DRY CREEK
FLOOD MITIGATION STUDY

FINAL REPORT

City of Port Alberni
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Port Alberni, BC
V9Y 1V8

23 September, 2013

nhc
northwest hydraulic consultants
water resource specialists

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EXECUTIVE SUMMARY

The City of Port Alberni (City) retained Northwest Hydraulic Consultants Ltd. (NHC) to conduct a flood investigation on the lower section of Dry Creek, in Port Alberni, BC. The study area extended over a 1.6 km reach, starting 400 m upstream of 4th Avenue down to Alberni Inlet. The objective of the study was to assess ways to reduce flooding and improve the conveyance of the channel. The US Army Corps of Engineers (USACE) HEC-RAS program was used to develop a one-dimensional numerical flow model to investigate the creek's response to different flood scenarios generated by a combination of high ocean levels and peak discharges.

Topographic surveys of the channel were made in 2012 by Koers & Associates Engineering Ltd. and this information was used to develop the base hydraulic model of the creek. The model was run to simulate a range of flood scenarios generated by a combination of high ocean levels and peak discharges. The model results showed that the key bridges in the study reach surcharged at relatively low discharges (2-year to 10-year return period). Road bridges in British Columbia commonly are designed to have a clearance of 1.5 m during a 200-year flood. The structures would need to be raised by an amount between 1.6 m and 1.97 m (without channel improvements or bridge lengthening) to meet this requirement.

Three flood mitigation options were developed through discussions at meetings with the City. The analysed options included:

- Option 1: Napier Street Diversion
- Option 2: Bridge Improvements
- Option 3: Bridge and Channel Improvements.

Of the three options that were modelled, Option 3 was found to be the most effective option to lower water levels in the study reach. The most complicated project from a hydrotechnical perspective is Option 1. Some potential challenges with Option 1 would include: balancing the flow split between the creek and the diversion pipe to match design targets; minimising hydraulic losses at the inlet and outlet of the diversion; and handling trash, wood debris and sediment effectively. The least effective option was Option 2.

All options presented in this report would benefit from a sediment management plan. Conceptually, the plan may include a sediment trap several hundred metres upstream of 4th Avenue. The trap would require periodic excavation to maintain its effectiveness.

Additional hydraulic studies would be required for detailed design of the selected option. Example optimizations include channel dimensions, final channel and bank grades, bridge deck heights, and others. We recommend that the model be calibrated and verified at higher flows than were observed in 2012. If post-2006 historical flood limits cannot be identified to calibrate the model then one method that could be used is to measure the flow and stage at various cross sections during a significant flood in 2013/14.

Credits and Acknowledgements

The following NHC staff worked on this project:

- Graham Hill, P.Eng. – Project Manager
- Dave McLean, P.Eng. – Review Principal
- Vanessa O'Connor, P.Eng. – Hydraulic Modelling
- Dave Vincent, P.Eng. – Hydrology
- Josef Drechsler, GIS Specialist – Data Analysis and Numerical Model Input.

Topographic surveys of the creek were carried out by Koers & Associates Engineering Ltd.

The study was conducted under the direction of Mr. Guy Cicon, P.Eng. City Engineer, City of Port Alberni.

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1 INTRODUCTION

1.1 SCOPE OF WORK

The City of Port Alberni (City) retained Northwest Hydraulic Consultants Ltd. (NHC) to conduct a flood investigation on the lower section of Dry Creek, in Port Alberni, BC. The study area was the lower 1.6 km reach that flowed from 400 m upstream of 4th Avenue down to Alberni Inlet – the model extends 580 m downstream of the pulp and paper mill Conveyor Bridge (Figure 1). The study assessed flood issues on Dry Creek related to culvert and bridge capacities, stream bed and hydraulic gradients, and flood berm locations. The objective of the study was to assess ways to reduce flooding and improve the conveyance of the channel. Subsequent project phases will be directed towards reducing flood damages to the area. The results of this study were not intended, and should not be used to provide detailed floodplain maps for establishing flood construction levels or flood risks for establishing flood hazard by-laws.

1.2 METHODOLOGY

NHC reviewed background reports, data, digital contour data, and flood photos that the City provided. A reconnaissance field inspection of the study area was conducted with Koers & Associates Engineering Ltd. (Koers). During the site visit the general topography of the area, channel conditions, bed and overbank roughness, bank vegetation, areas that have been subject to flooding in the past, and other aspects were reviewed. Approximately 70 cross section locations were identified during the field review; data collection requirements were reviewed with the surveyor. Koers conducted the creek surveys using a total station survey instrument. Digital contour data was provided by the City for the project area floodplain and Canada Hydrographic Survey (CHS) data[1] was used for coverage in the estuary and Alberni Inlet. Various data sources were analysed using GIS software.

Water level recorders were installed in the creek at two locations, one upstream of 4th Avenue and the other downstream of 3rd Avenue, to collect continuous water level records throughout the winter to assist with verifying the model. It was intended for a manual flow measurement to be conducted during the peak of a flood event. However, the floods in 2012/13 were relatively infrequent and generally small, and a flow measurement was not collected.

Provincial flood guidelines recommend flood protection works be designed for the 200-year flood event; this corresponds to a 0.5% chance of the design flood occurring in any given year. Dry Creek is an ungauged watershed, thus NHC undertook a regional hydrologic analysis. Various return interval flows for the 2- to 200-year floods were estimated. Tide statistics were analyzed for the Port Alberni tide station and used for the numerical modelling input. The US Army Corps of Engineers (USACE) HEC-RAS backwater program was used to develop a one-dimensional numerical flow model to investigate the creek's response to different flood scenarios generated by a combination of high ocean levels and peak discharges.

[1] Canadian Hydrographic Service, Alberni Inlet Chart No. 3668.

The survey information was used to develop the base model. Three flood mitigation options were hydraulically assessed. The option concepts were developed through discussion at meetings with the City and Koers. NHC met with the City and Koers at the 50% and 95% stage to discuss the project.

