eDoc 135995 (308 pp)

CITY OF PRINCE GEORGE




FLOOD RISK EVALUATION AND FLOOD CONTROL SOLUTIONS PHASE 1- FINAL REPORT

MAY 2009

nhc
northwest hydraulic consultants

McElhanney Consulting Services Ltd.
Environmental Dynamics Inc.
M. Miles and Associates Ltd.

CITY OF PRINCE GEORGE FLOOD RISK EVALUATION AND FLOOD CONTROL SOLUTIONS PHASE 1- FINAL REPORT

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May 2009
3-4920

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ACKNOWLEDGEMENTS AND CREDITS

This project is conducted under the guidance of Dave Dyer, P.Eng., Chief Engineer - City of Prince George, who throughout the project has provided information, direction and advice. Bob Radloff, P.Eng., Director Development Services and Dan Milburn, MCIP, Manager of Long Range Planning, both of City of Prince George, reviewed the report and provided valuable comments.

Background information and comments were received from Lyle Larsen, BC Ministry of Environment Water Stewardship Division. Input was also received from several environmental agencies and the assistance of Byron Nutton of Fisheries and Oceans Canada is gratefully acknowledged. Lynne Campo, Water Survey of Canada made available published hydrometric data and archived material. Input was also obtained from stakeholders in Prince George through open meetings organized by Steve Litke, Program Manager – Fraser Basin Council and Joan Chess, Manager, Upper Fraser Region of Fraser Basin Council. The Lheidli T'enneh First Nation assisted with field work and environmental investigations.

The development of flood control options and corresponding cost estimates were carried out chiefly by McElhanney Consulting Services Ltd. (MCSL), under the direction of Bill Cheung, P.Eng. Geomorphologic and sedimentology investigations were completed by Mike Miles, P.Geo. of M. Miles Associates Ltd. (MMA) and environmental investigations were undertaken by Environmental Dynamics Inc. (EDI), led by Rob Van Schubert, R.P.Bio. The project team was managed by Bruce Walsh, P.Eng. of Northwest Hydraulic Consultants Ltd. (NHC). Ice analyses were performed by David Andres, P.Eng. and NHC also undertook the hydrologic and hydraulic investigations, with modelling and graphics output completed by Guilherme de Lima, Ph.D. Project engineering was by Monica Mannerström, P.Eng. who compiled the report, with Charles Neill, P.Eng. and David McLean, P.Eng. providing an internal review. Kevin Brown Communications Ltd., although not directly involved in Phase 1 of the project, is also part of the team and will assist with the launch of this report and public consultations in Phase 2.

EXECUTIVE SUMMARY

Objectives and Background

The City of Prince George experienced severe ice-related flooding during the winter of 2007-08, when inundation of lands along the lower Nechako River caused extensive damage. This ice event had an estimated return period of about 90 years, meaning that such a high flood level can be expected to occur on average about once every 90 years. Just a few months before, in the spring of 2007, high water levels in the Fraser River had caused localized flooding of low-lying areas along the Fraser and in the area of the Nechako-Fraser confluence. This spring event had an estimated return period of about 20 years.

Prompted by these two events, the City of Prince George initiated the current study and retained a consulting team lead by Northwest Hydraulic Consultants Ltd. to evaluate flood risks and develop flood control solutions. The work is divided into two parts, with the first part focusing on evaluating flood risks and identifying flood control options (as described in this report), and the second part involving public consultations, and selection and development of preferred flood-control solutions.

In the Fraser River, flooding normally occurs in the spring, caused by melting of large snow-packs combined with sudden rises in temperature and/or heavy rains. In the Nechako River, on the other hand, the most critical condition is ice-related flooding that occurs during fall freeze-up. When November-December flows in the Nechako exceed a certain threshold and there is a prolonged period of cold weather, ice-related flooding may occur. Since 1957 the Nechako flow at Prince George has been partly regulated by Rio Tinto Alcan's Kenney Dam, almost 300 km upstream. The current mode of operating the reservoir tends to reduce winter flows during freeze-up and to delay the summer peak until after the Fraser River has peaked, thereby reducing the risks of both open-water and ice-related flooding.

Numerous fish species are found in the Nechako and Fraser Rivers, including different types of salmon and white sturgeon, an endangered species. Proposed flood control projects within and along the rivers must be approved by provincial and federal regulatory agencies before any work can proceed.

Project Approaches

The first step was to collect all relevant background information that could be used to assess flood risks and understand flood threats - such as past reports, historic air-photos, river flows and meteorological records. The river channel and floodplain were surveyed using the latest technology. Local residents provided general observations regarding channel changes. Environmental data such as information on fish habitat was also assembled.

To determine how a river has changed over time it is useful to look at consecutive historic air-photographs. The earliest air-photos of the Prince George area date from 1928. Later photos show how in the confluence area, floodplain zones were gradually subjected to urban development, backchannels were filled in, and vegetation extended on gravel bars (likely in response to the regulation of Nechako flows). However, a comparison of river cross-sections from 1979 and 2008 shows surprisingly little change in the main river channel itself. The hydraulic capacity of the channel remains much the same, and recent high floods do not seem to reflect significant changes to the flow regime or the river channel morphology. Effects on river flows of climate change and pine beetle infestations are presently undetectable, but could become significant in the future.

The BC Ministry of Environment (MOE) design standard for flood control works is the estimated 200-year flood level, plus a freeboard allowance (vertical separation between design flood level and top-of-dike) of 0.6 m to account for factors such as waves and uncertainty in the flood level estimate. This design level is called the Flood Construction Level (FCL) and is shown on the existing Prince George floodplain maps developed in 1997. The 200-year Nechako and Fraser water surface profiles were simulated and form the basis for designing flood control protection and updating the floodplain maps. Assuming a freeboard allowance of 0.6 m, the updated Nechako River FCL is on average 1.1 m higher than the 1997 levels and the Fraser River FCL is 0.3 m higher. These increases are the result of revised design flows and updated ice jam assessment techniques rather than changes to the river channels. A review of the 0.6 m freeboard allowance is recommended considering potential future changes to the design flows caused by pine beetle infestations, climate change and possible altered reservoir operating regimes.

Identified areas at risk of flooding within the City include seven locations along the Nechako and another seven along the Fraser. The areas near the confluence are vulnerable to both ice-related flooding from the Nechako and backwater flooding from the Fraser, and are considered to have the highest priority for receiving protection. Potential flood control options include:

1) River solutions such as gravel bar scalping, dredging and flood relief side-channels.
2) Building dikes or raising roads with provision for internal drainage and seepage prevention.
3) Land use changes.
4) Local flood-proofing.
5) Providing no permanent protection and continuing to rely on emergency protection.

Options were evaluated in terms of their technical performance, environmental impacts and overall costs (both direct and indirect). All options were assigned a general ranking to show which appear best suited for each area, then a filtering process was applied. All options remaining after filtering will go forward to public consultations.

Discussion of Flood Control Options

Gravel extractions can be effective for lowering flood levels in some rivers. After careful investigation it was concluded that this would not be the case at Prince George. Some gravel build-up has occurred in the confluence area and to some extent affects open-water profiles when Fraser water levels are low, it does not however affect the ice-related or backwater-generated design flood conditions. With respect to ice-related flooding, removing gravel would increase flow areas, which would reduce velocities and encourage more ice to accumulate. Similarly, the Fraser backwater condition from open-water floods would not be alleviated. Removals of up to 2 million cubic metres were modelled but did not provide a benefit. The effects of gravel removals are summarized in Appendix H of the report. The analyses took into account observed and surveyed channel changes, potential sediment supply sources, flow variations as a result of reservoir regulation and floodplain changes.

Enlarging existing side-channels or introducing new side-channels can reduce ice-related flood levels in the main channel downstream of the side-channel entrances, as long as the entrances and side-channels remain ice-free. The Cottonwood Island side-channel provided flood relief in the winter of 2007-08 and enlarging it to carry more flow would be beneficial.

Dikes alongside rivers are expensive because they have to be rock-protected against erosion and the protection must be maintained over time. They also tend to damage riparian habitat and to a limited extent raise flood levels. Dikes set back from the river are often preferable. During flooding, groundwater levels rise - any dike or road-raising project must consider groundwater seepage and provide internal drainage. Environmental permits are required for building dikes.

Land use decisions in the past have resulted in urban development within some highly flood-prone areas of Prince George. Land use changes, whereby properties are purchased and developments are removed, may be the best option for some locations. This was done in the Island Cache area after the large flood in 1972. The option is maintenance-free and offers opportunities to provide environmental compensation for developments elsewhere.

Local flood-proofing such as raising buildings, driveways, well-casings and septic fields may be practical for single-family developments.

Conclusions and Recommendations

Flood control options for each risk area were ranked based on costs, environmental impacts and other factors. The highest ranking options, for the risk areas listed in order of priority, are summarized in the attached Conclusions and Recommendations table, as well as shown on the Summary Map.

The complete suite of options for Prince George would have a total cost of about $35.4 M. The cost estimates provided in this report are order of magnitude estimates and will be refined following public consultations. Improvements to the Cottonwood Island side-channel are also recommended and the feasibility of a Nechako north shore flood relief side-channel should be assessed in detail.

It is recommended that the project proceed to public consultations, and selection and development of the preferred flood control solutions. The present floodplain maps are outdated and need to be revised.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS (C)	RECOMMENDATIONS (R)
Flood Risk Evaluation	
C1. The dominant 200-year flood threat at Prince George for the Nechako River from the City boundary to about 1,250 m downstream of Cameron Street Bridge (to cross-section N6) is ice-related flooding. Downstream of this section and throughout the Fraser River study reach, the Fraser freshet is the dominant 200-year flood threat.	R1. To provide an effective response during flooding, it is recommended that the City of Prince George develop a flood response plan which should, among other elements, include: a. A real-time forecasting procedure for Fraser River freshet floods using flows predicted by MOE's River Forecast Centre and the hydraulic model developed for this project. b. A tool to monitor antecedent conditions conducive to ice jamming, when flows are greater than 200 m^3/s in combination with prolonged cold periods of temperatures less than -5^oC. A continuous recording gauge should be introduced at John Hart or Cameron Street Bridge to provide accurate flow and water level information.
C2. Historic air-photograph comparisons of Nechako River from 1928 to present indicate: a. the floodplain has been extensively developed; b. many side-channels have filled in; and, c. the extent (size) of vegetated islands has increased. The floodplain and river channel configurations will continue to evolve in the future. The design profiles developed reflect present channel conditions and may be subject to change.	R2. During future large flow events, high watermarks should be recorded and checked against the current numerical models for both freshet and ice-related floods on the Nechako River and freshet events on the Fraser River.

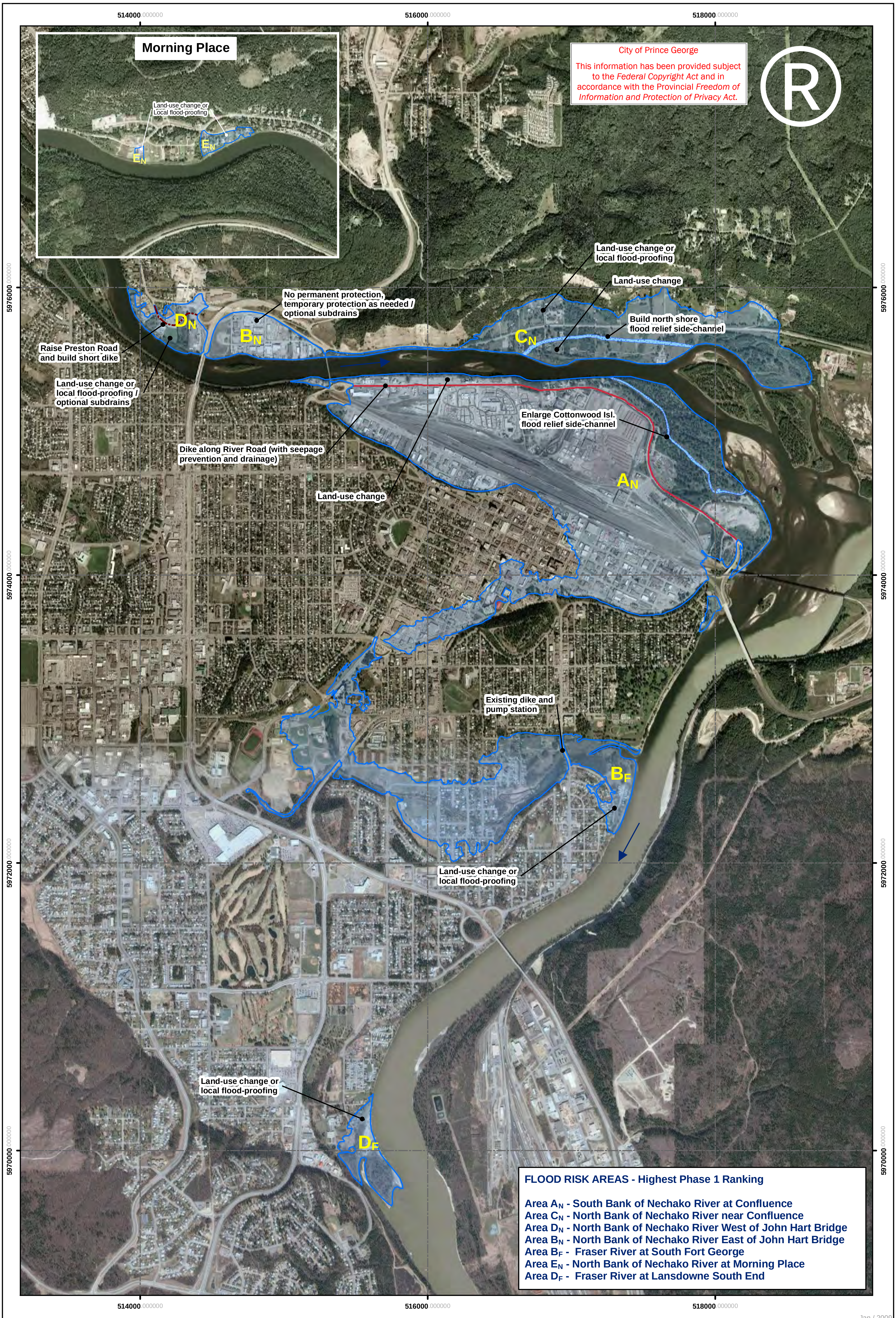
C3. Recent high ice-related and freshet flooding is not a result of river channel changes. A comparison of Nechako and Fraser River cross-sections from 1979/1995 and 2008 indicate: a. There is little change in terms of thalweg (lowest point) elevations, average bed elevations or cross-sectional areas. There is no evidence of significant aggradation or degradation, although the channel sections have changed shape as a result of gravel bar shifting. b. In the Nechako River, there is no apparent channel change upstream of the Foothills Bridge, some random increases and decreases in bed levels between the Foothills and John Hart Bridges and a general lowering of the bed downstream of Cameron Street Bridge. The most downstream cross-section (N1) shows some deposition. c. In the Fraser River, the thalweg at the CN Rail Bridge has in-filled, whereas the channel between the CN Rail Bridge and the Yellowhead Bridge has lowered. At the confluence (cross-sections F26 and F27), the average bed level has increased.	R3. In order to assess future channel changes more precisely, it is recommended that the river bed at the confluence be monitored. The 2008 grid bathymetric survey can be used as the baseline condition. Gravel storage and shifting of bars has taken place both before and after the construction of Kenney Dam. It should be recognized that this is a natural consequence of the flatter gradient within the lower Nechako River. Build-up of material may occur over a series of low/medium flow years with intermittent material removal during high flow years or ice-floods.
C4. Current operation of the Nechako Reservoir reduces the risk of flooding at Prince George. The present operating regime tends to lower winter flows during freeze-up which reduces the potential for ice-related flooding. In the spring, the reservoir delays the Nechako freshet peak by up to a month or until well after the Fraser River has peaked. Generally, the magnitude of the Nechako peak flow has been reduced by the operation of the reservoir.	R4. MOE in cooperation with Rio Tinto Alcan should be encouraged to predict the likely reservoir operations during a 200-year flood, so that the reducing effect on the design flow at Prince George can be estimated. Similarly, the extent to which flow releases can be reduced during freeze-up should be explored. If changes are introduced to the reservoir operation, the Nechako freshet and ice design flows need to be reviewed.

C5. The return periods of recent events are: a. Ice related (Nechako River) i. 2007-08 - estimated return period of 90 years. (In some instances, WSC reported flows at the different gauges along Nechako River appear not to add up in the downstream direction with reported tributary flows.) b. Freshet: (Fraser River) i. 2002 - estimated return period of 14 years; ii. 2007 - estimated return period of 19 years; iii. 2008 - estimated return period of 16 years.	R5. a) WSC should be requested to investigate apparent discrepancies in reported flows along the Nechako River, particularly for winter periods. b) The conversion to geodetic elevations at the Shelley gauge needs to be verified.
C6. Based on analysis of historic floods and available WSC flow records, the estimated 200-year design flows are: a. 1,450 m3/s for the Nechako River at Prince George (6% increase from the previous design flow used for the 1997 floodplain mapping). b. 5,660 m3/s for the Fraser River at Shelley (2% increase from previous design flow). c. 6,360 m3/s for Fraser River below Nechako River (3% increase from previous design flow).	R6. a) The analysis of hydraulic conditions on the Nechako and Fraser Rivers indicates a significant deviation from the previous design flood profiles. It is recommended that Prince George work with the Ministry of Environment to adopt the revised water surface design flood profiles. b) Considering the limited clearance of the CNR Bridge, CNR should be informed regarding the revised higher 200-year flood profile for the Fraser River.
C7. The floodplain mapping developed in 1997 is no longer valid. The primary reasons are: a. The previous study did not include ice modelling on the Nechako River. b. The updated design flows are higher, being based on longer record periods. c. On average, the Nechako River ice-related flood profile is 1.1 m higher than previously adopted. The revised Fraser River flood profile is on average 0.3 m higher. The rise in the profiles will expand the floodplain areas correspondingly.	R7. It is recommended that Prince George update the 1997 Floodplain Mapping based on the revised 200-year water surface profiles plus a freeboard allowance.

C8. Climate change and Mountain Pine Beetle infestation adds greater uncertainty to both winter and freshet flows. However, the recent above average freshet peaks and ice related flooding is unlikely the result of consistent change in the river basin or changing meteorological conditions. If a flow increase of 20% (assumed probable maximum) were to occur it would result in a corresponding average water level increase of 1.0 m for the Fraser River 200-year flood and 0.6 m for the Nechako River 200-year freshet flood.	R8. a) In consultation with MOE's Inspector of Dikes' office, an appropriate freeboard allowance for determining Flood Construction Levels at Prince George should be determined. A freeboard of 0.6 m, as generally assumed in this report, should be considered a minimum. In view of the increased uncertainty of climate change and Mountain Pine Beetle impacts, consideration should be given to increasing the Ministry of Environment standard freeboard allowance of 0.6 metres to 1.0 metres. b) More detailed hydrologic analysis and modelling would be required to examine how climate change and Mountain Pine Beetle infestation might change the flow regime in the Nechako and Fraser Rivers at Prince George. Results from current investigations of both factors by MOE's River Forecast Centre should be reviewed when available, and the need for additional work assessed.
Flood Control Solutions	
C9. Modelling various sizes and shapes of sediment removals (both bar scalping and dredging) for ice and open water conditions indicated that during 200-year flood conditions, the water surface profile does not change as a result of the removals. Sediment removals in the Nechako River would likely increase the amount of ice accumulation during ice-related flood events. The confluence ice levels and freshet backwater levels are set by the Fraser River hydraulic conditions below the confluence. Increasing the flow capacity of this steep, confined river reach through channel improvements is not practical.	R9. Sediment removal from the Nechako River or the Fraser River confluence is not considered a viable flood control solution for Prince George. Under present conditions, it is recommended that Prince George does not further pursue sediment removal from the main channels as a flood mitigation measure.
C10. Restoring and increasing the conveyance of Nechako River side-channels would reduce ice-related flood levels in the main channel downstream of the side-channel	R10. It is recommended that Prince George consider increasing the conveyance capacity of the Cottonwood Island side-channel by sediment excavation and debris removal. An

	entrances, as long as the entrances and channels remain ice-free. This applies to the existing Cottonwood Island side-channel and if land-use prescriptions allow, extension and recovery of the in-filled channel along the north bank.		inlet structure at the channel entrance would be required. If allowed by land-use change, reclamation of the side-channel previously in-filled by development along the north bank should also be considered.
C11.	Seven areas at risk of flooding were identified along the Nechako River and another seven along the Fraser River. The south and north banks of the Nechako River at the confluence are at greatest risk, since they are susceptible to flooding from both Fraser freshets and Nechako ice jams. Highest ranking solutions for the risk areas in order of priority are (order of magnitude cost estimates are shown in parenthesis): a. Area A_N - South Bank of Nechako River at Confluence - Build dike on river side of River Road, providing internal drainage and reducing groundwater seepage. Introduce land-use change north of River Road. ($15.5 M) b. Area C_N - North Bank of Nechako River near Confluence – Introduce land-use/zoning changes south of PG Pulpmill Road. On north side of road land-use change or local flood-proofing can be considered. ($9.3 M) c. Area D_N - North Bank of Nechako River West of John Hart Bridge - Raise Preston Road. Introduce land-use/zoning changes or local flood-proofing on river side of road. In the river side area, subdrains/ emergency protection may reduce flooding of buildings/basements.($1.2 M raising of road only) d. Area B_N - North Bank of Nechako River East of John Hart Bridge - No permanent protection, provide temporary protection as needed. Residents should be	R11.	a) It is recommended that the City of Prince George consider the solutions listed under Conclusion 11 and advance with the City's public consultation strategy. All options remaining after the medium filtering process (see Section 6.6) should be put forward for public consultation, with emphasis on the options that ranked the highest. b) Dike designs need to include internal drainage provisions and groundwater seepage prevention. c) Of all flood control solutions considered, land-use change involves the least maintenance and should be considered first where feasible. d) For evaluating environmental impacts of flood control solutions, it should be determined whether the Lower Nechako River is a sturgeon spawning area.

encouraged to include subdrains to reduce the potential for groundwater effects. Introduce land-use/zoning changes. e. Area B_F – South Fort George – Introduce land-use/ zoning changes as necessary. Optionally local flood-proofing can be considered in some locations. ($1.4 M) f. Area E_N – Morning Place – Introduce land-use/ zoning changes as necessary. Optionally, local flood-proofing can be considered in some locations. ($1.4 M) g. Area D_F – Lansdowne South End – Introduce land-use/zoning changes as necessary. Optionally local flood-proofing can be considered in some locations. ($0.8 M) h. Area F_N – South Bank of Nechako River at Foot Hills Bridge - Land-use/zoning changes as necessary. i. Area G_N – South Bank of Nechako River between John Hart and Foothills Bridges - Land-use/zoning changes as necessary. j. Area A_F – West bank at Yellowhead Highway - land-use/zoning changes as necessary. k. Area C_F – Hudson's Bay Slough west of Queensway – Review adequacy of existing protection. l. Area E_F – West Bank at Island – Undeveloped, introduce land-use/zoning changes as necessary. m. Area F_F – Northwood Pulp mill Road - Land-use/ zoning changes as necessary. Raise Landooz Road for access. ($5.8 M) n. Area G_F – Across River from Shelley - Land-use/ zoning changes.	



Note:
A total of 14 risk areas were identified.
Please refer to Phase 1 Report for lower priority areas.

0 0.25 0.5 1 1.5 2 Kilometres

Jan / 2009

Legend

1997 Floodplain (to be updated)

UTM Zone 10 (NAD 83) - Units: Metres
Notes: Satellite Images from Gogle Earth

City of Prince George nhc

Fraser River and Nechako River
Flood Control Solutions
(with Highest Phase 1 Ranking)

TABLE OF CONTENTS

1 INTRODUCTION 1
1.1 Background 1
1.1.1 Project Initiation 1
1.1.2 Previous Floodplain Mapping 2
1.2 Terms of Reference 2
1.2.1 Phase 1 – Flood Risk Evaluation 2
1.2.2 Phase 2 – Flood Control Solutions 4

2 BIOPHYSICAL DESCRIPTION 5
2.1 Study Area 5
2.2 River Morphology 5
2.2.1 Nechako River 5
2.2.2 Fraser River 5
2.3 Nechako Reservoir 6
2.3.1 Flood Reduction 6
2.3.2 Effects of Reservoir on Flow Regime and Morphology 7
2.4 Channel Changes 7
2.4.1 Nechako River 8
2.4.2 Fraser River 9
2.4.3 Present and Future Channel Conditions 10
2.5 Environmental Setting 11
2.5.1 General Description 11
2.5.2 Salmonid Habitat 12
2.5.3 White Sturgeon 13

3 OPEN WATER FLOOD HYDROLOGY AND HYDRAULICS 15
3.1 Historic Floods and Hydrometric Records 15
3.2 Fraser River Freshet Design Flows Upstream of Nechako River 16
3.3 Nechako River Freshet Design Flows 17
3.4 Fraser River Freshet Design Flows Downstream of Nechako River 19
3.5 Potential Future Impact of Climate and Basin Change 21

3.5.1 Climate Change 21
3.5.2 Mountain Pine Beetle 22
3.5.3 Change Predictions Applied to Flooding at Prince George 23
3.6 Hydraulic Analysis 23
3.6.1 Model Development 23
3.6.2 Model Calibration and Validation 24
3.6.3 Design Freshet Flood Profiles 25
3.6.4 Flood Profile Sensitivity Analysis 26
3.6.5 Design Frequency and Freeboard Assessment 27

4 ICE-RELATED WATER LEVELS 29
4.1 Basic Hydraulic Concepts 29
4.2 Generalized Freeze-up Processes 30
4.3 Ice-Related Flooding Assessment 31
4.3.1 Fraser River 31
4.3.2 Nechako River 32
4.3.3 Frequency Analysis of Peak Freeze-up Water Level 34
4.4 Effect of Climate and Basin Change 34
4.5 Effect of Gravel Removals 35

5 FLOOD RISK EVALUATION 36
5.1 Flood Threat Analysis 36
5.1.1 Flood Levels at Prince George 36
5.1.2 Floods in Fraser River 36
5.1.3 Floods in Nechako River 37
5.1.4 Ice-Related versus Open-Water Flood Levels 37
5.2 Identification of Risk Areas 38
5.3 Asset Inventory 39
5.3.1 General Description of Assets 39
5.3.2 Overview of Flood Risks to Assets 40
5.3.3 Nechako River Risk Areas 40
5.3.4 Fraser River Risk Areas 42
5.4 Assessment of Flood Threats 43

6 FLOOD CONTROL OPTIONS 45
6.1 Identification of Flood Control Options 45
6.2 Hydraulic Effectiveness of Flood Control Options 46
6.2.1 No Permanent Protection 46
6.2.2 Land Acquisition / Land Use Change 47
6.2.3 Internal Drainage 47
6.2.4 Individually Raise / Flood-proof Essential Developments 47
6.2.5 Reactivating / Modifying Side-Channels For Flood Relief 47
6.2.6 Diking - Setback Diking, Raising Existing Roads, Riverbank Diking 48
6.2.7 Instream Sediment Removal 49
6.2.8 Upstream Flow Control 50
6.3 Environmental Considerations 51
6.3.1 No Permanent Protection 51
6.3.2 Land Acquisition / Land Use Change 51
6.3.3 Internal Drainage 52
6.3.4 Individually Raise / Floodproof Essential Development 52
6.3.5 Reactivating / Modifying Channels for Flood Relief 52
6.3.6 Diking - Setback Diking, Raising Existing Roads, Riverbank Diking 52
6.3.7 Instream Sediment Removal 53
6.4 Initial Review of Flood Control Options 54
6.5 Description of Selected Flood Control Options 55
6.5.1 Nechako River 55
6.5.2 Fraser River 61
6.6 Assessment of Flood Control Options (Medium Filtering) 63
6.6.1 Financial Costs 63
6.6.2 Environmental Impacts 63
6.7 Ranking of Flood Control Options 64

7 PHASE 2 WORK PROGRAM 68
7.1 Completion of Phase 1 68
7.2 Public and Related Consultations 68
7.3 Tentative Flood Control Solutions 68

7.4 Final Reporting 69
7.5 Floodplain Maps 70

8 CONCLUSIONS AND RECOMMENDATIONS 71

9 REFERENCES 77

10 GLOSSARY 83
10.1 Abbreviations 83
10.2 Technical Terms 83

LIST OF TABLES

Table 2.1 Nechako River Thalweg Elevation Changes
Table 2.2 Nechako River Average Bed Elevation Changes
Table 2.3 Nechako River Flow Area Changes
Table 2.4 Fraser River Thalweg Elevation Changes
Table 2.5 Fraser River Average Bed Elevation Changes
Table 2.6 Fraser River Flow Area Changes
Table 2.7 General Migration and Spawning Timing Windows for Sport Fish or Fish of Special Concern Documented within the Study Area
Table 3.1 Historic Freshet Flooding at Prince George
Table 3.2 Water Survey Canada Key Gauges
Table 3.3 Nechako Calibration/Validation
Table 3.4 Fraser Calibration/Validation
Table 3.5 Nechako Freshet Design Water Surface Profiles
Table 3.6 Fraser Freshet Design Water Surface Profiles
Table 3.7 Nechako 200-Year Open Water Surface Profile – Sensitivity to Roughness and Flow Variation
Table 3.8 Fraser 200-Year Water Surface Profile – Sensitivity to Roughness and Flow Variation
Table 4.1 Freeze-Up Data, Fraser River at Prince George
Table 4.2 Summary of High Ice-Related Water Levels on the Nechako River at Prince George
Table 4.3 Summary of ^{o}C-Days of Freezing
Table 4.4 Summary of Ice-Related Water Levels for a Range of Return Periods
Table 5.1 Nechako Freshet Design Water Surface and Ice Profiles with FCL's
Table 5.2 Fraser Freshet Design Water Surface Profiles with FCL's
Table 6.1 Environmental Considerations and Anticipated Applicable Legislation by Flood Control Option
Table 6.2 Flood Control Solutions – Nechako River
Table 6.3 Flood Control Solutions – Fraser River
Table 6.4 Flood Control Solutions – Cost Analyses

LIST OF FIGURES

Figure 2.1	Location Map
Figure 2.2	Comparison of Nechako River Cross-Sections, N1-N5
Figure 2.3	Comparison of Nechako River Cross-Sections, N6-N33
Figure 2.4	Nechako River Bed Changes
Figure 2.5	Aggradation / Degradation Comparison
Figure 2.6	September 2, 1928 Air Photos of Prince George
Figure 2.7	1946 Air Photo Mosaic Showing 1948 Flood Limits
Figure 2.8	2006 Air Photo Mosaic Showing 1948 Flood Limits
Figure 2.9	Historical Changes in Channel Conditions, Nechako River Upstream of the Fraser River Confluence 1946-2006
Figure 2.10	Comparison of Fraser River Cross-Sections
Figure 2.11	Fraser River Bed Changes
Figure 2.12	Historical Changes in Channel Conditions, Fraser River in the Vicinity of the Nechako Confluence (1946-2008)
Figure 3.1	Fraser River at Shelley, Annual Peak Flows 1950-2007
Figure 3.2	Nechako River at Isle Pierre, Annual Peak Flows 1950-2007
Figure 3.3	Fraser River at South Fort George, Annual Peak Water Levels 1947-2007
Figure 3.4	Nechako/Fraser River Timing of Freshet Peak
Figure 3.5	Fraser River at Shelley, Monthly Flows
Figure 3.6	Nechako River at Isle Pierre, Monthly Flows
Figure 3.7	Fraser River at South Fort George, Monthly Water Levels
Figure 3.8	Nechako and Fraser Rivers, Extent of LiDAR Survey
Figure 3.9	Nechako River 200-Year Open Water Surface Profiles
Figure 3.10	Nechako River Open Water 20-Year and 200-Year Flood Profiles
Figure 3.11	Fraser River 200-Year Open Water Surface Profiles
Figure 3.12	Fraser River 200-Year and 20-Year Water Surface Profiles
Figure 3.13	Nechako River 200-Year Open Water Surface Profiles - Sensitivity to Roughness Variation
Figure 3.14	Fraser River 200-Year Open Water Surface Profiles – Sensitivity to Roughness Variation
Figure 3.15	Nechako River 200-Year Open Water Surface Profiles - Sensitivity to Flow Variation
Figure 3.16	Fraser River 200-Year Open Water Surface Profiles – Sensitivity to Flow Variation
Figure 4.1	Schematic of Ice Cover Formation, Profile
Figure 4.2	Schematic of Ice Cover Formation, Cross-Sections
Figure 4.3	South Fort George Freeze-Up Date
Figure 4.4	Fraser River Freeze-Up Conditions
Figure 4.5	Freeze-Up Degree-Day Frequency Curve
Figure 4.6	South Fort George Open Water and Ice-Related Rating Curves
Figure 4.7	Nechako River Conditions for Ice-Related Flooding
Figure 4.8	Nechako River Reported Ice-Related Water Levels

Figure 4.9 2007 Recorded Ice-Related Water Levels, Nechako River
Figure 4.10 Cameron Street Bridge Rating Curves
Figure 4.11 Ice Cover Advancement, 1996 and 2007
Figure 4.12 Degree-Days of Freezing Frequency Curve
Figure 4.13 Nechako Post-Freeze-Up Flow Probability
Figure 4.14 Historical Freeze-Up Elevation Frequency Curve
Figure 5.1 Nechako River Open Water and Ice-Related Flood Profiles
Figure 5.2 Nechako River Extent of Open Water and Ice-Related Flood Conditions
Figure 6.1 Nechako River Gravel Removal
Figure 6.2 Nechako River Gravel Deposition
Figure 6.3 Flood Control Solutions – Nechako Area A_N
Figure 6.4 Flood Control Solutions – Nechako Areas B_N and D_N
Figure 6.5 Flood Control Solutions – Nechako Area C_N
Figure 6.6 Flood Control Solutions – Nechako Area E_N
Figure 6.7 Flood Control Solutions – Fraser Area B_F
Figure 6.8 Flood Control Solutions – Fraser Area D_F

List of Maps

Map 1 Fraser River above Nechako River Cross-Section Locations
Map 2 Nechako River Cross-Section Locations
Map 3 Fraser River below Nechako River Cross-Section Locations
Map 4 Flood Risk Areas - Fraser River Upstream of Nechako Confluence
Map 5 Flood Risk Areas - Nechako River
Map 6 Flood Risk Areas - Fraser River Downstream of Nechako Confluence

List of Appendices

Appendix A Terms of Reference
Appendix B Fluvial Geomorphology
Appendix C Environmental Setting
Appendix D Flood Frequency Analyses
Appendix E Detailed Ice Analyses
Appendix F Initial Flood Control Solutions – Progress Report 1
Appendix G Groundwater Report by Thurber Engineering Ltd.
Appendix H Discussion of Gravel Removals at Nechako-Fraser Confluence

1 INTRODUCTION

1.1 BACKGROUND

1.1.1 PROJECT INITIATION

Some parts of City of Prince George were flooded during the 2007 spring freshet and others during the ice jam in the winter of 2007-08. The freshet flooding affected lands at the confluence of the Fraser and Nechako Rivers, along the Fraser River at Landooz Road, and the Farrell Crescent and Regents Crescent areas. The Nechako River ice jam flooded residential properties in the areas of PG Pulpmill Road, Pozer Road, Preston Road and Morning Place. Flooded industrial areas included North Nechako Road, Ongman Road, McAlhoney Road, River Road, Foley Crescent and Kelliher Road. One of the City's water supply wells was threatened, but not affected because of flood-proofing improvements made around 1999.

Some freshet flooding of the Fraser River floodplain occurs about every five years. The last major flood (return period greater than 50 years) occurred in 1972, after which the residents of the Island Cache area at the confluence were relocated and the residences removed.

Severe ice jam flooding on the Nechako River has been recorded 12 times since the early 1900's (Klohn-Crippen 1997). The 2007-08 ice-related flood levels appear to have exceeded any observed over at least the past 50 years. On two occasions during the event (December 31, 2007 and January 5, 2008) ice levels breached temporary berms and sand-gabion dikes that had been constructed to the 200-year flood level. During the event Northwest Hydraulic Consultants Ltd. (NHC) provided on-going advice, McElhanney Consulting Services Ltd. (MCSL) were involved with designing and implementing emergency flood protection, and Environmental Dynamics Inc.(EDI) provided environmental monitoring.

These recent events initiated the need to review the risk of both freshet and ice-related flooding, especially at the Nechako/Fraser confluence where several industries, the CN railway yard and inter-modal facility, and much of the downtown area are at risk of flooding. Severe freshet and ice-jam conditions give cause not only high surface-water levels but also high groundwater levels and consequent local flooding in various parts of the floodplain.

As in 2007, flooding in Prince George in any year can result from either high freshet flows or ice jamming. Typically, spring freshets cause more severe flooding in the Fraser River, whereas ice jamming is more critical for the Nechako River and typically causes flooding during freeze-up. In most years, the Nechako ice cover at Prince George forms as frazil floes[1] that accumulate against the ice cover on the Fraser River. The probability of high ice-related water levels along the Nechako is related to the combined probability of cold temperatures and high Nechako flows during the freeze-up period. The City of Prince George is proceeding with a flood risk evaluation and flood control solutions project to consider the long term options to reduce the risk of flooding and to protect floodplain lands within the City.

[1] Technical terms are defined in Section 10 – Glossary of Technical Terms.

1.1.2 *PREVIOUS FLOODPLAIN MAPPING*

BC Ministry of Environment (MOE) prepared floodplain maps for Prince George in 1983. The maps were updated by Klohn Crippen in 1997 in the form of 12 map sheets and a design brief. The updated mapping followed MOE standard procedures and was reviewed and adopted by MOE.

The 1997 maps were based on hydraulic modelling using river cross-sections surveyed in 1979 and 1995. There was no overlap of 1979 and 1995 cross-sections, and potential channel changes over the intervening years could not be identified. The 1997 hydraulic model was calibrated to high water marks from 1972 and 1990.

Ice-jam modelling was not included in the 1997 study, although it was recognized that ice jamming on the Nechako River could cause higher flood levels than freshet conditions. A contingency for ice conditions was provided by increasing the standard freeboard allowance from 0.6 m to 1.8 m in the reach upstream of Cross-Section 7 (which is roughly 750 m below Cameron Street Bridge). This freeboard increase was based primarily on water levels observed during the 1996 jam. Downstream of Cross-Section 7 (**Map 1**), where freshet conditions were determined to generate more severe conditions, the standard freeboard of 0.6 m was adopted.

In view of the 2007 ice jam flooding, recent relatively high freshet flows, and possible channel changes within the confluence area, City of Prince George decided it was necessary to review and update the 1997 floodplain maps.

1.2 TERMS OF REFERENCE

The present study is divided into two phases. Phase 1 consists of a comprehensive flood risk evaluation as described in this report. Phase 2, the development of conceptual flood control solutions, will commence after release of this Phase 1 report and is scheduled to be completed in the next six months. Terms of reference for both phases are summarized below.

1.2.1 *PHASE 1 – FLOOD RISK EVALUATION*

The City of Prince George, prepared the complete Terms of Reference for the project as included in **Appendix A**. The scope of work for the Phase 1 component includes:

- Risk Analysis
- Feasibility Assessment
- Preparation of Summary Report

Risk Analysis

The risk analysis was summarized in Progress Report 1 issued in June, 2008. For completeness, key findings from the progress report are incorporated in the present report.

The risk analysis was broken into five stages:

- Threat Analysis - use available information to determine how often specified events occur and the magnitude of the consequences.
- Consequence Analysis – review infrastructure, residential, commercial and industrial assets potentially at threat within the floodplain.
- Flood Relief Options – categorize floodplain areas prone to flooding and identify flood relief options for these areas, together with conceptual-level costs for the purpose of comparative analysis and priority setting.
- Priority Setting – use a decision-matrix, benefit-cost analysis or other suitable method to prioritize the flood relief options, considering public safety, environmental impact, land values, economic impact, life-cycle cost of mitigation measures, etc; prepare priority assessment.
- Coarse Filtering – summarize results of the above analysis in a report, with the objective of eliminating flood relief options not recommended in view of the risk analysis or further investigation of mitigation measures during the feasibility assessment; present options for further analysis in the feasibility assessment.

Feasibility Assessment

The Terms of Reference (see **Appendix A** for details) specified that following the risk analysis, a feasibility assessment should be conducted for the recommended flood relief options, encompassing:

- Data Collection and Review
- Hydrological Analysis
- Soils and Geotechnical Investigation
- River Hydraulics, Freshet and Ice-Related Flooding Analysis
- Environmental Impacts
- Floodplain (Internal) Drainage Considerations
- Property Acquisition
- Medium Filtering

As part of the feasibility assessment, the City of Prince George retained Thurber Engineering Ltd. to carry out soils and geotechnical investigations. Results of this work were presented under separate cover (Thurber Engineering 2008) and are mentioned in Section 6.2.3. The findings from the other components of the feasibility assessment are summarized in this report and will be presented to City of Prince George staff and to the Mayor and Council.

1.2.2 PHASE 2 – FLOOD CONTROL SOLUTIONS

Phase 2 encompasses participation in public consultations and a selection of flood control solutions:

Public Consultations

Public meetings are planned for shortly after the release of the Phase 1 report. Input from these meetings will be used to select viable flood control solutions.

Selected Flood Control Solutions

Summarize the results of the public consultation process and revise previously recommended solutions for flood control and risk reduction. Specific tasks include:

- Flood Control Infrastructure – based on the flood risk evaluation and public consultations, identify and evaluate the proposed infrastructure measures complete with cost estimates (Class D) and timelines for property acquisition, regulatory approvals, design and construction.
- Land Use – identify land use changes that are considered necessary on the basis of the risk analysis and the feasibility assessment, providing timelines and implementation strategies.
- River Solutions – as required, review with regulatory agencies any in-river solutions (such as gravel extraction and flood relief side-channels) that satisfy the risk analysis and feasibility assessment; identify processes required to obtain approvals, with cost estimates and timelines.
- Floodplain Mapping (outside present budget) – based on the river hydraulics and ice-related flooding analyses and in conjunction with the BC Ministry of Environment, prepare revised floodplain mapping for the City of Prince George; mapping to be prepared in accordance with the Fraser Basin Council Floodplain Mapping Guidelines and Specifications, March 2004, in digital format compatible with the City's GIS Mapping system. A design brief supporting the analysis is to accompany the mapping.

2 BIOPHYSICAL DESCRIPTION

2.1 STUDY AREA

The City of Prince George, with a population of roughly 80,000, is situated at the confluence of the Fraser and Nechako Rivers. The Lheidli T'enneh (People of the Confluence) First Nation has inhabited the Prince George area for millennia. European settlement began when the North West Company established a fur trading post at Fort George in 1807 but it was not until 1909 that the town sites at South and Central Fort George were settled and in 1915 the City of Prince George was founded. The study area is shown in **Figure 2.1** and encompasses the area within the Prince George city boundaries.

The Fraser River drainage area at Shelley, just upstream of Prince George, is 32,400 km^2. The considerably larger Nechako River basin of 47,100 km^2 is partly regulated by Kenney Dam and a portion of the runoff is diverted to the Kemano power-plant. The Nechako River freshet mean annual peak flow is only about one quarter of the Fraser peak flow.

2.2 RIVER MORPHOLOGY

2.2.1 NECHAKO RIVER

The lower Nechako River can generally be characterized as having a riffle-pool morphology. Most of the mainstem channels are characterized by coarse substrates complicated by backeddies, riffles and shallow pools. The lower Nechako River has two large island complexes, Cottonwood Island and Fish Trap Island, and one permanent tributary, McMillan Creek. McMillan Creek enters the Nechako approximately 3 km upstream from the mouth, near the Cameron Street Bridge. There are also three off-channel sloughs: at Fish Trap Island, near Howie's Marine boat launch, and near the upstream end of the study area.

The reach-average channel slope is 0.8 m/km. The bank-full width of the channel is typically 150 to 200 m, but is wider and divided into multiple channels in the confluence area. Velocities range from 1.8 to 2.0 m/s at low flow and up to 3.6 m/s at flood flows.

2.2.2 FRASER RIVER

The Fraser River upstream of the Nechako confluence has an irregularly meandering pattern, with a few large islands and some point bars. The channel has historically been laterally unstable and shows evidence of large meander scrolls. Downstream of the confluence the channel has a more sinuous and incised form, without islands and only limited side bars. This reach appears to have been quite stable over time. The confluence area is very wide, perhaps three times the expected regime width, and contains large gravel bars.

The river has an average slope of roughly 0.25 m/km upstream and 0.47 m/km downstream of the confluence. The channel width averages about 400 m upstream of the confluence, increasing to 800-900 m at the confluence and then reducing to about 300 m downstream.

Flow velocities range from 1.5 to 2.0 m/s upstream and 2.5 to 3.5 m/s downstream during design flood conditions.

Within the City Limits, the morphology of the Fraser River can be characterized as large channel glide. Large-scale biophysical assessments of the Fraser River have typically delineated a reach break at the confluence of the Nechako River, where there is a distinct increase in discharge (Nowotny and Hickey 1993). The banks and nearshore areas of the upstream reach are dominated by fine substrates, whereas those of the downstream reach consist primarily of embedded cobbles and coarse gravel. Fraser River tributaries within the City Limits include Rancheree Creek entering Fraser Vista (Goose) Slough, Foreman Creek, Bittner Creek, Parkridge Creek, Haggith Creek, Brodman Creek, two unnamed creeks and Hudson’s Bay Slough.

2.3 NECHAKO RESERVOIR

2.3.1 FLOOD REDUCTION

Kenney Dam was built in 1952, and since 1957 the Nechako Reservoir behind the dam has been fully regulated. Rio Tinto Alcan is in charge of reservoir operation and diverts a portion of flow to Kemano for power generation. The reservoir amalgamates and redirects several watersheds. The rivers and lakes of Ootsa, Intata, Whitesail, Chelaslie, Tetachuk, Tahtsa and Natalkuz were linked to form a reservoir area of over 900 km^2. Flow releases to the Nechako River are controlled at the Skins Lake spillway. Kenney Dam is located about 295 km above the Nechako/Fraser confluence and controls only about one-third of the Nechako drainage area, but this portion has the highest unit run-off. The Nautley River, draining Francois Lake and Fraser Lake, enters the Nechako River upstream of Vanderhoof. The Stuart River, draining Stuart Lake, flows into the Nechako between Vanderhoof and Isle Pierre (Insert, **Figure 2.1)**.

The operating procedure of the Nechako Reservoir has changed over time. Initially, powerhouse flows were lower than at present because of a lower installed generating capacity. In the early 1980’s monthly minimum flows and cooling flows were imposed to reduce summer water temperatures in the Nechako River. Future inflows to the Nechako reservoir may not be significantly different from those in the past, but outflows at Skins Lake, which reflect past operating conditions, could change further in the future.

Rio Tinto Alcan is not legally bound to operate the reservoir for flood reduction purposes. However, the present operating guidelines, in contrast to those of the early 1960’s that resulted in relatively high winter releases, tend to reduce winter flows in order to avoid ice-jam flooding in Prince George. Also, during critical years, the reservoir has been operated for freshet flood relief, reducing and delaying the Nechako peak flow and thereby reducing flood flows as far downstream as Vancouver (NHC 2008a).

2.3.2 Effects of Reservoir on Flow Regime and Morphology

In general, reservoir regulation reduces flood peaks and reduces or eliminates sediment supply from upstream of a dam. The Nechako Reservoir diverts flow to Kemano, also affecting mean and minimum discharges released to the Nechako River. Reid Crowther & Partners and NHC (1987) evaluated changes to the flow regime and geomorphology introduced by Kenney Dam in the reach between Cheslatta Falls and Vanderhoof. As expected, the changes were found to be more pronounced near the dam, reducing in the downstream direction as more unregulated flow enters the system. The average annual flood at Vanderhoof was estimated to be about 50% of the pre-regulation average. As the return period of the annual flood increases, the reduction becomes less - based on data for 1957-79, the 100-year flood was estimated to be 90% of the pre-regulation value. The duration of a given flood flow was also found to be reduced, and the time of the peak was delayed from June to July.

The relationship between regulation and downstream channel morphology is not well understood and the rate of response, as well as the time required for adjustment to a new equilibrium, is unclear. In some reaches of the Nechako River, accumulation of sediment occurred long before construction of the dam. Regulation appears to have induced a change in the rate of sediment accumulation, but without knowing previous natural rates it is difficult to estimate changes induced by regulation. Reid Crowther & Partners and NHC (1987) reported a reduction of channel width (mainly through vegetation encroachment), a reduction in the total length of active backchannels, and some accumulation of sand and fine gravels in the Cheslatta Falls-Vanderhoof reach. The report recommended future sediment sampling and monitoring of cross-sections and vegetation extent.

NHC (2003) extended the geomorphic assessment to the Vanderhoof-Isle Pierre reach as part of a White Sturgeon habitat evaluation. The average annual flow at Isle Pierre was estimated to be 63% of the pre-regulation flow. The study did not detect evidence of large scale geomorphic change downstream of Stuart River as far as Isle Pierre. The effects of the reservoir on gravel accumulation, fish habitat and other environmental factors at Prince George are difficult to determine. As will be discussed in Section 2.5, the river still provides high salmonid habitat ratings, and white sturgeon is still found in the river although the population is declining.

2.4 Channel Changes

Channel changes in the Nechako and Fraser River channels within the City limits were reviewed in order to examine how the local geomorphology, flow capacity and ice processes may have changed over time and what future characteristics can be predicted. Repeat channel surveys were compared, historic air-photography reviewed, specific gauge analyses conducted and sediment sources identified. Separate reports (MMA 2008a and MMA 2008b) detail the air-photography review and the sediment source investigations.

River cross-sections established for previous floodplain mapping studies were re-surveyed to provide current information on channel bathymetry, as described in Section 3.6.1. Locations of the surveyed sections are indicated on **Maps 1 to 3**.

All these investigations are described or summarized below.

2.4.1 NECHAKO RIVER

Cross-Section Comparison

The 2008 Nechako River cross-sections are compared with the 1979 and 1995 cross-sections in **Figures 2.2** and **2.3**. Changes in the long profile (as indicated by the channel thalweg and average bed elevation) are illustrated in **Figure 2.4 a** and **b**. These data are also listed in **Tables 2.1** and **2.2**, respectively. The percentage change in channel area below the predicted elevation of the 20-year flood has also been calculated (**Table 2.3** and **Figure 2.4 c**).

The above analyses indicate that channel morphometry has not changed significantly upstream of approximately HEC-RAS Station 8,000 m (or Cross-Section N21). In the section of channel between Stations 8,000 m and 2,000 m (Cross-Section N21 to N4) the thalweg elevation has lowered by up to 1.5 m since 1979 (or 1995, depending on the Section) and the average river bed elevation has lowered by a maximum of 0.74 m at Station 2938 m (Cross-Section N6). These changes have resulted in a 15% increase in channel cross-sectional area.

In the area downstream of Station 2000 m (Cross-Section N4), the thalweg elevation has risen at two sections (N1 and N3), the average bed elevation has lowered slightly (N3) or remained about the same (N1 and N2), and the channel cross-section area has increased by up to 6% (N3), remained the same (N2), or decreased by 6% (indicating aggradation) at N1.

The results are also shown in plan view in **Figure 2.5**. The figure assumes that the aggradation (bed rise) or degradation (bed lowering) reported at a section extends halfway to the next upstream and downstream sections. The results for the thalweg elevation, average bed elevation and flow area do not always agree, since the changes are typically quite small. However, there is some indication of aggradation at Cross-Section N1 and general degradation from N2 to N11.

A specific gauge analysis at Isle Pierre, 61 km upstream of the confluence (as described in **Appendix B)** did not show significant trends in the relationship of water level to discharge and indicates that the channel at the gauge site is probably stable.

Air-Photography Interpretation

The earliest available air photography of Prince George was flown in 1928 (**Figure 2.6**). This imagery illustrates the sizeable distributary channels which formerly existed along the lower Nechako River near the Fraser River confluence. These secondary channels provided flood conveyance capacity, particularly when the main channel was frozen over, and also potential fish habitat. Subsequent urban development has substantially reduced the number and size of these features. **Figures 2.7** and **2.8** compare the 1948 flood limits[2] with river conditions in 1946 and 2006, further illustrating the loss of both floodplain areas and secondary channels. The lost flood storage and conveyance capacity cannot be readily restored without reversing land use decisions made over the last 50 years.

A separate report (MMA 2008a) compiles a series of historical airphotos for the Nechako River between the Foothills Bridge and the Fraser River confluence, spanning the period between 1946 and 2008. This analysis documents the development of vegetation on previously barren gravel bars, and some loss of secondary channels flowing around instream bars or islands due to sediment deposition or vegetation growth.

The largest change in channel characteristics along the lower 10 km of the Nechako River has occurred near the Fraser confluence (**Figure 2.9)**. These photographs illustrate post-1946 land use encroachments into the floodplain, vegetation development on former gravel bars, the loss of small secondary channels and the recent formation of a mid-channel gravel bar in the vicinity of River Km 294 (below Kenney Dam). This area, illustrated on **Plate B.1** in **Appendix B**, is located between Sections N2 and N3 and is poorly defined by the available cross-sectional data. Gravel storage and shifting of bars has taken place both before and after the construction of Kenney Dam and is a natural consequence of the flatter gradient within the lower Nechako River. Build-up of material may occur over a series of low/medium flow years with intermittent material removal during high flow years or ice-floods.

Sediment Sources and Bed Material Transport

A separate report (MMA 2008b) describes sediment sources to the Nechako River in the 35 km length of channel between the Chilako River confluence and Prince George. Key components of this work are included in **Appendix B**. The analyses indicate that there are significant sediment source areas in lower Nechako River which cannot be readily stabilized. These sites erode during periods of high flow and the resulting sediment load (as well as that derived from farther upstream) is gradually conveyed downstream.

Calculations were undertaken to estimate the bed material transport capacity of the Nechako River for a range of discharges, as summarized in **Appendix B**. Actual loads are supply dependent and were not assessed. The calculated potential transport capacity is highly dependent on the assumed material size. Large fluctuations occur in the calculated annual loads, implying that unusual floods such as the 2007 freshet considerably exceeded threshold conditions and resulted in a substantial capacity to transport bed material.

2.4.2 FRASER RIVER

Cross-Section Comparison

Fraser River cross sections used in the analysis are illustrated on **Maps 1** and **3** and are compared in **Figure 2.10**. Changes in thalweg elevation, average bed elevation, and cross-

[2] From Klohn-Crippen, 1997.

sectional area below the predicted 20-year flood elevation were computed. The data are compiled in **Tables 2.4** to **2.6** and the results are illustrated in **Figure 2.11**.

The area of most interest to this study is located between the Nechako confluence and the Yellowhead Bridge (Sections F27 to F20.3). The surveys indicate that the channel thalweg at the Grand Trunk Pacific Railway Bridge (**Plate B.8 – Appendix B**) infilled locally by 0.9 to 2.3 m (at cross-sections F23 and F25, about 30 m apart). Other areas showed random rises and falls in the thalweg. Changes in the average bed elevation ranged from a drop of 0.8 m between the Yellowhead and Grand Trunk bridges (Cross-Section F22) to a rise of 0.3 m adjacent to the Nechako confluence. Changes in channel cross-section area range from a decrease of 4% at the railway bridge (indicating aggradation) to an increase of 3% (indicating degradation) between the two bridges. The results are shown in plan view in **Figure 2.5**. Again, there are inconsistencies between the three sets of comparisons because the changes are relatively small.

A specific gauge analysis for the Water Survey Canada gauge at Shelley, 23 km upstream of the confluence (**Appendix B)** showed no indications of a time trend, implying that there has been no significant scour or fill in the Fraser River in that vicinity over the period of record.

Air Photography Interpretation

As previously noted, substantial land use and channel changes have occurred since 1946 along the Fraser River in the vicinity of the Nechako River confluence. As illustrated in **Figure 2.12**, the right (north) abutment of the Yellowhead Bridge extends into the river channel. Land development has also infilled secondary channels and floodplain areas upstream of the bridge.

Comparison of photos from 1946 and 2003 indicates the development of a series of gravel bars at the Grand Trunk Pacific Railway Bridge. These features are not evident on the 2008 airphotos, which were flown during a period of higher river discharge.

Sediment Sources

A separate report (MMA 2008b) describes sediment sources to the Fraser River in the 35 km length between the Salmon River confluence and Prince George. As summarized in **Appendix B,** the two largest sources are the Salmon River, conveying bedload, and a rapidly eroding fluvial terrace 30 km upstream of Prince George. The potential for material from these sources to be deposited at the Nechako River confluence cannot be quantified without detailed sediment transport modelling.

2.4.3 PRESENT AND FUTURE CHANNEL CONDITIONS

Early air-photographs from before construction of Kenney Dam show an active fan at the confluence with Fraser River, with shifting gravel bars and side-channels. According to public perception, significant sediment accumulation has occurred in this area in recent years.

The cross-section comparison suggests some build-up on Nechako River immediately upstream of Fraser River (Cross-Section N1) and some accumulation on Fraser River at the confluence (Sections F26 and F27) over the past thirty years, whereas Nechako and Fraser River cross-sections elsewhere show no change or a general lowering of the bed. Since only two sets of surveys are available, intervening changes are unknown and the observed changes could be the result of recent high flows in the Nechako River. The Fraser River downstream of the confluence is relatively steep and has a high bedload transport capacity, so that the confluence area may undergo change after the next large Fraser freshet. The airphoto analysis provides a useful qualitative overview but cannot provide quantitative results.

Future channel conditions in the lower Nechako River will be affected by land use, climate change, sediment availability, vegetation evolution and the operating regime of Kenney Dam, which may be altered if changes are made to the reservoir.

Salvage logging and increased risk of fire as a result of Mountain Pine Beetle infestation may also affect future channel evolution. A worst case scenario could involve substantially increased sediment loadings and increased flood flows (Hélie et al. 2005; Uunila et al. 2006; BC Forest Practices Board 2007; and Redding et al. 2007). In this scenario, accelerated sediment deposition could occur in the lower Nechako River at Prince George.

A large flood or fire could cause an abrupt change in sediment regime. However, it is more likely that the Mountain Pine Beetle effects will be incremental and be subject to multi-year lag times. Potential channel changes could therefore be detected at an early stage through appropriate monitoring. It is recommended that a program be developed to monitor changes in channel morphometry, water level and discharge in the Prince George area.

2.5 ENVIRONMENTAL SETTING

2.5.1 *GENERAL DESCRIPTION*

A detailed description of the environmental setting is provided in **Appendix C**. The following sections outline some key issues. The study area lies within the Sub-boreal Spruce biogeoclimatic zone, which covers much of the central interior of British Columbia (MOF 1991). This zone is characterized by seasonal extremes of temperature with warm short summers and cold snowy winters. Annual precipitation ranges from 440 to 900 mm. Vegetation is dominated by coniferous forests with hybrid Engelmann white spruce and subalpine fir as climax species. Seral species include lodgepole pine, trembling aspen, paper birch and Douglas fir. Floodplains of major rivers, as in the study area, often have forests of black cottonwood with a smaller component of spruce (MOF 1991).

Numerous fish species within the study area include salmonids (sockeye salmon, Chinook salmon, coho salmon, pink salmon, rainbow trout, and mountain whitefish), burbot, non-sport fish (chiselmouth, prickly sculpin, slimy sculpin, largescale sucker, longnose sucker, white sucker, bridgelip sucker, pacific lamprey, redside shiner, northern pikeminnow, peamouth chub, brassy minnow, longnose dace and leopard dace) and two species of concern (white sturgeon, bull trout[3]) identified by the British Columbia Conservation Data Center[4]. The Conservation Data Centre (CDC) is a part of the Environmental Stewardship Division of the Ministry of Environment which collects, maintains and distributes information on species[5] and ecological communities at risk in B.C. Within the study area the white sturgeon[6] has been red-listed and the bull trout is blue-listed. The provincial Red list includes species extirpated, endangered or threatened[7], while the Blue list includes species and communities especially sensitive to human activities or natural events. **Table 2.7** provides an overview of the important life stages of salmonid species as well as species of special concern documented within the study area. Spawning and incubation timing windows are provided, although not all listed species are known to spawn or incubate within the study area. More detailed life history information for these species is included in the following subsections.

2.5.2 *SALMONID HABITAT*

Nearshore Habitats

The Nechako River is an important salmon river. It has been estimated that the Nechako watershed provides approximately 23% of the total Fraser River sockeye salmon production (CSTC 2008). The value of the commercial salmon catch associated with the Nechako River watershed may be as much as $70 million annually (Rankin 1993 in CSTC 2008).

The Nechako River at the Fraser confluence contains active and inactive side-channels. Active side-channels are typically permanently or seasonally wetted and contain an abundance of nearshore vegetation, large woody debris and undercut banks which provide good quality summer rearing for most juvenile salmonids. Off-channel habitats also provide refuge areas for outmigrating salmon fry and foraging habitats for resident fish species. Inactive side-channels typically do not contain water except perhaps during extreme flood events. Historic airphoto analysis of the lower river suggests that many of the inactive side-channels have been progressively revegetating with terrestrial species since the onset of river regulation in the 1950s (MMA 2008a).

A comprehensive inventory and rating of salmonid habitats of the Nechako and Fraser Rivers within Prince George city limits was completed by Fisheries and Oceans Canada in 1992 (Nowotny and Hickey 1993). Streambank sections were delineated according to a general

[3] Bull trout are also salmonids. White sturgeon and burbot may be considered sport fish although they are not salmonids and as endangered species white sturgeon may not be harmed, killed or taken within the Omineca Region (BC 2008).

[4] This list of fish species likely present at the confluence was prepared by merging the fish species list for each of the Nechako and Fraser Rivers (FFSBC 2005) and removing species distributed in other areas of these large rivers (i.e. the lower sections of the Fraser River) according to distributions in McPhail 2007.

[5] Vertebrate, vascular plant species and ecological communities at risk have been identified in B.C. A list of invertebrates, mosses and lichens at risk is being created.

[6] The following three white sturgeon populations in the Omineca Region are red-listed: Nechako River population, Upper Fraser River population and Middle Fraser River population.

[7] Not all Red-listed species will become formally designated as extirpated, endangered or threatened under the *Wildlife Act*. The Red list serves to identify species at risk that should at minimum be considered candidates for one of these legal designations.

consistency of habitat variables (e.g. substrate type; water depth; habitat type; bank composition and stability; instream, bank and upland vegetation; and upland status). Based on the collective quality of habitat variables, each section was assessed for rearing, spawning and over-wintering habitat value and rated into a category of high, medium or low.

Significant changes to river morphology and fish habitat may have occurred since 1992. A field data collection program was initiated in 2008 to verify and update this information and document current baseline conditions. The methodology of Nowotny and Hickey (1993) was used as the basis for the 2008 field activities and to update the habitat mapping information.

Results of the 2008 salmonid habitat inventory within the study area are presented in tabular form and illustrated on three 1:10,000 scale maps displaying the location and ratings of streambank sections (**Appendix C.1**). The 1992 assessment delineated 81 streambank sections along the Nechako River, 42 of which were rated as high quality habitat. In 2008, twenty additional sections were identified, which suggests either slight differences in methodology or an increase in habitat diversity. A total of 53 streambank sections were rated as high quality habitat in 2008. Only minor habitat changes had occurred along the Fraser River portion of this study.

Mid-channel Habitats

In order to gain an understanding of mesohabitat characteristics on the lower Nechako River, a Level 1 Fish Habitat Assessment (FHAP) was conducted in the fall of 2008 from the Fraser confluence to Wilson Park, approximately 8 km upstream. The FHAP procedures can be used to help predict the effects of certain instream work activities on aquatic resources.

Results of the FHAP show that even under summer base flow conditions, the lower river is predominantly composed of continuous riffle (areas of turbulent fast-flowing water) or glide (areas of fast flowing, non-turbulent water) habitat units. These characteristics are typical of watercourses with relatively flat bottoms in cross-section (Johnston and Slaney 1996). There is a distinct lack of pool habitats, which are generally important for supporting fish over the winter months (**Appendix C.1**).

2.5.3 WHITE STURGEON

Current Status

The white sturgeon was ranked as an endangered species by the Committee on the Status of Endangered Wildlife in Canada (in November 2003) and both sturgeon populations that may be found within the Nechako-Fraser confluence are red-listed by the BC Conservation Data Centre. Both of these populations[8] were also added to Schedule 1 of the *Species at Risk Act* (SARA) in 2006.

[8] Four populations of white sturgeon, the Upper Fraser, Nechako, Columbia and Kootenay, were added to Schedule 1 of SARA in 2006.

In 2001, the upper Fraser River population of white sturgeon was estimated at 815 fish (Yarmish and Toth 2002), of which 185 were estimated as mature (DFO 2007). RL&L (2000) also suggested that this population consists mostly of juveniles and subadults. The growth rate of this population is slow, like that of the Nechako River population (RL&L 2000).

The Nechako River sturgeon population in 1999 was estimated at 571 fish and displayed an age structure similar to those in other regulated rivers (RL&L 2000). RL&L (2000) found that the population was dominated by older fish and displayed poor juvenile recruitment. 305 mature white sturgeon are thought to exist in this population, with little or no juvenile recruitment since 1967 (DFO 2007). The population is declining and at risk of extirpation due to decades of recruitment failure. Model projections suggest that recovery efforts are required to restore recruitment and a self-sustaining population (DFO 2007; RL&L 2000).

Recovery efforts have been headed by the Nechako White Sturgeon Recovery Initiative. This organization is concerned with discovering the reason(s) for sturgeon recruitment failure in the Nechako watershed and establishes habitat protection and restoration and other management works. The short-term goal of the Initiative is to create a conservation fish culture program to sustain the population while the long-term goal of re-establishing a self-sustaining population is being realized (Nechako White Sturgeon Recovery Initiative 2008). Since 2006, over 8000 juvenile white sturgeon have been released (BC 2008).

Critical Habitat

Potentially critical habitats for white sturgeon include important areas in which adults feed and “stage” prior to migration to spawning grounds, spawning sites, and rearing locations for larvae and juveniles (DFO 2007). A study by RL&L (2000) suggested the following areas presented suitable habitat that may be used as spawning sites for the Nechako River population: Isle Pierre, Whitemud, Hulatt rapids, Nautley River and the lower Stuart River. Both spawning and overwintering sites have been located near Vanderhoof. Threats to sturgeon habitat include instream activities such as gravel removal, development of riparian and/or foreshore areas, river regulation, upstream use of land and water, and effluent discharges (DFO 2007).

Although white sturgeon research on the Nechako and Fraser Rivers has been conducted over a number of years, no known study has specifically examined habitat at the confluence. As there is a potential for critical habitat within this area, EDI in conjunction with Lheidli T’enneh First Nation (LTN) and Upper Fraser Fisheries Conservation Alliance (UFFCA), began field inspections in the confluence area that may aid in determining whether this area should be considered as critical sturgeon habitat. As an investigation of this nature requires extensive study, the results of the 2008 field investigations (**Appendix C.2**) give only a preliminary picture of the situation.

Table 2.1 – Nechako River Thalweg Elevation Changes

Thalweg Change - Nechako River				
XS	Dist. (m)	El. MOE (m)	El. NHC (m)	Diff. (m)
XS N1	452	560.62	561.67	1.05
XS N2	889	561.49	561.36	-0.13
XS N3	1337	561.91	562.54	0.63
XS N4	1957	562.35	561.87	-0.48
XS N5	2518	562.26	562.18	-0.08
XS N6	2938	564.60	563.10	-1.50
XS N7	3423	565.27	564.56	-0.71
XS N8	3792	565.76	565.24	-0.52
XS N11	4201	564.87	564.19	-0.68
XS N12	4745	565.78	565.29	-0.49
XS N15	5118	565.04	565.36	0.32
XS N16	5541	565.03	564.91	-0.12
XS N17	5932	566.21	566.46	0.25
XS N18*	6402	566.99	567.14	0.15
XS N19*	6913	567.79	567.93	0.14
XS N20*	7456	568.27	568.24	-0.03
XS N21*	8098	568.60	568.66	0.06
XS N27*	11148	569.61	569.48	-0.13
XS N30*	12896	571.65	571.67	0.02
XS N33*	15135	573.86	573.53	-0.33

NOTES: 1 - MOE Cross sections are from 1979 survey or if indicated by (*) from 1995 survey.

Table 2.2 - Nechako River Average Bed Elevation Changes

Average Bed Level Change - Nechako River				
XS	Dist. (m)	El. MOE (m)	El. NHC (m)	Diff. (m)
XS N1	452	563.03	562.97	-0.07
XS N2	889	563.68	563.65	-0.03
XS N3	1337	563.98	563.78	-0.20
XS N4	1957	563.87	563.93	0.06
XS N5	2518	564.45	564.29	-0.16
XS N6	2938	565.44	564.70	-0.74
XS N7	3423	565.87	565.52	-0.36
XS N8	3792	566.46	565.94	-0.53
XS N11	4201	566.87	566.44	-0.44
XS N12	4745	567.77	567.77	0.00
XS N15	5118	567.59	567.57	-0.02
XS N16	5541	567.50	567.20	-0.30
XS N17	5932	568.34	568.20	-0.14
XS N18*	6402	568.06	568.37	0.31
XS N19*	6913	569.18	569.23	0.05
XS N20*	7456	570.64	570.59	-0.05
XS N21*	8098	569.73	569.58	-0.16
XS N27*	11148	571.16	570.90	-0.26
XS N30*	12896	572.86	573.35	0.49
XS N33*	15135	574.85	574.77	-0.07

NOTES: 1 - MOE Cross sections are from 1979 survey or if indicated by (*) from 1995 survey.

Table 2.3 - Nechako River Flow Area Changes

Area Change - Nechako River				
XS	Dist. (m)	A. MOE (m^2)	A. NHC (m^2)	Diff. (%)
XS N1	452	4706	4440	-5.7
XS N2	889	3451	3511	1.8
XS N3	1337	3017	3212	6.5
XS N4	1957	912	1016	11.3
XS N5	2518	712	736	3.5
XS N6	2938	661	760	15.1
XS N7	3423	576	620	7.8
XS N8	3792	511	579	13.3
XS N11	4201	536	600	11.9
XS N12	4745	553	545	-1.4
XS N15	5118	576	556	-3.4
XS N16	5541	466	461	-1.0
XS N17	5932	529	516	-2.3
XS N18*	6402	539	544	0.9
XS N19*	6913	529	501	-5.3
XS N20*	7456	485	475	-2.2
XS N21*	8098	456	445	-2.5
XS N27*	11148	394	393	-0.4
XS N30*	12896	355	349	-1.9
XS N33*	15135	330	334	1.5

NOTES: 1 - MOE Cross sections are from 1979 survey or if indicated by (*) from 1995 survey.
2 - Area calculation based on 20-year flood cross-sectional area

Table 2.4 – Fraser River Thalweg Elevation Changes

Thalweg Change - Fraser River				
XS	Dist. (m)	El. MOE (m)	El. NHC (m)	Diff. (m)
XS F10	7716	554.97	555.21	0.24
XS F15	10156	556.01	556.29	0.28
XS F18	10786	557.76	557.72	-0.04
XS F19	11701	557.48	557.61	0.13
XS F20	12639	557.53	557.61	0.08
XS F21*	13059	558.17	558.13	-0.04
XS F22	13430	559.64	559.61	-0.03
XS F23	13680	555.19	556.07	0.88
XS F25	13714	553.89	556.22	2.33
XS F26	13868	557.60	557.23	-0.37
XS F27	14446	558.73	558.98	0.25
XS F31	15668	556.76	555.47	-1.29
XS F33	17276	560.24	560.19	-0.05
NOTES: 1 - MOE Cross sections are from 1979 survey or if indicated by (*) from 1995 survey.				

Table 2.5 – Fraser River Average Bed Elevation Changes

Average Bed Level Change - Fraser River				
XS	Dist. (m)	El. MOE (m)	El. NHC (m)	Diff. (m)
XS F10	7716	557.77	557.47	-0.31
XS F15	10156	559.63	559.71	0.08
XS F18	10786	559.62	559.31	-0.31
XS F19	11701	561.14	560.64	-0.51
XS F20	12639	559.26	558.87	-0.39
XS F21*	13059	560.68	560.78	0.11
XS F22	13430	562.97	562.16	-0.81
XS F23	13680	561.88	561.95	0.08
XS F25	13714	562.28	562.15	-0.13
XS F26	13868	562.18	562.45	0.28
XS F27	14446	561.01	561.27	0.26
XS F31	15668	560.39	560.14	-0.25
XS F33	17276	561.83	562.05	0.22
NOTES: 1 - MOE Cross sections are from 1979 survey or if indicated by (*) from 1995 survey.				

Table 2.6 – Fraser River Flow Area Changes

Area Change - Fraser River				
XS	Dist. (m)	A. MOE (m^2)	A. NHC (m^2)	Diff. (%)
XS F10	7716	2667	2673	0.2
XS F15	10156	1881	1876	-0.3
XS F18	10786	1727	1734	0.4
XS F19	11701	2109	2101	-0.4
XS F20	12639	2036	2018	-0.9
XS F21*	13059	3176	3129	-1.5
XS F22	13430	4799	4957	3.3
XS F23	13680	5377	5165	-3.9
XS F25	13714	5078	4907	-3.4
XS F26	13868	4437	4451	0.3
XS F27	14446	2578	2608	1.2
XS F31	15668	1879	1920	2.2
XS F33	17276	2289	2238	-2.2

NOTES: 1 - MOE Cross sections are from 1979 survey or if indicated by (*) from 1995 survey.
2 - Area calculation based on 20-year flood cross-sectional area

Table 2.7 General migration and spawning timing windows for sport fish or fish of special concern documented within the study area (from McPhail 2007 and Scott and Crossman 1973).

Species	Spawning period	Adult migration period	Incubation period	Juvenile outmigration period
Rainbow trout	Late April - June	April -May	May – Mid July	n/a
Bull trout	September - November	August - September	September to June	n/a
Mountain whitefish	October - November	September - October	November to June	n/a
Chinook salmon	July - November	July - September	August to May	Spring - early fall.
Sockeye salmon	August - November	June to late August	November to spring	Spring
Pink salmon	August - October	Late July and August	November to spring	Late February – late May
Coho salmon	September – December	September – October	December to spring	February – June
White Sturgeon	After peak spring discharge (likely June to July)	n/a	July	n/a

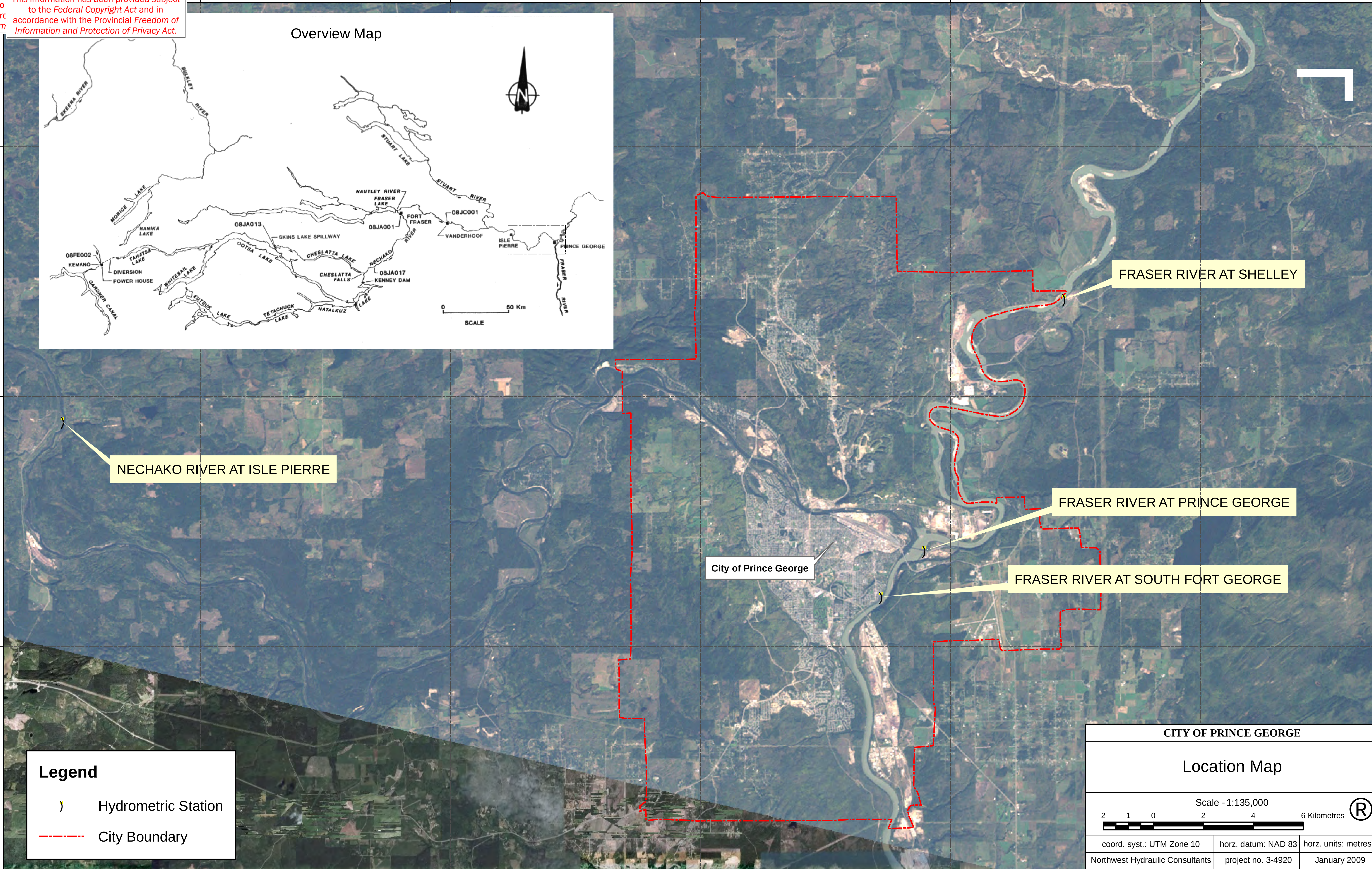
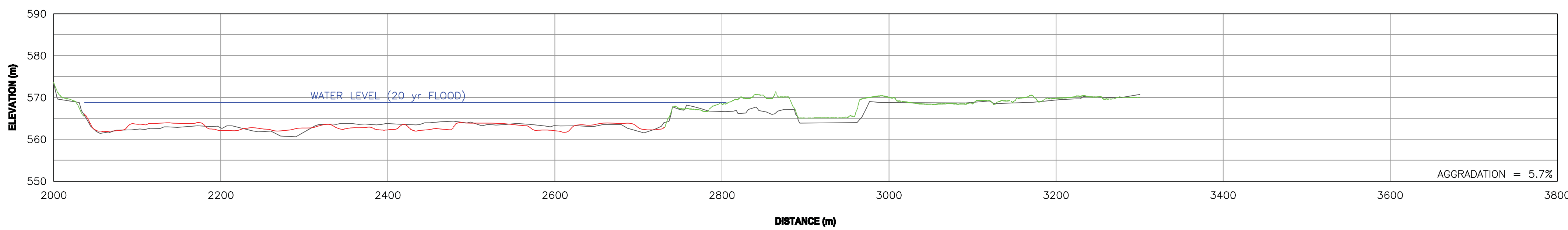
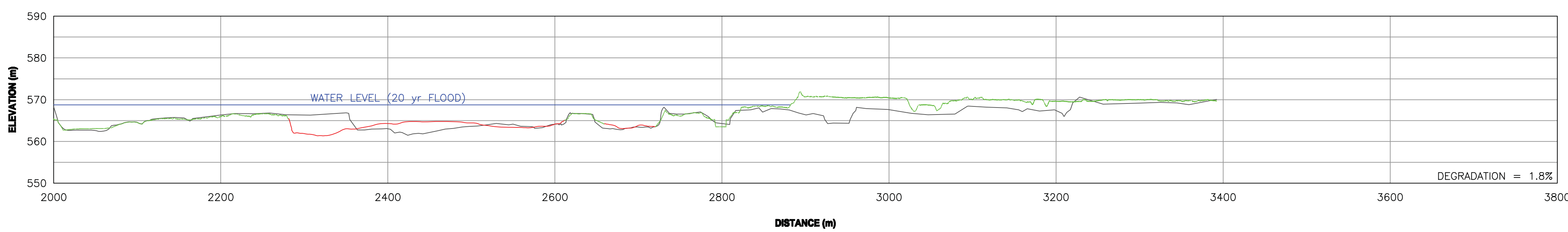

Overview Map
SKEENA RIVER
BULKLEY RIVER
MORICE LAKE
NANIKA LAKE
STUART LAKE
STUART RIVER
NAUTLEY RIVER
FRASER LAKE
FORT FRASER
08JC001
08JA001
08JA013
SKINS LAKE SPILLWAY
VANDERHOOF
ISLE PIERRE
PRINCE GEORGE
FRASER RIVER
NECHAKO RIVER
08FE002
KEMANO
DIVERSION
POWER HOUSE
TAHATSA LAKE
OOTSA LAKE
CHESLATTA LAKE
CHESLATTA FALLS
08JA017
KENNEY DAM
WHITESAIL LAKE
GARDNER CANAL
EUTSUK LAKE
TETACHUCK LAKE
NATALKUZ LAKE
0 50 Km
SCALE
NECHAKO RIVER AT ISLE PIERRE
FRASER RIVER AT SHELLEY
FRASER RIVER AT PRINCE GEORGE
FRASER RIVER AT SOUTH FORT GEORGE
City of Prince George
490000
500000
510000
520000
530000
5990000
5980000
5970000
Legend
Hydrometric Station
City Boundary
CITY OF PRINCE GEORGE
Location Map
Scale - 1:135,000
2 1 0 2 4 6 Kilometres
coord. syst.: UTM Zone 10
horz. datum: NAD 83
horz. units: metres
Northwest Hydraulic Consultants
project no. 3-4920
January 2009
Landsat 7 sattelite image by Geobase.ca

Figure 2.1



XS N1



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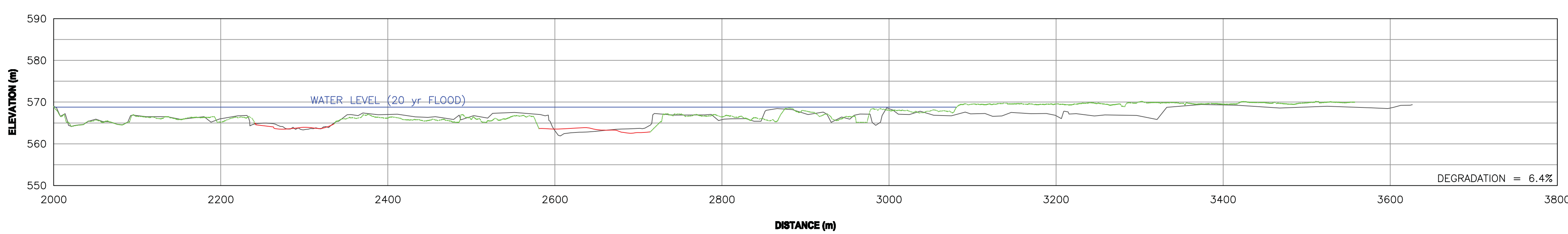

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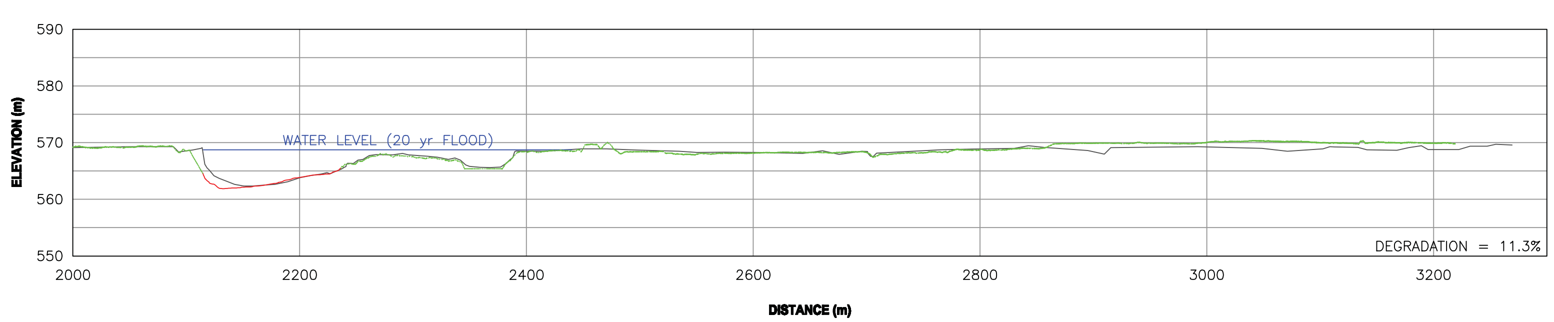

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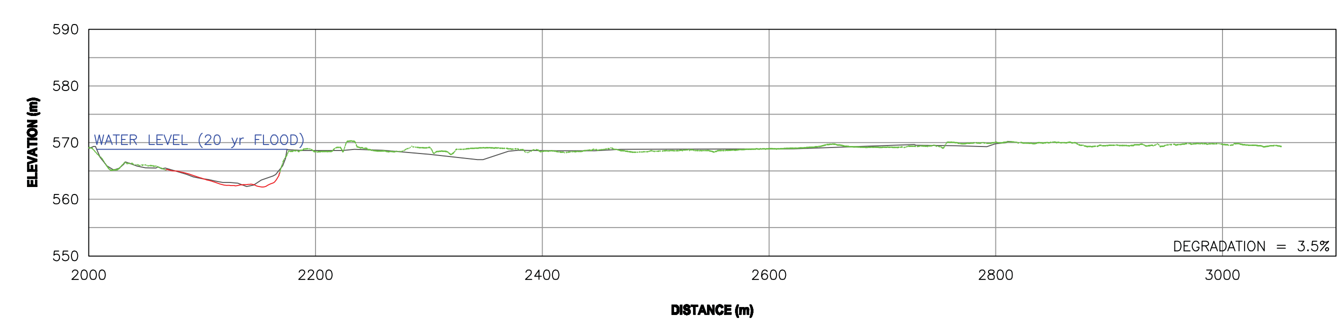


XS N5

NOTES:

1. ALL CROSS-SECTIONS ARE VIEWED DOWNSTREAM.
2. CROSS- SECTION LOCATION AND NUMBERING SAME AS KLOHN-CRIPPEN (1997) SEE MAPS ________
3. AGGREDATION / DEGRADATION VALUES REFER TO THE PERCENTAGE CHANGE IN CROSS-SECIONAL FLOW AREA AT THE 20-YEAR FLOOD LEVEL AS SHOWN.

