# COWICHAN VALLEY NOVEMBER 2009 FLOODING – DOCUMENTATION AND ASSESSMENT

## FINAL REPORT

MUNICIPALITY of North COWICHAN

nhc
northwest hydraulic consultants
water resource specialists

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# 1 INTRODUCTION

## 1.1 EVENT SUMMARY

In late November 2009, a series of frontal systems hit coastal British Columbia. Flood warnings were issued across Vancouver Island as several rivers experienced very high flows. The worst flooding occurred in the Cowichan Valley on Friday, November 20. Following more than a week of rain, the Cowichan and Koksilah Rivers and several creeks overflowed their banks. Over 50 home were flooded in North Cowichan and the City of Duncan; dozens of homes were flooded "up to the doorknobs". Residents were evacuated, roads and schools were flooded and closed, and property damage was extensive. Between November 15 and 26, the MNC raised dikes and filled gaps and low spots in certain critical areas near the flooded areas around Lakes Road.

## 1.2 INTEGRATED FLOOD HAZARD MANAGEMENT PLAN

In 2008, Northwest Hydraulic Consultants (NHC) was retained by the Cowichan Valley Regional District (CVRD), in partnership with Cowichan Tribes, the City of Duncan and the Municipality of North Cowichan (MNC) to update existing floodplain mapping and to develop an Integrated Flood Management Plan (IFMP) for the Lower Cowichan-Koksilah River floodplain, including major tributaries. This study was completed in September 2009 and included the development of a flood model and floodplain mapping. Beyond the technical tools, this plan promoted an integrated approach to flood management with the goal of "reducing risk to all communities on the floodplain, while protecting aquatic and riparian habitat and addressing the cultural values of the river". Ten planning strategies were developed to support the project goals, and over twenty priority and long-term actions were recommended. Of particular relevance to this project, was the recommendation that the lagoons dikes be upgraded and that a new dike be constructed along Lakes Road as a priority project.

## 1.3 PURPOSE OF EVENT ASSESSMENT

On November 26th, 2009 Northwest Hydraulic Consultants (NHC) was retained to complete an assessment of the November 20th flooding event. The assessment includes data collection and surveying of high water marks, running of the previously developed MIKEFlood model to simulate the 2009 flood, assessing the value of the temporary "no-post" barrier instalment on Lakes Road, and to provide recommendations based on the assessment. This report outlines our methodology and findings.

# 2 DATA COLLECTION

A comprehensive data collection effort was made that involved collecting primary and secondary source data. The data collection methodology and results are outlined in this chapter.

## 2.1 PHOTO AND VIDEO RECORDS

On November 20, 2009, NHC personnel visited the affected area and took photos around the peak of the flood. Photos and video footage collected on or shortly after the flood event were mainly supplied to NHC by the relevant jurisdictions. Media coverage was in depth; photos as well as twenty minutes of overflight video from CTV news were obtained online. A complete summary of photos and video footage is presented in Table 2-1.

**Table 2-1: Summary of photo and video records used in for analysis**

| Source | Type | Date of Coverage | Area of Coverage |
|---|---|---|---|
| Brad Rushton, DFO | Overflight photos | Nov-2009 | Cowichan River, Koksilah River |
| Times Colonist | Ground and overflight photos | 16-Nov-2009, 20-Nov-2009 | Cowichan River, Somenos River |
| MNC | Ground photos and video | 17-Nov, 18-Nov, 20-Nov, 24-Nov, 26-Nov, 27-Nov | JUB Lagoons |
| CBC | Ground photos | 20-Nov-2009 | Cowichan River, Somenos River |
| CTV | Ground photos, overflight photos and video | 20-Nov-2009 | Cowichan River, Somenos River, Somenos Lake |
| NHC | Ground photos | 20-Nov-2009 | Cowichan River, Somenos River |
| MNC and/or CVRD | Helicopter Flight Video | 21-Nov-2009 | Cowichan River |
| MNC and/or CVRD | Overflight photos | 21-Nov-2009 | Cowichan River, Somenos River, Somenos Lake |
| MNC and/or CVRD | Helicopter Flight Video | 26-Nov-2009 | Cowichan, Koksilah and Somenos Rivers |
| MNC and/or CVRD | Helicopter Flight Photos | 26-Nov-2009 | Cowichan, Koksilah and Somenos Rivers |

## 2.2 Climate and Hydrology Data

Climate data from nearby Environment Canada stations was collected to aid in the analysis. These included:

| | |
|---|---|
| Duncan Glenora (1022571) | Elevation 84 m |
| Duncan Kelvin Creek (1012573) | Elevation 103 m |
| North Cowichan (1015630) | Elevation 60 m |

The Water Survey of Canada provided hourly flow data for two stations:

Cowichan Lake near Lake Cowichan (08HA009)

Cowichan River near Duncan (08HA011)

Daily data, with some peak flows was also provided for:

Koksilah River at Cowichan Station (08HA033)

Unfortunately, WSC had not processed the records for the tributary gauge to the Somenos:

Bing's Creek (08HA016)

The WSC also provided updated rating curve information for the Cowichan River gauge, including information from a flow survey that was conducted on November $20^{th}$, 2010.

## 2.3 Survey

NHC and MNC staff surveyed high water marks on the Cowichan River, Somenos Creek and Koksilah River during the period of December 2 – 9, 2009. The key areas that were covered included:

- Cowichan River near JUB Lagoon,
- Lee Street – Fish Gut Alley (Rotary Channel)
- Somenos Creek, Lakes Road – Beverly Street
- Holmes Creek – RCMP Detachment
- Lower Cowichan River (Pimbury Bridge and Tooshley Island Dike)

Locations of major log jams on the Cowichan River were also recorded. The information is plotted on the attached base map (Map 1). The MNC constructed a temporary "no-post" barrier along portions of Lakes Road. Information on the elevation of the concrete barrier was supplied by the MNC in the form of a survey plan (2009 Flood Plan.pdf).

# 3 CLIMATE AND HYDROLOGY

## 3.1 CLIMATE

In late November 2009, a series of frontal systems hit coastal British Columbia. Flood warnings were issued across Vancouver Island as several rivers experienced very high flows. Average daily precipitation from the three low elevation gauges within the Cowichan/Koksilah watersheds are presented in Figure 4.1. Mean daily temperature is also presented. Significant rainfall amounts were observed on November 15th, 16th, 18th and 19th. The high rainfall amounts in combination with snowmelt from high temperatures and rain-on-snow resulted in significant flow volumes in the Cowichan and Koksilah rivers and their tributaries. The temperature in the valley peaked at 11.3 ° C on November 15th, with higher than seasonal temperatures lasting until the end of the month.

## 3.2 HYDROLOGY

Flow hydrographs in addition to basic climate information for the ten days around the November 20th event are presented in Figure 4.1. These discharges were provided by the WSC for this reporting; however they have not been officially adopted, are subject to review and are considered preliminary.

The gauge at Cowichan River Near Duncan (08HA011) showed a peak discharge of 420 $m^3/s$ at 07:00 PST on November 20. At 12:07 PST, discharge was measured manually at 407.4 $m^3/s$. The discharge dropped gradually over the next couple of days, with a lower peak at 330 $m^3/s$ on Sunday, November 22. The peak earlier in the week, before the heavy rains, was 395 $m^3/s$ on November 17.

A discharge measurement around noon showed the rating curve underestimated the discharge (407 $m^3/s$ measured versus 367 $m^3/s$ from the rating curve). Therefore, it is likely the estimated peak discharge of 420 $m^3/s$ was also under-predicted and a more realistic estimate of the peak discharge is approximately 460 $m^3/s$. Pending WSC's final published estimate, we have used their preliminary data for modelling and assessment.

The WSC gauge on the Koksilah River (08HA003) showed a peak discharge of 219 $m^3/s$ at 05:10 on the 17th – three days before the Cowichan River peak. On the 20th at 03:00 the flow was recorded to be 214 $m^3/s$. No significant increase in flow was observed on 22nd. Similar to the Cowichan River gauge, the discharge dropped gradually over the next few days.

Unfortunately, WSC had not processed the records for the tributary gauge to the Somenos – 08HA016 Bings Creek. This data, once processed, will be valuable in assessing the impact of local inflows to the Somenos system.

## 3.3 OCEAN LEVEL

There is no tide gauge in Cowichan Bay to measure actual water levels. However, the Canadian Hydrographic Service provided NHC with adjusted tide levels for Cowichan Bay[1]. The adjusted tide levels are based on the predicted tide levels and include a storm surge adjustment based on measured storm surges at nearby stations. Tide levels from CHS are presented in Figure 3.1. The recorded high tide at Cowichan Bay on November 20 was 1.9 m GSC at 09:00 PST.

## 3.4 HISTORICAL CONTEXT

Figure 3.2 compares hydrographs from floods in November 2009, December 2007 and November 2006. The 2009 flood was higher in magnitude and had a longer duration than either of these recent events. Table 3.1 summarizes other historic floods on the Cowichan and compares the 5-day precipitation totals (at Duncan) and peak discharges. The total rainfall volume in 2009 was considerably higher than in previous years. The 2009 instantaneous maximum discharge was the highest since 1986 (virtually identical) and only the record flood of 1961 was significantly higher in magnitude (558 $m^3/s$). However, a flood frequency analysis indicated the 2009 flood event was not particularly severe, having a return period of approximately 7 years (based on instantaneous maximum discharges). By comparison, the 25-year and 200-year instantaneous flood discharges are 572 $m^3/s$ and 703 $m^3/s$ respectively (NHC, 2009).

**Table 3.1: Historic flood events on Cowichan River**

| Flood Event | 5-Day Precipitation (mm) | Peak Discharge ($m^3/s$) |
|---|---|---|
| Nov 2009 | 268 | 460 (estimate) |
| Dec 2007 | 164 | 411 |
| Nov 2006 | 176 | 426 |
| Jan 1986 | 114 | 447 (estimate) |
| Dec 1980 | 155 | 425 |
| Jan 1961 | 136 | 558 |

The adjusted tide level of 1.7 m GSC is not particularly high in comparison to extreme tides. For example, the 25-year and 200-year extreme ocean levels in Cowichan Bay were estimated to be 2.3 m and 2.5 m (without freeboard) respectively in NHC (2009).

[1] Referred to as pseudo tide levels by CHS.