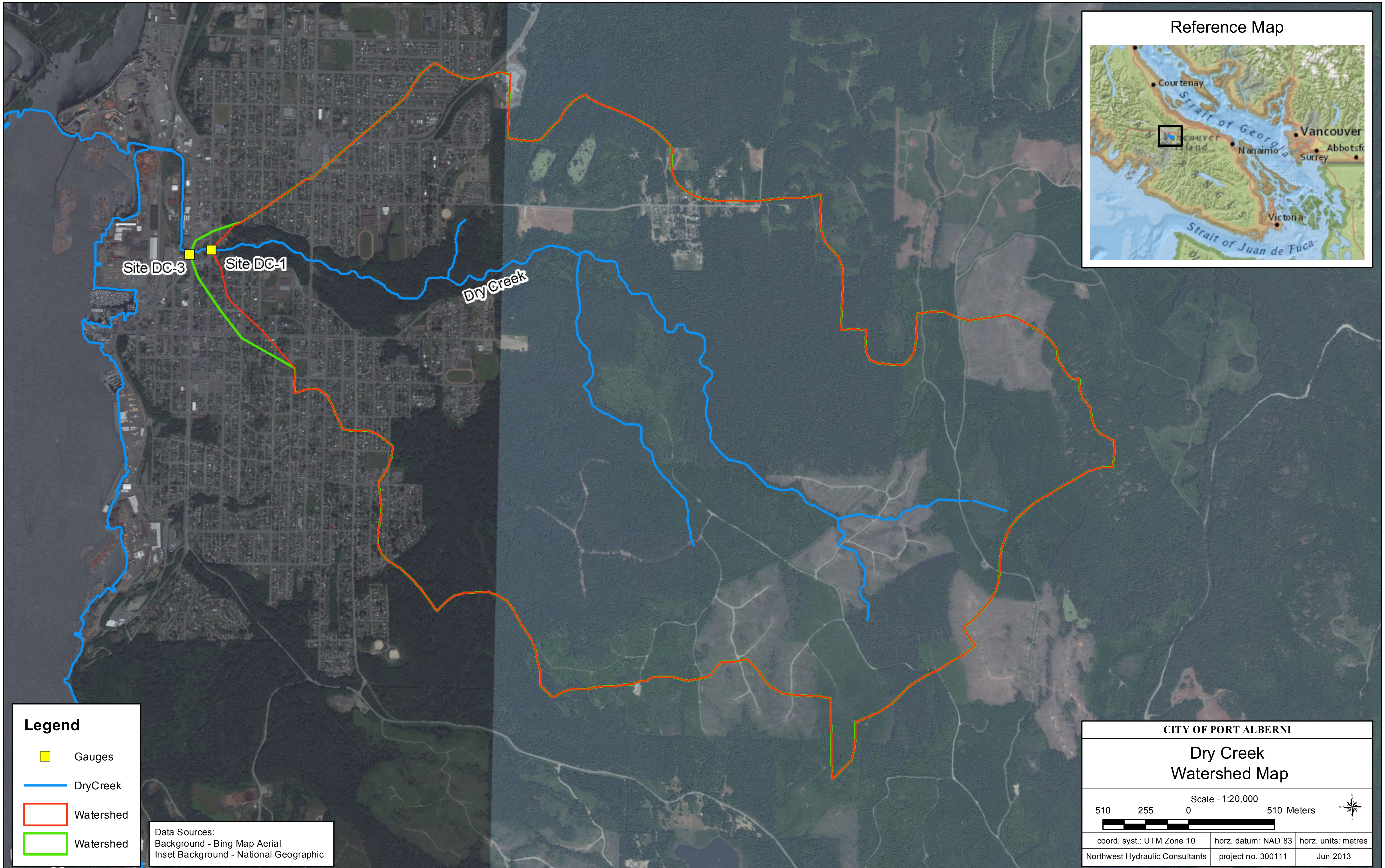
Figure 1. The Dry Creek flood study area is indicated by the yellow line.

2 SITE CONDITIONS

The Dry Creek, gazetted name Owatchet Creek, watershed is predominantly forest land, which has relatively gentle topographic relief since the watershed does not extend into the steeper terrain to the east. This forest area is under active forest management, ranging from recently harvested through all levels of regeneration. Surficial materials are dominated by sandy gravel underlain by compact glacial till (D. Vincent, personal observation). Approximately 2 km^2 of the watershed is urban, developed as mixed use residential, commercial and industrial. Of the developed portion of the watershed, approximately 50% is served by storm sewers that discharge to Dry Creek. Dry Creek watershed characteristics relative to the 4th Avenue Bridge are shown in Table 1 and an overview of the watershed is shown in Figure 2.

Table 1. Dry Creek watershed characteristics, relative to the 4th Avenue Bridge (from TRIM data).

Drainage Area (km^2)	Mean Elevation (m)	Min Elevation (m)	Max Elevation (m)	Lake Area (ha)	Stream Length (km)	Forest Area (ha)	Average Annual Precipitation 1961-1990 (mm)
11.9	157	5	314.0	2.7	6.04	988.7	2,145


Reference Map
Courtenay
Strait of Georgia
Vancouver
Abbotsf
Surrey
Nanaimo
Victoria
Strait of Juan de Fuca
Site DC-3
Site DC-1
Dry Creek
Legend
Gauges
DryCreek
Watershed
Watershed
Data Sources:
Background - Bing Map Aerial
Inset Background - National Geographic
CITY OF PORT ALBERNI
Dry Creek
Watershed Map
Scale - 1:20,000
510 255 0 510 Meters
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horz. datum: NAD 83
horz. units: metres
Northwest Hydraulic Consultants
project no. 300111
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Figure 2

The upstream extent of the study reach is 500 m upstream of 4th Avenue. The floodplain in the entire study reach is a large alluvial deposit. Above 4th Avenue the floodplain is vegetated with mature mixed forest. Substrate size is gravel, cobble and boulder. The average bed grain size (D_{50}) is approximately 0.15 m. (Photo 1).

Photo 1. The channel upstream of 4th Avenue looking downstream.

Below 4th Avenue the bank vegetation is mixed. Between 4th Avenue and 3rd Avenue the channel has a restaurant constructed above the channel (Restaurant Bridge). The banks have mixed rock revetment, vegetated soils, and concrete retaining walls.

Downstream of the 3rd Avenue Bridge, Dry Creek is an artificial channel that runs alongside mixed commercial and industrial land before discharging into the Alberni inlet (Photo 2). The gradient is low. High tide influence is up to approximately 3rd Avenue.

Photo 2. Downstream of 3rd Avenue the channel is artificially straight.

There are eight bridge crossings in the study reach. The bridge crossings are located at 4th Avenue, the restaurant (between 3rd and 4th Avenue), at 3rd Avenue, a rail bridge aligned with the end of Bute Street near 3rd Avenue, and four crossings on the pulp and paper mill site (Figure 1 and Photo 3 to Photo 10).

Photo 3. 4th Avenue Bridge looking downstream (Model Station 1072).

Photo 4. Restaurant Bridge looking downstream (Model Station 988).

Photo 5. 3rd Avenue Bridge looking downstream (Model Station 965).

Photo 6. Rail Bridge aligned with the end of Bute Street (Bute Rail Bridge) (Model Station 408).

Photo 7. Rail Bridge on the pulp and paper mill site looking upstream (Model Station 226.5).

Photo 8. Industrial Road Bridge looking downstream (Model Station 170).

Photo 9. Pipe Bridge looking downstream (Model Station 129).

Photo 10. Conveyor Bridge looking upstream (Model Station 0).

3 HYDROLOGICAL CONDITIONS

3.1 FLOOD DISCHARGES

The drainage area near the 4th Avenue Bridge is 11.9 km^2. Between the upstream side of the 4th Avenue Bridge (Site DC-1) and the downstream side of the 3rd Avenue Bridge (Site DC-3) an area of approximately 10 ha is drained into Dry Creek by storm sewers. This area is intensely developed and dominated by paved roads and commercial areas. Two larger diameter storm sewers discharge under the 3rd Avenue Bridge into Dry Creek.