LEGEND

- WATER LEVEL
- MOE 1979
- MOE 1995
- nhc 2008
- LiDAR 2008

NO.	DATE	REVISION	DR.	CHK.	APPR.

nhc northwest hydraulic consultants

City of Prince George

Flood Risk Evaluation and Flood Control Solutions

Comparison of Nechako River Cross-sections

SHEET SIZE D

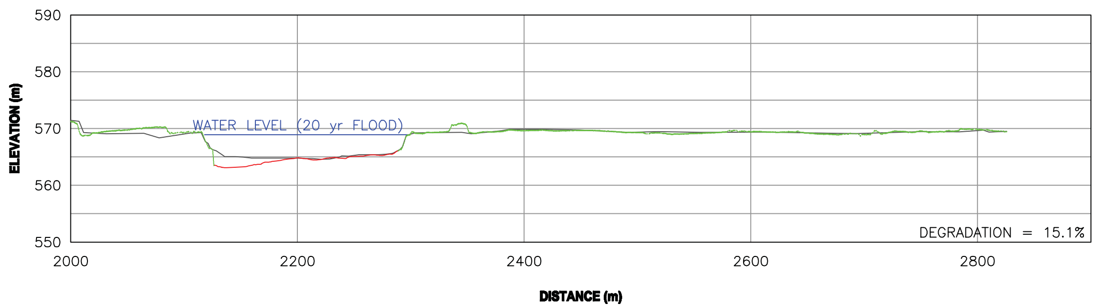
SCALE AS NOTED

DATE Oct, 2008

DRAWING NUMBER: FIGURE 2.2

SHT.No.

REV.



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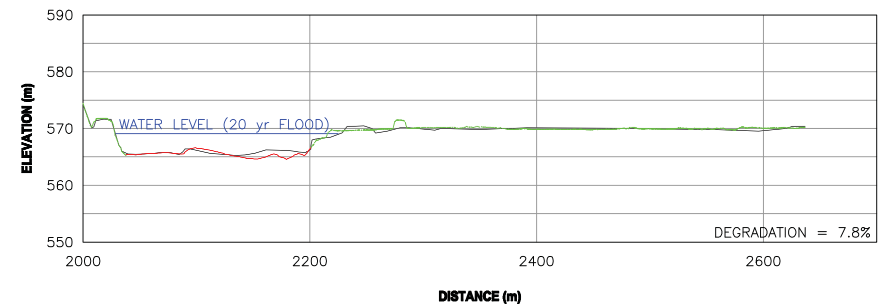

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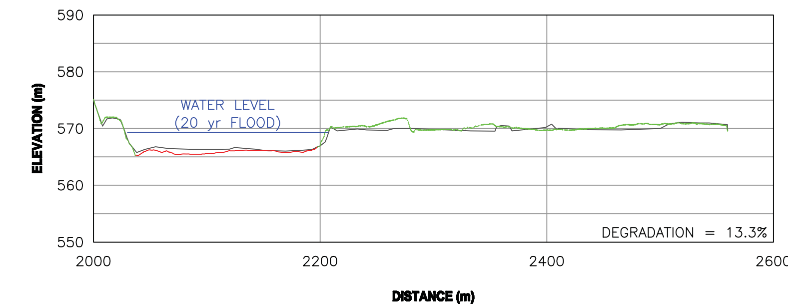

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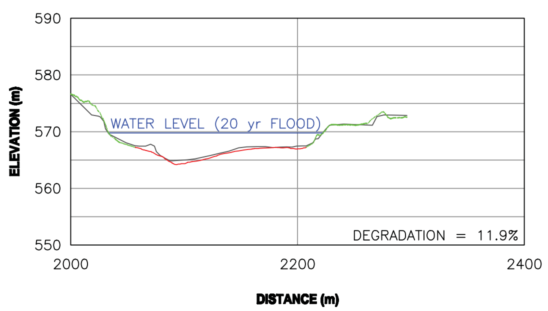

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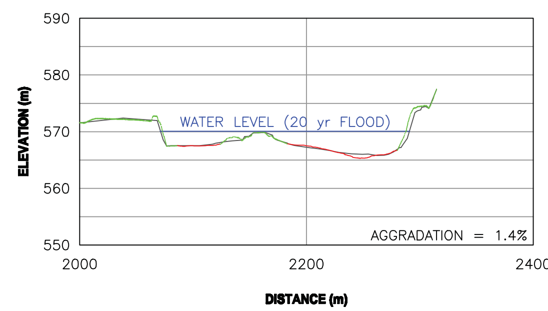

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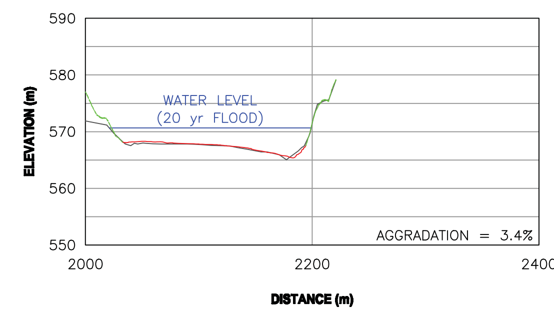

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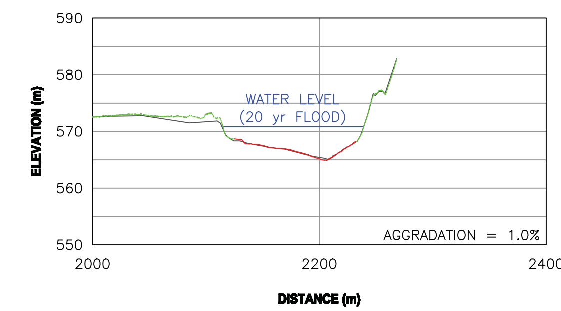

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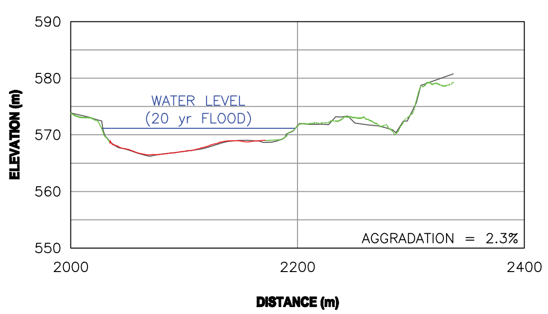

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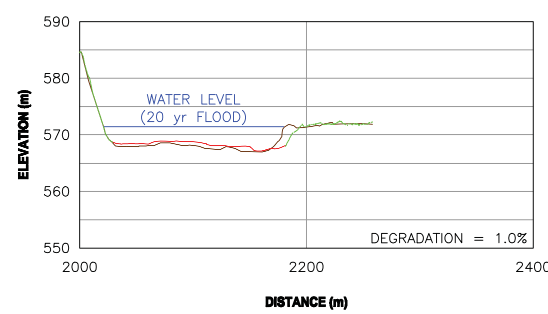

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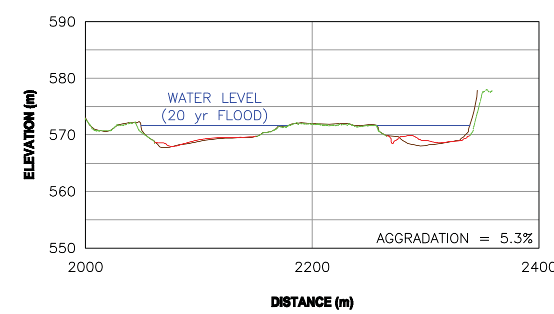

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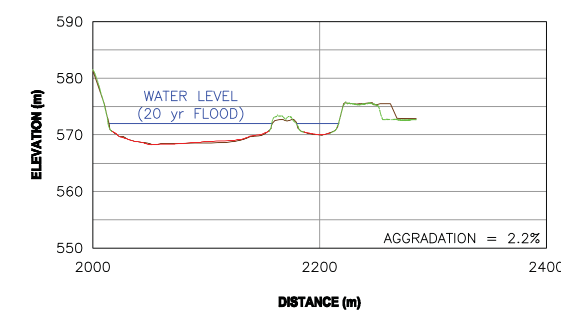

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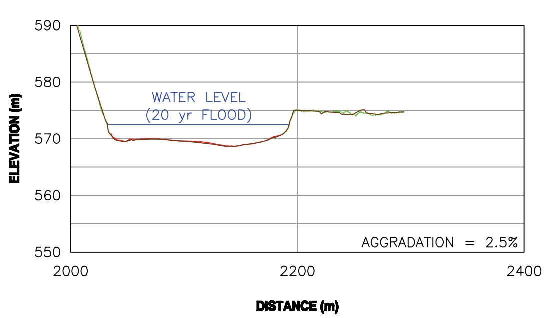

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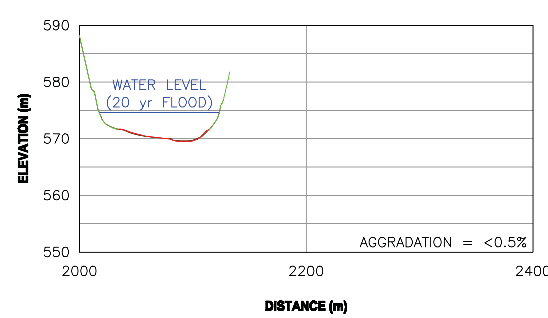

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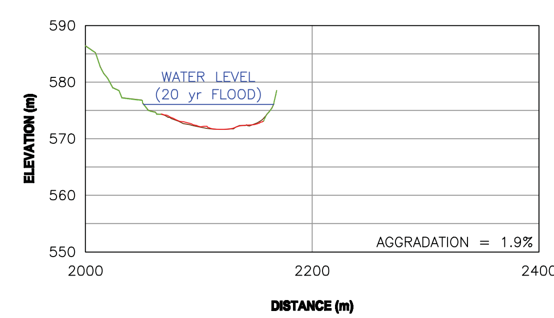

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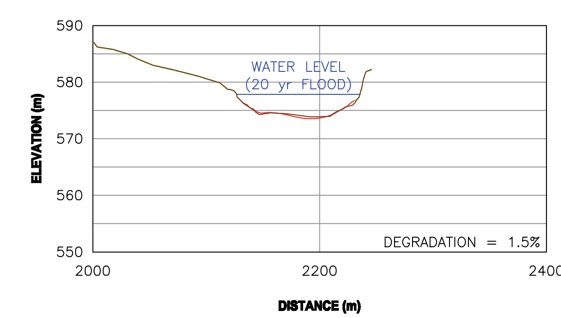


XS N33

NOTES:

1. ALL CROSS-SECTIONS ARE VIEWED DOWNSTREAM.
2. CROSS- SECTION LOCATION AND NUMBERING SAME AS KLOHN-CRIPPEN (1997) SEE MAPS
3. AGGREDATION / DEGRADATION VALUES REFER TO THE PERCENTAGE CHANGE IN CROSS-SECIONAL FLOW AREA AT THE 20-YEAR FLOOD LEVEL AS SHOWN.

LEGEND

- WATER LEVEL
- MOE 1979
- MOE 1995
- nhc 2008
- LiDAR 2008

NO.	DATE	REVISION	DR.	CHK.	APPR.

nhc northwest hydraulic consultants

City of Prince George

Flood Risk Evaluation and Flood Control Solutions

Comparison of Nechako River Cross-sections

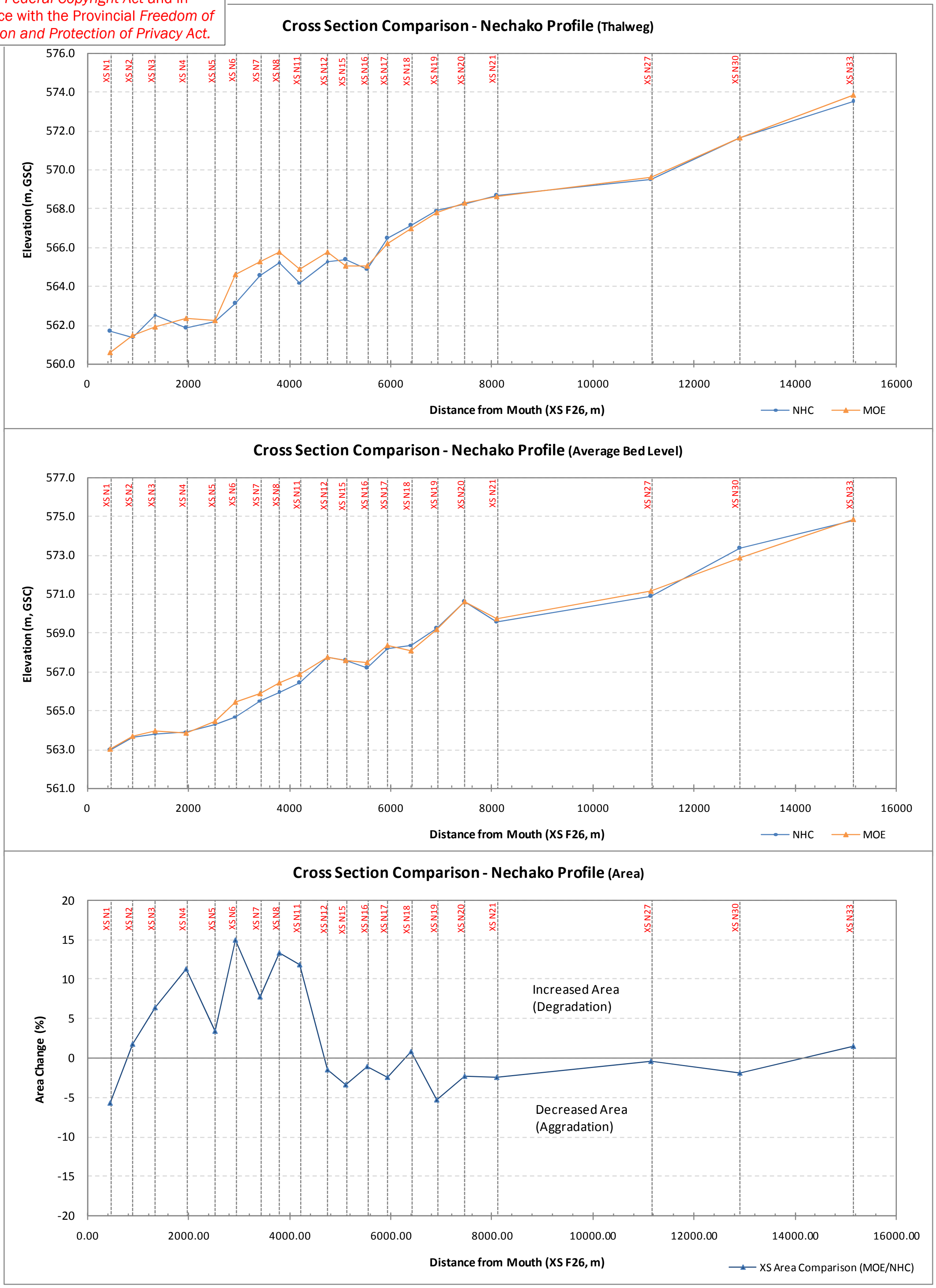
SHEET SIZE D
SCALE AS NOTED
DATE Oct, 2008

DRAWING NUMBER
FIGURE 2.3
SHT.No.
REV.

(a)

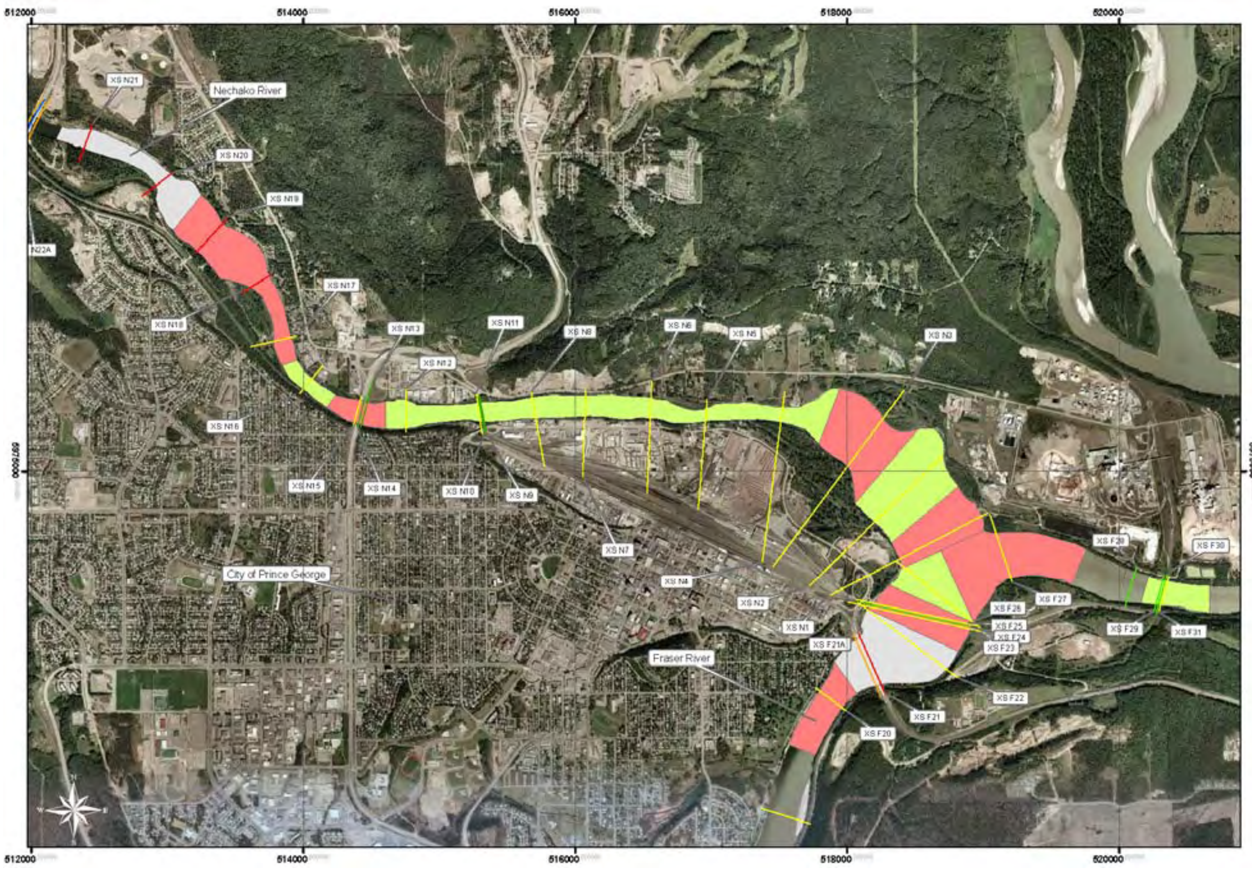
(b)

(c)

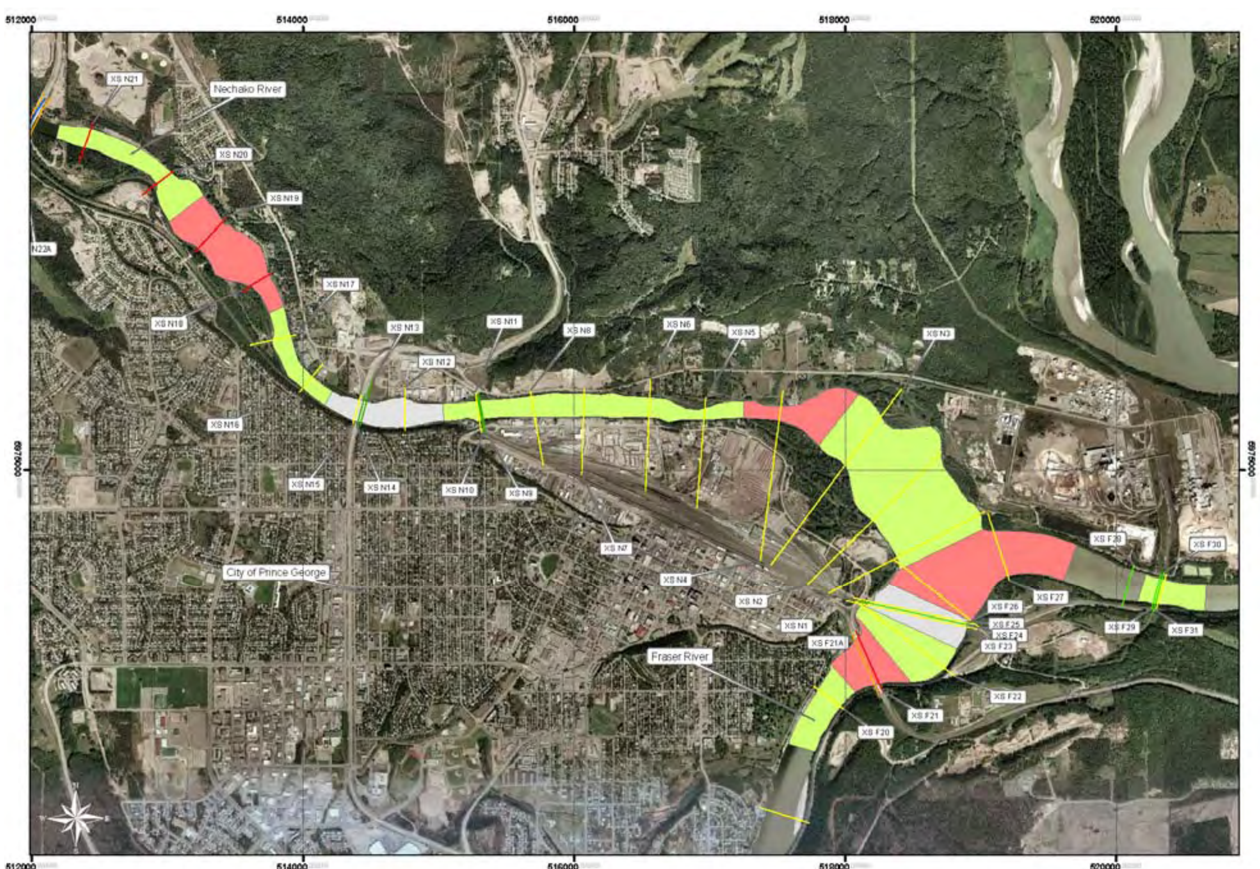


City of Prince George	nhc
Nechako River Bed Changes	
January 2009	Figure 2.4

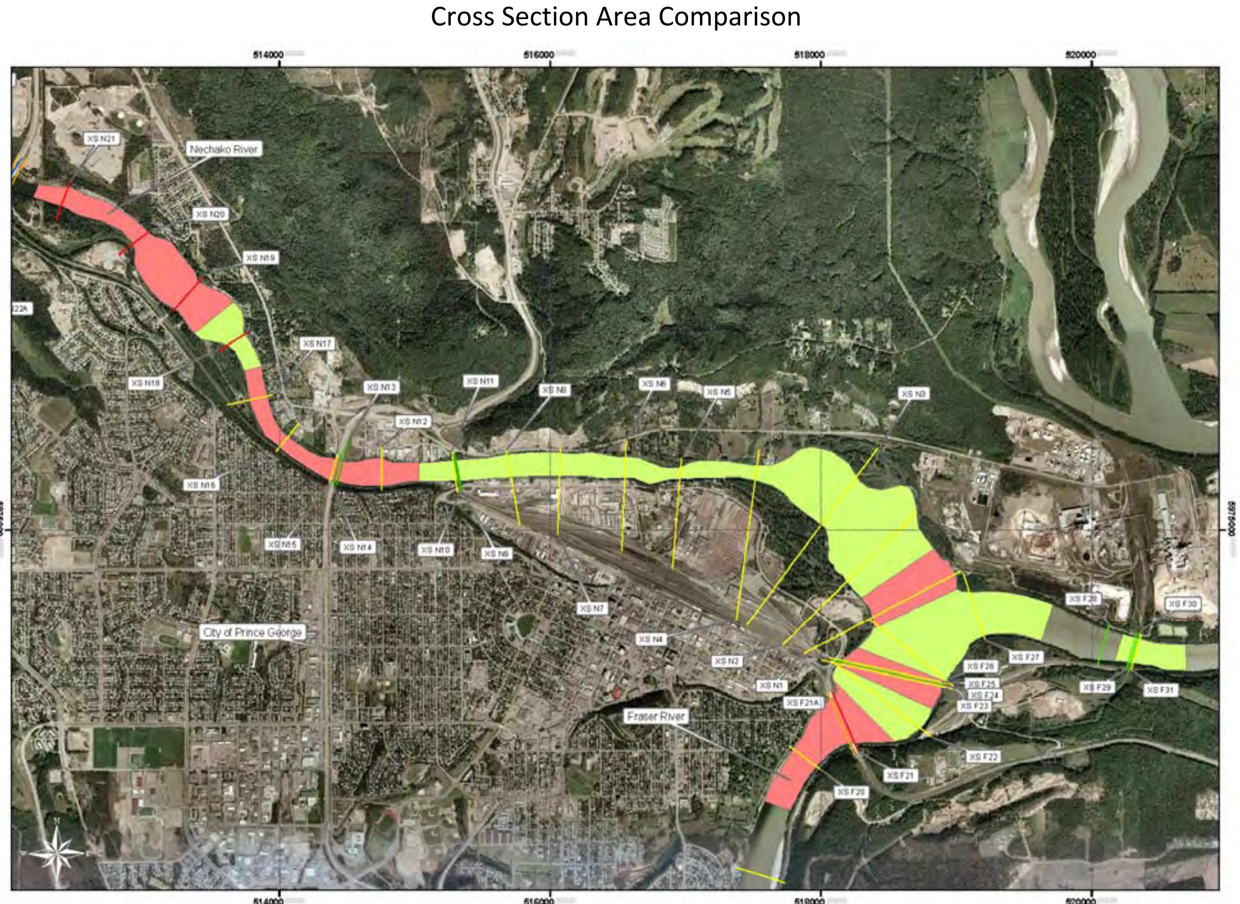
Thalweg Comparison



Average Bed Level Comparison



Cross Section Area Comparison



Legend

- Aggradation
- Degradation
- No Changes

City of Prince George

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City of Prince George	nhc
Aggradation / Degradation Comparison	
January 2009	Figure 2.5

Figure 2.6: September 2, 1928 air photos of Prince George.

BC280 #95 | August 18, 1946

A	May 7, 2008	Issued for discussion

APPROXIMATE SCALE: 1:7,500
DATE: May 7, 2008
DRAWN: S. Allegretto
DESIGNED: S. Allegretto
CHECKED: M. Miles
APPROVED:

M. MILES AND ASSOCIATES LTD.
645 ISLAND ROAD, VICTORIA, BC, V8S 2T7
Phone: 250-595-0653 Fax: 250-595-7367 email: mikemiles@shaw.ca

CLIENT:
CITY OF PRINCE GEORGE
1100 PATRICIA BOULEVARD
PRINCE GEORGE, BC
V2L 3V9

NECHAKO RIVER
AIR PHOTOGRAPH MOSAIC

1946 AIR PHOTO MOSAIC SHOWING
1948 FLOOD LIMITS

FIGURE 2.7

PROJECT # 322
Km # 292 to 294
REV: A

Orthophoto	Nechako River at Isle Pierre 202 m³/s	APPROXIMATE SCALE: 1:7,500	M. MILES AND ASSOCIATES LTD. 645 ISLAND ROAD, VICTORIA, BC, V8S 2T7
May 3, 2006	Fraser River at Shelley 948 m³/s	DATE: May 12, 2008	Phone: 250-595-0653 Fax: 250-595-7367 email: mikemiles@shaw.ca
REFERENCED DRAWING NO.	REFERENCED DRAWING DESCRIPTION	DRAWN: S. Allegretto	CLIENT: CITY OF PRINCE GEORGE 1100 PATRICIA BOULEVARD PRINCE GEORGE, BC V2L 3V9
A May 12, 2008	Issued for discussion	DESIGNED: S. Allegretto	
		CHECKED: M. Miles	
		APPROVED:	

NECHAKO RIVER AIR PHOTOGRAPH MOSAIC

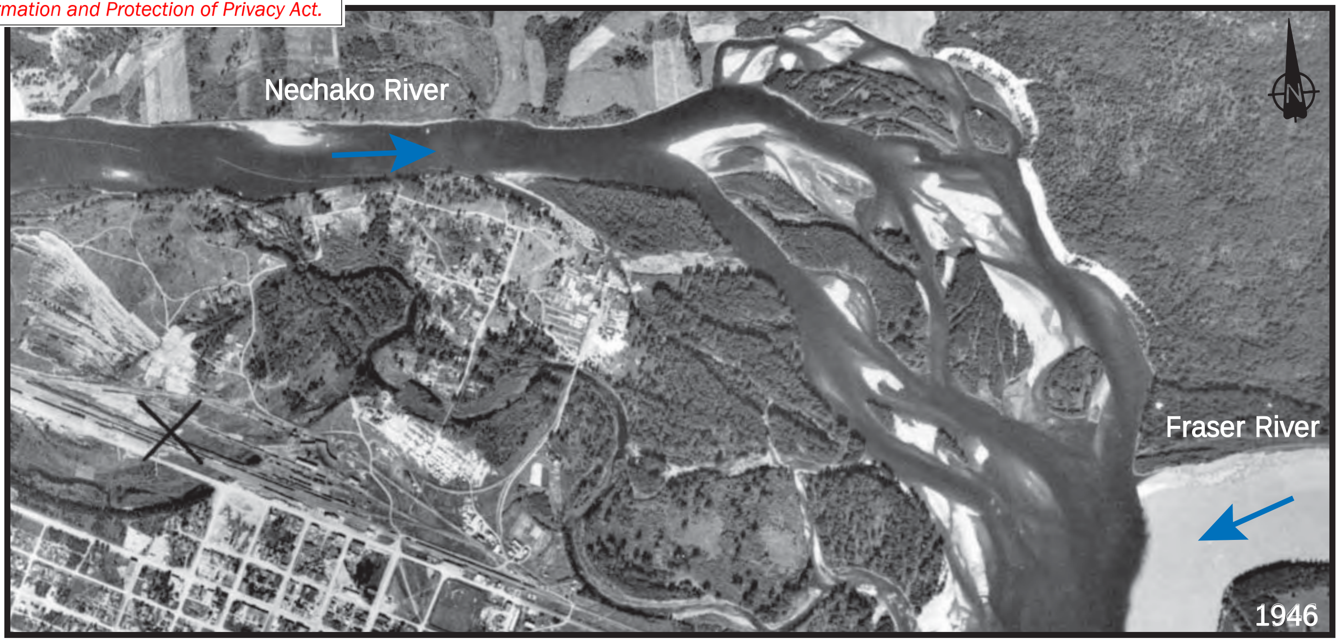
2006 AIR PHOTO MOSAIC SHOWING 1948 FLOOD LIMITS

FIGURE 2.8

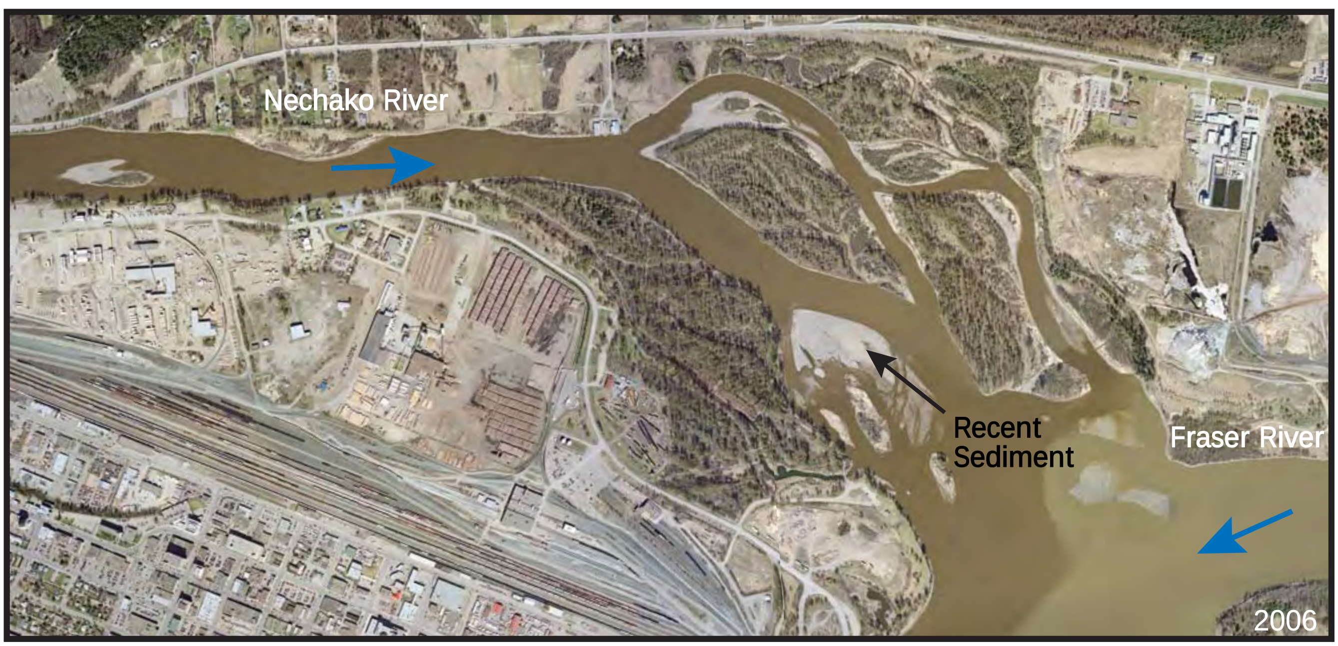
PROJECT # 322

Km # 292 to 294

REV: **A**

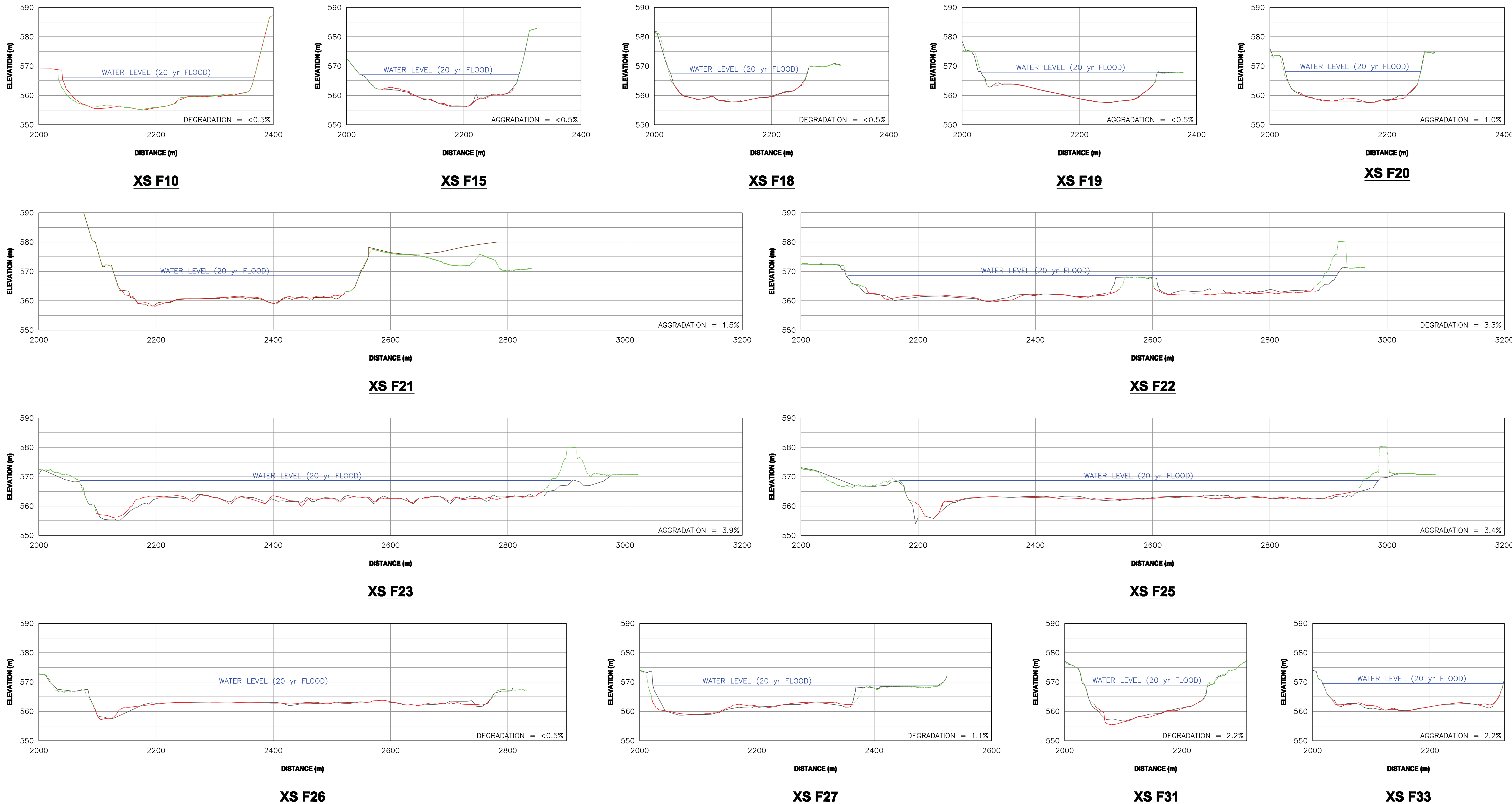


Nechako River at Isle Pierre	na
Fraser River at Shelley	na



Nechako River at Isle Pierre	202 m^3/s
Fraser River at Shelley	948 m^3/s
South Fort George	5.46 m^3/s

Figure 2.9: Historical changes in channel conditions, Nechako River upstream of the Fraser River confluence (1946 to 2006).



NOTES:

1. ALL CROSS-SECTIONS ARE VIEWED DOWNSTREAM.
2. CROSS- SECTION LOCATION AND NUMBERING SAME AS KLOHN-CRIPPEN (1997) SEE MAPS ________
3. AGGREDATION / DEGRADATION VALUES REFER TO THE PERCENTAGE CHANGE IN CROSS-SECIONAL FLOW AREA AT THE 20-YEAR FLOOD LEVEL AS SHOWN.

LEGEND

- WATER LEVEL
- MOE 1979
- MOE 1995
- nhc 2008
- LiDAR 2008

NO.	DATE	REVISION	DR.	CHK.	APPR.

nhc northwest hydraulic consultants

City of Prince George

Flood Risk Evaluation and Flood Control Solutions

Comparison of Fraser River Cross-sections

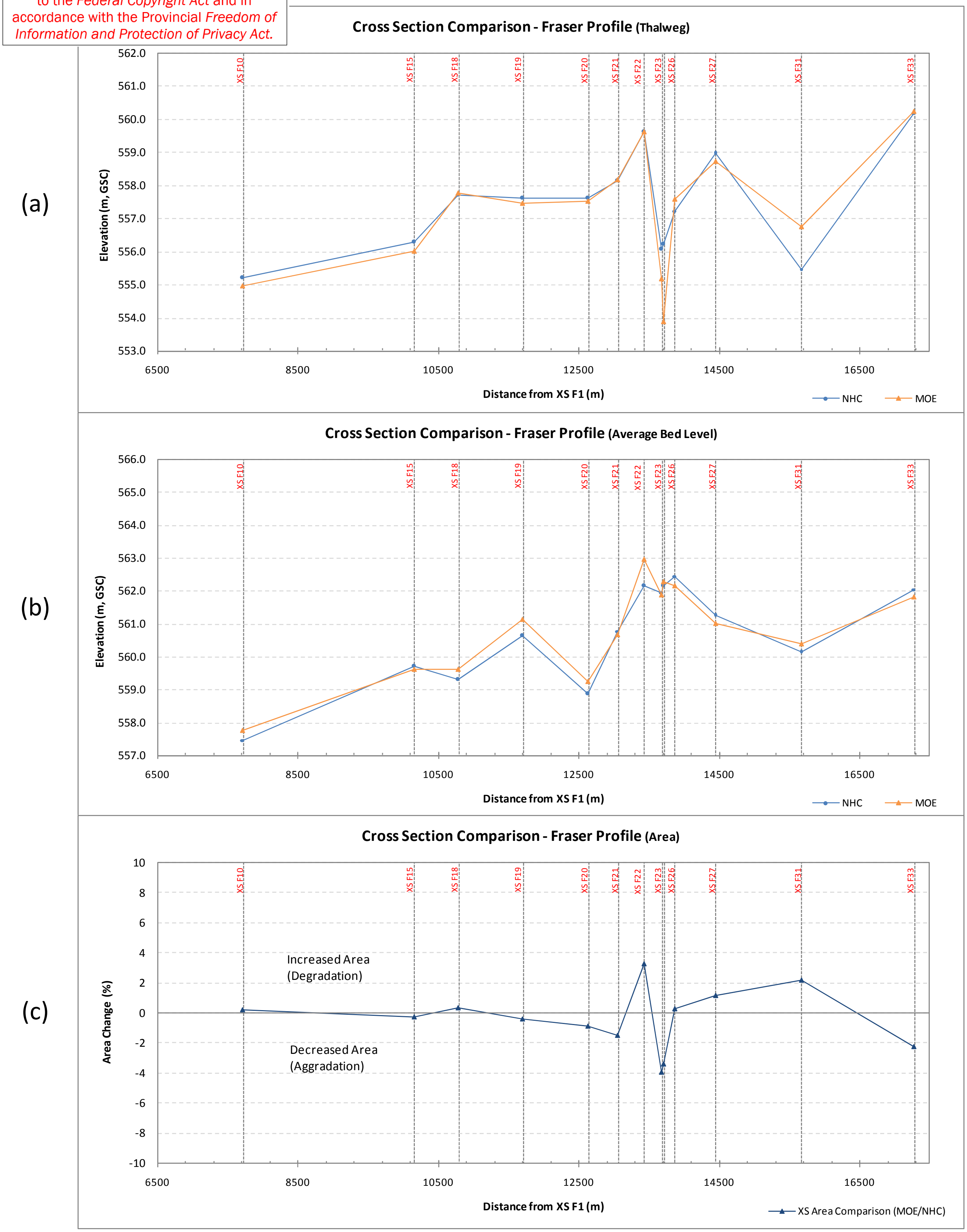
SHEET SIZE D

SCALE AS NOTED

DATE Oct, 2008

DRAWING NUMBER FIGURE 2.10

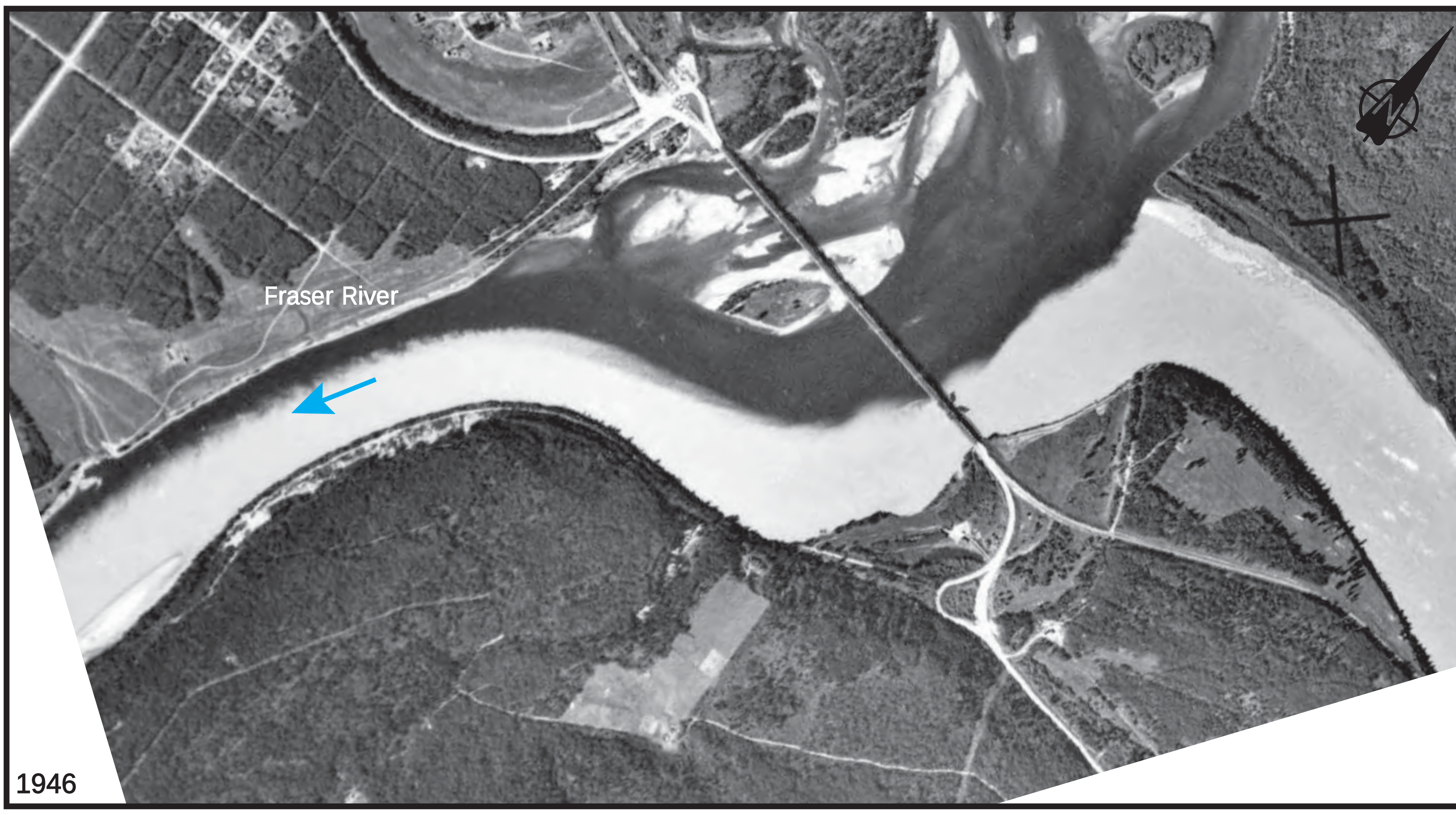
SHT.No. REV.



City of Prince George

Fraser River
Bed Changes

January 2009 | Figure 2.11



Nechako River at Isle Pierre na Fraser River at Shelley na South Fort George na

Nechako River at Isle Pierre 235 m^3/s Fraser River at Shelley 752 m^3/s South Fort George 5.02 m

Nechako River at Isle Pierre 539 m^3/s Fraser River at Shelley 1,850 m^3/s South Fort George 7.0m

Figure 2.12: Historical changes in channel conditions, Fraser River in the vicinity of the Nechako confluence (1946-2008).

3 OPEN WATER FLOOD HYDROLOGY AND HYDRAULICS

For the design of flood control works, the BC Ministry of Environment minimum design standard is the 200-year flood. Higher standards have been stipulated in some cases - for example, the design flow for the Fraser River downstream of Hope is the flood of 1894, estimated to have a return period in the order of 500 years.

An in-depth review of Nechako and Fraser River flows was carried out and flood frequency analyses were conducted as described below, to determine the appropriate freshet design flows for the Fraser River above the Nechako River confluence, for the Nechako River at Prince George, and for the Fraser River below the confluence. Flow contributions from minor tributaries that enter within the City were neglected. The flood frequency results were used for calculating 200-year water surface profiles along the rivers.

3.1 HISTORIC FLOODS AND HYDROMETRIC RECORDS

For reliable flood frequency analysis, it is generally important to trace historical flood records as far back as possible, so that any unusually large floods that may have preceded systematic records can be included in the analysis. For the Prince George area, however, only limited historical information is available. D. Septer (2007) described flooding in Northern British Columbia based on eyewitness accounts and newspaper reports covering the period 1820 to 2006. Klohn Crippen (1997) provided some information on Fraser and Nechako River flooding. Water Survey Canada (WSC) provided unpublished flow and water level records from their archives. For the frequency analyses described herein, published flow records were extended as far as possible based on available historical information and correlation with other gauges.

Major freshet floods in the Fraser River are summarized in **Table 3.1**. All water levels were converted to GSC datum at South Fort George. The flood of 1894, according to recent analysis by NHC (2008a), was the largest flood at Hope in at least the last 160 years. According to WSC information from 1962, the 1894 flood level at the Fraser-Nechako confluence was estimated to be El. 569.5 m GSC - the same as the 200-year water level computed by Klohn-Crippen (1997).

Published flow records were obtained for the WSC stations listed in **Table 3.2**. Gauge locations are shown in **Figure 2.1** and annual peak flow histograms for *Station 08KB001, Fraser River at Shelley* and *Station 08JC002, Nechako River at Isle Pierre* are shown in **Figures 3.1** and **3.2**. An annual peak water level histogram for *Station 08KE018, Fraser River at South Fort George* is shown in **Figure 3.3**. The South Fort George record was extended for the period 1947-1967 based on water level records for *Station 08KE001, Fraser River at Prince George*, located 2.5 km upstream. For the year 1968, daily water level records are available for both stations; based on linear regression the following expression relating water levels was developed:

$$WL_{\text{South Fort George}} = 0.98 \times WL_{\text{Prince George}} + 9.77 \qquad (r^2=0.99)$$

Other relevant Nechako River flow gauges are *Station 08JA013, Skins Lake Spillway, Nechako Reservoir* and *Station 08JC001, Nechako River at Vanderhoof*. Nechako tributary flow records are available for *Station 08JB003, Nautley River near Fort Fraser* and *Station 08JE001, Stuart River near Fort St. James*. The records at Skins Lake Spillway are provided by Rio Tinto Alcan based on reservoir levels and gate settings, whereas the other records are regular WSC stations. When the Nechako stations are reporting accurately, flows at different points along the river and from the various tributaries add up to the flow reported at the most downstream station of Isle Pierre. In general, the freshet flows add up fairly well but winter flows are more problematic. Freeze-up conditions may suddenly increase water levels and if ice-free rating tables are applied to estimate ice-covered flows, large errors may occur. For example, in December of 2007, the flow at the upstream Vanderhoof station was reported to be higher than at downstream Isle Pierre although the Stuart River enters between the two stations and had flows exceeding 130 m^3/s. It is recommended that WSC more closely monitor these gauges.

Figure 3.4 shows the average dates of peak events on the Fraser and Nechako Rivers:

- On average, the Fraser River at Shelley has peaked around June 10. Over the past sixty years there appears to be no trend towards earlier or later peaks.
- The annual maximum daily water level at Prince George is mainly a function of Fraser River flows. Water levels at South Fort George, downstream of the confluence, typically peak about one day later than at Shelley.
- In general, peaks in the Nechako River at Isle Pierre occur later than in the Fraser. Over the period of record, reservoir operations have delayed the date of the Nechako peak by up to a month.

Monthly flows for Fraser River at Shelley and Nechako River at Isle Pierre are plotted in **Figures 3.5** and **3.6**, and monthly water levels at South Fort George are shown in **Figure 3.7**. The figures also show maximum and minimum values for the period of record, to illustrate the range that can be expected in a given month of the year.

As part of the hydrologic investigations the Klohn Crippen (1997) design flows were reviewed, as well as three memoranda by Nichols (1981a), Nichols (1981b) and Wyman (1981).

3.2 FRASER RIVER FRESHET DESIGN FLOWS UPSTREAM OF NECHAKO RIVER

WSC Station 08KB001, Fraser River at Shelley, is located near the upstream end of the Fraser River study reach. The available 59-year record from 1950 to 2008 is near continuous. In addition to the flood of 1894, very large floods are known to have occurred in 1936 and 1948 and attempts were made to include this information. The 1894 flood at Hope was estimated to have a magnitude of 17,000 m^3/s (NHC, 2008a). There are no flow estimates for the upper Fraser basin for 1894, but an unpublished graph from 1962 in the WSC archives suggests a water level of El. 569.3 m GSC at the South Fort George gauge site. The 1894

Nechako flow is not known, hence the flow at Shelley cannot be estimated based on the water level alone. The Shelley drainage area is only 32,400 km^2 compared to 217,000 km^2 at Hope and correlation between the two gauges is fairly poor, as might be expected, but suggests an 1894 flow at Shelley in the order of 6,000 m^3/s. The 1936 and 1948 floods at Shelley were estimated through correlation with the flow record for *Station 08MD013, Fraser River at Big Bar Creek*, with a drainage area of 146,000 km^2, in operation from 1935 to 1972. A linear regression between the annual maximum flows for Shelley and Big Bar Creek for the joint period of record from 1950 to 1972 yielded the following equation:

$$Q_{Shelley} = 0.46 \times Q_{Big\ Bar} + 845 \qquad (r^2=0.8)$$

Observed and extended maximum annual daily flows for Fraser River at Shelley are listed in **Appendix D**. Since instantaneous maxima at Shelley are only about 1% higher than daily maxima, frequency analyses were limited to daily values. (According to BC Ministry of Environment standards, a minimum freeboard allowance of 0.6 m is to be applied to water surface profiles based on daily maxima and 0.3 m to those based on instantaneous maxima. Since the difference between instantaneous and daily peak flows is small in this case, the 0.6 m freeboard governs.)

Frequency analysis used the software "HydroFreq" developed at the University of Alberta (**Appendix D**). The program computes General Extreme Value, Log Normal III, Log Pearson III and Pearson III distributions. Results for all distributions are presented in **Appendix D**. For the design profile the Log Pearson III distribution was selected – as also used by the US Geological Survey and Federal Emergency Management Agency (FEMA).

For Fraser River at Shelley, the following design flood estimates based on the period 1935-2007, with 1894 as a historical outlier, are recommended:

Return Period (Years)	Fraser River above Nechako - Flow (m^3/s)
20	4,470
50	4,940
100	5,300
200	5,660

The updated 20-year flow is the same as used by Klohn-Crippen (1997). The new 200-year flood estimate of 5,660 m^3/s is slightly (2%) higher than the previous value of 5,560 m^3/s.

3.3 NECHAKO RIVER FRESHET DESIGN FLOWS

Typically, the Nechako and Fraser River freshet peak flows do not coincide, so that adding the Nechako and Fraser 200-year floods would yield a flood value with a return period well above 200 years. Instead, the Nechako River design water surface profile was based on the following two scenarios:

- The Nechako River 200-year flood and coincident Fraser River flow.
- The Fraser River 200-year flood and coincident Nechako River flow.

The two profiles were then overlaid and the higher used to develop the design freshet profile for the river. The first condition is expected to yield higher water levels in the upper and middle study reaches while the second condition, described in Section 3.4, likely governs near the confluence. The coincident Fraser River flow was determined by estimating the 200-year Fraser flow for the period June 20 to July 20, or during the time interval when the Nechako annual peak occurs. The coincident Nechako flow was estimated as the difference between Fraser flows below and above the confluence as described in Section 3.4.

The 1950-2008 flow record for Nechako River at Isle Pierre (nearest WSC Station) is statistically non-homogenous, because the reservoir operating regime has changed over time. As part of a recent flood assessment study for Vanderhoof, NHC (2008b) produced a simulated Nechako River flow record for 1957-2006 at Vanderhoof that supposes present reservoir operations to have existed over the period. This simulated homogenous record indicated a somewhat reduced risk of high ice-related flows compared to the actual historical record. Nechako freshet flows, on the other hand, could actually be increased by regulation but be further delayed. Those simulations are under review by Rio Tinto Alcan and the Province of British Columbia, but have not yet been accepted, therefore the results were used for sensitivity analyses only. An enquiry to MOE drew the following response from Mr. G. Davidson, Director (personal communication):

> "*While there is ongoing discussion with Rio Tinto Alcan (RTA) to improve inflow forecasting and flood routing operations there are currently no plans to dramatically alter flood operations on the Nechako. Alcan continues to operate their facilities within the current water license.*
>
> *What may lead to a change in operations would be a change in the works. The Province and RTA are currently considering options related to the installation of a water release facility at the Kenney Dam*[9]*. Installation of such a facility would change water release operations and would likely affect flood flows. However, it is still too soon to predict what type of a facility may be constructed.*
>
> *In addition, RTA continues to look at opportunities to enhance aluminum production at their Kitimat facility. Some options related to this may include changes to hydraulic works associated with the Kemano hydroelectric facility. Changes such as dredging of Tahtsa Narrows or increased penstock capacity could improve the ability to manage large reservoir inflows. However, again it is too early to say if or when these projects may go ahead.*
>
> *The bottom line is that there is currently no plan to dramatically alter the RTA works, the water licenses, or the flood routing operations. There may be some opportunity to make minor improvements to flood forecasting and flood release operations. So for the purposes of (*the Prince George*) analysis, I would assume releases similar to previous years.*"

Consequently, to estimate the Nechako River 200-year flood, the flow record for Isle Pierre was routed using an area ratio adjustment to Prince George and a frequency analysis carried

[9] Plans for this facility were suspended in October 2008 but other developments may be considered in the future.

out for the period 1957 to 2007. The Log Pearson Type III distribution yields the following results:

Return Period (Years)	Nechako River at Prince George Flows (m^3/s)
20	1,050
50	1,200
100	1,320
200	1,450

The new Nechako 200-year flow of 1,450 m^3/s, used to model the water surface profile, is 6% higher than the previous estimate of 1,365 m^3/s by Klohn Crippen (1997). If the above-described simulated Nechako flow record (NHC 2008b) were used, the 200-year estimate would be considerably higher at 1,870 m^3/s. However, since ice-related flooding is known to produce the highest flood levels on the Nechako, the freshet design flow was not further refined. Also, since maximum instantaneous peaks at Isle Pierre average only 0.5% higher than daily flows, the latter were used in the frequency analysis.

In the hydraulic modelling of water surface profiles, the Nechako downstream starting level is set by the coincident Fraser River water level at the confluence. To determine an appropriate Fraser River flow to coincide with the Nechako 200-year flood, Fraser River flows at Shelley from June 20th to July 20th each year, corresponding to the Nechako peak period, were analyzed. Since Fraser River flows are generally considerably higher than Nechako flows, water levels at the confluence are largely dependent on Fraser flows. Based on the Log Pearson Type III distribution the following values were adopted as coincident with the Nechako return period floods:

NechakoReturn Period (Years)	Corresponding (June 20th to July 20th) Fraser River at Prince George - Flow (m^3/s)
20	3,710
50	3,940
100	4,070
200	4,190

In other words, to model the Nechako River 200-year flood, starting levels at the confluence were computed using a Fraser River inflow of 4,190 m^3/s and outflow of 5,640 m^3/s, equal to the sum of 4,190 m^3/s (Fraser) and 1,450 m^3/s (Nechako).

3.4 Fraser River Freshet Design Flows Downstream of Nechako River

To generate Fraser River flood estimates downstream of the confluence, the daily flows for Fraser River at Shelley were combined with the daily flows for Nechako River at Prince George (recorded at Isle Pierre and routed to Prince George) for the period 1957 to 2006. Based on the Log Pearson Type III distribution the following estimates were obtained:

Return Period (Years)	Fraser River below Confluence Flow (m^3/s)
20	5,130
50	5,630
100	6,000
200	6,360

These estimates are based on the 1957-2007 period only to account for regulation, whereas the design flows estimated for Shelley (Section 3.2) covered the period from 1935 to 2007. To approximate a longer flow record below the confluence, a separate frequency analysis was conducted on Shelley flows for 1957 to 2007. The ratio between the 1935-2007 and 1957-2007 results was then computed and applied to the design flows below the confluence as tabulated below (all flows are in m^3/s):

Return Period	Shelley (1935-2007)	Shelley (1957-2007)	Ratio: Shelley (1935-2007)/ (1957-2007)	Fraser below Confluence (1957-2007)	Fraser below Confluence (1935-2007)
20	4,470	4,430	1.009	5,130	5,180
50	4,940	4,900	1.007	5,630	5,670
100	5,300	5,260	1.006	6,000	6,040
200	5,660	5,630	1.005	6,360	6,390

The Nechako River flows coincident with the Fraser River design floods were estimated by simply subtracting the Shelley flows from the flows below the confluence giving the following values:

Fraser River Return Period (years)	Nechako River Flow (m^3/s)
20	710
50	730
100	730
200	730

To compute the Fraser River 200-year design flood profile, a flow of 5,660 m^3/s was used above the confluence, a flow of 6,390 m^3/s below the confluence, and a Nechako flow of 730 m^3/s equal to the difference between the two. Compared to the previous modelling (Klohn Crippen 1997) that used Fraser River flows of 5,560 m^3/s and 6,200 m^3/s, the revised flows are 2% and 3% higher.

3.5 POTENTIAL FUTURE IMPACT OF CLIMATE AND BASIN CHANGE

3.5.1 CLIMATE CHANGE

There is a strong consensus within the scientific community that anthropogenic climate change has contributed to warming observed in the latter part of the 20th century (IPCC 2007a, 2007b). It is expected that the global annual mean temperature will rise more than 3^{o}C over the next century. Predictions about changes in precipitation are much less certain.

A review of future climate impacts in British Columbia (Rodenhuis et al 2007) has recently been undertaken by the Pacific Climate Impacts Consortium (PCIC). The report was prepared to provide a comprehensive survey of the current knowledge of climate variability and change in British Columbia, and provides estimates of future climate conditions predicted for the 2050's. For the Fraser Plateau region, the temperature and precipitation are expected to increase as follows[10]:

Temperature Anomaly[11] (^{o}C)			Precipitation Anomaly (mm)		
Winter	Summer	Annual	Winter	Summer	Annual
2.4	1.8	1.9	9	3	7

These numbers agree with a recent study by PCIC (2008) for the Prince George region, which indicates that annual mean temperatures for 2041-2070 will increase by 2^{o}C to 3^{o}C, summer temperatures by 2^{o}C to 3^{o}C, and winter temperatures by 3^{o}C to 4^{o}C. The increases for precipitation are less certain, mainly because of natural variability (see Section 4.1 Rodenhuis et al 2007).

Warmer winter temperatures mean that more precipitation falls as rain rather than snow, resulting in increased winter runoff and decreased snowpack accumulation. The spring snow water equivalent (SWE) is projected to decrease across the greater part of the area by 5% to 20% (Rodenhuis et al 2007, PCIC 2008). Reductions in spring floods are expected because of reduction in the snowpack and warmer temperatures causing an earlier spring melt (Rodenhuis et al 2007).

Morrison et al (2002) modelled future flows on the Fraser River using projected temperatures and precipitations for 2070-2099. These results predict a modest 5% (150 m^3/s) increase in flow volume but a decrease in the mean annual peak flow at Hope of about 18% (1,600 m^3/s). The peaks occurred on average about 24 days earlier, although some peaks (13%) occurred later in the year as a result of summer or fall rain. Less snow will accumulate at lower elevations. Sushama et al (2006) also project a decrease in SWE, higher runoff during late fall and early winter, and earlier and smaller spring peaks.

[10] taken from Rodenhuis et al (2007), Table 4.1.1b.
[11] Anomaly refers to the projected change in future climate expressed as a difference from the model baseline which is the 1961-1990 baseline.

3.5.2 MOUNTAIN PINE BEETLE

The Mountain Pine Beetle (MPB) infestation is changing the landscape over much of British Columbia, affecting an estimated 13.5 million hectares of provincial crown forest (MOF 2008). Attributed at least in part to forest management practices and to climate change, the extent of the epidemic has extensive environmental, economic and social impacts. Hydrological changes and aquatic habitat effects have been studied in particular and are of interest to the study area.

Forecasting specific streamflow changes due to beetle infestation within watersheds is difficult as these changes originate at the forest stand level, where characteristics of each forest stand such as terrain, elevation and amount of infestation, dictate changes to their contribution of downstream streamflows (EDI 2008, Uunila et al 2006). On the basis of academic studies, however, generalized changes can be expected. As trees in a MPB-infested forest die, transpiration rates and interception of precipitation are reduced. Increases in forest soil water result and may contribute to poor surface water drainage and elevated water tables. In the Vanderhoof and Lakes Forest Districts, conversion of dry firm “summer” ground to wetter, less firm “winter” ground within dead-pine leading stands has been documented, making use of traditional heavy logging equipment difficult or impossible (Rex and Dubé 2006). Also near Vanderhoof, on the Nechako Plateau, it was found that a low ablation rate and increased ground snow accumulation in a dead stand of MPB-killed trees (compared to a live stand) resulted in a lengthened period of snowpack disappearance (Boon 1997). A modelling study in the Baker Creek watershed near Quesnel (drainage area 1,570 km^2) predicted a 30% increase in annual water yield and 60% increase in annual peak streamflows under the assumption that 75% of the mature pine were attacked by MPB in this watershed, which has been affected by past harvesting practices (BC FPB 2007). These increases in soil water, streamflow and water yield are expected to last several decades and could lead to decreased slope stability, increased flooding, and changes in water quality and aquatic habitat.

The effect of MPB on much larger systems such as the Fraser River Basin is more complex. Specific hydrologic modelling studies have not yet been undertaken (Alila 2007). Forest hydrology literature is dominated by stand-level knowledge and small paired watershed studies, often less than a few square kilometers in size. Applying this knowledge on its own to much larger watersheds affected by MPB is not reasonable (Alila 2007). The Ministry of Environment is currently investigating the effect of pine-beetle devastation on run-off to the Fraser River basin, and a VIC-model is being assembled (personal communication with Mr. Allan Chapman, MOE River Forecast Centre). This model will be used for evaluating the effects of tree-cover reduction on Fraser River peak flows, but no results are yet available.

3.5.3 Change Predictions Applied to Flooding at Prince George

Studies reviewed suggest that climate change will reduce spring peak flows at Prince George, while the effects of MPB will likely increase them. The interaction between the two processes is complex and no hydrologic modelling is available to allow an assessment of the combined effect on flows at Prince George. Hydraulic modelling of flood flows typically includes a sensitivity analysis to determine how the flood profile responds to variations in the assumed flow. Flow increases of 10% and 20% are typically used, and will be applied to the flows at Prince George until other information is available.

The studies suggest that winter flows will increase, but it is not possible to say by how much. This would be most important on the Nechako River, where the increase might result in more frequent flow conditions conducive to ice jamming (see Section 4.4). On the other hand, increased winter temperatures might reduce the tendency for frazil ice development (a key component for ice jamming - see Section 4.4), which may reduce the frequency of ice jamming.

3.6 Hydraulic Analysis

Hydraulic modelling was undertaken to simulate open water (freshet) flood profiles corresponding to the estimated Nechako and Fraser River design flows, using HEC-RAS, a one-dimensional hydrodynamic software developed by the US Army Corps of Engineers. Required inputs are channel and floodplain geometry, Manning's roughness coefficients, bridge details and boundary conditions consisting of reach inflows and downstream starting water levels. The developed model was calibrated and validated to observed water levels and then used to simulate design profiles. Its sensitivity to variations in roughness, flows and starting conditions was also assessed. The Nechako River 200-year open water flood profile was compared to the 200-year ice-related profile and the higher of the two taken as the design condition.

3.6.1 Model Development

From May 27 to 30, 2008, NHC with assistance from EDI surveyed 23 cross-sections on the Nechako River and 8 on the Fraser River, using a sonar depth sounder linked to a real-time kinetic (RTK) GPS. Water levels at the time of the survey were recorded at each section for model calibration purposes. Terrestrial benchmarks were surveyed using the RTK system twice daily for quality assurance. The cross-sections, at approximately the same locations as the 1979 and 1995 sections used in the Klohn Crippen (1997) study, are shown on **Maps 1** to **3**. The 2008 cross-sections were concentrated along the lower and middle Nechako River reaches and in the confluence area of the Fraser, where the most significant channel changes were expected. However, a comparison of the old and new surveys showed little change. Repeat surveys were not conducted for the upper end of the Nechako reach nor the upper and lower reaches of the Fraser River. In the immediate confluence area, the bathymetric survey was expanded to a grid survey to allow for future monitoring and optional two-dimensional hydraulic modelling.

To obtain up-to-date floodplain topography for the Lower Nechako and Fraser confluence areas, MCSL conducted a LiDAR (Light Detecting and Ranging) survey on June 30, 2008. The survey covered an area of approximately 19.3 km^2 as shown in **Figure 3.8**, with a two-point/m^2 density, corresponding to an accuracy of $\pm$20-25 cm or better. For floodplain areas outside the LiDAR area, topography was obtained from the old floodplain mapping based on 1993 air photography.

The bathymetric, topographic and LiDAR data were combined in GIS and the cross-sectional spacing along the thalweg extracted. Within the study area, there are three bridge crossings on the Nechako River and five on the Fraser River. Bridge information, available from the previous mapping study (Klohn Crippen 1997), was included in the model.

3.6.2 MODEL CALIBRATION AND VALIDATION

During the 2008 freshet, the Fraser River at Shelley peaked on May 22 with an estimated discharge of 4,310 m^3/s based on WSC's real time data (final approved flows not being available as of yet). During the bathymetric surveys from May 27 to 30, the real-time discharge dropped to an average of 3,300 m^3/s. As suggested by a WSC flow measurement obtained during the freshet and listed on the real-time data website, the rating curve presently in use may be too high by about 8% and a revision to the curve may be required. Since a calibration flow higher than the actual discharge would result in non-conservative roughness coefficients, a corresponding 8% adjustment was made to the real time flows, giving a calibration flow of 3,027 m^3/s.

During the calibration period, the Nechako River flow at Isle Pierre averaged 540 m^3/s. Again, a WSC flow measurement taken during the freshet suggested that the real-time data may be too high, in this case by about 3%. On the other hand, local inflows between Isle Pierre and Prince George were estimated to increase the flow by 2%. A calibration flow of 536 m^3/s was assumed.

HEC-RAS allows modelling of river junctions by two methods, based on either the conservation of energy or conservation of momentum. Based on the available calibration data, the energy method was found to be more representative. However, the flow pattern at the confluence is strongly two-dimensional, so that for more accurate results, two-dimensional modelling using a software like River2D is recommended.

In the calibration process, Manning roughness coefficients (n) were adjusted to provide the best fit of modelled to observed water levels. As the 2008 survey of high-water marks did not cover the entire study area, marks from 1990 were used to extend the calibration. Considering the only minor changes in the cross-sectional geometry over time, this was considered reasonable.

For the Nechako River, a roughness coefficient of 0.031 was adopted for the reach from Cross-Section N1 to N27, and 0.032 upstream of N27. Adopted Fraser River coefficients ranged from 0.027 to 0.030. Adopted overbank coefficients ranged from 0.05 for open fields to 0.10 for densely vegetated areas.

For an independent validation, high-water marks from 1972 were used. Generally, good agreement was found between observed and computed values. Calibration flows, adopted roughness values and deviations of modelled from observed water levels are summarized in **Table 3.3** for Nechako River and **Table 3.4** for Fraser River. Average absolute errors range from 0.06 m (2008 - Nechako River) to 0.18 m (1972 – Fraser River). Suspect observed data were not used in the error calculations. During large floods, significant super-elevation of flow occurs in sharp river bends, resulting in substantial water level differences between the banks. Because water levels at the WSC Shelley gauge were difficult to match using realistic roughness values, it is recommended that the gauge benchmark be confirmed.

For all simulated profiles, the starting condition was assumed to be normal flow at the downstream end of the Fraser River study reach. The sensitivity of the model to this boundary condition as well as to variations in roughness and flows was examined as part of the sensitivity assessments described in Section 3.6.4.

3.6.3 DESIGN FRESHET FLOOD PROFILES

Nechako River

Using the calibrated model, water surface profiles for the design flow were simulated and compared with the Klohn Crippen (1997) results. Since the future Nechako operating regime, particularly during very high flows, is not clearly defined, the 200-year flood based on past recorded flows (1,450 m^3/s) was adopted as the design flow. The corresponding profile is shown in **Figure 3.9**. Also shown is the backwater profile for the 200-year Fraser River flood of 5,660 m^3/s and the coincident Nechako design flow of 730 m^3/s. The latter condition results in higher water levels over a distance of 3.8 km upstream of the confluence, to roughly Cross-Sections N8. The final 200-year freshet profile is represented by the combination of the two profiles, using whichever is higher at each section.

Figure 3.10 shows the 20-year and 200-year water surface profiles and the thalweg. The 20-year profile is included because it is typically incorporated on floodplain maps along with the 200-year design condition. Water levels are listed in **Table 3.5**.

Fraser River

The Fraser River 200-year water surface profile is shown in **Figure 3.11.** It is consistently higher than the Klohn Crippen (1997) profile as a result of historical and recent floods being included in the frequency analysis.

Figure 3.12 compares the 20- and 200-year Fraser River water surface profiles and also shows the thalweg profile. Corresponding water levels are listed in **Table 3.6**. Flood Construction Levels are discussed in Section 5.1.

The CNR trestle bridge at the confluence has a sloping low chord, with a clearance above the 200-year water surface profile of only 0.2 m on the left bank and 1.4 m on the right bank. Large quantities of debris are transported by the Fraser River and a substantial log jam could occur at the upstream side of the bridge during the 200-year flood. The river section is quite wide and a log jam may not significantly alter the upstream water surface profile but could damage the bridge. CNR should be informed about the updated flood profile.

Section 2.4 compared the old and new river cross-sections in terms of thalweg elevations, average bed elevations and flow areas. As part of the hydraulic analyses a fourth comparison was carried out by importing the cross-sections surveyed in 1979 into the 2008 HEC-RAS model. This allowed direct comparison of the simulated 200-year flood profiles for both sets of cross-sections, without influence from other model parameters. The two profiles were within a few centimetres of each other, further confirming that the conveyance of Fraser and Nechako Rivers has not significantly changed at the confluence over the past 30 years.

3.6.4 Flood Profile Sensitivity Analysis

The sensitivity of the Nechako and Fraser River design flood profiles (base-case) to variations in roughness, flow and starting levels was evaluated. This involved adjusting each variable and then determining the resulting deviation from the base profile.

The roughness values for the Nechako River were increased by 10% over the entire reach. This caused 200-year freshet flood levels to rise on average 0.29 m above the base profile. A similar roughness increase raised Fraser River water levels on average by 0.44 m. Sensitivity test results are plotted in **Figures 3.13** and **3.14** and listed in **Tables 3.7** and **3.8**.

Sensitivity to discharge variations was evaluated by increasing both Nechako and Fraser River design flows by 10% and by 20% (Section 3.5.3). Results are shown in **Figures 3.15** and **3.16**. Corresponding average water level rises were 0.32 m and 0.61 m in the Nechako and 0.51 m and 1.00 m in Fraser. The Nechako profile corresponding to a 200-year flood based on simulated reservoir outflows for a tentative present-day operating regime (Section 3.3 and NHC 2008b) is also shown.

For the base-case, the Fraser River 200-year starting level at Cross-Section F1 is 563.15 m, based on normal flow assumptions. This level was raised by 0.5 m and 1 m and corresponding flood profiles were computed. The 0.5 m increase raised the profile over a distance of roughly 10 km. The 1.0 m rise raised the profile over about 17 km, to above the Nechako confluence.

