 m^3/s, lower tide scenario)
1	3.35	3.28	2.53
2		3.32	
3		3.58	
4	3.7	3.66	2.8
5	3.71	3.67	2.79
6		3.66	
7		3.92	
8	4.07	4.07	3.17
9		4.07	
10		4.08	
11		4.08	
12		4.08	
13		4.2	
14	4.4	4.4	3.83
15		4.5	
16		4.63	
17		4.75	
18	4.94	4.94	4.68
19		5.78	

[1]KWL. 1998. Lower Mackay Creek Management Plan. Prepared for the District of North Vancouver (DNV). December, 1998.
[2]Section numbering is from original report

Mosquito Creek downstream of Larson Road, Original Source: NHC (1997)[1]

Section[2]	Water Surface Elevation (m GSC) 200-year flood ($72\ m^3/s$)
700	16.08
485	10.67
380	8.99
280	6.06
200	5.4
180	5.17
160	4.61
140	3.94
120	3.86
100	3.8
80	3.52
60	3.57
40	3.3
20	2.74

Mosquito Creek at William Griffin Park, Original Source: NHC (2008)[3]

	Water Surface Elevation (m GSC)		
Section[2]	200-year flood ($46\ m^3/s$)	100-year flood ($40\ m^3/s$)	10-year flood ($26\ m^3/s$)
4	54.98	54.88	54.61
5	55.39	55.29	55.01
6	55.97	55.85	55.55
7	56.61	56.38	56.06
8	56.68	56.55	56.28
9	57.59	57.52	57.27
10	57.89	57.81	57.57
11	57.91	57.78	57.64
12	58.09	58.05	57.93
13	59	58.94	58.8
14	59.48	59.38	59.17
15	59.52	59.47	59.33

[1]NHC. 1997. Mosquito Creek Bridge Crossing. Prepared for Earth Tech Inc. April 1997.
[2]Section numbering is from original report
[3]NHC. 2008. Mosquito Creek Bank Protection (William Griffin Park). Report prepared for the District of North Vancouver, April 2008.

Seymour River (lower 4 km), Original Source: MELP (1995)[1]

Section[2]	200-year Maximum Daily flood (lower tide scenario)[3,4]	200-year Instantaneous flood (lower tide scenario)[4]	200-year Instantaneous flood (high tide scenario)[4]	Notes (from MELP, 1995)
1.9	1.9	1.9		
2	1.13	1.86	3.4	
2.9	1.25	2.14		downstream edge of railway bridge
3	1.69	2.64	3.4	CNR bridge
4	2.45	3.71	3.4	
4.5	2.37	3.63	3.4	concrete weir just upstream of section 4
5	2.75	3.81	3.43	d/s of Dollarton Bridge
6	2.66	3.52	3.74	Dollarton Bridge
7	2.86	3.95	4.36	Dollarton Bridge
8	4.04	5.17	5.55	deposition area
9	4.92	6.11	6.37	d/s Maplewood Farm
10	5.68	6.29	6.45	Maplewood/I.R. No.2
11	7.33	7.81	7.65	Maplewood/I.R. No.2
12	7.96	8.88	8.89	Maplewood/I.R. No. 2 at Mt. Seymour Pkwy Bridge
13	8.29	9.12	9.05	Seymour Parkway Bridge
14	8.45	9.3	9.19	Seymour Parkway Bridge
15	8.77	9.92	9.59	u/s Seymour Pkwy Bridge
16	9.88	10.69	10.56	
17	11.43	12.2	12.04	
17.9	11.31	12.01		d/s edge of Grantham Rd
18	11.89	12.93	12.39	Grantham Road Bridge
19	12.56	13.66	13.65	
25	13.83	14.48	14.55	
20	15.16	16.08	15.99	
26	16.62	17.36	17.39	
21	18.06	18.7	18.7	
22	21.77	22.4	22.38	
23	24.47	25.3		incised
24	27.87	28.58		incised

[1]MELP. 1995. Design Brief on the Floodplain Mapping Study. Prepared by the Ministry of Environment, Lands and Parks (MELP), Water Management Division. January, 1995.

[2]Section numbering is from original report

[3]200-yr max daily flood used to represent 20-yr instantaneous flood elevations

[4]from MELP (1995) flood profiles Table 1 (200-yr Daily and 200-yr Instant.) and Table 3 (200-yr Instant.); From MELP (1995) pg. 7 - flood elevations are equal to the 200-yr Max Daily elevation plus 0.6 m or the 200-yr Instant. elevation plus 0.3 m, whichever is greater - the flood elevations shown on the mapping are generally the 200-yr Instant. Elevations.