The runoff conditions in the region were described in the BC Ministry of Environment floodplain mapping project for Somass River, Kitsuksis Creek and other local drainages (BCMoELP, 1997[2]). Based on their regional hydrology plot, a 10-year instantaneous maximum discharge from Dry Creek would be 30 m^3/s. Two other methods were used to estimate peak discharge from Dry Creek. These included the Rational Method and an in-house Regional Method that was adopted from studies by Sumioka et al. (1998)[3]. Table 2 compares the estimated discharges using the Rational and Regional Methods. Both methods agree closely to the 10 year estimate from BCMoELP's floodplain mapping study. The Regional Method produced slightly higher values than the Rational Method. For this study the Rational Method values were adopted since it relied on local information near the site.

Table 2: Estimated instantaneous maximum discharges

Return Period (Years)	Rational Method (m3/s)	Regional Method (m3/s)
2	18	21.5
10	30	30.8
25	34	36.9
50	36	40.9
100	38	46.0
200	44	

[2] BCMoELP 1997: A Design Brief on the Floodplain Mapping Project For the Somass River and Tributaries at Port Alberni, BC, Floodplain Mapping Program, March 1997.

[3] Sumioka, S., Kresch, D. and K. Kasnick. 1998. Magnitude and Frequency of Floods in Washington, US, Geological Survey Water Resources Investigation Report 7-4288, 91pg.

3.2 OCEAN LEVELS

Published ocean level statistics at Port Alberni were obtained from Fisheries & Oceans Canada[4]. These levels are reported in local Chart Datum and were converted to Canadian Geodetic Datum. Table 3 summarizes the key statistics.

Table 3: Adopted tide levels at Port Alberni

Tide Condition	Abbreviation	Chart Datum (CD m)	Geodetic Datum (CGD m)
Maximum Observed	Max	4.4	2.5
Higher High Water Large Tide	HHWLT	3.9	2.0
Higher High Water Mean Tide	HHWMT	3.1	1.2
Mean Sea Level	MSL	1.9	0.0
Lower Low Water Mean Tide	LLWMT	1.4	-0.5
Lower Low Water Large Tide	LLWLT	-0.8	-2.7

HHWLT represents the average of the highest tides predicted to occur in each year over a 19 year period. HHWMT is the average of all predicted high tides occurring during the 19 year period. The maximum observed tide represents the actual highest ocean level recorded at the Port Alberni tide gauge.

BCMoELP used a starting water level of 2.6 m CGD at tide water for their HEC-RAS model of Somass River and Kitsuksis Creek and varied the starting levels from 2.0 to 2.9 m as a sensitivity analysis. Their adopted 200-year coastal flood level (no freeboard) was elevation 3.0 m CGD.

A starting ocean level of 2.5 m CGD was used in this study for most of the model runs.

3.3 WATER LEVEL RECORDERS

Water level recorders were installed in the creek at two locations: one upstream of 4th Avenue and the other downstream of 3rd Avenue. The water level recorders were Solinst Levelogger Edges. A Solinst Barologger Edge was used to record barometric pressures for post data processing corrections. The recorders were set to collect continuous water level records on 10 minute intervals throughout the winter from October 20, 2012 to February 20, 2013 to assist with verifying the model. It was intended for a manual flow measurement to be conducted during the peak of a flood event. However, the floods in 2012/13 were relatively infrequent and generally small, and the flow measurement was not collected.

[4] Fisheries & Oceans Canada, 2013. Canadian Tide and Current Tables, Discovery Passage and West Coast of Vancouver Island, Volume 6, Ottawa.

Figure 3 shows the corrected water level recorder data overlaid with the Port Alberni tide data. The week of December 13, 2012 was characterized by a series of unusually high tides but relatively little rainfall or runoff. During this period the peak water levels at the 3rd Avenue Bridge were controlled by the tide, while there was no discernible tidal influence further upstream at the 4th Avenue Bridge.

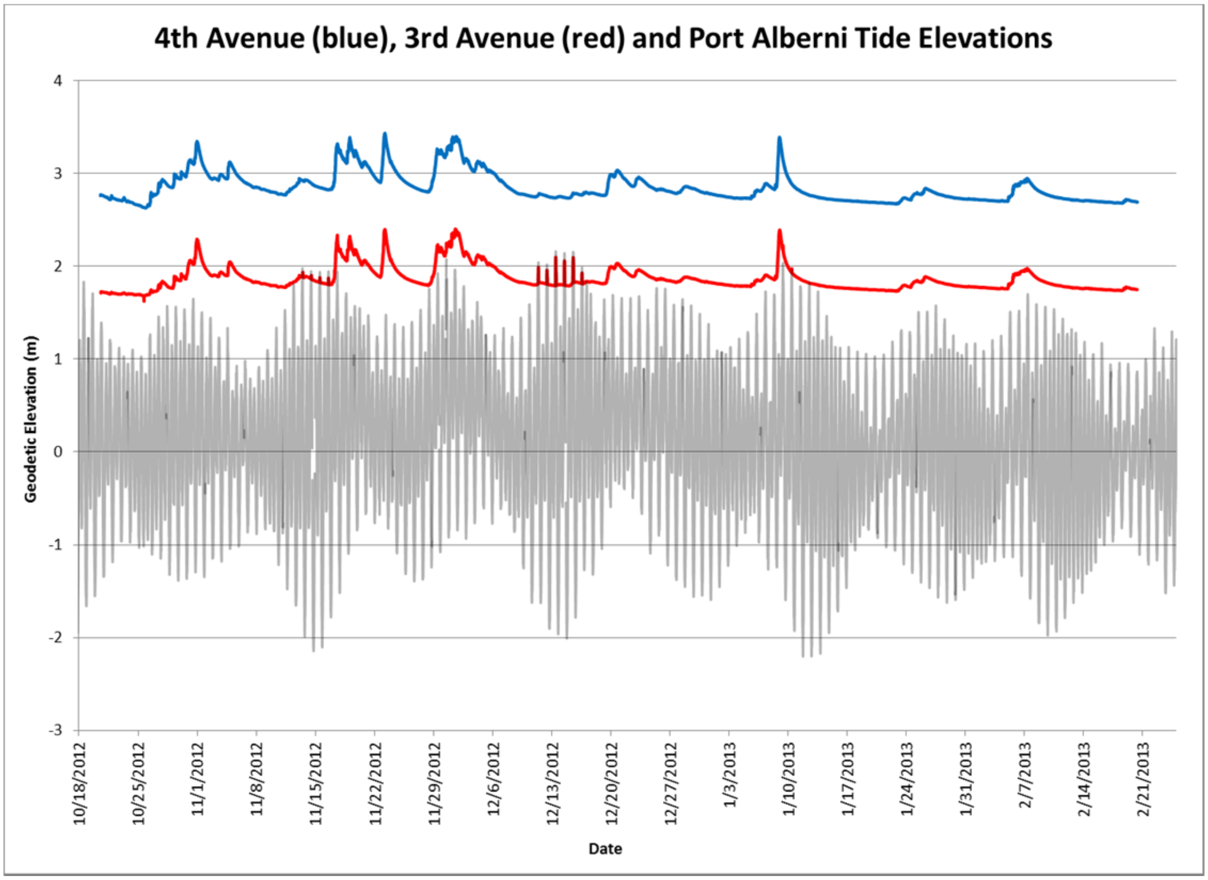

Figure 3. Water level and tide data for the winter of 2012/13.