These sensitivity assessments suggest that the computed design flood profile is fairly sensitive to relatively minor variations in roughness, flow, and starting levels. The model was calibrated to Nechako flows in the 540 to 800 m^3/s range, and to Fraser River flows in the ranges of 3,300 to 4,800 m^3/s upstream of the Nechako and 3,560 to 5,200 m^3/s downstream. These flows are considerably lower than the design discharges. Since roughness may vary somewhat with discharge, it is recommended that high water marks be observed in future large floods, in order to validate the model and update the design profiles if required.

3.6.5 DESIGN FREQUENCY AND FREEBOARD ASSESSMENT

In British Columbia, the 200-year flood (0.5% risk of exceedance) is commonly adopted for the design of dikes and for assessing flood hazards. On the Lower Fraser River, the 1894 flood of record (return period of about 500 years) has been used by the joint federal/provincial Fraser River Flood Control Program and the BC Ministry of Environment. Other agencies including Indian and Northern Affairs Canada use the 200-year flood level.

Looking at these BC design flood standards in a global context, it is now commonly held that the level of flood protection should depend on the importance of the area being protected and the potential for loss of life and damage. Where there is a great threat to life if flood control facilities fail, much rarer design floods are often specified. For example, in China along some sections of the Yellow River, the design return period ranges from 500 to 2,000 years (annual exceedance probability 0.2% to 0.05%). In the Netherlands, where much of the country is below sea level, very high standards of protection are used. In Central Holland, coastal dikes are designed against a 10,000-year storm surge, and river dikes against a 1,250-year flood. Poland uses the 1,000-year flood for critical river levees.

The tops of river dikes are normally required to be set at a freeboard above the design flood level to prevent overtopping caused by:

- Waves (wind and ice consolidation generated)
- Wind setup
- Tidal surges
- Hydraulic jumps and standing waves in the channel
- Super-elevation of the water surface in bends
- Unforeseen raising of water levels due to sedimentation or an increase in channel roughness due to bedforms or vegetation
- Effects of floating debris or ice
- Settlement of the dikes or underlying floodplain
- Other uncertainties in the hydrology and hydraulics

Freeboard in British Columbia is typically specified to be 0.6 m. This value is within the range commonly specified elsewhere for “typical” conditions where the risk of deaths or unacceptable damage is low. However, the specified amount of freeboard for a particular diking project may depend on several factors including:

- Height of the dikes
- Type of construction material used to build the dikes
- Top width of the dikes
- Flow velocity and degree of curvature of the channel
- Value of the land protected
- Potential loss of life if the dikes were to fail

A review of freeboard requirements in other countries (McArthur 1991) provides the following examples:

> ***Germany:*** The lowest allowable value is 0.8 m. It can be as high as 1.5 m for populated areas. A variety of sophisticated methods are used for computing the design discharge, water surface elevation and freeboard.
>
> ***Hungary:*** A fixed value of 1.0 m or 1.5 m is used, depending on wave conditions and potential for erosion of the dikes.
>
> ***Japan:*** The freeboard increases with the magnitude of the design discharge. For small streams (flow less than 200 m^3/s) the minimum freeboard is 0.6 m. For large rivers (flow greater than 10,000 m^3/s), a freeboard of 2.0 m is used.
>
> ***Netherlands:*** Freeboard is computed using a detailed analysis related to the specific characteristics of the dikes and local hydraulic conditions. The minimum freeboard provided is always greater than or equal to 0.5 m. For sea dikes, the minimum freeboard is computed using the 2% significant wave run-up condition applied during the design high water event (10,000-year return period). Besides freeboard, an allowance for sea-level rise is added to the design height of the dikes to cover the design period (50 years).

There appears to be insufficient information at present with respect to risks to determine the appropriate freeboard for the Nechako and Fraser Rivers. The commonly accepted B.C. value of 0.6 m appears to be at the lower end of the range used for highly developed urban areas in other jurisdictions.

The sensitivity analysis indicated that the base-case simulated flood profile for the Fraser/ Nechako Rivers are sensitive to changes in channel roughness and discharge, and that corresponding rises in the profile could use up a significant portion of a 0.6 m freeboard. A larger freeboard may be warranted, particularly if the combined effect of climate change and Mountain Pine-Beetle infestation increases peak flows.

Table 3.1 Historic Freshet Flooding at Prince George

Year	Gauge Height (Old Datum)	Gauge Height (New Datum)	PG WL (m) GSC (1)	SFG WL (m) GSC (2)	General Comparison (4)	Description of Damage (4)
1875	-	-	-	-	9.9 m above Low Water at Quesnel or higher than ever known before (since 1860?).	Several buildings flooded. Year was likely 1876 rather than 1875, based on record at Mission.
1894	-	11.5	569.5	569.3 (3)	Estimated water level from WSC file (1962).(Design flood - Fraser River downstream of Hope).	Severe flooding throughout BC.
1911	25 ? ft	-	568.6 ?	567.9? (3)	-	City flooded.
1920	-	-	-	-	Water at "danger point".	-
1936	21.8 ft ? 1867.5 ft approx	-	569.2	568.5 (3)	Within 5 ft of of CNR Bridge decking. Highest observed since 1911.	Vanderhoof flooded. Vanderhoof -Prince George HWY flooded. Water up to 1st Street and Fraser Avenue (south side of RR tracks).
1939	19.7 ft	-	566.94	566.3 (3)	-	East End Flats flooded.First Avenue flooded in one location. Sloughs filled to capacity.
1948	26.36 ft 1866.7 ft	-	568.98	568.3 (3)	-	Refer to inundation boundaries.
1954	24.92 ft	-	568.53	567.8 (3)	-	-
1964	-	-	568.33	567.6 (3)	-	400 residents evacuated from the Cache.
1967	-	9.96	568.22	567.74	-	North Nechako threatened. Cache flooded. Dike improvements made.
1972	-	10.44	-	568.22	-	Cottonwood Isl and SFG flooded.
1990	-	9.90	-	567.68	-	Foreman Flats, Cottonwood Island, Paddlewheel Park flooded. Farrell, Hazelton, Inlander Streets - people left homes. Landsdowne & Pulpmill Rd basements flooded. Lawsuit.
1997	-	9.88	-	567.66	-	Increased water table - 2nd & 3rd Avenue businesses affected. Damage at $1M. Shelley and Foreman Flats partly evacuated. Nechako flooding - bank erosion at Miworth and Prince George, Island Drive and Bergman Rd. GeoNorth recommended riprap at Aspen Lane. Relocate homes along Island Park Drive.
2002	-	9.73	-	567.51	-	-
2007	-	9.83	-	567.61	-	-
2008	-	9.70	-	567.48	-	-

Notes: 1. PG = WSC gauge Fraser River at Prince George
2. SFG = WSC gauge Fraser River at South Fort George
3. Estimated based on water level at Prince George gauge
4. Septer (2007)

Table 3.2: Water Survey Canada Key Gauges

Station No	Station Name	Drainage Area (km^2)	Period of Record	Number of Years	Type of Record
08JC002	Nechako River at Isle Pierre	42,500	1950-2008	59	Flow
08KB001	Fraser River at Shelley	32,400	1950-2008	59	Flow
08KE001	Fraser River at Prince George	79,500	1947-1968	22	Water Level only
08KE018	Fraser River at South Fort George	79,900	1968-2008	41	Water Level only
08MD013	Fraser River at Big Bar Creek	146,000	1935-1972	38	Flow
08JA013	Skins Lake Spillway, Nechako Reservoir	---	1956-2008	53	Flow
08JC001	Nechako River at Vanderhoof	25,100	1948-2008	61	Flow
08JB003	Nautley River near Fort Fraser	6,030	1950-2008	59	Flow
08JE001	Stuart River near Fort St. James	14,600	1929-2008	80	Flow

Table 3.3 - Nechako Calibration/Validation

Nechako River Calibration Summary

XS Name	Channel n - value	Calibration 2008			Calibration 1990			Calibration 1972		
		W.L. Sim.	W.L. Obs.	Sim. - Obs	W.L. Sim.	W.L. Obs.	Sim. - Obs	W.L. Sim.	W.L. Obs.	Sim. - Obs
XS N34	0.032	578.05	--	--	577.59	--	--	578.82	--	--
XS N33	0.032	577.67	577.75	-0.08	577.21	--	--	578.43	--	--
XS N32	0.032	576.84	--	--	576.46	--	--	577.47	--	--
XS N31	0.032	576.10	--	--	575.69	--	--	576.79	--	--
XS N30	0.032	575.37	575.43	-0.06	574.88	--	--	576.16	--	--
XS N29	0.032	574.96	--	--	574.48	--	--	575.76	--	--
XS N28	0.032	574.40	--	--	573.92	--	--	575.19	--	--
XS N27	0.031	573.93	573.87	0.06	573.47	--	--	574.69	--	--
XS N26	0.031	573.60	573.55	0.05	573.16	--	--	574.33	--	--
XS N25	0.031	573.24	573.27	-0.03	572.82	--	--	573.94	--	--
XS N24	0.031	572.85	--	--	572.44	--	--	573.55	--	--
XS N23	0.031	572.54	--	--	572.13	--	--	573.23	--	--
XS N22B	0.031	572.24	--	--	571.85	--	--	572.89	--	--
XS N22A	0.031	572.20	572.34	-0.14	571.82	--	--	572.84	--	--
XS N21	0.031	571.97	571.58	***0.39***	571.61	--	--	572.60	--	--
XS N20	0.031	571.51	571.59	-0.08	571.19	--	--	572.10	--	--
XS N19	0.031	570.99	571.01	-0.02	570.67	--	--	571.62	--	--
XS N18	0.031	570.49	570.42	0.07	570.18	--	--	571.19	--	--
XS N17	0.031	570.05	569.92	0.13	569.81	--	--	570.83	--	--
XS N16	0.031	569.71	569.71	0.00	569.56	--	--	570.50	--	--
XS N15	0.031	569.32	569.31	0.01	569.33	569.28	0.05	570.21	570.19	0.02
XS N14	0.031	569.29	--	--	569.31	569.27	0.04	570.20	570.18	0.02
XS N12	0.031	568.96	568.90	0.06	569.17	569.18	-0.01	570.01	570.06	-0.05
XS N11	0.031	568.49	568.34	0.15	569.02	569.02	0.00	569.78	569.80	-0.02
XS N9	0.031	568.39	--	--	569.00	569.00	0.00	569.74	569.78	-0.04
XS N8	0.031	567.99	568.02	-0.03	568.93	568.79	0.14	569.61	569.50	0.11
XS N7	0.031	567.69	567.69	0.00	568.90	568.62	0.28	569.53	569.38	0.15
XS N6	0.031	567.53	567.49	0.04	568.87	568.25	0.62	569.48	569.34	0.14
XS N5	0.031	567.33	567.35	-0.02	568.84	568.56	0.28	569.36	569.30	0.06
XS N4	0.031	567.24	567.28	-0.04	568.83	568.88	-0.05	569.34	569.29	0.05
XS N3	0.031	567.22	567.25	-0.03	568.83	568.64	0.19	569.35	569.28	0.07
XS N2	0.031	567.21	567.24	-0.03	568.82	568.72	0.10	569.34	569.29	0.05
XS N1	0.031	567.21	567.29	-0.08	568.82	568.76	0.06	569.34	--	--
Error				+- 0.06			+- 0.14			+- 0.07

NOTES: 1. - For the 1972 and 1990 Floods the observed values were calculated based on linear interpolation of available water marks.
2. - For the 1972 observed water marks in Nechako River the distance from the starting point was adjusted by -459.4 m
3. - Suspect observed data shown in Italics and not included in average error calculation.
4. - All water levels and elevations are in metres (GSC).

Table 3.4 - Fraser Calibration/Validation

Fraser River Calibration Summary										
XS Name	Channel n - value	Calibration 2008			Calibration 1990			Calibration 1972		
		W.L. Sim.	W.L. Obs.	Sim. - Obs	W.L. Sim.	W.L. Obs.	Sim. - Obs	W.L. Sim.	W.L. Obs.	Sim. - Obs
XS F61	0.027	573.96	--	--	575.76	--	--	575.94	--	--
XS F60	0.027	573.66	573.20	0.46	575.47	574.86	0.61	575.66	575.07	0.59
XS F59	0.027	573.44	--	--	575.24	574.86	0.38	575.43	--	--
XS F58	0.027	573.30	--	--	575.14	574.79	0.35	575.33	--	--
XS F57	0.027	573.06	--	--	574.83	574.59	0.24	575.03	--	--
XS F56	0.027	572.91	--	--	574.73	574.42	0.31	574.93	--	--
XS F55	0.027	572.65	--	--	574.40	574.19	0.21	574.60	--	--
XS F54	0.028	572.25	--	--	574.15	573.99	0.16	574.36	--	--
XS F53	0.028	571.63	--	--	573.67	573.80	-0.13	573.90	--	--
XS F52B	0.028	571.42	--	--	573.44	573.59	-0.15	573.68	--	--
XS F52	0.028	571.41	--	--	573.42	573.58	-0.16	573.66	--	--
XS F51	0.028	571.37	--	--	573.37	573.31	0.06	573.61	--	--
XS F50	0.028	571.13	--	--	573.12	573.09	0.03	573.36	--	--
XS F49	0.028	571.14	--	--	573.16	573.04	0.12	573.41	--	--
XS F48	0.028	570.71	--	--	572.41	572.91	-0.50	572.63	--	--
XS F47	0.028	570.63	--	--	572.40	572.53	-0.13	572.63	--	--
XS F46	0.028	570.35	--	--	572.11	572.11	0.00	572.36	--	--
XS F45	0.027	570.10	--	--	571.88	571.66	0.22	572.14	--	--
XS F44	0.027	569.93	--	--	571.71	571.33	0.38	571.97	--	--
XS F43	0.027	569.79	--	--	571.56	571.14	0.42	571.83	--	--
XS F42	0.027	569.56	--	--	571.32	571.18	0.14	571.61	--	--
XS F41	0.027	569.33	--	--	571.06	571.32	-0.26	571.36	--	--
XS F40	0.029	569.09	--	--	570.95	570.90	0.05	571.27	--	--
XS F39	0.029	568.88	--	--	570.77	570.70	0.07	571.13	--	--
XS F38	0.029	568.75	--	--	570.65	570.64	0.01	571.01	--	--
XS F37	0.029	568.65	--	--	570.57	570.54	0.03	570.94	--	--
XS F36	0.030	568.45	--	--	570.27	570.44	-0.17	570.64	--	--
XS F35	0.030	568.28	--	--	570.11	570.25	-0.14	570.49	--	--
XS F34	0.030	568.17	--	--	569.97	570.13	-0.16	570.36	--	--
XS F33	0.029	567.93	567.86	0.07	569.71	569.61	0.10	570.13	--	--
XS F32	0.029	567.57	567.60	-0.03	569.20	569.06	0.14	569.65	569.42	0.23
XS F31	0.029	567.40	567.39	0.01	568.95	568.84	0.11	569.43	569.32	0.11
XS F30	0.029	567.43	567.30	0.13	569.02	568.83	0.19	569.49	569.32	0.17
XS F29	0.029	567.40	--	--	568.96	568.83	0.13	569.44	569.32	0.12
XS F28	0.029	567.36	567.43	-0.07	568.92	568.78	0.14	569.40	569.26	0.14
XS F27	0.030	567.18	567.22	-0.04	568.75	568.72	0.03	569.26	569.19	0.07
XS F26	0.030	567.11	--	--	568.72	568.55	0.17	569.24	569.18	0.06
XS F25	0.030	567.10	--	--	568.72	568.50	0.22	569.24	569.17	0.07
XS F23	0.030	567.09	--	--	568.71	568.49	0.22	569.23	569.16	0.07
XS F22	0.030	567.07	--	--	568.69	568.40	0.29	569.20	569.02	0.18
XS F21	0.029	566.96	--	--	568.55	568.27	0.28	569.06	568.62	0.44
XS F21A	0.029	566.92	--	--	568.51	568.25	0.26	569.01	568.56	0.45
XS F20	0.028	566.71	--	--	568.22	568.11	0.11	568.69	568.40	0.29
XS F19	0.028	566.41	--	--	567.92	567.67	0.25	568.40	568.00	0.40
XS F18	0.028	565.93	565.52	***0.41***	567.38	567.14	0.24	567.83	567.64	0.19
XS F16	0.028	565.66	--	--	567.10	566.97	0.13	567.56	567.49	0.07
XS F15	0.028	565.66	--	--	567.10	566.97	0.13	567.56	567.48	0.08
XS F14	0.028	565.45	--	--	566.89	566.84	0.05	567.35	567.41	-0.06
XS F13	0.028	565.22	--	--	566.67	566.67	0.00	567.13	567.36	-0.23
XS F12	0.028	565.14	--	--	566.63	566.53	0.10	567.11	567.28	-0.17
XS F11	0.030	564.96	563.00	***1.96***	566.49	566.45	0.04	566.98	567.25	-0.27
XS F10	0.030	564.79	--	--	566.30	566.22	0.08	566.78	566.85	-0.07
XS F9	0.030	564.51	--	--	565.96	565.97	-0.01	566.42	--	--
XS F8	0.030	563.92	--	--	565.28	565.42	-0.14	565.72	--	--
XS F7	0.030	563.54	--	--	564.86	565.02	-0.16	565.29	--	--
XS F6	0.030	562.94	--	--	564.28	564.40	-0.12	564.72	--	--
XS F5	0.030	562.44	--	--	563.80	563.80	0.00	564.26	--	--
XS F4	0.029	561.84	--	--	563.24	562.99	0.25	563.71	--	--
XS F3	0.029	561.34	--	--	562.55	562.21	0.34	562.98	--	--
XS F2	0.029	561.14	--	--	562.31	--	--	562.73	--	--
XS F1	0.029	560.87	--	--	562.01	--	--	562.44	--	--
Error				+- 0.06			+- 0.15			+- 0.18

NOTES: 1. - For the 1972 and 1990 Floods the observed values were calculated based on linear interpolation of available water marks.
2. - Suspect observed data shown in Italics and not included in average error calculation.
3. - All water levels and elevations are in metres (GSC).

Table 3.5 – Nechako Freshet Design Water Surface Profiles

XS Name	Distance (m)	Channel n - value	Freshet Design Profile (m GSC)	
			20-yr	200-yr
XS N34	15573	0.032	579.47	580.38
XS N33	15135	0.032	579.05	579.92
XS N32	14045	0.032	578.00	578.76
XS N31	13385	0.032	577.39	578.27
XS N30	12896	0.032	576.79	577.68
XS N29	12489	0.032	576.38	577.25
XS N28	11814	0.032	575.82	576.69
XS N27	11148	0.031	575.30	576.13
XS N26	10627	0.031	574.92	575.72
XS N25	10060	0.031	574.50	575.27
XS N24	9495	0.031	574.11	574.88
XS N23	9025	0.031	573.76	574.52
XS N22B	8555	0.031	573.40	574.12
XS N22A	8496	0.031	573.34	574.04
XS N21	8098	0.031	573.08	573.77
XS N20	7456	0.031	572.53	573.16
XS N19	6913	0.031	572.07	572.80
XS N18	6402	0.031	571.62	572.34
XS N17	5932	0.031	571.21	571.95
XS N16	5541	0.031	570.77	571.45
XS N15	5118	0.031	570.39	571.10
XS N14	5087	0.031	570.36	571.06
XS N12	4745	0.031	570.07	570.81
XS N11	4201	0.031	569.63	570.40
XS N9	4175	0.031	569.54	570.32
XS N8	3792	0.031	569.23	570.03
XS N7	3423	0.031	569.03	569.98
XS N6	2938	0.031	568.97	569.95
XS N5	2518	0.031	568.85	569.88
XS N4	1957	0.031	568.82	569.88
XS N3	1337	0.031	568.82	569.88
XS N2	889	0.031	568.81	569.88
XS N1	452	0.031	568.81	569.88

Table 3.6 – Fraser Freshet Design Water Surface Profiles

XS Name	Distance (m)	Channel n - value	Freshet Design Profile (m GSC)	
			20-yr	200-yr
XS F61	39338	0.027	575.45	576.56
XS F60	38312	0.027	575.17	576.29
XS F59	37532	0.027	574.94	576.05
XS F58	36837	0.027	574.83	575.97
XS F57	35961	0.027	574.54	575.65
XS F56	35186	0.027	574.43	575.57
XS F55	34290	0.027	574.11	575.22
XS F54	33364	0.028	573.84	575.03
XS F53	32073	0.028	573.35	574.59
XS F52B	31433	0.028	573.13	574.35
XS F52	31419	0.028	573.11	574.34
XS F51	30981	0.028	573.07	574.28
XS F50	30378	0.028	572.82	574.03
XS F49	29697	0.028	572.85	574.08
XS F48	29099	0.028	572.16	573.19
XS F47	28429	0.028	572.14	573.22
XS F46	27700	0.028	571.86	572.94
XS F45	26813	0.027	571.64	572.73
XS F44	26090	0.027	571.47	572.56
XS F43	25674	0.027	571.33	572.42
XS F42	24521	0.027	571.11	572.20
XS F41	23856	0.027	570.86	571.93
XS F40	22730	0.029	570.74	571.89
XS F39	21595	0.029	570.56	571.75
XS F38	20958	0.029	570.45	571.64
XS F37	20290	0.029	570.38	571.57
XS F36	19666	0.030	570.11	571.24
XS F35	18831	0.030	569.95	571.10
XS F34	18281	0.030	569.83	570.95
XS F33	17276	0.029	569.59	570.71
XS F32	16322	0.029	569.14	570.18
XS F31	15668	0.029	568.93	569.93
XS F30	15650	0.029	568.98	570.01
XS F29	15632	0.029	568.93	569.95
XS F28	15421	0.029	568.90	569.92
XS F27	14446	0.030	568.75	569.78
XS F26	13868	0.030	568.71	569.77
XS F25	13714	0.030	568.71	569.77
XS F23	13680	0.030	568.70	569.76
XS F22	13430	0.030	568.68	569.74
XS F21	13059	0.029	568.54	569.59
XS F21A	13004	0.029	568.50	569.53
XS F20	12639	0.028	568.21	569.19
XS F19	11701	0.028	567.91	568.90
XS F18	10786	0.028	567.37	568.32
XS F16	10176	0.028	567.10	568.05
XS F15	10156	0.028	567.10	568.04
XS F14	9680	0.028	566.90	567.84
XS F13	9093	0.028	566.68	567.63
XS F12	8686	0.028	566.64	567.62
XS F11	8417	0.030	566.50	567.51
XS F10	7716	0.030	566.31	567.31
XS F9	7010	0.030	565.97	566.93
XS F8	5804	0.030	565.31	566.23
XS F7	5004	0.030	564.90	565.81
XS F6	4144	0.030	564.34	565.27
XS F5	3317	0.030	563.89	564.85
XS F4	2203	0.029	563.36	564.35
XS F3	1422	0.029	562.73	563.62
XS F2	735	0.029	562.51	563.40
XS F1	0	0.029	562.25	563.15

Table 3.7 – Nechako 200-Year Open Water Surface Profile – Sensitivity to Roughness and Flow Variation.

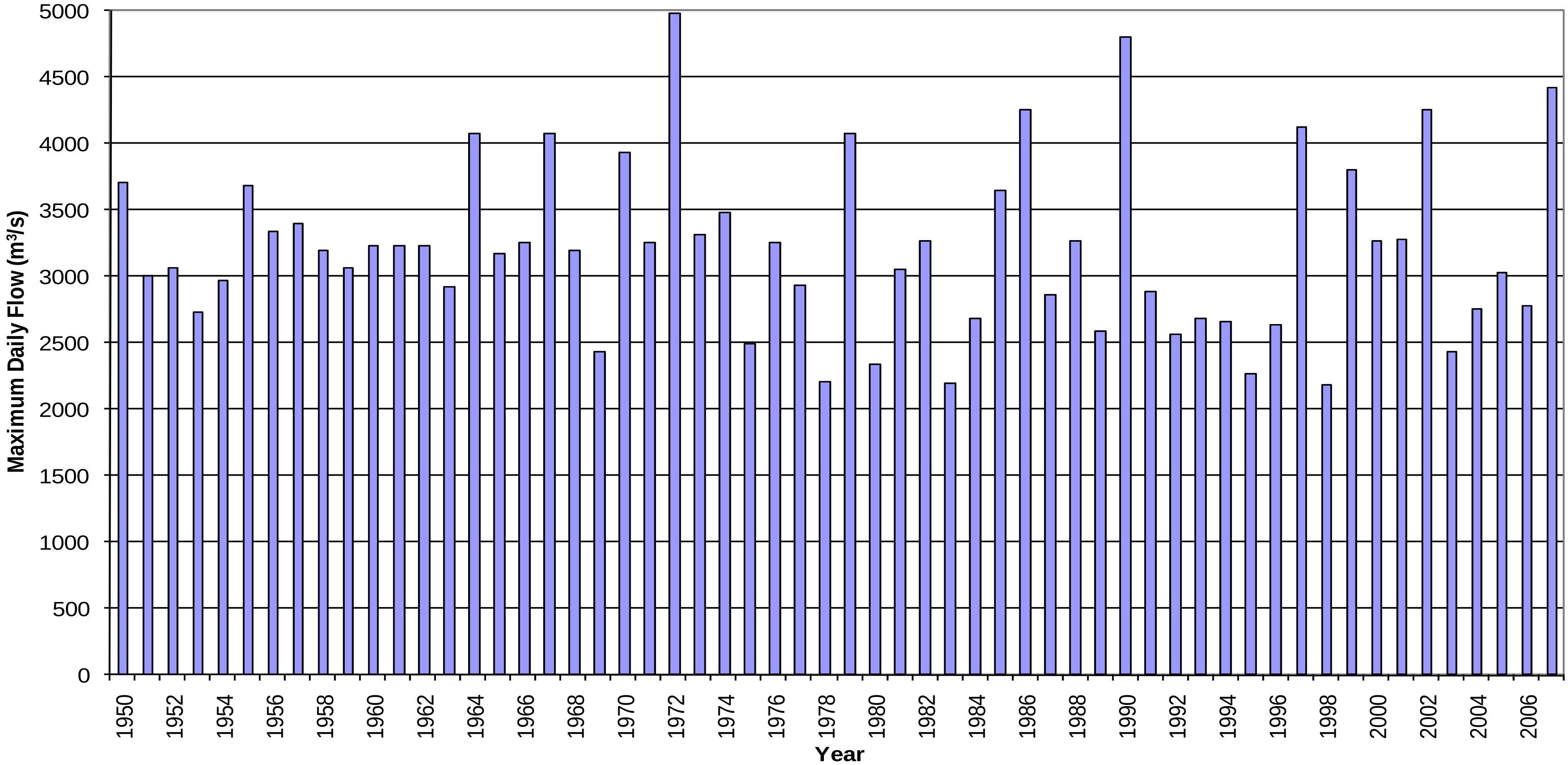
XS Name	W S Elev. (m GSC) (Q = 1450 m^3/s)	n+10% (W.L. Diff.)	Q+10% (W.L. Diff.)	Q+20% (W.L. Diff.)	1870 m^3/s [(1)] (W. L. Diff.)
XS N34	580.38	0.27	0.30	0.59	0.84
XS N33	579.92	0.27	0.28	0.55	0.79
XS N32	578.76	0.27	0.26	0.51	0.73
XS N31	578.27	0.27	0.30	0.58	0.83
XS N30	577.68	0.29	0.30	0.57	0.82
XS N29	577.25	0.29	0.28	0.55	0.78
XS N28	576.69	0.28	0.28	0.54	0.77
XS N27	576.13	0.28	0.27	0.52	0.74
XS N26	575.72	0.27	0.27	0.51	0.72
XS N25	575.27	0.26	0.26	0.48	0.69
XS N24	574.88	0.25	0.26	0.48	0.68
XS N23	574.52	0.24	0.25	0.44	0.63
XS N22B	574.12	0.23	0.24	0.40	0.58
XS N22A	574.04	0.23	0.23	0.38	0.56
XS N21	573.77	0.22	0.24	0.37	0.54
XS N20	573.16	0.23	0.23	0.46	0.62
XS N19	572.80	0.22	0.25	0.50	0.66
XS N18	572.34	0.23	0.25	0.50	0.65
XS N17	571.95	0.24	0.27	0.53	0.66
XS N16	571.45	0.26	0.26	0.51	0.58
XS N15	571.10	0.26	0.28	0.55	0.59
XS N14	571.06	0.27	0.29	0.56	0.59
XS N12	570.81	0.28	0.32	0.60	0.60
XS N11	570.40	0.30	0.35	0.66	0.57
XS N9	570.32	0.31	0.35	0.67	0.56
XS N8	570.04	0.34	0.39	0.72	0.54
XS N7	569.84	0.35	0.41	0.76	0.52
XS N6	569.69	0.36	0.44	0.80	0.51
XS N5	569.32	0.39	0.44	0.90	0.35
XS N4	569.23	0.40	0.49	0.97	0.36
XS N3	569.25	0.38	0.48	0.95	0.37
XS N2	569.23	0.39	0.49	0.96	0.37
XS N1	569.23	0.39	0.49	0.96	0.36
Average	---	0.29	0.32	0.61	0.61

Notes: (1) 200-yr flow based on simulated Nechako Reservoir Operation.
(2) All water levels are in metres (GSC).

Table 3.8 – Fraser 200-Year Open Water Surface Profile – Sensitivity to Roughness and Flow Variation

XS Name	W S Elev. (m GSC) (Q = 5660 / 6390 m^3/s)	n+10% (W.L. Diff.)	Q+10% (W.L. Diff.)	Q+20% (W.L. Diff.)
XS F61	576.56	0.44	0.51	1.01
XS F60	576.29	0.43	0.51	1.01
XS F59	576.05	0.42	0.51	1.01
XS F58	575.97	0.42	0.52	1.03
XS F57	575.65	0.42	0.51	1.01
XS F56	575.57	0.41	0.52	1.03
XS F55	575.22	0.42	0.51	1.01
XS F54	575.03	0.40	0.54	1.08
XS F53	574.59	0.40	0.56	1.11
XS F52B	574.35	0.41	0.56	1.10
XS F52	574.34	0.41	0.55	1.09
XS F51	574.28	0.41	0.56	1.10
XS F50	574.03	0.42	0.56	1.10
XS F49	574.08	0.41	0.57	1.12
XS F48	573.19	0.46	0.47	0.93
XS F47	573.22	0.44	0.50	0.99
XS F46	572.94	0.46	0.50	0.99
XS F45	572.73	0.44	0.50	0.99
XS F44	572.56	0.44	0.51	1.00
XS F43	572.42	0.45	0.51	1.01
XS F42	572.2	0.44	0.51	1.01
XS F41	571.93	0.45	0.51	1.01
XS F40	571.89	0.43	0.54	1.06
XS F39	571.75	0.44	0.55	1.09
XS F38	571.64	0.45	0.56	1.10
XS F37	571.57	0.45	0.56	1.11
XS F36	571.24	0.46	0.54	1.06
XS F35	571.1	0.45	0.54	1.07
XS F34	570.95	0.45	0.54	1.06
XS F33	570.71	0.45	0.54	1.06
XS F32	570.18	0.47	0.51	1.01
XS F31	569.93	0.45	0.50	0.98
XS F30	570.01	0.44	0.50	1.00
XS F29	569.95	0.45	0.50	0.99
XS F28	569.92	0.44	0.50	1.00
XS F27	569.78	0.43	0.52	1.03
XS F26	569.77	0.42	0.53	1.04
XS F25	569.77	0.42	0.53	1.04
XS F23	569.76	0.42	0.53	1.04
XS F22	569.74	0.42	0.52	1.04
XS F21	569.59	0.43	0.51	1.02
XS F21A	569.53	0.44	0.52	1.02
XS F20	569.19	0.45	0.48	0.95
XS F19	568.9	0.45	0.49	0.97
XS F18	568.32	0.46	0.47	0.93
XS F16	568.05	0.45	0.46	0.93
XS F15	568.04	0.45	0.47	0.93
XS F14	567.84	0.45	0.47	0.94
XS F13	567.63	0.44	0.47	0.94
XS F12	567.62	0.43	0.49	0.97
XS F11	567.51	0.44	0.50	1.00
XS F10	567.31	0.43	0.49	0.97
XS F9	566.93	0.45	0.48	0.94
XS F8	566.23	0.45	0.46	0.90
XS F7	565.81	0.44	0.45	0.88
XS F6	565.27	0.46	0.47	0.92
XS F5	564.85	0.46	0.48	0.94
XS F4	564.35	0.46	0.49	0.97
XS F3	563.62	0.48	0.44	0.86
XS F2	563.4	0.45	0.44	0.86
XS F1	563.15	0.45	0.45	0.88
Average	---	0.44	0.51	1.00

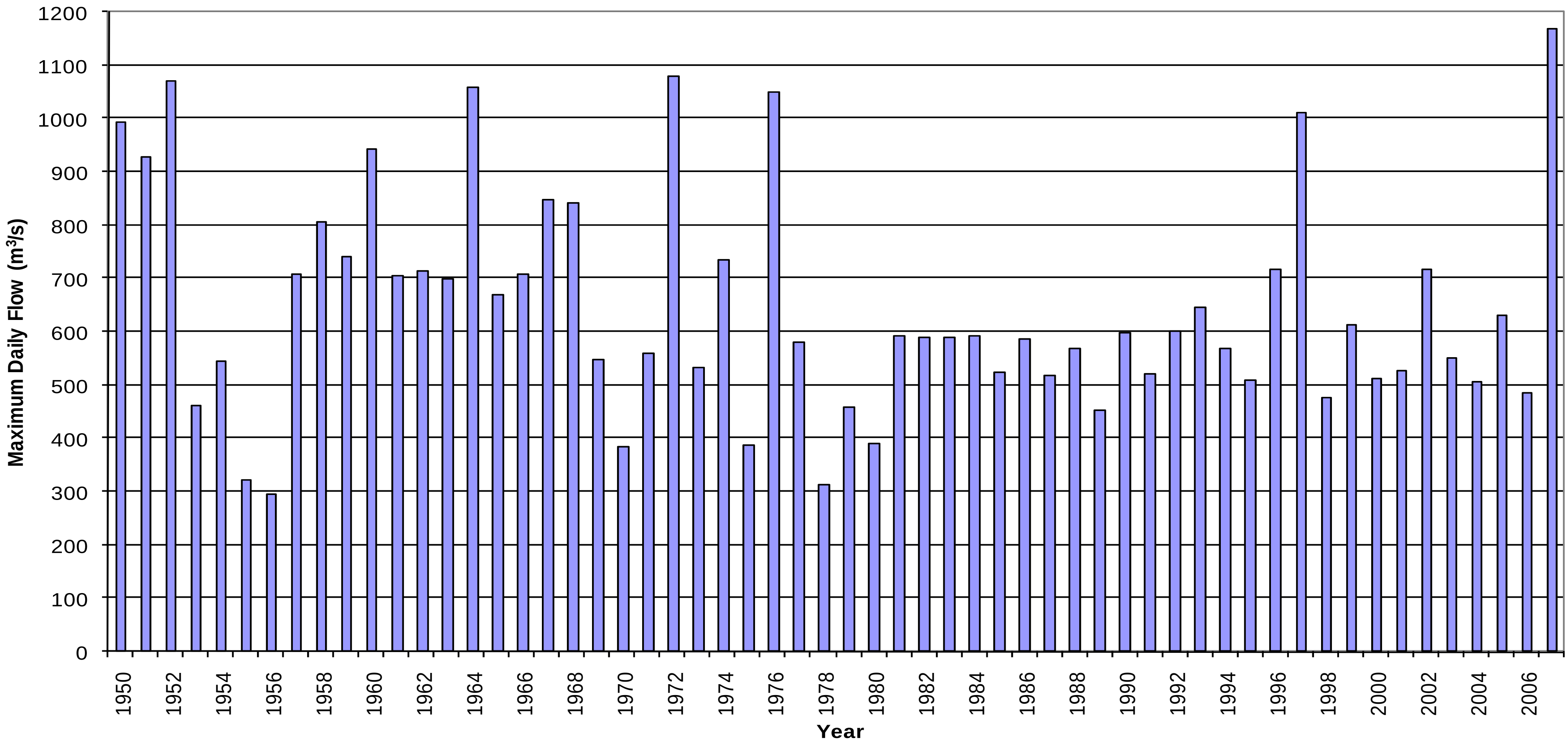
Note: (1) All water levels are in metres (GSC).



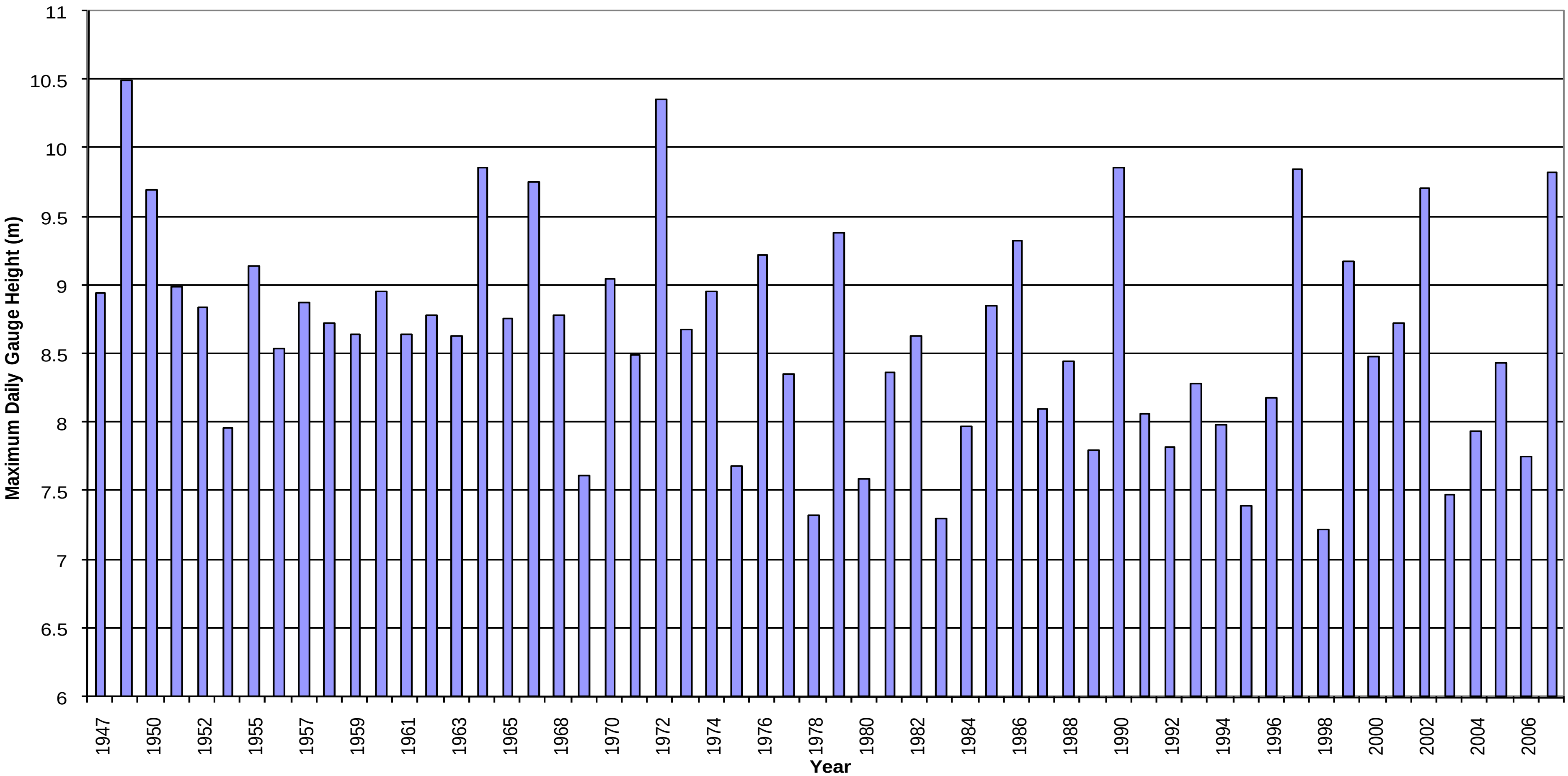
City of Prince George nhc

Fraser River at Shelley
Annual Peak Flows 1950 - 2007

January 2009	Figure 3.1

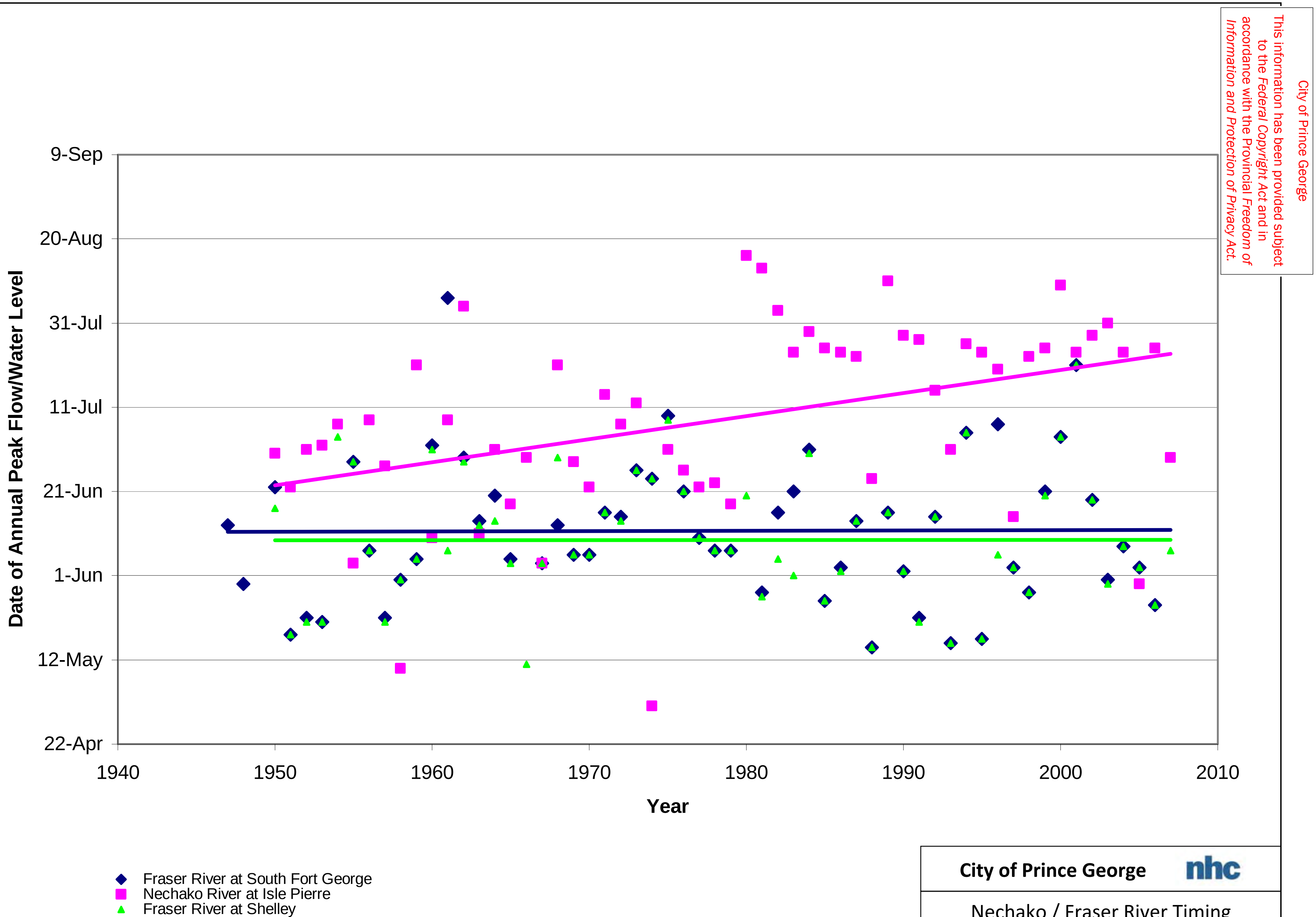


City of Prince George	nhc
Nechako River at Isle Pierre Annual Peak Flows 1950 - 2007	
January 2009	Figure 3.2

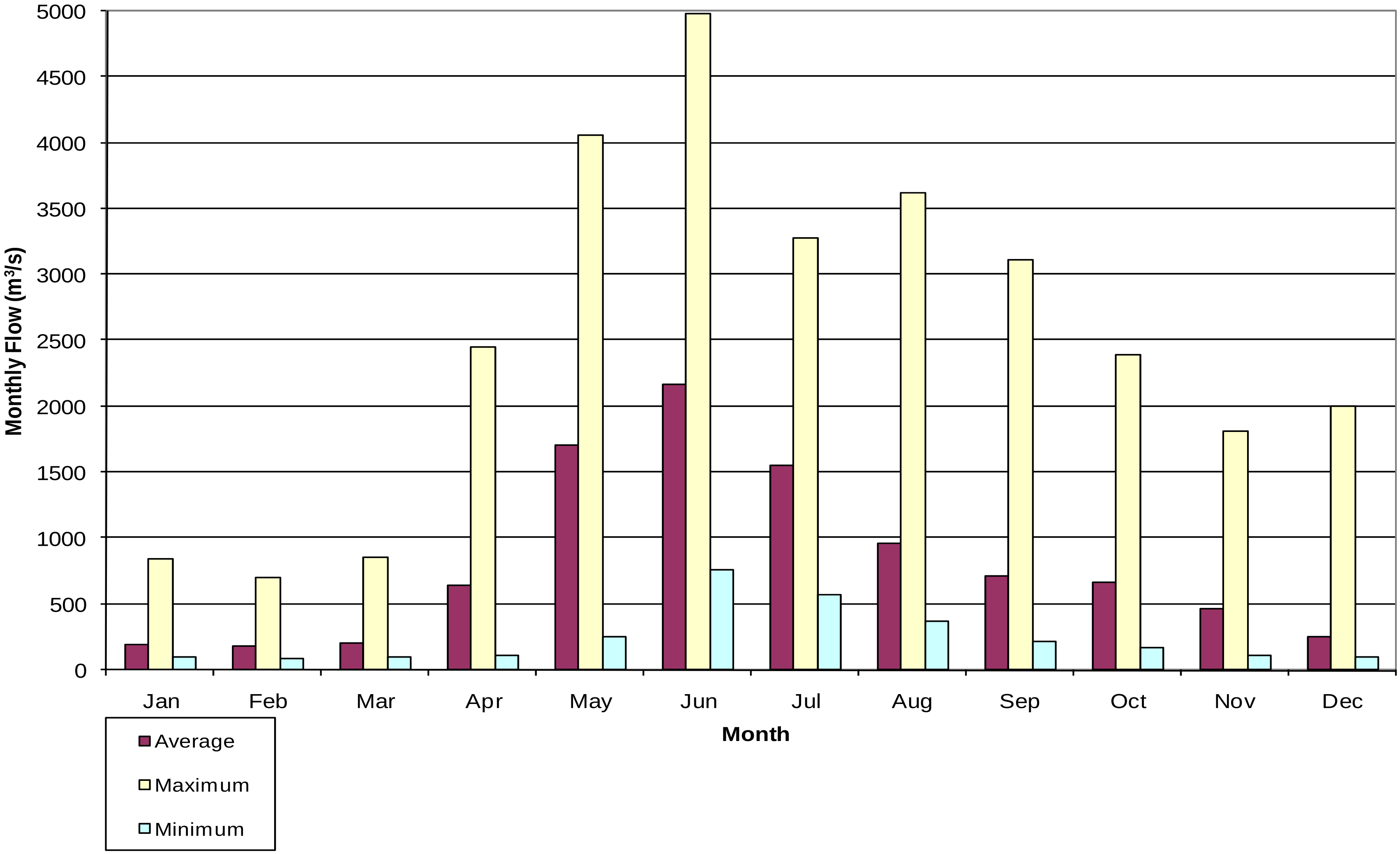


Notes:
1. 1947-1967 water levels based on adjusted record for WSC gauge at Prince George.
2. Datum 0 = 557.784 m GSC
3. SFG - South Fort George

City of Prince George	nhc
Fraser River at SFG Annual Peak WL's 1947 - 2007	
January 2009	Figure 3.3



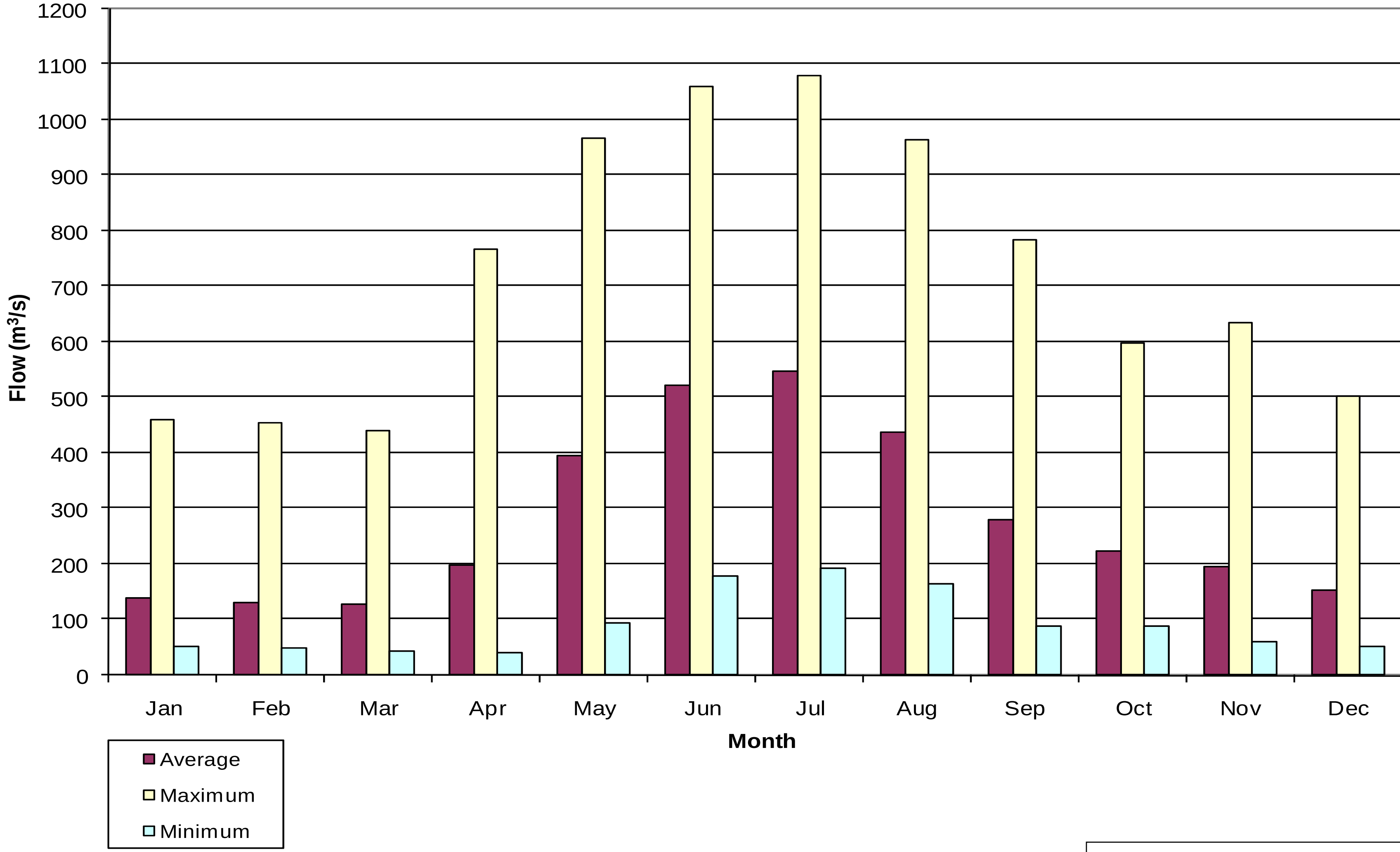
City of Prince George	
Nechako / Fraser River Timing of Freshet Peak	
January 2009	Figure 3.4



City of Prince George

Fraser River at Shelley
Monthly Flows

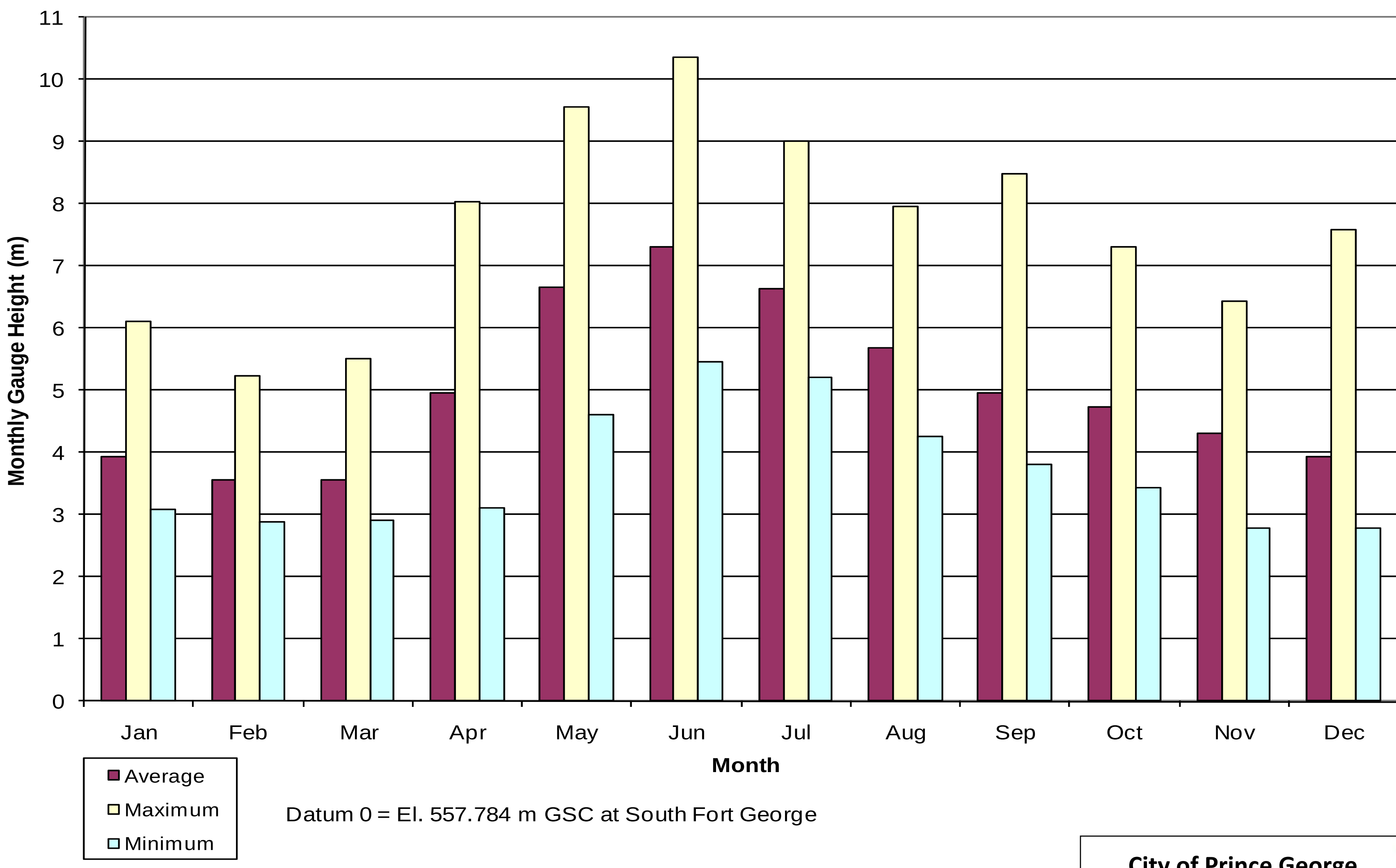
January 2009	Figure 3.5



City of Prince George

Nechako River at Isle Pierre
Monthly Flows

January 2009	Figure 3.6



City of Prince George nhc

Fraser River at SFG
Monthly Water Levels

January 2009 | Figure 3.7

0 250 500 1,000 1,500 2,000 Metres

Scale: 1:30,000

Legend - LiDAR Survey

Extent of LiDAR Survey

Coord. System: UTM Zone 10
Datum: NAD 83
Units: Metres
Notes: Satellite image from Google Earth

City of Prince George nhc

Nechako and Fraser Rivers
Extent of LiDAR Survey

January 2009 | Figure 3.8

City of Prince George

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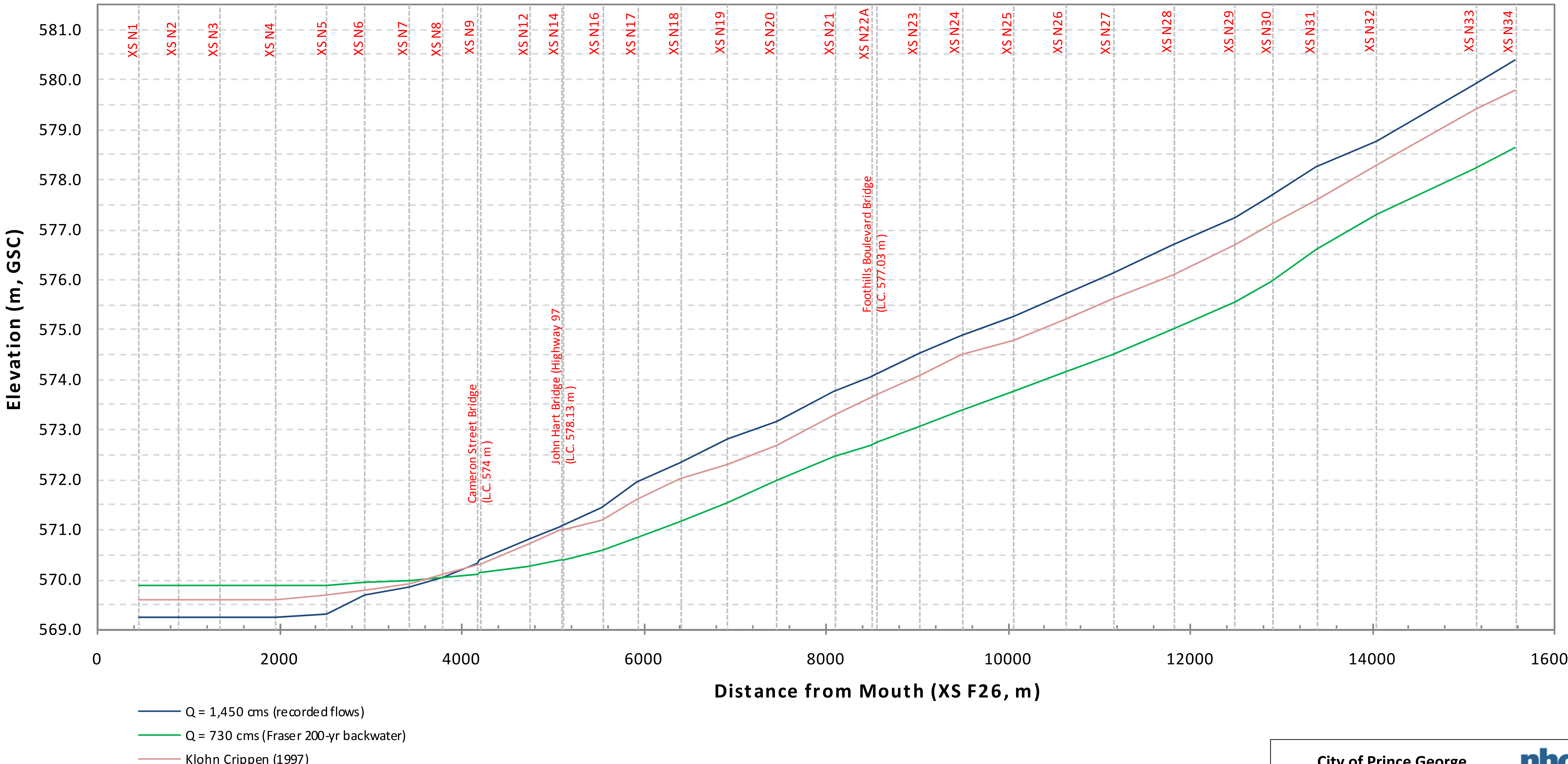
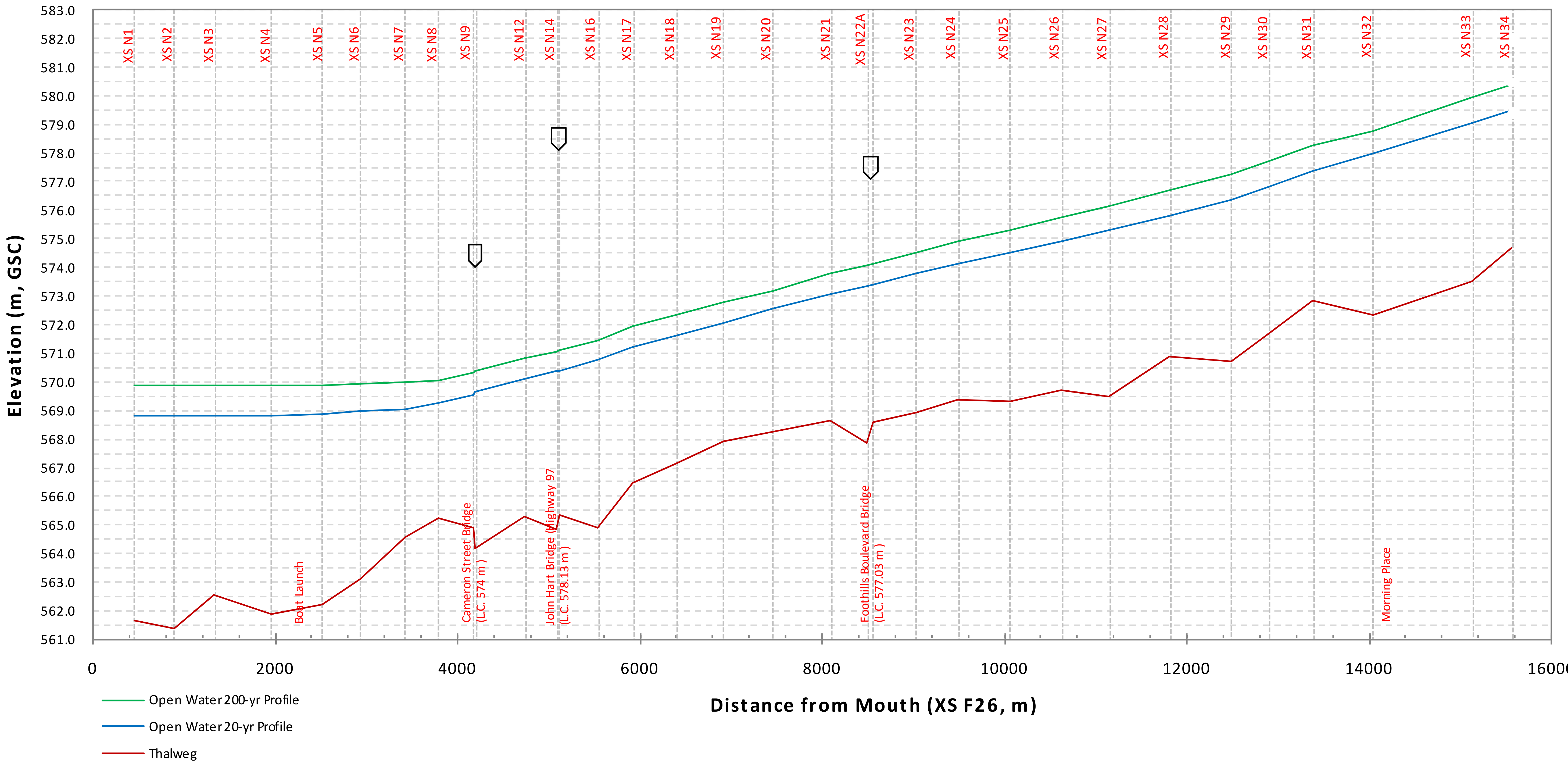


City of Prince George	nhc
Nechako River 200-Yr Open Water Surface Profiles	
January 2009	Figure 3.9

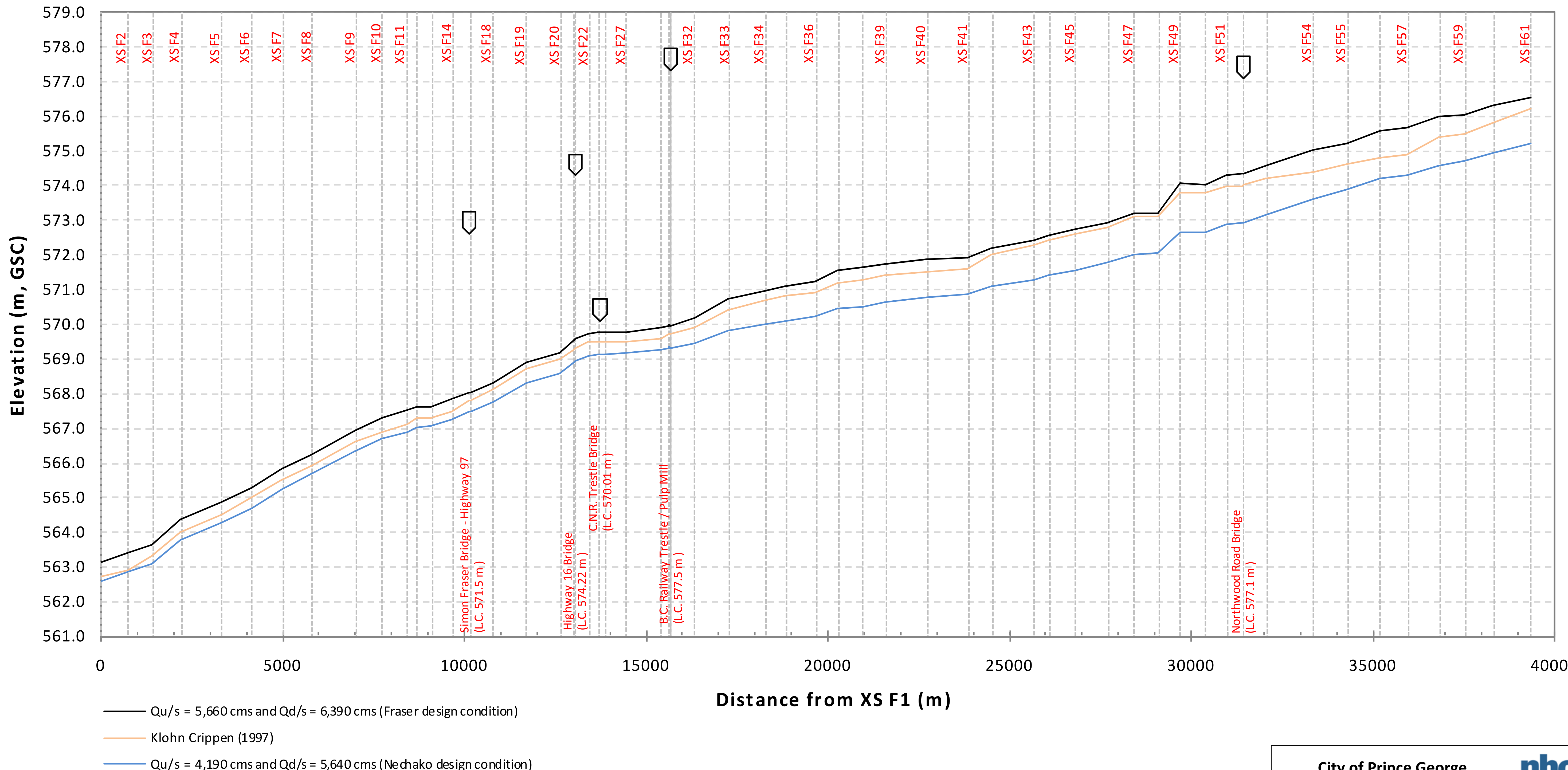


City of Prince George

Nechako River Open Water
20-yr and 200-yr Flood Profiles

January 2009

Figure 3.10

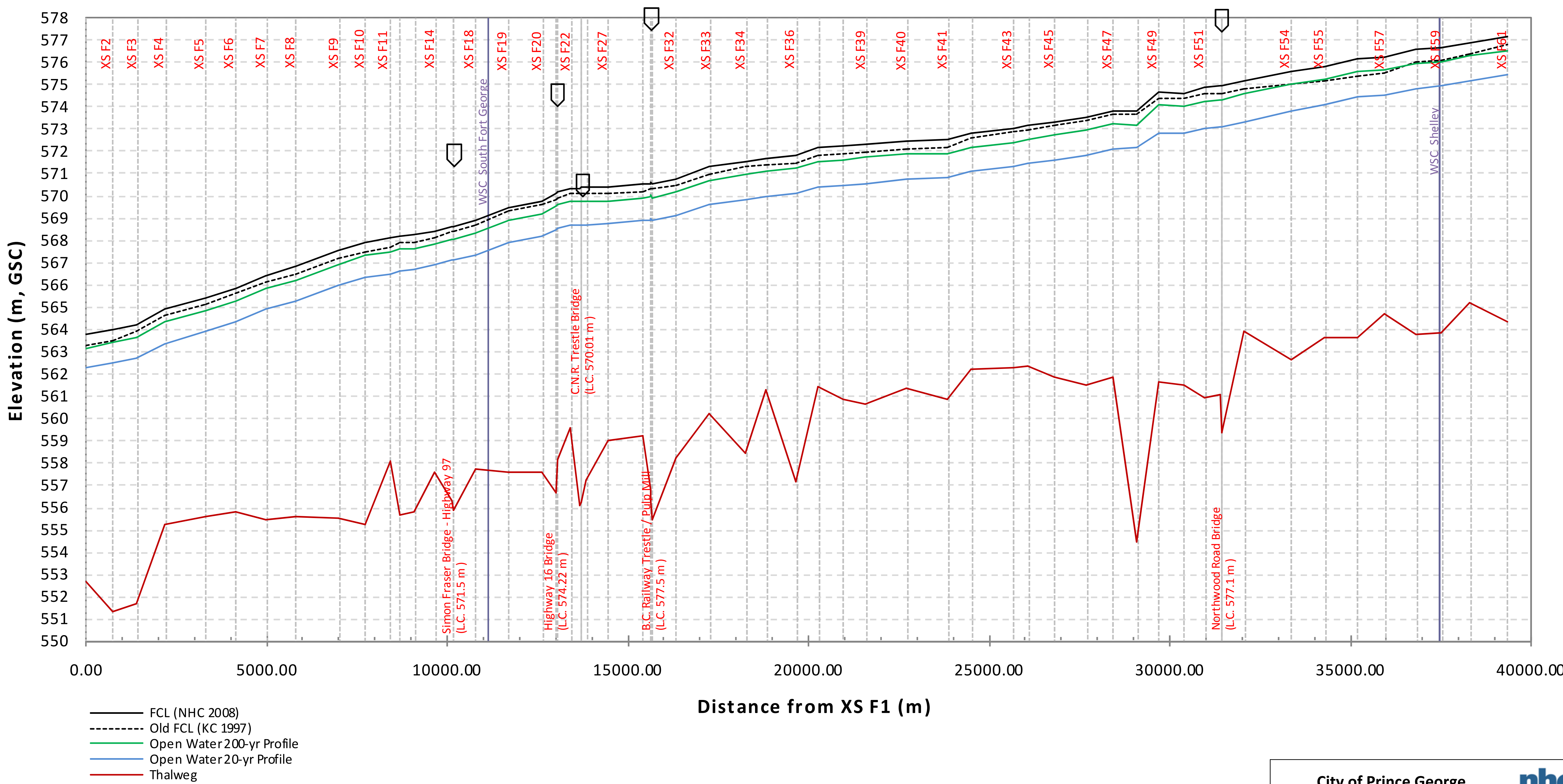


City of Prince George

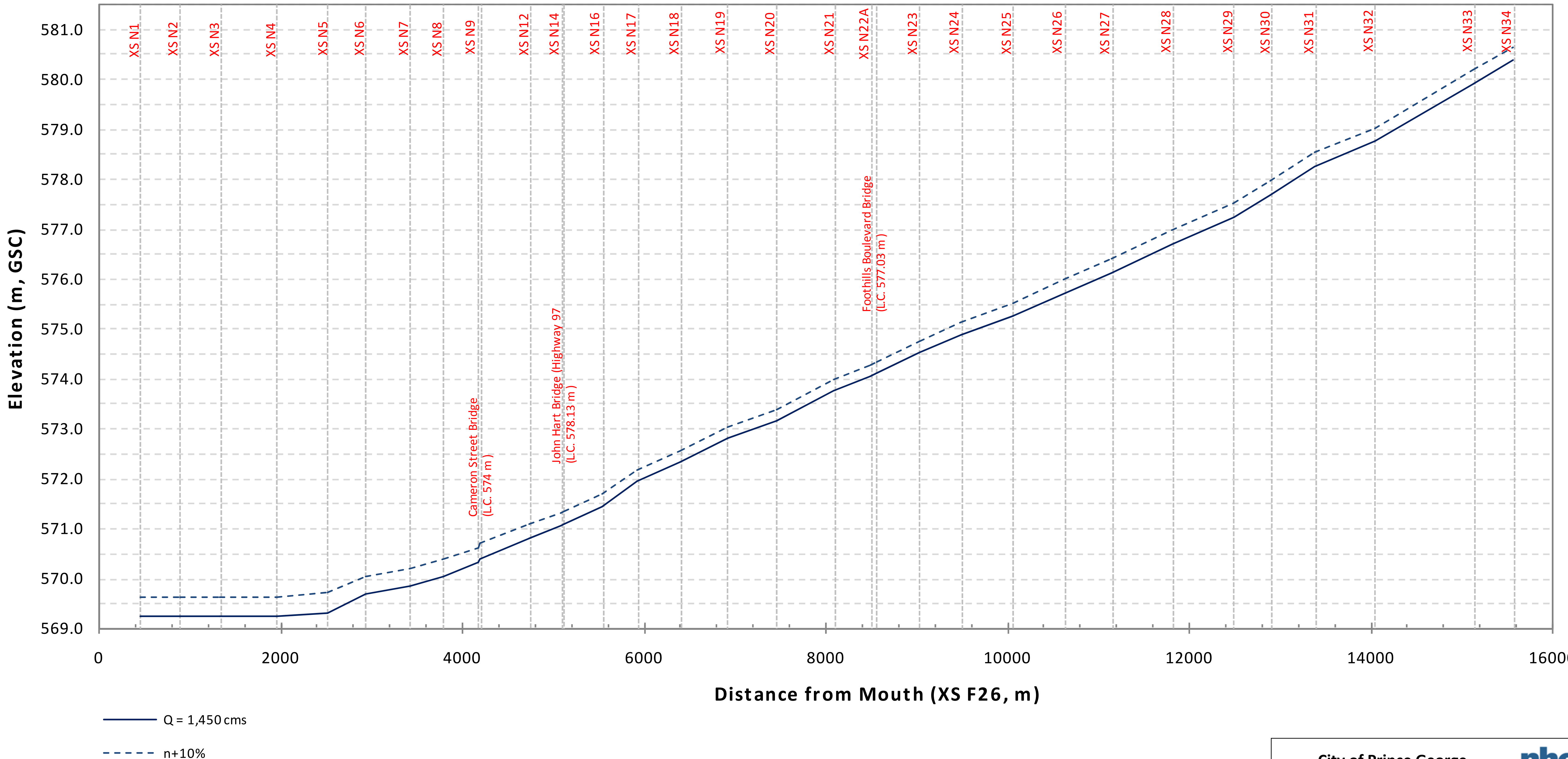
Fraser River
200-Yr Open Water Surface Profiles

January 2009

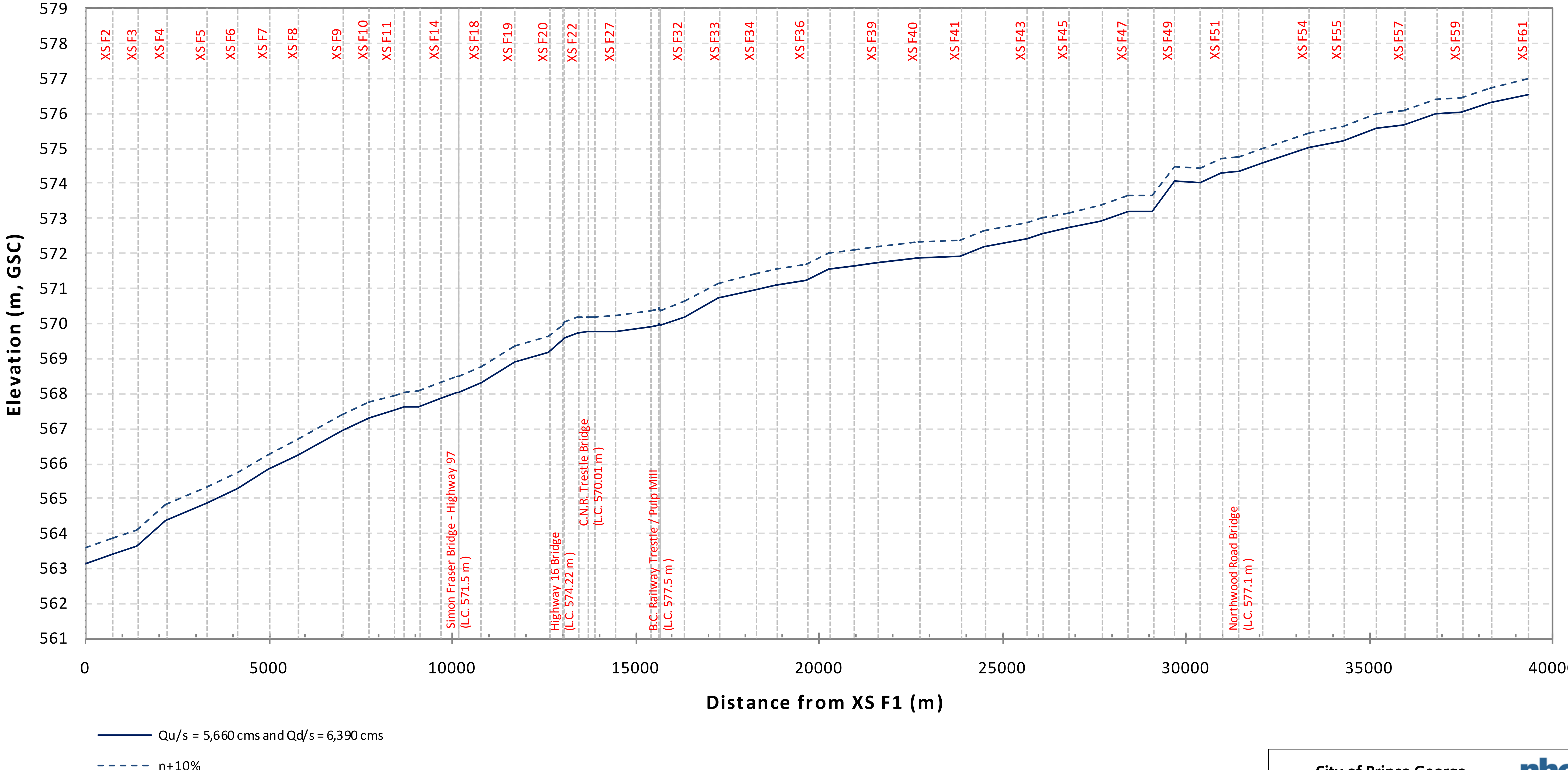
Figure 3.11



City of Prince George	nhc
Fraser River 200-Yr and 20-Yr Water Surface Profiles	
January 2009	Figure 3.12



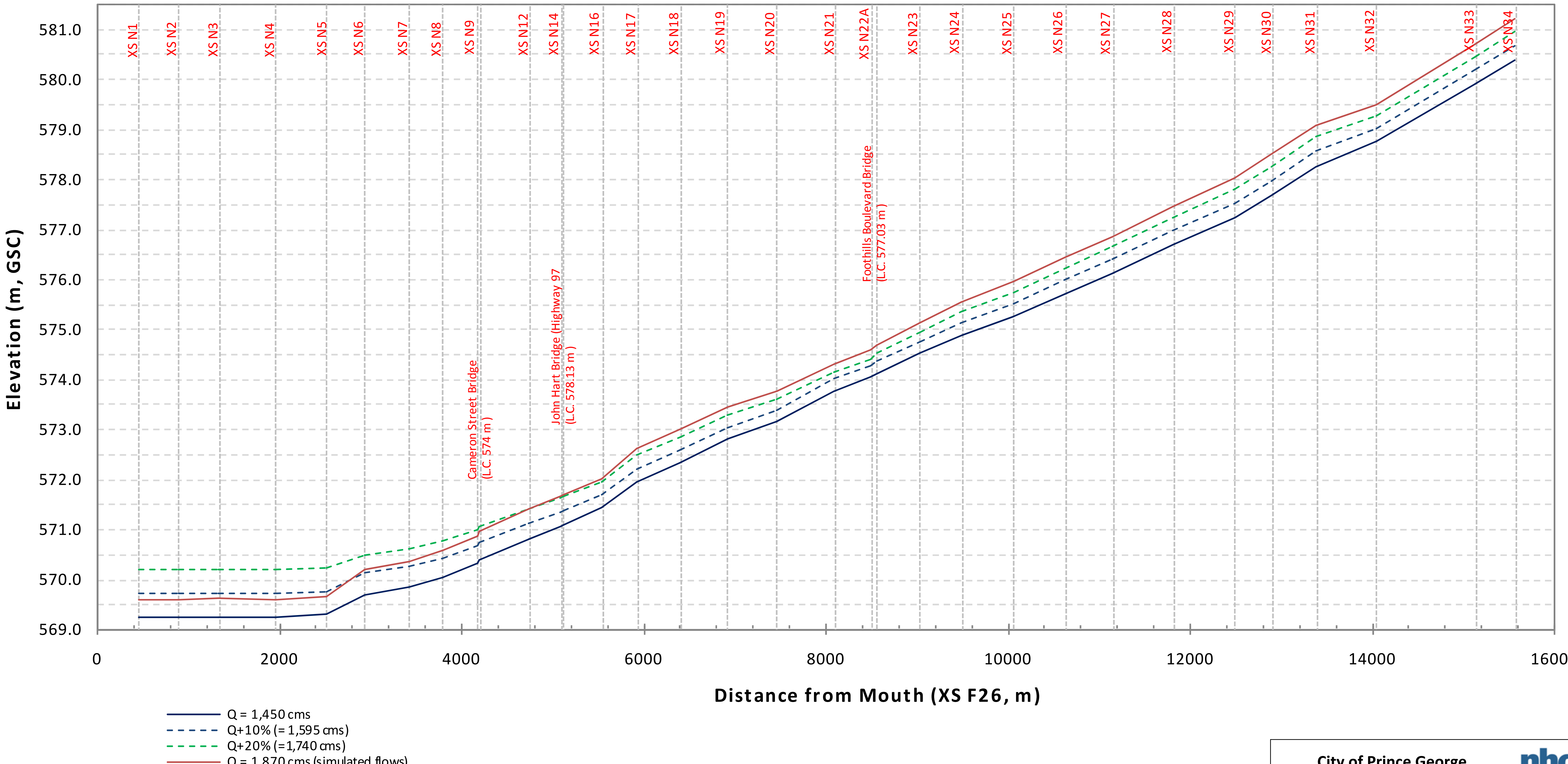
City of Prince George	nhc
Nechako River 200-Yr Open Water Surface Profiles Sensitivity to Roughness Variation	
January 2009	Figure 3.13



City of Prince George | nhc

Fraser River
200-Yr Open Water Surface Profiles
Sensitivity to Roughness Variation

January 2009 | Figure 3.14

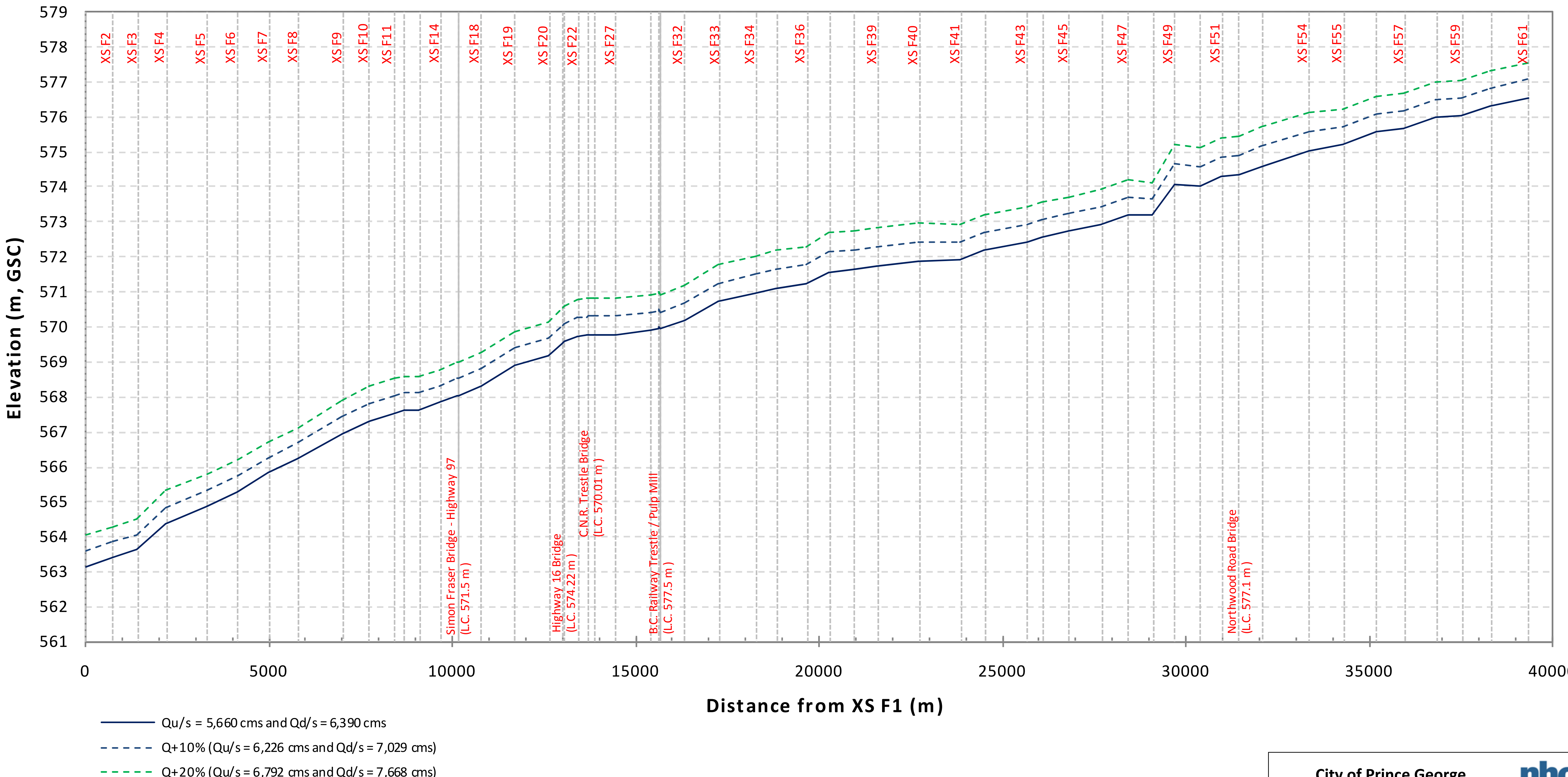


City of Prince George

Nechako River
200-Yr Open Water Surface Profiles
Sensitivity to Flow Variation

January 2009

Figure 3.15



City of Prince George	nhc
Fraser River 200-Yr Open Water Surface Profiles Sensitivity to Flow Variation	
January 2009	Figure 3.16

4 ICE-RELATED WATER LEVELS

Prince George is situated at the confluence of two large rivers which both experience freeze-up jams in the early winter and break-up jams in the spring.