# 4 MAPPING

## 4.1 METHODOLOGY

Flood extents were delineated and mapped using ArcGIS software based on photos and overflight video footage taken from November 16 - 26, 2009 (Map 1). The nature of the information was summarized in Table 2.1.

Information collected closest in time to the peak of flooding on Nov 20, 2009 was relied on more heavily for mapping purposes. Visual coverage of the flooding event was extensive in and around the City of Duncan, and as a result, mapping of flood extents is considered to be fairly accurate here. High water marks (HWMs) that were surveyed by NHC field personnel using a Real-Time Kinematic (RTK) GPS on December 2-4, 2009 were also used to supplement photo and video footage and assist in determination of flood extents.

There was insufficient data to map flooding along the Koksilah River, however, HWMs, where surveyed, are shown on the map. Flooding of the Cowichan Tribes lands and in the Lower Cowichan River/Cowichan Bay area was also not well-documented, and approximate flood extents are represented by a dashed line on the map. Mapping of flood limits in the bay area was aided by elevation contour data, and modelling of high tides and discharge from the upper watershed.

## 4.2 DISCUSSION

Some observations in key areas:

- RCMP building/Holmes Creek
    - Observed high waters of 8.5 m
    - The parking lot at the RCMP building flooded as a result of backwatering of Holmes Creek upstream of the culvert
    - Although most of the flooding of Somenos Lake along the west side was contained by Highway 1, a short length of Highway 1 along the edge was overtopped.
- Lakes Road
    - Observed high waters of 7.8 m.
    - Floodwaters began flowing across Lakes Road on the morning of November 20$^{th}$. Soon after, a sandbag and tarp dike was constructed along the road, which stemmed further flow across the road. However, some water damage had already occurred at the time of the sandbag wall construction.
    - A temporary No Post Barrier was installed a few days later.

* JUB Lagoons
    * Observed high waters of 8.5 m
    * High water levels within the lagoon and along the Cowichan River resulted in overtopping of the JUB Lagoon dike along the southeast section.  Although the water surface profile was level along a section normal to the dike, the direction of flow is not certain.
    * The Cowichan River dike does not connect with the JUB Lagoon Dike, i.e. there is a gap between the two dikes.  However, no water was observed flowing from the Cowichan River to the residential neighbourhood on the landward side of the dike.  Water ponded in the area bounded by Lakes Road, the JUB Lagoon Dike and the Cowichan River Dike.  A leaky storm sewer pipe that drains water from the City of Duncan Public Works Yard and flows into the Cowichan River after passing under the Cowichan River dike may be responsible for the ponding.
* Rotary Creek /Fish-gut alley
    * Observed high waters of 8.8 m
    * Fish-gut alley refers to a side channel of the Cowichan River, which is bounded on the north and south by two sports fields and discharges south of the hatchery.
    * Flooding along fish-gut alley prompted emergency sandbags to be installed along Lee St. residents' rear property line.  This sandbag wall is now known as Lee Dike.

# 5 NUMERICAL MODELLING

A hydrodynamic model was developed in 2008 as part of the Cowichan Valley Integrated Flood Management Plan. The model uses the software package MIKE Flood, developed by the Danish Hydraulic Institute (DHI). This program consists of a combination of one-dimensional (MIKE11) and two-dimensional (MIKE21) numerical models. MIKE Flood is ideal for riverine and coastal flood mapping since it allows the application of appropriate spatial resolution by modelling narrow rivers using one-dimensional solvers whereas overland flow is modelled using two spatial dimensions.

MIKE11 is used for representing the confined sections of the river channels where the flow remains below bankfull stage. The model can simulate water levels, discharges, and mean velocities in the branched network of channels that form the entire Cowichan/Koksilah River system and its tributaries. The model also simulates tidal effects in the lower reaches and unsteady flow variations during flood events.

The MIKE21 model simulates the water depth and flow across the floodplain in two spatial dimensions, which provides a means for representing the direction and magnitude of velocities in a grid over the entire floodplain surface. All values are "depth-averaged", which is appropriate for the relatively shallow flows that that occur on the floodplain.

The two models are seamlessly connected using the overarching MIKE Flood software. The MIKE Flood links are established along the top of banks or dike crests through a series of weir equations that connect a MIKE21 grid cell with the nearest MIKE11 channel station. Once the link is established, MIKE Flood tracks the water surface elevations in both MIKE11 and MIKE21. If either model overtops the elevation of the connection point, water is transferred from one model domain into the other.

## 5.1 MODEL DEVELOPMENT

The MIKEFlood model includes the Cowichan River from upstream of the Allenby Bridge down to Cowichan Bay. The model also includes the Koksilah River, Somenos Creek and Somenos Lake. As part of the 2008 IFMP, the model was tested, calibrated and verified using available field measurements. This same model was used to simulate the recent November 2009 flood event. Dikes included in the model reflect as much as possible the elevations and condition of the structures at the time of the November 2009 flood. More detailed information on the model is included in the 2009 IFMP report (Volume 2 – Technical Investigations).

## 5.2 MODEL BOUNDARY CONDITIONS

The boundary conditions for the MIKE11 model consist of upstream inflow boundaries and downstream water level boundaries. The following boundary conditions were specified for the simulation of the November 2009 flood. Further details are provided in Section 3 of this report.

- **Inflow at upstream ends:**

  Inflows for the Cowichan River were based on hourly discharges from WSC's Cowichan River near Duncan (08HA011) gauge. Inflows for the Koksilah River were daily flows from WSC's Koksilah River at Cowichan Station (08HA003) gauge. Inflow hydrographs are plotted in Figure 3.1.

- **Tributary inflows:**

  Discharges for the main tributaries (Kelvin Creek, Glenora Creek, Bing's Creek, Averyll Creek, Richards Creek, Quamichan Creek, unnamed tributary and Tzouhalem Creek) were included as point sources and are based on 25-year flows (Figure 5.1) obtained from the hydrology analysis for ungauged tributaries completed as part of the Cowichan Valley IFMP (Volume 2 – Technical Investigations). 25-year flows were used in the absence of better data; when the Bing's Creek gauge data becomes available, this assumption should be reviewed.

- **Tidal water levels:**

  Levels in Cowichan Bay at the mouth of the South and North branches of the Cowichan River were based on pseudo water levels time series provided by CHS for Cowichan Bay (Station #7310). The pseudo-observed tide levels (Figure 3.1) include a storm surge adjustment based on measured values at nearby stations.

## 5.3 Model Results

The model computes water levels in the river channels and outputs flood extents and water depths on the floodplain. These model outputs were compared with surveyed HWMs and observed flood extents to assess the model's performance.

In general, the model results agreed well with surveyed and observed data. Longitudinal profiles comparing computed water levels and observed HWMs along the modelled reaches are plotted in Figures 5.2 to 5.5.

For the Cowichan River, the 2009 HWMs are generally higher than HWMs from the 2007 flood. Exceptions occur at the downstream tidally-influenced portion of the river and also along the Koksilah River, where flooding was more severe in 2007 than in 2009.

The modelled 2009 Cowichan and Somenos water surface profiles match or envelop the 2009 surveyed HWMs except along the portion of the Cowichan near the JUB lagoons (Figure 5.2) where modelled water levels are lower by more than 0.3 m and HWMs are closer to the modelled 25-year flood profile. The modelled Koksilah River water surface profile also exceeds the surveyed HWMs by more than 0.3 m. The comparison of surveyed and modelled levels is shown spatially in Figure

5.6, where discrepancies along the lower Koksilah River and on the Cowichan River near the lagoon are evident.

Figure 5.7 shows the computed extents of flooding overlain with the documented flood extents from photos and over flights. The figure shows good agreement between the model and observed flood extents. Discrepancies between the two occur due to ponding in isolated, low-lying areas since the model only computes riparian flooding from the main river channels.

Modelling results show that the crest of the "no-post" barrier is at the level of a 20-year flood. However, this does not mean that the barrier will protect against a 20-year flood.

## 5.4 Discussion

The MIKE Flood model was tested, calibrated and verified in 2008 using available field measurements, including observed high water marks from the 2007 flood. When the model was calibrated, no information was available to directly quantify the distribution of flow between the main channel and the floodplain during flood events. Standard hydraulic methods and experience were relied on to assign realistic roughness values for the floodplain. The simulation of the November 2009 flood confirms that the model is capable of predicting flood extents, water levels, and provides insights into the progression of floods in the Lower Cowichan Valley. The model performed exceptionally well, with modelled and observed lateral extents and high water levels matching extremely closely. The model should be seen as a valid and useful tool for flood management planning for the region.

The model does have limitations that need to be taken into consideration. First, the model assumes the river bed and banks are fixed. However, bank erosion, sedimentation and log jam formation can all occur during major floods and these processes can affect the local hydraulic conditions considerably. The differences (> - 0.3 m) between HWMs and computed water levels in the reach near the lagoon and the confluence with the Somenos can be attributed to changes in the channel bathymetry since the model's channel cross-sections were surveyed in 2008. Unfortunately, the model is already outdated in this dynamic and very important section of the Cowichan River.

Some minor differences between observed and modelled water levels can be attributed to dikes and structures which were represented in the model as accurately as possible and err on the conservative side. The crest elevations of Mission Road Dike, Tooshley Island Dike, and the upstream portion of the Hatchery Dike were smoothed out due to the resolution of the grid on the floodplain. The flood structure and gate near the mouth ofthe North Cowichan (see Figure 5.7) was not included in the model and results in the inundation of the land upstream of the flood gate. In the model, the crest elevations of the coastal dikes were averaged out since these structures do not meet the requirements of standard dikes.

It should be noted that the computed flood extents represent riparian flooding from the main river channels. The model is not intended for representing localised ponding on isolated, low-lying portions of the floodplain caused by the accumulation of rainwater or melting snow. Localised ponding is controlled by rainfall intensity, local topography, drainage characteristics of the soil and the capacity of drainage structures such as culverts and ditches. Localised ponding was observed in Rotary Park, at the RCMP building, and in an isolated side channel on the right bank of the Cowichan immediately downstream of the Silver Bridge (Hwy1).

# 6 EVENT ASSESSMENT

The most serious flooding in November 2009 occurred along portions of Somenos Creek and in the vicinity of Lakes Road – Beverly Street. A review of the model output showed extreme tide levels in Cowichan Bay do not significantly affect flood levels in the mainstem of the Cowichan River (above the north and south branches) or in Somenos Creek. Therefore, the flooding experienced in November 2009 was not significantly affected by the tide. The mode of flooding was primarily related to elevated flows in the Cowichan and Somenos systems.