4 NUMERICAL MODEL DEVELOPMENT

The numerical model used for this study was the US Army Corps of Engineers' (USACE) HEC-RAS one-dimensional backwater program. HEC-RAS can perform unsteady flow computations along with computing the effects of bridges, culverts, weirs, and other structures. It includes features that enable modelling of dike breaching and overtopping; pumping stations; floodplain storage cells; and pressurized culverts. HEC-RAS is available free of charge and is widely adopted for flood modelling in Canada and the United States.

The survey information was used to develop the base model. The base model was used to investigate the creek system's response to different flood scenarios generated by a combination of high ocean levels and peak discharges. The total model length was 2,150 m. The downstream station (-582) started in Alberni Inlet. Station 0 was at the pulp and paper mill conveyor bridge. The bridge stations are provided in Table 4, and an overview of the model cross sections is shown in Figure 4.

Table 4. Summary of Bridge Stations

Bridge Station (m)	Bridge Description
0	Pulp and paper mill conveyor
129	Pulp and paper mill pipeline bridge
170	Industrial road access road
226.5	Railway bridge
408	Railway bridge near Bute St.
965	3rd Avenue
988	Restaurant
1072	4th Avenue

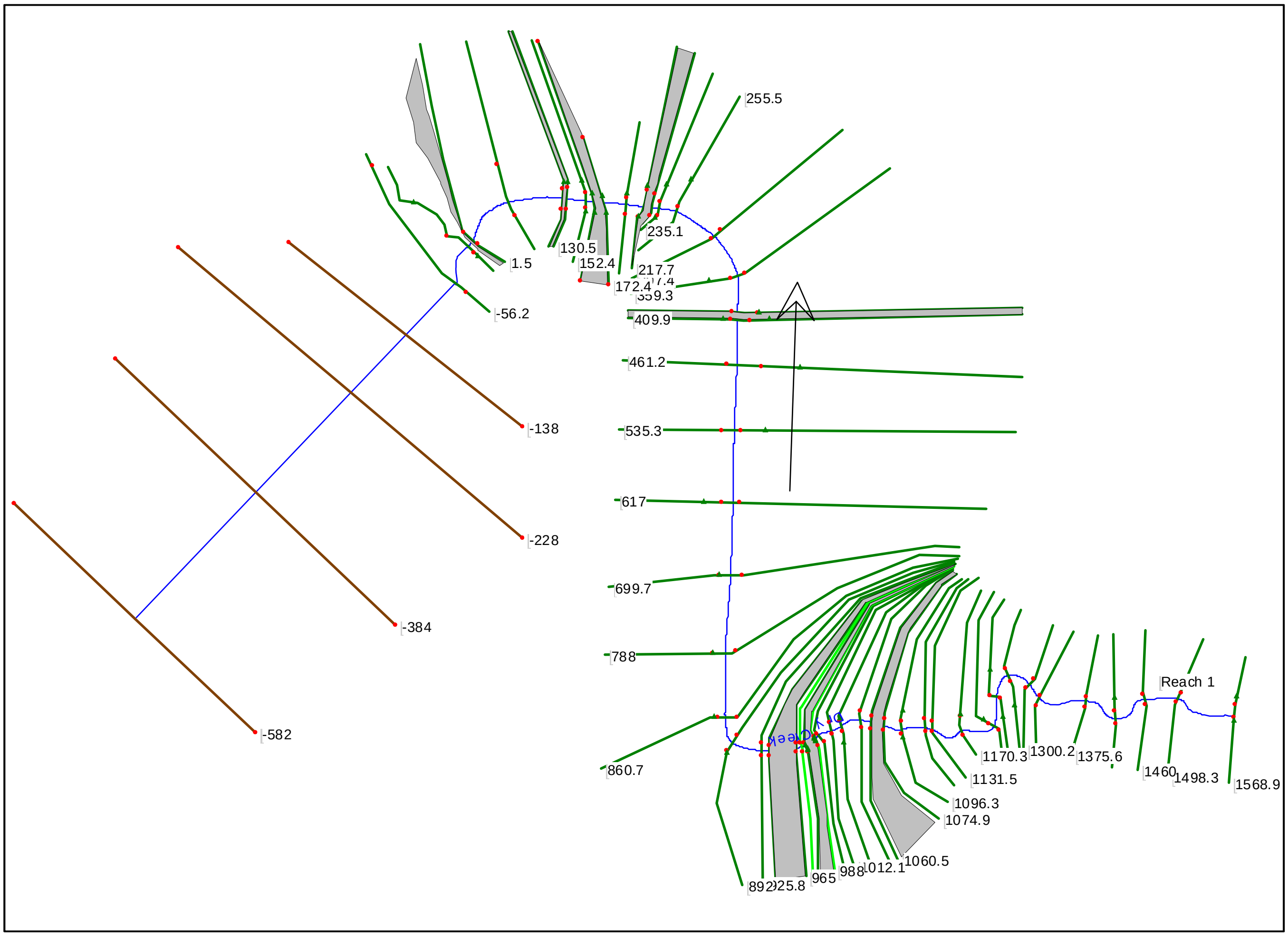

Figure 4. Numerical model schematic.

The Manning's 'n' roughness coefficients used in the model ranged from 0.04 above Station 892 to 0.022 at the Alberni Inlet. Overbank 'n' values were 0.1. Ineffective flow areas were set based on observations from the site visits and from air photo interpretations. A model sensitivity analysis was carried out for varying tailwater (tide) elevations, and varying flows.

4.1 Base Case Results

Figure 5 shows the computed flood profiles for the 2-year, 25-year and 200-year flood condition. The starting ocean level was set to el. 2.5 m CGD for all runs. The horizontal distances on the graph correspond to the cross section station values which correspond to cumulative channel distances starting at Station 0 (Conveyor structure at the mouth of the river). The model extends out into the ocean a further 582 m. However, these ocean sections are not included in the plot. The graph shows that during high flood flows (greater than the 25-year flood) the level of the ocean governs flood conditions up to about Station 800 m. Further upstream, the water levels are governed mainly by the discharge in the creek.