On the Fraser River, the records indicate that break-up jams result in higher water levels, however given the high banks of the river, ice-related flooding does not appear to be a concern.

On the Nechako River, the most serious ice-related flooding appears to occur at freeze-up, which is the focus of discussion in this section. The ice-related water levels are later compared with ice-free freshet flood profiles in Section 5; the higher of the two profiles governs the adopted design flood profile.

The HEC-RAS software used for modelling ice-free water surface profiles has a routine for simulating ice-related flood levels. However, ice levels in the Nechako River are not only a function of discharge but also dependent on other factors such as temperature, ice supply and conditions at the confluence and instead the probability-based approach described in this section was adopted. A more technical discussion of some ice-related topics can be found in **Appendix E.**

4.1 BASIC HYDRAULIC CONCEPTS

The formation of an ice cover is complex and some basic hydraulic concepts are required to understand the processes. The first useful concept is continuity, which means that under steady-state conditions the flow remains the same at different points along a river if no local inflows are present. For instance, the flow at Morning Place must be roughly the same as the flow near the confluence. If the cross-sectional flow area increases from one point to another, there must be a corresponding decrease in the velocity to maintain continuity. A decrease in the flow area would result in an increase in the velocity. For a river, a change in area is reflected by a change in the depth of flow.

The second concept is that the velocity is affected by the condition of the bed, banks and, during the winter, by the ice cover. For a given discharge, the velocity will decrease as the “roughness” increases, or increase if the “roughness” decreases. A channel with a boulder bed will normally be rougher than a channel with a gravel bed. A river with bars and multiple channels will be rougher than a single channel of uniform shape. A channel covered with ice will be rougher than the same channel not covered with ice. In all these cases, for a given flow in the river, the rougher channel will have a lower velocity, and according to continuity, a greater depth.

The third concept is that slush ice can move along the bottom of the ice cover if the velocity is high enough. The moving slush is referred to in this report as “cover load”. If the velocity is not high enough the slush will accumulate, which will reduce the flow area. As the flow area reduces, continuity requires the velocity to increase until it is high enough to begin moving the slush.

Key references that track developments in ice hydraulics include Pariset and Hausser (1961), Pariset, Hausser and Gagnon (1966), Beltaos (1983), and Shen et al. (1984, 1990, 1993). A practical summary of techniques for analysis of river ice problems is a compendium edited by Ashton (1986).

4.2 GENERALIZED FREEZE-UP PROCESSES

Ice production and ice cover formation by the accumulation of floating ice pans are common processes on northern rivers. **Figures 4.1 and 4.2** show the freeze-up process from a schematic perspective, with accompanying photographs to illustrate the appearance of the river during freeze-up.

In general, the initial ice cover on a river forms by the combination of shore ice growth and the accumulation of frazil "pans". Small frazil crystals form throughout the flow when the water temperature cools to 0 ^{o}C, then coalesce into slush accumulations that float to the surface to form "pans". Evidence indicates that the “pans” appear at Prince George when the air temperature is less than -5 ^{o}C.

At Prince George, frazil ice that is generated on the Nechako River floats downstream and is carried away by the Fraser River while the Fraser River is open. Lodgement of the Nechako ice pans only begins when an ice cover forms on the Fraser River at the confluence. As the ice covers form and more ice pans accumulate against the Fraser River ice cover, the water level rises quickly due to the increased roughness, which floats the accumulating ice higher above the bed.

Once lodgement has occurred, the ice cover begins to advance upstream. Two types of ice cover can form - “juxtaposed” and “consolidated” - depending on the flow in the river and the air temperature.

If the channel velocity is low enough, a “juxtaposed” cover forms by the accumulation of a single layer of frazil pans. The ice cover advances upstream at a rate determined by the velocity and concentration of the arriving frazil ice pans. The pans can freeze if the air temperature is sufficiently low, which strengthens the ice cover. Slush beneath the ice pans is moved downstream as “cover load”.

The “juxtaposed” ice cover can suddenly collapse to form a “consolidated” ice cover if the downstream-acting forces exceed the strength of the “juxtaposed” cover. If this occurs, the broken pieces of ice will shove together to form a thicker cover, sometimes releasing a wave of ice and water, known as a “jave”. The thickness of the “consolidated” ice cover will depend on the strength of the ice and the flow - higher flows will produce a thicker “consolidated” cover. Secondary consolidations often occur when river flow and air temperature conditions fluctuate significantly.

As an ice cover forms, the water level will rise due to the additional “roughness” caused by the ice cover, and the ice rises with it. Eventually the ice accumulation or jam will reach equilibrium where the downstream-acting hydraulic forces are balanced by the upstream-acting resistance of the ice accumulation involving both external and internal forces.

4.3 ICE-RELATED FLOODING ASSESSMENT

The assessment of ice-related flooding requires the collection and analysis of historical data on ice jams and accumulations, air temperatures and river flows. Data and observations show that the initial ice cover on the Nechako River forms by lodgement of floating ice against a pre-existing ice cover on the Fraser River. Thus, the timing of freeze-up on the Nechako River depends on the timing of freeze-up on the Fraser.

The following sections discuss the conditions on the Fraser River that lead to ice lodgement followed by accumulation and upstream advance on the Nechako River. This analysis is then used to estimate the probability of flood-producing ice jams occurring in the future.

4.3.1 FRASER RIVER

Historic Water Levels

The historical water level record at the WSC gauge, *Fraser River at South Fort George*, was used to determine the freeze-up date. **Figure 4.3** shows some typical historical water level records, where the sudden rise in the water level indicates the date of freeze-up. After freeze-up, water levels can change due to destabilization of the ice cover by mechanical processes, changes in flow, or in the case of Prince George, by industry warm water effluent melting the ice cover.

Table 4.1 summarizes the freeze-up dates and the corresponding hydro-meteorological characteristics for those years when the freeze-up date could be confidently determined. These hydro-meteorological parameters include the accumulated degree-days of freezing[12] at freeze-up, the approximate flow at South Fort George, the post-freeze-up climate characteristics at Prince George, and the freeze-up water level at the confluence of the Nechako and Fraser Rivers.

Timing of Freeze-up

Figure 4.4 shows the relationship between the Fraser River discharge and the degree-days of freezing that produced freeze-up on the Fraser River. Further analysis of this data provides **Figure 4.5** which shows the frequency curve of the degree-days required to produce freeze-up. There would only be about a 10 percent chance of freeze-up after 100°C-days of freezing, 50 percent chance after 200°C-days, and a 90 percent chance of freeze-up after 400 °C-days.

Ice-Related Water Levels

Approximate open water and ice-related rating curves at the confluence are shown in **Figure 4.6**. The peak freeze-up levels are also shown in **Figure 4.6**, relative to the open water rating curve. It is evident that the water level increases of between 0.4 and 3.3 m at freeze-up can occur due to the effects of the ice cover. The upper range of the data reflects

[12] The sum of the average daily degrees below freezing for a specified time period

an ice cover thickness that would be representative of an equilibrium ice jam. A more in-depth discussion of the figure is provided in **Appendix E.1**.

4.3.2 NECHAKO RIVER

Historic Water Levels

Campbell (1990) provides a summary of historical freeze-up water levels experienced in Prince George since the 1920's. Most of the peak freeze-up levels have been observed at the City Gauge located at Cameron Street Bridge which provides a historical index of ice jam events. **Table 4.2** summarizes the water levels associated with freeze-up. It is evident from these records that Prince George has been affected by high freeze-up related water levels during its entire history.

Prior to 1940, the water levels (adjusted to reflect conditions at the City Gauge near the Cameron Street Bridge) approached or exceeded El. 572.0 m GSC five times. There likely were other high freeze-up water events, but these would not have been recorded because they probably did not overtop the railway grade and cause enough disruption for the residents to take note. That is, the elevation of the railway tracks is probably the significant “perception level” in existence before the City Gauge became operational. Since 1956, after the installation of the City Gauge, most of the significant events would have been documented (hence the denser record) until the gauge was removed in 1976. The freeze-up levels approached or exceeded El. 570.0 m GSC on four occasions during the period 1956-1976. The maximum water elevation recorded was El. 570.7 m GSC in 1959-60.

Only two events appear to have caused concern in the post-1976 record – 1996 and 2007. Both of these events produced water levels at Cameron Street Bridge close to and in excess of El. 570.0 m GSC. Both of these events were documented with some rigour and therefore provide a basis to quantify the characteristics of the ice accumulations and the subsequent freeze-up levels within the City. The 1996 event appears to be the seventh highest on record and the 2007 event the sixth highest and the highest since records of any sort have been kept. Since regulation in the early 1950’s, it appears that these two events have been the two largest. Thus, from a simple extrapolation, the 2007 freeze-up is at least a 50-year event and the 1996 is at least a 25-year event.

Figure 4.7 provides a histogram of Nechako flows during freeze-up and coinciding air temperatures over a 10-day period. Highlighted years correspond to events when flood levels exceeded El. 569.0 m GSC at Cameron Street Bridge, an approximate threshold level for initiation of flooding. The figure shows that typically a discharge of at least 200 m^3/s in combination with average air-temperatures colder than -5°C, is required to initiate ice-related flooding. These conditions were prevalent in the early1960’s and early 1970’s but did not occur from the mid-1970’s to mid-1990’s.

Figure 4.8 shows the maximum ice-related water level along the Nechako River between the Fraser River and Morning Place for the 1996 and 2007 events. **Figure 4.9** summarizes the measured water levels at five locations during the 2007 event. It is clear that the formation of the ice cover caused water levels to increase by 1.0 to 3.9 m due to the influence of the ice cover. At the Fraser River and Cottonwood Island locations the water level increases were limited by the ability for the water to escape via the various back channels of the Nechako River.

Ice-Related Water Levels

Figure 4.10 shows both the open water and the equilibrium ice jam rating curve at the Cameron Street Bridge, along with the available peak freeze-up levels and their corresponding estimated discharges. The equilibrium ice jam rating curve provides the upper envelope to these data as would be expected since the equilibrium ice jam condition always represents the maximum possible water level that could occur for a given discharge under ice conditions.

The 3.8 m and 3.9 m increase in water levels at the Cameron Street Bridge and the Boat Launch (**Figure 4.9**) represent reasonably well the equilibrium ice jam levels associated with a single channel of uniform slope and more or less uniform shape conveying the entire flow of the Nechako River.

Effects of Ice Supply

Ice supply plays an important role in determining the peak freeze-up water levels, and two important characteristics can be deduced from the 1996 and 2007 ice jam data. These are (1) the amount of cooling required to produce sufficient ice to allow the ice cover to start its upstream advance and (2) the rate of ice cover advance. These are relatively important because they define the probability of upstream locations being affected by ice in any given year.

After allowing for two days of ice production to account for the ice already in the Nechako River, about 70 °C-days of freezing is required to produce enough ice to accumulate on the Fraser River between South Fort George and the confluence to allow the ice cover to begin its upstream advance (**Figure 4.11**). Furthermore, after accounting for rapid temporary advances of the juxtaposed ice cover (before its eventual consolidation), the ice cover appears to advance upstream at a rate of about 0.13 km/°C-day. So, for every 10 °C-days of freezing, the ice cover advances upstream by about 1.3 km for the range of flows in excess of about 200 m^3/s, that might result in ice-related flooding. (For a note on ice volumes refer to **Appendix E.2**).

On the basis of the above calculations, **Table 4.3** shows the severity of cold weather required to produce enough ice for the cover to advance upstream to a given point. Experience suggests that once freeze-up has occurred on the Fraser River, there is only a limited period when ice production on the Nechako River can contribute to formation of an ice cover at Prince George. A period of 20 days has been adopted on the assumption that shore growth upstream of Prince George will cut off the upstream ice supply after that time. If an equilibrium accumulation cover has not formed within 20 days, any ice cover that does form is likely to be from lateral growth of shore ice, with relatively low water levels.

Figure 4.12 shows the results of the frequency analysis on which is based the annual probability of achieving the required degree-days of freezing (within the 20 day period) to form an equilibrium ice cover at the locations listed in **Table 4.3**.

4.3.3 FREQUENCY ANALYSIS OF PEAK FREEZE-UP WATER LEVEL

The probability of experiencing a given freeze-up level at any location each year is a function of:

- the probability of experiencing a given flow at freeze-up **Figure 4.13**;
- the probability of experiencing the required amount of cold weather to allow an ice cover to form at that location (**Table 4.3**); and,
- the probability of a stable equilibrium ice cover forming at that location.

The calculated frequency curves are shown in **Figure 4.14** and the ice related water levels for various return periods (including 0.6 m freeboard) are summarized in **Table 4.4**. The 200-year ice-related design flood level (including 0.6 m freeboard allowance) at Cameron Street Bridge is El. 572.3 m. During the winter of 2007-08, the maximum reported water level at Cameron Street Bridge was El. 571.3 m GSC, or about 1 m below the revised design level. The 2007-08 event is estimated to have had a return period of 90 years.

A more detailed explanation of the frequency analysis procedure can be found in **Appendix E.3**.

4.4 EFFECT OF CLIMATE AND BASIN CHANGE

As mentioned earlier, the severity of freeze-up is determined mostly by the combined effects of ambient air temperatures and river flows. In response to changing climate, changes can be expected in both air temperatures and precipitation. Winter air temperature would tend to rise, on the average reducing the amount of ice produced during freeze-up. However, since severe ice events usually occur with a relatively cold air mass over Prince George, a rise of say 2°C from an ambient value of -20 to -25°C would not significantly reduce the likelihood of a high freeze-up level if river flows were high. Likewise, precipitation changes arising from climate change are considered unlikely to have a significant impact on river flows during freeze-up.

With respect to Mountain Pine Beetle infestation, it seems likely that its hydrological effects may be substantially larger than those of climate change, but they are expected to last no more than a few decades. Nevertheless, the amount of water in surface storage may increase, producing higher lake and shallower groundwater levels and possibly leading to higher flows before and during the freeze-up period. This might mean that the 200 m^3/s freeze-up flow criterion at Prince George would be exceeded more often, the flows at freeze-up would be systematically greater, and the freeze-up levels would be systematically higher.

The freeze-up rating curve of **Figure 4.10** indicates that for every 50 m^3/s increase in freeze-up flow, the water level increases by about 0.3 m. Thus, at the 200-year freeze-up level the standard 0.6 m freeboard could accommodate a flow increase due to the changing basin conditions of about 100 m^3/s, which appears to be adequate. However, if there is any concern about the validity of these estimates, the freeboard could be increased to 1.0 m.

4.5 Effect of Gravel Removals

Gravel removal, in the form of bar-scalping or dredging, has been mentioned as one option for reducing the potential for ice-related flooding. However, some reasons why dredging will not help are explained below (a more theoretical discussion is included in **Appendix E.4**.):

- The ice cover on the Fraser River begins by forming downstream of Prince George and eventually progresses upstream to the confluence. Typically, the Fraser first freezes over at a location roughly 30 km downstream of the Nechako, at the Fort George Canyon (Personal Communication with Mr. Lyle Larsen, MOE). The eventual elevation of the ice cover at the confluence is controlled by hydraulic conditions in the Fraser River many kilometres downstream. Dredging the Fraser River near the confluence will not change the ice cover elevation, and Nechako frazil will continue to lodge at elevations indicated by the historical record.
- If the ice cover elevation at the confluence is unchanged, dredging the Nechako River will effectively increase the cross-sectional area of the channel. This would reduce the velocity (according to continuity), making it more likely for ice pans to lodge at the Fraser, advancing the date for forming a stable ice cover, and contributing to a more rapid upstream advance. The elevation of the ice cover would not be lowered by the dredging.
- Dredging the Nechako at the confluence will not change the flow-dependent ice thickness that develops upstream of the Boat Launch. The ice-related rating curve (**Figure 4.6**) and frequency curves (**Figure 4.14**) would remain unchanged by dredging.
- If the velocity is low enough, incoming frazil slush accumulates under the ice, gradually reducing the flow area until the velocity is high enough to transport the slush. Dredging effectively increases the flow area and is likely to aggravate slush accumulation, which could also aggravate ice jam conditions. The geometric shape of the dredged channel does not affect the outcome.
- Since initial lodgement of ice does not occur on the gravel bars at the confluence, dredging in this area will not alter the lodgement process.
- Sediment deposition has occurred between the confluence and the CNR Bridge (Section 2.4.2). Dredging this material will not change the ice cover level at the confluence, which is governed by Fraser River conditions downstream of Prince George.

A summary discussion of gravel removals is provided in Appendix H.

Table 4.1 Freeze-up data, Fraser River at Prince George

Year	Freeze-up Date at South Fort George (mm/dd)	Degree Days of Freezing at Prince George (^{0}C-day)	Fraser River Flow at South Fort George (m^3/s)	Freeze-up Levels at Nechako River Confluence		Mean Temperature On Freeze-up Date (^{0}C)	Air Temperature at Prince George (^{0}C) For 10 Days After Freeze-up			Degree Days of Freezing After 20 Days (^{0}C-days)	Nechako River Flow Characteristics For 10 Days After Freeze-up (m^3/s)			
				Pre-Freeze-up (m)	Peak Freeze-up (m)		Ave Max	Ave Mean	Ave Min		Mean	Max	Min	On Date of Freeze-up
1949-1950	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1950-1951	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1951-1952	Nov 30	102.4	359	562.10	562.51	-2.8	-4.8	1.4	-9.7	124.2	157	161	150	161
1952-1953	Dec 17	109.6	164	562.02	562.38	-8.4	-7.9	-3.6	-15.0	132.8	58	61	56	61
1953-1954	Dec 22	100.2	358	562.40	562.56	-3.6	-1.5	0.3	-4.5	98	116	120	112	120
1954-1955	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1955-1956	Nov 26	330.2	372	562.46	563.49	-33.4	-11.0	-1.4	-33.4	207.0	72	79	67	79
1956-1957	Dec 06	163.1	323	562.09	563.44	-27.5	-14.1	-2.5	-27.5	220.2	67	67	66	67
1957-1958	Dec 24	104.6	831	563.23	563.69	-1.1	-5.3	-1.1	-10.6	55.9	415	439	374	430
1958-1959	Dec 11	122.9	508	562.66	564.41	-5.0	-1.9	2.2	-6.9	73.9	310	334	263	326
1959-1960	Nov 22	134.1	1096	562.95	563.48	0.0	-1.2	4.7	-8.6	9.5	396	453	368	453
1960-1961	Dec 11	133.0	558	562.87	563.08	-1.7	-9.6	2.8	-17.0	138.5	242	297	200	297
1961-1962	Dec 10	261.1	302	562.63	563.74	-26.9	-14.3	-4.5	-26.9	240.4	85	85	85	85
1962-1963	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1963-1964	Nov 29	126.5	578	562.37	563.23	-0.6	-3.0	0.3	-10.9	112.4	173	204	144	204
1964-1965	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1965-1966	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1966-1967	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1967-1968	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1968-1969	Dec 26	282.2	439	563.29	565.52	-20.3	-25.3	0.3	-35.3	427.7	218	222	215	218
1969-1970	Jan 21	434.7	413	564.24	564.24	-7.5	-4.4	-0.3	-7.5	85.4	233	235	231	235
1970-1971	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 4.1 Freeze-up data, Fraser River at Prince George (cont.)

Year	Freeze-up Date at South Fort George (mm/dd)	Degree Days of Freezing at Prince George (^{0}C-day)	Fraser River Flow at South Fort George (m^3/s)	Freeze-up Levels at Nechako River Confluence		Mean Temperature On Freeze-up Date (^{0}C)	Air Temperature at Prince George (^{0}C) For 10 Days After Freeze-up			Degree Days of Freezing After 20 Days (^{0}C-days)	Nechako River Flow Characteristics For 10 Days After Freeze-up (m^3/s)			
				Pre-Freeze-up (m)	Peak Freeze-up (m)		Ave Max	Ave Mean	Ave Min		Mean	Max	Min	On Date of Freeze-up
1971-1972	Dec 17	226.3	478	562.63	564.53	-10.9	-20.4	-5.0	-33.4	344.4	193	195	191	195
1972-1973	Dec 07	175.9	351	562.63	564.70	-24.7	-16.1	-2.0	-24.7	240.2	157	175	139	139
1973-1974	Dec 08	299.8	459	562.77	562.96	-5.3	-4.1	-0.6	-10.6	72.4	125	126	124	124
1974-1975	Dec 06	103.9	443	562.96	563.19	-4.5	-2.6	2.2	-8.6	53.7	187	197	173	197
1975-1976	Dec 19	304.7	390	563.26	564.97	-4.2	-2.0	2.5	-9.5	97.0	172	177	170	177
1976-1977	Dec 22	91.0	584	563.50	564.02	-1.4	-4.9	-0.3	-8.6	151.5	290	294	286	294
1977-1978	Nov 26	142.3	275	562.25	564.89	-4.1	-7.7	2.7	-26.5	255.9	139	142	137	142
1978-1979	Dec 31	517.9	295	562.70	564.13	-38.1	-29.2	-19.9	-38.1	545.1	113	113	113	113
1979-1980	Jan 11	462.8	185	562.44	563.51	-23.9	-12.2	-0.5	-23.9	177.3	57	59	55	59
1980-1981	Dec 07	160.4	426	562.02	563.94	-17.3	-1.3	7.8	-17.3	184.0	126	164	105	107
1981-1982	Jan 03	366.5	254	562.40	563.84	-24.3	-18.5	-5.1	-31.9	345.9	79	81	79	80
1982-1983	Nov 27	175.4	369	562.42	564.13	-0.2	-3.4	0.2	-13.3	106.2	120	122	117	122
1983-1984	Dec 23	397.5	284	562.68	563.78	-25.1	-18.0	1.8	-28.8	241.4	95	95	95	95
1984-1985	Dec 23	474.5	293	562.64	564.04	-20.5	-25.3	-11.7	-39.0	342.2	108	113	104	113
1985-1986	Nov 21	215.8	333	562.68	564.02	-21.9	-26.8	-20.0	-31.8	402.4	90	94	88	94
1986-1987	Nov 18	148.8	305	562.56	563.13	-12.1	-2.6	3.5	-12.7	88.7	116	123	104	112
1987-1988	Jan 06	267.4	259	562.47	563.49	-25.1	-12.1	-0.7	-25.1	187.0	101	101	100	101
1988-1989	Jan 08	355.1	285	562.57	563.91	-18.2	-7.2	0.1	-18.2	161.3	105	107	102	107
1989-1990	Dec 29	126.0	739	562.14	564.87	0.0	-0.6	2.1	-5.8	30.8	107	112	103	112
1990-1991	Dec 22	186.9	316	562.62	564.15	-19.8	-17.1	-4.5	-33.4	505.1	74	76	72	73
1991-1992	Nov 15	81.6	563	563.27	563.82	2.9	1.1	3.6	-2.3	1.2	126	128	122	125
1992-1993	Dec 28	324.9	278	562.68	564.68	-24.5	-25.1	-20.1	-30.0	432.5	111	123	106	123
1993-1994	Dec 04	109.6	413	562.46	563.00	-3.1	-3.3	3.5	-11.0	47.7	119	123	116	123

Table 4.1 Freeze-up data, Fraser River at Prince George (cont.)

Year	Freeze-up Date at South Fort George (mm/dd)	Degree Days of Freezing at Prince George (^{0}C-day)	Fraser River Flow at South Fort George (m^3/s)	Freeze-up Levels at Nechako River Confluence		Mean Temperature On Freeze-up Date (^{0}C)	Air Temperature at Prince George (^{0}C) For 10 Days After Freeze-up			Degree Days of Freezing After 20 Days (^{0}C-days)	Nechako River Flow Characteristics For 10 Days After Freeze-up (m^3/s)			
				Pre-Freeze-up (m)	Peak Freeze-up (m)		Ave Max	Ave Mean	Ave Min		Mean	Max	Min	On Date of Freeze-up
1994-1995	Dec 10	214.9	298	562.56	563.74	-5.7	-3.6	5.5	-9.5	50.1	109	113	105	110
1995-1996	Dec 11	296.0	339	562.71	564.03	-16.6	-6.4	-1.0	-16.6	179.4	113	124	85	85
1996-1997	Nov 23	186.6	486	563.16	565.14	-23.2	-8.5	0.5	-23.2	165.9	194	202	188	196
1997-1998	Jan 11	357.6	363	562.74	564.51	-29.0	-13.3	-3.4	-29.0	170.7	179	189	163	163
1998-1999	Dec 30	246.3	297	562.26	564.13	-6.0	-6.0	1.2	-15.1	100.5	98	102	94	94
1999-2000	Jan 19	296.0	299	562.60	563.89	-21.2	-14.2	-3.9	-21.5	228.8	98	99	96	96
2000-2001	Dec 15	185.8	376	562.22	563.77	-23.7	-11.3	-4.0	-23.7	172.5	153	161	148	161
2001-2002	Jan 02	338.0	376	562.69	563.93	-0.1	1.1	6.0	-3.6	48.2	120	122	118	121
2002-2003	Jan 05	103.6	359	562.49	562.93	3.6	-4.7	7.4	-12.7	112.4	121	124	118	124
2003-2004	Jan 05	397.8	247	562.62	563.94	-30.9	-8.8	4.8	-30.9	137.1	115	120	110	110
2004-2005	Dec 23	115.3	632	563.46	563.81	-2.2	-10.3	0.9	-22.8	271.1	134	140	127	140
2005-2006	Dec 13	147.5	610	562.83	563.35	-5.6	-8.0	1.7	-13.2	79.1	191	205	183	205
2006-2007	Dec 05	241.0	298	562.94	563.40	-3.5	0.6	3.0	-3.5	29.8	87	88	85	88
2007-2008	Dec 09	265.1	-	562.13	564.63	-17.7	-2.8	-5.9	-9.0	152.1	279	282	274	274

Table 4.2 Summary of high ice-related water levels on the Nechako River at Prince George (after Campbell, 1990, with additions)

Date	Maximum Water Elevation (m)	Approximate Discharge (m^3/s) [(3)]	Comments
Dec, 1917	>571.7 [(1)]	-	Level measured at CN Station, 2200 m downstream of Cameron Street Bridge
Early 1920's	>571.7 [(1)]	-	Level measured at CN Station, 2200 m downstream of Cameron Street Bridge
Late 1920's	572.1	-	Cameron Street Bridge
Dec, 1933	>572.3 [(1)]	-	Level measured at CN Station, 2200 m downstream of Cameron Street Bridge
Jan, 1937	>572.3 [(1)]	-	Level measured at CN Station, 2200 m downstream of Cameron Street Bridge
Mar, 1957	>569.4	311	Cameron Street Bridge (likely breakup)
Mar 7, 1960	570.7	212	Cameron Street Bridge (unknown type)
Feb 5, 1961	569.6	142	Cameron Street Bridge (unknown type)
Jan 22, 1963	569.4	143	Cameron Street Bridge (likely freeze-up)
Dec 15, 1964	568.9	171	Cameron Street Bridge (freeze-up)
Jan 3, 1968	568.9	140	Cameron Street Bridge (freeze-up)
Dec 27, 1968	568.8	219	Cameron Street Bridge (freeze-up)
Jan 26, 1970	>570.4	233	Cameron Street Bridge (likely freeze-up)
Dec 10, 1970	569.6	143	Cameron Street Bridge (freeze-up)
Dec 22, 1971	569.1	193	Cameron Street Bridge (freeze-up)
Apr 3, 1972	567.5	205	Cameron Street Bridge (likely breakup)
Dec 18, 1972	570.0	182	Cameron Street Bridge (freeze-up)
Jan 22, 1974	569.0	107	Cameron Street Bridge (likely freeze-up)
Jan 15, 1975	569.0	139	Cameron Street Bridge (likely freeze-up)
Jan 12, 1976	569.8	162	Cameron Street Bridge (likely freeze-up)
Nov 28, 1996	570.9	220 [(2)]	Cameron Street Bridge (freeze-up)
Jan 01, 2008	571.3	250 [(2)]	Cameron Street Bridge (freeze-up)

Notes:
1. The measured water level was adjusted to reflect the stage at Cameron Street Bridge.
2. Estimated from preliminary flows provided by Water Survey of Canada.
3. Average Discharge (m^3/s)

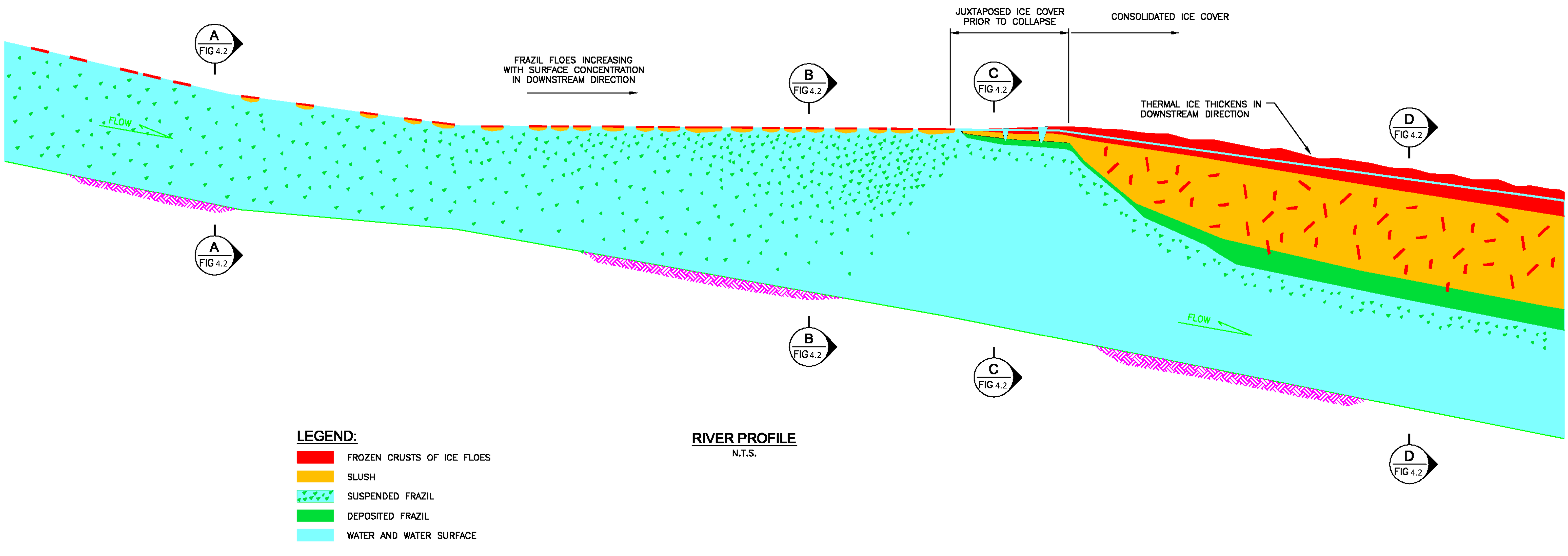
Table 4.3 Summary of ^{0}C-days of freezing within twenty days of the start of freeze-up that is required to form an equilibrium ice cover at locations along the Nechako River within Prince George

Location	Distance Upstream of Fraser River (km)	Degree-days of Freezing Required to Form Ice Cover (^{0}C-days)	Annual Probability of Experiencing Required ^{0}C-days of Freezing (%)
Water Intake	1.4	81	78
Boat Launch	1.7	83	77
Winton Global	2.7	91	73
Cameron Street Bridge	3.7	98	71
John Hart Bridge	4.6	105	68
Water Intake	5.5	112	65
Foothills Bridge	8.0	130	58
Rosia/Riverview Road	9.0	140	54
Morning Place	13.5	170	42
Upstream City Limits	14.0	180	38

Table 4.4 Summary of ice-related water levels for a range of return periods

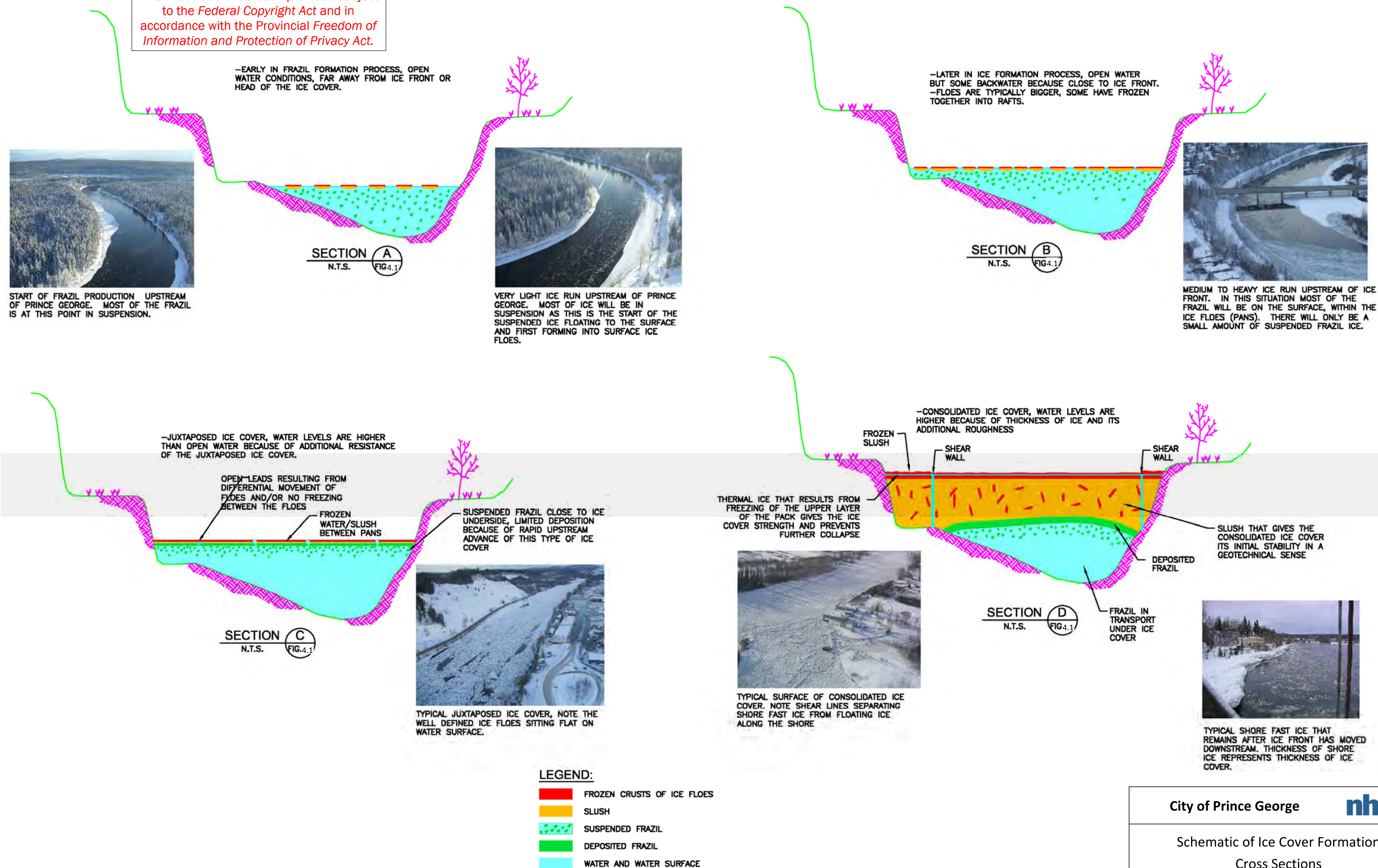
Location	Ice-Related Water Level (m) for Return Period (yrs) [1]				1997 Floodplain Map	Change from 1997
	20	50	100	200	200-yr FCL (Klohn Crippen)	
Boat Launch	568.5	569	569.3	569.7	570.4[2]	---
Cameron Street Bridge	571	571.5	572	572.3	571.7	+0.6
John Hart Bridge	572.1	572.6	573.3	573.7	572.6	+1.1
Foothills Bridge	575.7	576.2	576.6	577	575.5	+1.5
Morning Place	579.1	580.1	581.3	581.5	580.5	+1.0

Notes: 1. Includes 0.6 m freeboard allowance.
2. Freshet flooding governs in this part of the river.

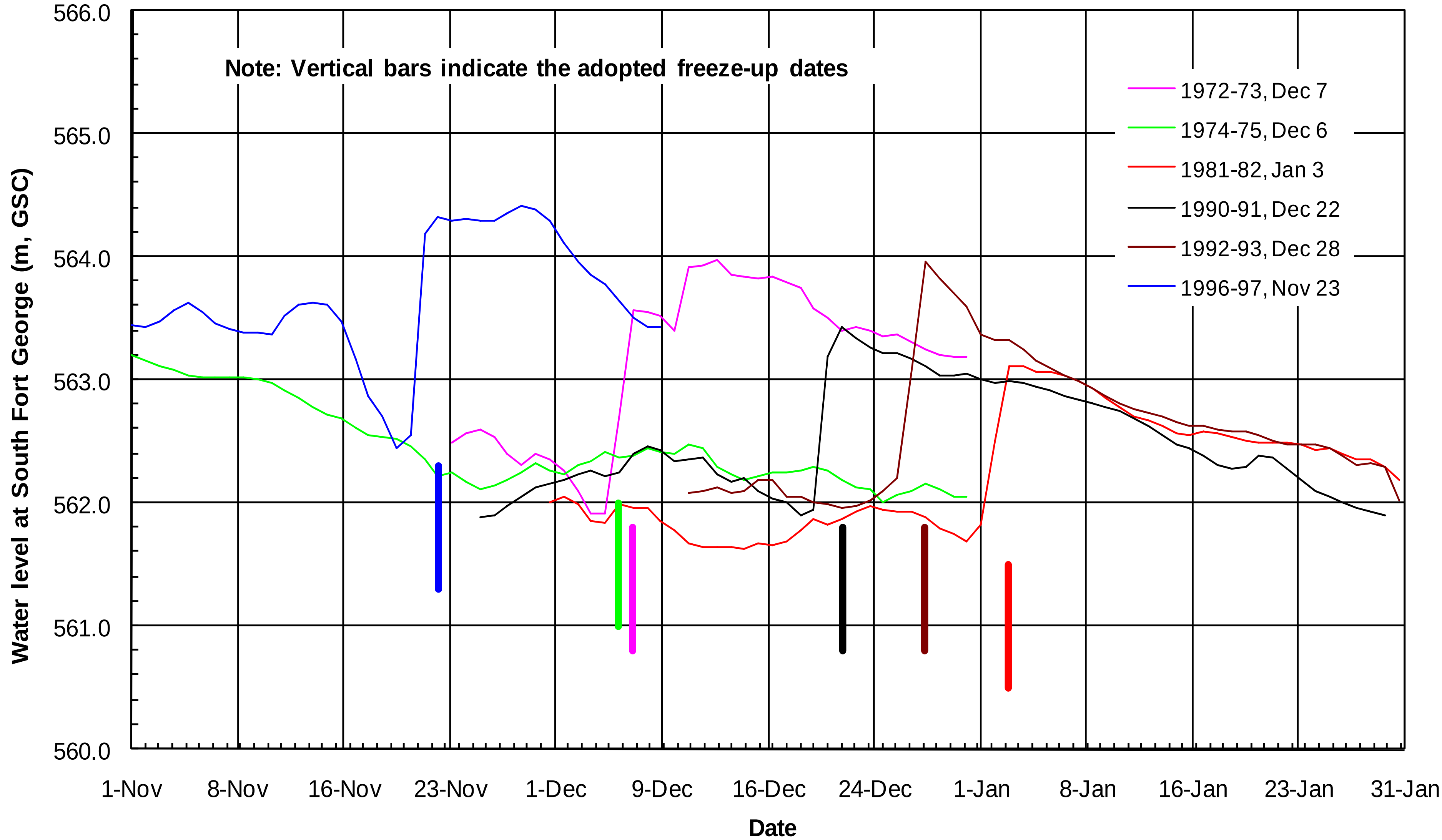


RIVER PROFILE
N.T.S.

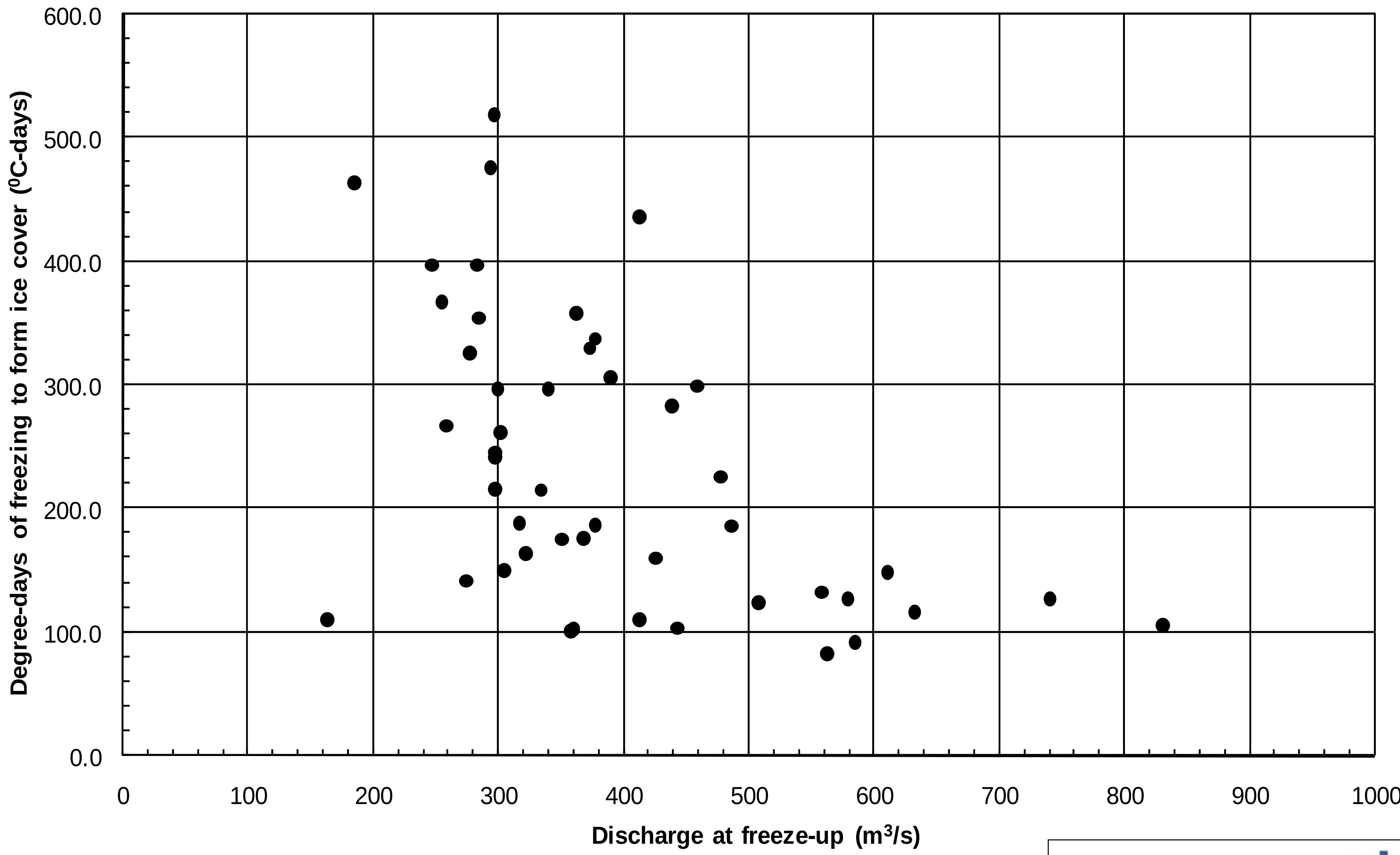
City of Prince George	nhc
Schematic of Ice Cover Formation Profile	
January 2009	Figure 4.1



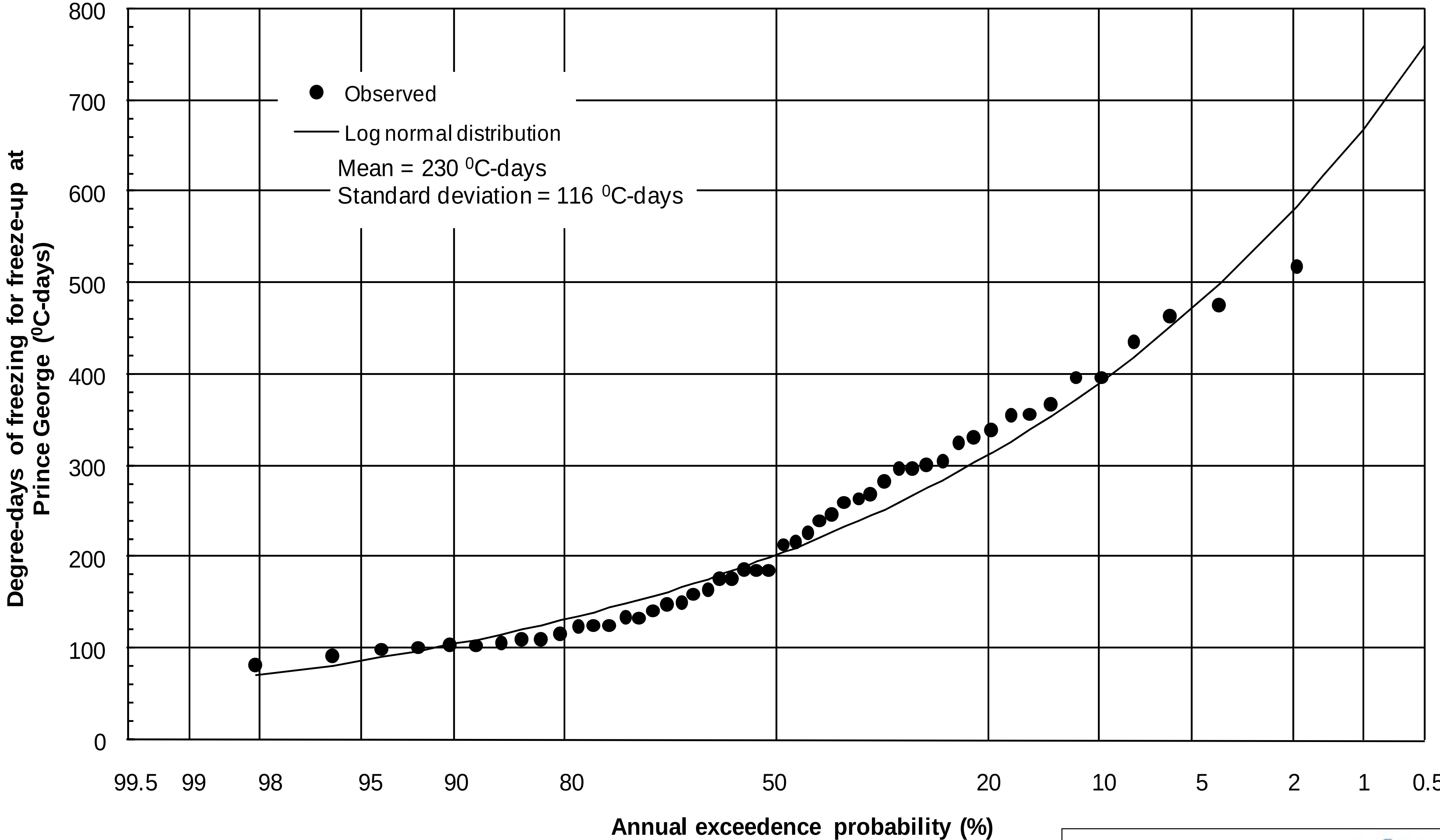
City of Prince George	nhc
Schematic of Ice Cover Formation Cross Sections	
January 2009	Figure 4.2



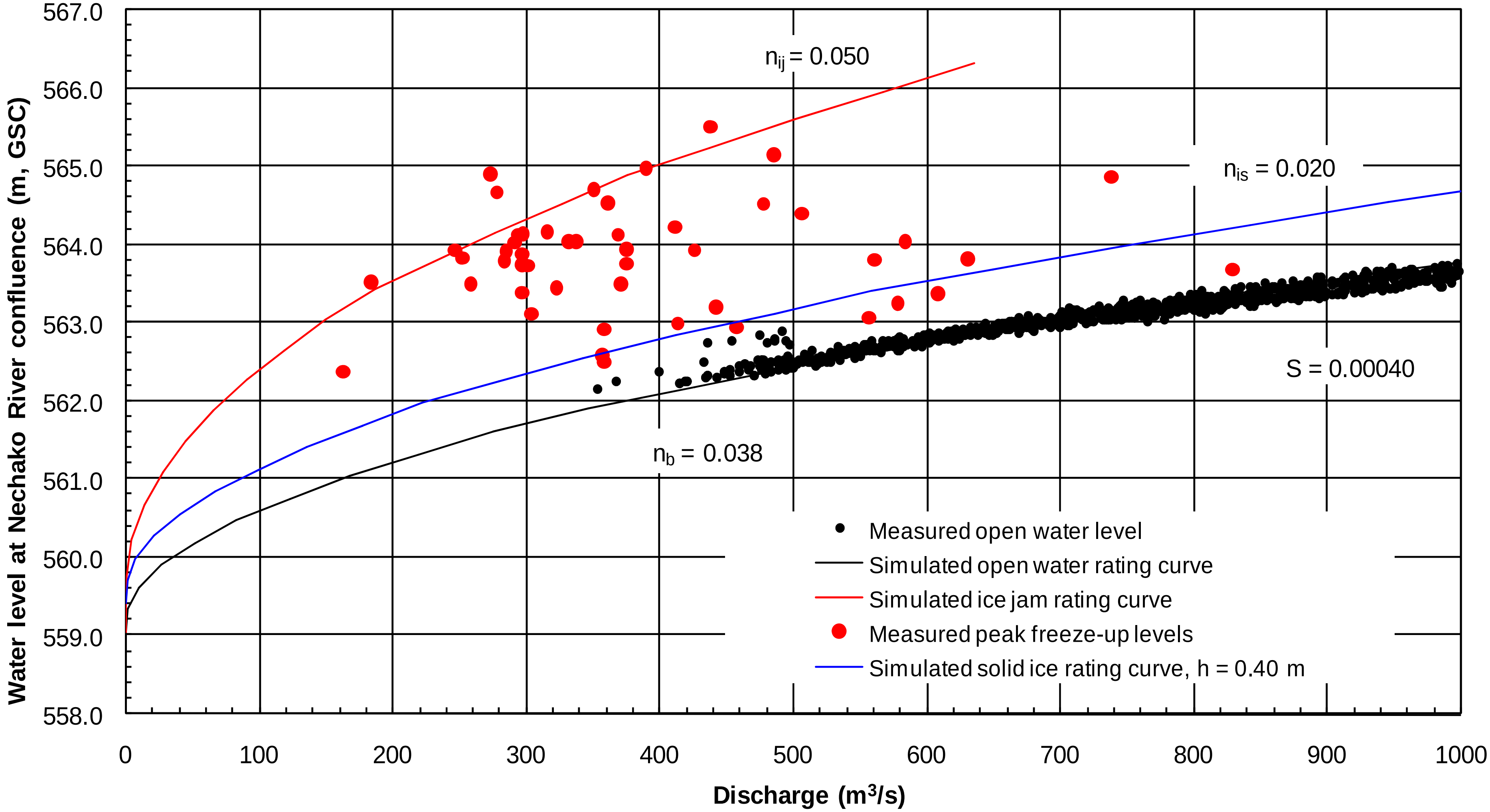
City of Prince George	nhc
South Fort George Freeze-Up Date	
January 2009	Figure 4.3



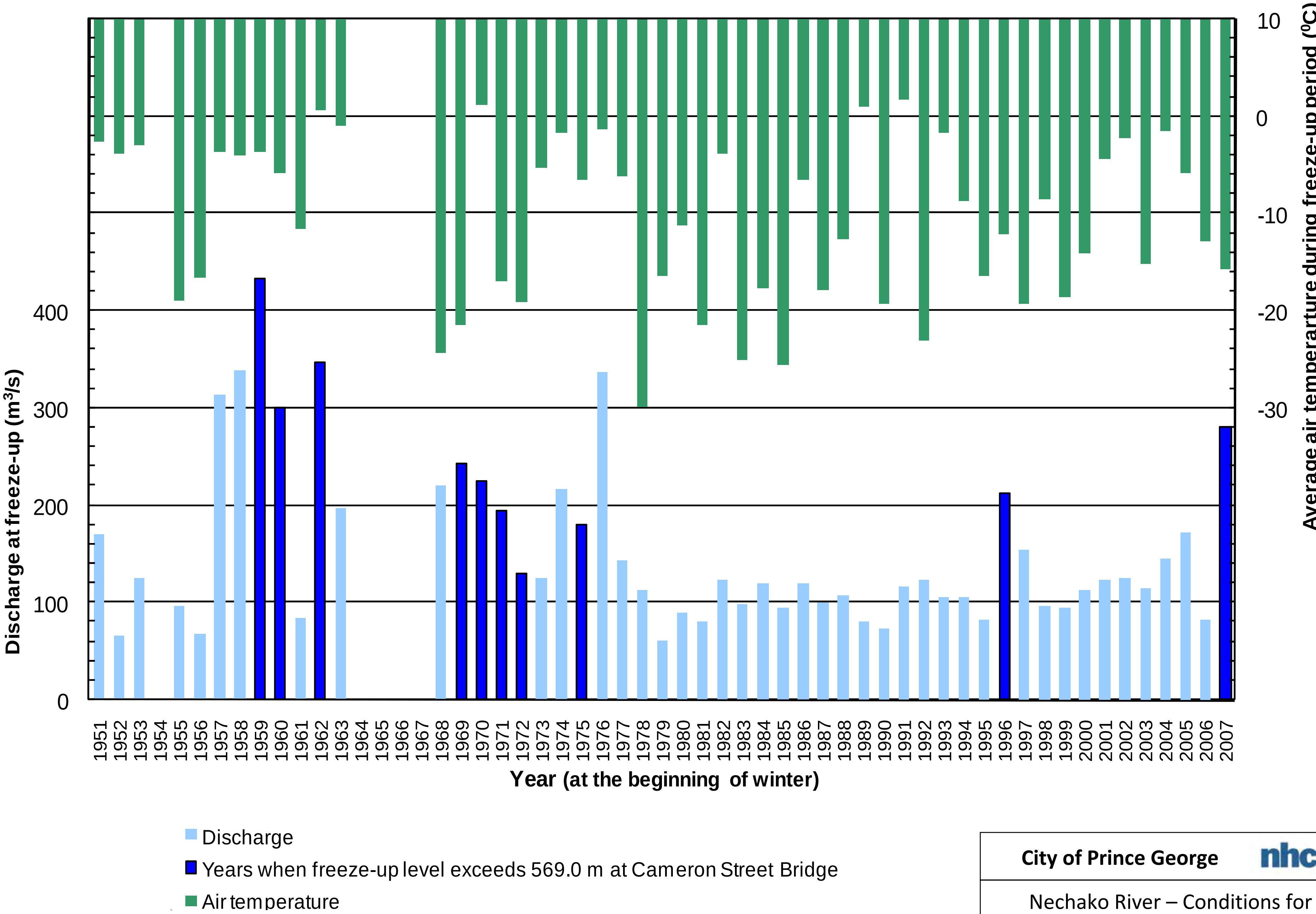
City of Prince George	nhc
Fraser River Freeze-Up Conditions	
January 2009	Figure 4.4



City of Prince George	nhc
Freeze-Up Degree-Day Frequency Curve	
January 2009	Figure 4.5

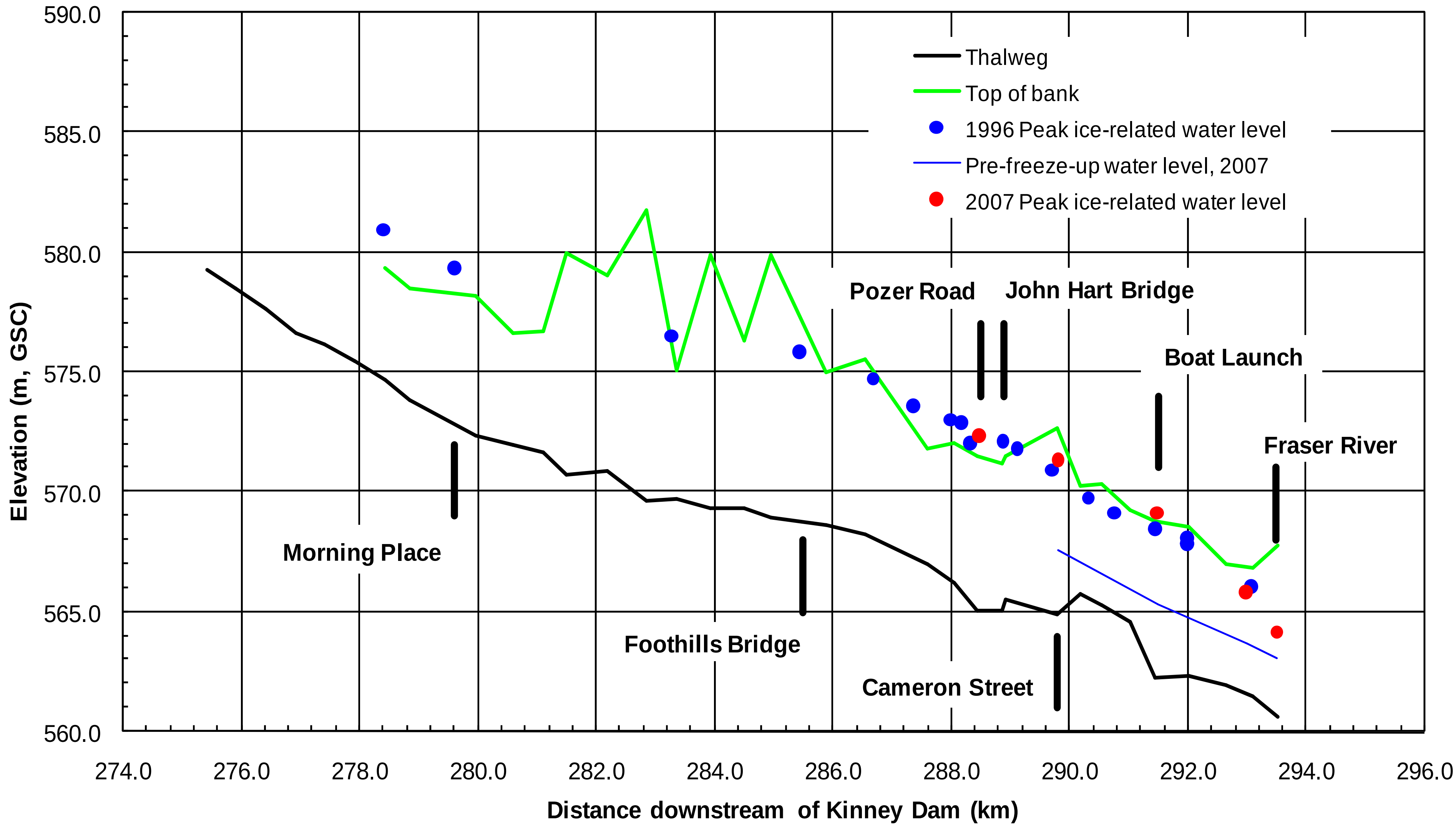


City of Prince George	nhc
South Fort George Open Water and Ice-Related Rating Curves	
January 2009	Figure 4.6

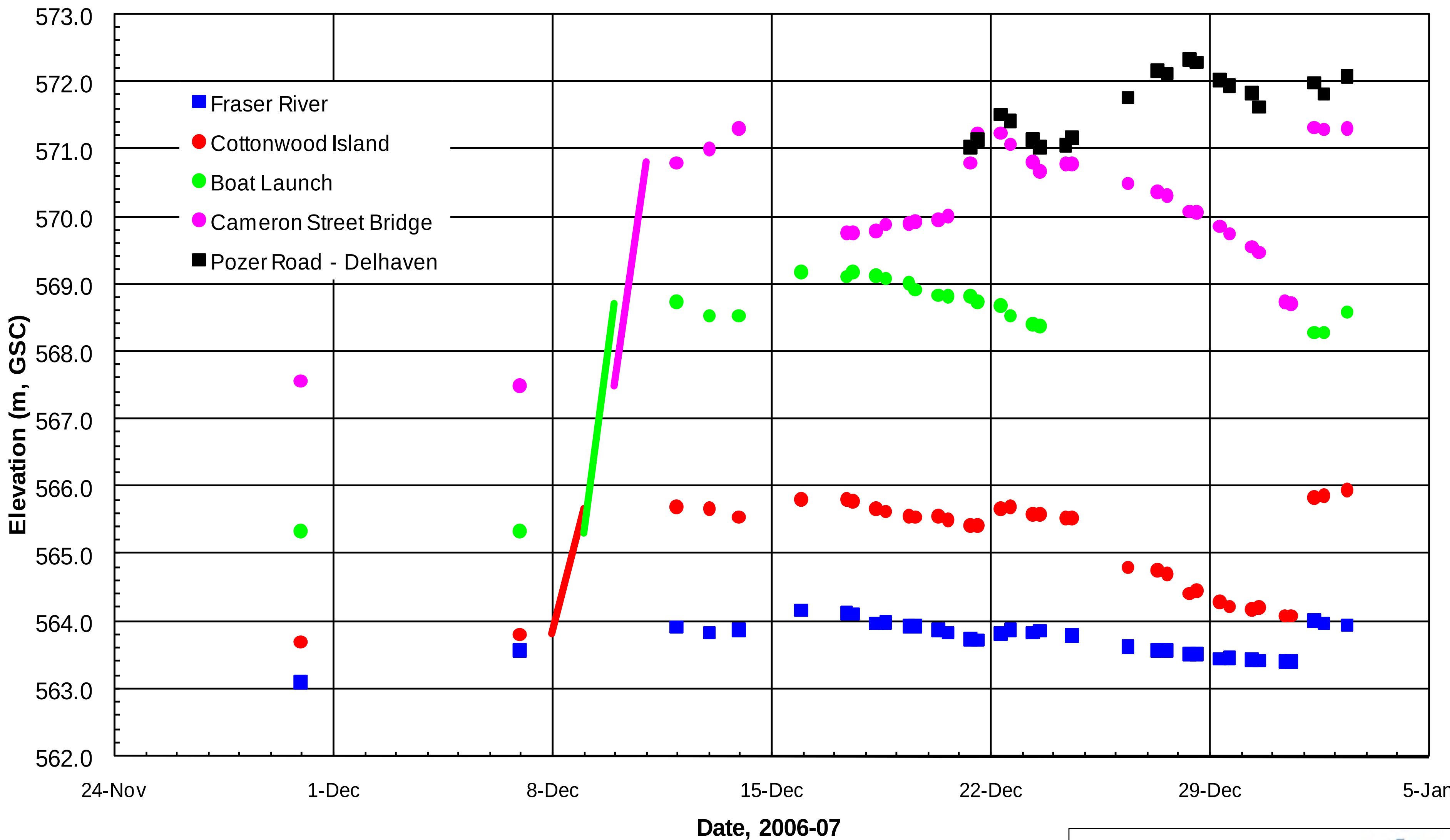


Note: Refer to Table 4.1

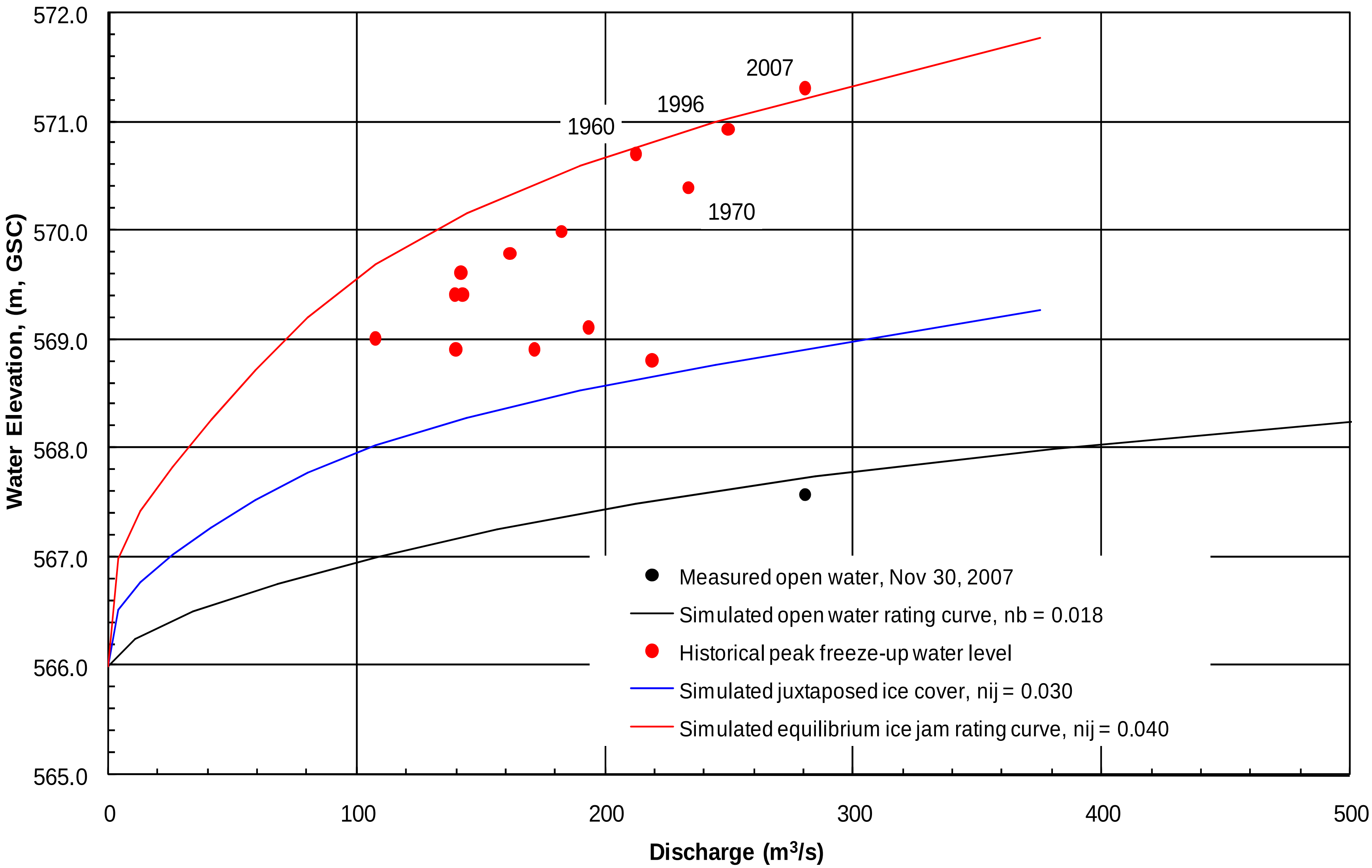
City of Prince George	nhc
Nechako River – Conditions for Ice-Related Flooding	
January 2009	Figure 4.7



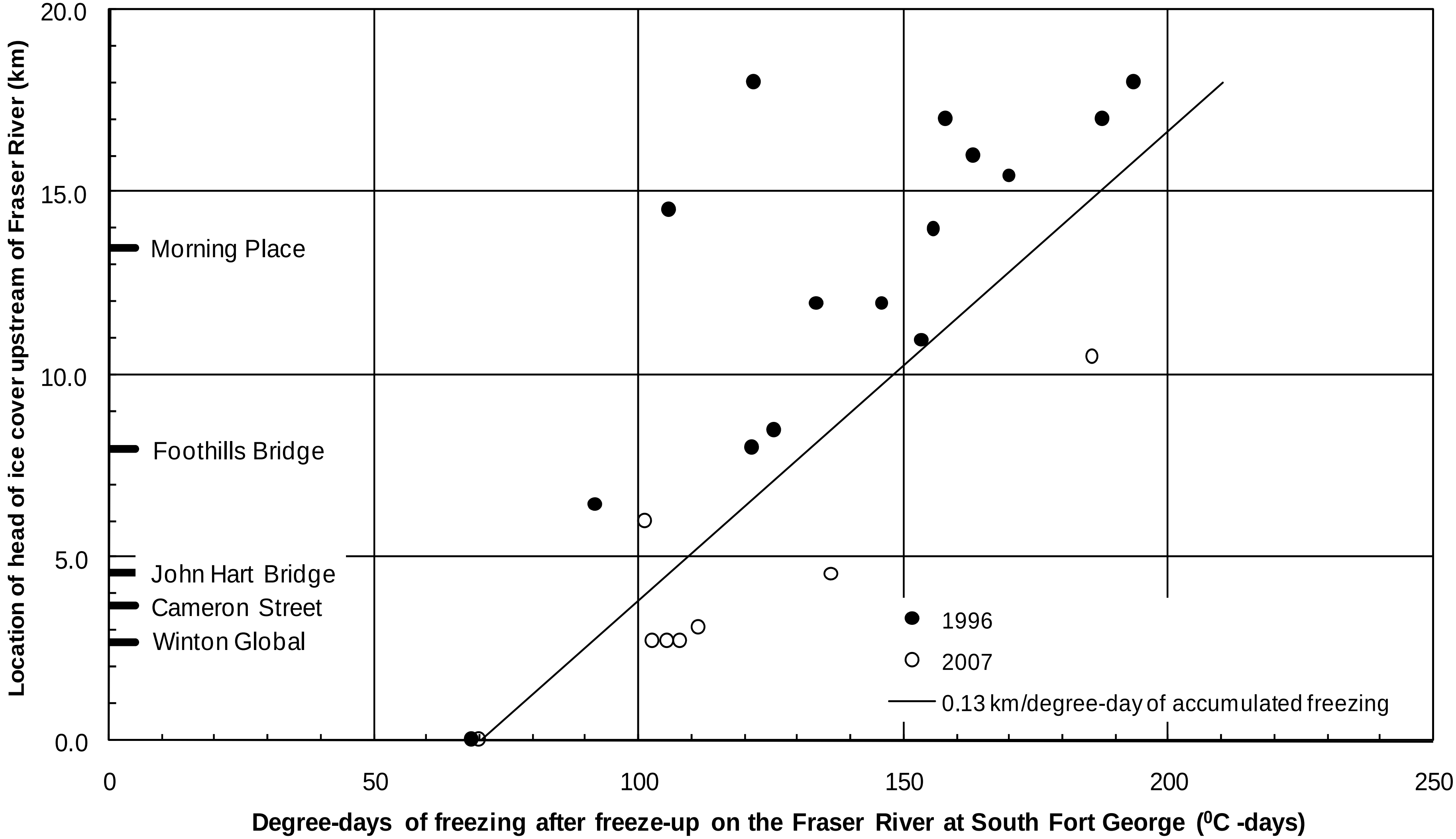
City of Prince George	nhc
Nechako River Reported Ice-Related Water Levels	
November 2008	Figure 4.8



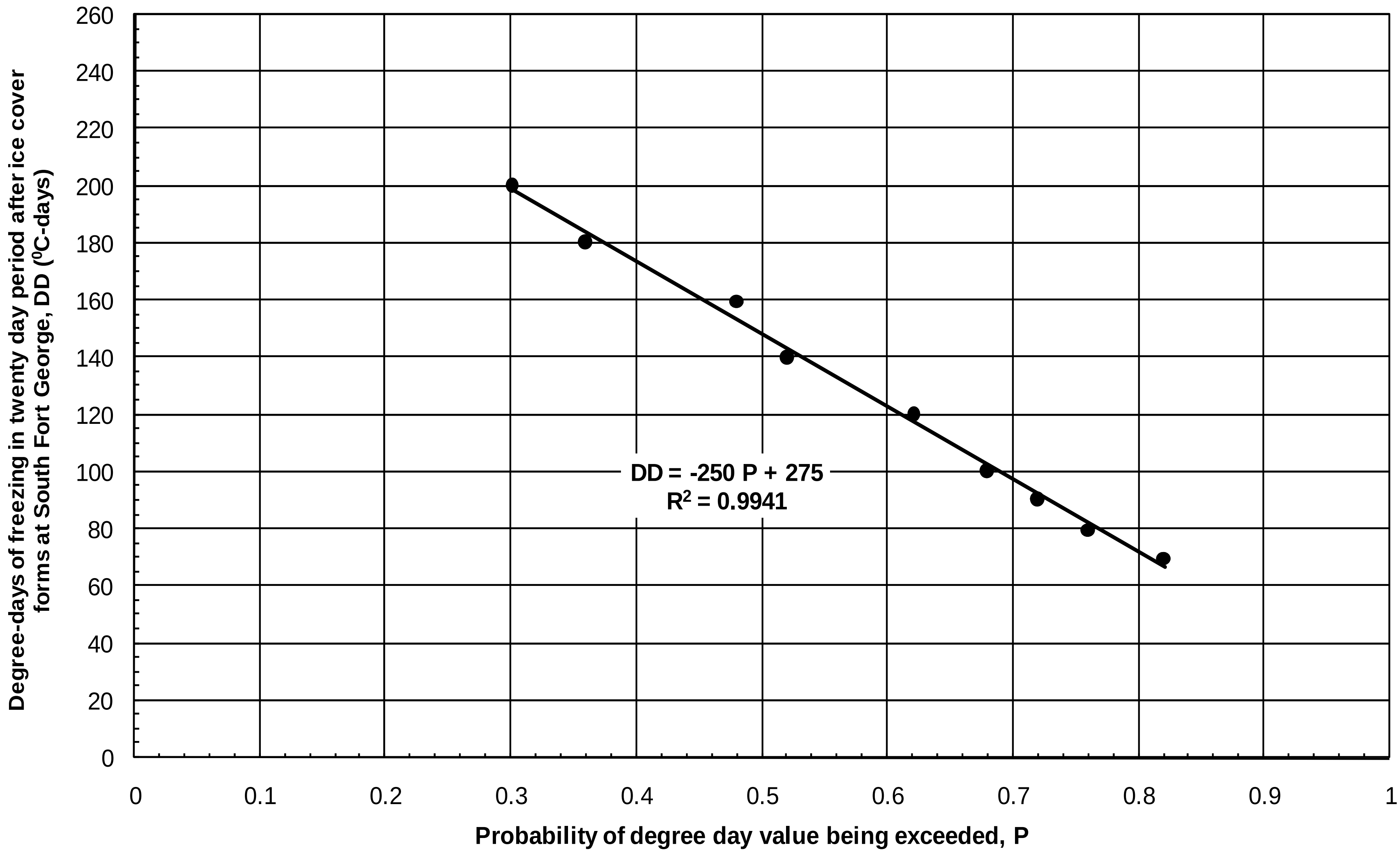
City of Prince George	nhc
2007 Recorded Ice-Related Water Levels, Nechako River	
January 2009	Figure 4.9



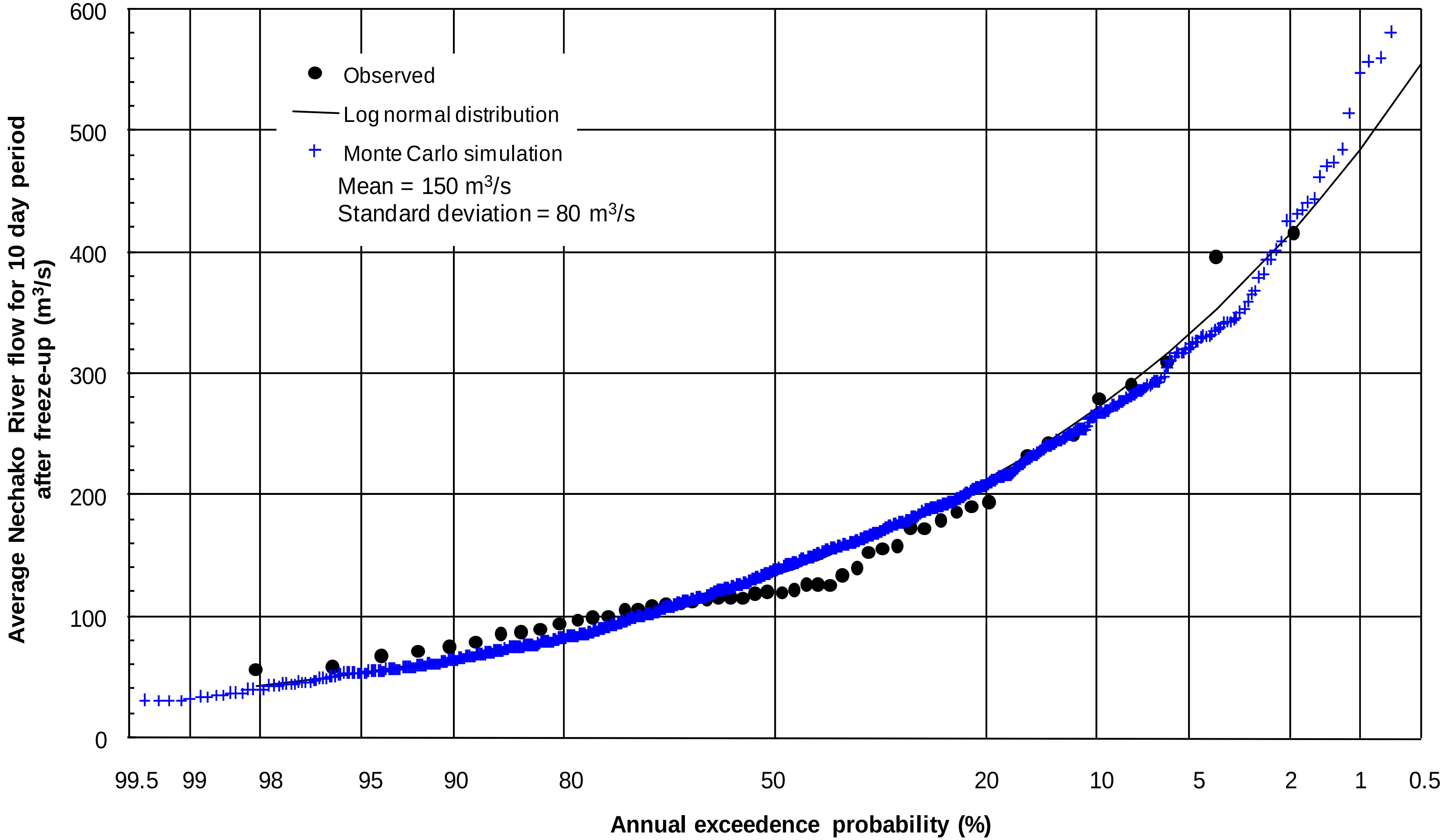
City of Prince George	
Cameron Street Bridge Rating Curves	
January 2009	Figure 4.10



City of Prince George	nhc
Ice Cover Advancement, 1996 and 2007	
January 2009	Figure 4.11



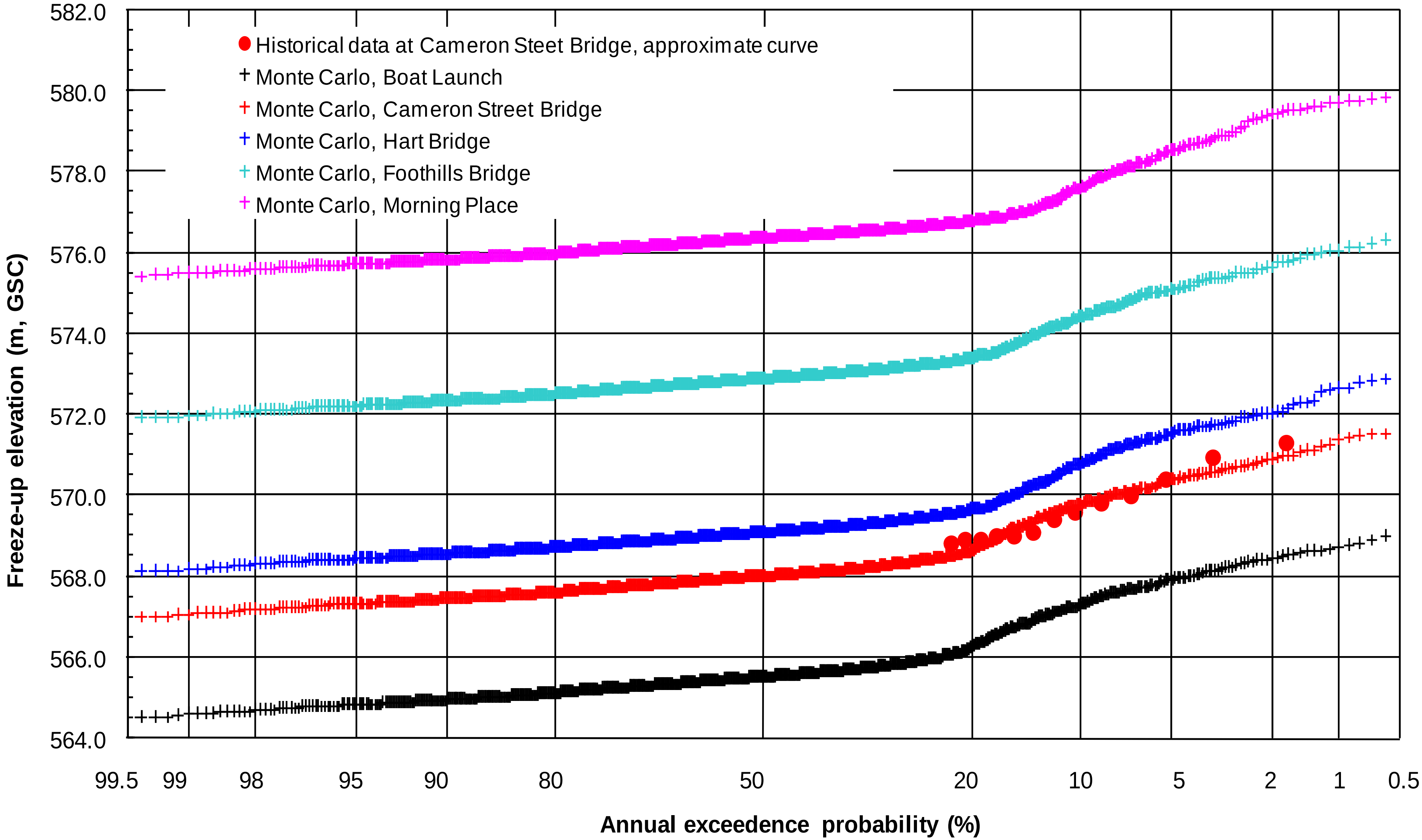
City of Prince George	nhc
Degree Days of Freezing Frequency Curve	
January 2009	Figure 4.12



City of Prince George nhc

Nechako Post-Freeze-Up Flow Probability

January 2009 | Figure 4.13



City of Prince George	nhc
Historical Freeze-Up Elevation Frequency Curve	
January 2009	Figure 4.14

5 FLOOD RISK EVALUATION

Two distinct flood hazards have been identified at City of Prince George, due to either high freshet flows or ice jamming. Typically, the freshet causes the more severe flooding in the Fraser River whereas ice jamming, particularly during freeze-up, is the more critical condition for the Nechako River. Section 3 estimated the 200-year freshet flows for both the Fraser and Nechako Rivers and simulated the corresponding open water flood profiles. Ice processes and ice-related flood levels were outlined in Section 4. The present section compares the results of the two flood analyses and determines which condition produces the more severe flooding within the City boundaries.