Photo 6-1: Cowichan River at Highway #1 bridge near peak flow on November 20th, 2009.

## 6.1 LAKES ROAD

Representative flood levels near the Lakes Road area were as follows:

- 2009 observed high water: 7.8 m
- 2009 modelled high water: 7.9 m
- 2007 modelled high water: 7.4 to 7.5 m
- 25-year modelled high water: 8.1 m
- 200-year modelled high water: 8.8 m

By comparison, the elevation of Lakes Road (edge of pavement) is generally at 7.5 m (based on survey plan *2009 Flood Plan.pdf*), so that much of Lakes Road was overtopped by up to 0.2 m during the November 2009 flood (Map 1) (flood depths in low-lying land behind the road were considerably greater).

The MNC installed an emergency flood wall along Lakes Road using concrete "no-post" barriers (Photo 6-2). The top elevation of the barriers varies between 8.2 and 8.4 m (described as "> 8.1 m" on survey plan *2009 Flood Plan.pdf.* The top of the barriers coincides closely to the estimated 25 year flood level (without freeboard) along Somenos Creek. We understand the emergency barrier is not intended as a permanent solution to the flooding problem but is intended to reduce the threat of a repetition of the November 2009 flood during the remaining flood season (peak flows have typically occurred between December and March). The barrier will mainly reduce the extent of flooding from water entering via Somenos Creek. It will not prevent inundation from flood water that enters through the mainstem of the Cowichan River (via JUB lagoon dikes or the present opening between the JUB Lagoons and the Cowichan Dike) or from internal flooding due to excess precipitation behind the dikes. Furthermore, in the event of a very extreme flood it may be necessary to open portions of the barrier to allow drainage out of the inundated areas, or to provide pump water over the barrier.


Photo 6-2: Construction of temporary no-post barrier on Lakes Road.

Photo 6-3 shows the pump station near Beverly Street on November 20th. The maximum water level in this location reached about 7.7 m. By comparison, NHC (2009) estimated the 200-year flood level (without freeboard) is approximately 8.8 m (just below the top of the railing).


Photo 6-3: Pump station near Beverly Street November 20, 2009

## 6.2 JUB LAGOONS

An inadequate dike currently separates the JUB lagoons from the Cowichan and Somenos Rivers. This is documented in the September 2009 IFMP reporting. The inadequacy of this dike was clearly shown on November 20th, when water was observed passing over the dike (Photo 6-4). Fully treated effluent from the lagoons flowed into the river (documented in video footage), and some river water is assumed to have passed into the lagoons. The failure of this diking system has serious implications to public and environmental health well-beyond simple structural damage resulting from floodwaters.

Photo 6-4: Overtopping of JUB Lagoon dike on November 20th, 2009.

## 6.3 RCMP Building

The parking lot at the RCMP building flooded as a result of backwatering of Holmes Creek upstream of the culvert and from high levels in Somenos Lake. Local flows into Holmes Creek are not known, however we estimate that they were greater than a 25-year event. The downstream bridge crossings at Canada Avenue and Highway #1 clearly do not have the capacity to convey this volume of flow, which results in the backwatering of the low-lying area around the RCMP building. It should be noted that the estimated 200-year flood level (without freeboard) is approximately 9.4 m in this area, while the main floor slab elevation is 8.8 m.

## 6.4 Lee Street

Flooding of properties along Lee Street was a result of conditions along Fish-gut alley/Rotary channel. This watercourse is a side channel of the Cowichan River that is bounded on the north and south by two sports fields and discharges south of the hatchery. Two culverts pass through Cowichan River dike near chainage 300 and 400 allowing water to drain from Rotary Park and flow into the Cowichan River.

A map of the storm network in the area was provided by the City of Duncan. There are two storm mains that discharge into Fish-gut alley. Assuming no spatial variation, and using the 5-day precipitation value of 268 mm across the fish-gut catchment area, the volume of rainfall being funnelled into the channel is about 226,000 $m^3$. As a conservative estimate, the fish-gut channel is only able to accommodate a volume of about 41,000 $m^3$. There was significantly more inflow during the November 2009 flood event than channel capacity for the water. This conclusion assumes no outflow over a five-day period, a scenario which is likely to have occurred given the high water levels on the river side of Cowichan River dike. The result of the analysis suggests that there was no seepage from the river side to the land side of the dike, which was previously thought to account for flooding in the area.

Photo 6-5: Lee St Sandbag Dike running through backyards.

# 7 RECOMMENDED ACTIONS

Given the severity of the damage incurred as a result of the November 2009 flood we have proposed several actions to mitigate future flood damage in the Somenos watershed. These actions are primarily based on the actions presented in the IFHMP, and are in line with the goals and strategies of the plan (Appendix B).

Each of the actions presented below should reduce flood hazard in specific regions of the Somenos watershed. However, it is important to note that each of these projects on their own will not protect everybody. And therefore, the priority projects listed below should be balanced against the mitigation and adaptation strategies presented in Section 7.2. Economic, social and environmental costs and benefits should be considered for each of the proposed projects early in project scoping and design; this will aid in the justification of the project to funding bodies.

## 7.1 PRIORITY ACTIONS

### *UPGRADE OF JUB LAGOON DIKE AND OUTFALL*

The updated hydraulic investigations indicate that a high priority should be given to upgrading the dikes at the JUB sewage lagoons and the adjoining Cowichan (City of Duncan) Dike. The need for upgrading protection at the JUB dike was identified previously (Willis Cunliffe and Tait 1992). However, due to a lack of funds and commitment from all stakeholders no action was taken. It is our understanding that consideration is being given to modifying the JUB sewage treatment facility, possibly even re-locating it. If the facility was moved, the existing JUB dikes would still need to be raised since they are lower than the Cowichan Dike. If the JUB treatment facility remains operational for several years or more, then the flood protection issue is more serious, since a failure of the lagoons during a flood would be very undesirable. In this case, we recommend upgrading the dike to a higher standard than a 200-year flood. The upgrading should include riprap erosion protection since there is a significant risk of the river avulsing into the side-channel (Fish Gut Alley) that runs along the toe of the dike. Furthermore, a design review of the plant operations during extreme flood conditions is needed to establish adequate freeboard for effluent storage in the lagoons.

Proposed upgrades to the JUB Sewage Lagoon dike will increase freeboard around the overall 1.1 km perimeter giving rise to an estimated 5 m horizontal displacement beyond the existing structure. As an added measure of flood protection 670 m x 5 m of rock armouring is proposed along the toe of the upgraded dike given the serious implication of failure for this dike. An estimated 6,700 m$^2$ of sensitive aquatic and riparian habitat associated with lower Fish Gut Alley channel may be altered depending on the design.

Class 'C' costs for the upgrade of the JUB lagoons dike were prepared by NHC for the Municipality of North Cowichan (NHC 2010). The estimated engineer cost for the upgrade of the JUB dike and outfall was $2.3 million.

### *LAKES ROAD DIKE AND BEVERLY STREET PUMP STATIONS*

The Lakes Road Dike was proposed in 1992 to protect residents in Duncan, the Municipality of North Cowichan and Cowichan Tribes from backwater flooding in Somenos Creek. Although pump stations and control structures were constructed to treat interior drainage, the dikes were not constructed and the land is still subject to potential backwater inundation. The total length of diking required is approximately 2,900 m, with the alignment following portions of Lakes Road and Beverly Street. Willis Cunliffe and Tait (1992) estimated the cost of the Somenos diking program was $712,000. The Willis Cunliffe and Tait study included constructing a large spur to deflect the Cowichan River southward in an attempt to restore its previous channel alignment. This re-location was intended to reduce flood levels at the mouth of Somenos Creek. At the time, this project was not supported by the Cowichan Tribes as there was some concern about the downstream impacts from the channel shift. Based on the results of the current investigation, this project would have created a wide range of impacts to habitat, river stability and river hydraulics. Therefore, the spur dike is not recommended at this stage.

The proposed location of Lakes Road dike is suitably set back from the active Somenos flood channel bisecting agricultural fields and more critical community infrastructure. In three locations the proposed dike alignment approaches moderately sensitive riparian habitat potentially encroaching an overall 415 m along its 2.8 km length. Cumulative ecological effects of the new dike are expected to be minor with mitigative measures in place.

Recommended measures to offset potentially adverse ecological effects include the utilization of bioengineering methods along low elevation portions of the dike encroaching into riparian habitat. While the control of tree species is required on dikes, proposed installations of live brush layering and live stakes using willow species is intended to provide additional slope stability and reasonably restore adjacent riparian habitat. Bioengineering installations increase long-term stability by reinforcing fill material and armouring as roots develop, adding significant resistance to sliding or shear displacement.

Class 'C' costs for the upgrade of Lakes Road Dike were prepared by NHC for the Municipality of North Cowichan (NHC 2010). The estimated engineering cost for the upgrade of the JUB dike and outfall was $3.0 million.

In addition to the dike upgrades, the capacity of the two existing Beverly Steet pump stations need to be assessed. The addition of a third pump station may be required.

It should be noted that if the Lakes Road dike were to be upgraded without also completing the upgrade of the JUB Lagoon dikes, there is a possibility that with a failure at the lagoons site (which was overtopped in November 2009) a new dike along Lakes Road could hold water and pond effluent on the lee side of the dike exacerbating flood damages.

### *CHANNEL MAINTENANCE PROGRAM*

An adaptive maintenance program or series of programs needs to be implemented to address the state of the existing dikes as well as the mainstem, side-channels and riparian zone of the Cowichan Rivers. This program should aim to (1) provide long-term benefits to aquatic habitat and (2) gradually result in reduced flood damages to property and important infrastructure. The scope of these measures will need to be defined through consultation with agencies and local governments.

A plan for developing a plan for periodic gravel and debris removal at two sites on the Cowichan River that were identified in the IFHMP should be prepared. The lower site is opposite the JUB outfall and was excavated in 2007; the upper site is immediately upstream of the rail bridge.

Log jam removal is also suggested in the IFHMP, this would be appropriate for the large debris jams that accrued during the 2009 flood event as shown on Map 1. In particular, the jams near the confluence of the Somenos and Cowichan Rivers should be removed.

