Date: November 14, 2006

Lower Fraser River Hydraulic Model – Summary of Results

I. ISSUE

In September 2005, the Fraser Basin Council (FBC) retained Northwest Hydraulic Consultants Ltd. (nhc) to undertake a program of one-dimensional hydraulic modeling on the lower Fraser River using the MIKE 11 software developed by Danish Hydraulic Institute. The study area includes the lower Fraser River from the mouth of the Harrison River to the Strait of Georgia, encompassing the North, Middle and South Arms, including Canoe Pass, as well as Pitt River to Pitt Lake inlet. The overall objective was to generate an up-to-date design flood profile based on the following two scenarios:

- The 1894 Fraser River freshet flood combined with spring high tide conditions (Fraser freshet profile).
- The 1 in 200-year winter storm surge flood with winter high tide conditions combined with a Fraser River winter flow (the winter storm surge profile).

The modeled flood profile in 2006 is higher than the estimates that were made in 1969, which have been used as a basis to rehabilitate lower Fraser River dikes under the Fraser River Flood Control Program. The results from this study show that widespread dike overtopping and dike failures would occur throughout the region in the event of a re-occurrence of the 1894 flood of record.

II. BACKGROUND

In 2003, the Fraser Basin Council and the BC Ministry of Environment initiated a multi-year project to develop a hydraulic model of the lower river (focusing on the reach from Sumas Mountain to Richmond). The Fraser Basin Council is a nongovernmental, not-for-profit organization working in collaboration with others to resolve long-standing sustainability issues in the Fraser Basin. It should be stated at the outset that although the Fraser Basin Council has convened and facilitated numerous processes to assist in resolving Fraser River flood protection, gravel management and related issues, the Council has no jurisdiction or decision-making authority in these matters. The Fraser Basin Council along with provincial, federal, local governments and other partners have been pro-active in completing this study, as flood protection and dike safety are critical sustainability issues in the region. More than 20 Fraser Valley communities, including First Nations, are protected by over 300 km of Fraser River diking between Agassiz and Delta (including the sea dikes). Almost 250 km of these dikes were reconstructed by the federal/provincial Fraser River Flood Control Program between 1968 and 1994. The dike design levels (estimated flood water level plus 0.6 m freeboard) for reconstruction were established in 1969 by the federal Inland Waters Directorate. This profile was based on high water marks from the 1948 and 1894 floods, plus limited computer modeling. The 1894 flood is the largest flood in the last 112 years.

The main purpose of this project is to provide an up-to-date evaluation of the design flood profile for the lower Fraser River based on simulating a re-occurrence of the 1894 Fraser River flood of record, considering current river and floodplain conditions. Project objectives include:

- Update the dike design profile and assess the adequacy of existing diking systems;
- Better understand the effects of sedimentation and dredging on the dike design profile;
- Provide a flood level forecasting tool during spring freshet floods; and,
- Assist with land use planning decisions and floodproofing practices.

The project has been supported by financial and in-kind contributions from the BC Ministry of the Environment, Canadian Coast Guard, Public Works and Government Services Canada, Fraser River Port Authority and local governments, including the Greater Vancouver Regional District, Surrey, Richmond, Delta, Abbotsford, Township of Langley, Maple Ridge and Pitt Meadows.

III. FLOOD SCENARIO AND MODEL ASSUMPTIONS

The results of this study – an up-to-date design flood profile for the lower Fraser River – are based on the estimated 1894 Fraser River flood combined with high spring tide conditions (the Fraser freshet profile), and the 200-year winter storm surge with high tide combined with a Fraser River winter flow condition (the winter storm surge profile). The modeled Fraser freshet and winter storm surge profiles were overlaid and the higher of the two profiles was used to develop an overall design flood profile. The adopted design discharge for the 2006 flood model is based upon the 1894 flood of record with an estimated peak discharge of 17,000 m^3/s at Hope. This design discharge increases to 18,900 m^3/s at Mission and 19,600 m^3/s at New Westminster, when adding inflows for tributaries downstream of Hope. The adopted design discharge for the flood model assumes containment of the river by the existing dike system downstream of Hope under current and future floodplain conditions.