A general risk analysis was completed in the first stage of the project and was summarized in Progress Report 1, issued in June of 2008. Based on the technical investigations completed to date, this work can now be expanded on.

5.1 FLOOD THREAT ANALYSIS

5.1.1 FLOOD LEVELS AT PRINCE GEORGE

Section 3.1 described historic freshet floods on the Fraser and Nechako Rivers. **Maps 4, 5** and **6** show the extent of flooding reported during the floods of 1948 and 1972. Recorded and estimated water levels at South Fort George(SFG) for these and other relevant floods are:

Year	Water Level, SFG (m) GSC	Height above 2007 Water Level (m)
1894	569.3 (estimate, accuracy unknown)	1.7
1948	568.3	0.7
1972	568.1	0.5
2007	567.6	-

In general, it is not possible to assign return periods to flood levels since the river cross-section at South Fort George may have changed over time. With present channel conditions, the simulated 200-year flood level at this location is about El. 568.6 m GSC or over 1 m higher than the flood level reached in 2007.

5.1.2 FLOODS IN FRASER RIVER

Freshet flows, generated by snowmelt in combination with sudden high temperatures and/or heavy precipitation during the spring time, consistently produce the annual peak flow for both the Fraser and Nechako Rivers.

The flow record for Fraser River at Shelley, 23 km upstream of the Nechako confluence, covers the period from 1950 to 2008. The six highest recorded floods for this period are:

Year - Date	Fraser River Flow (m^3/s)	Approximate Return Period (years)
1972 – June 14	4,980	55
1990 – June 2	4,800	39
2007 – June 7	4,420	19
2008[13]- May 22	4,310	16
2002 – June 19	4,260	14
1986 – June 2	4,260	14

It is interesting that three of the floods occurred in the past seven years, reflecting a period of above-average peak flows. The recent above-average freshet peaks probably do not reflect any significant change to the river basin. Flow records for Fraser River at Hope dating back to 1912 show periods of below- and above-average annual flows lasting about 30 years. It is possible that a new above-average period has started.

5.1.3 Floods in Nechako River

Since 1952, Kenney Dam has reduced Nechako River flows. The effect of the present or future operating regimes on Nechako annual peaks at Prince George is not exactly known and it is recommended that this be evaluated in cooperation with Rio Tinto Alcan and MOE. The six highest flows recorded at Isle Pierre (61 km upstream of the confluence) are:

Year - date	Nechako River Flow (m^3/s)	Approximate Return Period (years)
2007 – June 29	1,170	50
1972 – July 7	1,080	27
1952 – July 1	1,070	27
1964 – July 1	1,060	25
1976 – June 26	1,050	24
1997 – June 15	1,010	19

The 1948 flood, prior to regulation, is estimated to have exceeded 1,500 m^3/s at Isle Pierre. Flood flows at Prince George are approximately 2% higher than at Isle Pierre. The regulated 20-year and 200-year freshet flows at Prince George are respectively 1,050 m^3/s and 1,450 m^3/s and correspond to water levels of El. 569.5 m GSC and El. 570.3 m GSC at Cameron Street Bridge.

5.1.4 Ice-Related versus Open-Water Flood Levels

Table 4.2 summarized historic ice-related flood levels at Cameron Street Bridge. Early records from the 1920's and 1930's (prior to regulation) indicate flood levels in excess of El. 572 m GSC. Flood levels of El. 570.9 m GSC and El. 571.3 m GSC were reported for 1996 and 2008 respectively, or 0.6 m and 1.0 m higher than the regulated ice-free 200-year

[13] Based on WSC real-time data.

level at the bridge. Based on the ice analysis, the 2008 ice-related event at Cameron Street Bridge had a return period in the order of 90 years.

Figure 5.1 compares the Nechako open water freshet profile with the ice-related profile. Except downstream of Cross-Section N6, the ice-related 200-year profile is higher. This profile, corresponding to equilibrium ice-conditions, is recommended for the design of flood control works. Ice-related water levels for the 20-, 50-, and 100-year ice events are also shown along with the 20-year open water profile. As discussed in Section 3.6.5, a minimum freeboard allowance of 0.6 m should be added to the water surface profile to give the Flood Construction Level (FCL) at any point along the river.

The new design profile is considerably higher than the previous one (**Table 5.1** and **Figure 5.1**). In some locations, the 2007 and 2008 ice-related flood levels overtopped the previous FCL's. Revised design water surface profiles and FCL's are listed in **Table 5.1**. **Figure 5.2** shows where ice-related flood conditions or Fraser backwater conditions govern. The figure also indicates the following range of FCL increases compared to the previous mapping:

Rise in FCL (m)	Reach defined by Cross-sections
0.00 – 0.50	N1 – N6
0.50 – 1.00	N6 – N12
1.00 – 1.50	N12 – N20, N30 – N34
1.50 – 1.75	N20 – N30

As part of Phase 2 of this project, the floodplain mapping for Prince George will be updated accordingly.

On the Fraser River, the open-water (freshet) flood levels are considerably higher than the ice-related levels. A detailed comparison was not carried out. FCL's are based on freshet levels as listed in **Table 5.2** and shown in **Figure 3.12**.

5.2 IDENTIFICATION OF RISK AREAS

In Progress Report 1, developed land areas within the 1997 floodplain boundaries were identified as areas at risk, potentially requiring flood control solutions. The areas are shown on **Maps 4** to **6**. Also indicated on the maps are the 1997 floodplain boundaries, the outline of areas flooded during the freshets of 1948 and 1972, and the flooding caused by the 2007-2008 ice jams. In the confluence area, the 1948 flood limits generally match the floodplain boundaries derived in 1997. The areas flooded during the winter 2007-08 are typically within the 1997 designated floodplain, except near Morning Place. **Maps 4 to 6** also indicate areas where high groundwater levels caused flooding during the 2007-2008 ice jams.

Because the revised FCL's are higher than the specified 1997 levels, the dimensions of the risk areas will increase somewhat, depending on the topography of each area. Correspondingly, asset values may be higher than formerly estimated.

Map 5 identifies seven flood risk areas along the Nechako River, as follows:

- Area A_N – South Bank of Nechako River at Confluence
- Area B_N – North Bank of Nechako River east of John Hart Bridge
- Area C_N – North Bank of Nechako River near Confluence
- Area D_N – North Bank of Nechako River west of John Hart Bridge
- Area E_N – North Bank of Nechako River at Morning Place
- Area F_N – South Bank of Nechako River at Foot Hills Bridge
- Area G_N – South Bank of Nechako River between John Hart and Foothills Bridges

Maps 4 and **6** identify another seven flood risk areas along the Fraser River, as follows:

- Area A_F – West bank at Yellowhead Highway
- Area B_F – South Fort George
- Area C_F – Hudson's Bay Slough west of Queensway
- Area D_F – Lansdowne south end
- Area E_F – West Bank at Island
- Area F_F – Northwood Pulpmill Road
- Area G_F – Across River from Shelley

In accordance with the project Terms of Reference, flood-prone areas outside the City of Prince George municipal boundaries, such as Foreman Flats and Shelley, are not included.

5.3 ASSET INVENTORY

5.3.1 GENERAL DESCRIPTION OF ASSETS

Assets include residential, commercial, industrial and non-profit properties located within the Nechako and Fraser River floodplains, as well as publicly owned infrastructure and private utilities located in road allowances and lanes. For the private properties, assessed values of land and improvements are used. Where appropriate, a more detailed breakdown of specific properties is provided depending on the mitigation option being contemplated.

Public-owned infrastructure includes roadways, bridges, community wells, trails, parks, water-mains, sanitary sewers and storm sewers including outfalls. Private utilities include hydro, telephone, natural gas and cable services generally located within road allowances. These assets tend to be linear in nature with a roadway generally having parallel installations of water and sewer mains, storm sewers, gas lines and hydro/telephone/cable lines. This infrastructure can, however, include specific components such as pump houses, vaults or regulating stations that are outside the typical linear installations.

Portions of the utility infrastructure provide local service to adjoining private properties. For mitigation options involving land use changes, this infrastructure can be decommissioned by removing surface features such as pavement or pole lines and by plugging or removing underground lines.

Other infrastructure services off-site areas or specific site conditions. This category includes some storm sewers, and major structures such as water-well pumping stations. Relocation of such facilities may not be practical or desirable.

5.3.2 OVERVIEW OF FLOOD RISKS TO ASSETS

A flood event poses direct risks to assets from inundation by floodwater or rising groundwater, and from erosion or structural damage by flowing water or moving ice. Activities associated with the flood response, such as emergency diking, may also affect assets. Road surfaces, appurtenances such as pad-mounted transformers and structures may be immediately at risk. Inundation generally has greater effects on private properties than on linear assets, due to damage to buildings, contents and equipment. Other considerations are:

- Storm and sanitary sewers may become surcharged, causing backups in buildings. Inundation may cause sediment and debris to deposit in piping, vaults and ducts, incurring costs for later cleaning and removal.
- Underground pressure mains such as natural gas lines, water-mains or sewage force-mains are unlikely to be affected by inundation unless the underlying soil is de-stabilized. Buried cables and vaults are also generally treated to resist inundation, but access to them may be affected. (As protection of public water utilities received priority during the 2007-2008 ice jam event, it can be expected that efforts to protect them would be made in future similar events.)
- Flowing water or moving ice may damage structures and surface appurtenances, and in extreme cases also threaten buried facilities if new flood channels are cut. Ice jams may also threaten overhead lines by striking the poles.
- Emergency works during a flood may damage surface features such as pole lines, landscaping, trees and fences through encroachment of temporary dikes. Heavy mobile equipment and temporary dikes may also damage shallow buried ducts and piping. Temporary dikes may also limit access to businesses, residences and utilities.

In addition to immediate effects to assets within flooded areas, floods also have consequential impacts due to temporary loss of use of residences and businesses, including wage losses to employees.

5.3.3 NECHAKO RIVER RISK AREAS

Urban and other developments within the risk areas were reviewed. Site visits were made to most areas, and a helicopter reconnaissance was conducted on October 8, 2008. Descriptions of the various areas on **Map 5** follow.

Area A_N (South Bank of Nechako River at Confluence)

This complex area includes a portion of downtown Prince George, commercial areas along 1st Avenue, the CN Rail yards, forestry-related industries along River Road, some residences and sparsely developed areas such as log storage yards, Cottonwood Island Park and the Railway Museum. As indicated on **Map 5**, ice-jam flooding in 2007/2008 affected businesses and residences in various places, particularly along River Road. Groundwater flooding associated with the ice jam affected properties along the west end of 1st Avenue.

The major effects on public infrastructure during the 2007/2008 ice-jam event were restricted use of River Road due to temporary dike construction, and damage to facilities at Cottonwood Island Park. Power and telephone lines are mainly overhead and were unaffected except for tilting of a few poles. Because access along River Road is considered important, the roadway has since been raised to permit vehicle access during floods. Considering the significant increases to the Nechako 200-year design levels as a result of the ice analysis contained in Section 4, top-of-road elevations should be reviewed.

The freshet floods in 1948 and 1972 appear to have affected mainly the eastern portion of the area, with little effect on properties affected in the winter of 2007/2008. The limits of the 1948 flood included densely developed downtown areas.

Area B_N (North Bank of Nechako River East of John Hart Bridge)

This area contains a mixture of commercial and light industrial uses and was directly affected by emergency works in response to the ice-jam flooding in 2007/2008. It does not appear to have been affected by the freshet flood events of 1948 and 1972. Except for some property on the west side beside Highway 97, most of the area has been developed.

Area C_N (North Bank of Nechako River near Confluence)

This area contains a major water intake and well facility for Canfor and is the corridor for Prince George Pulpmill Road, but otherwise consists predominantly of low-density residential development. The west end experienced ice-jam and groundwater flooding in 2007/2008, and the whole area appears vulnerable to freshet flooding as in 1948 and 1972. Erosion of the north river bank is becoming more of a threat to properties and residences.

Prince George Pulpmill Road is a major asset in this area, being the sole road access to major industrial sites to the east, including two pulp mills, a refinery, chemical plants, industrial contractors, etc. Pulpmill Road was also used as a staging area during the 2007/2008 ice-jam event for evacuating residents and deploying equipment. Presently, the road surface is above the revised Flood Construction Level.

Area D_N (North Bank of Nechako River West of John Hart Bridge)

Major facilities are the Pacific Western Brewing Company and a school. The floodplain contains several residential properties and a portion of North Nechako Road as well as a ramp access to Highway 97. Flooding from the 2007/2008 ice-jam event threatened residences in the Del Haven multifamily complex.

Area E_N (North Bank of Nechako River at Morning Place)

This area is residential. Direct impacts from the 2007/2008 ice jam were related to the installation and removal of temporary gabion works alongside residential properties.

Area F_N (South Bank of Nechako River at Foothills Bridge)

This area is mostly undeveloped land, known as Fishtrap Island. However it contains a major water well and pump station that supplies the City. Some ice-jam related flooding took place at the Foothills bridge in 2007/2008 , but the pump station site did not appear to be affected.

Area G_N (South Bank of Nechako River between John Hart and Foothills Bridges)

This area, accessible through Wilson Park, is similar to Fishtrap Island in that it is predominantly undeveloped but contains a major water well and pump station. Some ice-jam flooding appears to have taken place near the pump station in 2007/2008.

5.3.4 Fraser River Risk Areas

Area A_F (West Bank at Yellowhead Bridge)

This relatively small area has some basic landscaping but is otherwise undeveloped. Existing infrastructure is limited to a storm outfall, a sanitary sewer force-main and a gravity sewer. The area appears to be outside the influence of ice-jam flooding on the Nechako River, but is vulnerable to freshet flooding from the Fraser River.

Area B_F (South Fort George)

This area is part of the Hudson's Bay Slough system and is bounded by Queensway Road and the Fraser River. The area has some residential development on Farrell Street and a recreational baseball diamond but is otherwise undeveloped. It serves as a discharge location for two storm sewer trunk lines, and contains a sewage lift station.

Area C_F (Hudson's Bay Slough West of Queensway)

This area follows the Hudson's Bay Slough creek system and includes part of Winnipeg Street up to a topographical divide from Area A_N. More recent residential areas between Queensway and Upland Street would have been inundated in the 1948 and 1972 floods. The area includes part of Highway 16 near Strathcona Avenue, and the upper reach of the Slough may affect a BC Hydro substation at Winnipeg Street.

Area D_F (Lansdowne South End)

This area is mostly undeveloped but includes part of the City's sewage treatment plant. A 900 mm diameter outfall pipe traverses the area to discharge treated effluent into the Fraser River. It is not known to what extent this area was affected by freshet flooding in 1948 and 1972.

Area E_F (West Bank at Island)

This area consists of agricultural land with a barn at its northeast corner.

Area F_F (Northwood Pulp Road)

This area surrounds the Northwood Pulpmill complex, which lies on high ground above 200-year levels. It contains parts of the Northwood Pulp Road, several private paved and gravel roads, a private bridge crossing, log storage areas and some treatment lagoons for the plant site. Landooz Road passing through the area is the sole access for several low-density residential properties in the northeast corner of the city, as well as the North Shelley community outside the City Limits.

Area G_F (Across River from Shelley)

Land in this area is either undeveloped or agricultural. A natural gas transmission main traverses the area to a crossing structure over the Fraser River. Area G_F can be considered to extend beyond the City Limits into Fort George Indian Reserve No. 2 and to the North Shelley community.

5.4 ASSESSMENT OF FLOOD THREATS

Map 5 demonstrates that threats to assets are not evenly distributed. Areas near the confluence are affected by both ice-related flooding and freshet flooding, while others are affected by only one type of event. Freshet and ice flood events are not completely independent. Following the severe freshet flooding in June 2007, particularly within the Nechako basin, the watershed was probably more saturated than in normal years, tending to produce above-average runoff in the subsequent fall and winter. Fully lowering the Nechako Reservoir to typical fall levels may have been difficult in view of the prolonged high flow releases necessary in the summer and fall, and early November flows were well above normal.

Fraser freshet flooding is the critical condition along the Fraser River and along the Nechako River as far upstream as Cross-Section N6. The revised FCL's are on average 0.3 m higher than those specified in 1997, due to slight increases in the 200-year design flows. Consequently the flood boundaries shift farther from the river, increasing the size of the identified risk areas. Upstream of Nechako Cross-Section N6, the recommended FCL's have risen substantially (average 1.1 m), resulting in potentially much larger floodplain areas where the land is relatively flat.

The Fraser freshet flood magnitude is a function of the accumulated spring snowpack, and to a lesser degree temperatures and precipitation during snowmelt. Freeze-up conditions leading to ice-jam floods are a function of temperatures and Nechako River flows, as described in Section 4.

Based on the flood threats and asset inventories described above, the identified risk areas can be listed tentatively in descending order of priority as follows:

1. Area A_N - South Bank of Nechako River at Confluence. At risk during freshet and freeze-up. Includes downtown core south of the railway, the railway, and industrial lands to the north.
2. Area C_N - North Bank of Nechako River near Confluence. At risk during freshet and at freeze-up. Relatively sparsely populated.
3. Area D_N - North Bank of Nechako River west of John Hart Bridge. Primary risk is ice-related. Low-lying, densely developed, includes multi-family housing.
4. Area B_N - North Bank of Nechako River east of John Hart Bridge. The primary threat is ice-related flooding. The area is low-lying and densely developed with mainly commercial and light industrial uses.
5. Area B_F – South Fort George. The primary threat is freshet flooding and flooding commences at relatively low return period floods of 15 to 20 years. The area is low-lying and contains residential development.
6. Area E_N – Morning Place. The primary threat is ice-related flooding. The area is relatively low-lying and contains residential development.
7. Area D_F – Lansdowne South End. The area is at risk of freshet flooding and contains some residential development.

The following areas which presently exhibit only limited development may not need flood protection measures. In some cases future development should be discouraged by appropriate zoning.

- Area F_N – South Bank at Foothills Bridge.
- Area G_N – South Bank between John Hart and Foothills Bridges.
- Area A_F – West bank at Yellowhead Highway
- Area E_F – West Bank at Island
- Area F_F – Northwood Pulpmill Road
- Area G_F – Across River from Shelley

Area C_F – Hudson's Bay Slough west of Queensway, is a densely developed low-lying area protected by the Queensway road embankment which acts as a standard dike. An adjacent pump-station provides for internal drainage. Considering the revised FCL's, the adequacy of this protection will be verified in Phase 2.

Table 5.1 – Nechako Freshet Design Water Surface and Ice Profiles with FCL's

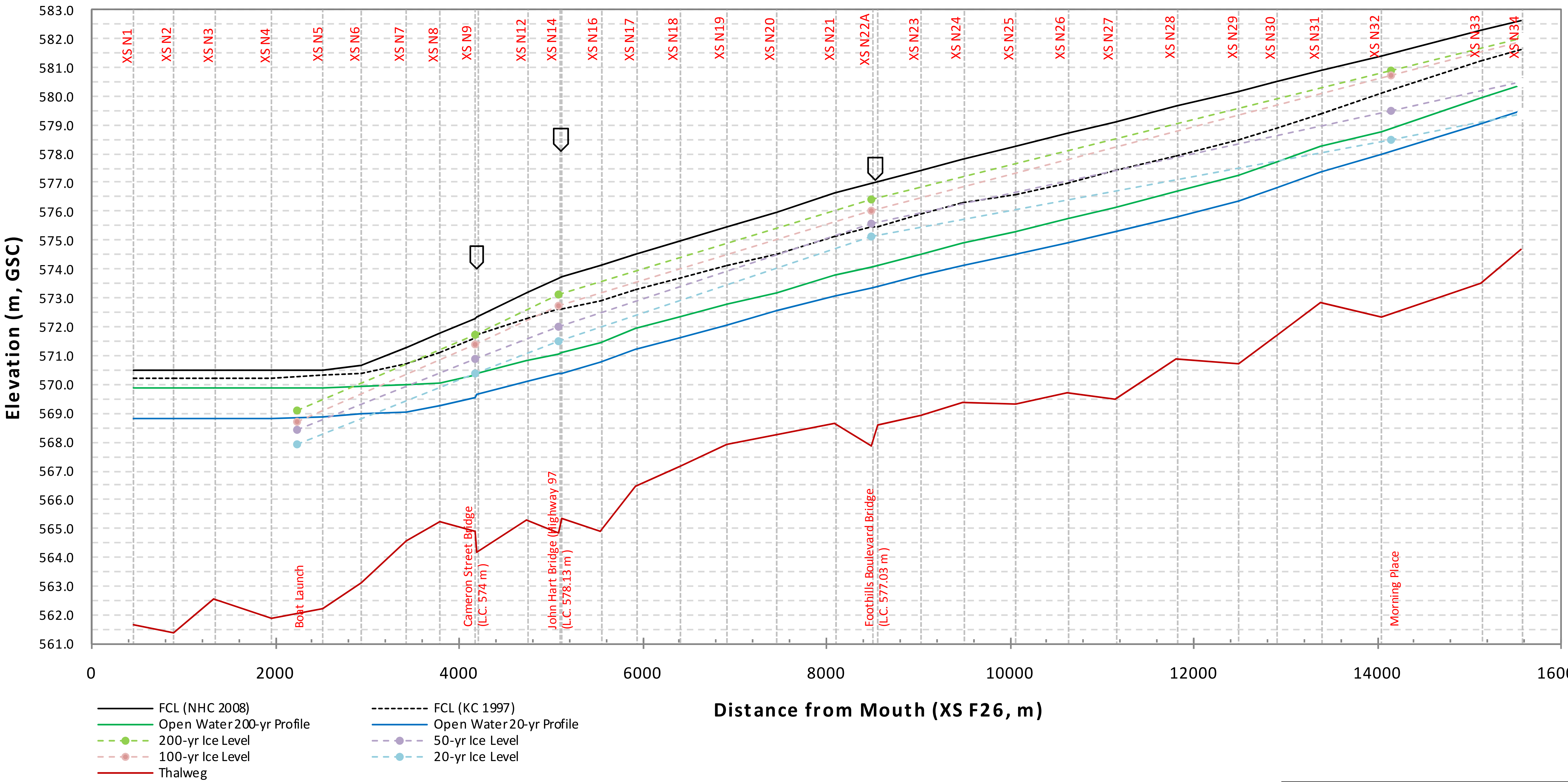
XS Name	Distance (m)	Channel n - value	Freshet Design Profile		Ice-Related	NHC FCL's	Old FCL's	Increase (m)
			20-yr	200-yr	Design Profile (200-yr)	Freshet or Ice	Klohn Crippen	
XS N34	15573	0.032	579.47	580.38	***582.03***	582.63	581.60	1.03
XS N33	15135	0.032	579.05	579.92	***581.68***	582.28	581.20	1.08
XS N32	14045	0.032	578.00	578.76	***580.81***	581.41	580.10	1.31
XS N31	13385	0.032	577.39	578.27	***580.29***	580.89	579.40	1.49
XS N30	12896	0.032	576.79	577.68	***579.90***	580.50	578.90	1.60
XS N29	12489	0.032	576.38	577.25	***579.57***	580.17	578.50	1.67
XS N28	11814	0.032	575.82	576.69	***579.04***	579.64	577.90	1.74
XS N27	11148	0.031	575.30	576.13	***578.51***	579.11	577.40	1.71
XS N26	10627	0.031	574.92	575.72	***578.09***	578.69	577.00	1.69
XS N25	10060	0.031	574.50	575.27	***577.64***	578.24	576.60	1.64
XS N24	9495	0.031	574.11	574.88	***577.19***	577.79	576.30	1.49
XS N23	9025	0.031	573.76	574.52	***576.82***	577.42	575.90	1.52
XS N22B	8555	0.031	573.40	574.12	***576.45***	577.05	575.49	1.56
XS N22A	8496	0.031	573.34	574.04	***576.40***	577.00	575.44	1.56
XS N21	8098	0.031	573.08	573.77	***576.01***	576.61	575.10	1.51
XS N20	7456	0.031	572.53	573.16	***575.39***	575.99	574.50	1.49
XS N19	6913	0.031	572.07	572.80	***574.87***	575.47	574.10	1.37
XS N18	6402	0.031	571.62	572.34	***574.37***	574.97	573.70	1.27
XS N17	5932	0.031	571.21	571.95	***573.92***	574.52	573.30	1.22
XS N16	5541	0.031	570.77	571.45	***573.54***	574.14	572.90	1.24
XS N15	5118	0.031	570.39	571.10	***573.13***	573.73	572.60	1.13
XS N14	5087	0.031	570.36	571.06	***573.10***	573.70	572.60	1.10
XS N12	4745	0.031	570.07	570.81	***572.58***	573.18	572.30	0.88
XS N11	4201	0.031	569.63	570.40	***571.74***	572.34	571.70	0.64
XS N9	4175	0.031	569.54	570.32	***571.70***	572.30	571.60	0.70
XS N8	3792	0.031	569.23	570.03	***571.18***	571.78	571.10	0.68
XS N7	3423	0.031	569.03	569.98	***570.69***	571.29	570.70	0.59
XS N6	2938	0.031	568.97	569.95	***570.03***	570.63	570.40	0.23
XS N5	2518	0.031	568.85	***569.88***	569.46	570.48	570.30	0.18
XS N4	1957	0.031	568.82	***569.88***	---	570.48	570.20	0.28
XS N3	1337	0.031	568.82	***569.88***	---	570.48	570.20	0.28
XS N2	889	0.031	568.81	***569.88***	---	570.48	570.20	0.28
XS N1	452	0.031	568.81	***569.88***	---	570.48	570.20	0.28
Average	---	---	---	---	---	---	---	1.10

Notes: (1) Governing flood levels are shown in bold. FCL's include 0.6 m freeboard.
(2) All water levels and elevations are in metres (GSC).

Table 5.2 – Fraser Freshet Design Water Surface Profiles and FCL's

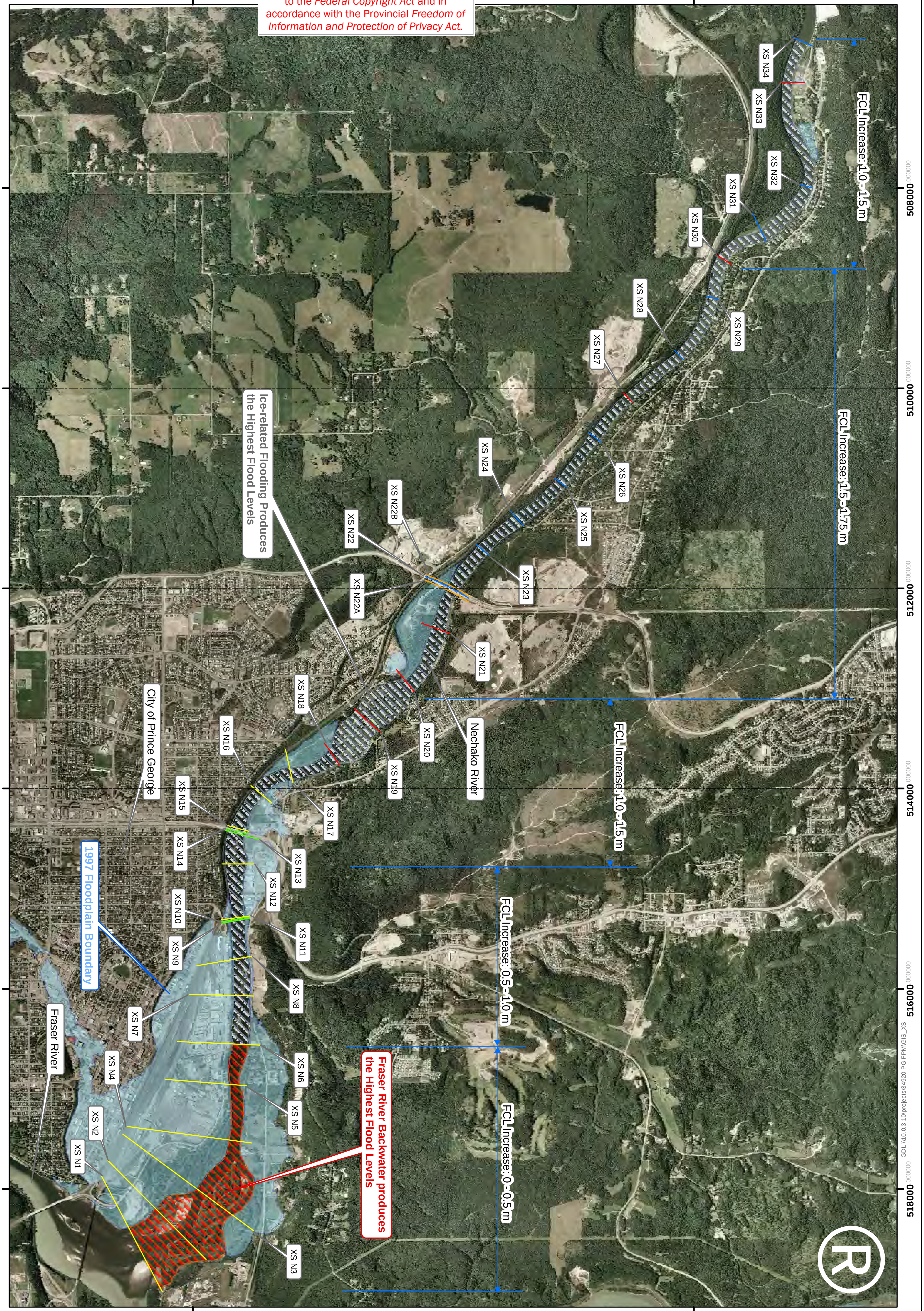
XS Name	Distance (m)	Channel n - value	Freshet Design Flow		NHC FCL's	Old FCL's	Increase (m)
			20-yr	200-yr	Freshet	Klohn Crippen	
XS F61	39338	0.027	575.45	576.56	577.16	576.80	0.36
XS F60	38312	0.027	575.17	576.29	576.89	576.40	0.49
XS F59	37532	0.027	574.94	576.05	576.65	576.10	0.55
XS F58	36837	0.027	574.83	575.97	576.57	576.00	0.57
XS F57	35961	0.027	574.54	575.65	576.25	575.50	0.75
XS F56	35186	0.027	574.43	575.57	576.17	575.40	0.77
XS F55	34290	0.027	574.11	575.22	575.82	575.20	0.62
XS F54	33364	0.028	573.84	575.03	575.63	575.00	0.63
XS F53	32073	0.028	573.35	574.59	575.19	574.80	0.39
XS F52B	31433	0.028	573.13	574.35	574.95	574.60	0.35
XS F52	31419	0.028	573.11	574.34	574.94	574.60	0.34
XS F51	30981	0.028	573.07	574.28	574.88	574.60	0.28
XS F50	30378	0.028	572.82	574.03	574.63	574.40	0.23
XS F49	29697	0.028	572.85	574.08	574.68	574.40	0.28
XS F48	29099	0.028	572.16	573.19	573.79	573.70	0.09
XS F47	28429	0.028	572.14	573.22	573.82	573.70	0.12
XS F46	27700	0.028	571.86	572.94	573.54	573.40	0.14
XS F45	26813	0.027	571.64	572.73	573.33	573.20	0.13
XS F44	26090	0.027	571.47	572.56	573.16	573.00	0.16
XS F43	25674	0.027	571.33	572.42	573.02	572.90	0.12
XS F42	24521	0.027	571.11	572.20	572.80	572.60	0.20
XS F41	23856	0.027	570.86	571.93	572.53	572.20	0.33
XS F40	22730	0.029	570.74	571.89	572.49	572.10	0.39
XS F39	21595	0.029	570.56	571.75	572.35	572.00	0.35
XS F38	20958	0.029	570.45	571.64	572.24	571.90	0.34
XS F37	20290	0.029	570.38	571.57	572.17	571.80	0.37
XS F36	19666	0.030	570.11	571.24	571.84	571.50	0.34
XS F35	18831	0.030	569.95	571.10	571.70	571.40	0.30
XS F34	18281	0.030	569.83	570.95	571.55	571.30	0.25
XS F33	17276	0.029	569.59	570.71	571.31	571.00	0.31
XS F32	16322	0.029	569.14	570.18	570.78	570.50	0.28
XS F31	15668	0.029	568.93	569.93	570.53	570.30	0.23
XS F30	15650	0.029	568.98	570.01	570.61	570.30	0.31
XS F29	15632	0.029	568.93	569.95	570.55	570.30	0.25
XS F28	15421	0.029	568.90	569.92	570.52	570.20	0.32
XS F27	14446	0.030	568.75	569.78	570.38	570.10	0.28
XS F26	13868	0.030	568.71	569.77	570.37	570.10	0.27
XS F25	13714	0.030	568.71	569.77	570.37	570.10	0.27
XS F23	13680	0.030	568.70	569.76	570.36	570.10	0.26
XS F22	13430	0.030	568.68	569.74	570.34	570.10	0.24
XS F21	13059	0.029	568.54	569.59	570.19	569.90	0.29
XS F21A	13004	0.029	568.50	569.53	570.13	569.86	0.27
XS F20	12639	0.028	568.21	569.19	569.79	569.60	0.19
XS F19	11701	0.028	567.91	568.90	569.50	569.30	0.20
XS F18	10786	0.028	567.37	568.32	568.92	568.70	0.22
XS F16	10176	0.028	567.10	568.05	568.65	568.40	0.25
XS F15	10156	0.028	567.10	568.04	568.64	568.40	0.24
XS F14	9680	0.028	566.90	567.84	568.44	568.10	0.34
XS F13	9093	0.028	566.68	567.63	568.23	567.90	0.33
XS F12	8686	0.028	566.64	567.62	568.22	567.90	0.32
XS F11	8417	0.030	566.50	567.51	568.11	567.70	0.41
XS F10	7716	0.030	566.31	567.31	567.91	567.50	0.41
XS F9	7010	0.030	565.97	566.93	567.53	567.20	0.33
XS F8	5804	0.030	565.31	566.23	566.83	566.50	0.33
XS F7	5004	0.030	564.90	565.81	566.41	566.10	0.31
XS F6	4144	0.030	564.34	565.27	565.87	565.60	0.27
XS F5	3317	0.030	563.89	564.85	565.45	565.10	0.35
XS F4	2203	0.029	563.36	564.35	564.95	564.60	0.35
XS F3	1422	0.029	562.73	563.62	564.22	563.90	0.32
XS F2	735	0.029	562.51	563.40	564.00	563.50	0.50
XS F1	0	0.029	562.25	563.15	563.75	563.30	0.45
Average	---	---	---	---	---	---	0.33

Notes: (1) Freshet levels are consistently higher than ice levels (FCL's include 0.6 m freeboard).
(2) All water levels and elevations are in metres (GSC).



Note: Flood Construction Level (FCL) = 200-yr ice-related or freshet design level, whichever is higher, plus a freeboard allowance of 0.6 m.

City of Prince George	nhc
Nechako River Open Water and Ice-Related Flood Profiles	
January 2009	Figure 5.1



0 250 500 1,000 1,500 2,000 Metres

Scale: 1:35,000

Legend - Year of Survey

- XS (1995 & 2008)
- XS (1979 & 2008)
- XS (2008)
- XS (1995)
- XS (1979)

Coord. System:	UTM Zone 10
Datum:	NAD 83
Units:	Metres
Notes:	Satellite image from Google Earth

City of Prince George nhc

Nechako River

Extent of Open Water and Ice-Related Flood Conditions

January 2009	Figure 5.2

6 FLOOD CONTROL OPTIONS

6.1 IDENTIFICATION OF FLOOD CONTROL OPTIONS

Using **Maps 4** to **6,** potential preliminary flood relief options were developed for each risk area as listed in Progress Report 1 (NHC et. al. 2008c) and in the summary table included in **Appendix F** of this report. The options encompass both structural and non-structural solutions and are grouped by Risk Area as discussed in Section 5 above. Nechako River flood control options with potential benefits to several areas are listed as a separate group. The options fall into the following broad categories:

- No permanent protection
- Land acquisition / land use change
- Internal drainage
- Individually raising / floodproofing of essential developments
- Re-activation / modification of natural secondary channels as flood relief channels
- Diking (including riverside, setback, and raised roads or platforms for temporary protection)
- In-channel sediment removal
- Upstream flow control

Ice jam prevention strategies are also included in **Appendix F**. The temporary works installed by the City and some property owners during the 2007-2008 ice jam were reviewed and their effectiveness briefly evaluated. Prior to the ice jam, design work was in progress to upgrade and raise River Road. This work, along with a report on Prince George diking options (Doughty-Davies and Morley 1974) was reviewed.

The initial flood control solutions were reviewed (as described in Progress Report 1) in terms of general hydraulic, infrastructure, environmental and geomorphic considerations. The options were initially assessed using a decision-matrix approach on the basis of this pre-feasibility screening. At the time, technical investigations had not been completed and none of the options were eliminated from further investigation. Each option was assessed for its suitability as a flood control solution by rating the following eight factors:

- Flood risk following implementation of the option
- Construction difficulty and long-term maintenance requirements
- Access problems during floods
- Internal drainage problems
- Environmental impacts
- Risk of causing river instabilities
- Direct costs
- Social costs (such as loss of productivity, inconvenience and disruption)

Each factor was rated on a scale from 1 (low) to 3 (high), based on the apparent relevance of that factor to the flood control solutions. Environmental impact ratings were based on the assumption that the amount of environmental permitting required for each control option is roughly correlated with the severity of environmental impact.

The individual factors are not all equally important for a particular flood control solution. To compensate, weights were assigned to the individual factors. The ‘risk after implementing’, ‘environmental impact’, ‘direct cost’ and ‘social cost’ factors were most heavily weighted at a value of 3. ‘Construction/maintenance’ and ‘river instability risk’ were weighted at 2. ‘Access problems’ and ‘drainage problems’ were weighted at 1.

After multiplying the relevance index by the weighting, the various options for a particular area were ranked according to the weighted ratings to provide a preliminary comparison of options. In general, set-back dikes and land use changes rank higher than river dikes. Ring dikes protecting only small compartments of the floodplain typically received a low ranking. Providing no permanent protection and relying only on emergency protection also ranked low. It was noted that options involving direct work in or beside the rivers would trigger federal and provincial reviews and likely result in requirements for environmental compensation.

6.2 HYDRAULIC EFFECTIVENESS OF FLOOD CONTROL OPTIONS

Following the risk analysis (Section 5), the identified flood control options were evaluated from a technical and hydraulic engineering perspective, as described below. This evaluation is based in part on HEC-RAS one-dimensional numerical modelling of channel hydraulics.

6.2.1 NO PERMANENT PROTECTION

The floodplain within City of Prince George is largely developed and some areas have experienced frequent flooding, every five to ten years. Flooding of low-lying areas is expected to continue. Whereas the ice-related flooding during the winter of 2007-08 had an approximate return period of about 90 years, severe freshet flooding has not been experienced since the flood of 1972, estimated to have a return period of just over 50 years (at Shelley).

Neither freshet nor ice-related flooding has a “flashy” behaviour. Normally some warning of flood risk is available. For freshet floods this takes the form of an exceptionally large spring snow-pack and high atmospheric temperature or heavy rainfall forecasts. For ice-related freeze-up flooding it takes the form of high fall to early winter flow releases at Skins Lake spillway (Kenney Dam), combined with heavy run-off from the unregulated portion of the basin plus a prolonged cold snap. Nevertheless, severe flooding generally entails some risk of loss of life and potential legal consequences for not providing protection to known risk areas.

With no permanent protection in place, the City is repeatedly on call to provide emergency response when needed. Besides, it is probably infeasible to provide temporary flood protection able to withstand a 200-year Fraser River freshet flood or ice-related Nechako River flood.

During high freshets, the HEC-RAS hydraulic model could be run in real-time forecasting mode using flows predicted by the MOE River Forecast Centre, to provide advance warning of anticipated flood levels at risk areas without protection. A similar ice-related flood forecast tool could be developed, taking into account Nechako Reservoir levels, Fraser and Nechako River flows and long-range weather forecasts.

6.2.2 LAND ACQUISITION / LAND USE CHANGE

Land use change provides permanent flood protection without a need for on-going maintenance. Land use change was introduced in the Island Cache area by Cottonwood Island following the flood of 1972, when low-cost housing prone to flooding was removed. From a hydraulic perspective, land use change provides more space for the river, increasing floodplain storage and potentially reducing requirements for bank protection.

6.2.3 INTERNAL DRAINAGE

Particularly in the confluence area, the soil is highly porous and seepage flows can cause localized flooding in low-lying areas away from the river, as shown on **Map 5**. Groundwater studies were conducted by GeoNorth (2006 and 2008) and a more detailed evaluation of drainage along River Road was conducted by Thurber Engineering (2008). Thurber's summary report is provided in **Appendix G**.

Infilled former back-channels identified in the air-photography review (Section 2.4.1) can provide seepage routes for groundwater. If diking is proposed as a flood control solution, seepage will need to be assessed and these channels may need to be blocked.

Wherever dikes are proposed, internal drainage will need to be included in the plan, incorporating flood-boxes, pump-stations or temporary pumping.

6.2.4 INDIVIDUALLY RAISE / FLOOD-PROOF ESSENTIAL DEVELOPMENTS

Individually raising or flood-proofing essential development has little impact on river hydraulics. Access issues may arise where roads leading to the flood-proofed development have not been raised above the FCL.

6.2.5 REACTIVATING / MODIFYING SIDE-CHANNELS FOR FLOOD RELIEF

As previously shown, Nechako River flood levels are determined either by backwater from Fraser River freshet flood levels or by local ice-related flooding. Flood relief side-channels, in the form of re-opened former secondary channels or newly excavated channels, would not help during the freshet backwater condition and would be beneficial only for the ice-related condition. During high open-water Nechako flows, with low Fraser levels and no backwater, flood relief channels would provide some additional capacity, but they would not affect the 200-year flood levels used to determine FCL's.

The increase in flow capacity of the Cottonwood side-channel that would result from gravel removal at its outlet was assessed using a local HEC-RAS model based on six surveyed cross-sections. On the basis of the bridge failures that occurred during the ice jam of 2007/2008, peak flows through the side-channel were estimated to be in the order of 60 m^3/s. Different gravel removal scenarios were evaluated. It appeared that by scalping the bar at the channel outlet to winter low-water level, and by widening the constricted bridge opening just upstream of the bar, the flow capacity of the side-channel could be increased by roughly 5 to 10%. Additional excavation in the channel could further increase its flow capacity.

During freeze-up, as long as the main channel remains ice-free at a side-channel entrance, flow can enter the side-channel, thereby tending to reduce flood levels in the main channel downstream of the entrance. **Figure 4.10** showed a simulated equilibrium ice-jam rating curve at Cameron Street Bridge. Assuming that one or more side-channels could carry a combined discharge of say 100 m^3/s, reducing the main channel discharge for example from 250 m^3/s to 150 m^3/s, the maximum theoretical water-level reduction would be about 0.7 m downstream of the side-channel entrances. Such a reduction could reduce the return period of the flood level from 200 to around 50 years, but have limited benefit upstream of the entrances. Since the Cottonwood side-channel entrance is within the Nechako River reach where Fraser River backwater determines design flood levels, increasing the capacity of the side-channel would not reduce the flood construction levels.

A side-channel reduces ice-related water levels only while the main channel at the side-channel entrance and the side-channel itself are ice free and affect mainly the river reach downstream of the entrance. To maximize their benefit, channel entrances should be located as far upstream as possible. An inlet control structure, blocking ice from entering the side-channel but allowing through-flow is required.

6.2.6 DIKING - SETBACK DIKING, RAISING EXISTING ROADS, RIVERBANK DIKING

The construction of dikes falls under the jurisdiction of MOE's Inspector of Dikes Office, and approval must be sought under the Dike Maintenance Act. In general, dikes must be constructed to at least the 200-year maximum daily flood level plus a freeboard allowance of 0.6 m, or the 200-year maximum instantaneous flood level plus a freeboard allowance of 0.3 m, whichever is higher. An Operation and Maintenance Manual must be developed and signed and adopted by the Local Dike Authority.

The sensitivity of the Nechako River open-water 200-year flood profile (upstream of backwater effects from the Fraser River) to different dike options along the river was evaluated in the HEC-RAS model. Water levels were found to be fairly insensitive to the degree of flow confinement by dikes on the floodplain as follows:

- Riverbank dikes on both the north and south banks below Cross-Section N11, as outlined in Section 6.4.1, would raise the open-water design profile by approximately 0.11 m.
- A north or south dike alone would raise water levels by 0.05 m.
- On the other hand, if both the River and Prince George Pulpmill roadways were completely removed, the existing profile would be lowered by up to 0.13 m.

It is more difficult to assess the impact of riverbank dikes on ice-related flood levels. Based on experience from other rivers, similar variations as for the open water conditions are expected.

For some areas, as described below in Sections 6.4.1 and 6.4.2, dikes with crest elevations below the MOE 200-year standard are suggested as an option. Such dikes would be unlikely to obtain approval under the Dike Maintenance Act. They should be viewed simply as platforms for constructing temporary emergency protection. The public would need to be informed about the purpose of these dikes, to avoid generating a false sense of security.

6.2.7 INSTREAM SEDIMENT REMOVAL

There is a public perception that large amounts of gravel have accumulated in the lower reaches of the Nechako River and at the confluence. This perception is supported to some extent by the review of historic air-photographs (see Section 2.4.1), but is not consistently confirmed by comparison of historical and recent cross-section surveys. The 2008 grid survey at the confluence will provide a basis for future comparison, if monitoring is undertaken as recommended.

To evaluate the effects of gravel removal in the main channels of the Nechako and Fraser Rivers under open water conditions, assumed dredging scenarios were introduced in the model for a range of flows. **Figure 6.1** shows simulated profiles for a 450,000 m^3 removal extending downstream from Cross-Sections N4 to N1 (1200 m x 80 m x 4.7 m average thickness). Since the 200-year and 20-year flood profiles are set by downstream Fraser River water levels, dredging produces essentially no change. However, under 2-year flood conditions with typical corresponding Fraser levels, there is a maximum drop of about 1 m at N4 tailing out to virtually zero at N1. For very low flows (say 50 m^3/s in the Nechako and 100 m^3/s in the Fraser) the water level drops as much as 1.8 m and 0.74 m at Cross-Sections N3 and N1, respectively. So that whereas dredging can lower water surface profiles for low and medium flows, there is apparently no benefit for the Nechako River 20-year and 200-year flood profiles.

The effects of a 70,000 m^3 deposition downstream of Cross-Section N6 were similarly assessed. Over a length of 2,000 m, a 45 m width of channel was infilled by up to 1 m as shown in **Figure 6.2**. Again, low and medium flow profiles were affected somewhat, but there was essentially no difference in the 20-year and 200-year profiles.

Comparison of surveyed cross-sections suggested that material has built up at the CNR Bridge on the Fraser River. The impact of removing 180,000 m^3 of this material was investigated in the model and was found to lower the 200-year flood profile by less than a few centimetres. From the air-photography review, the CNR Bridge appeared to act as somewhat of a constriction. However, the channel in this location is quite wide and complete removal of the bridge in the model only marginally lowered the 200-year flood profile.

A significantly larger gravel extraction was also modelled, simulating a 5-year removal program of 400,000 m^3/year from the confluence area between Nechako Cross-Section N4 and Fraser Cross-Section F25. The main channel depth was increased by 5 m over a width of 250 m and length of 2,100 m. The result was that the Nechako 200-year flood profile was locally lowered by a small amount at Cross-Sections N6 and N7, but was otherwise unchanged. Where water levels are backwater controlled, dredging clearly does not help. Downstream of the confluence, the Fraser River flows in a steep, confined channel; and reducing water levels in this reach, which sets water levels at the confluence, is not practical.

Scalping of material from bars is generally less effective in lowering water levels than channel dredging and was not separately modelled.

Gravel deposits in the Fraser River are not believed to aggravate ice-related flood levels in the Nechako or Fraser Rivers. Removing gravel in the Nechako would not reduce ice-related flood levels as discussed in Section 4.5. Removals of any configuration would increase the flow area, reduce velocities and encourage ice-cover formation. A summary discussion of gravel removals is provided in Appendix H.

In general, flow regulation by a reservoir reduces flood peaks and the sediment transport capacity of a river. The morphologic effects of Kenney Dam flow regulation on the Nechako River are most apparent near the reservoir and reduce downstream as more unregulated flows enter the river. Over time, regulated systems find a new equilibrium in response to an altered flow regime. It is not clear to what extent the reservoir has attributed to the material depositions implied by the air-photo analysis. However, they appear not to have exacerbated the 20 or 200-year ice-related or freshet flooding, although profiles corresponding to relatively low open water flows may have changed.

6.2.8 UPSTREAM FLOW CONTROL

The regulation effect of Nechako reservoir on downstream flood flows diminishes with increasing flood magnitude, and its effect on a 200-year flood is not clearly known. However, since ice-related flooding is the governing flood condition on the Nechako at Prince George, the reservoir's ability to reduce freeze-up flows is more critical. During November and December, the flow originating from upstream of Kenney Dam is proportionally smaller than from below the dam, because the upper watershed is at higher elevations and precipitation is more often snow than rain. Consequently, in the freeze-up period a larger percentage of the Prince George flow originates from the unregulated basin below the dam.

The present operating regime is designed to reduce flows during the freeze-up, and a further reduction would likely be possible only if more flow were diverted to Kemano through an expansion of the generating facility. The City cannot pursue this option on its own. Increased diversions, if physically possible, could have significant environmental impacts and would probably trigger complex provincial and federal reviews requiring multi-year studies and extensive negotiations and agreements. For these reasons, upstream flow control has not been included as a short-term flood control option. However, it is recommended that MOE in cooperation with Rio Tinto Alcan explore the extent to which flow releases can be reduced during freeze-up.

6.3 Environmental Considerations

Potential environmental impacts associated with the flood control options listed in **Table 6.1** are reviewed and summarized below. The discussion is general, and the extent to which various environmental effects apply will depend on specific designs and construction scenarios. Permitting required for each control option is based on the assumption that the degree of permitting is roughly correlated with the degree of impact. Potential effects of construction were not evaluated as they are highly dependent on construction methodology and generally can be mitigated.

6.3.1 No Permanent Protection

No environmental regulatory approvals are required, since existing floodplain and habitat diversity is maintained. Consequently, this option was assigned a coarse-filtering result of “Low environmental impact”. However, it is likely to imply temporary or emergency flood control works when flooding occurs, which may bring up a range of environmental considerations specific to the particular response.

6.3.2 Land Acquisition / Land Use Change

Acquisition of land at risk of flooding and its conversion to less susceptible uses (e.g. park, green-space or other land use that excludes residential or commercial development) is the most preferred option from an environmental perspective. Flooding would be allowed to occur freely in these areas, thereby restoring as much functional floodplain as possible. No regulatory approvals are known to be required for this option, therefore, the coarse-filtering result for this option was ranked as “Low environmental impact”. However, extensive clean-up in terms of demolishing and removing structures, oil tanks and other potential environmental hazards could be required.

Benefits from implementing the land use change option in some areas might be used to offset unavoidable habitat damage from less environmentally friendly options in other areas. It should be a component of any long-term flood control strategy for the City.

6.3.3 INTERNAL DRAINAGE

Potential environmental effects of drainage projects are difficult to predict without specific designs, but new or upgraded stormwater outfalls may result in minor habitat alterations. Consequently, a coarse-filtering result of "Low environmental impact" was assigned. Some inter-action with regulatory agencies would be required after design parameters are developed, and a *Water Act* notification would be required. Consultation with Fisheries and Oceans Canada (DFO) would be advisable to determine if the design may constitute a HADD, although this result seems unlikely.

6.3.4 INDIVIDUALLY RAISE / FLOODPROOF ESSENTIAL DEVELOPMENT

If individually raising/floodproofing existing essential development involves no increase in development footprint into the riparian area, it is not expected to present more detrimental effects than the current state. A "Low environmental impact" ranking was assigned to this option.

6.3.5 REACTIVATING / MODIFYING CHANNELS FOR FLOOD RELIEF

Modifying existing secondary channels such as the Cottonwood Island side-channel, and reactivating historical back channels within areas A_N and C_N, has been proposed in order to increase flood relief capacity during ice-jam events. This could cause significant environmental disturbance and would likely require substantial provincial and/or federal regulatory reviews, resulting in a "High environmental impact" rating. Potential effects could include damage to fish habitat, or increased erosion and scour.

Some adverse effects could probably be offset by incorporating habitat enhancement features into the designs. For example, summer dissolved oxygen levels in the Cottonwood Island side-channel are currently below minimum thresholds for the maintenance of salmonid life stages, due to lack of surface water inflow in low water periods. Developing the side-channel for flood relief could allow the introduction of small, highly oxygenated Nechako River flows through the summer.

Stream diversion projects are subject to *Water Act* approval, and may also trigger requirement for approvals under the BC *Environmental Assessment Act* (BCEAA), the *Fisheries Act* or the *Canadian Environmental Assessment Act* (CEAA).

6.3.6 DIKING - SETBACK DIKING, RAISING EXISTING ROADS, RIVERBANK DIKING

Riverbank dikes isolate the floodplain from the active channel and can cause a number of biophysical effects. For example, Kukulka and Jay (2003) estimated that diking had reduced important shallow-water salmonid habitat in the lower Columbia River by 52%. Riverbank dikes also result in losses of riparian vegetation, which is often important for controlling erosion, conserving soil and maintaining habitat complexity. While some of these effects can be mitigated by following best practices for vegetation management (BC MELP and DFO 1999), permanent alterations to shoreline habitats are likely unavoidable.

Provincial and federal environmental regulatory approvals would be required, resulting in a "High environmental impact" rating. The extensive shoreline modification for a riverbank dike would almost certainly cause a HADD (Harmful Alteration, Disruption or Destruction) under the federal *Fisheries Act.* Issuance of a Section 35 Authorization for the HADD would trigger federal review under CEAA. Under Part 5 of the *Reviewable Projects Regulation*, dikes to protect an area of 10 sq.km or more are also reviewable under the BCEAA. Potential effects on wildlife and migratory bird habitats would likely necessitate more comprehensive habitat assessments under *Species at Risk Act* (SARA), *Migratory Birds Convention Act* and the *Wildlife Act*.

Lower dikes that provide less than 200-year protection may have smaller footprints, but they offer little environmental benefit over full-height designs since the same types of habitat impact would still occur. Therefore this type of dike requires similar regulatory approvals and has been given a "High environmental impact" rating.

There is an advantage to raising existing roads or building dikes along roads since the construction can take place within an existing right-of-way. In most cases setback dikes are preferable to riverbank dikes because some functional floodplain area is retained adjacent to the channel. If standard riparian setback allowances specified by MOE are observed, setback dikes should comply with most environmental legislation. They have been given a "Medium environmental impact" rating.

6.3.7 INSTREAM SEDIMENT REMOVAL

Instream sediment removal may be accomplished by bar scalping or dredging. The following discussion pertains to the Nechako/Fraser confluence area. Although bar scalping is usually done in the dry, it may still have an impact on aquatic habitat (Packer et al. 2005), for example by creating wider cross-sections with less sediment transport capacity. Scalping can also reduce rearing habitat for juvenile salmonids (Wiegand 1991 in Brown et al. 1998).

Dredging differs from bar scalping in that it is done within the wetted cross-section. Environmental effects are similar to those described for scalping, but with the added risk of immediate impacts on water quality and fish habitat. These may be mitigated by temporary isolation during construction, but are unlikely to be fully avoidable.

Both scalping and dredging would probably require *Fisheries Act* authorizations and a CEAA screening review. BCEAA review would also be triggered if two or more hectares of foreshore or submerged land are to be dredged. Comprehensive studies would be required to ensure that dredging would have no impact on SARA-listed white sturgeon and their habitat. A rating of "High environmental impact" has been assigned.

6.4 INITIAL REVIEW OF FLOOD CONTROL OPTIONS

In the light of the technical and initial environmental assessments described in Sections 6.2 and 6.3, the initially selected flood control options were reviewed. Options considered unlikely to perform satisfactorily, unjustifiably expensive or environmentally unacceptable were eliminated as indicated in **Tables 6.2** and **6.3** under the heading "Comments for Phase 1 Costing and Medium Filtering".

Maintaining the status quo by providing no permanent protection is not necessarily a practical option. Costs were developed for this option, however, to provide a baseline for comparison with other options. Drainage improvements are not an option in themselves but must be included with most of the diking options. In general, ring-diking or dikes that protect small localized areas, is not practical from an available space and local drainage perspective; local flood-proofing by raising buildings is preferable. Low dikes provide a temporary platform for emergency works but do not protect against the design flood. Practicable options for each area are considered to be as follows:

Nechako River

- Area A_N – South Bank of Nechako River at Confluence
  - River dike
  - Dike on river side of River Road
  - Build set-back dike along railway
  - Land use change

- Area B_N – North Bank of Nechako River east of John Hart Bridge
  - Dike next to river (full height)
  - Platform for temporary protection along river
  - Raise McAloney and Ongman Roads
  - Land use change

- Area C_N – North Bank of Nechako River near Confluence
  - River dike
  - Ring dike at development
  - Land use change/flood-proofing

- Area D_N – North Bank of Nechako River west of John Hart Bridge
  - Dike next to river (full height)
  - Platform for temporary protection along river
  - Raise Preston Road
  - Land use change

- Area E_N – North Bank of Nechako River at Morning Place
  - Dike next to river (full height)
  - Platform for temporary protection along river
  - Individual flood-proofing
  - Land use change

- General
  - Enlarge Cottonwood Island side-channel
  - Excavate and straighten historic back-channel (South of river)
  - Channel through Area C_N

Fraser River

- Area A_F – West bank of Fraser River at Yellowhead Highway
  - Dike next to river (full height)
  - Platform for temporary protection along river
  - Individual flood-proofing
  - Land use change

- Area B_F – Fraser River at South Fort George
  - Dike next to river (full height)
  - Platform for temporary protection along river
  - Land use change

- Area D_F – Fraser River at Lansdowne south end
  - Dike next to river (full height)
  - Platform for temporary protection along river
  - Individual flood-proofing
  - Land use change

- Area F_F – Fraser River at Northwood Pulpmill Road
  - Raise Landooz Road for access

6.5 DESCRIPTION OF SELECTED FLOOD CONTROL OPTIONS

The possible options identified in Section 6.4 are further described below. Approximate costs are summarized in **Table 6.4**.

6.5.1 NECHAKO RIVER

Area A_N (South Bank of Nechako River at Confluence)

Mitigation options (**Figure 6.3)** include three permanent dike arrangements. In all three cases groundwater issues also need to be addressed.

The first arrangement involves a **dike adjacent to the Nechako River** and along a back channel at Cottonwood Island. This option is similar to the Heritage Trail Dike concept developed by Associated Engineering in their August 2007 report titled "*East of Queensway and River Road Floodproofing Concept Study*". This report proposed the use of imported fill to construct a dike 4 m wide on top with 3:1 side slopes where site conditions permitted.

A significant departure from the Associated Engineering concept is the assumption that the City will acquire properties between River Road and the Nechako River and remove structures that conflict with the dike location, thereby eliminating the previous need for retaining walls to reduce the dike footprint. The dike encroaches onto the river bank, which will need riprap slope protection and environmental mitigation and compensation. As the dike will impede surface drainage, flood boxes and pumping stations will be needed. Associated Engineering's cost estimate has been revised to include pump stations and an allowance for seepage cut-off, yielding an estimated cost of $17.0 M.

The second option involves a **dike adjacent to River Road**, between the road and the riverbank. River Road was raised during the 2007-08 ice-related flooding and widened afterwards. The as-yet unpaved road is not as high as the revised 200-year ice-related profile plus freeboard, so that further raising could be considered. However, access issues may arise. A design for a 2 m deep sub-drain along the road, including pumping, has been developed (**Appendix G**).

It is assumed that the City will acquire the properties between River Road and the Nechako River and remove any structures that conflict with the dike location. The dike will be set back from the river but could still have some impact on the riverbank. Riprap slope protection, and environmental permitting, mitigation and compensation will be necessary.

At the Railway Museum the dike will deflect around the Cottonwood Island parking lot and museum site, to accommodate the existing railway spur that crosses River Road to access the museum. The cost estimate assumes that the dike top will be grassed and not paved, and does not include trail construction or improvements to River Road. As with Dike Option 1, floodboxes and pump stations will be needed to deal with surface drainage south of River Road. The estimated cost for the dike is $15.5 M.

The third option involves a **setback dike located alongside the CN Rail tracks**. For the cost estimate, it is assumed that the dike crosses River Road by the Railway Museum and for the eastern portion of River Road, runs parallel to the road. The dike will need to be constructed with breaches for existing railway spur lines to the Railway Museum and a log storage yard. Realigning the dike to go around the spur lines does not appear to be feasible because it would interfere with the operation of the log storage yard and a breach would still be present where the spur line crosses River Road.

The estimated cost of this setback dike is $8.5 M. This dike offers no protection to properties located between the river and the dike. Individual ring dikes are possible to provide additional flood protection but the aggregate costs of these individual dikes are likely to raise the overall cost such that they are comparable to those of constructing a riverbank dike or a dike along River Road.

Alternatively, the capital cost of **land use change** over the entire area was estimated at $23.2 M.

Area B_N (North Bank of Nechako River East of John Hart Bridge)

The primary dike mitigation options for this area are a dike constructed along the riverbank and the raising of existing road beds to act as a dike as shown on **Figure 6.4**.

The **riverbank dike** concept is similar to that proposed for the Heritage Trail Dike and will include lock block retaining walls where existing structures limit the available area along the riverbank. Riprap rock protection would be installed as required. The western portion of the dike ties into the embankment for the John Hart Bridge and passes through undeveloped industrial land. This portion of the dike can likely be set back from the bank to avoid undesirable environmental impacts.

The remainder of the dike lies in constricted areas and lock block retaining walls are necessary to reduce the dike footprint. Riprap rock protection and environmental permitting, mitigation and compensation are likely required. Flood boxes and a pumping station will be needed because the dike will block surface drainage. The order of magnitude cost estimate for the riverbank dike is $3.5 M.

A variant of the riverbank dike concept is a **low profile dike** following the same alignment. This platform for temporary protection will have a top surface below the 200-year flood level and act as a base for gabions or other temporary flood protection works when needed. There are potential savings in construction cost through the reduction of imported fill material and the shorter height of retaining walls but there is unlikely to be any significant reduction in riverbank protection or environmental mitigation requirements. The estimated cost for the low profile riverbank dike is $2.7 M.

The third dike concept for Area B_N is the **raising of McAloney Road and Ongman Road** to act as a dike. An earth dike will connect to the raised portion of McAloney Road and extend to the embankment for Highway 97 to the west. This alternative avoids many of the environmental and riverbank protection issues associated with the riverbank dike but will be disruptive to businesses along McAloney and Ongman Roads and will offer no flood protection to those properties on the south side of the roadway.

Elevating the roadway will require adjusting grades along Richard Road, Tomlin Road and the north leg of Ongman Road to match the higher road elevation. Affected portions of these existing roads could extend 100 m or more from the intersections. Driveways and accesses to existing businesses would be similarly affected and some existing parking lots and truck loading bays fronting onto McAloney and Ongman Roads would be rendered unusable. The roadways also have existing water and sewer mains, hydro poles and gas lines. The cost estimate includes an allowance for adjustments to existing surface appurtenances but does not account for any major upgrading work that may be desirable before the road is raised.

The estimated cost for locating diking along the existing roads is $3.9 M.

Alternatively, the capital cost of **land use change** over the entire area was estimated at $8.8 M.

Area C_N (North Bank of Nechako River near Confluence)

Area C_N contains broadly spaced residential development as well as Canfor's water intake and well facility. Much of the residential development is clustered in the western portion of the area around Wolczuk Road and Cutbank Road. The Prince George Pulpmill Road already meets dike height requirements and is assumed to be geotechnically sound but groundwater intrusion resulted in flooding on the north side of the road during the 2007/2008 ice jam event. Properties on the south side of the road were affected directly by the ice jam flooding.

Figure 6.5 shows a **dike along the riverbank** as a possible mitigation option for this area at an estimated cost of $10.1 M. This dike is costly, triggers concerns about environmental and flood conveyance impacts and benefits a relatively small number of existing residences. The Canfor facility is located at the waterline of the Nechako River and thus the dike would have to bypass the buildings.

An alternative concept is to construct a **local ring dike** around a cluster of existing residences on the south side of PG Pulpmill Road. The proposed ring dike would begin approximately 0.3 km west of Cutbank Road, run east along the riverbank and tie back to PG Pulpmill Road approximately 0.1 km east of Wolczuk Road. Lock block retaining walls and riprap slope protection would be necessary. Bank erosion along the north bank is becoming more of a problem and maintaining the dike would be expensive, significantly exceeding the initially estimated cost of $3.4 M. Land use changes are preferable and the ring dike option was not explored further. (Reference to aerial photos on the City's website indicates that there are three properties on the south side of PG Pulpmill Road that would have buildings that would lie outside of the area protected by this dike configuration.)

Alternatively, the capital cost of **land use change** over the entire area was estimated at $9.3 M.

Area D_N (North Bank of Nechako River West of John Hart Bridge)

Figure 6.4 shows two primary mitigation options for this area.

One option is a **dike constructed along the riverbank** and tying into the embankment for the John Hart Bridge. The riverbank dike encroaches onto the river bank and riprap rock protection as well as environmental mitigation and compensation will be necessary. The dike also passes through constricted areas by the Del Haven multifamily development, Howie's Marine and the Pacific Western Brewery. Lock block retaining walls will be necessary to reduce the dike footprint. Some portions of the dike pass through undeveloped land and it might be possible to set back part of the dike to reduce impact on the riverbank. The dike would block river views and probably be unsightly and undesirable to some residents.

The riverbank dike provides protection to virtually all of Area D_N including a portion of North Nechako Road and ramps connecting to Highway 97. The dike will be a barrier to surface drainage and flood boxes and a pumping station will be needed. The dike will also affect an existing dock area serving Howie's Marine and a new dock and access will likely be needed. The order of magnitude cost estimate for the riverbank dike is $3.3 M.

Alternatively, the riverbank dike could be a **low profile dike**, or platform for emergency works, following the same alignment but having a top surface below the 200-year flood level. In the event of a major flood, the dike would act as a base for temporary flood protection works such as gabions. There are potential savings in construction cost through the reduction in retaining wall height and the amount of imported fill material but there will be little or no change in riverbank protection or environmental permitting and mitigation requirements. The estimated cost for the low profile riverbank dike is $2.6 M. The dike in itself would not provide adequate protection or meet MOE standards.

Another dike concept for Area D_N is the **raising of Preston Road** to act as a dike along with a section of earth dike set back from the river. The earth dike could continue from the end of Preston Road east to the embankment for Highway 97 or deflect north to tie to North Nechako Road. Tying the dike into the highway embankment has the advantage of providing flood protection to North Nechako Road. This alternative has little or no impact on the existing riverbank but the higher roadway will make access to adjoining residences and parking areas less convenient. This alternative offers no flood protection to those properties, such as Del Haven, located on the south side of Preston Road. The estimated cost for raising Preston Road and extending a dike to the highway embankment is $1.2 M.

Alternatively, the capital cost of **land use change** over the entire area was estimated at $6.7 M.

Area E_N (North Bank of Nechako River at Morning Place)

This area is residential property predominantly along the road Morning Place.

Diking options appear to be limited to a **dike constructed along the riverbank** as shown on **Figure 6.6**. There is little opportunity for setting back the dike and riprap rock protection will be necessary for the full length. The dike covers a relatively small area and though flood boxes will likely be necessary, pump stations might not be required. The estimated cost of the riverbank dike is $2.1 M.

To reduce costs, a **low profile dike** could be constructed following the same alignment but having a top surface below the 200-year flood level. In the event of a major flood, the dike would act as a base for temporary flood protection works such as gabions. The estimated cost for the low profile riverbank dike is $1.6 M. Some properties have existing accesses to the river for boat launches that might be more feasible to accommodate with a low profile dike.

Approximately eight residential lots lie in Area E_N and **individual flood proofing** for existing structures is a possible alternative. For comparison, flood proofing would need to incur costs in the order of $200,000 for each lot to yield an overall cost similar to that of the low profile dike.

Alternatively, the capital cost of **land use change** over the entire area was estimated at $1.4 M.

Area F_N (South Bank of Nechako River at Foothills Bridge)

The impact of the raised FCL's on the pumping station and a well in the area needs to be assessed and further development restricted through zoning.

Area G_N (South Bank of Nechako River between John Hart and Foothills Bridges)

The impact of the raised FCL's on the pumping station and a well in the area needs to be assessed and further development restricted through zoning.

General Lower Nechako River Area

General flood mitigation options for the Nechako River near the confluence with the Fraser River are described in **Table 6.2** and **Figure 6.3** and involve reactivating or improving former side-channels along the river.

On the south side of the river, flood relief options include enlarging an existing back channel in Cottonwood Island Park and opening up a historic back channel through existing industrial development.

The **Cottonwood Island channel** experienced high flows during the 2007/2008 ice jam event that resulted in the destruction of several pedestrian bridges and causeways that had been part of a trail system in the park. Reinstating these crossings will form part of the works for enlarging the channel. For the purpose of the cost estimate, it is assumed that the channel will be deepened by approximately 2 m and that it will follow its existing alignment. The cost estimate includes allowances for a control structure and environmental mitigation and compensation. The estimated cost for enlarging the Cottonwood Island Channel is $3.0 M.

A **historic back channel** meanders through Area A_N that has been filled and developed as industrial land, the CN Rail yard and log storage yards. As shown on **Figure 6.1**, the channel's historic location crosses River Road at four locations. The cost estimate assumes that portions of the channel are realigned to eliminate two of the River Road crossings and reduce impacts on the existing industrial development. One portion will be realigned to follow a direct route from the area of Foley Crescent east to where the channel crosses River Road by the Railway Museum. The realigned channel passes through areas now used for log storage and eliminates a meander that otherwise would have affected several building structures. Excavation of the channel could also uncover significant environmental hazards such as deleterious material that was used as fuel.

On the east side of River Road the channel is realigned to go around the Railway Museum grounds and run parallel to River Road until it intercepts its historical location approximately 200 m from the confluence with the Fraser River. The channel traverses private property, making property acquisition necessary and some environmental mitigation may be necessary where the channel joins the Fraser River. The estimated cost of opening up the historic back channel is $9.0 M and does not include any clean up cost for deleterious material.

A **historic channel** is also present on the north side of the Nechako River in **Area C_N**. The channel passes through several residential properties with crossings at Cutbank Road and Wolczuk Road. Upgrading this channel will require land use change in the affected locations. The estimated cost of upgrading the north shore flood relief channel is $7.6 M.

6.5.2 FRASER RIVER

Area A_F (West Bank at Yellowhead Bridge)

This area is predominantly lawn area with a recreation trail beside the abutment of the Yellowhead Bridge but also takes in portions of several residential properties along the riverbank.

Diking options appear to be limited to a **dike constructed along the riverbank**. There is little opportunity for setting back the dike and riprap slope protection will be necessary for the full length. Lock block retaining walls can be used to minimize encroachment onto private property. The dike covers a relatively small area and though flood boxes will likely be necessary, pump stations might not be required. The estimated cost of the riverbank dike is $1.5 M.