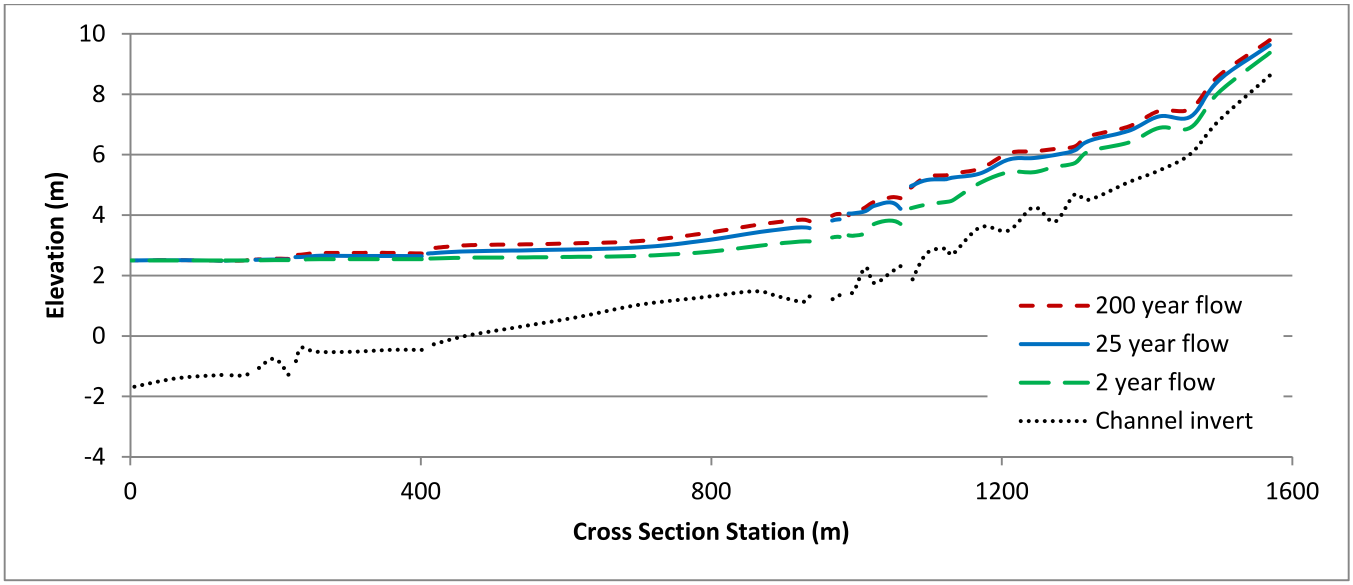

Figure 5. Computed water surface profiles for three flood discharges; ocean level is el. 2.5 m CGD

The effect of flow constrictions at the bridges at Station 408, 965, 988 and 1072 can be seen on the profiles. Figure 6 shows the estimated mean channel velocity along the creek at the 200-year flood. The low velocity in the tidally affected reach reflects the effect of running the model for a high tide condition; the velocities would be much greater in the lower reach during an ebbing tide. The velocity remained relatively low through to Station 965 (3rd Avenue Bridge), but reaches up to 3.72 m/s at Station 1060.5, just below the 4th Avenue Bridge.

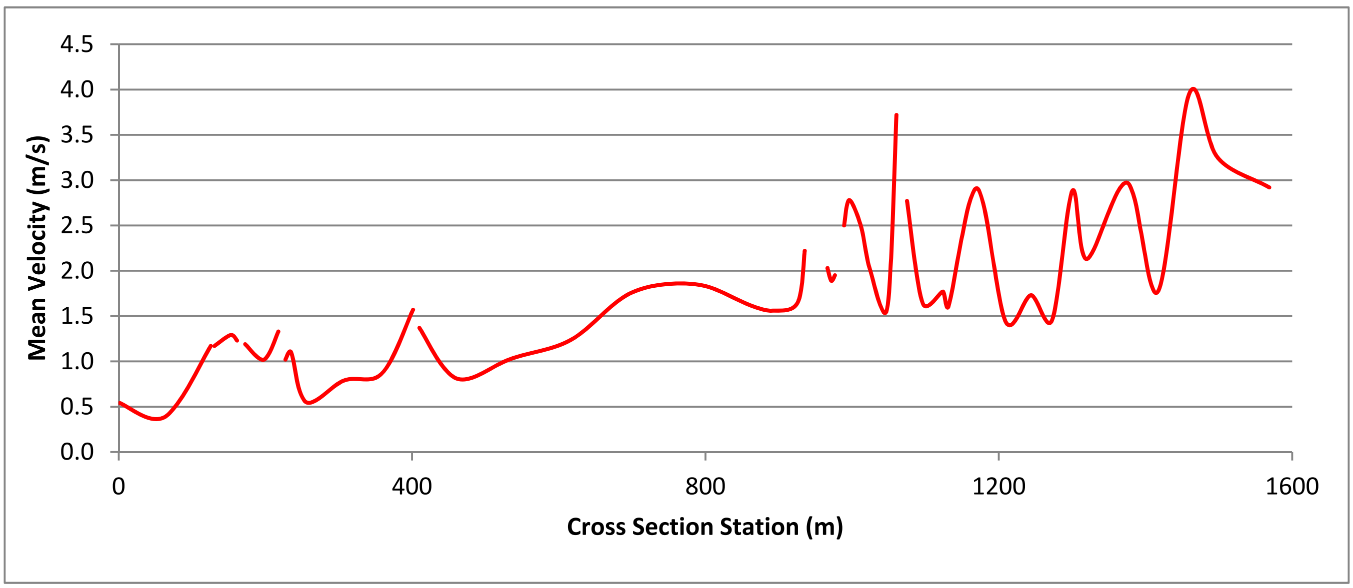

Figure 6. Estimated mean velocity along Dry Creek at a 200-year flood condition

Above Station 1000 m, the velocities fluctuate considerably, reaching up to 4.0 m/s. Velocities of greater than 3.5 m/s are expected to create significant channel erosion and may represent localized flow constrictions or anomalous cross section surveys.

4.2 SENSITIVITY ANALYSIS – VARYING OCEAN LEVEL

The starting water level for the base case run was set to el. 2.5 m CGD, which is the highest recorded ocean level in Alberni Inlet. A sensitivity run was made changing the ocean level to el. 1.2 m CGD (Higher High Water Mean Tide).

Figure 7 shows that the effect of a 1.2 m change in ocean level along Dry Creek for two different discharges. The 1.2 m change in ocean level induced a 0.8 m change in creek level at the bridge near Station 408 during a 100 year flood. The influence of the 1.2 m change in tide levels did not extend past about Station 900 (downstream of 3rd Avenue Bridge near Station 965) at high flows.