## 7.2 NON-STRUCTURAL MEASURES AND BEST MANAGEMENT PRACTICES

The identified priority projects cannot protect all habitable areas within the Somenos watershed. In keeping with the goals and strategies presented in the plan, four additional flood management tools may be considered for areas outside of the priority project boundaries.

### *PROPERTY ACQUISITION*

Acqusition of buildings in a hazard prone area ensures that they will no longer be subject to damage. Acquisition is usually undertaken by a government agency so the cost is not borne by the property owner, and the land is usually converted to public use, such as a park or open space. Acquiring and clearing buildings is not only the most effective protection measure available, it is also a way to convert a problem area into a community asset and obtain environmental benefits. Acquisition, followed by demolition, is most appropriate for buildings that are difficult to move-such as larger slab foundation or masonry structures, and for dilapidated structures where moving them is not cost effective.

Currently there are no official mechanisms at the provincial or federal level to acquire or re-locate homes subject to flood hazard. However, at the municipal level, both the City of Prince George and the Township of Langley have recently acquired flood-prone properties after completing cost-benefit studies.  The studies compared the cost of acquiring properties versus protecting them with structural measures.

### *PROPERTY ELEVATION*

Elevating a building above the flood level is often a good on-site property protection method for flooding. It should be designed to keep floodwater below the high damage-prone part of the building. Alternatives include elevation on continuous foundation walls (creating an enclosed space below the building), elevation on compacted earthen fill and elevating on piles or piers. Raising a building above the flood level is cheaper than moving it and can be less disruptive to a neighborhood. With landscaping and other measures, elevated buildings can look attractive and be readily accepted by owners and neighbors. However, the elevated building will be surrounded by water during a flood and may not be usable.  Also, buildings elevated with fill are only appropriate within the 'flood fringe', as 'floodway' areas have active conveyance and any filling of the floodway will impact other users of the floodplain.

### *INVISIBLE FLOOD CONTROL WALLS*

Invisible Flood Control Walls (IFCW) are a relatively new technology.  They are aremovable floodwall that is erected only when flood waters threaten.  IFCW are being used all over in the world, and are particularly appropriate for river systems that are subject to predictable increases in water levels, such as during a spring freshet.  However, IFCW are worthwhile considering for the Somenos in areas where temporary barriers have been built in the past, where space is premium or where unobstructed views and access are important for non-flood periods.

### *DRY AND WET FLOODPROOFING*

**Dry floodproofing** involves sealing a building to ensure that floodwaters cannot get inside. All areas below the flood protection level are made watertight. Walls are coated with waterproofing compounds or plastic sheeting. Doors, windows and vents are closed permanently. While openings could be covered with removable shields or sandbags, this requires human intervention. Dry floodproofing is generally feasible only in shallow flooding areas (60 cm or less).

**Wet floodproofing** means letting the water in and removing everything that could be damaged by a flood. There are several ways to modify a building so that floodwaters are allowed inside, but minimal damage is done to the building and its contents. These techniques range from moving a few valuable items to rebuilding the flood-able area. Wet floodproofing is a technique most often used to protect existing buildings. It is used in new construction only for enclosed areas below the flood construction level under elevated buildings.

In the latter case, structural components below the flood level must be of materials that are not subject to water damage. For example, concrete block walls instead of wooden studs and gypsum wallboard. The furnace, water heater and laundry facilities are permanently relocated to a higher floor. Where the flooding is not deep, these appliances can be raised on blocks or platforms.

# 8 CONCLUSIONS

The November 2009 storm event resulted in a significant increase in water levels in both the Cowichan and Somenos systems. Flooding of the floodplain occurred as a result, in the case of the Somenos system ultimately flooding homes and requiring the evacuation of over 300 people.

The storm and flow events on the system although damaging were not very large, being in the order of a 7-year flow event. This type of event will likely reoccur (a severe 200-year event will be at least 1 m higher than the flood of 2009). The local governments need to plan for this type of event in order to mitigate future flood damages. The IFMP and this document can be used as a guide.

The temporary no-post barrier constructed along Lakes road was built with a top elevation approximately equal to the elevation of a 20-year flood. However, there is no guarantee that this barrier would keep this level of water back in future as it is not considered a standard dike.

The majority of flooding and damage occurred in the Somenos system. However, it is important to consider that there are many other areas of high flood hazard in the lower Cowichan Valley. These are clearly shown on the flood hazard maps prepared as a part of the IFMP. Resources, when available, should be allocated/considered for all areas within the floodway and floodfringe zones.

The modeling tool prepared as part of the IFMP performed well when modelling this event. The modelled extents and water levels matched documented extents and water levels closely. The poorest match between the model and observed data was found in the area adjacent to the JUB lagoons. This is likely due to changes in the river morphology in this section of the river since the model was developed. This highlights the inherent error associated with modelling a dynamic river system, and shows the need for properly considered freeboard requirements when preparing flood infrastructure and policy.

# 9 REFERENCES

NHC 2009. Lower Cowichan /Koksilah River Integrated Flood Management and Mapping Plan, Technical Investigations April 21, 2009

NHC 2010. Approximate Cost of Flood Mitigation Works on Somenos Creek – Cowichan River. Memo prepared for District of North Cowichan. 10 March, 2010.

Willis Cunliffe Tait & Company Ltd. 1992. Preliminary Design Report, Somenos Creek and Cowichan River, Flood Control Program 1992. Prepared for The District of North Cowichan, September 1992.