The hydraulic model was developed using field data collected in 2005, including comprehensive bathymetric surveys of the channel, LIDAR topographic surveys of the floodplain and ADCP velocity measurements to estimate flow splits at major channel branches. The model was calibrated and verified initially using recorded data from 2002, 1999 and 1997 high flow events. Peak discharges from these floods ranged between 11,000 cubic metres per second (m^3/s) and 12,200 m^3/s at Mission. Later, a secondary "historic model" was developed for the reach between Mission and New Westminster, using channel and floodplain topography from 1951 to 1953. This secondary model was used to estimate the channel roughness during floods in 1948, 1950, 1969 and 1972.

An assessment of floodplain conditions in 1894 was undertaken to estimate the flood attenuation, flood storage and over bank spilling effects during the 1894 flood and to estimate how these factors may have reduced the actual discharge and observed water levels at Mission during the flood. Taking into account these factors, the peak discharge in the river channel at Mission during the flood of 1894 was estimated to be 16,500 m^3/s. Also, actual tributary inflows below Hope during the 1894 flood may have been different than the assumed conditions adopted for the design flood in the model. For these reasons, it was concluded that the actual 1894 historic flood discharge and water levels are not directly comparable to the design flood profile computed by the model in 2006 using current river conditions.

Channel roughness (n-value) along sand bed rivers is subject to considerable variation with changing flow conditions due to the formation of sand dunes on the riverbed. A higher / lower n-value would result in a higher / lower flood profile. During very high flows the roughness may decrease substantially if the dunes wash out and flat bed conditions develop; however, field observations during floods in 1950, 1986 and 1997 showed no evidence of dunes washing out. The n-value was estimated to be 0.03 using the 2002 data (maximum discharge of 11,300 m^3/s at Mission). Based on flow estimates for the 1948 flood and observed water levels, the average n-value was found to be 0.027 or approximately 10% lower. Based on this assessment of Fraser River data, a value of 0.027 was adopted for the design flood profile computations between Douglas Island and Mission. However, there remains uncertainty about the appropriate n-value, which cannot be verified until the model is re-calibrated after a large flood event.

A statistical analysis of storm surges and astronomical tide levels was carried out to assess the design flood profile associated with a 1 in 200-year winter storm surge (at a 95% confidence interval). The Empirical Simulation Technique, developed by the US Army Corps of Engineers for the Federal Emergency Management Agency was used in this study. The Fraser River 200-year winter discharge of 9,180 m^3/s at Mission was used to estimate the winter flood profile. It was found that the winter flood level in the estuary was virtually independent of the discharge and was governed primarily by the ocean level. The final results for the winter storm surge profile assume no rise in sea level and no subsidence of the delta. The report does review recent published literature on sea level rise and local land subsidence. The report suggests a potential net rise of 0.6 metres over the next century.

IV. RESULTS

The winter storm surge profile exceeds the freshet profile in the lower 28 km of the river, or downstream from a point 1.4 km downstream of the Alex Fraser Bridge. Upstream of that point, the Fraser River freshet flood profile is the dominant flood hazard.

Comparisons were made between the flood profile computed in 2006 and that estimated and published from previous studies in 1969. The winter design profile downstream of the Alex Fraser Bridge is about 0.3 m higher than the previous profile. In the transition from the winter to freshet profile, the updated profile is slightly lower than the previous profile. However, upstream of New Westminster the updated profile becomes increasingly higher.

- The results from this study show that widespread dike overtopping and dike failures would occur throughout the region in the event of a re-occurrence of the 1894 flood of record.
- The increase in predicted water levels suggests that dikes from Chilliwack and Kent to Surrey and Coquitlam would be overtopped at one or more locations. At the design flow of 18,900 m^3/s at Mission, the dikes at Chilliwack, Kent (downstream end), Matsqui, Dewdney, Mission, Silverdale, Pitt Polder, Pitt Meadows (South), City of Coquitlam (Coquitlam Diking District), City of Abbotsford (Matsqui and Glen Valley), Langley (Nathan and West Langley), Barnston Island and Surrey (Bridgeview and South Westminster) would all be overtopped at one or more locations. The Nicomen Island dike would be overtopped over most of its length. In addition, freeboard (see page 7) would be compromised at Pitt Meadows (North and Middle) and Langley (Salmon).
- For the winter storm surge flood, with the specified 200-year frequency the total water level was estimated to be 2.9 m GSC datum (at a 95% confidence interval). Freeboard would be inadequate at Delta (Westham Island, Fraser Shore and Marina Gardens) and Richmond (Fraser Shore and Lulu Island). The Delta dike at Fraser Shore would be overtopped at one location.
- Current dike elevations were derived from a variety of sources including recent LIDAR topographic surveys, recent surveys undertaken by diking authorities, or as-built dike crest elevations where recent survey data was unavailable. In some cases updated dike elevation data is warranted.