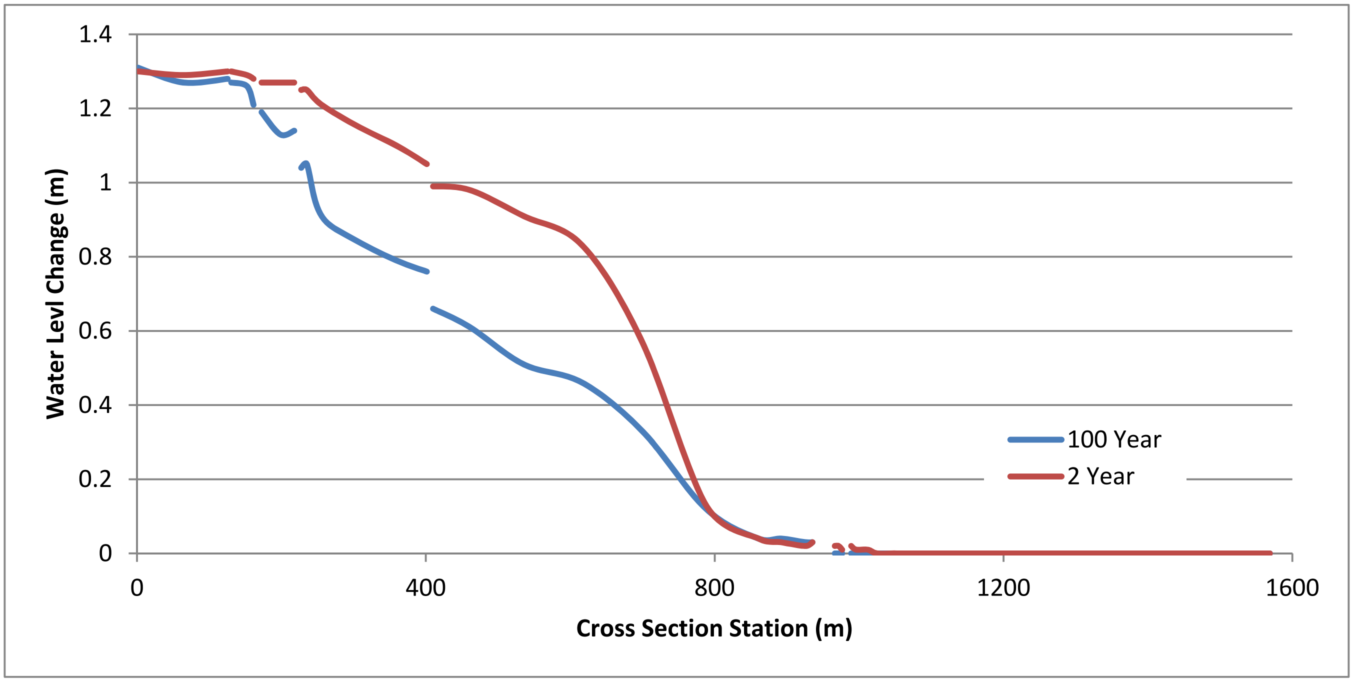

Figure 7. Effect of varying ocean levels on computed water levels

4.3 SENSITIVITY ANALYSIS – VARYING DISCHARGE

A sensitivity analysis was made by keeping the ocean level fixed at el. 2.5 m (highest observed level) and varying the discharge from 18 m^3/s (2-year flood) to 44 m^3/s (200-year flood). The effect of increasing the flood discharge above the 2-year flood discharge is illustrated below in Figure 8. The plot shows the water level is insensitive to discharges downstream of the bridge near Station 400. Upstream of about Station 800, the effect of discharge is much more significant. For example, near the 4th Avenue Bridge, the water level during a 200-year flood is 0.80 to 1.0 m higher than at a 2-year flood. Further upstream, the difference reduces to 0.5 m to 0.6 m.

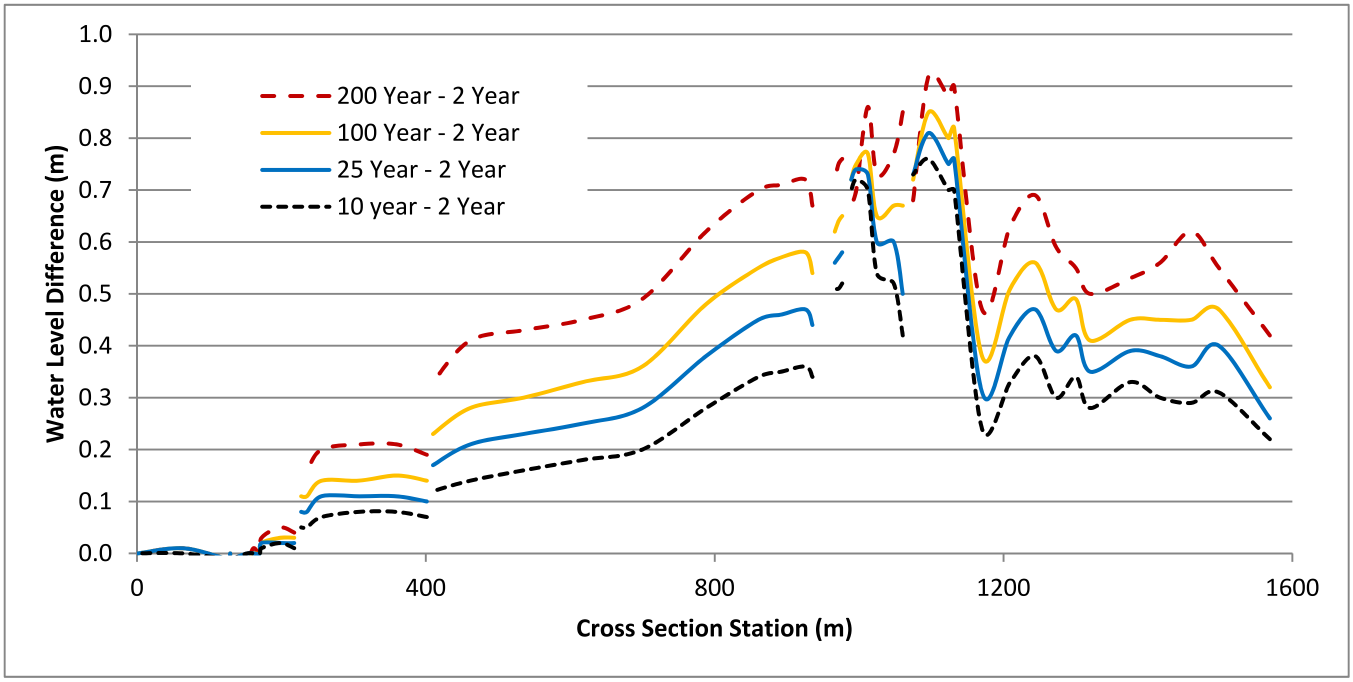

Figure 8. Effect of varying discharge on water levels

4.4 Calibration, Validation and Verification

Calibration forms an important part of model development. Calibration involves fine-tuning parameters such as channel/floodplain roughness and expansion/contraction coefficients to ensure that simulated water levels correspond to a particular flood event with estimated flows and ocean levels. The model accuracy is influenced by the magnitude of the flows used for calibration and validation compared to the adopted design flow. At flow well outside the calibration/validation range, the accuracy of the model is difficult to assess.

Model validation involves using the calibrated model to simulate a second independent flood event and comparing the computed values with observed flood extents and flood depths. A good agreement during the model validation increases confidence in the model's ability to simulate other unknown conditions.

The most recent significant flood in the area occurred in 2006. Flood extents/levels are available for that event, however, a culvert crossing on the pulp and paper mill property was severely damaged during the 2006 event, and was subsequently removed completely (Photo 11). Post-2006 calibration/validation data was not available for this study.