Alternatively, a **low profile dike** could be constructed following the same alignment but having a top surface below the 200-year flood level. In the event of a major flood, the dike would act as a base for temporary flood protection works such as gabions. The estimated cost for the low profile riverbank dike is $0.8 M. Limitations of this type of diking was discussed in Section 6.2.6.

Though several residential lots impinge on Area A_F, only three structures appear to be at risk during flood events. **Individual flood proofing** for these existing structures and some sanitary sewer manholes is a possible alternative. For comparison, flood proofing would need to incur costs in the order of $200,000 for each building to yield an overall cost similar to that of the low profile dike.

Alternatively, the capital cost of **land use change** over the entire area was estimated at $2.5 M.

Area B_F (South Fort George)

This area is a portion of South Fort George straddling the Hudson's Bay Slough east of Queensway (**Figure 6.7**). It is low-lying and partly flooded quite frequently.

A possible mitigation option is to **construct a dike** to protect existing residences on Farrell Street and Regents Crescent. The dike would follow the riverbank for most of its length and then deflect west to tie into Regents Crescent. The area between Farrell Street and the riverbank is constricted by existing residences and out-buildings and lock block walls will be necessary to minimize the dike footprint. Even with the retaining wall, there will be conflicts with structures and it will likely be necessary to remove three existing buildings to accommodate the dike.

The limited area available will not allow the dike to be set back and riprap slope protection will be necessary along the riverbank. A flood box and pump station will likely be necessary to deal with drainage behind the dike. The estimated cost of the dike around Farrell Street is $2.9 M.

To reduce costs, the dike could be constructed with a **lower top elevation** but following the same alignment. In the event of a major flood, the dike would act as a base for temporary flood protection works such as gabions. The estimated cost for a low profile dike is $1.5 M. Considering how frequently this area gets flooded, this may not be a good option and land use change or individual floodproofing could be preferable.

Alternatively, the capital cost of **land use change** over the entire area was estimated at $1.4 M.

Area C_F (Hudson's Bay Slough West of Queensway)

Queensway acts as a dike, protecting this area, and a pump-station accommodates internal drainage flows. The top-of-road elevation should be compared to the revised FCL's and the pumping capacity verified.

Area D_F (Lansdowne South End)

Area D_F is predominantly undeveloped but does have several residential properties at the ends of Lansdowne Road and Wiens Road as shown in **Figure 6.8**.

An earth **dike** could be extended to protect these residences. The dike would follow the riverbank and, with the exception of one lot at the end of Wiens Road, would fall outside of the property limits. The dike would be a barrier to future extension of Lansdowne Road and further development should be prevented through zoning. The estimated cost of the dike is $1.6 M.

Alternatively, the dike could be constructed with a **lower top elevation** and would act as a base for temporary flood protection works in the event of an emergency. The estimated cost for a low profile dike is $0.7 M. There appear to be four residences that would be at risk in the event of a flood. Individual flood proofing would need to incur costs of approximately $150,000 per structure to yield an overall cost comparable to that of the low profile dike.

Alternatively, the capital cost of **land use change** over the entire area was estimated at $0.8 M.

Area E_F (West Bank at Island)

Development should be restricted through zoning.

Area F_F (Northwood Pulp Road)

Area F_F has a mixture of undeveloped land, agricultural areas, log storage and isolated buildings. Northwood Bridge crosses the Fraser in this area. The Canfor pulp mill complex is surrounded by Area F_F but appears to mainly be on high ground not within the 1997 floodplain limit. The Northwood Pulp Road and the CN rail tracks accessing the pulp mill traverse Area F_F but appear to be largely constructed above potential flood levels.

Landooz Road traverses the length of Area F_F and is the sole road access for a residential area at the northeast City Limit. Landooz Road is vulnerable to inundation in the event of a flood and vehicle access to the areas noted could be blocked. Landooz Road could be raised for access purposes at an estimated cost of $5.8M.

Area G_F (Across River from Shelley)

Further development should be restricted through zoning.

6.6 ASSESSMENT OF FLOOD CONTROL OPTIONS (MEDIUM FILTERING)

The purpose of the medium filtering process was to eliminate flood relief options not deemed practical following the feasibility assessment and recommend options for further evaluation in Phase 2 of the project.

6.6.1 FINANCIAL COSTS

The costs developed for the potential options are summarized in **Table 6.4** along with asset values of the development within each risk area.

Life cycle costs are included in the table and were evaluated over a 50-year period based on:

- Assessed property values;
- Capital, operation and maintenance costs of the flood control works; and,
- Predicted flood damage costs such as municipal infrastructure damage, utility infrastructure damage, lost wages, business cost, emergency response cost, residential property damage and flood recovery costs.

Computed cost comparison ratios are shown in **Table 6.4.** For a given risk area and flood control option, this is the ratio between the cost of a "No Protection" alternative and the cost of the option. Ratios greater than 1.00 means that there is a benefit to adopting the given flood control option – the greater the ratio the greater the benefit.

6.6.2 ENVIRONMENTAL IMPACTS

It is difficult to make quantitative estimates of environmental costs until actual designs are developed and alternative construction techniques are explored. Rather, environmental costs are qualified in **Table 6.4** as low (L), medium (M) or high (H). A low rating means that there is no applicable legislation associated with the option. A medium rating means that the option would generally involve consultation with DFO and potential review under the BC Environmental Assessment Act. A high rating means that the option will require authorization under the federal Fisheries Act, the Canadian Environmental Assessment Act, the BC Environmental Assessment Act and the BC Water Act. Other considerations that affect the overall ranking are also included in **Table 6.4**. General environmental considerations and anticipated legislation by flood control option were summarized in **Table 6.1.**

Applicable federal and provincial legislation is described in more detail in **Appendix C**.

6.7 Ranking of Flood Control Options

Cost comparison ratios as referred to in Section 6.6.1 are used as the primary factor for ranking the flood control options for each risk area, as shown in **Table 6.4**. Options ranked "n/a" indicate that the option is not recommended, although cost comparison ratios are shown for those cases.

Section 5.4 provided a tentative indication of where flood threats are most severe and asset values high. Using this information, the following options appear most attractive for the risk areas ranked in descending order of priority. (The list may be modified in Phase 2 after discussions with the City of Prince George, government agencies and other stakeholders.)

1. Area A_N - South Bank of Nechako River at Confluence - Build dike on river side of River Road, providing internal drainage and reducing groundwater seepage.
2. Area C_N - North Bank of Nechako River near Confluence - Introduce land use change south of PG Pulpmill Road. On north side of road land use change or local flood-proofing can be considered.
3. Area D_N - North Bank of Nechako River West of John Hart Bridge - Raise Preston Road. Consider land use change or local flood-proofing on river side of road.
4. Area B_N - North Bank of Nechako River East of John Hart Bridge - No permanent protection. Provide temporary protection as needed.
5. Area B_F – South Fort George - Introduce land use change as necessary. Optionally local flood-proofing can be considered in some locations.
6. Area E_N – Morning Place - Introduce land use change as necessary. Optionally local flood-proofing can be considered in some locations.
7. Area D_F – Lansdowne South End - Introduce land use change as necessary. Optionally local flood-proofing can be considered in some locations.

Improvements to the Cottonwood Island side-channel are recommended, and the feasibility of a north side-channel should be investigated in more detail.

The following areas do not urgently require flood control solutions, but should be appropriately zoned to prevent or discourage further development:

- Area F_N – South Bank at Foothills Bridge.
- Area G_N – South Bank between John Hart and Foothills Bridges.
- Area A_F – West bank at Yellowhead Highway
- Area E_F – West Bank at Island
- Area F_F – Northwood Pulpmill Road
- Area G_F – Across River from Shelley

Area C_F – Hudson's Bay Slough west of Queensway has flood protection in place.

Cost ratios, capital costs and environmental impact ratings (Low, Medium and High) for all options are summarized on the next two pages.

Nechako River – Summary of Options

Risk Area/Option	Priority	Cost Ratio	Capital Cost $M	Env. Cost	Ranking
Area A_N – South Bank of Nechako River at Confluence	1				
No protection		1.00		L	5
River dike		1.54	17.0	H	4
Dike on river side of River Road		1.64	15.5	M	1
Build set-back dike along railway		1.58	8.5	L	3
Land use change		1.60	23.2	L	2
Area B_N – North Bank of Nechako River east of John Hart Bridge	4				
No protection		1.00		L	1
Dike next to river (full height)		0.98	3.5	H	n/a
Platform for temp protection		0.88	2.7	H	2
Raise McAlonEy and Ongman Roads		0.77	3.9	M	3
Land use change		0.52	8.8	L	4
Area C_N – North Bank of Nechako River near Confluence	2				
No protection		1.00		L	2
River dike		0.73	10.1	H	n/a
Ring dike		-	3.4	H	n/a
Land use change		0.88	9.3	L	1
Area D_N – North Bank of Nechako River west of John Hart Bridge	3				
No protection		1.00		L	2
Dike next to river (full height)		1.12	3.3	H	n/a
Platform for temporary protection		0.95	2.6	H	3
Raise Preston Road		1.13	1.2	M	1
Land use change		0.76	6.7	L	4
Area E_N – North Bank of Nechako River at Morning Place	6				
No protection		1.00		L	2
Dike next to river (full height)		1.06	2.1	H	n/a
Platform for temporary protection		0.93	1.6	H	3
Land use change		2.05	1.4	L	1
General					
Enlarge Cottonwood Isl. sidechanel			3.0	H	1
Excavate historic back-channel			9.0	H	3
Channel through Area C_N			7.6	H	2

Fraser River – Summary of Options

Risk Area/Option	Priority	Cost Ratio	Capital Cost $M	Env. Cost	Ranking
Area A_F – West bank at Yellowhead Highway					
No protection		1.00		L	1
Dike next to river (full height)		0.79	1.5	H	3
Platform for temporary protection		0.96	0.8	H	2
Land use change		0.58	2.5	L	4
Area B_F – South Fort George	5				
No protection		1.00		L	2
Dike next to river (full height)		1.03	2.9	H	4
Platform for temporary protection		1.07	1.5	H	3
Land use change		2.46	1.4	L	1
Area D_F – Lansdowne south end	7				
No protection		1.00		L	2
Dike next to river (full height)		0.76	1.6	H	4
Platform for temporary protection		1.03	0.7	H	3
Land use change		1.68	0.8	L	1
Area F_F – Northwood Pulpmill Road					
No protection		-		L	-
Raise Landooz Road for access		-	5.8	M	-

Table 6.1 - Environmental considerations and anticipated applicable legislation, by flood control option.

Option	Coarse-Filtering Result*	Brief Environmental Considerations	Anticipated Applicable Legislation	Additional Comments
Land acquisition/Land use change	1	Restores functional floodplain areas	None	Acquired lands could be reclaimed to increase natural riparian areas (which would have numerous benefits). May be considered as compensation for HADD of another control option.
No permanent protection, provide temporary works as required	1	No new environmental impacts expected in absence of permanent protection. The functionality of the floodplain area for the river system is also maintained in the absence of dikes which constrict floodwaters. Potential environmental considerations associated with temporary works depends on design of those works.	None	Negative environmental effects may also be realized in the haste of installing temporary flood control works.
Modify 1st Avenue storm drains	1	Not expected to present significantly different negative environmental effects than the current state.	*Water Act* notification, consultation with DFO	Not likely to be used as a flood control option on its own.
Individually raise/floodproof essential development	1 [1]	Not expected to present significantly different negative environmental effects than the current state.	None	Potential small interference with natural floodplain processes. Negative environmental effects may also be realized in the haste of installing temporary flood control works.
Raising existing roads	2	Potential for minor riparian area encroachment.	consultation with DFO, potential for BCEAA review	Potential small interference with natural floodplain processes.
Setback diking	2	Potential for minor riparian area encroachment.	consultation with DFO, potential for BCEAA review	Potential small interference with natural floodplain processes.
Reactivating/modifying channels as floodways	3	Potential alteration or destruction of instream and riparian fish habitat. Potential streambank erosion and streambed scour. Federal review will be triggered.	*Fisheries Act* authorization, BC *Environmental Assessment Act* review, *Canadian Environmental Assessment Act* review, *Water Act* approval	Partial restoration of historic floodplain processes. Potential increased fish habitat values in Cottonwood Island side channel.
Riverbank diking	3	Riparian habitat encroachment. HADD. Potential streambank erosion and streambed scour. Federal review will be triggered.	*Fisheries Act* authorization, CEAA review, BCEAA review, *Water Act* approval, SARA, *Migratory Birds Convention Act*, *Wildlife Act*	Interference with natural floodplain processes. Largescale environmental permitting required.
Bar scalping	3	Disturbance of river bed. HADD. Federal review will be triggered.	*Fisheries Act* authorization, CEAA review, *Water Act* approval, SARA, *Wildlife Act*	Potential severe environmental effects. Interferes with natural floodplain processes. Largescale environmental permitting required.
Dredging	3	Disturbance of river bed. HADD. Federal review will be triggered.	*Fisheries Act* authorization, CEAA review, *Water Act* approval, SARA, *Wildlife Act*	Potential severe environmental effects. Interferes with natural floodplain processes. Largescale environmental permitting required.

* 1 = Low, 2 = Medium, 3 = High risk.

[1] Note that upon re-evaluation the ranking of this option has been changed from "Medium" to "Low" from the original coarse-filter decision matrix based on the assumption that there will be no increase in development footprint into the riparian area.

Table 6.2: Flood Control Solutions - Nechako River

			June 2008 Progress Report						Comments for Phase 1 Costing and Medium Filtering
Flood Control Options	**Mitigation Sub-Options**	**Alternate Designs**	**Hydraulic Considerations**	**Infrastructure Considerations**	**Environmental Considerations**	**Geomorphology Considerations**	**General Evaluation**	**Previous Matrix Ranking Index**	
Area A_N (Southbank at confluence)									
No permanent protection, provide temporary works as required			On-going flood risk.	Emergency response on call.	No new environmental impacts expected in absence of permanent protection. Potential environmental considerations associated with temporary works depends on design of those works. For example, release of deleterious substances is possible with use of amphibex and warm water release.	The effects of ongoing sediment deposition must be considered.	Not acceptable in the long term.	9	-Operate as usual; respond to flooding as it occurs. -Develop costs to provide comparison to other options. -Hot oil plant remains a significant environmental threat.
Diking	Construct dike next to river and along Cottonwood Island back channel		Need erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, seal old channel entrances, pump&treat internal flows.	Access limited for construction and maintenance.	Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review will be triggered.**	Reduced flood conveyance area. Sub-surface flow will continue to cause flooding hazard.	Significant environmental, river encroachment and access issues. Feasible but still need to deal with groundwater problems.	8	-Significant environmental, river encroachment and access issues, make this option undesirable. -Develop costs to provide comparison with other options.
	Construct set-back dike along a raised River Road. (City considers raising River Road common to all the options and construction to raise the road proceeded in July 2008.)	Do nothing for development outside road	Some erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, seal old channel entrances, pump&treat internal flows.	Continued flood risk outside road.	Potential minor riparian habitat encroachment.	Maintains exising flood conveyance area.	Feasible but still need to deal with groundwater problems.	6	-Owners of development outside dike to consider construction and maintenance of local ring dikes; if temporary dikes constructed during events some encroachment issues would ensue. -Hot oil plant remains a significant environmental threat. -Not recommended; land-use change outside of dike provides best alternative.
		Extend dike locally to protect development outside dike	Need erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, seal old channel entrances, pump&treat internal flows.	Access limited for construction and maintenance.	Potential riparian habitat encroachment. **Federal review potentially triggered.**	Reduces flood conveyance area. Sub-surface flow is still an issue.	Feasible but still need to deal with groundwater problems.	4	-Hydraulically similar to riverside dike; required height of local dikes makes construction impractical; no conveyance advantage if local dikes used to protect development on riverside of dike. -Long-term risk to performance of main dike. -Hot oil plant remains a significant environmental threat. -Not recommended; land-use change outside of dike provides best alternative.
		Land-use change outside dike	Some erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, seal old channel entrances, pump&treat internal flows.	Business issues.	Potential minor riparian habitat encroachment.	Maintains or increases conveyance area	Feasible but still need to deal with groundwater problems. Significant economic/business issues.	1	-Possible option. -Develop costs for comparison with other options.
		Raise development outside dike	Need erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, seal old channel entrances, pump&treat internal flows.	Business access issues.	Potential minor riparian habitat encroachment.	Modest reduction in conveyance area	Feasible but still need to deal with groundwater problems.	5	-City floodplain bylaw requires all new development to be floodproofed and built to the flood construction level. Owners of existing development to consider improvements to floodproof and raise their developments. Required height of raised structures may be impractical. Raised development would introduce encroachment issues during a flood event, and affect performance of main dike. -Hot oil plant remains a significant environmental threat. -Not recommended; land-use change outside of dike provides best alternative.
	Build setback dike along railway.	Individually ring dike some development outside dike	Provide seepage cut-off, seal old channel entrances, pump&treat any internal flows.	Business access issues.	Potential minor riparian habitat encroachment.	Maintains conveyance area	Good from river engineering perspective but expensive.	7	-Owners of existing developments to consider construction and maintenance of local ring dikes; if ring dikes not constructed there would effectively be no change from current conditions for most of the development within the floodplain; required height of local dikes require large footprint and is not practical; local ring dikes may result in long-term risk to performance of main dike; ring dikes could introduce encroachment issues. -Develop costs for dike, but do not include ring dikes.
		Land-use change outside dike	Provide seepage cut-off, seal old channel entrances, pump&treat any internal flows.		Potential minor riparian habitat encroachment.	Restores former conveyance area	Good from river engineering, environmental and geomorphological perspective but expensive.	2	-Costs similar to land-use change over entire floodplain.
Land-use change over entire floodplain				Unlikely to include railroad and downtown area.	Restores functional floodplain areas	Restores former conveyance area	Unlikely to include downtown area.	3	-Develop cost for comparison with other options. -Use this cost to assess option of setback dike along railway with land-use change outside of dike.
Improve internal drainage.	Approx 2 m deep subdrain and groundwater pumping.		Groundwater governed by river levels, not effective without diking.	Large pump capacity required	Potential for existing groundwater contamination in industrial areas. Testing and treatment may need to be considered.	It could be difficult to significantly lower ground water levels	Expensive. Expected to be difficult to reduce groundwater levels during flood. Would be undertaken as part of a diking option.	n/a	-Not practical as a stand alone solution but would be completed in conjunction with diking.
	Ditch and pump.		Groundwater governed by river levels, not effective without diking.	Complex ditch network. Difficult to fit in with in with existing infrastructure.	Potential for ditch water contamination in industrial areas. Testing and treatment may need to be considered.	Large deep ditches might improve drainage.	Expensive. Expected to be difficult to reduce groundwater levels during flood. Would be undertaken as part of a diking option.	n/a	-Included in cost estimates for diking options shown above.
Area B_N (Northbank east of John Hart Bridge)									
No permanent protection, provide temporary works as required					No new environmental impacts expected in absence of permanent protection. Potential environmental considerations associated with temporary works depends on design of those works. For example, release of deleterious substances is possible with use of amphibex and warm water release.	Status quo - check rates of local sediment accumulation	Not acceptable in the long term.	2	-Operate as usual; respond to flooding as it occurs. -Develop costs to provide comparison to other options.
Land-use change over entire floodplain					nil	No significant change but reduces future flood protection requirements	Expensive.	1	-Possible option. -Develop costs for comparison with other options.
Diking	Construct dike next to river		Need erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.	Access issues. Property concerns, no right of way currently exists for diking.	Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	No significant change - but reduces flood storage area	Environmental and access issues.	7	-Significant environmental, river encroachment and access issues, make this option undesirable. Temporary dike is still in place. -Develop costs to provide comparison with other options.
	Raise McAloney and Ongman Roads	Land-used change outside road	Install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.	Access issues	Potential minor riparian habitat encroachment.	No significant change - but reduces flood storage area	Feasible but expensive.	2	-Possible option. -Develop costs for comparison with other options.
		Do nothing for development outside road	Install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.	Access issues	Potential minor riparian habitat encroachment.	Maintains flood storage area	Feasible	6	-Possible option. -Develop costs for comparison with other options.
	Construct low dike providing base for temporary high water protection	Same sub-options as for full height dike	Temporarily raise dike as needed using gabions or lock blocks.	Emergency response on call.	Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	No significant change - but reduces flood storage area	Feasible	4	-Possible option. -Develop costs for comparison with other options.
Individually raise/flood proof any essential development/basements					Potential minor riparian habitat encroachment.		Feasible but expensive.	5	-City floodplain bylaw requires all new development to be floodproofed and built to the flood construction level. Owners of existing development to consider improvements to floodproof and raise their developments. Required height of raised structures may be impractical. -Not recommended.

Table 6.2: Flood Control Solutions - Nechako River

			June 2008 Progress Report						Comments for Phase 1 Costing and Medium Filtering
Flood Control Options	**Mitigation Sub-Options**	**Alternate Designs**	**Hydraulic Considerations**	**Infrastructure Considerations**	**Environmental Considerations**	**Geomorphology Considerations**	**General Evaluation**	**Previous Matrix Ranking Index**	
Area C_N (Northbank near confluence)									
No permanent protection, provide temporary works as required			PG Pulpmill Road shown as dike on provincial dike mapping.		No new environmental impacts expected in absence of permanent protection. Potential environmental considerations associated with temporary works depends on design of those works. For example, release of deleterious substances is possible with use of amphibex and warm water release.	On-going sediment deposition would increase flood hazard	Not acceptable in the long term. Groundwater remains a concern.	7	-Operate as usual; respond to flooding as it occurs. -Develop costs to provide comparison to other options.
Land-use change over entire floodplain					Restores functional floodplain areas	Some conveyance increase.	Good from river engineering, environmental and geomorphological perspective but expensive. (May provide restoration of historical side channel.)	1	-Possible option. -Develop costs for comparison with other options.
Diking	Construct dike next to river		Need erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.	Maintenance issues	Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	Decrease flood conveyance/storage area	Not advisable. Groundwater remains a concern.	9	-Significant environmental, river encroachment and access issues; benefits a relatively small number of existing residences. -Not recommended but develop costs to provide comparison with other options.
	Raise PG Pulpmill Road if necessary and install seepage prevention to ensure dike meets standards or build new standard dike along road	Do nothing for development outside road	Install flapgates on culverts and prevent seepage, raise as necessary.	Access issues	If a new dike is built along road: Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered**	Road is away from river, little geomorphological impact	Groundwater problems north of road.	5	-PG Pulpmill Road is above the required flood level.
		Build local dikes to protect development outside road	Install flapgates on culverts and prevent seepage. Install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.	Access issues	Potential riparian habitat encroachment. **Federal review potentially triggered.**	Minor reduction in flood conveyance or storage area	Groundwater problems north of road. May not be practical.	4	-PG Pulpmill Road is above the required flood level. -Construct dike to protect some residences to the south of the road. - High erosion risk, not recommended.
		Land-use change outside road	Install flapgates on culverts and prevent seepage, raise as necessary.	Access issues	Potential minor riparian habitat encroachment (associated with raising the road).	Minor increase in flood conveyance or storage area	Feasible but groundwater problems north of road.	2	-Possible option. -Develop costs for comparison with other options.
		Raise/flood proof development outside road	Install flapgates on culverts and prevent seepage, raise as necessary.	Access issues	Potential minor riparian habitat encroachment.	Road is away from river, little geomorphological impact	Feasible but groundwater problems north of road.	3	-City floodplain bylaw requires all new development to be floodproofed and built to the flood construction level. Owners of existing development to consider improvements to floodproof and raise their developments. Required height of raised structures may be impractical. -Not recommended; land-use change provides best alternative.
		Individually ring dike some development, land-use change for remaining properties	Install flapgates on culverts and prevent seepage. Install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.	Access issues	Potential riparian habitat encroachment (i.e. if ring dikes are next to river). **Federal review potentially triggered.**	Minor reduction in flood conveyance or storage area	Feasible but groundwater problems north of road.	5	-City floodplain bylaw requires all new development to be floodproofed and built to the flood construction level. Owners of existing development to consider improvements to floodproof and raise their developments. Required height of raised structures may be impractical. -Not recommended; land-use change provides best alternative.
Individually raise/flood proof any essential development, land-use change for remaining properties				Most impact if north side of dike bought out	Potential minor riparian habitat encroachment.	Reduces need for future flood protection in hazardous location	Feasible but expensive.	7	-City floodplain bylaw requires all new development to be floodproofed and built to the flood construction level. Owners of existing development to consider improvements to floodproof and raise their developments. Required height of raised structures may be impractical. -Not recommended; land-use change provides best alternative.
Groundwater control pumping (North of road)			Groundwater governed by river levels, not effective without diking. Cut-off walls/seepage control required in addition to diking.	Large pump capacity required	Potential for existing groundwater contamination in industrial areas. Testing and treatment may need to be considered.	May be difficult to significantly reduce groundwater levels	Expensive. Expected to be difficult to reduce groundwater levels during flood. Would be undertaken as part of a diking option.	n/a	-Further geotechnical investigations required.
Area D_N (Northbank west of John Hart Bridge)									
No permanent protection, provide temporary works as required				Emergency response on call.	No new environmental impacts expected in absence of permanent protection. Potential environmental considerations associated with temporary works depends on design of those works. For example, release of deleterious substances is possible with use of amphibex and warm water release.	Status quo	Not acceptable in the long term.	2	-Operate as usual; respond to flooding as it occurs. -Develop costs to provide comparison to other options.
Land-use change over entire floodplain					Restores functional floodplain areas	Reduces need for future flood protection in hazardous location	Good from river engineering perspective but expensive and politically difficult.	1	-Possible option. -Develop costs for comparison with other options.
Diking	Construct dike next to river		Need erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.		Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	Decrease flood conveyance/storage area	May not be practical	7	-Significant environmental, river encroachment and access issues, make this option undesirable. -Develop costs to provide comparison with other options.
	Raise Preston Road	Land-use change outside road	Install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.		Potential minor riparian habitat encroachment.	Could possibly affect left bank side channel/island	Feasible but groundwater problems north of road.	2	-Possible option. -Develop costs for comparison with other options.
		Flood proof development outside road	Install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.		Potential minor riparian habitat encroachment.	Minor reduction in flood storage area	Feasible but groundwater problems north of road.	6	-City floodplain bylaw requires all new development to be floodproofed and built to the flood construction level. Owners of existing development to consider improvements to floodproof and raise their developments.Required height of raised structures may be impractical; not recommended.
	Low dike providing base for temporary high water protection	Same sub-options as for full height dike	Temporarily raise dike as needed using gabions or lock blocks.	Emergency response on call.	Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	No significant change - but reduces flood storage area	Feasible	4	-Possible option. -Develop costs for comparison with other options.
Individually raise/flood proof any essential development/basements, land-use change for remaining properties					Potential minor riparian habitat encroachment.	Minimises loss in flood storage area. Reduces need for future flood protection in hazardous location	Feasible.	5	-City floodplain bylaw requires all new development to be floodproofed and built to the flood construction level. Owners of existing development to consider improvements to floodproof and raise their developments. Required height of raised structures may be impractical. -Not recommended.

Table 6.2: Flood Control Solutions - Nechako River

			June 2008 Progress Report						Comments for Phase 1 Costing and Medium Filtering
Flood Control Options	**Mitigation Sub-Options**	**Alternate Designs**	**Hydraulic Considerations**	**Infrastructure Considerations**	**Environmental Considerations**	**Geomorphology Considerations**	**General Evaluation**	**Previous Matrix Ranking Index**	
Area E_N (Morning Place)									
No permanent protection, provide temporary works as required				Emergency response on call.	No new environmental impacts expected in absence of permanent protection. Potential environmental considerations associated with temporary works depends on design of those works. For example, release of deleterious substances is possible with use of amphibex and warm water release.	Status quo	Not acceptable in the long term.	4	-Operate as usual; respond to flooding as it occurs. -Develop costs to provide comparison to other options.
Diking	Construct dike next to river		Need erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.	Maintenance issues	Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	Could destabilize downstream left bank terrace	Not advisable	5	-Significant environmental, river encroachment and access issues; benefits a relatively small number of existing residences. -Not recommended but develop costs to provide comparison with other options.
	Construct low dike providing base for temporary high water protection		Temporarily raise dike as needed using gabions or lock blocks.	Emergency response on call.	Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	No significant change - but reduces flood storage area	Feasible	3	-Possible option. -Develop costs for comparison with other options.
Individually raise/flood proof any essential development					Potential minor riparian habitat encroachment.	Minor reduction in flood storage area	Feasible	2	City floodplain bylaw requires all new development to be floodproofed and built to the flood construction level. Owners of existing development to consider improvements to floodproof and raise their developments. Required height of raised structures may be impractical.
Land-use change over entire floodplain					Restores functional floodplain areas	Little benefit, but reduces need for future flood protection in hazardous location.	Feasible	1	-Possible option. -Develop costs for comparison with other options.
Area F_N (Southbank at Foot Hills Bridge)									
Prevent future development and flood proof existing development if necessary			No hydraulic impact	Limited existing development.	Potential minor riparian habitat encroachment.	Investigate sidechannel to see if any infilling can be removed.	Feasible	1	-Ensure appropriate zoning.
Area G_N (Southbank U/S of John Hart Bridge)									
Prevent future development and flood proof existing development if necessary			No hydraulic impact.	Limited existing development.	Potential minor riparian habitat encroachment.	Reduces need for future flood protection in hazardous location.	Feasible	1	-Ensure appropriate zoning.
General Lower Nechako Area									
Floodways	Enlarge Cottonwood Island back-channel		May need erosion protection and series of bridges.	Potential ice jam relief. Ongoing maintenance.	Stream morphology change to entire back channel. Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review will be triggered.**	Would partially restore historic conveyance area	Feasible but not a solution by itself.		-Possible option to provide ice jam relief; cost developed as part of Emergency Management BC funding request. -Has no significant effect on open water (freshet) design flood profile.
	Open up/straighten historic channel between River Road and Railroad.		May need erosion protection and series of bridges.	Potential ice jam relief. Ongoing maintenance. Only possible with landuse changes	Stream morphology change. Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review will be triggered.**	Would partially restore historic conveyance area	Feasible but not a solution by itself.		-Straightens sections of the historic back channel to reduce number of crossings of River Road. -Possibility to use as relief channel during ice jam events. -Has no significant effect on open water (freshet) design flood profile.
	Channel through Area C_N, south of PG Pulpmill Road				Stream morphology change. Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review will be triggered.**	Possible maintenance dredging.	Feasible but not a solution by itself.		-Possible option to provide ice jam relief; would require land-use change south of PG Pulpmill Road. -Has no significant effect on open water (freshet) design flood profile.
Improve drainage	Modify 1st Avenue storm drains				Design specific - to be assessed individually.		Feasible but not a solution by itself.		-Further geotechnical investigations required.
Enlarge main river channel by dredging	Bar scalping		Monitoring and maintenance required.		Disturbance of river bed, likely HADD. **Federal review will be triggered.**	Maintenance excavation could be needed due to ongoing sediment deposition. Ice jam initiation and freshet flooding may still occur on Fraser River	Feasible but not a solution by itself.		-Bar scalping downstream of the Cottonwood island backchannel included in Emergency Management BC funding request. Bar-scalping in main channel is not recommended.
	Bar scalping and instream excavation		Monitoring and maintenance required.		Disturbance of river bed, likely HADD. **Federal review will be triggered.**	Maintenance excavation could be needed due to ongoing sediment deposition. Ice jam initiation and freshet flooding may still occur on Fraser River	Feasible but not a solution by itself.		-No benefit to reduce either open water (freshet) or ice jam flooding conditions. Not recommended.
Flow regulation	Enlarge storage behind Kenney Dam				Detailed and complex provincial and **federal reviews required**. Multi-year environmental studies likely required for permitting.	Larger riparian/shoreline impacts	Expensive. Not a solution by itself.		-Requires negotiation with Rio Tinto - Alcan; not within project timeframe. -Operation already providing benefits for reducing winter flows and delaying freshet.
	Build new storage				Detailed and complex provincial and **federal reviews required**. Multi-year environmental studies likely required for permitting.	Larger riparian/shoreline impacts	Expensive. Not a solution by itself.		-Requires negotiation with Rio Tinto - Alcan; not within project timeframe.
	Revise operating procedure				Detailed and complex provincial and **federal reviews required**. Multi-year environmental studies likely required for permitting.	Complex issue including effects on water temperature, sediment transport, bank stability.	Feasible.		-Requires extensive negotiation with Rio Tinto - Alcan; not within project timeframe. -Operation already providing benefits for reducing winter flows and delaying freshet.

Table 6.3: Flood Control Solutions - Fraser River

	June 2008 Progress Report						Comments for Phase 1 Costing and Medium Filtering
Mitigation Options	**Hydraulic Considerations**	**Infrastructure Considerations**	**Environmental Considerations**	**Geomorphology Considerations**	**General Evaluation**	**Previous Matrix Ranking Index**	
Area A_F (Yellowhead Bridge)							
No permanent protection, provide temporary works as required		Emergency response on call	No new environmental impacts expected in absence of permanent protection. Potential environmental considerations associated with temporary works depends on design of those works.			3	-Operate as usual; respond to flooding as it occurs. -Develop costs to provide comparison to other options.
Diking next to river	Need erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.	D/S tie-in may be difficult	Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	Area next to bridge abutment, no measurable impact. Minor loss in flood storage area.	Feasible	4	-Feasible option; develop costs for comparison.
Low dike next to river	Low dike providing base for temporary high water protection	Emergency response on call	Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**			5	-Feasible option; develop costs for comparison.
Land-use changes			Restores functional floodplain areas		Feasible	1	-Feasible option; develop costs for comparison.
Raise/flood proof any development			Potential minor riparian habitat encroachment.		Feasible	2	-City floodplain bylaw requires all new development to be floodproofed and built to the flood construction level. Owners of existing development to consider improvements to floodproof and raise their developments. Required height of raised structures may be impractical.Compare low dike option with resulting per resident cost.
Area B_F (South Fort George)							
No permanent protection, provide temporary works as required		Emergency response on call	No new environmental impacts expected in absence of permanent protection. Potential environmental considerations associated with temporary works depends on design of those works.		Not acceptable in the long term.	3	-Operate as usual; respond to flooding as it occurs. -Develop costs to provide comparison to other options.
Diking-next to river/slough	Need erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.		Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	Drains or pumps may be needed to prevent water being trapped behind dyke. Reduces flood storage area and cuts off a possible flood drainage channel.	May not be feasible	4	-Develop costs for comparison.
Individually raise/flood proof any essential development, buy out rest		Emergency response on call	Potential minor riparian habitat encroachment.	Could reactivate sizeable flood relief channel	Feasible	2	-City floodplain bylaw requires all new development to be floodproofed and built to the flood construction level. Owners of existing development to consider improvements to floodproof and raise their developments. Required height of raised structures may be impractical. Compare low dike option with resulting per resident cost.
Land-use changes			Restores functional floodplain areas	Could reactivate sizeable flood relief channel	Flooding occurs frequently, this may be best option.	1	-Feasible option; develop costs for comparison.
Area C_F (Hudson Bay Slough West of Queensway)							
Queensway acts as dike. Flap-gated culverts and pumping station installed. Verify that protection is adequate at revised 200-year flood level and upgrade if needed.		Emergency response on call	No new environmental impacts.		Area already protected by road dike. Determine if additional pumping capacity is required.	1	-Road/dike sufficiently high; may need additional pumping; expect relatively minimal costs.
Land-use changes					Most likely not required.		-Most likely not required.
Provide seepage cut-off.					Most likely not required.		-To be considered if existing pump capacity is inadequate and additional pumping is difficult to provide.
Individually raise/flood proof any essential development/basements			Potential minor riparian habitat encroachment.		May not be required.		-City floodplain bylaw requires all new development to be floodproofed and built to the flood construction level. Owners of existing development to consider improvements to floodproof and raise their developments. Required height of raised structures may be impractical.
Area D_F (Lansdowne south end)							
No permanent protection, provide temporary works as required		Emergency response on call	No new environmental impacts expected in absence of permanent protection. Potential environmental considerations associated with temporary works depends on design of those works.		Not acceptable in the long term.	3	-Operate as usual; respond to flooding as it occurs; prevent future development with appropriate zoning. -Develop costs to provide comparison to other options.
Land-use changes			Restores functional floodplain areas		Feasible	1	-Feasible option; develop costs for comparison.
Provide diking for part of area.			Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	No significant reduction in flood conveyance capacity	Feasible but expensive	4	- Limited space for dike construction.
Individually raise/flood proof any essential development			Potential minor riparian habitat encroachment.	Impacts will be determined by the number of sites	Feasible	2	-City floodplain bylaw requires all new development to be floodproofed and built to the flood construction level. Owners of existing development to consider improvements to floodproof and raise their developments. Required height of raised structures may be impractical. Compare low dike option with resulting per resident cost.
Area E_F (Westbank at island)							
No permanent protection, provide temporary works as required		Emergency response on call	No new environmental impacts expected in absence of permanent protection. Potential environmental considerations associated with temporary works depends on design of those works.		Feasible solution considering limited development.	3	-Operate as usual; respond to flooding as it occurs. -Prevent further development with appropriate zoning.
Land-use changes			Restores functional floodplain areas		Feasible	2	-Not required.
Diking	May need erosion protection, provide seepage cut-off, pump internal flows.		Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	No significant reduction in flood conveyance capacity	May not be economically justifiable.	4	-Not required.
Individually raise/flood proof any essential development/basements or move/isolate and land-use changes			Potential minor riparian habitat encroachment.	Impacts will be determined by the number of sites	Feasible	1	-Not required.
Area F_F (Northwood Pulpmill Road)							
No permanent protection, provide temporary works as required		Emergency response on call	No new environmental impacts expected in absence of permanent protection. Potential environmental considerations associated with temporary works depends on design of those works.		Feasible solution considering limited development.	4	-Access issue; raise Landooz Road; develop costs.
Ring Diking set-back from river	Provide seepage cut-off, pump internal flows.		Potential minor riparian habitat encroachment.		Feasible but expensive	3	
Individually raise/flood proof any essential development			Potential minor riparian habitat encroachment.	Impacts will be determined by the number of sites	Feasible	2	
At any vulnerable development in floodplain, alter land-use			Restores functional floodplain areas	Maintains flood conveyance storage area	Feasible	1	
Area G_F (Across River from Shelley)							
Prevent future development. Flood proof existing development as necessary			Potential minor riparian habitat encroachment.	An appropriate plan	Feasible	1	-No associated costs

Table 6.4 Flood Control Solutions - Cost Analyses

Flood Risk Area: **A_N - South Bank of Nechako River at Confluence**

INVENTORY					
Sub-areas	**North of River Road**	**River Road to railway**	**Railway and area to the south of it**		
General asset description	A few residential/industrial properties	Numerous industrial properties	Commercial and residential, downtown core		
Asset inventory by sub-area:					
- Infrastructure & public assets		$ 9,590,000	$ 31,214,000		
- Property value	$ 4,706,000	$ 33,923,000	$ 69,350,000		
Total assets/sub-area	$ 4,706,000	$ 43,513,000	$ 100,564,000		
OPTIONS					
Flood control option	**No protection**	**River dike**	**Build dike on river side of River Road.**	**Build set-back dike along railway**	**Land-use change**
Flood control sub-option	1. No permanent protection, provide temporary works as required	2. Build dike next to river and along Cottonwood Island back channel. (Raise River Rd.)	5. Introduce land-use changes outside dike. (Raise River Rd).	7. Individually ring dike some development outside the dike (ring dikes not included). Raise River Rd.	9. Change land-use in entire area
Area protected	None	Entire Area	River Road to Railway	Area South of Railway	None
COSTING					
Expected damage ($) over 50 yr period with option installed	$ 4,160,000	$ 822,000	$ 822,000	$ 1,643,000	$ 822,000
Capital cost of option($)	N/A	$ 17,014,000	$ 15,518,000	$ 8,534,000	$ 23,228,000
Annual Operation/maintenance cost ($)	N/A	$ 49,000	$ 47,500	$ 35,500	N/A
Social cost ($)	$ 21,964,000	$ 4,393,000	$ 4,393,000	$ 8,785,000	$ 4,393,000
Total 50 yr life cycle cost ($)	$40,260,000	$ 26,145,000	$ 24,616,000	$ 25,420,000	$ 25,174,000
MEDIUM FILTERING					
Cost Comparison ratio	1.00	1.54	1.64	1.58	1.60
Environmental costs (L,M,H)	L	H	M	L	L
Non-monetary considerations	Env. cost dependent on timing and nature of emergency response				
RANKING	5	4	1	3	2

Flood Risk Area: **B_N - North Bank of Nechako River East of John Hart Bridge**

INVENTORY					
General asset description	Numerous industrial properties				
Asset inventory by sub-area:					
- Infrastructure & public assets	$ 2,076,000				
- Property value	$ 7,980,000				
Total assets/sub-area	$ 10,056,000				
OPTIONS					
Flood control option	**No protection**	**River dike**		**Raise McAlony and Ongman Roads**	**Land-use change**
Flood control sub-option	1. No permanent protection, provide temporary works as required	2. Build dike next to Nechako River	3. Build low dike next to Nechako River	4. Do nothing for development outside dike	5. Change land-use in entire area
Area protected	None	Entire area	None	North of road	Entire area
COSTING					
Expected damage ($) over 50 yr period with option installed	$ 153,000	$ 31,000	$ 77,000	$ 61,200	$ 31,000
Capital cost of option($)	N/A	$ 3,520,000	$ 2,696,000	$ 3,913,000	$ 8,778,000
Annual Operation/maintenance cost ($)	N/A	$ 14,500	$ 14,500	$ 13,500	N/A
Social cost ($)	$ 2,550,000	$ 510,000	$ 1,275,000	$ 1,020,000	N/A
Total 50 yr life cycle cost ($)	$4,700,000	$ 4,780,000	$ 5,362,000	$ 6,090,000	$ 9,016,000
MEDIUM FILTERING					
Cost Comparison ratio	1.00	0.98	0.88	0.77	0.52
Environmental costs (L,M,H)	L	H	H	M	L
Non-monetary considerations	Env. cost dependent on timing and nature of emergency response				
RANKING	1	N/A	2	3	4

Flood Risk Area: **C_N - North Bank of Nechako River near Confluence**

INVENTORY			
General asset description	A few residential/industrial properties		
Asset inventory by sub-area:			
- Infrastructure & public assets	$ 1,370,000		
- Property value	$ 18,649,000		
Total assets/sub-area	$ 20,019,000		
OPTIONS			
Flood control option	**No protection**	**River Dike**	**Land-use change**
Flood control sub-option	1. No permanent protection, provide temporary works as required	2. Build dike next to Nechako River	5. Change land-use in entire area
Area protected	None	Entire area	Entire area
COSTING			
Expected damage ($) over 50 yr period with option installed	$ 8,798,000	$ 1,760,000	$ 1,760,000
Capital cost of option($)	N/A	$ 10,122,000	$ 9,333,000
Annual Operation/maintenance cost ($)	N/A	$ 23,000	N/A
Social cost ($)	$ 1,693,000	$ 339,000	N/A
Total 50 yr life cycle cost ($)	$9,251,000	$ 12,749,000	$ 10,518,000
MEDIUM FILTERING			
Cost Comparison ratio	1.00	0.73	0.88
Environmental costs (L,M,H)	L	H	L
Non-monetary considerations	Env. cost dependent on timing and nature of emergency response		
RANKING	2	N/A	1

Flood Risk Area: **D_N - North Bank of Nechako River West of John Hart Bridge**

INVENTORY					
General asset description	A few residential/industrial properties				
Asset inventory by sub-area:					
- Infrastructure & public assets	$ 1,068,000				
- Property value	$ 6,128,000				
Total assets/sub-area	$ 7,196,000				
OPTIONS					
Flood control option	**No protection**	**River dike**		**Raise Preston Road**	**Land-use change**
Flood control sub-option	1. No permanent protection, provide temporary works as required	2. Build dike next to Nechako River	3. Build low dike next to Nechako River	4. Do nothing for development outside dike	5. Change land-use in entire area
Area protected	None	Entire area	None	North of road	Entire area
COSTING					
Expected damage ($) over 50 yr period with option installed	$ 5,886,000	$ 1,177,000	$ 2,943,000	$ 3,531,000	$ 1,177,000
Capital cost of option($)	N/A	$ 3,308,000	$ 2,587,000	$ 1,208,000	$ 6,741,000
Annual Operation/maintenance cost ($)	N/A	$ 14,000	$ 14,000	$ 12,500	N/A
Social cost ($)	$ 2,617,000	$ 524,000	$ 1,307,000	$ 1,570,000	N/A
Total 50 yr life cycle cost ($)	$5,233,000	$ 4,663,000	$ 5,512,000	$ 4,623,000	$ 6,923,000
MEDIUM FILTERING					
Cost Comparison ratio	1.00	1.12	0.95	1.13	0.76
Environmental costs (L,M,H)	L	H	H	M	L
Non-monetary considerations	Env. cost dependent on timing and nature of emergency response	Residents might consider dike unsightly.			
RANKING	2	N/A	3	1	4

Table 6.4 Flood Control Solutions - Cost Analyses

Flood Risk Area: **E_N - Morning Place**

INVENTORY				
General asset description	Residential properties			
Asset inventory by sub-area:				
- Infrastructure & public assets				
- Property value	$ 1,243,000			
Total assets/sub-area	$ 1,243,000			
OPTIONS				
Flood control option	**No protection**	**River dike**		**Land-use change**
Flood control sub-option	1. No permanent protection, provide temporary works as required	2. Build dike next to Nechako River	3. Build low dike next to Nechako River	5. Change land-use in entire area
Area protected	None	Entire area	None	Entire area
COSTING				
Expected damage ($) over 50 yr period with option installed	$ 4,150,000	$ 830,000	$ 2,075,000	$ 830,000
Capital cost of option($)	N/A	$ 2,139,000	$ 1,600,000	$ 1,367,000
Annual Operation/maintenance cost ($)	N/A	$ 2,500	$ 2,500	N/A
Social cost ($)	$ 480,000	$ 96,000	$ 240,000	N/A
Total 50 yr life cycle cost ($)	$2,939,000	$ 2,782,000	$ 3,161,000	$ 1,431,000
MEDIUM FILTERING				
Cost Comparison ratio	1.00	1.06	0.93	2.05
Environmental costs (L,M,H)	L	H	H	L
Non-monetary considerations	Env. cost dependent on timing and nature of emergency response	Residents might consider dike unsightly.		
RANKING	2	N/A	3	1

Flood Risk Area: **General Lower Nechako Area**

INVENTORY			
Sub-areas	**North of River Road**	**River Road to railway**	**Railway and area to the south of it**
General asset description	A few residential/industrial properties	Numerous industrial properties	Commercial and residential, downtown core
Asset inventory by sub-area:			
- Infrastructure & public assets		$ 9,590,000	$ 31,214,000
- Property value	$ 4,706,000	$ 33,923,000	$ 69,350,000
Total assets/sub-area	$ 4,706,000	$ 43,513,000	$ 100,564,000
OPTIONS			
Flood control option		**Floodways**	
Flood control sub-option	1. Enlarge Cottonwood Island side channel	2. Excavate and straigten historic backchannel	3. Channel through Area C_N
Area protected	Entire area	Entire area	Entire area
COSTING			
Expected damage ($) over 50 yr period with option installed			
Capital cost of option($)	$ 2,961,000	$ 9,040,000	$ 7,600,000
Annual Operation/maintenance cost ($)			
Social cost ($)			
Total 50 yr life cycle cost ($)			
MEDIUM FILTERING			
Cost Comparison ratio			
Environmental costs (L,M,H)	L	L	L
Non-monetary considerations	Opportunity to enhance existing fish habitat	Opportunity to restore side channel habitats	Creation of new fish habitat
RANKING	1	3	2

Flood Risk Area: **A_F - West Bank at Yellowhead Bridge**

INVENTORY				
General asset description	Park area bordered by residential			
Asset inventory by sub-area:				
- Infrastructure & public assets	$ 113,000			
- Property value	$ 2,236,000			
Total assets/sub-area	$ 2,349,000			
OPTIONS				
Flood control option	**No protection**	**River dike**		**Land-use change**
Flood control sub-option	1. No permanent protection, provide temporary works as required	2. Build dike next to Fraser River	3. Build low dike next to Fraser River	5. Change land-use in entire area
Area protected	None	Entire area	None	Entire area
COSTING				
Expected damage ($) over 50 yr period	$ 433,000	$ 87,000	$ 217,000	$ 3,600
Capital cost of option($)	N/A	$ 1,524,000	$ 760,000	$ 2,460,000
Annual Operation/maintenance cost ($)	N/A	$ 1,500	$ 1,500	N/A
Social cost ($)	$ 48,000	$ 10,000	$ 24,000	N/A
Total 50 yr life cycle cost ($)	$1,450,000	$ 1,847,000	$ 1,518,000	$ 2,488,000
MEDIUM FILTERING				
Cost Comparison ratio	1.00	0.79	0.96	0.58
Environmental costs (L,M,H)	L	H	H	L
Non-monetary considerations	Env. cost dependent on timing and nature of emergency response	Residents might consider dike unsightly.	Residents might consider dike unsightly.	
RANKING	1	3	2	4

Flood Risk Area: **B_F - South Fort George**

INVENTORY				
General asset description	Some residential			
Asset inventory by sub-area:				
- Infrastructure & public assets	$ 1,378,000			
- Property value	$ 3,550,000			
Total assets/sub-area	$ 4,928,000			
OPTIONS				
Flood control option	**No protection**	**River dike**		**Land-use change**
Flood control sub-option	1. No permanent protection, provide temporary works as required	2. Build dike next to Fraser River around Farrell Street and Regent Crescent	3. Build low dike next to Fraser River	5. Change land-use in entire area
Area protected	None	Developed area	None	Entire area
COSTING				
Expected damage ($) over 50 yr period	$ 8,169,000	$ 1,634,000	$ 4,085,000	$ 29,000
Capital cost of option($)	N/A	$ 2,854,000	$ 1,502,000	$ 1,430,000
Annual Operation/maintenance cost ($)	N/A	$ 13,000	$ 13,000	N/A
Social cost ($)	$ 928,000	$ 186,000	$ 464,000	N/A
Total 50 yr life cycle cost ($)	$4,075,000	$ 3,955,000	$ 3,825,000	$ 1,655,000
MEDIUM FILTERING				
Cost Comparison ratio	1.00	1.03	1.07	2.46
Environmental costs (L,M,H)	L	H	H	L
Non-monetary considerations	Env. cost dependent on timing and nature of emergency response			
RANKING	2	4	3	1

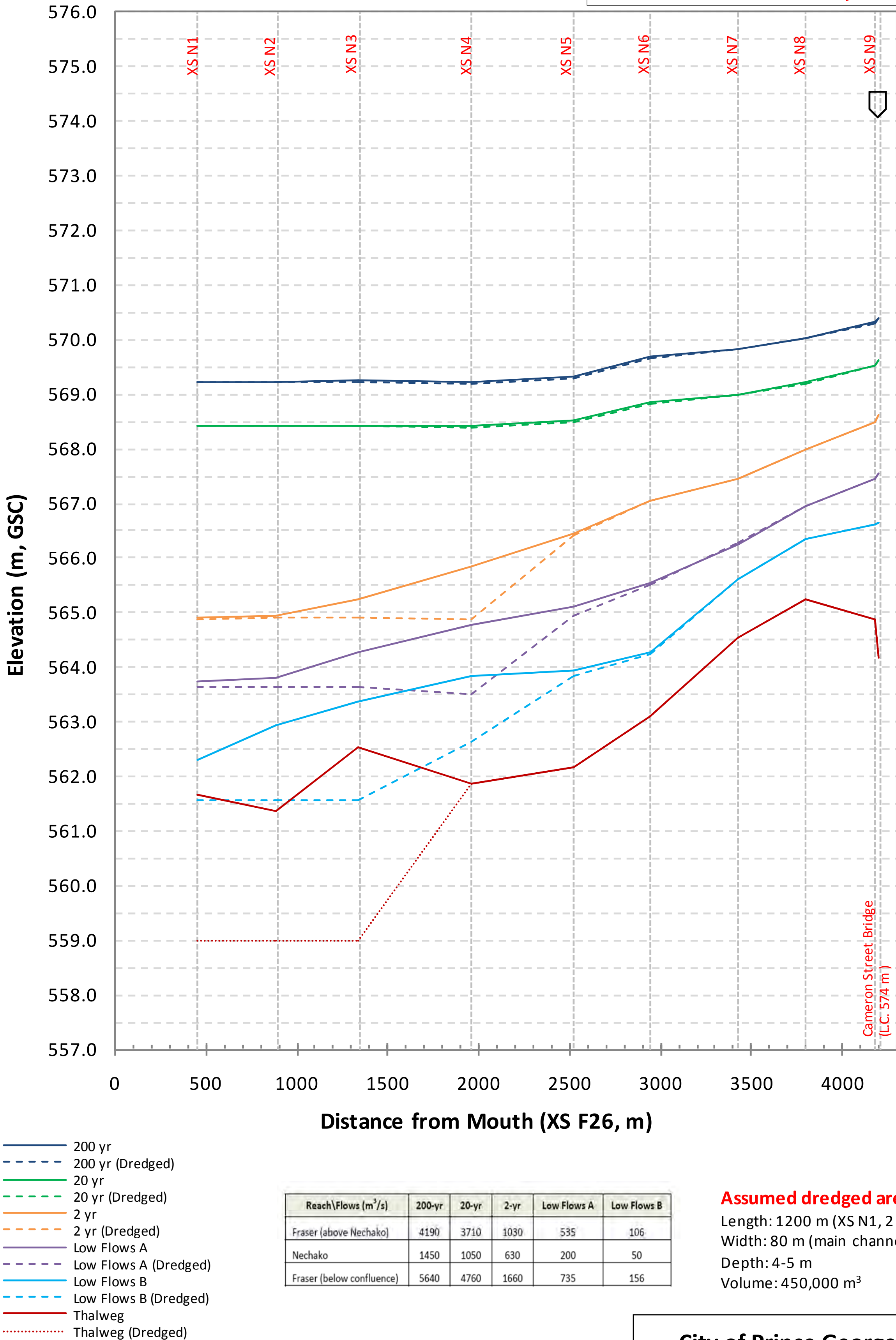
Table 6.4 Flood Control Solutions - Cost Analyses

Flood Risk Area: **D_F - Lansdowne South End**

INVENTORY				
General asset description	Some residential			
Asset inventory by sub-area:				
- Infrastructure & public assets	$ 427,000			
- Property value	$ 760,000			
Total assets/sub-area	$ 1,187,000			
OPTIONS				
Flood control option	**No protection**	**River dike**		**Land-use change**
Flood control sub-option	1. No permanent protection, provide temporary works as required	2. Build dike next to Fraser River	3. Build low dike next to Fraser River	5. Change land-use in entire area
Area protected	None	Developed area	None	Entire area
COSTING				
Expected damage ($) over 50 yr period with option installed	$ 1,761,000	$ 352,000	$ 880,000	$ 4,000
Capital cost of option($)	N/A	$ 1,592,000	$ 651,000	$ 836,000
Annual Operation/maintenance cost ($)	N/A	$ 1,500	$ 1,500	N/A
Social cost ($)	$ 202,000	$ 41,000	$ 101,000	N/A
Total 50 yr life cycle cost ($)	$1,450,000	$ 1,915,000	$ 1,409,000	$ 864,000
MEDIUM FILTERING				
Cost Comparison ratio	1.00	0.76	1.03	1.68
Environmental costs (L,M,H)	L	H	H	L
Non-monetary considerations	Env. cost dependent on timing and nature of emergency response			
RANKING	2	4	3	1

Flood Risk Area: **F_F - Northwood Pulp Road**

INVENTORY		
General asset description	Industrial and residential	
Asset inventory by sub-area:		
- Infrastructure & public assets	$ 3,741,000	
- Property value		
Total assets/sub-area	$ 3,741,000	
OPTIONS		
Flood control option	**No protection**	**Dike**
Flood control sub-option	1. No permanent protection, provide temporary works as required	2. Raise Landooz Road for access only
Area protected	None	Developed area
COSTING		
Expected damage ($) over 50 yr period with option installed		
Capital cost of option($)		$ 5,851,000
Annual Operation/maintenance cost ($)		
Social cost ($)		
Total 50 yr life cycle cost ($)		
MEDIUM FILTERING		
Cost Comparison ratio		
Environmental costs (L,M,H)	L	M
Non-monetary considerations	Env. cost dependent on timing and nature of emergency response	
RANKING	---	---



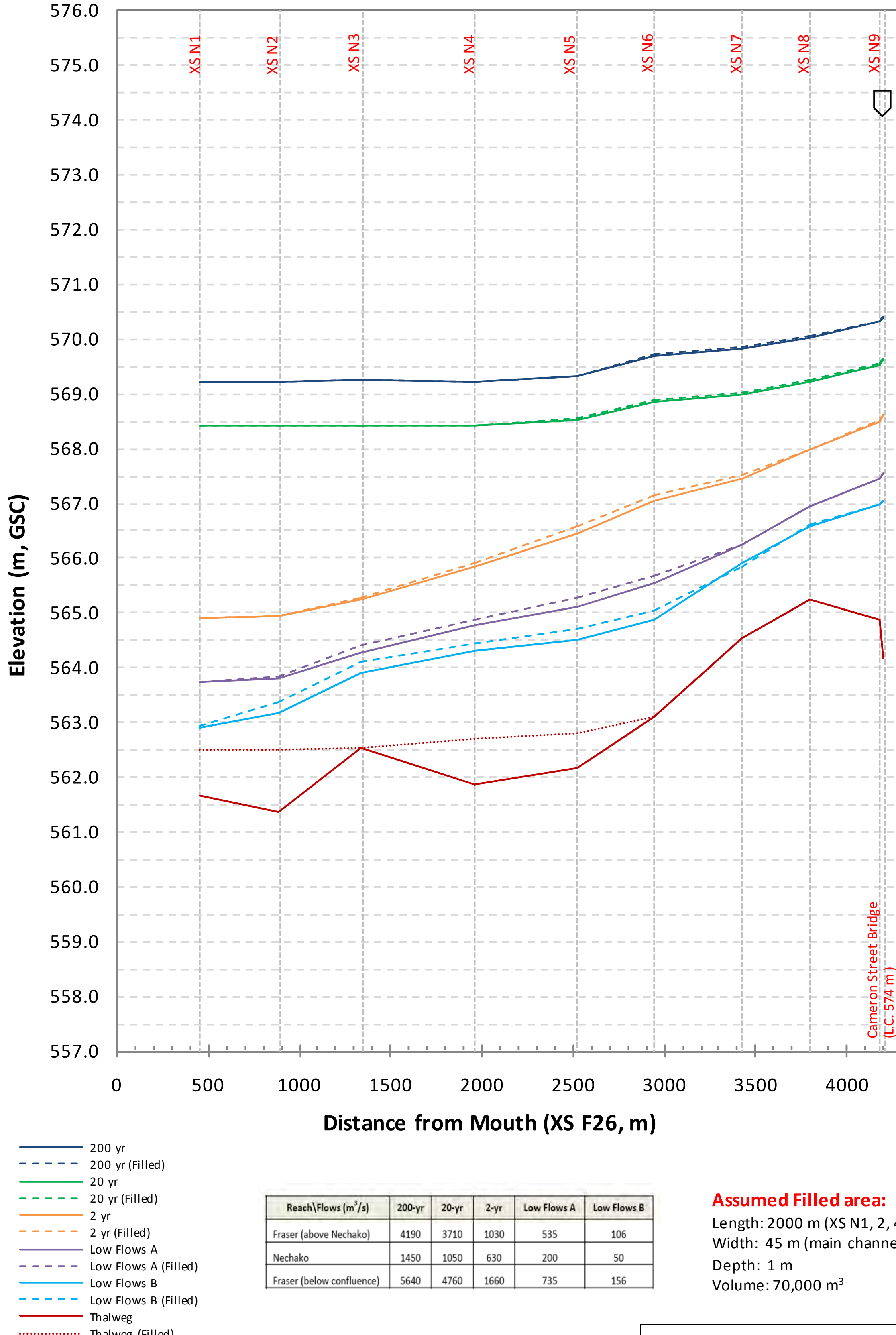
Reach\Flows (m^3/s)	200-yr	20-yr	2-yr	Low Flows A	Low Flows B
Fraser (above Nechako)	4190	3710	1030	535	106
Nechako	1450	1050	630	200	50
Fraser (below confluence)	5640	4760	1660	735	156

Assumed dredged area:
Length: 1200 m (XS N1, 2 & 3)
Width: 80 m (main channel)
Depth: 4-5 m
Volume: 450,000 m^3

City of Prince George nhc

Nechako River
Gravel Removal

January 2009 | Figure 6.1



Reach\Flows (m^3/s)	200-yr	20-yr	2-yr	Low Flows A	Low Flows B
Fraser (above Nechako)	4190	3710	1030	535	106
Nechako	1450	1050	630	200	50
Fraser (below confluence)	5640	4760	1660	735	156

Assumed Filled area:
Length: 2000 m (XS N1, 2, 4 & 5)
Width: 45 m (main channel)
Depth: 1 m
Volume: 70,000 m^3

City of Prince George nhc

Nechako River
Gravel Deposition

January 2009 | Figure 6.2

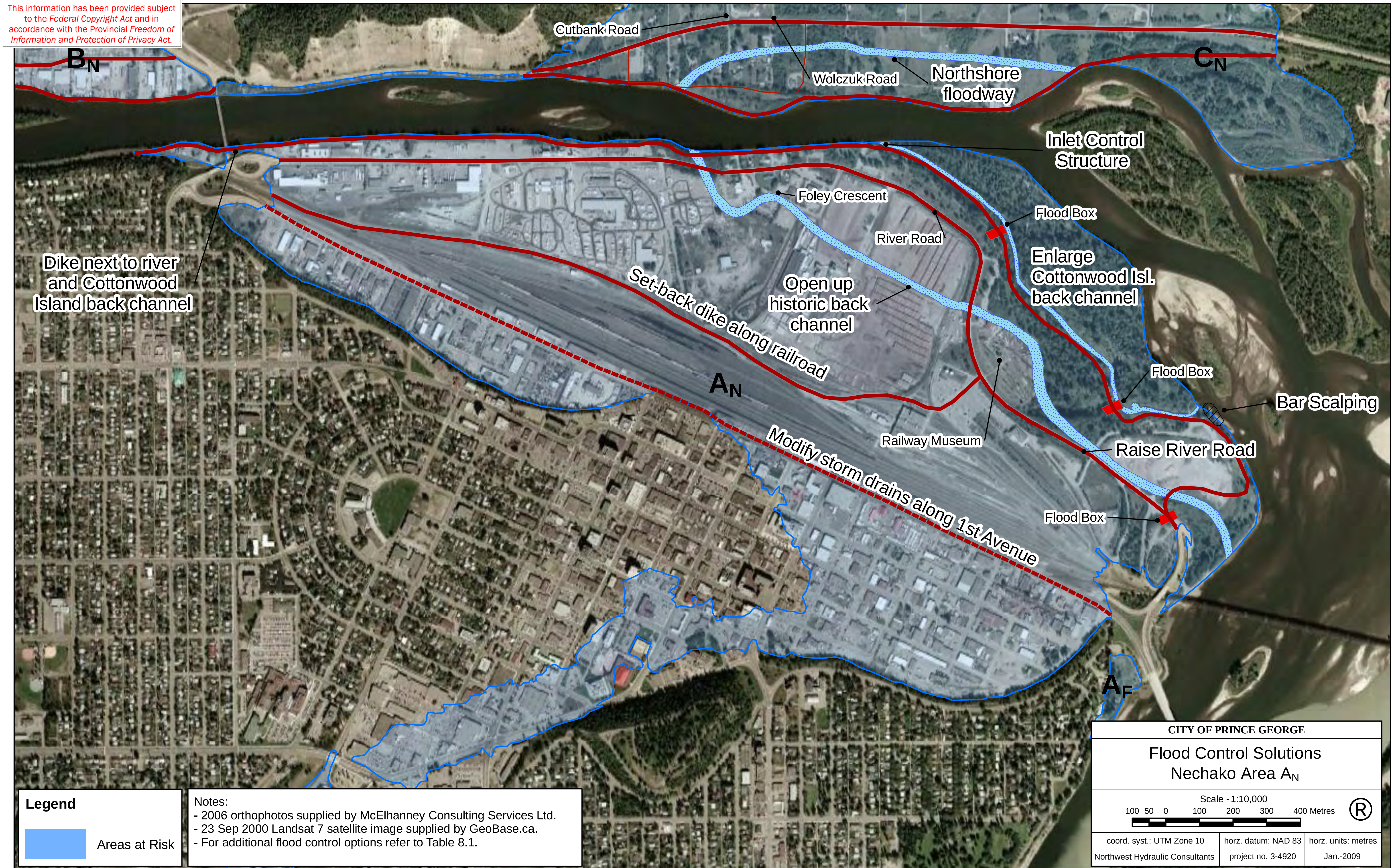
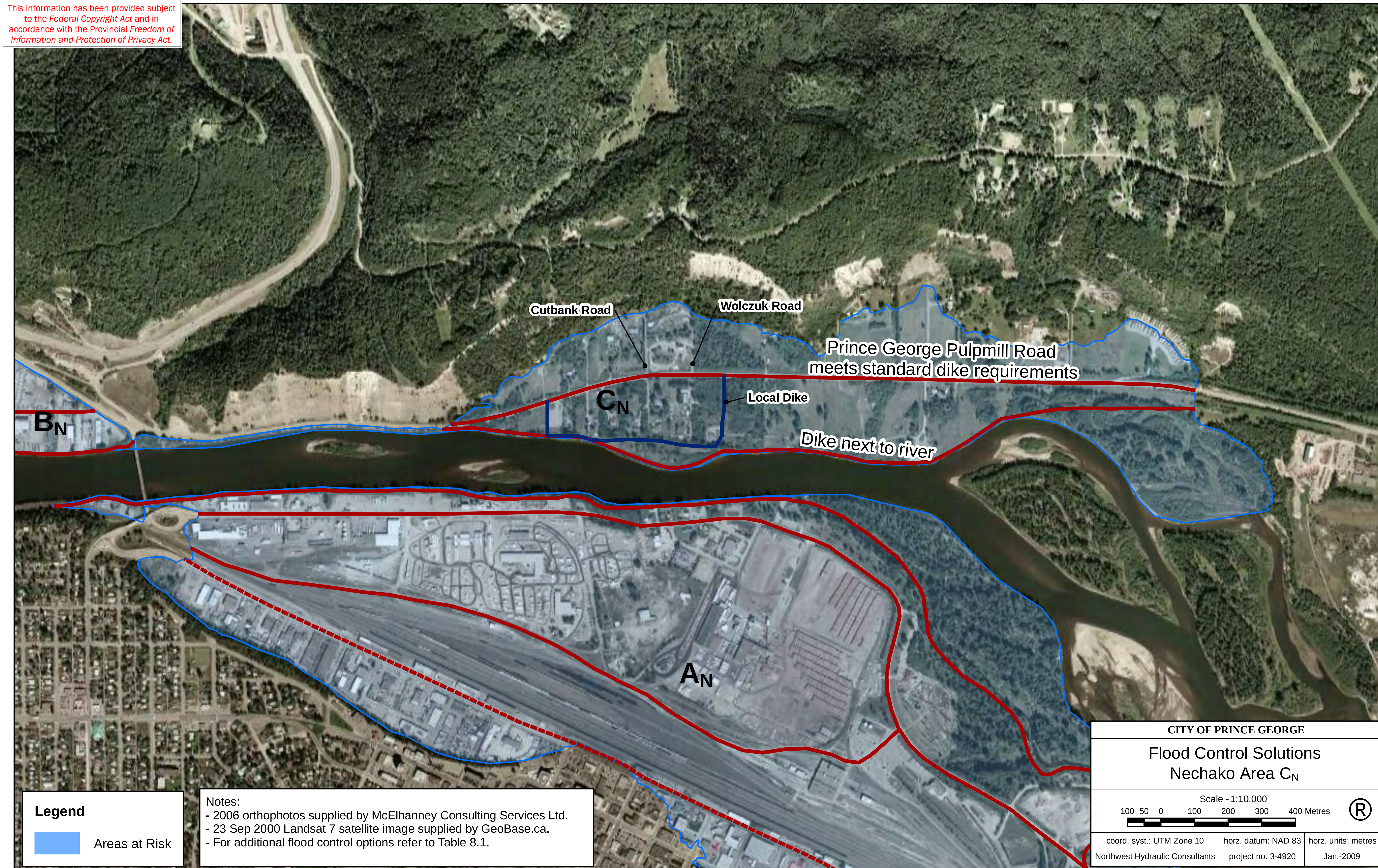

Cutbank Road
Wolczuk Road
Northshore floodway
B_N
C_N
Inlet Control Structure
Foley Crescent
Flood Box
River Road
Enlarge Cottonwood Isl. back channel
Dike next to river and Cottonwood Island back channel
Set-back dike along railroad
Open up historic back channel
A_N
Flood Box
Bar Scalping
Railway Museum
Raise River Road
Modify storm drains along 1st Avenue
Flood Box
A_F
Legend
Areas at Risk
Notes:
- 2006 orthophotos supplied by McElhanney Consulting Services Ltd.
- 23 Sep 2000 Landsat 7 satellite image supplied by GeoBase.ca.
- For additional flood control options refer to Table 8.1.
CITY OF PRINCE GEORGE
Flood Control Solutions
Nechako Area A_N
Scale - 1:10,000
100 50 0 100 200 300 400 Metres
coord. syst.: UTM Zone 10
horz. datum: NAD 83
horz. units: metres
Northwest Hydraulic Consultants
project no. 3-4920
Jan.-2009
GDL, Y:\34920 PG FPM\GIS\34920_CM_CloseUpAreasAtRisk1_An_Nov2008.mxd

Figure 6.3


G_N
Raise Preston Road
North Nechako Road
D_N
Dike next to river
B_N
Raise McAloney and Ongman Roads
Dike next to river
C_N
Legend
Areas at Risk
Notes:
- 2006 orthophotos supplied by McElhanney Consulting Services Ltd.
- 23 Sep 2000 Landsat 7 satellite image supplied by GeoBase.ca.
- For additional flood control options refer to Table 8.1.
CITY OF PRINCE GEORGE
Flood Control Solutions
Nechako Areas B_N and D_N
Scale - 1:5,000
100 50 0 100 200 Metres
coord. syst.: UTM Zone 10
horz. datum: NAD 83
horz. units: metres
Northwest Hydraulic Consultants
project no. 3-4920
Jan.-2009

Figure 6.4



Legend

Areas at Risk

Notes:
- 2006 orthophotos supplied by McElhanney Consulting Services Ltd.
- 23 Sep 2000 Landsat 7 satellite image supplied by GeoBase.ca.
- For additional flood control options refer to Table 8.1.

CITY OF PRINCE GEORGE

Flood Control Solutions
Nechako Area C_N

Scale - 1:10,000
100 50 0 100 200 300 400 Metres

coord. syst.: UTM Zone 10	horz. datum: NAD 83	horz. units: metres
Northwest Hydraulic Consultants	project no. 3-4920	Jan.-2009

GDL, Y:\34920 PG FPM\GIS\34920_CM_CloseUpAreasAtRisk1_Cn_Nov2008.mxd

Figure 6.5

GDL, Y:\34920 PG FPM\GIS\34920_CM_CloseUpAreasAtRisk1_En_Nov2008.mxd

Figure 6.6

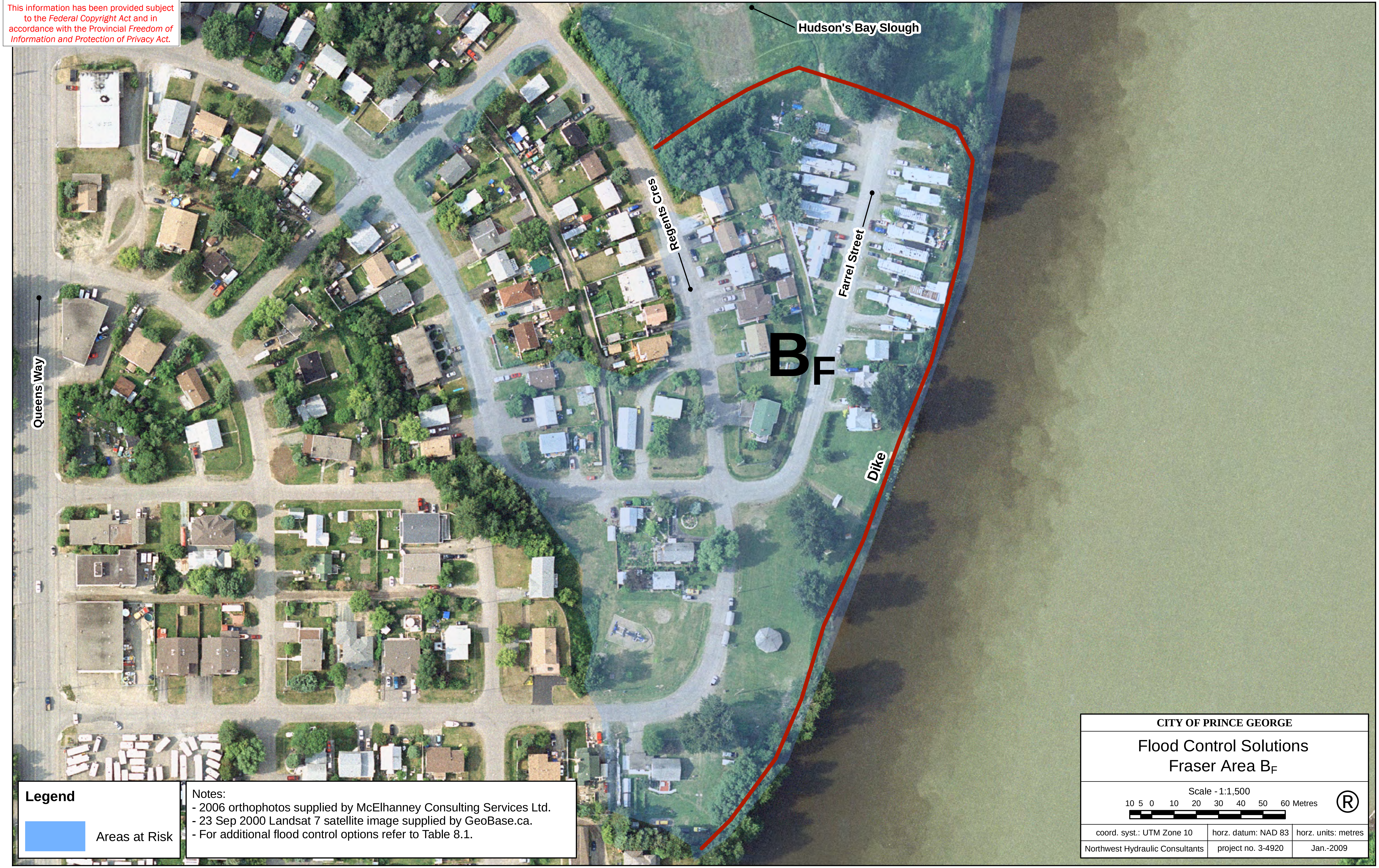


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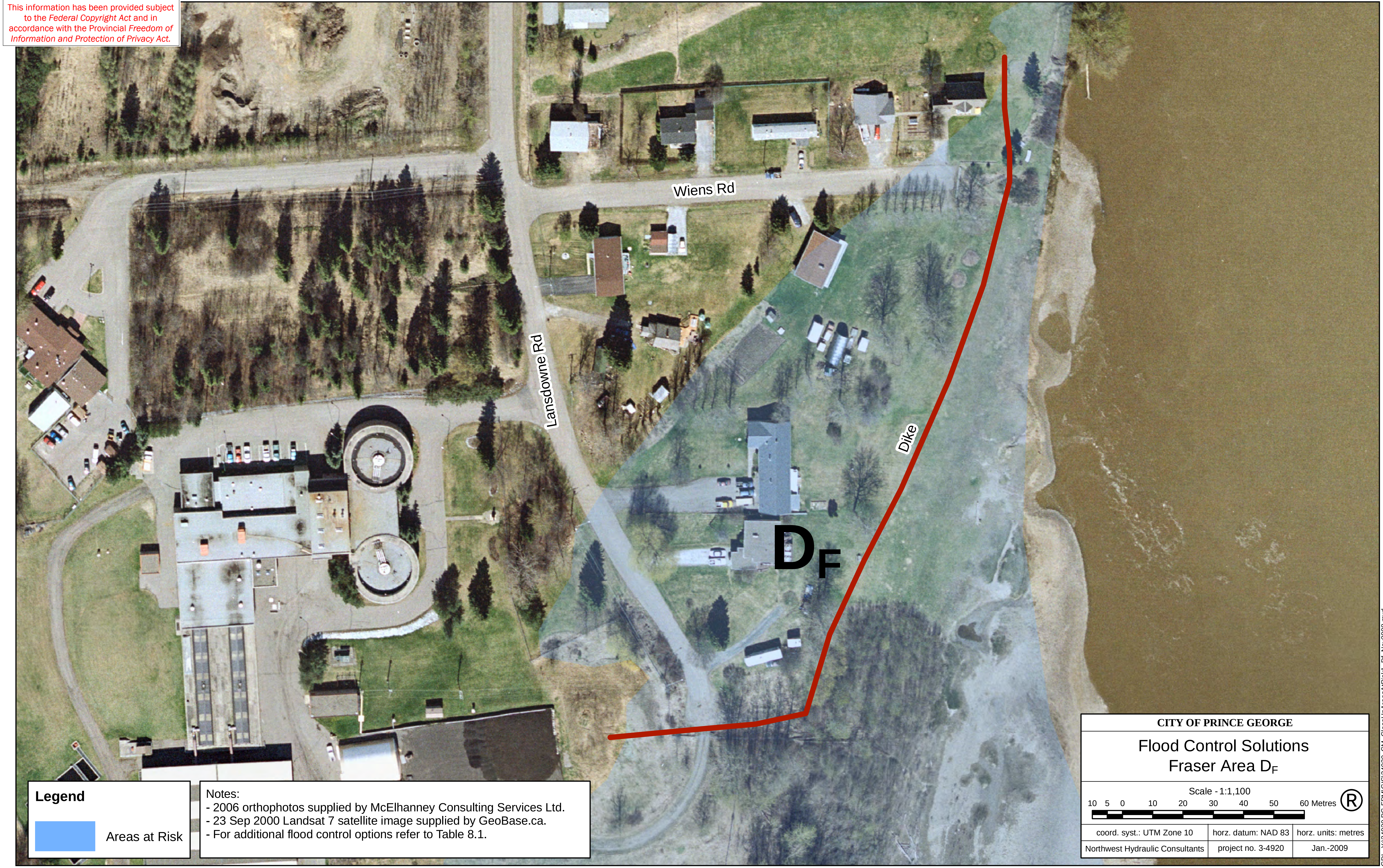
Figure 6.7



Notes:
- 2006 orthophotos supplied by McElhanney Consulting Services Ltd.
- 23 Sep 2000 Landsat 7 satellite image supplied by GeoBase.ca.
- For additional flood control options refer to Table 8.1.

CITY OF PRINCE GEORGE

Flood Control Solutions
Fraser Area D_F

Scale - 1:1,100

10 5 0 10 20 30 40 50 60 Metres

coord. syst.: UTM Zone 10	horz. datum: NAD 83	horz. units: metres
Northwest Hydraulic Consultants	project no. 3-4920	Jan.-2009

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Figure 6.8

7 PHASE 2 WORK PROGRAM

7.1 COMPLETION OF PHASE 1

Phase 1 as described in this report evaluated flood risks and proposed flood control solutions. The flood control solutions were put through a medium filtering process to eliminate non-advantageous options. The remaining options were ranked to indicate which options appeared most appropriate. All options retained after the filtering (Section 6.7) will go forward to Phase 2 to seek input from the City and the public.

Release of the Phase 1 report will be facilitated by Kevin Brown Communications Ltd. It will initially be presented to City of Prince George Council, followed by a media meeting. The report will also be available on the City website and presented to the community at large.

Displays, pamphlets, digital slides for webpage use, and other educational materials will be prepared for the use of the City and Council.

A proposed work program for Phase 2 is outlined below.

7.2 PUBLIC AND RELATED CONSULTATIONS

The Fraser Basin Council will conduct public and related consultations following completion of Phase 1. Additional material will be prepared as necessary to present the flood risk evaluation and recommended flood control options. The public consultation process will also involve NHC, MCSL, EDI, MMA and KB. The purpose is to provide information on the project and obtain feed-back.