An initial evaluation of the flood protection capacity of the present diking systems was made by computing a series of water surface profiles for a range of flood discharges at Mission. These results were then compared to the 1894-profile published in 1969. Without compromising freeboard, the present capacity in the upstream reach of the study area is approximately 16,500 m^3/s, increasing to roughly 17,500 m^3/s at New Westminster. Additional detailed analysis using dike surveys showed the freeboard for Pitt Polder Dike could be compromised at a flow of roughly 14,500 m^3/s (equivalent to the 1950 flood). At a flow just exceeding 16,000 m^3/s the dike would be over-topped. Freeboard for the City of Coquitlam (Coquitlam Diking District) dike along the Pitt River would be compromised at a flow just over 15,500 m^3/s. The same holds for the Barnston Island dike and a small segment of the Surrey dike.

The final results of this project represent a comprehensive technical analysis using standard engineering practices, including calibration and verification utilizing data from different flood events. In addition the project used current computer modeling software, and best available data to calibrate and verify the model. In addition, confidence in the modeling has been supported by the development of a completely independent model (different software and river survey data), which produced similar results. It is now up to those responsible for managing flood hazards to determine how to apply this information, and what additional studies may be appropriate.

This briefing note represents a summary of key findings from this project, including the purpose, context, results and conclusions. A Final Technical Report will be available in December, which will include more details such as the methodology, sensitivity analyses, and several technical appendices.

V. CONCLUSIONS

The lower Fraser River and related flood hazard studies are highly complex. The engineers in 1969 simply did not have access to the sophisticated data gathering and analytical tools that are available today and could not explicitly deal with some of the river's complexities. Despite recent improvements in analytical tools, current studies also remain subject to sources of uncertainty. Federal, provincial, First Nations and local governments are advised to work collaboratively to examine the findings of this study and management options to help mitigate the Fraser River flood hazard, including costs and benefits.

In addition to applying these results to diking systems, it is also advisable that the following activities of local authorities take into consideration the final results:

- Establishing or refining local floodplain bylaws and/or flood construction levels;
- Updating Official Community Plans, development permit areas and other planning processes that relate to flood hazard management; and,
- Updating or refining local or regional emergency plans.

The Ministry of Environment under the *Dike Maintenance Act,* and through the office of the Inspector of Dikes, establishes standards for dike design, operation and maintenance; and issues approvals for changes to dikes and new dikes. Design criteria for dikes are updated from time to time based on the best available information. The Inspector of Dikes has advised that the study results and the new profile from Richmond to Chilliwack will now be adopted as the provincial standard for the Fraser River dikes.

However, significant further work is required before a major dike upgrading program is undertaken. Priority should be given to re-assessing the adopted design flow, which is currently based upon an estimate of the 1894 flood of record at Hope. This work should involve conducting hydrological studies and hydro-meteorological modeling to determine the magnitude and frequency of flood flows in the Fraser River Basin. The analysis should include simulations under present climatic conditions and anticipated future conditions to account for changes in climate and basin forest cover (due to potential effects of Mountain Pine Beetle infestation). The analysis should also include a risk analysis, which considers anticipated direct flood damages and indirect costs. The level of risk and appropriate design criteria for peak flow and associated freeboard requirements for dikes and developments should be assessed. Funding and governance arrangements for a major capital works program to rehabilitate the dikes and other mitigation options should be explored.