Photo 11. The flood on November 15, 2006 caused extensive flooding on the 3rd Avenue area.

When inadequate calibration and validation data is available, the model can be verified against observed water levels. Once the model has been calibrated and validated or verified, the model can be used to test for a range of flow conditions including the 200-year flood, although the model accuracy for the design event is difficult to assess.

Flood flows during the 2012/13 winter were not high. The water level recorders at 3rd and 4th Avenues recorded several relatively insignificant flow events. Manual flow measurements were not conducted during the hydrograph peaks.

The model was used to back-check the flows. Peak flows in Dry Creek between October 20, 2012 to February 20, 2013 were in the range of 6 m^3/s. For a 6 m^3/s flow, the modelled water levels immediately upstream of 4th Avenue at Station 1074.9 and immediately downstream of 3rd Avenue at Station 935.4 were compared to the measurements from the water level recorders; results are shown in Table 5.

Table 5. Comparison of water levels predicted by the model to measured water levels for 6 m^3/s

Location	Model Prediction (m)	Measured (m)
Upstream of 4th Avenue	3.37	3.43
Downstream of 3rd Avenue	2.49	2.39

4.5 EXISTING STRUCTURE CAPACITY

Table 6 summarizes the clearance and capacity of some of the existing bridges. All of these bridges surcharge at relatively low discharges (2-year to 10-year return period). Road bridges in British Columbia commonly are designed to have a clearance of 1.5 m during a 200-year flood. The structures would need to be raised by between 1.6 m and 1.97 m (without channel improvements or bridge lengthening) to meet this requirement.

Table 6: Clearance at existing bridges

Bridge	Cross Section Station (m)	Minimum Clearance for 200-Year Flood (m)	Comment
Railway Bridge	226.5	-0.10	Surcharges at 2-year flood
Bute Street Rail	408	-0.47	Surcharges at 2-year flood
3^{rd} Avenue	965	-0.40	Surcharges at 10-year flood
Restaurant	988	-0.10	Surcharges at 10-year flood
4^{th} Avenue	1072	-0.26	Surcharges at 5-year flood

5 FLOOD MITIGATION OPTIONS

5.1 GENERAL APPROACH

Three flood mitigation options were developed through discussion at meetings with the City and Koers. The options were developed using practical civil engineering practice and realistic project budgets in mind. Flood protection options such as floodproofing the area with bulk fill, diking, and/or abandoning the area for development were not extensively considered due to high costs and disruption to current land use (e.g. the flood-prone areas are already extensively developed).

The concepts that were shortlisted for this study were based on projects that are similar to other successful flood mitigation strategies in the region. The analysed options include:

- Option 1: Napier Street Diversion
- Option 2: Bridge Improvements
- Option 3: Bridge and Channel Improvements

For all options the dead end railway crossing west of Bute Street at Station 408 (Bute Street Rail Bridge) was removed. The crossing creates about 0.10 m of hydraulic losses for the 200-year flood. The structure appears to be unused and is falling into disrepair.

5.2 OPTION 1: NAPIER STREET DIVERSION

Option 1 is a diversion pipe from the creek channel at Station 1209.3, running underground and discharging at Station 788. The flow split values were determined by restricting the channel flow to the capacity of the existing structures without surcharging; all additional flow is diverted. The maximum creek channel flow is 24 m^3/s which requires the bypass to convey 20 m^3/s for a 200-year flood. The 24 m^3/s flow in the creek does not provide recommended freeboard at the structures.

Conceptually, for this option a concrete trimming weir would be constructed in the creek to divert flow into a pipe buried under Napier Street. Dry Creek would require a flow constriction immediately downstream of the diversion weir to modulate peak floods. The infrastructure would be configured such that low and moderate flows would be concentrated in the creek channel, and only peak flood flows would be diverted. The diverted flow would join Dry Creek at the west end of Napier Street.

Summary:

- Bute Street Rail Bridge: removed.
- Diversion flow of 20 m^3/s at Station 1209.3; re-joins at Station 788.

5.3 OPTION 2: BRIDGE IMPROVEMENTS

For Option 2, the 3rd Avenue crossing would be improved by adding a single additional box culvert with dimensions of 3 m wide by 2.5 m high.

The Restaurant Bridge would be removed and the creek banks would be graded to form a smoother hydraulic transition with the downstream 3rd Avenue crossing. Note that a series of runs were made to assess the effect of altering the 3rd Avenue Bridge dimensions. It was shown that the water levels for the 200-year flood are not very sensitive to the size of the bridge opening.

The 4th Avenue crossing width is currently approximately 6 m wide between the left and right abutments and the low bridge deck chord is at elevation 4.7 m. In this option the bridge was widened with a clear span structure, and the low bridge deck chord was raised above the 200-year water surface. The alignment of the abutments was improved to lower the hydraulic losses at the structure.

Summary:

- Bute Street Rail Bridge: removed.
- 3rd Avenue crossing: add 3 m wide by 2.5 m high box culvert.
- Section 966.4: widened the base towards right and set the bank slope at 2:1.
- Section 971.5: widened base towards right and set the right bank slope at 2:1.
- Restaurant Bridge: removed and graded the banks.
- Section 976.6: deleted the ineffective flow area, widened base towards right and set bank slope at 2:1.
- 4th Avenue crossing: replaced existing crossing with a 15 m span with low chord at 5.5 m and top chord at 6.0 m.

5.4 OPTION 3: BRIDGE AND CHANNEL IMPROVEMENTS

Option 3 is similar to Option 2 except that the channel is graded from the Bute Street Rail Bridge up to the 4th Avenue Bridge. The channel is lowered and widened to increase the potential hydraulic capacity.

Summary:

- Bute Street Rail Bridge: removed.
- 3rd Avenue crossing: added 3 m wide by 2.5 m high box culvert.

- Restaurant Bridge: Removed.
- 4th Avenue crossing: Replace with a 15 m span with low chord at 5 m and top chord at 5.5 m.
- Graded the channel lower and wider (12 m base width with 1.5:1 side slope) from Station 461.2 to Station 1072. The invert at the downstream end is -0.47 m and the channel grade was 0.314%.

5.5 RESULTS AND DISCUSSION

A comparison of the water levels for each option is shown in Figure 9 and a tabular summary of the water level changes is provided in Table 7.