# FIGURES

# Cowichan Valley - November 2009 Climate and Hydrology

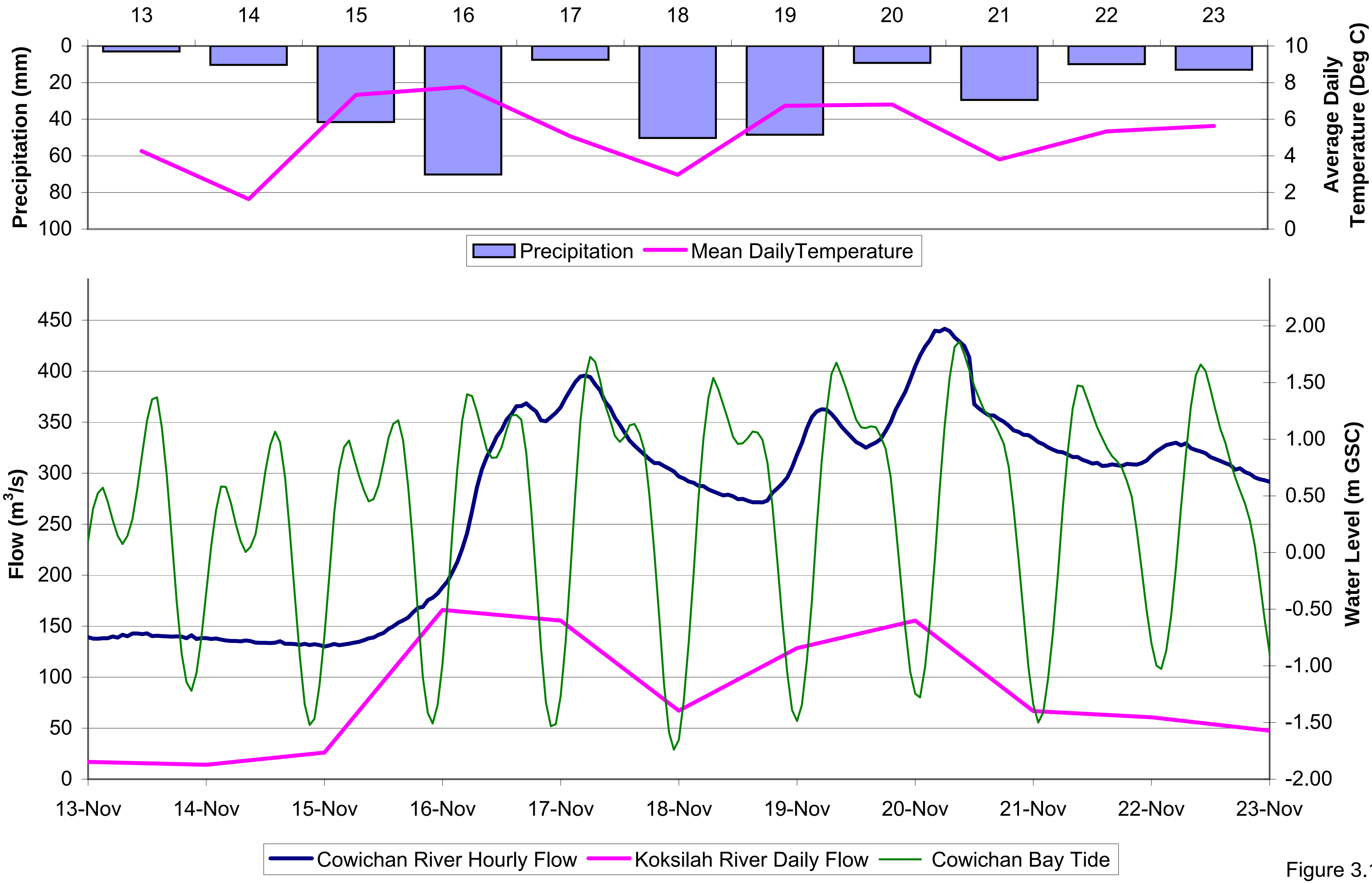



Figure 3.1

Historic Discharges on the Cowichan River at Duncan

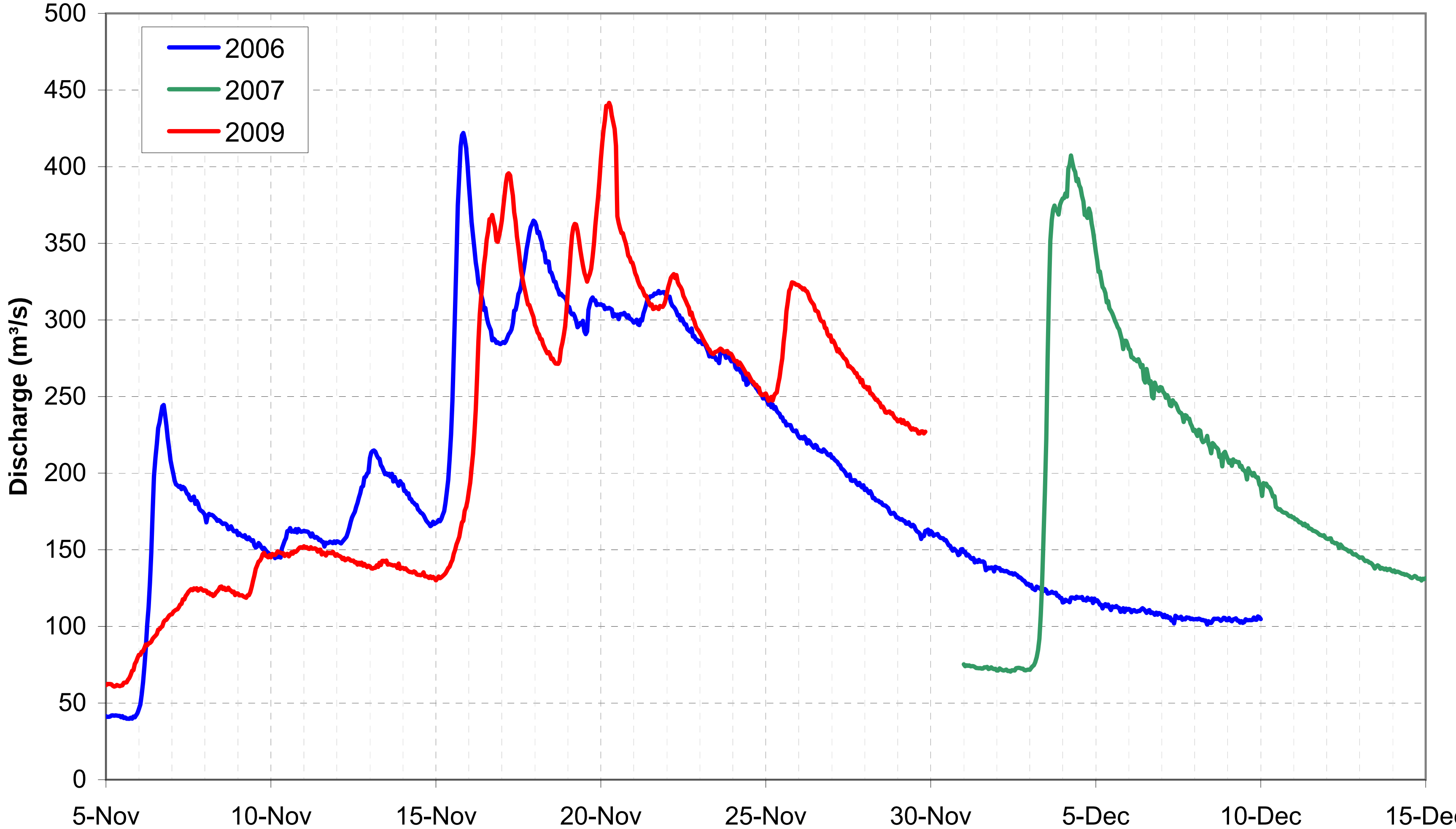



Figure 3.2

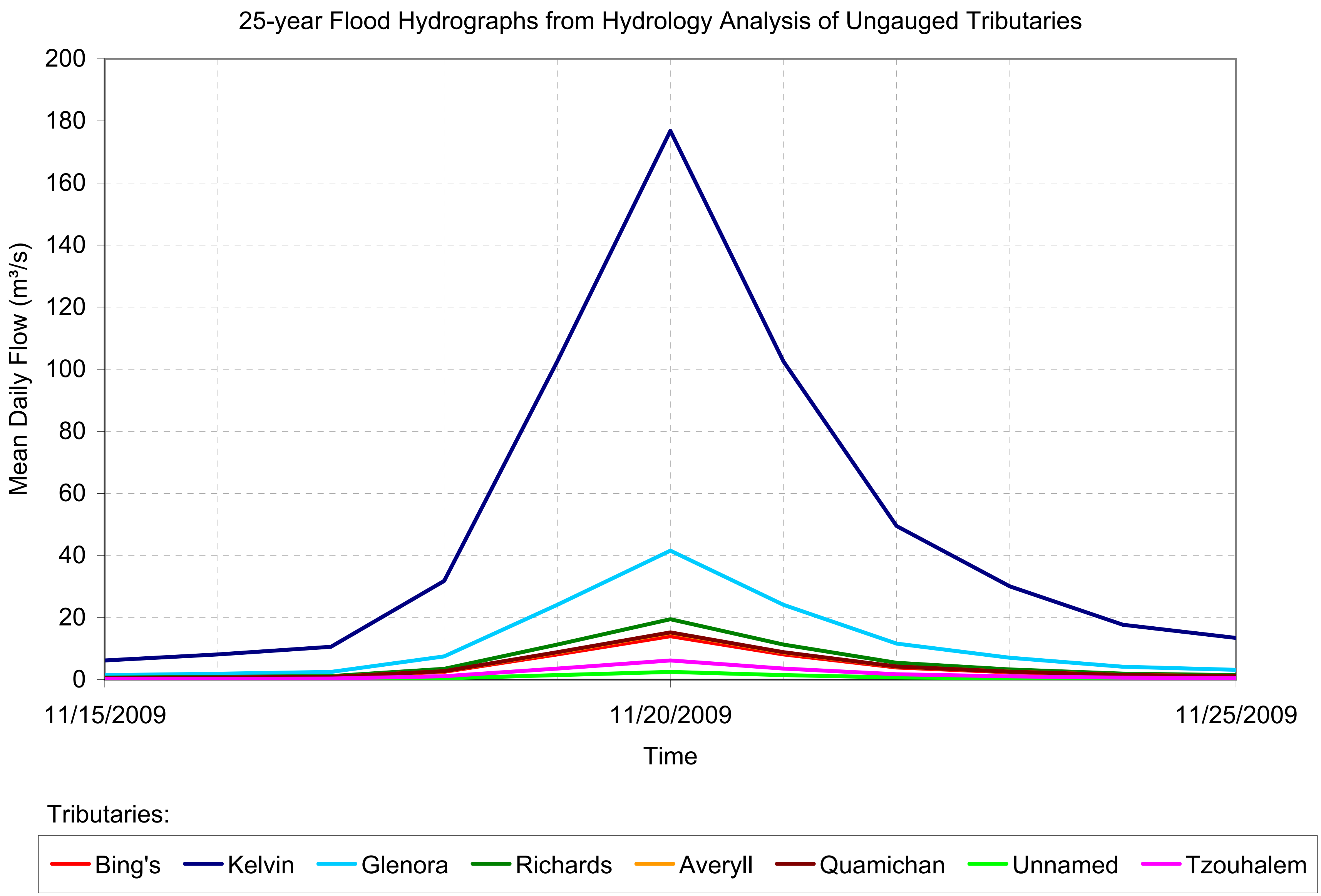
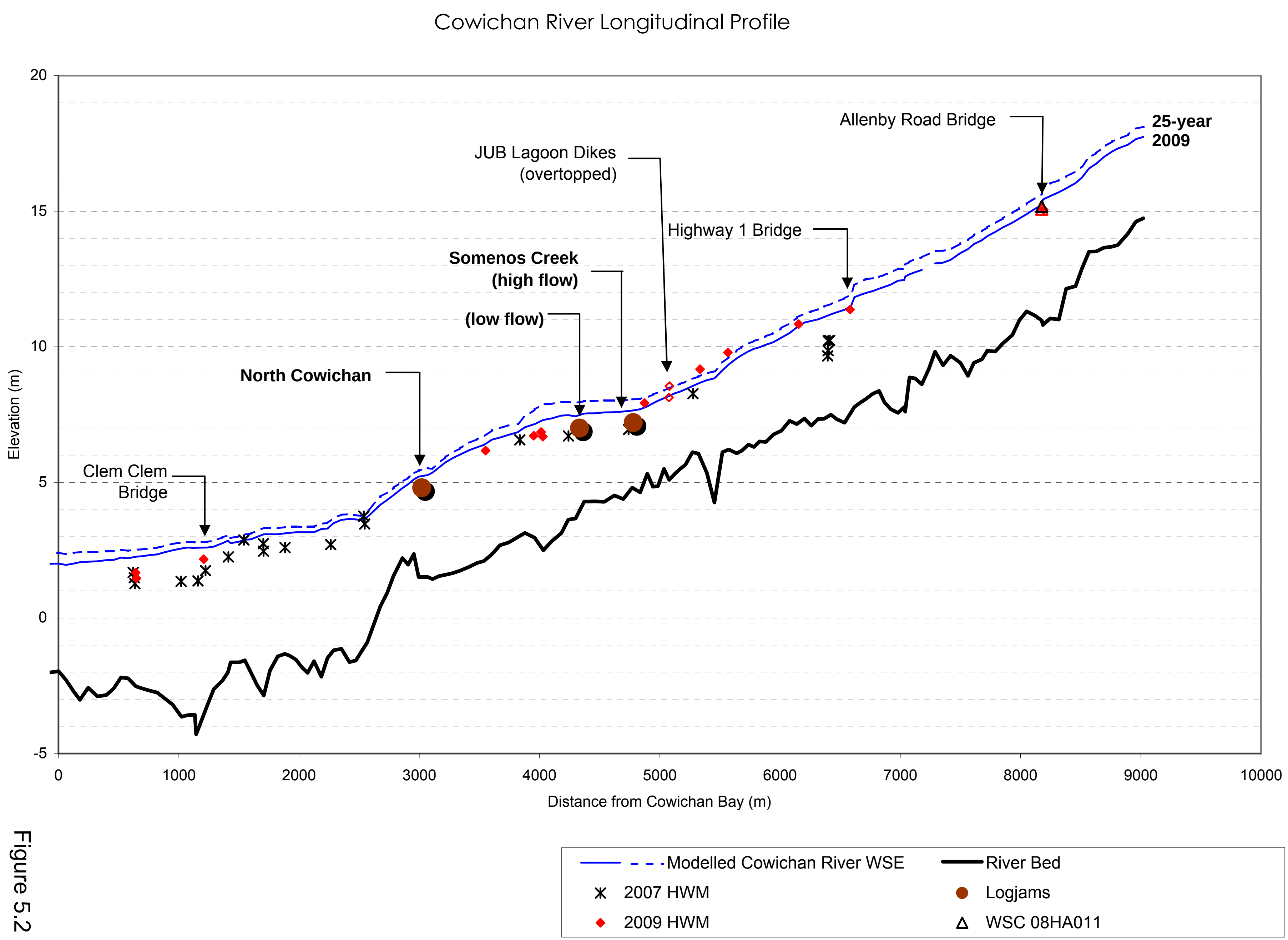
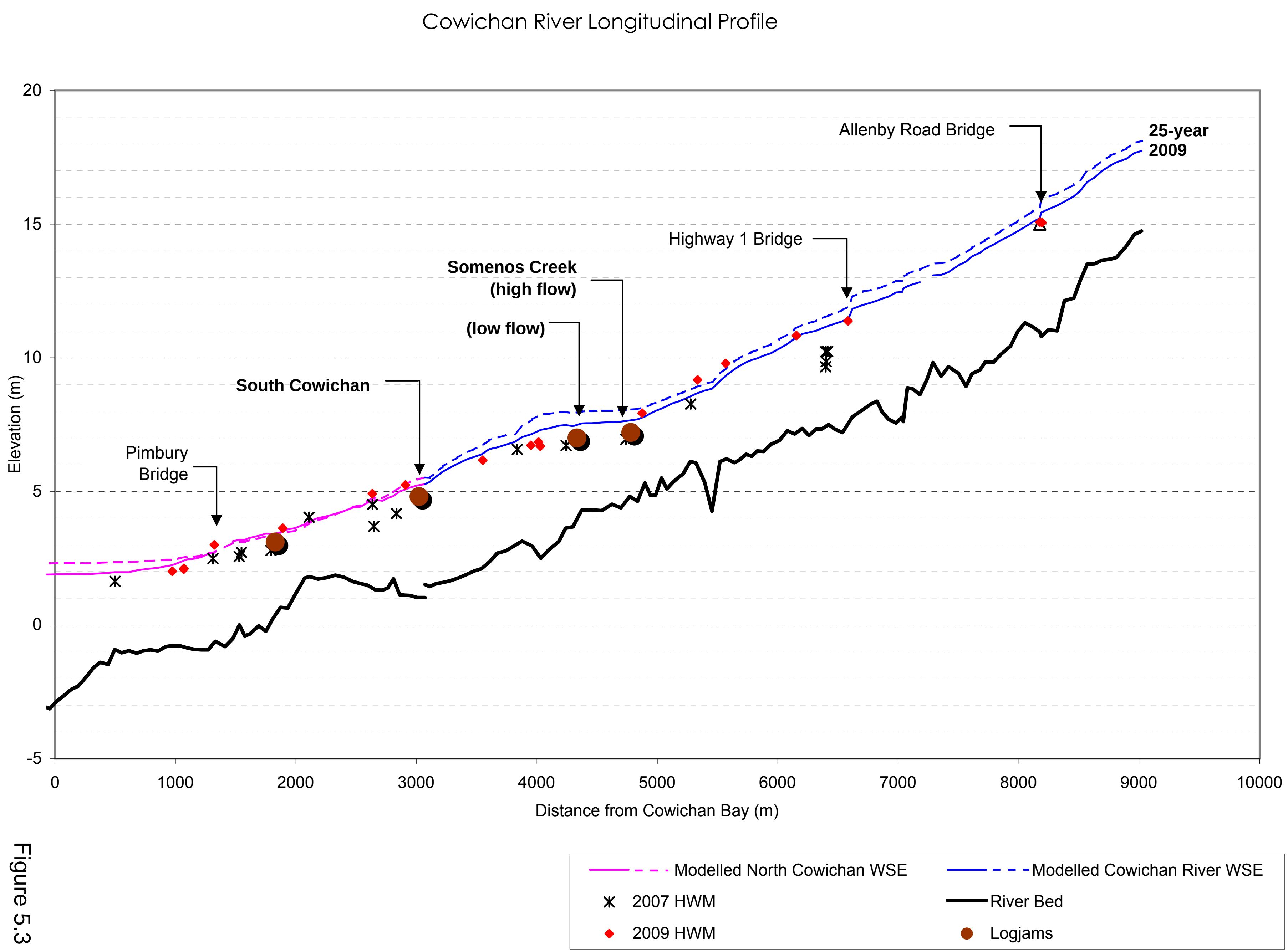