High priority should also be given to assessing all appropriate flood management strategies on the floodplain of the Fraser River and the institutional framework for implementation of those strategies. This should include the costs and benefits of both non-structural (land use planning, floodproofing practices, and emergency planning) and structural (flood protection dikes, erosion protection, river training structures, upstream storage, and dredging) flood management strategies.

The hydraulic model should be re-calibrated and verified if another large flood occurs (equal or greater than a 1972 flood event). This could confirm or revise the channel resistance coefficients used in the 2006 model. Model results are quite sensitive to variations in channel roughness. A 10% increase in roughness would, for example, increase water levels at Mission by a further 0.5 m. The model results are not highly sensitive to local topographic changes and it is anticipated the cross sections will not need to be updated for at least five to ten years unless an extreme flood occurs. The hydrometric gauging network on the river is an essential component for flood forecasting applications and for model calibration and verification. Secure funding is required to ensure these stations will be available in the future.

For more information about this issue, please contact Steve Litke, Program Manager, of the Fraser Basin Council's Integrated Flood Hazard Management Program at (604-488-5358) or slitke@fraserbasin.bc.ca.

VI. ATTACHMENTS

Summary of 2006 Modeled and 1969 Calculated Water Levels – Re-occurrence of the 1894 Flood Event

Municipality / Diking District	Location	2006 Modeled Water Level (m GSC)	1969 Calculated Water Level (m GSC)	Difference (m)
North Fraser				
City of Vancouver	West end UBC	2.88	2.62	0.26
	Burnaby border	3.03	2.68	0.35
City of Richmond	Sea Island: McDonald Slough	2.88	2.62	0.26
	Sea Island: West end at Middle Arm	2.89	2.62	0.27
	Middle and North Arm Confluence	2.89	2.62	0.27
	Terra Nova Park at Middle Arm	2.89	2.62	0.27
	New Westminster border	3.14	3.10	0.04
City of Burnaby	Vancouver border	3.03	2.68	0.35
	New Westminster border	3.26	3.17	0.09
City of New Westminster	Burnaby border	3.26	3.17	0.09
	Coquitlam border	4.24	3.95	0.29
City of Coquitlam	Burnaby border	4.24	3.95	0.29
	Port Coquitlam border	4.83	4.37	0.46
City of Port Coquitlam	Coquitlam border	4.83	4.37	0.46
	Pitt and Fraser Rivers confluence	5.08	4.50	0.58
	Pitt River at De Bouville Slough	4.90	4.57	0.33
District of Pitt Meadows	Pitt River at Sheridan Hill	4.90	4.57	0.33
	Pitt and Fraser Rivers confluence	5.08	4.50	0.58
	Maple Ridge border	6.05	5.11	0.94
District of Maple Ridge	Pitt Meadows border	6.05	5.11	0.94
	Whonnock Creek	7.69	6.71	0.98
	Mission border	7.96	7.00	0.96
District of Mission	Maple Ridge border	7.96	7.00	0.96
	Silverdale Creek	8.51	7.50	1.01
	Mission bridge	8.88	7.91	0.97
	FVRD border	9.30	8.40	0.90
FVRD	Mission border	9.30	8.40	0.90
	Nicomen Slough	9.84	9.05	0.79
South Fraser				
Corporation of Delta	Roberts Bank at Canoe Pass	2.87	2.59	0.28
	Massey Tunnel	2.93	2.65	0.28
	Surrey border	3.58	3.60	-0.02
	Westham Island: Roberts Bank at Canoe Pass	2.87	2.59	0.28
	Westham Island: Reifel Island at Ladner Reach	2.84	2.59	0.25
	Westham Island: Upstream end	2.88	2.59	0.29
City of Richmond	Steveston, Garry Point Park	2.84	2.59	0.25
	Massey Tunnel	2.93	2.71	0.22
	New Westminster Border	3.23	3.50	-0.27
City of New Westminster	City of Richmond Border	3.23	3.50	-0.27
	Trifurcation	3.84	3.60	0.24
City of Surrey	Delta border	3.58	3.60	-0.02
	Township of Langley border	5.91	5.05	0.86
Barnston Diking District	Barnston Island: downstream end	5.48	4.75	0.73