The meetings will likely be held over two days and will be divided into:

- Meeting with staff of regulatory agencies.
- Public open house with posted maps, graphs, and handouts.
- Technical presentations by NHC, MCSL, EDI, and MMA with assistance from KB.
- Question and answer session.
- Meetings with specific groups.

7.3 TENTATIVE FLOOD CONTROL SOLUTIONS

Results from the public consultation process will be summarized. The preferred flood control options from Phase 1 will be reviewed and revised as appropriate, based on input received from the public and related consultations. Subsequent work will focus on refining the options that are selected and developing their implementation plans. Subject to confirmation of the tentative flood control options, anticipated tasks include the following:

Flood Control Infrastructure

Complete elementary concept designs and approximate cost estimates for a dike on the river side of River Road in Area A_N (South bank of Nechako River at Confluence), and for the raising of Preston Road in Area D_N (North Bank of Nechako River). Timelines will be prepared for property acquisition, regulatory approvals, design and construction, taking into account results from the public consultations.

Land Use

Land use changes considered necessary on the basis of risk analysis and feasibility assessment were proposed for:

Area A_N - South Bank of Nechako River at Confluence (land area north of River Road)

Area C_N - North Bank of Nechako River near Confluence (including optional local flood proofing)

Area E_N – North Bank of Nechako River Morning Place (including optional local flood-proofing)

Area B_F – Fraser River at South Fort George (including optional local flood-proofing)

Area D_F – Fraser River at Lansdowne South End (including optional local flood-proofing)

Further work on land-use changes is not anticipated in Phase 2.

River Options

Extraction of gravel from the river channels was assessed as ineffective for lowering design flood profiles (Appendix H). However, side-channel diversions or relief floodways are considered to be potentially beneficial. The removal of gravel from a bar at the exit of the Cottonwood Island side-channel has already received environmental approval. Elementary concept designs for further side-channel improvements at Cottonwood Island and along the Nechako north bank will be prepared. Processes necessary to obtain further approvals will be outlined, and associated costs and timelines will be estimated.

No Permanent Protection

For areas Area B_N (North Bank of Nechako River East of John Hart Bridge) and Area A_F (West bank of Fraser River at Yellowhead Highway) no provision of permanent protection was identified as the least-cost solution.

7.4 FINAL REPORTING

Final Reporting

A Phase 2 report will be prepared that provides selected flood control options, conceptual designs, cost estimates, needed approvals and timelines for implementation.

7.5 FLOODPLAIN MAPS

Mapping

Revised floodplain mapping will be prepared for City of Prince George, in conjunction with BC Ministry of Environment and in accordance with the Fraser Basin Council's Floodplain Mapping Guidelines and Specifications of March 2004. (This task will be done outside the present Phase 2 budget.)

8. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS (C)	RECOMMENDATIONS (R)
Flood Risk Evaluation	
C1. The dominant 200-year flood threat at Prince George for the Nechako River from the City boundary to about 1,250 m downstream of Cameron Street Bridge (to cross-section N6) is ice-related flooding. Downstream of this section and throughout the Fraser River study reach, the Fraser freshet is the dominant 200-year flood threat.	R1. To provide an effective response during flooding, it is recommended that the City of Prince George develop a flood response plan which should, among other elements, include: a. A real-time forecasting procedure for Fraser River freshet floods using flows predicted by MOE's River Forecast Centre and the hydraulic model developed for this project. b. A tool to monitor antecedent conditions conducive to ice jamming, when flows are greater than 200 m^3/s in combination with prolonged cold periods of temperatures less than -5^oC. A continuous recording gauge should be introduced at John Hart or Cameron Street Bridge to provide accurate flow and water level information.
C2. Historic air-photograph comparisons of Nechako River from 1928 to present indicate: a. the floodplain has been extensively developed; b. many side-channels have filled in; and, c. the extent (size) of vegetated islands has increased. The floodplain and river channel configurations will continue to evolve in the future. The design profiles developed reflect present channel conditions and may be subject to change.	R2. During future large flow events, high watermarks should be recorded and checked against the current numerical models for both freshet and ice-related floods on the Nechako River and freshet events on the Fraser River.

C3. Recent high ice-related and freshet flooding is not a result of river channel changes. A comparison of Nechako and Fraser River cross-sections from 1979/1995 and 2008 indicate: a. There is little change in terms of thalweg (lowest point) elevations, average bed elevations or cross-sectional areas. There is no evidence of significant aggradation or degradation, although the channel sections have changed shape as a result of gravel bar shifting. b. In the Nechako River, there is no apparent channel change upstream of the Foothills Bridge, some random increases and decreases in bed levels between the Foothills and John Hart Bridges and a general lowering of the bed downstream of Cameron Street Bridge. The most downstream cross-section (N1) shows some deposition. c. In the Fraser River, the thalweg at the CN Rail Bridge has in-filled, whereas the channel between the CN Rail Bridge and the Yellowhead Bridge has lowered. At the confluence (cross-sections F26 and F27), the average bed level has increased.	R3. In order to assess future channel changes more precisely, it is recommended that the river bed at the confluence be monitored. The 2008 grid bathymetric survey can be used as the baseline condition. Gravel storage and shifting of bars has taken place both before and after the construction of Kenney Dam. It should be recognized that this is a natural consequence of the flatter gradient within the lower Nechako River. Build-up of material may occur over a series of low/medium flow years with intermittent material removal during high flow years or ice-floods.
C4. Current operation of the Nechako Reservoir reduces the risk of flooding at Prince George. The present operating regime tends to lower winter flows during freeze-up which reduces the potential for ice-related flooding. In the spring, the reservoir delays the Nechako freshet peak by up to a month or until well after the Fraser River has peaked. Generally, the magnitude of the Nechako peak flow has been reduced by the operation of the reservoir.	R4. MOE in cooperation with Rio Tinto Alcan should be encouraged to predict the likely reservoir operations during a 200-year flood, so that the reducing effect on the design flow at Prince George can be estimated. Similarly, the extent to which flow releases can be reduced during freeze-up should be explored. If changes are introduced to the reservoir operation, the Nechako freshet and ice design flows need to be reviewed.

C5. The return periods of recent events are: a. Ice related (Nechako River) i. 2007-08 - estimated return period of 90 years. (In some instances, WSC reported flows at the different gauges along Nechako River appear not to add up in the downstream direction with reported tributary flows.) b. Freshet: (Fraser River) i. 2002 - estimated return period of 14 years; ii. 2007 - estimated return period of 19 years; iii. 2008 - estimated return period of 16 years.	R5. a) WSC should be requested to investigate apparent discrepancies in reported flows along the Nechako River, particularly for winter periods. b) The conversion to geodetic elevations at the Shelley gauge needs to be verified.
C6. Based on analysis of historic floods and available WSC flow records, the estimated 200-year design flows are: a. 1,450 m3/s for the Nechako River at Prince George (6% increase from the previous design flow used for the 1997 floodplain mapping). b. 5,660 m3/s for the Fraser River at Shelley (2% increase from previous design flow). c. 6,360 m3/s for Fraser River below Nechako River (3% increase from previous design flow).	R6. a) The analysis of hydraulic conditions on the Nechako and Fraser Rivers indicates a significant deviation from the previous design flood profiles. It is recommended that Prince George work with the Ministry of Environment to adopt the revised water surface design flood profiles. b) Considering the limited clearance of the CNR Bridge, CNR should be informed regarding the revised higher 200-year flood profile for the Fraser River.
C7. The floodplain mapping developed in 1997 is no longer valid. The primary reasons are: a. The previous study did not include ice modelling on the Nechako River. b. The updated design flows are higher, being based on longer record periods. c. On average, the Nechako River ice-related flood profile is 1.1 m higher than previously adopted. The revised Fraser River flood profile is on average 0.3 m higher. The rise in the profiles will expand the floodplain areas correspondingly.	R7. It is recommended that Prince George update the 1997 Floodplain Mapping based on the revised 200-year water surface profiles plus a freeboard allowance.

C8. Climate change and Mountain Pine Beetle infestation adds greater uncertainty to both winter and freshet flows. However, the recent above average freshet peaks and ice related flooding is unlikely the result of consistent change in the river basin or changing meteorological conditions. If a flow increase of 20% (assumed probable maximum) were to occur it would result in a corresponding average water level increase of 1.0 m for the Fraser River 200-year flood and 0.6 m for the Nechako River 200-year freshet flood.	R8. a) In consultation with MOE's Inspector of Dikes' office, an appropriate freeboard allowance for determining Flood Construction Levels at Prince George should be determined. A freeboard of 0.6 m, as generally assumed in this report, should be considered a minimum. In view of the increased uncertainty of climate change and Mountain Pine Beetle impacts, consideration should be given to increasing the Ministry of Environment standard freeboard allowance of 0.6 metres to 1.0 metres. b) More detailed hydrologic analysis and modelling would be required to examine how climate change and Mountain Pine Beetle infestation might change the flow regime in the Nechako and Fraser Rivers at Prince George. Results from current investigations of both factors by MOE's River Forecast Centre should be reviewed when available, and the need for additional work assessed.
Flood Control Solutions	
C9. Modelling various sizes and shapes of sediment removals (both bar scalping and dredging) for ice and open water conditions indicated that during 200-year flood conditions, the water surface profile does not change as a result of the removals. Sediment removals in the Nechako River would likely increase the amount of ice accumulation during ice-related flood events. The confluence ice levels and freshet backwater levels are set by the Fraser River hydraulic conditions below the confluence. Increasing the flow capacity of this steep, confined river reach through channel improvements is not practical.	R9. Sediment removal from the Nechako River or the Fraser River confluence is not considered a viable flood control solution for Prince George. Under present conditions, it is recommended that Prince George does not further pursue sediment removal from the main channels as a flood mitigation measure.
C10. Restoring and increasing the conveyance of Nechako River side-channels would reduce ice-related flood levels in the main channel downstream of the side-channel	R10. It is recommended that Prince George consider increasing the conveyance capacity of the Cottonwood Island side-channel by sediment excavation and debris removal. An

	entrances, as long as the entrances and channels remain ice-free. This applies to the existing Cottonwood Island side-channel and if land-use prescriptions allow, extension and recovery of the in-filled channel along the north bank.		inlet structure at the channel entrance would be required. If allowed by land-use change, reclamation of the side-channel previously in-filled by development along the north bank should also be considered.
C11.	Seven areas at risk of flooding were identified along the Nechako River and another seven along the Fraser River. The south and north banks of the Nechako River at the confluence are at greatest risk, since they are susceptible to flooding from both Fraser freshets and Nechako ice jams. Highest ranking solutions for the risk areas in order of priority are (order of magnitude cost estimates are shown in parenthesis): a. Area A_N - South Bank of Nechako River at Confluence - Build dike on river side of River Road, providing internal drainage and reducing groundwater seepage. Introduce land-use change north of River Road. ($15.5 M) b. Area C_N - North Bank of Nechako River near Confluence – Introduce land-use/zoning changes south of PG Pulpmill Road. On north side of road land-use change or local flood-proofing can be considered. ($9.3 M) c. Area D_N - North Bank of Nechako River West of John Hart Bridge - Raise Preston Road. Introduce land-use/zoning changes or local flood-proofing on river side of road. In the river side area, subdrains/ emergency protection may reduce flooding of buildings/basements.($1.2 M raising of road only) d. Area B_N - North Bank of Nechako River East of John Hart Bridge - No permanent protection, provide temporary protection as needed. Residents should be	R11.	a) It is recommended that the City of Prince George consider the solutions listed under Conclusion 11 and advance with the City's public consultation strategy. All options remaining after the medium filtering process (see Section 6.6) should be put forward for public consultation, with emphasis on the options that ranked the highest. b) Dike designs need to include internal drainage provisions and groundwater seepage prevention. c) Of all flood control solutions considered, land-use change involves the least maintenance and should be considered first where feasible. d) For evaluating environmental impacts of flood control solutions, it should be determined whether the Lower Nechako River is a sturgeon spawning area.

encouraged to include subdrains to reduce the potential for groundwater effects. Introduce land-use/zoning changes. e. Area B_F – South Fort George – Introduce land-use/ zoning changes as necessary. Optionally local flood-proofing can be considered in some locations. ($1.4 M) f. Area E_N – Morning Place – Introduce land-use/ zoning changes as necessary. Optionally, local flood-proofing can be considered in some locations. ($1.4 M) g. Area D_F – Lansdowne South End – Introduce land-use/zoning changes as necessary. Optionally local flood-proofing can be considered in some locations. ($0.8 M) h. Area F_N – South Bank of Nechako River at Foot Hills Bridge - Land-use/zoning changes as necessary. i. Area G_N – South Bank of Nechako River between John Hart and Foothills Bridges - Land-use/zoning changes as necessary. j. Area A_F – West bank at Yellowhead Highway - land-use/zoning changes as necessary. k. Area C_F – Hudson's Bay Slough west of Queensway – Review adequacy of existing protection. l. Area E_F – West Bank at Island – Undeveloped, introduce land-use/zoning changes as necessary. m. Area F_F – Northwood Pulp mill Road - Land-use/ zoning changes as necessary. Raise Landooz Road for access. ($5.8 M) n. Area G_F – Across River from Shelley - Land-use/ zoning changes.	

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10 GLOSSARY

10.1 ABBREVIATIONS

AOX	Absorbable organo-halides
BCEAA	British Columbia Environmental Assessment Act
BGC	Biogeoclimatic
CDC	Conservation Data Centre
CEAA	Canadian Environmental Assessment Act
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
DFO	Department of Fisheries and Oceans
EDI	Environmental Dynamics Inc
FCL	Flood Construction Level
FEMA	Federal Emergency Management Agency
FHAP	Fish Habitat Assessment
GIS	Geographic Information System
GPS	Global Positioning System
HADD	Harmful alteration, disruption, or destruction
KBC	Kevin Brown Communications
LTN	Lheidli T'enneh First Nation
MMA	M Miles and Associates Ltd
MCSL	McElhanney Consulting Services Ltd
MBCA	Migratory Birds Convention Act
MOE	Ministry of Environment
NHC	Northwest Hydraulic Consultants Ltd
PCIP	Pacific Climate Impacts Consortium
PG	City of Prince George
RTA	Rio Tinto Alcan
RTK	Real-time kinetic GPS
SARA	Species at Risk Act
SBS	Sub-boreal spruce
UFFCA	Upper Fraser Fisheries Conservation Alliance
VIC	Variable Infiltration Capacity Macroscale Hydrologic Model (developed at University of Washington to compute run-off)
WMA	Wildlife Management Area
WSC	Water Survey of Canada

10.2 TECHNICAL TERMS

200-year flood
A flood that, on average, occurs once in 200 years.

Active channel
The portion of a river channel that actively conveys flow.

Adfluvial
Fish that live in lakes and migrate into rivers or streams to spawn.

Aerial radio-telemetry survey
The monitoring of radio transmitter-tagged fish from an airplane.

Aggradation
The geologic process by which stream beds, floodplains, and the bottoms of other water bodies are raised in elevation by the deposition of material eroded and transported from other areas. It is the opposite of degradation.

Aggregate mining
Extraction of sand, gravel and stone material, generally used as an engineered soil base for stability or in the form of concrete or asphalt products.

Alluvial
Pertains to alluvium deposited by a stream or flowing water.

Anadromous
Fish that spend all or part of their adult life in salt water and return to freshwater streams and rivers to spawn.

Backeddy
A circular current of water, diverging from and initially flowing contrary to the main current. It is usually formed at a point at which the flow passes some obstruction or on the inside of river bends.

Backwater
Raised water levels produced by obstructing or constricting a channel.

Bar scalping
Excavation from the tops of gravel bars during the dry season.

Bed Load
Material moving on or near the stream bed by rolling, sliding, and sometimes making brief excursions into the flow a few grain diameters above the bed, i.e. jumping. The term "saltation" is sometimes used in place of "jumping". Bed load is bed material that moves in continuous contact with the bed; contrast with "suspended load".

Bed Material
The sediment mixture of which the river bed is composed. In alluvial streams, bed material particles are likely to be moved at any moment or during some future flow condition.

Bed material transport index
Calculated values used to investigate changes in the sedimentation process in a river.

Bed Forms
Irregularities found on the bottom (bed) of a stream that are related to flow characteristics. They are given names such as "dunes", "ripples", and "antidunes". They are related to the transport of sediment and interact with the flow because they change the roughness of the stream bed.

Bed roughness
A numerical factor which expresses the frictional effect that the river bed exerts on the flow.

Boundary Conditions
Definition or statement of conditions or phenomena at the boundaries. Water levels, flows, concentrations, etc., that are specified at the boundaries of the area being modelled. A specified tailwater elevation and incoming upstream discharge are typical boundary conditions.

Braided Channel
A stream that is characterized by random interconnected channels divided by islands or bars. Bars which divide the stream into separate channels at low flows are often submerged at high flow.

Calibration
Adjustment of a model's parameters such as roughness or dispersion coefficients so that it reproduces observed prototype data to acceptable accuracy.

Channel
A natural or artificial waterway which periodically or continuously contains moving water.

Channel bathymetry
The depth of a river bed, generally collected by a sonar depth sounder. The data may be presented as a map with depth contour lines along the river bed.

Channel incision
A section of the channel where the streambed degrades until the critical bank height is exceeded and the bank fails, increasing channel width and sediment load.

Channel instability
Lateral or vertical shifts in a river channel.

Channel morphometry
The measurement of channels.

Confluence
The point where a tributary joins the mainstem of a river.

Consolidated cover
A previously juxtaposed ice cover that has collapsed and shoved in to a dense, thicker form.

Conveyance
A measure of the flow carrying capacity of a channel section. Flow is directly proportional to conveyance for steady flow. From Manning's equation, the proportionality factor is the square root of the energy slope.

Cooling flows
Flows released to lower the temperature of the water in a river.

Cover load
Ice slush transported under an ice cover.

Critical habitat
The geographic area occupied by listed or endangered species.

Cross Section
Depicts the shape of the channel in which a stream flows. Measured by surveying the stream bed elevation across the stream on a line perpendicular to the flow. Necessary data for the computation of hydraulic and sediment transport information.

Cross-sectional Area
The cross-sectional area is the area of a cross section perpendicular to the direction of flow beneath the water surface.

D50 value
D50 is a particle diameter at which 50% of the particles have diameters which are smaller than the D50 value.

Degradation
The geologic process by which stream beds, floodplains, and the bottoms of other water bodies are lowered in elevation by the removal of material from the boundary. It is the opposite of aggradation.

Degree-days of freezing
A measure of how cold it has been and how long it has been cold; it is usually calculated as a sum of average daily degrees below freezing for a specified time period.

Delta
A deposit of sediment formed where moving water (as from a stream at its mouth) is slowed by a body of standing water.

Depth of Flow
The depth of flow is the vertical distance from the bed of a stream to the water surface.

Deposition
The mechanical or chemical processes through which sediments accumulate in a (temporary) resting place. The raising of the stream bed by settlement of moving sediment that may be due to local changes in the flow, or during a single flood event.

Design Flood
A flood, which may occur in any given year, of such magnitude as to equal a flood having a particular recurrence interval (for example 200 years), based on a frequency analysis of unregulated historic flood records or by regional analysis where there is inadequate streamflow data available. The flood of record may also be used for the design flood if equal to or greater than the 200-year flood.

Design Flood Level
The observed or calculated elevation for the Design Flood and is used in the calculation of the Flood Construction Level.

Digital Elevation Models (DEMs)
DEMs model the elevation of the land (z-values) at regularly spaced intervals in x and y directions (easting and northings). DEMs are usually displayed as uniformly spaced grids. Because of the uniform point spacing, DEMs can "jump over" breaklines without identifying ditches, stream centerlines, steep banks, and other similar features. However, DEMs are simple data models, easy to store, and suitable for automated hydrologic analyses and modeling where breakline information is unimportant.

Dike
An embankment, wall, fill or piling constructed to prevent the flooding of land: A "private dike" means a dike built on private property without public funds to protect only the property of the person owning the private dike.

Diking Authority
A Diking Authority is defined as:

- the commissioners of a district to which part 2 of the Drainage, Ditch and Dike Act applies,
- a person owning or controlling a dike other than a private dike,
- a public authority designated by the minister as having any responsibility for maintenance of a dike other than a private dike,
- a regional district, a municipality, or an improvement district.

Discharge
The discharge, usually abbreviated as "Q", is the volume of a fluid or solid passing a cross section of a stream per unit time.

Disturbance regime
Various modes of widespread ecosystem disturbance, e.g., flood, fire, disease or wind, or a combination thereof.

Drainage basin
A drainage basin is an extent of land where water from rain or snow melt drains downhill into a body of water, such as a river, lake, reservoir, estuary, wetland, sea or ocean. The drainage basin acts like a funnel, collecting all the water within the area covered by the basin and channelling it into a waterway. The drainage basin includes both the streams and rivers that convey the water as well as the land surfaces from which water drains into those channels, and is separated topographically from adjacent basins by a geographical barrier such as a ridge, hill or mountain, which is known as a water divide.

Dredging
Dredging is an excavation activity or operation usually carried out at least partly underwater, in shallow seas or fresh water areas with the purpose of gathering up bottom sediments and disposing of them at a different location.

Dunes
Bed forms with triangular profile that advance downstream due to net deposition of particles on the steep downstream slope. Dunes move downstream at velocities that are small relative to the streamflow velocity.

Dynamic Model
A mathematical model of flow in an open channel that solves the complete unsteady flow equations (St. Venant equations for one-dimensional problems).

Earth dike
An earth dike is a berm or ridge of compacted soil located in a manner to channel water to a desired location. They are used to control erosion, sedimentation, or prevent flooding.

Equilibrium ice cover
A stable, consolidated ice-cover.

Erosion
The wearing away of the land surface by detachment and movement of soil and rock fragments through the action of moving water and other geological agents.

Fixed Bed Model
Model in which the bed and side materials are non-erodible; deposition does not occur either.

Flood Construction Level (FCL)
The FCL is the design flood level plus an allowance for freeboard. It is used to establish the elevation of habitable areas of buildings and the minimum crest level of a Standard Dike.

Where the Design Flood Level cannot be determined or where there are overriding factors, an assessed height above the natural boundary of the water-body or above the natural ground elevation may be used.

Flood profile
A graph of computed flood elevations at floodplain cross-sections.

Floodbox
They are installed in dikes to control the flow of upland water through creeks or sloughs into estuaries or rivers. Doors or lids are attached to the discharge ends of the culverts to control water flow, commonly referred to as tide gates or flap gates. Tide gates close during incoming (flood) tides to prevent tidal waters from moving upland. They open during outgoing (ebb) tides to allow upland water to flow through the culvert and into the receiving body of water.

Floodplain
A lowland area, whether diked, flood proofed, or not which, by reasons of land elevation, is susceptible to flooding from an adjoining watercourse, ocean, lake or other body of water and for administration purposes is taken to be that area submerged by the Design Flood plus freeboard.

Floodway
The stream channel and adjacent areas that carry flood flows.

Flow capacity
A description of how much fluid is being moved and how much work is being performed, usually measured in m^3 per second in river applications.

Flow resistance
Any factor within a channel that impedes the flow of fluid, such as surface roughness or sudden bends, contractions, or expansions.

Fluvial deposit
A sedimentary deposit of material transported by or suspended in a river.

Fluvial terrace
The portion of a river valley lying adjacent to the modern floodplain. Sediments of these landforms were deposited in the recent past (Quaternary) and are now undergoing dissection and destruction. They are not subject to flooding, except under the most extreme conditions. They are typically composed of non-to slightly-lithified sand and gravel.

Frazil
A collection of loose, randomly oriented needle-shaped ice crystals in water.

Frazil Floe
Frazil that has clustered to form ice pans or small sheets of ice.

Freeboard
A vertical distance added to the Designated Flood Level. Used to establish the Flood Construction Level.

Freeze-up
The formation of ice on open water.

Frequency
The number of repetitions of a random process in a certain time period.

Frequency curve
A graphical representation of a continuous frequency distribution.

Freshet
A flood resulting from spring thaw.

Froude number
A dimensionless number significant in classifying and analyzing open channel flow phenomena, based on velocity.

Gabion
A galvanized wire basket with a removable top. The basket, filled with selected stones, is used to stabilize banks to control erosion in streams and to prevent stream gravel from shifting.

Gauge Height
Also known as stage, gauge height is the height of the water in the stream above a reference point. Gauge height refers to the elevation of the water surface in the specific pool at a stream gauging station, not along the entire stream. Gauge height does not refer to the depth of the stream.

Gauging Station
A selected cross section of a stream channel where one or more variables are measured continuously or periodically to record discharge and other parameters.

Geodetic elevation
Survey datum set by Geologic Survey of Canada

Glacio-fluvial terrace
See fluvial terrace. Material originating from glacier.

Grid
Network of points covering the space or time-space domain of a numerical model or river bed. The points may be regularly or irregularly spaced.

Glide
A slow-moving, relatively shallow type of river run. Calm water flowing smoothly and gently, with moderately low velocities and little or no surface turbulence.

Groundwater
Water located beneath the ground surface in soil pore spaces.

GSC datum
See geodetic elevation.

Headwater
The source of a river or stream, i.e. the place from which the water in the river or stream originates.

HEC-RAS
An acronym for the U.S. Army Corps of Engineers Hydrologic Engineering Centers River Analysis System. HEC-RAS is a one-dimensional backwater software for modelling steady flow, unsteady flow, sediment transport and water temperature.

Hydraulic Depth
The hydraulic depth is the ratio of cross-sectional area to top width at any given elevation.

Hydraulic Modeling
A small-scale physical or numerical representation of a flow situation.

Hydraulic Shear
The transport of a fluid at different velocities at different positions within the flow.

Hydrograph
A graph showing, for a given point on a stream or channel, the discharge, water surface elevation, stage, velocity, available power, or other property of water with respect to time.

Ice cover
The accumulation of ice blanketing water surfaces.

Ice floes
Frozen masses that float on the water surface.

Ice jamming
Occurs when water builds up behind a blockage of ice.

Initial Conditions
The values of water levels, velocities, concentrations, etc., that are specified everywhere in the grid or mesh at the beginning of a model run. For iterative solutions, the initial conditions represent the first estimate of the variables the model is trying to compute.

Internal friction
The force resisting motion between the elements making up a material while it undergoes deformation.

Interstitial space
Space between (ice) crystals.

Juxtaposed cover
The accumulation of a single layer of frazil pans.

Lacustrine
Relating to a lake.

Large woody debris
Wood material (>10 cm dia. And >2 m long) that mainly enters stream channels from stream bank undercutting, windthrow, and slope failures. They provide habitat for Pacific Northwest salmon.

LiDAR
An acronym for Light Detection and Ranging, LiDAR is a collection of georeferenced digital earth surface data.

Local flow velocity
A vector field which is used to mathematically describe the motion of a fluid in a localized area.

Lock block retaining walls
A concrete modular block system that allows for quick and safe erection of a gravity retaining wall.

Lodgement
An accumulation or collection deposited in a place or remaining at rest.

Log Pearson Type III distribution
A statistical distribution of annual maximum discharges which help calculate flood occurrence for a given river or stream.

Low profile dike
A non-standard dike forming a platform for temporary emergency flood protection.

Manning's roughness coefficient, n
n is a coefficient of boundary roughness and accounts for energy loss due to the friction between the bed and the water. In fluvial hydraulics (movable boundary hydraulics), the Manning's n value usually includes the effects of other losses, such as grain roughness of the movable bed, form roughness of the movable bed, bank irregularities, vegetation, bend losses, and junction losses. Contraction and expansion losses are not included in Manning's n, and are typically accounted for separately.

Maximum daily flow
The maximum flow that occurs over the course of a single day.

Maximum instantaneous flow
The momentary maximum flow that occurs during a day.

Mean annual discharge
The discharge averaged over an entire year.

Meandering Stream
An alluvial stream characterized in planform by a series of pronounced alternating bends. The shape and existence of the bends in a meandering stream are a result of alluvial processes and not determined by the nature of the terrain (geology) through which the stream flows.

Monthly minimum flow
The smallest average flow reported for a particular month.

Natal stream
Location of the birth of a fish or other aquatic animal.

Numerical Model
A numerical model is the representation of a mathematical model as a sequence of instructions (program) for a computer. Given appropriate data, the execution of this sequence yields an approximate solution to the set of equations that comprise the mathematical model.

Off-channel habitat
Created by long-term processes of alluvial deposition, channel migration, and changes in stream bed elevation, they may be used by salmonid species such as chum or coho. Off-channel habitats include overflow, groundwater, and wall-based channels.

Outmigration
Fish moving from one body of water to another.

Overbank
In a river reach, the area between the bank of the main channel and the limits of the floodplain.

Overbank coefficient
A factor that accounts for energy loss due to the friction between the overbank bed and the water.

Overwintering
To pass through or wait out the winter season, or to pass through that period of the year when “winter” conditions (cold or sub-zero temperatures, ice, snow, limited food supplies) occur.

Point bar
An alluvial deposit adjoining a stream bank, usually on the inside of a bend.

Pool
A portion of a stream with reduced current velocity, often with water deeper than the surrounding areas, and which is frequently used by fish for resting or cover.

Porosity
A measure of the void spaces in a material, and is measured as a fraction, between 0–1, or as a percentage between 0–100%. Well sorted (grains of approximately all one size) materials have higher porosity than similarly sized poorly sorted materials (where smaller particles fill the gaps between larger particles).

Pro-rated flow
An estimated flow in a given river, calculated using a ratio by knowing the drainage area of the first river, and the flow and drainage area of a second river.

Rating curve
A chart that shows the relationship between the river flow and the stream stage. Increasing stream stage corresponds to an increasing stream discharge or flow.

Reach
A length of a stream or river.

Rearing habitat
Aquatic habitat used by juvenile fish that provides suitable depths, velocities and cover - overhead vegetation, woody debris, substrate or hydraulic cover - as well as food sources - drift, instream or drop - that provide fish growth.

Regulated flow
River flows controlled by releases at dams or other water-control structures.

Reservoir inflow
Generally comprised of tributary flow, watershed runoff, and precipitation.

Return period
An estimate of the time interval between events like a flood or river discharge of a certain intensity or size. It is a statistical measurement denoting the average recurrence interval over an extended period of time.

Riffle
A shallow rapids where the water flows swiftly over completely or partially submerged obstructions to produce surface agitation, but standing waves are absent.

Ring dike
A localized dike built around structures or land to protect it from flooding.

Riparian vegetation
The land adjacent to the normal high waterline in a stream or lake whose soils and vegetation are influenced by the presence of the ponded or channelized water.

Riprap
Stones placed as erosion protection.

River2D
A two dimensional depth-averaged finite element hydrodynamic model, customized for fish habitat evaluation studies.

Riverbank dike
Dikes built directly adjacent to rivers to protect against flooding that may occur from high tides, storm surge or flood flows.

Roughness
The roughness of the bed and banks of a stream or river. The greater the roughness, the greater the frictional resistance to flows; and hence, the greater the water surface elevation for any given discharge.

Roughness coefficient
Numerical measure of the frictional resistance to flow in a channel (see Manning's n).

Run
An area of swiftly flowing water, without surface agitation or waves, which approximates uniform flow and in which the slope of the water surface is roughly parallel to the overall gradient of the stream reach.

Run-off
The water flow which occurs when soil is infiltrated to full capacity and excess water, from rain, snowmelt, or other sources flows over the land.

Schematization
Representation of a continuum by discrete elements, e.g., dividing a real river into reaches with constant parameters.

Scour
The enlargement of a cross section by the removal of boundary material through the action of the fluid in motion.

Secondary channel
See Side-channel.

Secondary consolidation
Consolidation is a process by which a juxtaposed ice-cover is compressed into a thicker layer of ice. Secondary consolidation takes place after primary consolidation, and is caused by increased forces on the ice cover, sudden changes in the discharge or dramatic temperature fluctuations.

Sediment
(1) Particles derived from rocks or biological materials that have been transported by a fluid. (2) Solid material suspended in or settled from water. A collective term meaning an accumulation of soil, rock, and mineral particles transported or deposited by flowing water.

Sediment loading
The deposition of sediment load from one area of a channel to another. Sediment load is made up of organic and inorganic matter that is suspended in and carried by moving water, and coarse materials such as gravel, stones, and boulders that move along the bottom of the channel.

Sedimentation
Refers to the gravitational settling of suspended particles that are heavier than water.

Setback dike
Dikes that are constructed at a distance from the river channel in order to allow the river to occupy a portion of its floodplain.

Setlines
A long heavy fishing line to which several hooks are attached in series.

Shields number
A value used to denote conditions under which bed sediments are stable but on the verge of being moved.

Shore ice
Ice that forms along the river banks.

Side-channel
A lateral channel with an axis of flow roughly parallel to the main stem, which is fed by water from the main stem; a braid of a river with flow appreciably lower than the main channel.

Slope armouring
The protection of river banks or dike slopes.

Smolting
A seaward migrating juvenile salmonid, which is silvery in color, has become thinner in body form and is physiologically prepared for the transition from fresh-to saltwater.

Spawning
The production and depositing of large quantities of eggs in water, by marine animals such as amphibians and fish.

Specific gauge plot
At a specific location along a river, a graph showing the water level for a particular flow over time. Used to determine if the river channel at the specific location is aggrading or degrading.

Stage
Height of water surface above a specified elevation.

Stage-Discharge (Rating) Curve
Defines a relationship between discharge and water surface elevation at a given location.

Streambed scour
Lowering of streambed or undermining of foundations by erosive action of flowing water.

Substrate
The river bed material below the surface armouring.

Suspended sediment
Solid particles transported in a fluid media or found in deposit after transportation by flowing water, wind, glacier and gravitational action.

Terrace
A geological term for a flat platform of land created alongside of a river or sea, where, at some time in the past, the river has cut itself a deeper channel. The former floodplain of the river is therefore at a higher point and is known as a terrace. Rivers can create a sequence of terraces over millennia as they erode away more material.

Thalweg
The line following the lowest part of a valley, whether under water or not. Usually the line following the deepest part, generally close to the middle of a river channel.

Thermal ice
Ice formed in situ by freezing of the water or the water/frazil mixture.

Thermal load
Locally heated water preventing or delaying the formation of ice.

Threshold velocity
The minimum velocity at which wind or water begins to move particles of soil, sand, or other material at a given place under specified conditions.

Training Works
Any wall, dike or protective structure used to prevent a stream from leaving its channel at a given location. This includes any debris flow training structures including basins, trash racks, or other works.

Transport capacity
The capacity of a river to transport sediment.

Triangulated Irregular Networks (TIN)
A TIN is a set of adjacent, non-overlapping triangles, computed from irregularly spaced points with x/y coordinates and z-values. The TIN data structure is based on irregularly spaced point, line, and polygon data interpreted as mass points and breaklines.

Tributary
A stream or river which flows into a mainstem (or parent) river.

Turbidity
The cloudiness or haziness of a fluid caused by individual particles (suspended solids), that are generally invisible to the naked eye, similar to smoke in air. The measurement of turbidity is a key test of water quality.

Unsteady-State Model
Model in which the variables being investigated are time dependent.

Verification
Check of the behaviour of a calibrated model against a set of prototype conditions that was not used for calibration.

Water surface slope
Fall per unit length along the water surface centerline of the channel.

Watershed
An area of land (the catchment or drainage basin), bounded by a topographic height of land, that delivers water along a stream channel to a common outlet.

Wetted perimeter
The length of the line of intersection of the channel wetted surface with a cross-sectional plane normal to the direction of flow.

0 250 500 1,000 1,500 2,000 Metres Scale: 1:35,000

Legend - Year of Survey

- XS (1979 & 2008)
- XS (1995)
- XS (1979)

Coord. System: UTM Zone 10
Datum: NAD 83
Units: Metres
Notes: Satellite image from Google Earth

City of Prince George

nhc

Fraser River above Nechako River Cross-Section Locations

January 2009 | Map 1

0 250 500 1,000 1,500 2,000 Metres

Scale: 1:35,000

Legend - Year of Survey

- XS (1995 & 2008)
- XS (1995)
- XS (1979 & 2008)
- XS (1979)
- XS (2008)
- XS_C (2008)

Coord. System: UTM Zone 10
Datum: NAD 83
Units: Metres
Notes: Satellite image from Google Earth

City of Prince George nhc

Nechako River
Cross-Section Locations

January 2009 | Map 2

GDL V10.0.3.10\projects\34920 PG FPM\GIS_XS

0 250 500 1,000 1,500 2,000 Metres Scale: 1:35,000

Legend - Year of Survey

- XS (1995 & 2008)
- XS (1995)
- XS (1979 & 2008)
- XS (1979)
- XS (2008)

Coord. System: UTM Zone 10
Datum: NAD 83
Units: Metres
Notes: Satellite image from Google Earth

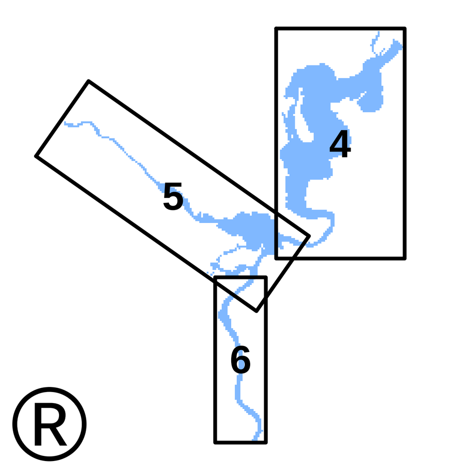
City of Prince George nhc

Fraser River below Nechako River
Cross-Section Locations

January 2009 | Map 3


CITY OF PRINCE GEORGE
Flood Risk Areas
Fraser River above Nechako,
Map 4
Scale - 1:15,000
500 250 0 500
Metres
coord. syst.: UTM Zone 10
horz. datum: NAD 83
horz. units: metres
northwest hydraulic consultants
project no. 3-4920
Jan-2009
Notes:
- 2006 orthophotos supplied by McElhanney Consultings Services Ltd.
- 23 Sep 2000 Landsat 7 satellite image supplied by GeoBase.ca.
Legend
Hydrometric Station
Flooded Area 1972
Flooded Area 1948
Areas at Risk
1997_Floodplain
Municipal Boundary
Map Panel Index
4
5
6
FRASER RIVER AT SHELLEY
FRASER RIVER AT PRINCE GEORGE
GF
FF
EF
Map Panel 4

Map Panel Index



Legend

- Hydrometric Station
- Ice Jam Flooding 2007/2008
- Groundwater Flooding 2007/2008
- Flooded Area 1972
- Flooded Area 1948
- Areas at Risk
- 1997 Floodplain
- Municipal Boundary

Notes:
- 2006 orthophotos supplied by McElhanney Consultings Services Ltd.
- 23 Sep 2000 Landsat 7 satellite image supplied by GeoBase.ca.

CITY OF PRINCE GEORGE

Flood Risk Areas
Nechako River and Fraser River below Nechako, Maps 5 and 6

Scale - 1:15,000

500 250 0 500 Metres

coord. syst.: UTM Zone 10	horz. datum: NAD 83	horz. units: metres
northwest hydraulic consultants	project no. 3-4920	Jan-2009

APPENDIX A

TERMS OF REFERENCE

CITY OF
PRINCE GEORGE

Terms of Reference for
Flood Risk Evaluation and Flood Control Solutions

Nechako and Fraser Rivers

February 2008

1. Introduction

Flooding of lands within the City of Prince George has occurred during the 2007 spring freshet and now during the winter ice jam beginning December 10, 2007. The freshet flooding affected lands at the confluence of the Fraser and Nechako Rivers and along the Fraser River at Landooz Road and the Farrell Crescent and Regents Crescent area. The Nechako River ice jam has flooded residential properties in the PG Pulpmill Road, Pozer Road, Preston Road and Morning Place areas. Flooded industrial areas include North Nechako Road, Ongman Road, McAlhoney Road, River Road, Foley Crescent and Kelliher Road. One of the City's water supply wells was threatened, but not affected because of floodproofing improvements made ten years ago.

Freshet flooding of the Fraser River threatens or occurs in the floodplain areas about every five years or so. The last major flood (greater than 20-year flood) occurred in the early 1970's after which the residents of the Island Cache area at the confluence were relocated and the residences removed.

Ice jam flooding on the Nechako River has been recorded 12 times since the early 1900's [Floodplain Mapping Fraser and Nechako Rivers at Prince George, Design Brief, Province of British Columbia, Ministry of Environment, Lands and Parks, Klohn-Crippen, May, 1997].

The current ice jam flooding event beginning December 10, 2007 in the City of Prince George appears to have surpassed the flooding experienced with passed events of the last 50 years. According to the 1997 Klohn-Crippen report, the Nechako discharge rate of 246 cubic metres per second recorded January 12, 2008 at the Foothills Bridge was only surpassed once during an ice jam event in March of 1957, when the discharge was recorded at 311 cubic metres per second. The sustained flow of the Nechako over the 2007-2008 winter appears to be caused by an extended discharge of flow from the Nechako Basin lakes and the reservoir that received runoff caused by snow levels of up to 200 percent during the winter of 2006-2007.

On two occasions during the current event, December 31, 2007 and January 5, 2008, ice jam compressions breached the temporary berms and sand gabion dykes that had been constructed to the 200-year flood level. The January 5th compression exceeded a level of up to 0.3 metres over the 200-year ice jam flood level.

These events have initiated the need to review the risk to the City of Prince George to both freshet and ice jam flood events, especially at the Nechako River and Fraser River confluence where several industries, the CN railway yard and inter-modal facility, and much of the downtown are at risk to flooding. The City of Prince George, with the assistance of Emergency Management BC, is proceeding with a flood risk evaluation and flood control solutions study to consider the long term options to reduce the risk of flooding and to protect floodplain lands within the City. The services of a qualified engineering firm are required to perform the flood risk evaluation and to develop solutions for flood control.

2. Background

Since construction of the Kenney Dam in the early 1950's, Nechako River flooding due to the effects of ice appears to occur mostly at freeze-up. During freeze-up, an ice cover forms on the Nechako River at Prince George in most years due to the accumulation of frazil floes against the ice cover on the Fraser River. The frazil is generated along the river upstream of Prince George in response to sub-zero air temperatures, with the frazil forming into ice floes as it moves downstream. The ultimate timing of when the ice cover begins to form on the Nechako River depends on when the ice cover forms on the Fraser River – it is unlikely that a cover will form on the Nechako River unless lodgement is initiated against ice on the Fraser River. The severity of the ice jam (peak water levels, thickness of the ice accumulation, and the length of the ice accumulation) is a function of both the flow on the Nechako River and the severity of the winter. The flow varies from year to year, depending on Alcan releases at Skins Lake Spillway, outflows from Fraser and Stuart Lakes, and local inflows from tributaries such as the Chilako River. The winter severity also is quite variable, and in years with prolonged periods of cold weather, sufficient ice can be generated to produce thick accumulations of ice that may extend several kilometres upstream of the Fraser River along the Nechako River.

Ultimately, the likelihood of experiencing high ice-related water levels along the Nechako is related to the combined risk of experiencing cold temperatures and high flows during freeze-up. This can happen quite frequently – for example water levels at freeze-up have approached or exceeded the 20-year open water level twice in the last ten years. In both cases, flood damages occurred due to both surface water flooding and high groundwater levels in the floodplain adjacent to the river.

The ice jam flooding event of 2007-2008 and spring freshet Fraser River flooding has raised questions with regard to the cause of the events, the solutions deployed to deal with the event, the adequacy of the City's floodplain mapping and the regulatory processes for development of lands with the floodplain.

3. Phase 1 - Flood Risk Evaluation

Phase 1 Report <u>Reference</u>

3.1 Risk Analysis

Section 5

The City of Prince George with the assistance of Emergency Management BC has prepared the following outline for the flood risk analysis. The analysis is broken into five stages: threat analysis, consequence analysis, flood relief options, priority setting and coarse filtering.

- **Threat Analysis** - A systematic use of available information to determine how often specified events occur and the magnitude of the consequences. For example, how often will the flood occur and how big will the flooding be? The analysis will require the preparation of: **Section 5.1**
    - o a review of the historical documentation of past flood events, including, river discharge prior to and during flood events, climate information and weather patterns leading up to and during flood events, and river levels during flood events; **Section 3** **Section 4**

  - a map to demonstrate the impact of the past flood events; **Maps 4-6**
  - a review of the development of the existing flood plain mapping and its reliability in predicting flood level frequency; **Section 1.1.2 and 3.6.3**
  - recommendations for the review during the feasibility assessment. **Progr. Report 1**

- **Consequence Analysis** – A review of infrastructure, residential, commercial and industrial assets within the flood plain. Tasks for this analysis include: **Section 5.3**
  - prepare an infrastructure inventory with replacement values of public-owned assets within the floodplain including roads, bridges, community wells, trails, parks, water and sanitary sewer pipelines, storm sewer outfalls, etc.;
  - prepare an inventory with replacement values of private-owned utility assets such as BC Hydro, Telus, Terasen, Shaw Cable and others;
  - prepare an inventory with assessed values of properties within the flood plain, including on-site assets;
  - assess and rank public-owned and private-owned assets on the basis of vulnerability to flooding, i.e. functionality and accessibility during a flood event, criticality of asset, flood damage costs, etc.
  - assess and rank properties based on vulnerability to flood damage, for example, floor elevation, setback from riverbank, extent of onsite flood-proofing, etc.

- **Flood Relief Options –** Categorize floodplain areas prone to flooding as identified during the 2007-2008 flooding event. Identify flood relief options for these areas with concept level costs for the purpose of comparative analysis and priority setting. Consider options that may include, but not limited to, land use change, permanent dyking (with or without groundwater cut-offs or sub-drains), side channel floodways, gravel extraction (dredging), and upstream diversion or regulation. Review impact of existing temporary works and works installed by property owners during the current ice-jam. **Section 6**

- **Priority Setting** – Use a decision-matrix, benefit-cost analysis or other suitable method to prioritize the flood relief options. Priority analysis to consider public safety, environmental impact, land values, economic impact, life-cycle cost of mitigation measures, etc. Prepare priority assessment. **Progr. Report 1 Appendix F**

- **Coarse Filtering** – Summarize results of the above analysis in a report with the objectives of eliminating flood relief options not recommended as a result of the risk analysis and in further investigating mitigation measures during the feasibility assessment. Present the options that will be further analyzed in the feasibility assessment. **Section 6.1**

3.2 Feasibility Assessment

Following the risk analysis, complete a feasibility assessment for the recommended flood relief options considered for the freshet and ice-jam flood events on the Nechako and Fraser Rivers.

1. **Data Collection and Review –** Obtain information not already compiled for the risk analysis. Data sources may include field investigations and obtaining topographic information from City GIS database. Collect data available from provincial and federal agencies. Review data for completeness and determine what further data collection is required and how it will be obtained. **Sections 3,4,5**

2. **Hydrological Analysis –** Using standard industry techniques and models to perform the hydrologic and flood frequency analyses for the Fraser River and Nechako River systems (see Appendix A). Consider the broad impacts of climate change using any available regional climate change models. Conduct a sensitivity analysis to present probability of flood level changes. **Section 3**

3. **Soils and Geotechnical Investigation –** Review available data from the City's ongoing River Confluence Groundwater Monitoring Program and from recent soils/geotechnical studies available from the City of Prince George. Conduct preliminary field investigations as necessary for the recommended flood relief options identified in the Risk Analysis. Determine availability of borrow material (suitable dike fill, riprap, impervious material, etc.). **Appendix G**

4. **River Hydraulics, Freshet and Ice-Related Flooding Analysis –** Refer to Appendix A for a description of the methodology for determining freeze-up characteristics, forecasting ice-related water levels and local river hydraulic characteristics. Consider allowance for ice jam wave events (javes) with respect to elevation of flood protection works and assess if design of works should allow for overtopping during such javes. Conduct bathymetric surveys at the confluence, bridge structures and at selected salient locations as necessary. Assess the recommended flood relief options with respect to their impact on river migration, existing bridges, the river banks, riparian area and riverfront properties upstream, downstream and lateral to the proposed works. **Section 3**

5. **Environmental Impacts –** Conduct preliminary environmental impact assessments for land-base or in-river flood relief options. Identify the processes necessary to obtain approvals complete with cost estimates and time lines – e.g. fisheries window for works within the river or riparian zone. Include concepts and preliminary costs for landscaping that is compatible with riparian and riverbank areas. **Section 6.3** **Section 6.6.2**

6. **Floodplain (Internal) Drainage Considerations** – Assess the requirement for drainage and groundwater diversion works in areas to be protected by flood protection works (i.e. dikes). Diversion works may include subdrains, pumpstations, floodboxes, ditches, relief wells, cut-offs, etc. Prepare preliminary cost estimates for such works. **Appendix G**

7. **Property Acquisition** – Identify lands to be purchased or rights-of-way to be obtained for construction of flood protection works. Prepare cost estimates based on assessed values and consultation with City's Real Estate Services Division. **Section 6.4**

8. **Medium Filtering –** Present the results of the above analysis in a report document with the objectives of eliminating flood relief options not feasible as a result of the feasibility assessment. Recommend flood control solutions that mitigate flooding and that will be further assessed and estimated for cost in Phase 2 - Flood Control Solutions. **Section 6.7**

3.3 Report

Present Phase 1 findings and report to City of Prince George Staff and to Mayor and Council.

4. Phase 2 - Flood Control Solutions

To be completed

4.1. Public Consultation

1. Allow for three separate trips to Prince George to participate in public meetings with stakeholders and property owners impacted by the recommendations of the Flood Risk Evaluation. Prepare displays, pamphlets, digital slides for webpage and other education materials for the City's use in presenting the results of the Flood Risk Evaluation and the recommended flood control solutions.

4.2. Select Flood Control Solutions

Summarize the results of the public consultation process and revise recommended solutions to control and provide protection from flooding or to reduce the risk of flooding for flood plain areas on the Fraser and Nechako Rivers.

- **Flood Control Infrastructure** – Based on the flood risk evaluation and public consultation process, identify and evaluate the proposed infrastructure measures complete with cost estimates (Class D) and timelines for property acquisition, regulatory approvals, design and construction.

- **Land Use** – Identify land use changes that are considered necessary from the risk analysis and the feasibility assessment. Provide timelines and implementation strategies.

- **River Solutions** – In-river solutions such as gravel extraction and side channel diversion/relief floodways that satisfy the risk analysis and feasibility assessment may require further review with regulatory agencies. Identify the processes necessary to obtain the necessary approvals complete with cost estimates and timelines.

- **Revise Flood Plain Mapping** – Based on forecasts presented in the river hydraulics and ice-related flooding analysis and in conjunction with the BC Ministry of Environment, recommend and prepare revised flood plain mapping for the City of Prince George. Floodplain mapping is to be prepared in accordance with the Fraser Basin Council Floodplain Mapping Guidelines and Specifications, March 2004. The floodplain mapping must be provided in digital format compatible with the City's GIS mapping system. A design brief providing support for the analysis must accompany the mapping.

5. Available References

- Floodplain Mapping Fraser and Nechako Rivers at Prince George, Design Brief, Province of British Columbia, Ministry of Environment, Lands and Parks, Klohn-Crippen, May, 1997
- Floodplain Mapping Guidelines and Specifications, Fraser Basin Council March 2004**.**
- Guidelines for Management of Flood Protection Works in BC
- Dike Design and Construction Guide
- Riprap Design and Construction Guide
- City of Prince George Flood Plain Regulation Bylaw No. 7855, 2007

6. Schedule

Complete Phase 1 within six months of notice to proceed and signing an agreement with the City of Prince George. Following acceptance of the Phase 1 Flood Risk Evaluation, proceed with Phase 2 Flood Control Solutions and complete within six months.

Submit a work plan schedule including milestone dates, submission dates, review periods, review meetings, and field work.

• Appendix A- Hydrologic, Hydraulic and Ice-Related Flooding Analyses

1. HYDROLOGIC AND HYDRAULIC ANALYSES

- Complete a hydrologic analysis of the Fraser River and Nechako River systems to estimate the magnitude of the 200-year flood that could inundate the floodplain areas along the Fraser and Nechako Rivers within in the City of Prince George.
- Complete a hydraulic analysis to determine the water surface profile of the 200-year flood for the Fraser and Nechako Rivers.
- Perform analyses in accordance with the Fraser Basin Council, <u>Floodplain Mapping Guidelines and Specifications, March 2004.</u>

2. ICE-RELATED FLOODING ANALYSIS

To deal with these ice concerns in a more systematic manner, the following is required: (1) develop a procedure to forecast the timing and severity of freeze-up, (2) develop an understanding of the risks of experiencing high ice-related water levels along the Nechako River, and (3) develop ways to mitigate the effects of high ice-related water levels through improvements to the infrastructure or by strengthening land use bylaws. It is proposed that the work be carried out in two phases: ***Phase 1*** would address the ice-related process identified in items (1) and (2) above, and would ultimately provide the design parameters for ***Phase 2***. ***Phase 2*** would address item (3) above and it would be mainly related to identifying and evaluating a range of flood mitigation measures. The scope of work specified herein addresses only ***Phase 1***. The scope of work for ***Phase 2*** will be defined after the completion of ***Phase 1***.

PHASE 1: FORECASTING METHODOLOGIES AND RISK ASSESSMENT

The effort here would focus on (1) establishing an understanding of the hydrologic and climate regime, (2) summarizing the historical freeze-up characteristics within the context of conventional ice hydraulics, (3) assessing the local hydraulic characteristics of the Nechako River/Fraser River and their contributions to lodgement and freeze-up levels, (4) assessing the effects of the changing climate, and (5) providing design guidelines for mitigation measures. The following is a list of the potential tasks that would be required to complete the assessment.

Hydrologic/Climate Regime

- Characterize the annual flow regime of the Nechako River since regulation, identifying peak flows, recession rates, and flow contributions from the various sub-basins. Put the flows into the context of annual precipitation patterns. Examine any existing flow forecasting methods and determine their applicability to forecast flows in November and December.

- Determine the accuracy of the daily winter flow estimates at Isle Pierre. Examine best practices for determining ice-affected flows and evaluate their efficacy. Assemble any available bathymetric data from the vicinity of the hydrometric gauge.
- Assess the water temperatures of outflows from Fraser and Stuart Lakes during the late fall and early winter. If data is unavailable, determine options to collect the appropriate air and water temperatures.
- Summarize the winter climate regime at Prince George within the context of freeze-up on the Fraser River at Old Fort George, the observed development of ice covers on the Nechako River. Temperature frequency-duration curves would be a convenient way to characterize the risks of experiencing severe temperature patterns during the freeze-up period.

Historical Freeze-up Characteristics

- Summarize the freeze-up dates and stage increases of the Fraser River at Old Fort George within the context of the background flows and ambient air temperatures. Provide frequency curves of the expected freeze-up date and any empirical relationships between the onset of freeze-up and water level increases and the ambient background conditions.
- Assess the historical flows on the Nechako River during freeze-up on the Fraser River and provide an indication of the risk of experiencing a given flow condition.
- Discuss the salient ice processes that contribute to freeze-up.
- Assess the historical freeze-up water level record on the Nechako River at Prince George, summarize the freeze-up levels and ambient flows, and put them into the context of conventional ice jam rating curves.
- Provide an assessment of the thickness of the ice accumulation, the volume of ice required to produce an ice cover of a given length, and the meteorological conditions required to generate that volume of ice.
- Develop procedures to forecast ice-related water levels and to estimate the climate conditions required to produce freeze-up ice accumulations of various lengths at various flows. Use this as a basis to assess the risk of a attaining a given ice-related water level at various locations along the Nechako River within the City of Prince George.

Local Hydraulic Characteristics – Nechako River at Prince George

- Summarize the historical channel bathymetry of the Lower Nechako River.
- Assess changes to the hydraulic regime of the Lower Nechako River over the last couple of decades. If required, undertake new bathymetric surveys at selected salient locations.
- Note that there is concern about the potential for ice conditions being exacerbated by aggradation at the mouth of the Nechako River and on the Fraser River. Assess the extent of this aggradation and determine if it has any effect on ice lodgement/transport within the context of backwater conditions on the Fraser River.
- Provide a quantitative assessment of the effects of changing bathymetry on the hydraulic characteristics of the river (slope, width, depth, velocity) for flow

conditions during freeze-up, and define the effects of these changes on the thickness of the ice accumulation and freeze-up levels.

Effects of Climate Change on Freeze-up Severity and Design Philosophy

- Chose the appropriate climate change scenarios that best apply to the interior region of British Columbia and identify changes in the precipitation and air temperatures that are expected to occur between now and 2080.
- Summarize the expected impacts that climate change may have on the severity of freeze-up, specifically related to the expected ice-related water level for the design event.

Mitigation Measures/Design Criteria

- Identify and evaluate a range of mitigation measures that could be applied to limit the severity of the ice accumulation or to limit the effects of the water level increases due to the ice accumulation.
- Recommend design criteria that would be used to design mitigation measures such as diking and/or flood proofing within the context of current British Columbia guidelines.

APPENDIX B
FLUVIAL GEOMORPHOLOGY

B.1 NECHAKO RIVER

B.1.1 *SPECIFIC GAUGE ANALYSES*

The Water Survey of Canada regularly measures the discharge at their stream gauging stations. This information is used to prepare a 'stage–discharge rating table' or 'curve' which specifies the relationship between water level and stream flow. This relationship is periodically revised if changes in channel dimensions or river bed elevation occur as a result of sediment accumulation, sediment evacuation, bank erosion or other factors.

A 'specific gauge plot' is a method of detecting trends in the series of stage–discharge relationships. In this technique the water level elevation associated with a range of flows is determined and the results are plotted as a time series based on the period of record over which each stage–discharge relationship was employed. The resulting graphs show how changing channel characteristics have affected water levels over time. In general, these water level variations result from changes in river bed elevation or channel cross-sectional area and can sometimes provide information on changes in sediment supply.

The WSC has operated a stream gauging station on Nechako River at Isle Pierre, since 1950. This site is located 61 km upstream of Prince George and 26 km upstream of the Chilako River confluence. As discussed in MMA (2008b), the Isle Pierre gauging station is upstream of numerous sediment sources which periodically contribute material to lower Nechako River.

A specific gauge plot for Nechako River at Isle Pierre is shown as **Figure B.1**. This graph covers the period between 1950 and 2007. The analysis evaluates stream discharges which are representative of extreme low (100 m^3/s), the mean annual discharge (275 m^3/s) and larger flows of up to 1,200 m^3/s (see MMA 2008b for representative hydrographs).

Figure B.1 does not show any unequivocal trend in water level elevation:

- The lowest flow of 100 m^3/s generally decreases in elevation over the period of record;
- Flows of 200 and 300 m^3/s maintain a more or less constant elevation; and,
- Peak flows of 600 to 1,200 m^3/s decrease in elevation between 1959 and 1979, marginally increase in elevation in the middle period of the record and then marginally decrease.

The small magnitude of the changes and inconsistencies between low and high flow values suggests that there are not significant trends in sediment supply or channel geometry data.

B.1.2 *SEDIMENT SOURCES*

A separate report has been prepared which describes sediment sources to Nechako River in the 35 km long section of channel located between the Chilako River confluence and Prince George (MMA., 2008b). The locations of the 15 identified sites are indicated on **Figure B.2**. A summary of site characteristics is presented on **Table B.1**. Identified sources include Chilako River, eroding glacio-fluvial terraces and more modern fluvial deposits.

The above analyses indicate that there are significant sediment source areas in lower Nechako River which cannot be readily stabilized. These sites will erode during periods of high flow and the resulting sediment load (as well as that derived from more upstream sections of Nechako River) will be conveyed downstream towards the Fraser River confluence.

B.1.3 Bed Material Transport

As discussed in Section 2.4.1, analyses of historical air photographs suggest that some gravel deposition has occurred in Nechako River at the confluence and this is supported by the cross-section comparison at Section N1. The area is illustrated on Plate B.1. Calculations were undertaken to determine how changes in discharge may have affected annual bed material transport capacity on lower Nechako River. **Plate B.1** shows a gravel bar (located between surveyed sections) which appears to have enlarged over time. The bed material transport equation proposed by Parker 1990 has been used for this analysis.

The capacity calculations used the average channel geometry in the 'transport' area which extends between cross-sections N4 and N19. Within this area an average water surface slope of 0.08% (0.0008 m/m) and an average channel width of 179 m have been adopted.

The analyses were undertaken based on simulated daily discharges for Nechako River at Prince George during the period between 1980 and 2007. This time series includes the maximum estimated daily flow of 1,227 m^3/s (in 1997) and the maximum annual discharge (476 m^3/s) when Nechako reservoir levels were lowered in the spring of 2007 to avoid over-topping Kenney Dam as a result of an unusually deep winter snow pack.

The surface bed material size was measured at the 9 locations on lower Necahko River indicated on **Figure B.3** using the tape grid method described in Yuzyk (1986) and Bunte and Abt (2001). The bed material data are summarized on **Table B.2**.

The bed material transport capacity was calculated for two grain size values. These are based on:

1. The comparatively small and more mobile gravel deposits at Km 288.5 (distance below Kenney Dam). The D_{50} or average value is 10 mm. This site is illustrated on **Plate B.2**; and,

2. An average of the bed material size observed at Km 289, downstream of John Hart Bridge, Km 291.5, Km 292 and Km 293. The average or D_{50} value is 32 mm. These sites are illustrated on **Plates B.3** to **B.7**.

The results of the transport calculations are summarized on **Tables B.3** and **B.4**. These calculations predict transport capacity not actual loads as mobile bed material is likely to be supply limited in lower Nechako River. The results are probably best employed as an index to illustrate the inter-annual variability in bed material transport. With these cautions, the analyses indicate that the average annual bed material transport capacity for the finer bed material size is approximately 240,000 m^3/yr. The predicted average annual transport capacity for the coarser bed material is approximately 2,000 m^3/yr. Actual rates, in years where flows are high enough to erode material from the upstream channel banks, is likely to be somewhere between these values.

The annual variability in this bed material transport index is significant. For example, the high flow conditions in 2007 [1] result in annual transport capacities which are 720% and 2,420% of average for the fine and coarse textured bed material sizes, respectively. These unusual flows exceeded threshold conditions and resulted in a substantial capacity to convey the observed bed material.

B.2 FRASER RIVER

B.2.1 SPECIFIC GAUGE ANALYSIS

The WSC has operated a stream gauging station on Fraser River at Shelley since 1950. This site is located 23 river km upstream of Prince George (see air photo mosaic in MMA, 2008b, Appendix 3) and 12 km downstream of the Salmon River confluence.

The specific gauge plot for this site is shown on **Figure B.4**. The evaluated discharges range from a low of 250 m^3/s, a mean annual discharge of 800 m^3/s and higher flows of up to 5,000 m^3/s. Representative hydrographs are again shown in MMA, 2008b.

The specific gauge plot does not show any well defined trends in water level elevation. All discharges show a modest decrease in elevation in the late-1950's and a poorly-defined trend of small decreases in elevation continues for flows of $\leq$2,000 m^3/s. The main conclusion of this analysis is that Fraser River in the vicinity of Shelley has not experienced any significant sediment accumulation over the period of record.

B.2.2 SEDIMENT SOURCES

A separate report has been prepared which describes sediment sources to Fraser River in the 35 km long section of channel located between the Salmon River confluence and Prince George. The locations of the six identified sites are indicated on **Figure B.5**. A summary of site characteristics is presented on **Table B.5**. The two largest sediment sources are Salmon River which is conveying significant quantities of bedload and a rapidly eroding fluvial terrace located 30 km upstream of Prince George.

Ground inspection and an analysis of historical air photos indicate that 3.6 x 10^6 m^3 of sand and gravel have been eroded from the fluvial terrace site over the period between 1946 and 2003. This corresponds to an average annual sediment loading of 64,000 m^3/yr. Actual rates of sediment production are likely to be episodic. Other sediment source areas include more slowly eroding sections of fluvial or lacustrine materials.

The above analyses indicate that there are sizeable sediment source areas upstream of Prince George which cannot be stabilized. A portion of the eroded materials, along with sediment supplied from upstream reaches of Fraser River, will be carried downstream and are available for deposition in areas such as the Nechako River confluence (**Plate B.8**).

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[1] See hydrograph in MMA, 2008b

TABLE B.1: SEDIMENT SOURCE SUMMARY, NECHAKO RIVER DOWNSTREAM OF CHILAKO RIVER

MOSAIC #	RIVER KM	RIVER KM U/S OF PG	RIVER BANK	LOCATION	TERRAIN UNIT	SEDIMENT SOURCE	LENGTH (m)	VOLUME OF SEDIMENT PRODUCTION[1]			RATE OF BANK RECESSION	EXISTING BANK PROTECTION	POTENTIAL BANK PROTECTION	EFFECTIVENESS	COST	ANTICIPATED BANK PROTECTION PERMITTING DIFFICULTY
								FINES	GRAVEL	COBBLES						
A1-2	259.3	35.2	Right	Chilako River	Flood plain & terrace	River bank & terrace erosion	n/a	L	M	U	Locally significant	None except possible at railway bridge	Variable	n/a	Large	Easy (bioengineering) to hard (rip-rap)
A1-4	263.9	30.6	Right		Fluvial terrace	Bank erosion	≥150	S	S	S	Slow	None	Low	Variable	Large	Moderately difficult
A1-4	265.2	29.3	Left		Glacio-fluvial terrace	Progressive bank erosion & sloughing	600	M	M	S	Moderate	None	Low	Variable	Large	Difficult
A1-4	266.0	28.5	Right		Site investigation required	Slope instability	≥150	S	S	S	Very slow	Road and riparian vegetation	To be determined	Probably good	Unknown	Easy
A1-5	267.4	27.1	Right	Miworth	Glacio-fluvial terrace	Progressive bank erosion & sloughing	1,100	L	M	S	Moderate	None	Low	Variable	Very large	Difficult
A1-7	271.5	23.0	Left		Fluvial terrace or flood plain	Progressive bank erosion	1,600	S	S	S	Low	None	Good	Good	Low	Easy
A1-8	273.5	21.0	Right	Island Park Drive	Glacio-fluvial terrace	Progressive bank erosion & sloughing	900	M	M	S	Moderate	Some	Low	Variable	Large	Difficult
A1-10	278.0	16.5	Right		Glacio-fluvial terrace	Progressive bank erosion & sloughing	450	S	S	S	Low	None	Moderate	Probably good	Low	Easy
A1-10	279.0	15.5	Right	Takla Forest Road	Glacio-fluvial terrace	Progressive bank erosion & sloughing	800	M	M	S	Moderate	Unprotected gravel road	Moderate	Variable	Large	Difficult
A1-11	281.0	13.5	Left	N. Nechako Road	Glacio-fluvial terrace	Progressive erosion & sloughing	400	S	S	S	Low	None	Good	Good	Low	Easy
A1-11	281.8	12.7	Left	Toombs Road	Glacio-fluvial terrace	Progressive bank erosion & sloughing	250	S	S	S	Low	None	Moderate	Good	Moderate	Difficult
A1-11	282.1	12.4	Right	Opposite Otway Road	Glacio-fluvial terrace?	Progressive erosion & sloughing	200	S	S	S	Low	None	To be determined	Good	Moderate	Moderate
A1-14	287.2	7.3	Left	Downstream Foothills Bridge	Glavio-fluvial terrace	Progressive bank erosion & sloughing	600	S	S	S	Low	None	Moderate	Variable	Large	Difficult
A1-14	288.5	6.0	Left	Hanbury Road	Glacio-fluvial terrace	Progressive bank erosion & sloughing	700	S	S	S	Low	None	Good	Probably good	Low	Easy
A1-15	291.4	3.1	Left	Prince George Pulpmill Road	Glacio-fluvial (and lacustrine?) terrace	Mass wasting	700	S	S	S	Very low	Paved road constructed at base of terrace between 1963 and 1968	None required	Good	Zero	n/a

[1] S = Small M = Moderate L = Large U = Unknown

TABLE B.2: BED MATERIAL SIZE DISTRIBUTION, NECHAKO RIVER AT PRINCE GEORGE

SAMPLE LOCATION (River Km)	% OF MATERIAL FINER THAN B-AXIS WIDTH (in mm) OF:															
	2	**3**	**4**	**6**	**8**	**11**	**16**	**23**	**32**	**45**	**64**	**91**	**128**	**181**	**256**	**362**
288	0	0	0	0	1	4.5	16	42	71	88	98	100	100	100	100	100
288.5	1	7	9	29	38	66	81	93	99	100	100	100	100	100	100	100
289	0	0	0	0	0	5	18	39	60	70	83	98	100	100	100	100
D/S John Hart Bridge	0	0	1	4	4	11	29	40	64	76	90	99	100	100	100	100
291.5	4	4	4	4	4	4	5	9	18	33	52	74	84	99	100	100
292	39	39	39	40	41	44	48	54	68	81	95	99	100	100	100	100
293	1	1	1	1	1	4	9	29	25	78	96	99	100	100	100	100
294A	49	50	51	59	61	69	79	86	94	99	100	100	100	100	100	100
294B	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Average 288 to 294B	**21.6**	**22.3**	**22.8**	**26.3**	**27.8**	**34.2**	**42.8**	**54.7**	**66.6**	**80.6**	**90.4**	**96.6**	**98.2**	**99.9**	**100**	**100**
Average 289, J. Hart, 291.5, 292 & 293	**8.8**	**8.8**	**9.0**	**9.8**	**10**	**13.6**	**21.8**	**34.2**	**47**	**67.6**	**83.2**	**93.8**	**96.8**	**99.8**	**100**	**100**

TABLE B.3: ESTIMATED ANNUAL BED MATERIAL TRANSPORT FOR A COMPARATIVELY FINE BED MATERIAL (D_{50} = 10 mm)

YEAR	MAXIMUM DAILY DISCHARGE (m³/s)	AVERAGE ANNUAL DISCHARGE (m³/s)	ANNUAL BED MATERIAL TRANSPORT CAPACITY				% OF LONG TERM AVERAGE
			(kg/min)	(kg)	(tonnes)	(m³)	
1980	422	172	125.25	66,009,283	66009	44006	29
1981	605	247	527.61	277,309,241	277309	184873	123
1982	615	250	621.61	326,719,530	326720	217813	145
1983	636	216	341.14	179,305,286	179305	119537	80
1984	604	238	433.36	228,395,946	228396	152264	101
1985	501	204	273.16	143,572,213	143572	95715	64
1986	632	218	392.07	206,072,307	206072	137382	91
1987	524	225	368.15	193,497,590	193498	128998	86
1988	626	254	632.22	333,206,019	333206	222137	148
1989	496	193	246.66	129,644,916	129645	86430	58
1990	626	257	562.85	295,832,173	295832	197221	131
1991	569	226	516.57	271,511,505	271512	181008	120
1992	575	279	584.46	308,031,954	308032	205355	137
1993	705	256	578.76	304,196,676	304197	202798	135
1994	605	260	615.13	323,310,909	323311	215541	143
1995*	450	232	366.73	192,751,133	192751	128501	86
1996	743	341	1,101.43	580,496,086	580496	386997	258
1997	1,227	441	2,776.35	1,459,247,458	1459247	972832	647
1998	500	219	297.60	156,420,873	156421	104281	69
1999	699	286	816.66	429,235,497	429235	286157	190
2000	563	241	383.16	201,942,333	201942	134628	90
2001	602	247	420.42	220,970,807	220971	147314	98
2002	913	341	1,360.32	714,984,192	714984	476656	317
2003	582	237	362.34	190,446,850	190447	126965	84
2004	530	236	303.50	159,955,428	159955	106637	71
2005*	594	296	604.69	317,824,118	317824	211883	141
2006	518	203	245.50	129,034,800	129035	86023	57
2007	1,185	476	3,087.66	1,622,875,147	1622875	1081917	720
AVERAGE	**637**	**260**	**676.62**	**355,814,295**	**355,814**	**237,210**	

Notes: The conversion between bed material transport in tonnes and m³ has assumed a density of 1.5 tonnes/m³.

All calculations are based on the bed material transport formula proposed by *Parker (1990)*.

* denotes a partial data record

TABLE B.4: ESTIMATED ANNUAL BED MATERIAL TRANSPORT FOR A COMPARATIVELY COARSE BED MATERIAL, (D_{50} = 32 mm)

YEAR	MAXIMUM DAILY DISCHARGE (m^3/s)	AVERAGE ANNUAL DISCHARGE (m^3/s)	ANNUAL BED MATERIAL TRANSPORT CAPACITY				% OF LONG TERM AVERAGE
			(kg/min)	(kg)	(tonnes)	(m^3)	
1980	422	172	0.04	19,046	19	13	1
1981	605	247	1.10	577,708	578	385	44
1982	615	250	1.40	733,450	733	489	56
1983	636	216	0.72	376,479	376	251	29
1984	604	238	0.67	354,753	355	237	27
1985	501	204	0.18	96,702	97	64	7
1986	632	218	0.72	379,994	380	253	29
1987	524	225	0.32	170,587	171	114	13
1988	626	254	1.88	988,879	989	659	76
1989	496	193	0.11	58,789	59	39	5
1990	626	257	1.15	605,057	605	403	46
1991	569	226	0.37	195,665	196	130	15
1992	575	279	0.81	428,616	429	286	33
1993	705	256	1.53	802,102	802	535	62
1994	605	260	0.96	505,409	505	337	39
1995*	450	232	0.11	60,128	60	40	5
1996	743	341	4.85	2,554,326	2554	1703	196
1997	1,227	441	57.20	30,062,796	30063	20042	2309
1998	500	219	0.16	81,558	82	54	6
1999	699	286	2.88	1,511,611	1512	1008	116
2000	563	241	0.46	242,897	243	162	19
2001	602	247	0.74	389,320	389	260	30
2002	913	341	11.24	5,905,936	5906	3937	454
2003	582	237	0.40	210,325	210	140	16
2004	530	236	0.20	105,244	105	70	8
2005*	594	296	1.33	700,797	701	467	54
2006	518	203	0.14	73,584	74	49	6
2007	1,185	476	59.99	31,529,320	31529	21020	2422
AVERAGE	**637**	**260**	**5.42**	**2,847,181**	**2,847**	**1,898**	

Notes: The conversion between bed material transport in tonnes and m^3 has assumed a density of 1.5 tonnes/m^3.

All calculations are based on the bed material transport formula proposed by *Parker (1990)*.

* denotes a partial data record

TABLE B.5: SEDIMENT SOURCE SUMMARY, FRASER RIVER DOWNSTREAM OF SALMON RIVER

MOSAIC #	RIVER KM	RIVER BANK	LOCATION	TERRAIN UNIT	SEDIMENT SOURCE	LENGTH (m)	VOLUME OF SEDIMENT PRODUCTION[1]			RATE OF BANK RECESSION	EXISTING BANK PROTECTION	POTENTIAL BANK PROTECTION	EFFECTIVENESS	COST	ANTICIPATED BANK PROTECTION PERMITTING DIFFICULTY
							FINES	GRAVEL	COBBLES						
A3-1	35.2	Right	Salmon River	Fluvial valley flat and fan	Bank Erosion	740	L	L	L	Moderate to large	None	High	Variable	Moderate	Moderate
A3-1	30.0	Right	BC Rail MP 478.1	Fluvial terrace	Progressive bank erosion & sloughing	1,300	L	L	M	High	None	Low	Moderate	Very large	Very difficult
A3-3	19.2	Right	P.G Sawmill	Fluvial terrace & lacustrine	Progressive bank erosion	1,800	S	S	S	Low	Rip-rap and spurs	Unknown	Unknown	Unknown	Unknown
A3-4	10.0	Right	Toombs Road	Fluvial terrace	Gully formation	70	M	S	S	Moderate	Railway grade and bridge at base of gully	Good	Good	Moderate	Easy
A3-4	9.0	Left	Denicola Crescent	Fluvial terrace	Progressive bank erosion	850	S	S	S	Low	None ?	Good	Moderate	Low to moderate	Easy to moderate
A3-4	7.2	Right	Hofferkamp Road	Fluvial terrace	Progressive bank erosion	800	S	S	S	Low	Partially protected with rip-rap	Good	Good	Moderate	Moderate

[1] S = Small M = Moderate L = Large U = Unknown

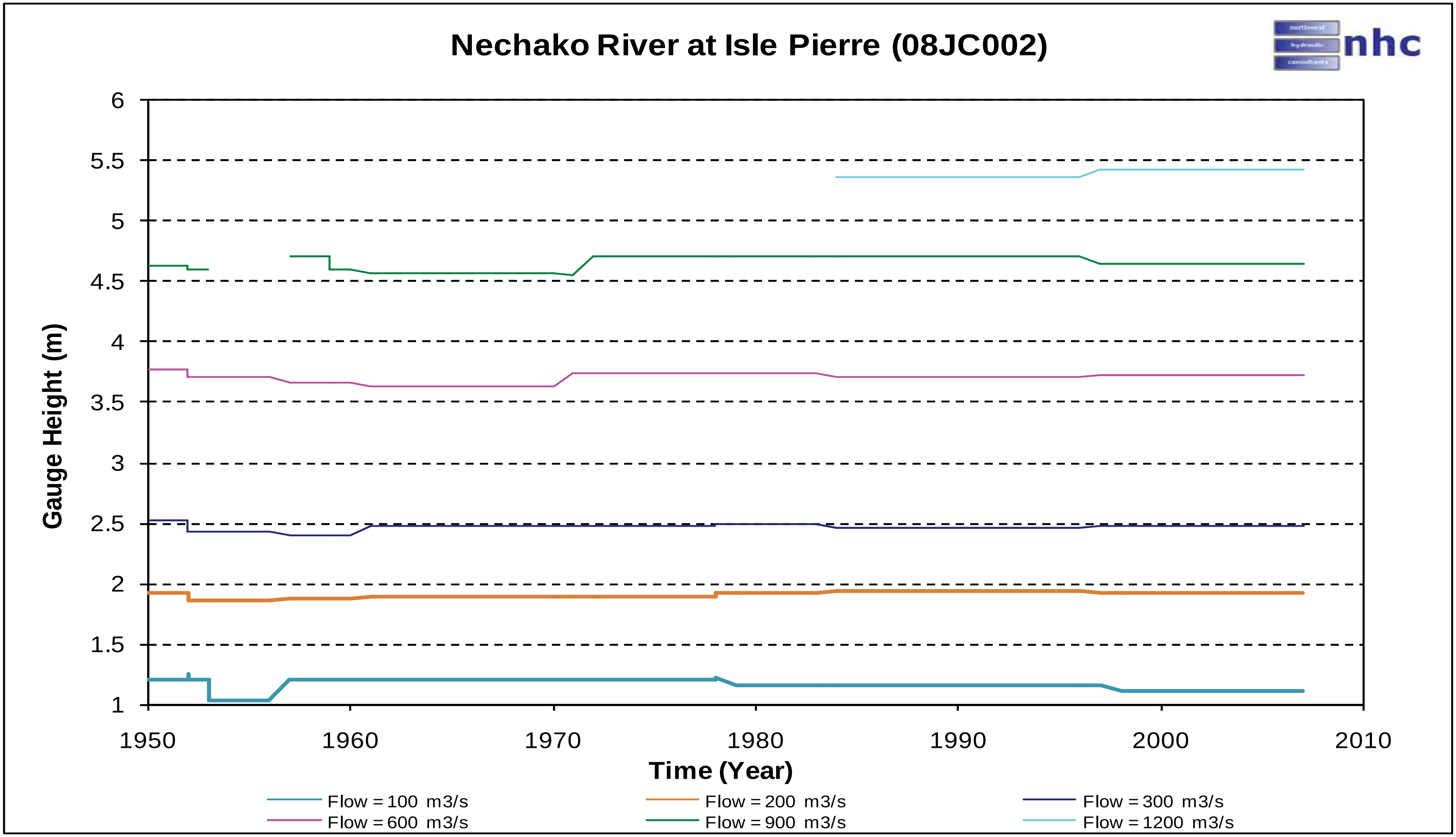


Figure B.1: Specific gauge plot, Nechako River at Isle Pierre (1950 to 2007).

Figure B.2: Location of principal sediment sources to the Nechako River (2003, 2005 & 2006 Google Earth images).