25-year Flood Hydrographs from Hydrology Analysis of Ungauged Tributaries
200
180
160
140
120
100
80
60
40
20
0
Mean Daily Flow (m³/s)
11/15/2009
11/20/2009
11/25/2009
Time
Tributaries:
Bing's
Kelvin
Glenora
Richards
Averyll
Quamichan
Unnamed
Tzouhalem

Figure 5.1



Cowichan River Longitudinal Profile
Elevation (m)
Distance from Cowichan Bay (m)
Allenby Road Bridge
25-year
2009
JUB Lagoon Dikes
(overtopped)
Highway 1 Bridge
Somenos Creek
(high flow)
(low flow)
North Cowichan
Clem Clem
Bridge
Modelled Cowichan River WSE
River Bed
2007 HWM
Logjams
2009 HWM
WSC 08HA011


Figure 5.2



Cowichan River Longitudinal Profile
Elevation (m)
Distance from Cowichan Bay (m)
20
15
10
5
0
-5
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Allenby Road Bridge
25-year
2009
Highway 1 Bridge
Somenos Creek
(high flow)
(low flow)
South Cowichan
Pimbury
Bridge
Modelled North Cowichan WSE
Modelled Cowichan River WSE
2007 HWM
River Bed
2009 HWM
Logjams


Figure 5.3

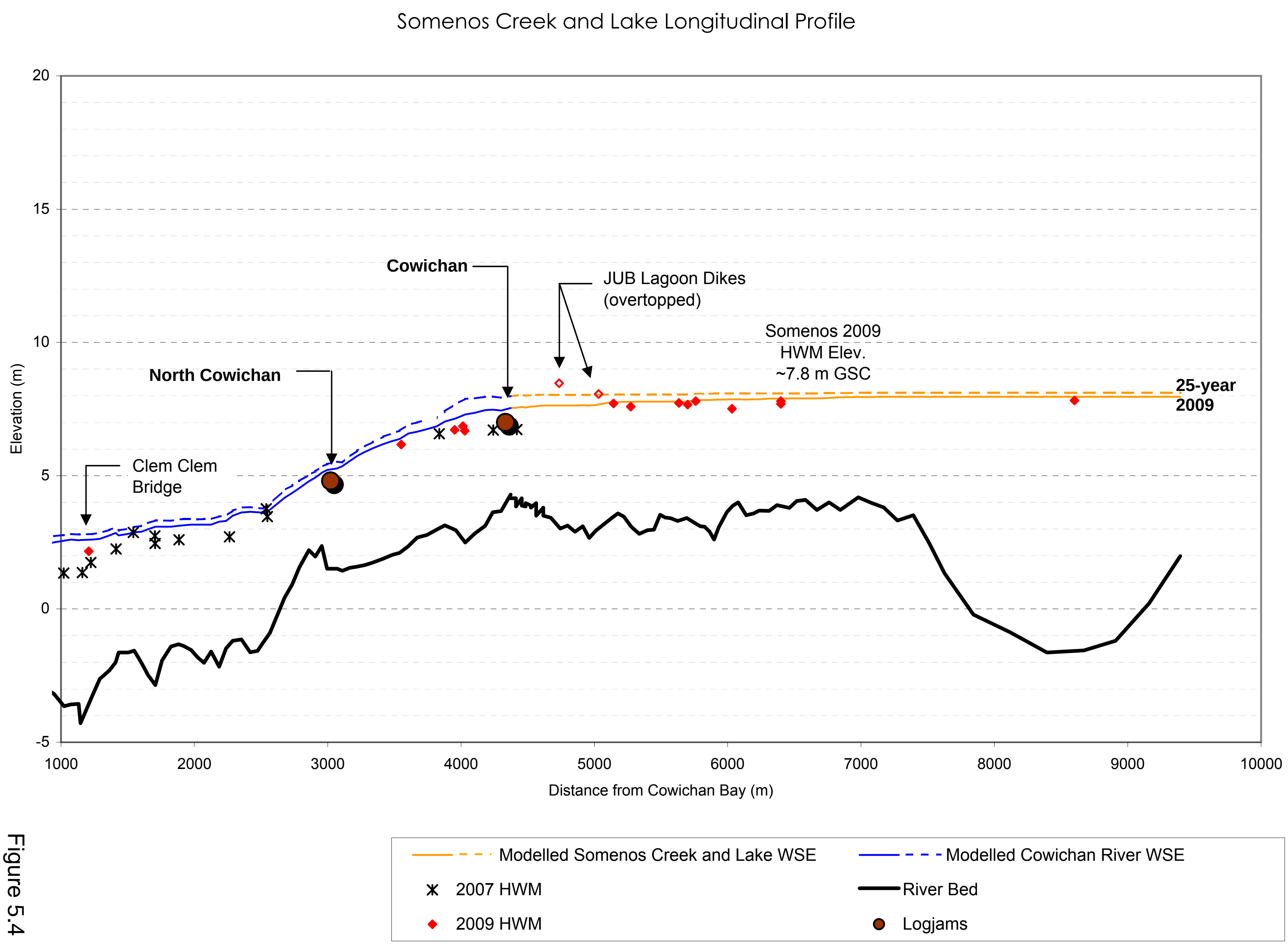
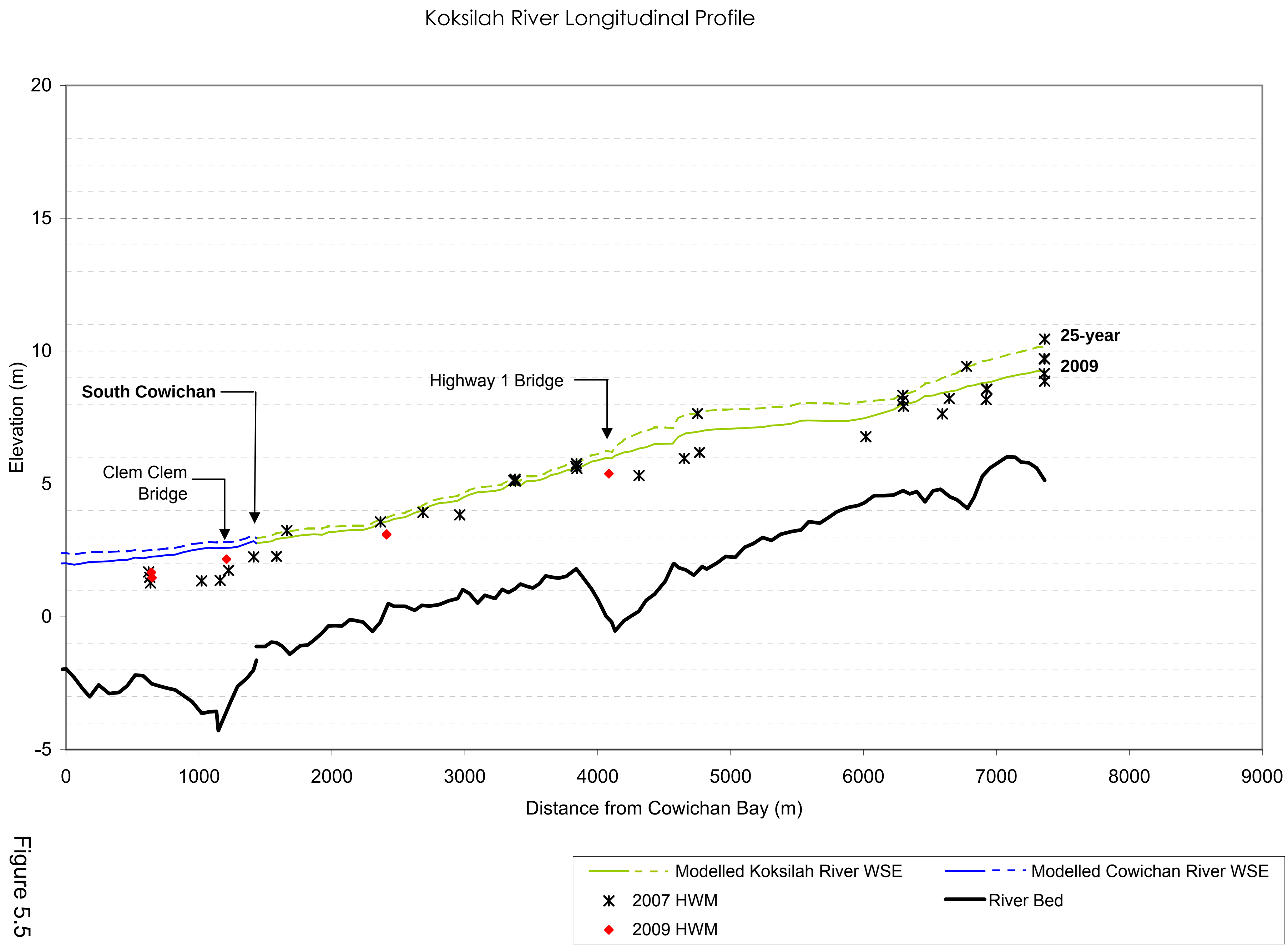