	Barnston Island: upstream end	6.03	5.11	0.92
Township of Langley	Surrey border	5.91	5.05	0.86
	Jacob-Haldi Bridge	6.97	5.95	1.02
	Abbotsford border	7.65	7.00	0.65
City of Abbotsford	Langley border	7.65	7.00	0.65
	Mission Bridge	8.88	7.91	0.97
	Sumas Mountain	9.65	8.84	0.81

Summary of 2006 Modeled and 2001 Modeled Water Levels – Re-occurrence of the 1894 Flood Event

Location	**2006 Modeled Water Level** (m GSC)	**UMA 2001 Water Level** (m GSC)	**Difference** (m)
Mission Bridge	8.89	7.99	0.90
D/S end Nicomen Slough	9.87	9.13	0.74
Confluence of Vedder Canal	10.29	9.61	0.68
D/S end Minto Channel	12.02	11.68	0.34
Confluence of Harrison River	13.69	13.52	0.17
Agassiz-Rosedale Bridge	18.80	18.79	0.01
U/S end Seabird Island	26.90	26.90	0.00
U/S extent of model	31.44	31.44	0.00

Relevant and Related Issues

Freeboard

Freeboard refers to an extra precaution that is typically added to the predicted design flood profile to account for uncertainty as well as other factors such as wave action. A freeboard of 0.6 m is typical in BC, meaning that dike crests are typically designed and constructed at an elevation 0.6 m higher than estimated water levels. When the expression “freeboard would be compromised” is used within this report, it refers to a circumstance where predicted water levels occur at an elevation that is within the 0.6 m of freeboard.

Dike Failure

Although this report and the final results of the 2006 hydraulic model identify specific locations where dike overtopping could occur, it is important to acknowledge that dikes can fail without being overtopped. For example, erosion, seepage, saturation and collapse are some of the processes by which dikes might fail prior to a situation where water levels overtop the crest of the dike. Therefore, it is important to emphasize that consideration be given to the overall strength and integrity of flood protection works in addition to concerns about overtopping of dikes by flood waters.

Sedimentation and Dredging

Some have cited dredging as a significant solution to managing the Fraser River flood risk. Dredging is a complex issue with varying relevance in different parts of the river. In some circumstances, rates of sedimentation of gravel and sand on the riverbed can have an influence on the flood profile, and similarly, dredging can – in some circumstances – contribute towards flood hazard management.

For example, river surveys and flood modeling in the Fraser River gravel reach (Hope to Mission) found that an increase in gravel deposition on the riverbed contributed to a rise in the flood profile. It is believed that gravel dredging may be a partial flood protection solution in this part of the river along with dike rehabilitation. If dredging is appropriate and approved, it should occur in strategic locations where flood protection benefits would result, and undertaken in a way that is sensitive to habitat and the environment. After substantial analysis and dialogue, a five-year agreement was signed by provincial and federal regulatory authorities to guide planning and decision-making with respect to gravel removal in the lower Fraser River. This agreement, developed with the best available technical information, outlines the timing, volumes and requirements of the permit approval process.

Although a comprehensive analysis of dredging scenarios was not within the scope of the 2006 hydraulic model study, sedimentation and dredging processes were considered within the sensitivity analyses. Regime bed scour elevations were estimated for the reach between Douglas Island and Mission, resulting in a minimal (0.13 m) reduction in predicted water levels. The effect of dredging and sedimentation on the flood profile was analyzed by simulating a significant reduction of dredging in the future and a subsequent rise in bed levels. For this analysis, bed levels were generally increased by 1 or 2 metres from Sandheads to Port Mann, resulting in an increase in predicted water levels of up to 0.4m at Port Mann and 0.1m at Mission.

Sedimentation and dredging processes appear to be even less influential in the lowest 28 km of the Fraser River, where the more significant flood threat is related to ocean storm surge events. Although dredging of the river channel might reduce the flood profile associated with the Fraser River freshet, it would not reduce the profile associated with the 1 in 200-year ocean winter storm surge, which is the dominant flood event that needs to be managed in this reach. The estimated peak water level (2.9 m GSC datum) is directly correlated to sea level, and would not be lowered with dredging of the channel.