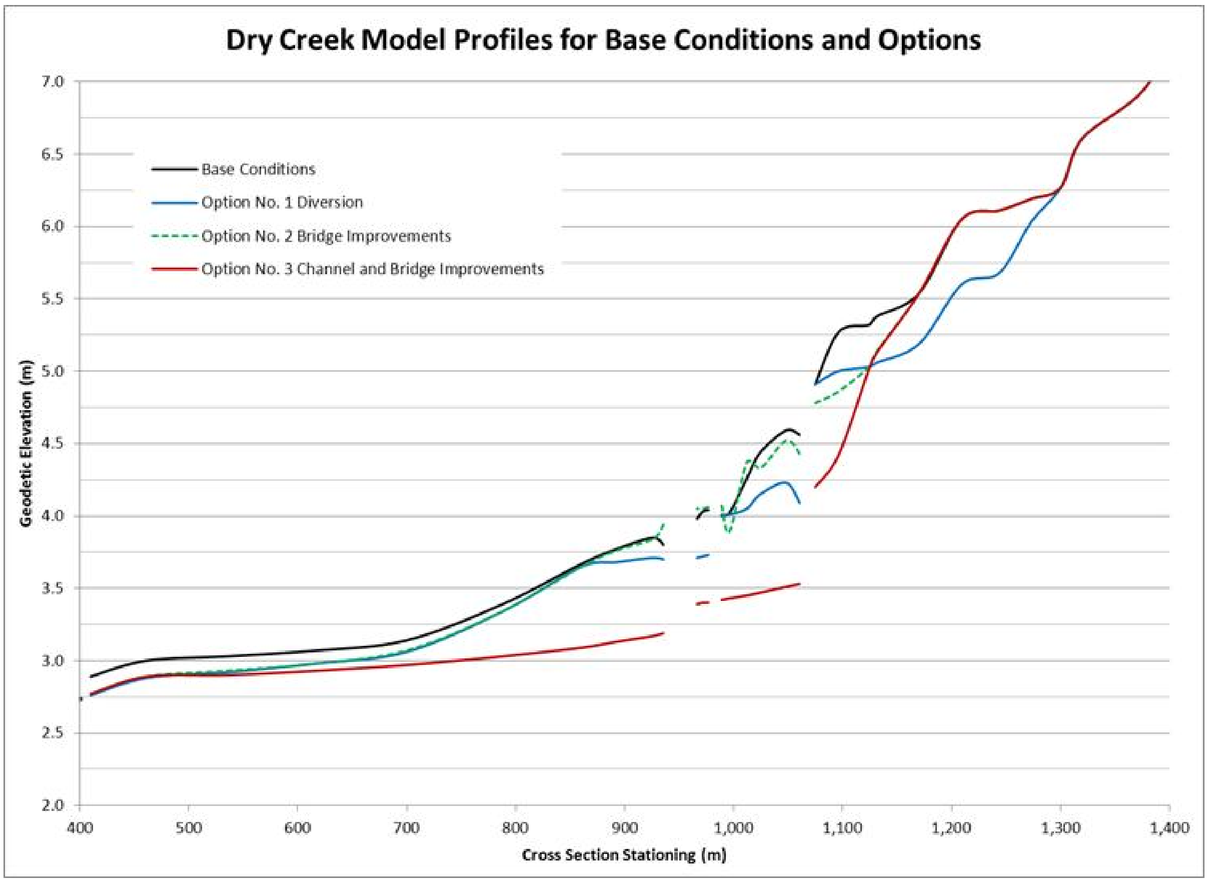

Figure 9: Flood profile of base conditions and 3 options

The most complicated project from a hydrotechnical perspective is Option 1. Some potential challenges with the project include: balancing the flow split between the creek and the diversion pipe to match design targets; minimising hydraulic losses at the inlet and outlet of the diversion; and handing trash, wood debris and sediment effectively. Environmental issues related to the diversion would also need to be addressed.

Option 2 lowered the flood levels upstream of 4th Avenue but had minimal benefits downstream of 4th Avenue.

Option 3 lowered the flood levels the most compared to the other two options. In addition, Option 3 carries fewer hydrotechnical unknowns, and thus is a lower risk project compared to Option 1.

Table 7. Summary of water level changes for each option. A positive value indicates a lower water level for the flood mitigation option.

Station (m)	Bridge Name	Base - Option 1 (m)	Base - Option 2 (m)	Base - Option 3 (m)
1300.2		0	0	0
1272.9		0.16	0	0
1243.9		0.43	0	0
1209.3		0.45	0	0
1170.3		0.35	0	0
1131.5		0.32	0.24	0.25
1123.9		0.29	0.29	0.31
1096.3		0.27	0.41	0.85
1074.9		0	0.13	0.71
1072	4th Avenue			
1060.5		0.47	0.13	1.03
1048		0.36	0.07	1.08
1024.5		0.29	0.11	0.97
1012.1		0.21	-0.11	0.81
996.1		0.01	0.13	0.59
989.085		-0.01	-0.07	0.58
988	Restaurant			
976.6		0.31	-0.02	0.64

Station (m)	Bridge Name	Base - Option 1 (m)	Base - Option 2 (m)	Base - Option 3 (m)
971.5		0.31	-0.02	0.63
966.4		0.27	-0.07	0.59
965	3rd Avenue			
935.4		0.1	-0.14	0.61
925.8		0.14	0.01	0.68
892		0.09	0.01	0.64
860.7		0.02	0.02	0.58
788		0.05	0.05	0.36
699.7		0.08	0.07	0.17
617		0.09	0.09	0.14
535.3		0.11	0.1	0.13
461.2		0.12	0.11	0.11
409.9		0.13	0.12	0.12
408	Bute Street Rail			

6 Conclusions And Recommendations

1. It is recommended that the model be calibrated and verified at higher flows than were observed in 2012/2013. If post-2006 historical flood limits cannot be identified to calibrate the model then one method that could be used is to measure the flow and stage at various cross sections during a significant flood in 2013/14.

2. Of the three options that were modelled, Option 3 appears to be the most effective in reducing flood levels. Compared to the other two options it provided the greatest lowering of water levels. Also, it has fewer hydrotechnical uncertainties compared to Option 1.

3. Additional modelling is required for detailed design of the selected option. Example optimizations include channel dimensions, final channel and bank grades, bridge deck heights, and others.

4. Extensive diking and bridge deck elevating is required to establish a freeboard of 0.5 m (secondary bridges) to 1.5 m (primary bridges). It is unlikely that the project will meet these targets. Therefore, it is recommended that an increased monitoring program be implemented during flood events to identify potential emergencies (i.e. blocked bridge openings).

5. All of the options summarized in this report will likely impact private property. It is recommended to layout the project concepts on a map that shows legal boundaries to identify land parcels that may be affected. For example, in Options 2 and 3 the restaurant property would have to be acquired. .

6. Fish habitat mitigation and compensation will be required as part of the environmental permit approval process. A partial list of potential projects include: refuge ponds, riparian vegetation enhancements, setback allowances, wood and boulder fish habitat features, and clear span bridges.

7. A scour and erosion assessment is recommended. Right bank grades downstream of 3rd Avenue appeared over-steep in areas. Other areas that are typically susceptible to erosion are on the outside of bends and at bridges. Erosion protection may be required.

8. It would be useful to re-run the model with a climate change scenario (e.g. +0.5 m for 50 years in 2060 and +1.0 m for 2110 conditions). It is outside the scope of this study to determine the coastal flood construction level (FCL).

9. All options presented in this report would benefit from a sediment management plan. Conceptually, the plan may include a sediment trap several hundred metres upstream of 4th Avenue. The trap would require periodic excavation to maintain its effectiveness.