Somenos Creek and Lake Longitudinal Profile
Elevation (m)
Distance from Cowichan Bay (m)
20
15
10
5
0
-5
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Cowichan
JUB Lagoon Dikes
(overtopped)
Somenos 2009
HWM Elev.
~7.8 m GSC
North Cowichan
25-year
2009
Clem Clem
Bridge
Modelled Somenos Creek and Lake WSE
Modelled Cowichan River WSE
2007 HWM
River Bed
2009 HWM
Logjams

Figure 5.4



Koksilah River Longitudinal Profile
Elevation (m)
Distance from Cowichan Bay (m)
20
15
10
5
0
-5
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
South Cowichan
Clem Clem
Bridge
Highway 1 Bridge
25-year
2009
Modelled Koksilah River WSE
Modelled Cowichan River WSE
2007 HWM
River Bed
2009 HWM


Figure 5.5

Legend

Difference in Observed HWM and
Peak Modelled Water Levels (m)

- < ± 0.1
- ± 0.1 to ± 0.3
- > ± 0.3

Modelled Channelized Flows
and Overbank Spilling

Notes:
- 2005 TerraRS from CVRD (to match LiDAR)
- 2004 Orthophotos from CVRD
- 2006/2007 MNC Quadrand Orthophotos from North Cowichan
- Simulation folder name: C_nhc_D_25_101_1.couple

**COWICHAN VALLEY NOVEMBER 2009 FLOODING DOCUMENTATION AND ASSESSMENT**

Comparison of Observed HWMs and
Peak Modelled Water Levels

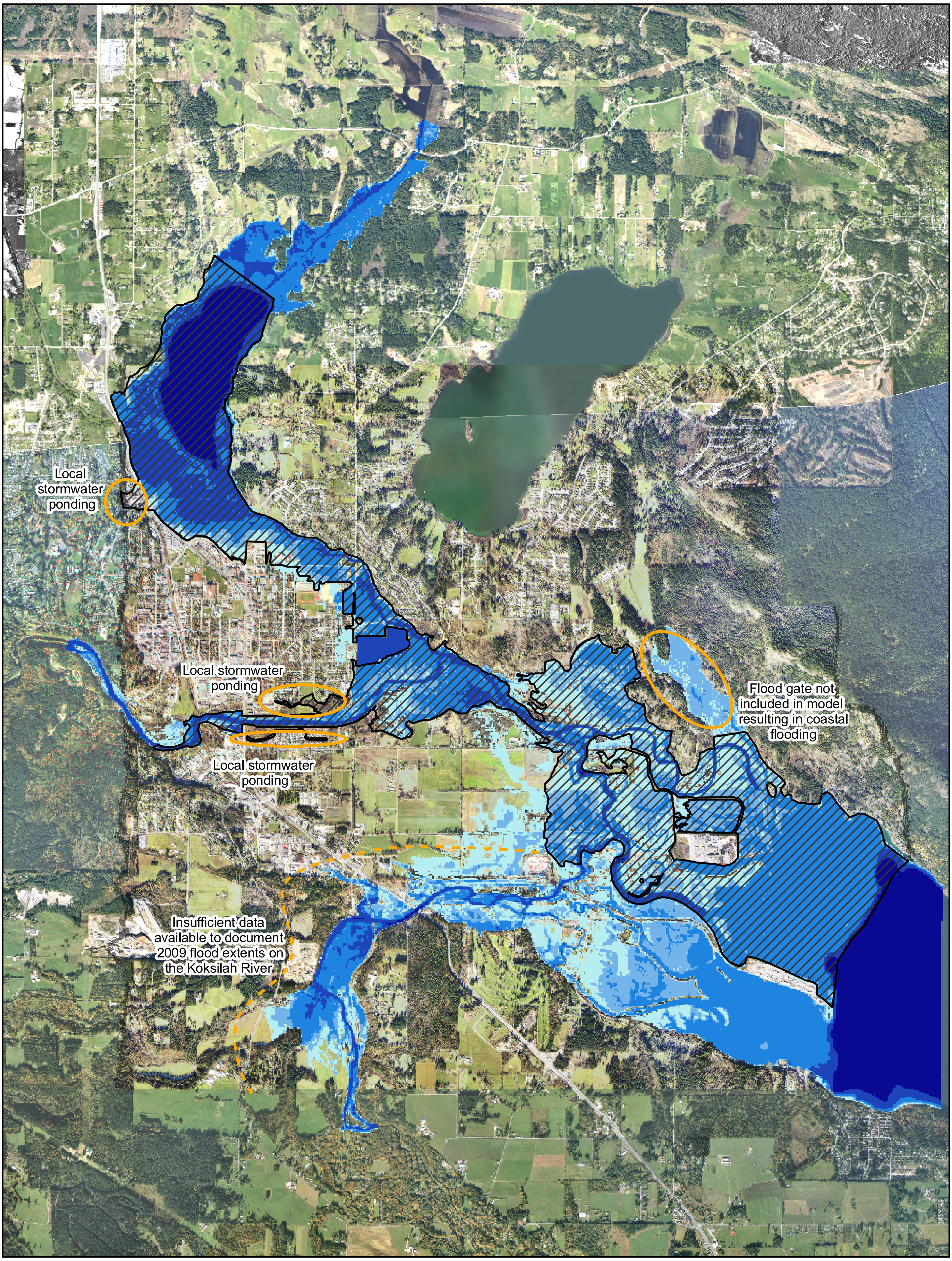
Scale - 1:35,000

1 0.5 0 1 Kilometers

| | | |
|---|---|---|
| coord. syst.: UTM Zone 10 | horz. datum: NAD 83 | horz. units: metres |
| northwest hydraulic consultants | project no. 3-5316 | March 2010 |

Figure 5.6

VFOC, X:\35316 Cowichan 2009 Flood\GIS\35316_Cowichan_VFOC_HWM_11x17_.mxd




Legend

Documented 2009 Flood Extents

**Modelled 2009 Flood Depth (m)**

- 0.15 - 0.6
- 0.6 - 1.0
- 1.0 - 2.0
- 2.0 - 5.0
- > 5.0

Notes:
- 2005 TerraRS from CVRD (to match LiDAR)
- 2004 Orthophotos from CVRD
- 2006/2007 MNC Quadrand Orthophotos from North Cowichan
- Simulation file name: 35316_Nov2009_HD.couple

**COWICHAN VALLEY NOVEMBER 2009 FLOODING DOCUMENTATION AND ASSESSMENT**

Comparison of Observed and Modelled Flooding Extents

Scale - 1:35,000

1 0.5 0 1 Kilometers

| | | |
|---|---|---|
| coord. syst.: UTM Zone 10 | horz. datum: NAD 83 | horz. units: metres |
| northwest hydraulic consultants | project no. 3-5316 | March 2010 |

Figure 5.7

JXD, X:\35316 Cowichan 2009 Flood\GIS\35316_Cowichan_JXD_FloodDepth_11x17_r1.mxd

# APPENDIX A - DIKE INSPECTIONS

The data collection included field inspections of flood infrastructure conducted on December 3 and 4, 2009. This memo summarises the general condition of the inspected dikes and identifies specific areas of concern or vulnerability.

Of the dikes located throughout the Cowichan floodplain, the following were included in the dike assessment:

- Cowichan River Dike
- JUB Lagoon Dikes
- Cowichan River South Side Dike
- South Side Spur Dike
- Quamichan Dike
- Hatchery Dike
- Lee Street Dike

## A.1 COWICHAN RIVER DIKE

**Water Course:** Cowichan River

**Location:** Left bank, starting at the JUB lagoons and ending at the Silver (Highway 1) Bridge

**Length:** 1371 m

**General Observations:** High water levels on the river side of the dike prevented observation of deterioration or damage on part of the slope and the toe of the dike. Two culverts pass through the dike near chainage 300 and 400 allowing water to drain from Rotary Park and flow into the Cowichan River. Near chainage 800, a portion of the Cowichan River Dike (on the landside) was excavated and replaced with a vertical wall of rock-filled gabions to allow more space for the athletic field. It should be ensured that the integrity and performance of the dike was not compromised during the alteration of the dike. Minor rutting was observed in some locations.

**Concerns:**

1. Seepage was observed (on Nov 20) through the Cowichan River Dike near chainage 100.

2. During the flood, water ponded in the area bounded by Lakes Road, the JUB Lagoon Dike and the Cowichan River Dike (see Photo 3-1). The Cowichan Dike does not connect to the JUB dikes, possibly allowing water to flow between the dikes. After the flood had receded, possible signs of seepage were observed near the toe of the Cowichan Dike near chainage 30.

Furthermore, a storm sewer drains water from the City of Duncan Public Works Yard and flows into the Cowichan River after passing under the Cowichan River dike near chainage 30. The culvert outflow does not have a control gate and signs that the pipe is cracked were noticeable near the Public Works Yard where water was seen bubbling up through cracks in the pavement. Similar leaks in the pipe are possible under the flooded area closer to the dike. The source of the water observed in Photo 3-1, is likely from one or a combination of the sources listed above.

Photo 3-1: Flooding on land side of Cowichan Dike near chainage 10.

3. Vegetation (including large trees) is present in or near the dike on the river side.

## A.2 JUB LAGOON DIKES

**Water Course:** Cowichan River and Somenos Creek

**Location:** Upstream of the confluence of Cowichan River and Somenos Creek

**Length:** 1542 m

**General Observations:** High water levels on both the river side and the lagoon side of the dike prevented a complete assessment of deterioration or damage on the lower part of the side slope and the toe of the dike. Fast flowing water was observed in a side channel running parallel to the dike.

**Concerns:**

1. Portion of the dike on the south of the middle cell (cell #5) is lower than the rest of the lagoon dike. It is suspected that the dike was overtopped during the flood along that lower portion but it is known that the water level in the lagoon was higher than the dike crest elevation. Effluent from the lagoon flowed over the dike and into the river.
2. Vegetation (including large trees) is present in and near the dike on the river side (see Photo 3-2).

Photo 3-2: Trees growing along crest of dike and near the toe on the river side.

## A.3 COWICHAN RIVER SOUTH SIDE DIKE

**Water Course:** Cowichan River

**Location:** Right bank, connects to the South Side Spur Dike downstream and ends at the Silver (Highway 1) Bridge

**Length:** 1022 m

**General Observations:** High water levels on the river side and overgrown vegetation obstructed the complete assessment of deterioration or damage on the lower side slope and toe of the dike. Large boulders prevent vehicle access along the dike crest. In localised areas, minor erosion was observed near the toe of the dike.

**Concerns:**

1. Overgrown vegetation (including large trees) is present in and near the dike on the river side and land side.
2. Thin bank protection or loss of riprap protection in some locations.

## A.4 SOUTH SIDE SPUR DIKE

**Water Course:** Cowichan River

**Location:** Right bank, starts roughly 400 m upstream from the Cowichan River and Somenos Creek confluence and connects to the Cowichan River South Side Dike upstream

**Length:** 645 m

**General Observations:** High water levels on the river side and overgrown vegetation obstructed the complete assessment of deterioration or damage on the lower side slope and toe of the dike. Debris prevents vehicle access along the dike crest. Water was flowing around the downstream end of dike and floods area between the dike and the Mission Road Dike.

**Concerns:**

1. Overgrown vegetation (including large trees) is present in and near the dike on the river side and land side.
2. No riprap protection along the majority of the dike. Note that fast flowing water was observed on the river side of the dike.
3. Significant erosion was observed along a 200 m-long section of the dike. Also, there was erosion due to fast currents along the toe and side of dike (see Photos 3-3 and 3-4).

Photos 3-3 and 3-4: Erosion due to fast currents between chainages 500 and 600.

## A.5 QUAMICHAN DIKE

**Water Course:** Cowichan River

**Location:** Left bank, starts roughly 400 m downstream from the North/South Cowichan River fork and ends roughly 400 m downstream of the Cowichan River and Somenos Creek confluence

**Length:** 1300 m

**General Observations:** High water levels on the river side and overgrown vegetation obstructed the complete assessment of deterioration or damage on the lower side slope and toe of the dike. Fast flowing water was observed along the unprotected river side of the dike. Water was flowing around the downstream end of the dike and north into Priest's Marsh on the land side of the dike.

**Concerns:**

1. Overgrown vegetation (including large trees) is present in and near the dike on the river side and land side (Photo 3-5).

Photo 3-5: Vegetation and large trees growing on both sides of Quamichan Dike.

2. No riprap protection along the majority of the dike. Note that fast flowing water was observed on the river side of the dike.
3. Uprooted tree and significant erosion of the dike was observed on the land side of the dike near chainage 1000. A small (now dry) channel with evidence of fast flows caused the erosion which led to the uprooting of the tree (Photos 3-6 and 3-7).


Photo 3-6: Eroded side of Quamichan Dike (land side); Photo 3-7: Large uprooted tree and erosion of the Quamichan Dike (land side) near chainage 1000.

4. Significant erosion along dike near chainage 100 (Photo3-8).

.

Photo 3-8: Gradual erosion of the Quamichan Dike (river side) near dike chainage 100.

## A.6 HATCHERY DIKE / MISSION ROAD DIKE

**Water Course:** Cowichan River

**Location:** Right bank, dike starts roughly 400 m downstream of the North/South Cowichan fork and connects to the Mission Road Dike upstream

**Length:** 1300 m

**General Observations:** High water levels on the river side and overgrown vegetation obstructed the complete assessment of deterioration or damage on the lower side slope and toe of the dike. Fast flowing water was observed along the unprotected river side of the dike. An intake structure (near chainage 1300) was built through the dike to allow conveyance of flow from the river side to habitat channels found on the land side of the dike. Water flows around the downstream end of the dike and backwaters on the landside of the dike in side channels that are now isolated from the main channel.

Mission Road Dike is completely overgrown with vegetation past chainage 300 and is not accessible by foot.

**Concerns:**

1. Significant erosion and loss of riprap protection was observed at dike chainage 400 (see Photo 3-9).

Photo 3-9: Significant erosion and loss of riprap protection

2. Erosion along Mission Road Dike near chainage 200 (Photo 3-10).

Photo 3-10: Erosion along Mission Road Dike.

3. Overgrown vegetation (including large trees) is present in and near the dike on the river side and land side of both Hatchery and Mission Road Dike(Photo 3-11).

Photo 3-11: Overgrown vegetation on Mission Road Dike.

## A.7 Lee Dike

**Water Course:** Rotary Creek/Fish Gut Channel

**Location:** Left bank, non-standard and temporary dike along Lee Street residents' rear property line

**Length:** ~100 m

**General Observations:**

High water levels on the river side and overgrown vegetation obstructed the complete assessment of deterioration or damage on the lower side slope and toe of the dike. Fast flowing water was observed along the unprotected river side of the dike. The non-standard dike was raised with sandbags as part of emergency protection installed in November 2009 (Photo 3-12).

**Concerns:**

1. Dike was overtopped during recent flood event (prior to sandbagging).
2. Trees, fences, and decks are in or near the dike.

Photo 3-12: Dike raised with sandbags.

3. Dike does not appear to be impermeable and seepage is suspected.

# APPENDIX B - 2009 INTEGRATED FLOOD MANAGEMENT PLAN GOALS AND STRATEGIES

In September of 2009, NHC presented the CVRD and its partners with an Integrated Flood Hazard Management Plan for the Lower Cowichan Valley. As part of this project three project goals and ten guiding strategies were defined as follows:

### Goal 1

The plan should aim to reduce flood risk to all communities on the floodplain, while protecting aquatic and riparian habitat and addressing the cultural values of the rivers.

### Goal 2

The plan should promote innovative methods of flood hazard management to minimize short and long-term economic, environmental and social costs and where possible, provide an increase in the environmental and social capital of the region.

### Goal 3

The plan should be achievable and should be supported by project stakeholders and the community at large. And, tools and recommended actions should be sustainable in the long-term.

**Strategy 1: Return the rivers to a more naturalized state.** The Cowichan River has been artificially straightened and confined by riprap and dikes. This type of channelized river generally requires a high degree of maintenance and repair. It also adversely impacts fisheries habitat by reducing habitat complexity. Therefore, restoring the river to a more "naturalized" channel configuration that has room to convey water within a broad floodway should be a part of a long-term strategy

**Strategy 2: Sustain the natural state of existing floodplain**. Remaining undeveloped floodplain areas should be sustained in a natural state. And, initiatives should be compatible or be integrated with programs that protect and enhance aquatic and riparian habitat

**Strategy 3: Site future development in areas with low flood hazard and low habitat sensitivity**. Future development should be sited in areas with low flood risk and low habitat sensitivity

**Strategy 4: Ensure new or upgraded flood protection structures do not adversely increase the overall flood hazard.** Based on past experience along the river, a "no-net adverse impact" flood level policy for future developments on the floodplain, including future diking and flood protection works, is needed. Constructing new dikes or extending existing ones should not increase the risk of flood damage in other vulnerable areas

**Strategy 5: Decrease vulnerability of existing development areas**: Where key infrastructure and residential areas currently lie on the floodway and cannot easily be moved, decrease the vulnerability of these people and structures. This can be achieved through floodproofing of existing structures, and through improvements to public education, flood warning and flood response systems.

**Strategy 6: Mitigate impacts of high flows on mainstem.** Impacts of high flows on mainstem should be mitigated by facilitating flow through suitable off-channel habitat

**Strategy 7: Maintain channel conveyance**. Consider and maintain sites of debris jams and debris/gravel accumulation. An "adaptive" maintenance approach that incorporates habitat enhancement as part of channel maintenance is needed

**Strategy 8: Create accessible and sustainable tools for flood management**. New tools developed for the project need to be designed so they can be used interactively and dynamically for emergency management, improved landuse planning, public awareness and education

**Strategy 9: Promote basin-wide planning initiatives.** Basin-wide planning is important, particularly since most of the flood water, sediment and debris originates upstream of jurisdictional boundaries in the basin headwaters.

**Strategy 10: Monitor and maintain flood management program.** Monitoring and maintenance are essential components of a flood management program. This should not just apply to dikes or bank protection works, but the channel as a whole.