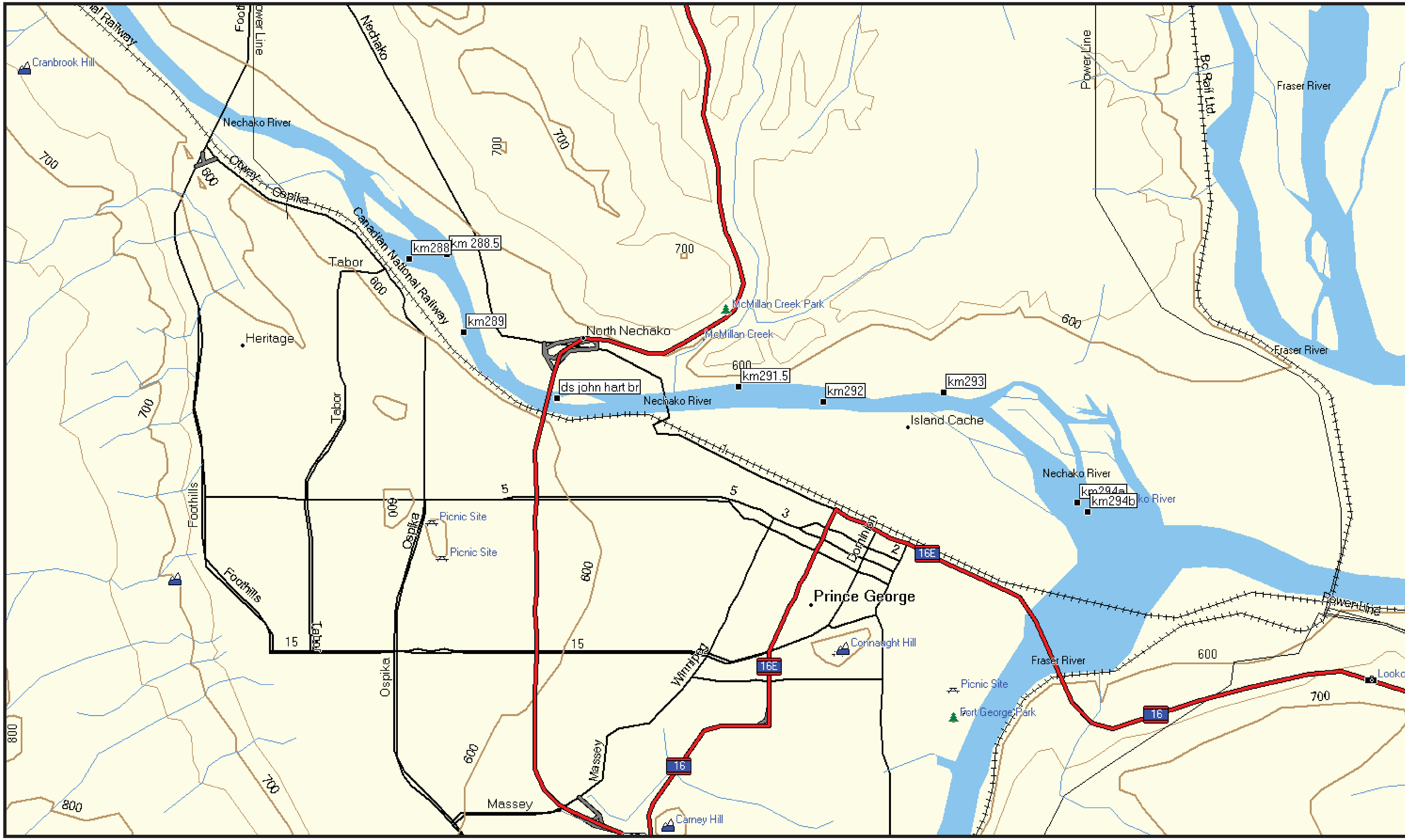


Figure B.3: Location of bed material sampling sites on lower Nechako River.

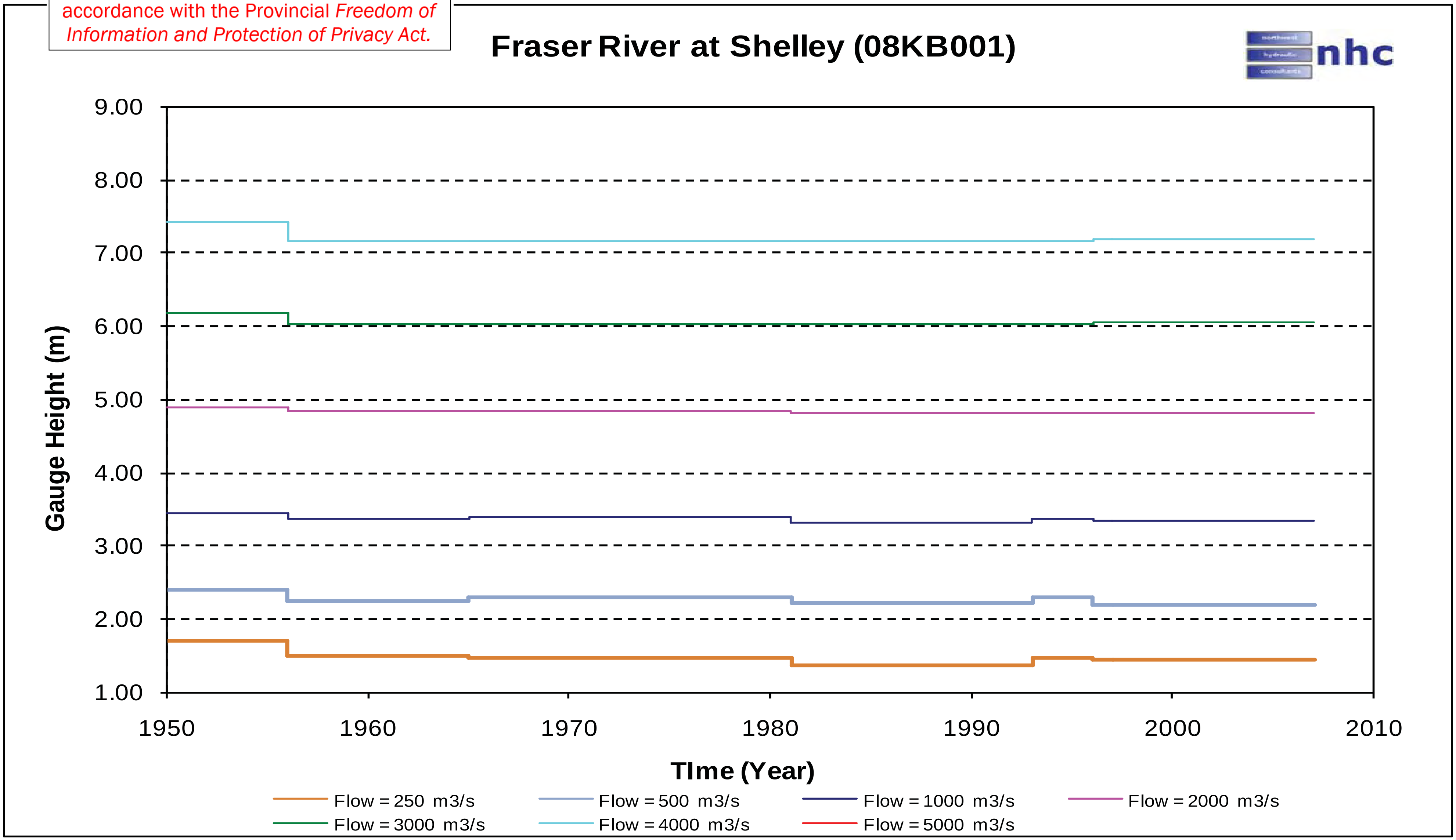
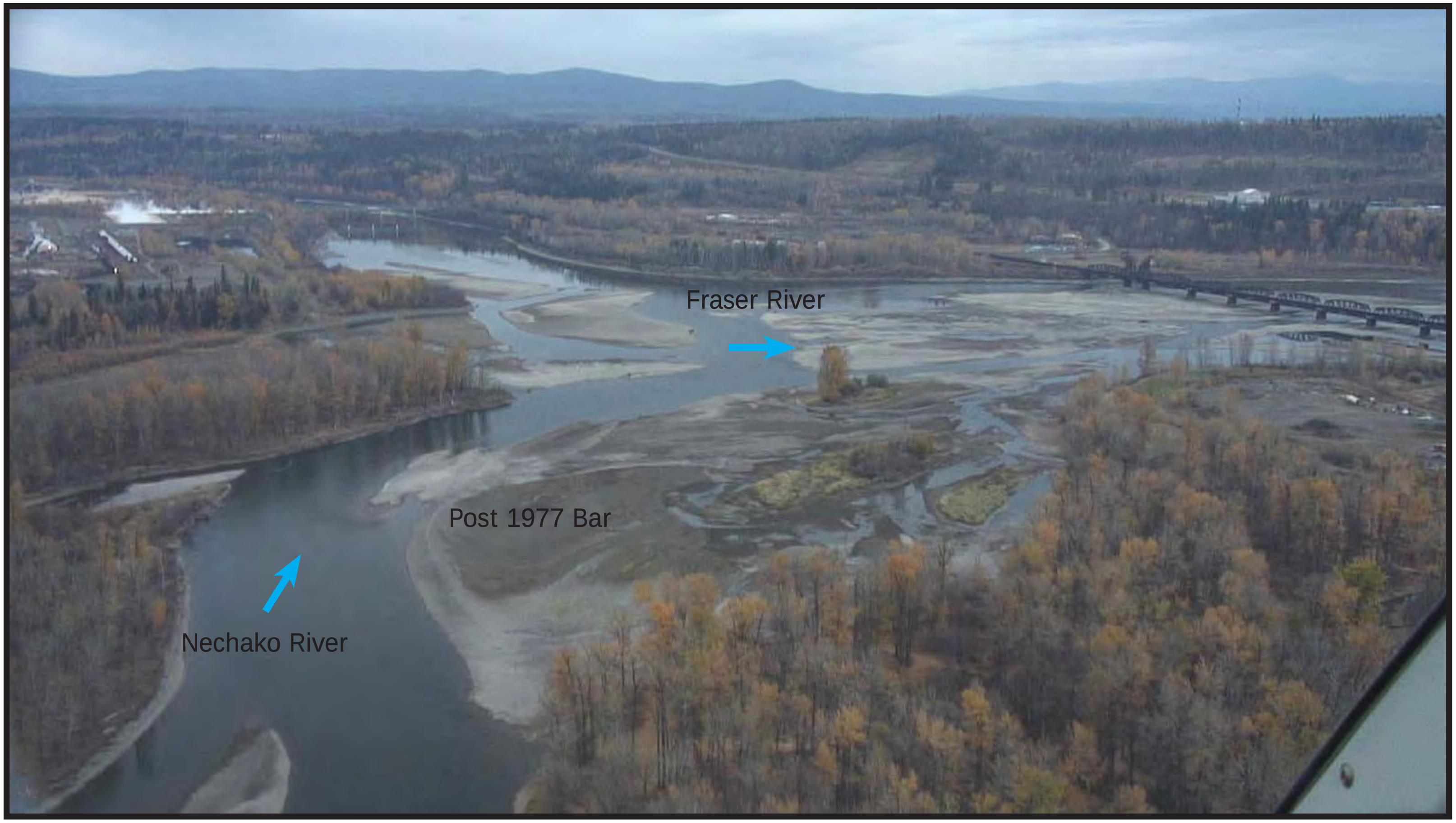


Figure B.4: Specific gauge plot, Fraser River at Shelley (1950 to 2007).

Figure B.5: Location of principal sediment sources to the Fraser River (2006 & 2004 Google Earth images).



October 18, 2006

MM Camcorder DSC 08269

Plate B.1: Looking downstream showing the gravel bar located between Sections 3 & 4 which has enlarged over the period since 1977.

Looking upstream P1010377

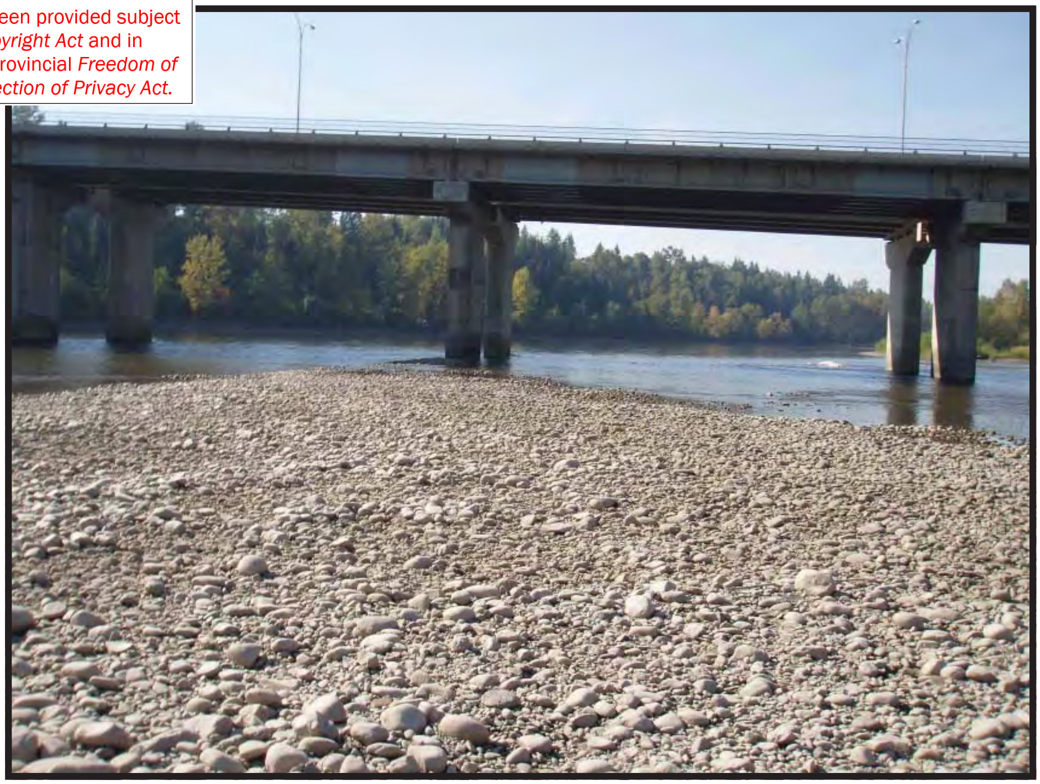
Looking downstream P1010378

Plate B.2: Bed material sample site at river Km 288.5

Looking upstream P1010380

Looking downstream P1010381

Plate B.3: Bed material sample site at river Km 289



Looking upstream P1010382

Looking downstream P1010383

Plate B.4: Bed material sample site located downstream of John Hart Bridge.

Looking upstream P1010384

Looking downstream P1010385

Plate B.5: Bed material sample site at river Km 291.5

Looking upstream P1010386

Looking downstream P1010387

Plate B.6: Bed material sample site at river Km 292.

Looking upstream P1010388

Looking downstream P1010389

Plate B.7: Bed material sample site at river Km 293

October 18, 2006

MM Camcorder DSC08276

Plate B.8: Looking downstream to the Grand Trunk Railway Bridge showing the extent of gravel bars at low water.

APPENDIX C
ENVIRONMENTAL SETTING

APPENDIX C - ENVIRONMENTAL SETTING

Information is presented at an overview level, to a sufficient level of detail so that the feasibility of conceptual flood control solutions can be evaluated and ranked according to their relative environmental merit. The scope of the assessment has been limited primarily to aquatic and riparian-based ecosystem components that are situated within and adjacent to the river floodplains. Environmental information has been collected from previously published reports, online databases and interviews with government agency representatives. Biophysical site descriptions were verified or updated by conducting several reconnaissance-level field investigations during the summer of 2008.

C.1 BIOPHYSICAL CONDITIONS

C.1.1 NECHAKO RIVER

The Nechako River has been a partially regulated river since 1952, when its upper sections were impounded by the construction of the Kenney Dam for hydroelectric power generation; 39 km of the river was eliminated by this manipulation (Slaney 1986). The downstream flows are therefore headwater regulated for electric power demands, but the hydrograph is also affected by rainfall and snowpack, Fraser River flood control measures and summer cooling flow releases to maintain suitable conditions for sockeye salmon migration and spawning (Fisheries and Oceans 1984 in Slaney 1986). As a result of the artificial manipulations of the hydrograph, peak flow in the lower Nechako does not typically occur until July.

The lower Nechako River can be generally characterized as riffle-pool morphology. Most of the mainstem channel banks are characterized by large substrates with enhanced complexity provided by backeddies, riffles and shallow pools. The lower Nechako River has two large island complexes, Cottonwood Island and Fish Trap Island and one permanent tributary, McMillan Creek (Nowotny and Hickey 1993). McMillan Creek is a highly productive fish-bearing system that is situated approximately 3 km upstream from the mouth of the Nechako (and enters the river near the Cameron Street bridge). There are also three off-channel sloughs along the Nechako River including Fish Trap Island Slough, another near Howie’s Marine boat launch basin and the last is unnamed and near the upstream end of the study area.

At the confluence of the rivers, the Nechako contains a number of active and inactive side-channels. Active side-channels are typically permanently or seasonally wetted and contain an abundance of nearshore vegetation, large woody debris and undercut banks which provide good quality summer rearing capabilities for most juvenile salmonids. Off-channel habitats also provide refuge areas for outmigrating salmon fry and foraging habitats for resident fish species. Inactive side channels typically do not contain water (except perhaps during extreme flood events) and provide limited fish habitat. Historic air photo analysis of the lower river seems to suggest many of the inactive side channels have been progressively revegetating with terrestrial species since the onset of river regulation in the 1950s (MMA 2008a).

The Nechako River, the largest tributary to the Fraser River, is an important salmon river. It has been estimated that the Nechako watershed provides approximately 23% of the total Fraser River sockeye salmon production (CSTC 2008). The value of the commercial salmon catch associated with the Nechako River watershed may be as much as $70 million annually (Rankin 1993 in CSTC 2008).

C.1.2 Fraser River

The Fraser River is an unregulated river and is one of the world's most productive salmon river systems (FBC 2004). Within city limits, the morphology of the Fraser River can be characterized as large channel glide. Large-scale biophysical assessments of the Fraser River have typically delineated a reach break at the confluence of the Nechako River, where there is a distinct change in discharge (Nowotny and Hickey 1993). The lower reach, below the Nechako River confluence, exhibits a subtle increase in gradient accompanied by a straighter channel pattern with less lateral migration and fewer off-channel habitats. The nearshore substrates of the lower reach consist primarily of embedded cobble and large gravel substrates. The banks and nearshore areas of the upper reach, above the confluence of the Nechako River, are dominated by fine substrates. The Fraser River has a number of tributaries within City Limits including: Rancheree Creek, a creek that enters Fraser Vista (Goose) Slough, Foreman Creek, Bittner Creek, Parkridge Creek, Haggith Creek, Brodman Creek, two unnamed creeks and Hudson's Bay Slough. Mainstem river margins, the lower reaches of tributary streams and off-channel areas in both reaches provide high quality summer rearing habitat for outmigrating salmon fry and resident fish species.

C.2 Water Quality

Water from the Nechako and Fraser Rivers is used for irrigation, livestock watering, and primary and secondary-contact recreation. Both rivers also support terrestrial wildlife species and sustain aquatic life. Nechako River water is used as a source of drinking water in some communities, although the municipal water supply for the City of Prince George is wholly serviced by groundwater wells.

Regular water quality monitoring was conducted on the Nechako River at the Cameron Street Bridge over a twenty-year period from 1985 to 2004 (Swain 2007). Results of this sampling program included:

- Total metal concentrations for aluminum, cadmium, chromium, cobalt, copper, lead, manganese, iron, silver and zinc periodically exceeded drinking water and aquatic life guidelines. Elevated levels of these metals were often associated with high turbidity, suggesting that these parameters were in particulate form and were not bioavailable.
- Summer water temperatures consistently exceeded the maximum guideline to protect migrating salmonids.

- Peak turbidity values appeared to increase over the last eight years of the reporting period, although no reasons for this trend were presented. (Bird et al, 2001, suggested that for the Chilako River, the loss of vegetation has affected the stream channel stability and by inference sediment loadings.)

Regular water quality monitoring was conducted on the Fraser River at Stone Creek over a 10-year period from 1990 to 2000 (MELP & EC, 2000). The main influences on water quality in the Fraser River downstream from Prince George include the effluents from three pulp mills, treated sewage discharges and non-point source runoff from forestry, agriculture and urban areas. No definitive water quality concerns were identified during this program, although occasional fecal coliform sampling suggested that fecal contamination may be a concern at this site. An improving trend was observed in the concentrations of adsorbable organo-halides (AOX), a general measure of chlorinated organics that are associated with pulp mill effluents.

C.3 FISHERIES

Numerous fish species are found within the study area including salmonids (sockeye salmon, Chinook salmon, coho salmon, pink salmon, rainbow trout, and mountain whitefish), burbot, non-sport fish (chiselmouth, prickly sculpin, slimy sculpin, largescale sucker, longnose sucker, white sucker, bridgelip sucker, pacific lamprey, redside shiner, northern pikeminnow, peamouth chub, brassy minnow, longnose dace and leopard dace) and two species of concern (white sturgeon, bull trout.[1]) identified by the British Columbia Conservation Data Center[2]. The Conservation Data Centre (CDC) is a part of the Environmental Stewardship Division of the Ministry of Environment which collects, maintains and distributes information on species[3] and ecological communities at risk in B.C. Within the study area the white sturgeon[4] has been red-listed and the bull trout is blue-listed. The provincial Red list includes those species that are extirpated, endangered or threatened in B.C.[5], while the Blue list includes species and communities of special concern due to characteristics that make them sensitive to human activities or natural events. **Table 2.7** (main report) provides an overview of the important life stages of salmonid species as well as species of special concern documented within the study area. Spawning and incubation timing windows have been provided even though not all species on the list have been documented to spawn or incubate within the study area

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[1] Bull trout are also salmonids. White sturgeon and burbot may be considered sport fish although they are not salmonids and as endangered species white sturgeon may not be harmed, killed or taken within the Omineca Region (BC 2008).

[2] This list of fish species likely present at the confluence was prepared by merging the fish species list for each of the Nechako and Fraser Rivers (FFSBC 2005) and removing species distributed in other areas of these large rivers (i.e. the lower sections of the Fraser River) according to distributions in McPhail 2007.

[3] Vertebrate, vascular plant species and ecological communities at risk have been identified in B.C. A list of invertebrates, mosses and lichens at risk is being created.

[4] The following three white sturgeon populations in the Omineca Region are red-listed: Nechako River population, Upper Fraser River population and Middle Fraser River population.

[5] Not all Red-listed species will become formally designated as extirpated, endangered or threatened under the *Wildlife Act*. The Red list serves to identify species at risk that should at minimum be considered candidates for one of these legal designations.

boundaries. More detailed life history information for these species is included in the following subsections.

C.3.1 Salmonids

Rainbow Trout

Rainbow trout is a native species widely distributed across British Columbia; however, its native range is unclear due to extensive and widespread introductions. This cool-water species can be found in a number of habitats; it can be broadly categorized into groups based on its five habitat types: anadromous, lacustrine, large river, stream and headwater. Anadromous rainbow trout are known as steelhead.

During the summer, trout inhabiting streams and rivers, are found in riffles, runs, glides and pools. Adults occupy deeper and faster waters than juveniles. In smaller streams, good quality habitat usually has a sufficient amount of overhanging cover, primarily in the form of riparian vegetation and large woody debris. Overwintering habitat in small streams consists of large pools that span the entire width of the channel. Preferred water temperatures are between 7 and 18°C.

Generally, the migration of rainbow trout to spawning streams occurs from late April to May and is triggered by rising water levels and temperature. Spawning habitat usually has a depth of 0.15 to 2.5 m and water velocities between 0.3 to 0.9 m/s. Typically, larger-bodied populations of rainbow trout spawn in deeper, faster-flowing water. Spawning occurs from late April to July (McPhail 2007).

Within the study area, high-quality rainbow trout habitat is known to occur in tributary streams such as McMillan Creek and Parkridge Creek. The distribution and life history of rainbow trout in the primary channels of the Fraser River and lower Nechako is not well understood. Preferred spawning and summer rearing habitat conditions are limited in these systems, suggesting that significant utilization of the mainstems by rainbow trout is unlikely.

Bull trout

The life history patterns of bull trout include adfluvial, fluvial and resident stream populations, which require rearing in cold headwaters streams for a portion of their juvenile life stage. The cold water temperature niche of bull trout limits the availability of spawning and rearing habitat and renders them sensitive to habitat alteration.

Fluvial populations of bull trout use the study area as a migration corridor to access spawning or forage areas in the upper Fraser and Nechako watersheds. Spawning occurs in the fall with migration to spawning areas beginning in August (McPhail, 2007). However, bull trout typically prefer cold water habitats during the early portions of their life cycle. As a result, the study area provides only marginal capacity for spawning and juvenile rearing.

Mountain Whitefish

Mountain whitefish are widely distributed along both slopes of the Rocky Mountains and are exclusive to western North America. In British Columbia mountain whitefish are primarily an interior species with riverine (life cycle completed entirely within flowing water), lacustrian (life cycle competed entirely within a lake), and adfluvial (life cycle involved migrations between lakes and rivers) populations and are absent from coastal islands. It is believed that fluvial populations undertake several migrations annually to fulfill life requirements (i.e., migration to seasonal feeding areas, spawning areas, and overwintering habitats; McPhail 2007).

Spawning by fluvial populations is usually conducted in flowing water in the fall or early winter (in October or November for most BC populations when temperatures drop below 10 ºC; McPhail 2007). Populations within large river systems (such as the Fraser and Nechako Rivers) likely migrate into smaller streams to spawn. Spawning is conducted at dusk or at night, which has limited the observation of spawning activities. It appears that there is no site preparation prior to the scattering of eggs over the substrate (McPhail 2007). Eggs become lodged within the interstitial spaces in the substrate where they incubate over the winter. Fry emerge in the spring or early summer and drift downstream before moving into shallow, low velocity areas along the river margins where they remain until early fall when the fry move into faster and deeper water (McPhail and Troffe 1998). This tendency to move into faster and deeper water continues as body size increases (McPhail and Troffe 1998).

Spawning has not been observed in the Prince George area, but it is inferred that spawning does occur in the lower Nechako and the mainstem Fraser based on the capture of ripe males with well developed spawning turbicles and the distribution of newly-emerged fry in the area (McPhail and Troffe 1998).

Anadromous Salmonid Life History

Most anadromous[6] salmonids returning to the Nechako River will likely migrate into the Stuart-Takla drainage basin or Nadina-Francois Lake drainage basin to spawn. Adult Chinook salmon migrating to these areas begin to arrive in the study area as early as June, while the late sockeye run can terminate as late as mid-November.

Salmon fry incubate through the winter months and emerge from the spawning beds in the spring. They outmigrate downstream, spending portions of their first and sometimes second year of life in lakes or along river margins. Side channels and other off-channel habitats are particularly productive areas that can often support high densities of salmon fry. The outmigration of salmon fry to the Fraser River estuary takes place from spring to early fall, depending on the species and natal stream.

[6] Anadromous = moving from the marine environment to freshwater to spawn

Chinook salmon

Chinook salmon tend to spawn in larger streams with faster water and more coarse substrates than the other species of Pacific salmon. However, Chinook may also spawn in smaller streams and sidechannels. As they tend to produce larger eggs, they require spawning sites with a subgravel flow of oxygen-rich water. Depth and water velocities of spawning sites range widely, but average 35 cm and 0.5 m/s respectively. In the Fraser River system, there are two peak runs of adult Chinook migrating to spawning grounds, one occurring in July, the second in September/October (McPhail 2007).

Although the study area does not appear to support spawning habitat for Chinook salmon (Nowotny and Hickey 1993), it is an important migration corridor and is used extensively for summer rearing by outmigrating young-of-the-year (Fraser et al. 1982 in Nowotny and Hickey 1993). Upper Fraser and Nechako stocks of Chinook salmon are stream-type, meaning they rear for one or sometimes two years in freshwater prior to smolting (Tutty and Yole 1978; Hickey and Lister MS 1981 in Nowotny and Hickey 1993). Outmigration studies on the Nechako River indicate that over 80% of young-of-the-year Chinook salmon leave the upper watershed during their first summer. Although population dynamics of juvenile Chinook in the lower Nechako River are not well understood, high summer water temperatures create sub-optimal rearing conditions, which may encourage these fish to move further downstream into the Fraser River.

Pink salmon

Pink salmon typically spawn at age 2 between September and October within their natal stream. Fish that spawn in the Fraser River or in its upper tributaries (e.g. the Nechako River) enter the river from the ocean 2 weeks earlier than other pinks. Eggs incubate within the gravel over the winter months, hatching into alevins within 1.5 to 3 months after being deposited. Fry emerge from the gravel 3 to 5 months after hatching and migrate downstream as soon as they are able (ranging from late February to late May). Pink salmon mature after two growing seasons in the ocean and then return to freshwater to spawn (McPhail 2007).

Of all the pacific salmon, pink salmon spend the least amount of time in freshwater as the fry migrate downstream to the ocean quickly after emerging and usually die within 2 months of returning to freshwater as adults. Therefore freshwater habitat is essentially limited to migration corridors and sites where spawning and egg incubation occurs. Pinks prefer spawning sites with clean gravel and subgravel flow, usually within shallow riffles 20 – 100 cm deep and water velocities between 0.3 and 1 m/s (McPhail 2007). Small numbers of pink salmon (relative to average Chinook or sockeye escapements) spawn at selected sites in the lower Nechako River, upstream of Cottonwood Island (Nutton pers. comm. 2008, ILMB 2008). Pinks in the upper Fraser system spawn only in odd-numbered years.

Sockeye salmon

Sockeye salmon return to their natal streams to spawn by four years of age. The majority of the Nechako sockeye salmon migrate into the Stuart-Takla drainage basin or Nadina-Francois Lake drainage basin to spawn. Adult sockeye migrating to these areas begin to arrive in the study area as early as June and terminate in late August.

Following emergence in the spring, sockeye fry typically rear within large lake environments for one year before outmigrating directly to the ocean as smolts the following spring.

Coho salmon

Most coho salmon spawn at 3 years old while some precocious jacks spawn at 2 years. Spawning usually occurs in areas with subgravel flow, water velocities between 0.3 and 0.91 m/s and substrate diameters of 3.9 to 13.7 cm. Water temperature during spawning is usually between 1 and 8 °C. Early spawning runs enter freshwater from September to October and spawn from late October to December. Later spawning runs enter in December or January and spawn quickly after (McPhail 2007).

Rearing habitats of fry typically include sidechannels, backwatered areas, and protected areas along shore margins. Movement into pools occurs as they get larger. Like Chinook, most young rear for one year (sometimes two years) in freshwater prior to smolting. Juveniles are occasionally captured in the Nechako River upstream of Vanderhoof, while reports of coho within the Fraser River upstream of the Nechako confluence are not well documented. Overwintering in freshwater usually occurs under cover features such as undercut banks, woody debris and cobbles (McPhail 2007).

Coho are found in all coastal drainages of BC, including the Fraser River up to Prince George and the Nechako River. Coho found above Hell's Gate within the Fraser, Nechako and Thompson Rivers comprise the genetically distinct Interior Fraser River population. This population, which includes the Upper Fraser subpopulation, was listed as Endangered by COSEWIC in 2002 (Centre for Applied Conservation Research 2007).

Nearshore Habitats

In 1992, a comprehensive inventory and rating of salmonid habitats of the Nechako and Fraser Rivers within Prince George city limits was completed by Fisheries and Oceans Canada (Nowotny and Hickey 1993). Streambank sections were delineated according to a general consistency of habitat variables (e.g. substrate type; water depth; habitat type; bank composition and stability; instream, bank and upland vegetation; and upland status). Based on the collective quality of habitat variables, each section was assessed for rearing, spawning and over-wintering habitat value and rated into a category of high, medium or low.

Since this work was completed over 15 years ago, significant changes to river morphology and fish habitat may have occurred over this time period. A field data collection program was initiated in 2008 to verify and update this information to document current baseline conditions. The methodology of Nowotny and Hickey (1993) was used as the basis for the 2008 field activities and to update the habitat mapping information.

Results of the 2008 salmonid habitat inventory within the study area are presented in tabular form and illustrated on three 1:10,000 scale maps displaying the location and ratings of streambank sections (**Appendix C.1**). The 1992 assessment delineated 81 streambank sections along the Nechako River, 42 of which were rated as high quality habitat. In 2008, twenty additional sections were identified, which suggests either slight differences in methodology or an increase in habitat diversity. A total of 53 streambank sections were rated as high quality habitat in 2008. Only minor habitat changes occurred along the Fraser River portion of this study.

Mid-channel Habitats

In order to gain an understanding of mesohabitat characteristics on the lower Nechako River, a Level 1 Fish Habitat Assessment (FHAP) was conducted in the fall of 2008 from its confluence with the Fraser River to Wilson Park; approximately 8 km upstream. The FHAP procedures provide an accurate and repeatable methodology that can be used to help predict the effects of certain instream work activities on aquatic resources.

Results of the FHAP show that even under summer base flow conditions, the lower river is predominantly composed of continuous riffle (areas of turbulent fast-flowing water) or glide (areas of fast flowing, non-turbulent water) habitat units. These characteristics are typical of watercourses with relatively flat bottoms in cross-section (Johnston and Slaney 1996). There is a distinct lack of primary (main channel) or secondary (side channel) pool habitats, which are generally important features for supporting fish over the winter months (**Appendix C.1**).

C.3.2 WHITE STURGEON

Life History

The white sturgeon is the largest freshwater fish species within British Columbia, growing up to 6 meters in length, weighing up to 650 kg and able to survive to over 100 years in age (DFO 2007). Within the Fraser River drainage, white sturgeon are found from the Fraser River estuary to at least Rearguard Falls (upstream of Prince George, BC) and within the Nechako River from its confluence with the Fraser River to upstream of Vanderhoof (McPhail 2007). There are six genetically distinct populations of white sturgeon in BC (upper Fraser, middle Fraser, lower Fraser, Nechako, Columbia and Kootenay). White sturgeon may also be found in large lakes associated with these river systems (e.g. Fraser Lake and Stuart Lake within the Nechako River drainage). At the confluence of the Fraser and Nechako Rivers, both upper Fraser white sturgeon and Nechako white sturgeon populations may be present.

White sturgeon occupy river mainstems, large tributaries, reservoirs and the large lakes associated with the large river system in which they are found. The specific types of habitat they use is not well known, but like other characteristics of white sturgeon, information is increasing since being added to Schedule 1 of the federal Species at Risk Act (SARA) and the B.C. provincial Red list. Within the upper Fraser River, white sturgeon juveniles are typically found within the lower reaches of large tributary streams or in the mainstem near tributary mouths. In the lower Fraser, juveniles have most often been found in warm water that is usually turbid, low-velocity and with a depth of greater than 5 m. Bed material in these areas is usually composed of sand and silt. Overwintering usually occurs in deep pools in the primary channel and movements during this time period may be very limited (often less than 200 m) (McPhail 2007).

Maturity is reached at different ages for males and females; males become mature in their early teens to early 20s and females in their mid- to late-twenties (lower Fraser population). Once becoming mature, young females may spawn about every four years, while older females may only spawn every 9 – 11 years. In BC, white sturgeon usually spawn after the peak spring discharge for the system they occupy when water temperatures are rising (McPhail 2007). It usually occurs in fast and turbulent water over coarse substrate (DFO 2007).

A study by Perrin and colleagues (2003) on white sturgeon spawning habitat in the lower Fraser River found that five of six identified spawning sites were within non-turbulent side channels of a braided section of river. The remaining spawning site was within the main channel of a confined section of river (without side channels). The average water depth at locations where eggs and larvae were captured was 2.9 m and water velocities averaged 1.8 m/s (eggs) and 1.0 m/s (larvae). However, spawning habitat is variable, for example within impounded sections of the Columbia River most identified spawning sites were within the trailraces of dams (Parsley and Kappenman 2000 in McPhail 2007).

The Nechako River white sturgeon population has experienced recruitment failure, which has resulted in the population exhibiting a modal age group much higher (36 – 39 years) than the usual 10 – 15 years. Due to this failure, there is little information on the juvenile population and their habitat. It has been proposed that the recruitment failure may be due to a major sediment release in early 1960s that has filled the interstitial spaces within gravel substrate at a spawning site near Vanderhoof (which interferes with larvae requirement of gravel for shelter) (McAdam et al. 2005).

Current Status of White Sturgeon – Nechako and Upper Fraser Populations

The white sturgeon was ranked as an endangered species by the Committee on the Status of Endangered Wildlife in Canada (in November 2003) and both sturgeon populations that may be found within the confluence of the Nechako River and Fraser River have been red-listed by the BC Conservation Data Centre. Both of these populations[7] were also added to Schedule 1 of the *Species at Risk Act* (SARA) in 2006. These designations

[7] Four populations of white sturgeon, the Upper Fraser, Nechako, Columbia and Kootenay, were added to Schedule 1 of SARA in 2006.

reflect the imperiled population status of the Nechako River and Upper Fraser River populations.

In 2001, the upper Fraser River population of white sturgeon was estimated at 815 fish (Yarmish and Toth 2002). The number of mature fish in this population has been estimated at 185 (DFO 2007). RL&L (2000) has also suggested that this population consists mostly of juveniles and subadults. The growth rate of this population is slow, like that of the Nechako River population (RL&L 2000).

The Nechako River population in 1999 was estimated at 571 fish and displayed a structure similar to sturgeon populations in other regulated rivers (RL&L 2000). RL&L (2000) found that the population was dominated by older fish and it displayed poor juvenile recruitment. 305 mature white sturgeon are currently thought to exist in this population (DFO 2007). Little or no juvenile recruitment is believed to have occurred since 1967 (DFO 2007). The population is declining and at risk of extirpation due to decades of recruitment failure. Model projections suggest that recovery efforts are required to restore recruitment and a self-sustaining population (DFO 2007; RL&L 2000).

Recovery efforts have been headed by the Nechako White Sturgeon Recovery Initiative. This organization is concerned with discovering the reason(s) for sturgeon recruitment failure in the Nechako watershed and establishes habitat protection and restoration and other management works. The short-term goal of the Initiative is to create a conservation fish culture program to sustain the population while the long-term goal of re-establishing a self-sustaining population is realized (Nechako White Sturgeon Recovery Initiative 2008). Since 2006, over 8000 juvenile white sturgeon have been released (BC 2008).

Critical Habitat

Potentially critical habitats for white sturgeon include important areas in which adults feed and “stage” prior to migration to spawning grounds, spawning sites, and rearing locations for larvae and juveniles (DFO 2007). A study by RL&L (2000) suggested the following areas presented suitable habitat that may be used as spawning sites for the Nechako River population: Isle Pierre, Whitemud, Hulatt rapids, Nautley River and the lower Stuart River. Both spawning and overwintering sites have been located near Vanderhoof. Threats to sturgeon habitat include instream activities such as gravel removal, development of riparian and/or foreshore areas, river regulation, upstream use of land and water and effluent discharges (DFO 2007).

Although a number of years of white sturgeon research on the Nechako and Fraser Rivers have been completed, no known study has specifically examined white sturgeon habitat at the confluence of the Nechako and Fraser Rivers. As there is a potential for the presence of critical habitat within this area, EDI in conjunction with Lheidli T’enneh First Nation (LTN) and Upper Fraser Fisheries Conservation Alliance (UFFCA), began field inspections in the confluence area that may aid in determining whether this area should be considered as critical habitat for sturgeon. As a determination of this nature requires extensive study, the results of the 2008 field investigations are preliminary only and should serve to begin understanding of the species' behavior and habitat utilization within the study area.

2008 Sturgeon Sampling

2008 field investigations of white sturgeon habitat in the vicinity of the confluence included aerial radio-telemetry surveys and sturgeon sampling using setlines (**Table C.1**).

Sturgeon Sampling by Setlines

White sturgeon sampling at the confluence of the Nechako and Fraser Rivers was conducted on a number of occasions in summer 2008 to help add to the understanding of the species' behavior and habitat utilization within the study area. As overwintering is known to occur in other areas of the rivers, potential use of the study area for rearing and spawning is of particular interest. Sampling for sturgeon was conducted using setlines with baited hooks, set overnight and retrieved the next day. Five sessions of sampling were conducted over the summer; three of which resulted in the capture of sturgeon. A total of twelve white sturgeon were captured with a total effort of 6497 hook hours. All captured sturgeon were measured and examined for tagging information, sex and general health. Coded wire tags were implanted in all fish for future identification and radio tags were implanted in selected adult or sub-adult fish.

Radio-telemetry Surveys

In response to concerns that white sturgeon may be in the vicinity of the 2007/08 ice jam and proposed temporary flood relief works (i.e. warm water release), EDI in conjunction with the Lheidli T'enneh First Nation and UFFCA conducted aerial radio-telemetry surveys of the upper Fraser River and lower Nechako River in January and May of 2008. Efforts were made to locate twelve white sturgeon caught (and radio-tagged) in the upper Fraser River between river kilometers 829 (near the Wright Creek confluence) and 950 (Grand Canyon at Longworth) in Fall 2007 by the LTN. In January, five of the twelve sturgeon were located; the individual located farthest downstream was at river kilometer 898 (near the McGregor River confluence) which is approximately 100 km upstream of the Nechako River confluence. On the May 8, 2008 aerial survey, seven white sturgeon were located; the individual located furthest downstream was approximately 15 km upstream of the Nechako River confluence (river km 810).

Appendix C.2 provides location information for each of the twelve radio-tagged white sturgeon at the time of tagging and on the dates of aerial surveys. White sturgeon that could not be located on aerial survey dates are listed as "not located." While the location of these fish was not known, it is possible that they were in areas too deep to detect the tag signal (e.g. the Grand Canyon at Longworth has depths exceeding 13 meters) or had moved into areas not incorporated into the survey (e.g. wintering areas near Vanderhoof).

C.4 Riparian Vegetation

Despite the amount of urban development that has taken place over the last 100 years in the Prince George area, there are still large expanses of intact riparian vegetation, particularly along the upper Nechako and the east bank of the Fraser River. Dominant forest cover within the riparian and nearby upland within the study area tends to follow a pattern based on the steepness of the river banks. In areas where banks are moderately steep or steeper, the dominant forest canopy cover is usually coniferous including species such as spruce, Douglas fir and/or lodgepole pine. For example, on the Fraser River, downstream of the Simon Fraser Bridge, the dominant riparian area tree species are spruce and fir. In more flat areas, where banks do not slope much higher than river levels, dominant forest canopy cover is usually deciduous, including species such as black cottonwood, trembling aspen and/or paper birch, or mixed with a combination of coniferous and deciduous species. These species assemblages are common along the Nechako River and the upper reach of the Fraser River. Common shrub species in these areas include wild rose, hardhack, black twinberry, red-osier dogwood, willow and alder (Nowotny and Hickey 1993). Within the Prince George forest district, there are 25 listed plant species (**Appendix C.3**). There are five listed plant communities within the SBSmh and seven listed plant communities within the SBSdw3, Prince George Forest District (CDC 2007) (**Appendices C.3 andC.4**).

C.5 Wildlife

Numerous wildlife species can be found near the confluence of the Nechako and Fraser Rivers. In 2003, Golder and Associates conducted a wildlife habitat assessment on Fishtrap Island. Wildlife observations or signs were found of the following species: deer species, red squirrel, beaver, river otter, bald eagle, American widgeon, mallard, belted kingfisher, woodpecker species, American crow and black-capped chickadee. Numerous other large mammals (e.g. moose and bear), small mammals (e.g. rodents, coyotes, muskrat, foxes), birds, amphibians and reptiles are known to be present in the study area.

The Prince George Naturalist Club has identified a variety of bird species at Cottonwood Island Park, Macmillan Creek Regional Park and Wilkins Park. All three of these parks are located along the Nechako River within the City limits. Passerines are abundant throughout all three locations.

C.5.1 Species at Risk

A search of the Conservation Data Centre (CDC)'s BC Species and Ecosystem Explorer revealed 20 provincially listed wildlife species that may occur within or near the study area. White sturgeon was the only red-listed species, while the following are blue-listed vertebrate species: Great Blue Heron (*herodias* subspecies), Short-eared Owl, American Bittern, Broad-winged Hawk, Bobolink, Sandhill Crane, Wolverine (*luscus* subspecies), Fisher, Northern Myotis, Long-billed Curlew, Caribou (northern mountain population), Bull Trout, Sharp-tailed Grouse (*columbianus* subspecies) and Grizzly Bear. Blue-listed invertebrates included Rocky Mountain Capshell, Mead's Sulphur, Pygmy Fossaria, Jutta Arctic (*chermocki* subspecies) and Forcipate Emerald (**Appendix C.5**).

SARA Schedule 1 species that may be within the project area (as revealed by a map search of the Species at Risk public registry) include the Long-billed Curlew, Western Toad and White Sturgeon[8] (EC 2004). The Long-billed Curlew and Western Toad are classified as Species of Special Concern on Schedule 1 which indicates that they have characteristics that may make them sensitive to human activities or natural events but are less at risk than species classified as Threatened or Endangered. These species and their habitat are protected under SARA.

Long-billed curlew (from MWLAP 2004)

The long-billed curlew is a large sandpiper, with long legs and a long decurved bill whose numbers and size of breeding range have decreased in the last century. Non-breeding birds are found throughout the south-central interior north to the Nechako Lowland while breeding occurs in the southern interior. The known extent of the northern portion of the breeding range in British Columbia includes the area from Lillooet north to Chubb Lake near Quesnel. A small population has been documented to breed near McBride.

Long-billed curlews breed in grasslands with open, low-lying vegetation which allow co-operative anti-predator mobbing behaviours. During the pre-laying and incubation periods of breeding, vegetation less than 10 cm tall is preferred, which increases up to a preference of 30 cm during the brood rearing period. Clutches are usually started between mid-April and mid-May and the young birds fledge between the end of June and mid-July. Threats to the habitat of curlews include urbanization, conversion of native grasslands to agricultural uses and intrusion by noxious weeds and forest encroachment.

Western toad (from Wind and Dupuis 2002)

Western toads are a widespread and abundant amphibian in Canada that have dry, bumpy skin, that can be highly variable in coloring but is usually mottled on the dorsal surface with a lighter-colored dorsal stripe. In British Columbia, they are found from the Rockies to the Pacific Coast. Its status in Canada as a species of Special Concern is due to its known vulnerability to a number of threats (e.g. urban and agricultural development, predation, climatic conditions, desiccation, UV radiation, disease) and the demonstrated potential for rapid population decline or extirpation as seen in the United States.

Western toads may breed in natural or artificial habitats including ponds, the edges of streams or lakes, ditches and road ruts. In BC, western toads may begin to breed when average minimum and maximum daily temperatures are above 0 ^{o}C and 10 ^{o}C respectively. Tadpoles usually hatch within 12 days and full metamorphosis generally takes three months from egg laying. Non-breeding habitats include wetlands, forests,

[8] Previously discussed in Section 7.4.2.

clearcuts, avalanche slopes and subalpine meadows. Toads may prefer areas with shrub cover as protection from predation and desiccation.

C.6 Environmental Legislation

C.6.1 Federal Legislation

The principal relevant items are reviewed below.

The federal *Fisheries Act* deals with three matters:

- management and control of recreational, commercial and First Nations fisheries;
- conservation and protection of fish and fish habitat; and,
- prevention of pollution.

Section 34(1) of the Act defines fish habitat as "*spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly to carry out their life processes.*" Section 35, the key habitat protection provision, prohibits “harmful alteration, disruption or destruction (HADD)” of fish habitat without an authorization from the Minister or through regulations under the Act.

The *Canadian Environmental Assessment Act* (CEAA) requires federal officials to consider the environmental effects of certain types of project before making any decisions or exercising any powers in relations to a proposed project. Generally speaking, the Act applies when a proposed project requires action or decision by a federal agency, such as:

- granting money or other financial assistance
- exercising a regulatory function such as issuing a license or authorization.

The *Species at Risk Act* (SARA) was created to protect indigenous animal and vegetation species by providing for recovery of species at risk and by ensuring that other species are not endangered or threatened.

The *Migratory Birds Convention Act* (MBCA) and its complementary Migratory Birds Regulation regulates activities potentially harmful to migratory birds, nests or eggs. Regulatory requirements are placed on hunting and other activities related to airports, agriculture, etc. (Some migratory birds originally excluded from protection are now covered under provincial or territorial legislation.)

C.6.1 Provincial Legislation

The principal relevant items are reviewed below.

The BC *Water Act* regulates the use of water from streams, lakes and rivers. Section 9, “Changes In and About a Stream,” requires that such activities be approved in writing by the comptroller, a regional water manager or an engineer. Typically, complex works require an approval from the Ministry of Environment, Water Stewardship Division.

Simpler projects that will not significantly affect the environment or other water users, do not require diversion of water, and can be completed within a short time frame, do not require an approval but must be notified to the Water Stewardship Division.

The BC *Wildlife Act* applies to nearly all forms of wildlife and their habitats. It authorizes the Minister to designate Wildlife Management Areas (WMA's) and allows the designation of endangered and threatened species (Section 6). The Act prohibits the alteration, damage or destruction of wildlife or their habitat within WMAs (Section 7). Land within a Wildlife Management Area (WMA) can be designated as a Critical Wildlife Area or Wildlife Sanctuary.

The *British Columbia Environmental Assessment Act* (BCEAA) establishes a process for reviewing potential environmental, social and economic impacts of proposed major projects. Projects subject to the EA process are indicated in the *Reviewable Projects Regulation* or designated by the Minister of Environment; in order to proceed, such projects must successfully complete the process and receive an EA certificate.

Table C.1 - Setline information for white sturgeon sampling conducted in Nechako and Fraser Rivers, 2008.

Location	Date	# of hooks per set	Hours/Set	Total Effort (hook hrs)	# of White Sturgeon Captured	Fork Lengths (cm)	Comments
Confluence of Nechako River with Fraser River	June 11-12/08	16, 15, 16, 16, 12, 16	16, 16.25, 16.1, 18.25, 18, 17.8	1550.2	6	89.5, 94, 137, 99.5, 142, 62.5	Sampling took place in area of confluence with four lines being set in Nechako River water and two lines set in Fraser River water.
Confluence of Nechako River with Fraser River	June 12-13/08	16, 16, 16, 16	18.5, 18.2, 17.7, 17.25	1146.4	1	~60	White sturgeon escaped prior to measurement. Sampling took place in area of confluence with all lines being set in Nechako River water.
Confluence of Nechako River with Fraser River	July 29-30/08	16, 13, 16, 16	19.6, 19.1, 21.1, 19.3	1208.3	0	N/A	Sampling took place in area of confluence with all lines being set in Nechako River water.
Fraser River, rkm 829.9 – 831.7, near Willow River confluence	Aug 6-7/08	16, 16, 8, 16	22, 22, 22, 22	1232	5	77, 75, 95, 78, 184	All sampling took place in Fraser River.
near Confluence of Nechako River with Fraser River	Sept 29-30/08	16, 16, 16, 16	21.25, 21.25, 21.25, 21.25	1360	0	N/A	Due to low water levels at the confluence of the Nechako River, sampling took place at the Cottonwood Park boat launch to the Canfor pumphouse on the Nechako River

APPENDIX C.1

2008 Nearshore Salmonid Habitat Inventory Results

Legend

Substrate	Bank Stability	Vegetation Abundance
O - Organics F - Fines G_S - Small Gravel G_L - Large Gravel Co - Cobble Bo - Boulder mm - Man made	U - Unstable M - Moderately stable S - Stable	nil S - Sparse (0-25%) I - Infrequent (25-50%) C - Common (50-75%) A - Abundant (75-100%)

Results

Nechako River Sites	1993 Original Rating	2008 Salmonid Habitat Value Rating	Upper Bank Substrates	Bank Stability	Submergent Species	Emergent Species	Lower Riparian Species	Upper Riparian Species	Upland Species
N1	Low	High	F(G_S)	S	S	NIL	I	S	C
N2	High	Med	G_S(F)	M	NIL	I	C	C	S
N3	High	Med	F(G_S)	M	NIL	NIL	C	A	A
N4	High	Med	F(G_S)	M	C	S	A	A	A
N5	High	High	F(G_S)	S	S	A	A	A	A
N6	Med	Med	F(G_S)	U	NIL	NIL	S	S	C
N7A		Med	F(G_S)	M	S	I	C	A	A
N7B	Med	High	F	S	C	C	A	A	A
N7C		High	F	M	NIL	S	A	A	A
N8	High	High	F	M	NIL	S	A	A	A
N9A	High	Med	F(G_S)	U	NIL	NIL	I	A	A
N9B		High	F(G_S)	M	S	S	A	A	A
N10A	High	High	F(G_L)	S	NIL	S	A	A	A
N10B		Med	G_S(Co)	M	NIL	NIL	C	A	A
N11	High	High	F(G_S)	S	S	S	A	A	A

Nechako River Sites	1993 Original Rating	2008 Salmonid Habitat Value Rating	Upper Bank Substrates	Bank Stability	Submergent Species	Emergent Species	Lower Riparian Species	Upper Riparian Species	Upland Species
N12A	High	High	F(G_S)	S	S	I	I	C	C
N12B		Med	F(G_S)	S	NIL	C	C	C	C
N12C		Low	F(G_S,mm)	S	NIL	A	I	I	A
N13	Med	Med	F(G_S)	M	NIL	NIL	A	A	A
N14A	Med	Low	F(Co,G_S)	U	NIL	NIL	S	C	C
N14B		High	F(Gs)	U	NIL	NIL	S	S	I
N15A	High	High	F	S	NIL	S	A	A	NIL
N15B		High	F	S	NIL	S	A	A	NIL
N15C		High	F	S	NIL	C	A	A	NIL
N15D		Med	F	S	NIL	C	A	A	NIL
N16	High	High	F	M	NIL	S	A	A	NIL
N17A	Low	High	G_S(F)	M	NIL	I	S	A	A
N17B		High	G_S(F)	M	I	S	S	A	A
N18	Med	Med	F	S	S	I	A	A	A
N19	Low	Low	G_S(F)	U	NIL	S	S	S	C
N20	High	Med	F	S	S	S	A	A	A
N21	High	Med	F	S	NIL	C	A	A	A
N22	Low	Low	mm	S	NIL	NIL	S	NIL	NIL
N23	Med	Med	G_L(G_S,Co,F)	U	NIL	S	S	S	I
N24A	High	High	Co(F)	M	S	C	C	I	I
N25	Med	Med	G_L(Co)	U	NIL	NIL	NIL	A	A
N26	High	Med	G_S(F)	S	NIL	A	A	A	A
N26A		High	F(G_S)	S	I	C	C	C	C
N27	Med	High	mm(G_L,G_S,F)	S	NIL	NIL	NIL	NIL	I
N28	High	High	F(Co,Bo)	S	I	I	I	C	A
N29	High	High	mm(Co,G_S)	M	NIL	NIL	NIL	NIL	C
N30	High	Med	G_L(F)	U	NIL	S	NIL	S	A
N31	High	Med	F	U	NIL	C	S	S	C
N32	High	High	G_S(F,G_L)	M	C	C	A	A	A
N33	Med	Med	mm(F)	S	NIL	NIL	C	NIL	NIL
N34A	High	Med	G_L(G_S)	S	I	S	A	A	A
N34B		High	G_S(F)	S	S	I	A	NIL	NIL
N35	Med	Med	F	U	NIL	I	S	C	A
N36	High	High	F(G_S)	S	NIL	A	C	S	NIL
N37	High	Med	F(mm)	S	S	C	C	C	S
N38	Med	Med	F(G_S)	S	A	C	C	NIL	NIL
N39	High	High	F(G_S)	S	S	C	S	S	S

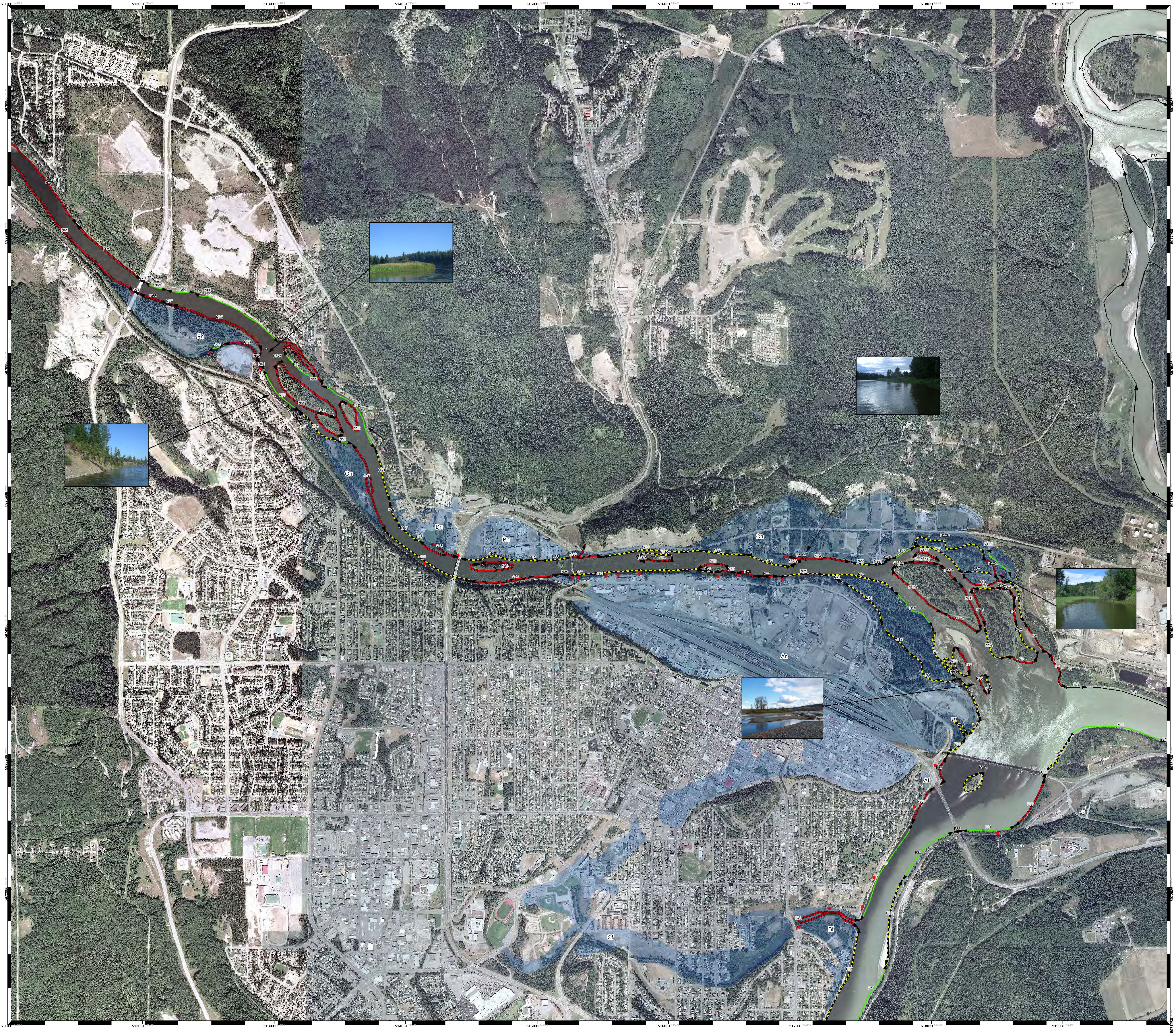
Nechako River Sites	1993 Original Rating	2008 Salmonid Habitat Value Rating	Upper Bank Substrates	Bank Stability	Submergent Species	Emergent Species	Lower Riparian Species	Upper Riparian Species	Upland Species
N40	Low	High	$G_L(G_S,F)$	M	NIL	NIL	S	S	NIL
N41	Med	Med	$F(G_S)$	M	S	S	S	S	NIL
N42	High	Med	$F(G_S)$	S	C	C	A	A	NIL
N43	High	High	$F(G_S)$	S	S	A	A	A	A
N44	Med	Med	F	S	NIL	S	C	C	NIL
N45	High	High	$F(G_S)$	S	A	A	A	C	NIL
N46	Low	Low	$F(G_S)$	M	A	C	C	S	NIL
N47	Med	Med	$F(G_S)$	S	S	C	C	C	C
N48	Med	Med	$F(G_S)$	M	S	C	C	C	NIL
N49	High	High	F	S	C	A	A	A	NIL
N50	Med	Med	$F(G_S)$	M	S	S	I	I	S
N51	High	Low	$Co(G_L,F)$	U	NIL	I	NIL	I	A
N52	High	High	F	S	C	A	C	C	NIL
N53	Low	Low	$G_L(G_S)$	M	NIL	S	S	I	C
N54	Med	Med	F	M	C	C	C	C	A
N55	High	High	$F(G_S)$	S	C	A	A	A	A
N56	High	High	$G_L(G_S)$	S	S	I	S	S	A
N57	Low	Low	F	M	S	I	C	C	A
N57A		High	$F(G_S)$	S	A	A	C	A	NIL
N58	Low	Low	$F(G_S)$	S	NIL	S	C	C	A
N59	High	High	$F(G_S)$	S	C	A	A	A	A
N60	Low	Low	F	M	NIL	S	C	I	A
N61	Low	Low	$mm(G_L,F)$	S	NIL	NIL	I	I	NIL
N62	Med	High	$F(G_S)$	M	NIL	S	A	A	NIL
N63	Low	High	$F(G_L)$	M/S	A	A	C	C	C
N64	Low	Low	$F(G_S)$	S	A	A	A	A	A
N65	High	High	$F(G_L)$	S	I	I	A	A	A
N66	Low	Low	$F(G_S)$	M	S	I	I	I	S
N67	Med	Low	$Co(G_L)$	M	NIL	S	S	NIL	NIL
N68	Med	High	$F(mm,G_S)$	S	NIL	S	NIL	NIL	NIL
N69	Low	Low	F	M	I	I	C	C	S
N70	Med	Med	F	M	S	I	C	I	A
N71	High	High	F	S	C	A	A	A	A
N72	High	High	$F(G_S)$	S	I	A	A	A	A
N73	Med	Med	F	S	I	C	A	A	C
N74	Med	Med	$Co(G_L,F)$	S	C	C	C	C	C
N75	Med	Med	$F(G_S)$	M	S	C	I	I	C

Nechako River Sites	1993 Original Rating	2008 Salmonid Habitat Value Rating	Upper Bank Substrates	Bank Stability	Submergent Species	Emergent Species	Lower Riparian Species	Upper Riparian Species	Upland Species
N76	High	High	F(G$_S$)	S	I	A	A	A	A
N77	High	High	F(G$_S$)	M	I	C	A	A	A
N78	High	High	F	S	I	I	C	C	S
N79	High	High	F	S	C	S	NIL	NIL	NIL
N80	High	High	F	S	I	C	C	C	A
N81	High	High	F (Co,G$_L$)	S	S	C	C	C	NIL
N82	n/a	High	F	S	NIL	S	S	NIL	NIL
N83	n/a	Med	F	M	NIL	NIL	C	C	NIL
N84	n/a	Med	F	M	NIL	A	C	NIL	NIL
N85	n/a	High	F	S	NIL	C	C	A	NIL
N86	n/a	Med	F(G$_S$)	S	NIL	I	C	A	NIL
N87	n/a	Med	F(G$_S$)	S	NIL	S	S	I	C

Fraser River Sites	1993 Original Rating	2008 Salmonid Habitat Value Rating	Upper Bank Substrates	Bank Stability	Submergent Species	Emergent Species	Lower Riparian Species	Upper Riparian Species	Upland Species
F17	Med	Med	F	M	S	C	A	A	A
F18	Low	Low	F	M	S	C	A	A	A
F19	Low	Med	F	U	S	S	S	C	A
F20	High	Med	F	S	S	A	A	A	A
F21	Med	Med	F	M	I	S	C	C	NIL
F22	Med	Med	F	S	I	C	C	A	A
F23	Med	Med	F(G$_S$)	M	S	I	C	A	I
F24	Low	Low	F	S	S	I	C	C	I
F25	Med	Med	F	M	S	S	C	C	NIL
F26	Low	Med	F	U	NIL	S	C	C	NIL
F27	Med	Med	F	M	S	I	C	C	I
F28	High	High	F(G$_S$)	S	C	C	C	C	C
F29	Med	Low	F	M	NIL	NIL	NIL	NIL	S
F31	Low	Low	F(G$_S$)	S	S	C	A	A	A
F32	Med	Med	mm(G$_S$,F)	M	NIL	S	S	I	NIL
F33	High	High	F(G$_S$)	S	NIL	S	A	A	NIL
F34	Low	Med	F(G$_S$)	M	NIL	NIL	I	C	C
F35	Med	High	mm	S	NIL	NIL	S	S	NIL

Fraser River Sites	1993 Original Rating	2008 Salmonid Habitat Value Rating	Upper Bank Substrates	Bank Stability	Submergent Species	Emergent Species	Lower Riparian Species	Upper Riparian Species	Upland Species
F36	High	High	mm(F)	S	I	S	I	C	I
F37	High	High	mm(G_L)	S	S	I	S	I	NIL
F38	Med	Med	F	S	NIL	S	C	C	C
F39	High	Med	F	M	S	C	C	C	I
F40	Med	Med	F	S	S	S	S	C	NIL
F41	Low	Med	F	U	NIL	NIL	I	A	A
F44	Low	Low	F(G_L,G_S)	M	NIL	NIL	NIL	C	I

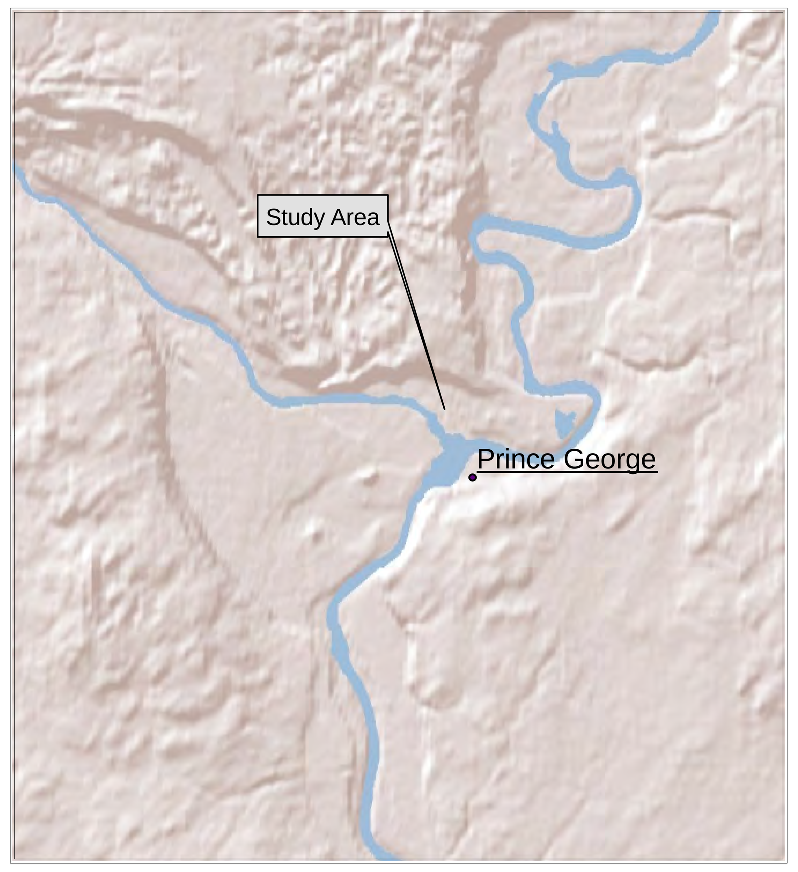
2008 NEARSHORE SALMONID HABITAT INVENTORY



Prince George Flood Risk Evaluation and Flood Control Solutions Study

Salmonid Habitat Value Rating

- Sites not assessed
- High
- Medium
- Low
- Site Photos
- Flood Control Solution Areas
- stormwater outfall
- City Boundary



Nechako River Mapsheet 1 of 2

N
W E
S

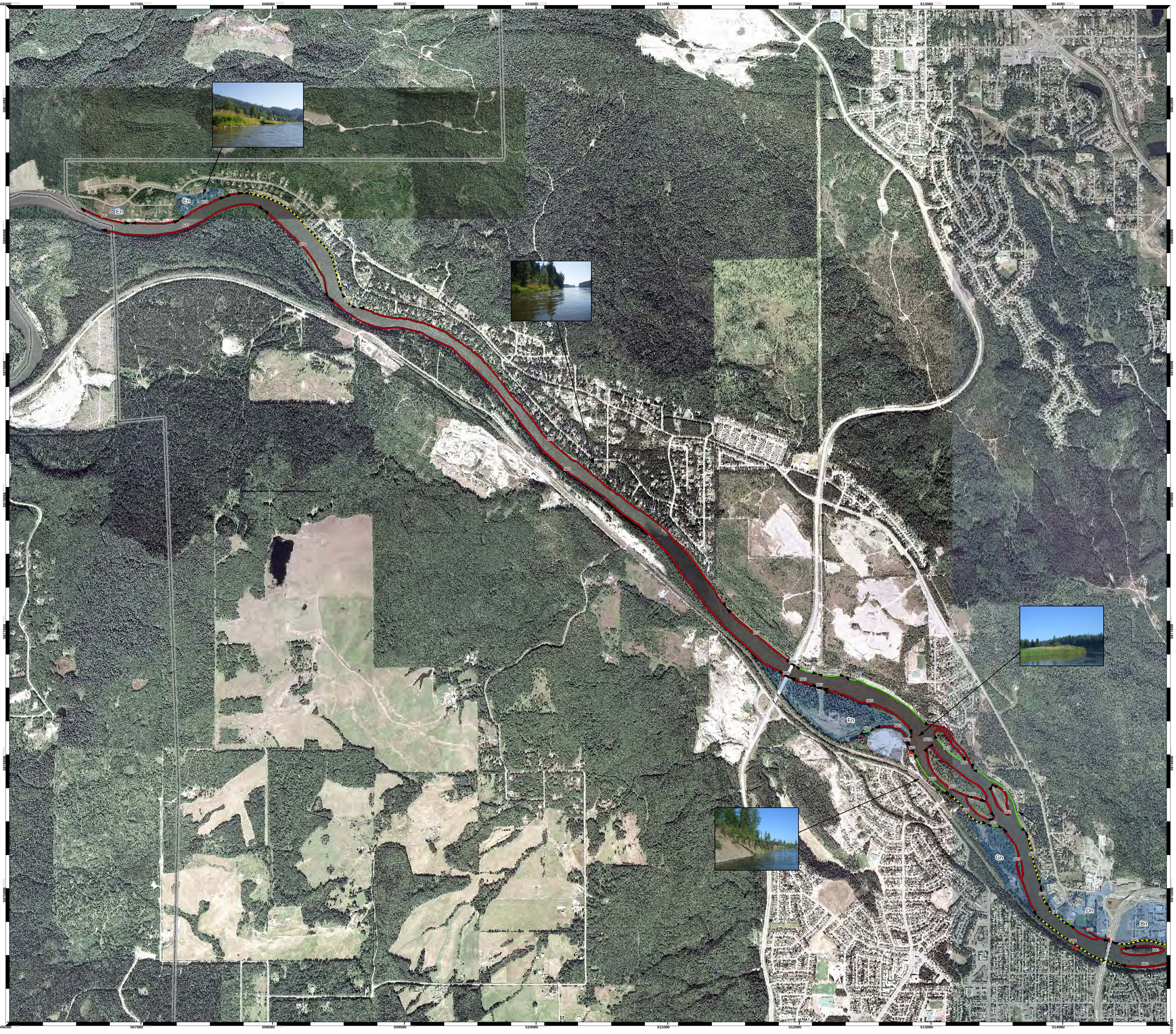
1:10,000

Meters
0 400 800 1,200

1 centimeter = 100 meters

Prepared by:	Prepared for: Northwest Hydraulic Consultants
EDI ENVIRONMENTAL DYNAMICS INC.	Designed by: Jess Anaka Date: November 2008

2008 NEARSHORE SALMONID HABITAT INVENTORY



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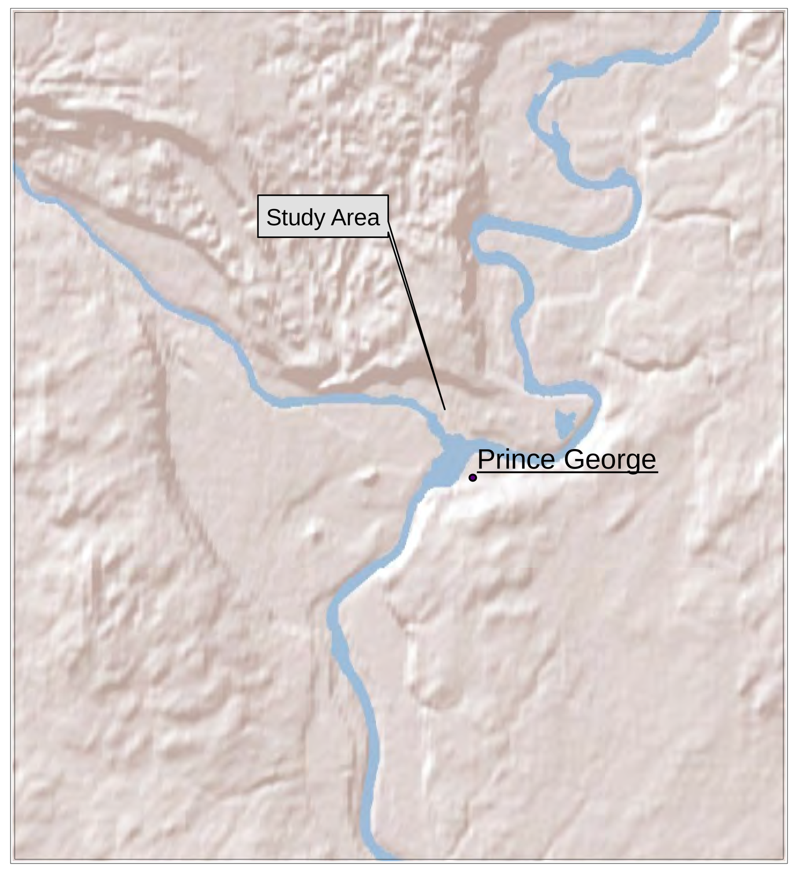
- stormwater outfall
- City Boundary



Nechako River Mapsheet 2 of 2

N E S W

1:10,000

Meters: 0 400 800 1,200

1 centimeter = 100 meters

Prepared by: EDI ENVIRONMENTAL DYNAMICS INC. *Natural Resource Consultants*

Prepared for: Northwest Hydraulic Consultants

Designed by: Jess Anaka

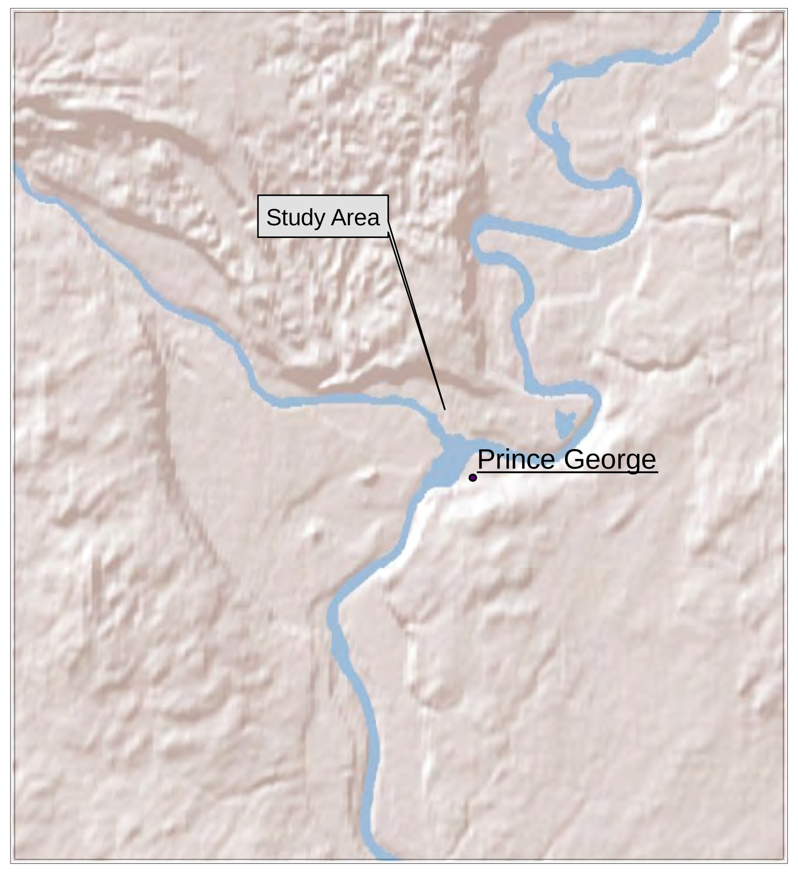
Date: November 2008

2008 NEARSHORE SALMONID HABITAT INVENTORY

Prince George Flood Risk Evaluation and Flood Control Solutions Study

Salmonid Habitat Value Rating

- Sites not assessed
- High
- Medium
- Low
- Site Photos
- Flood Control Solution Areas
- stormwater outfall
- City Boundary



Fraser River Mapsheet 1 of 1

N
W E
S

1:10,000

Meters
0 400 800 1,200

1 centimeter = 100 meters

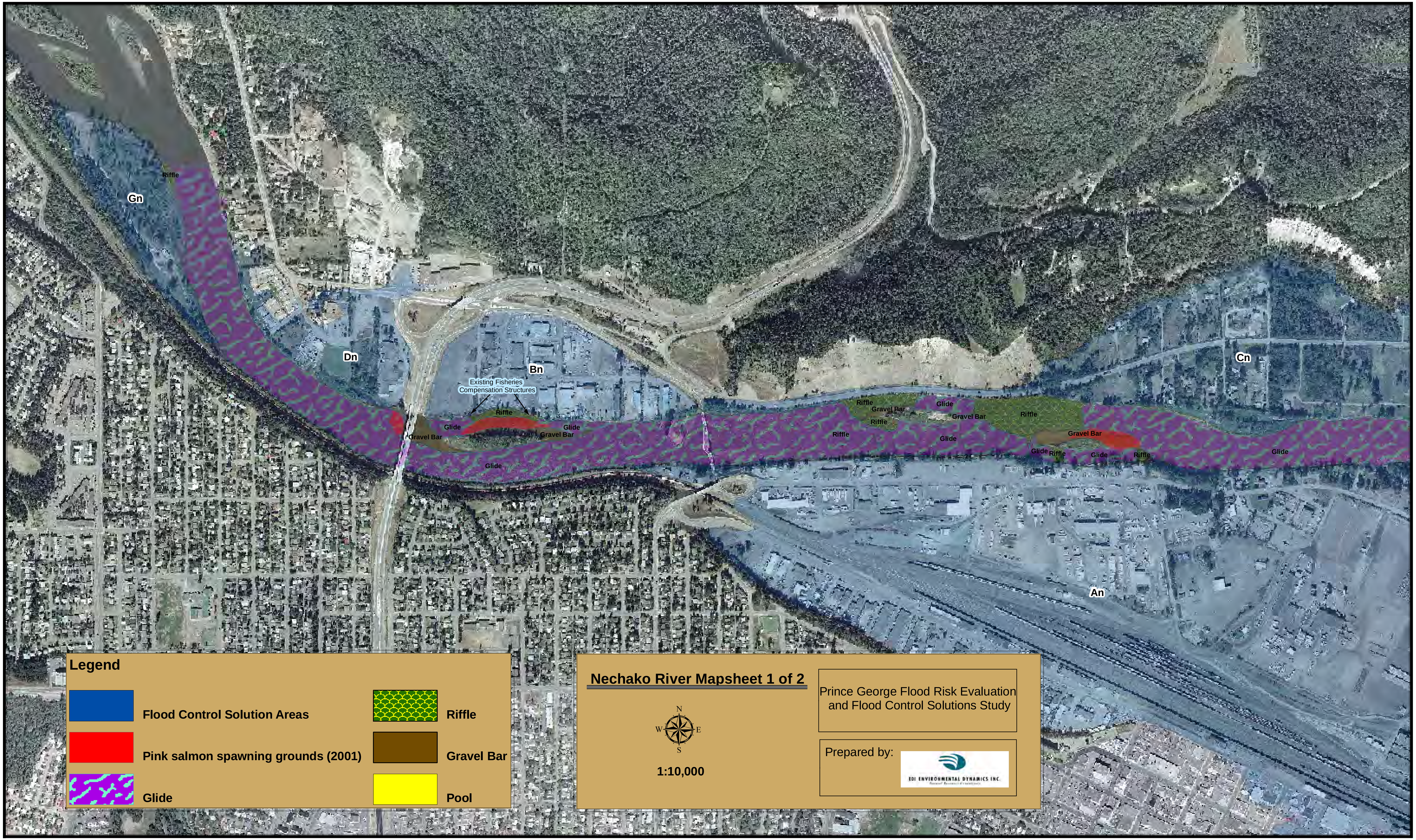
Prepared by:

EDI ENVIRONMENTAL DYNAMICS INC.
Natural Resource Consultants

Prepared for:
Northwest Hydraulic Consultants

Designed by: Jess Anaka
Date: November 2008

Nechako River Meso-Habitat Classification



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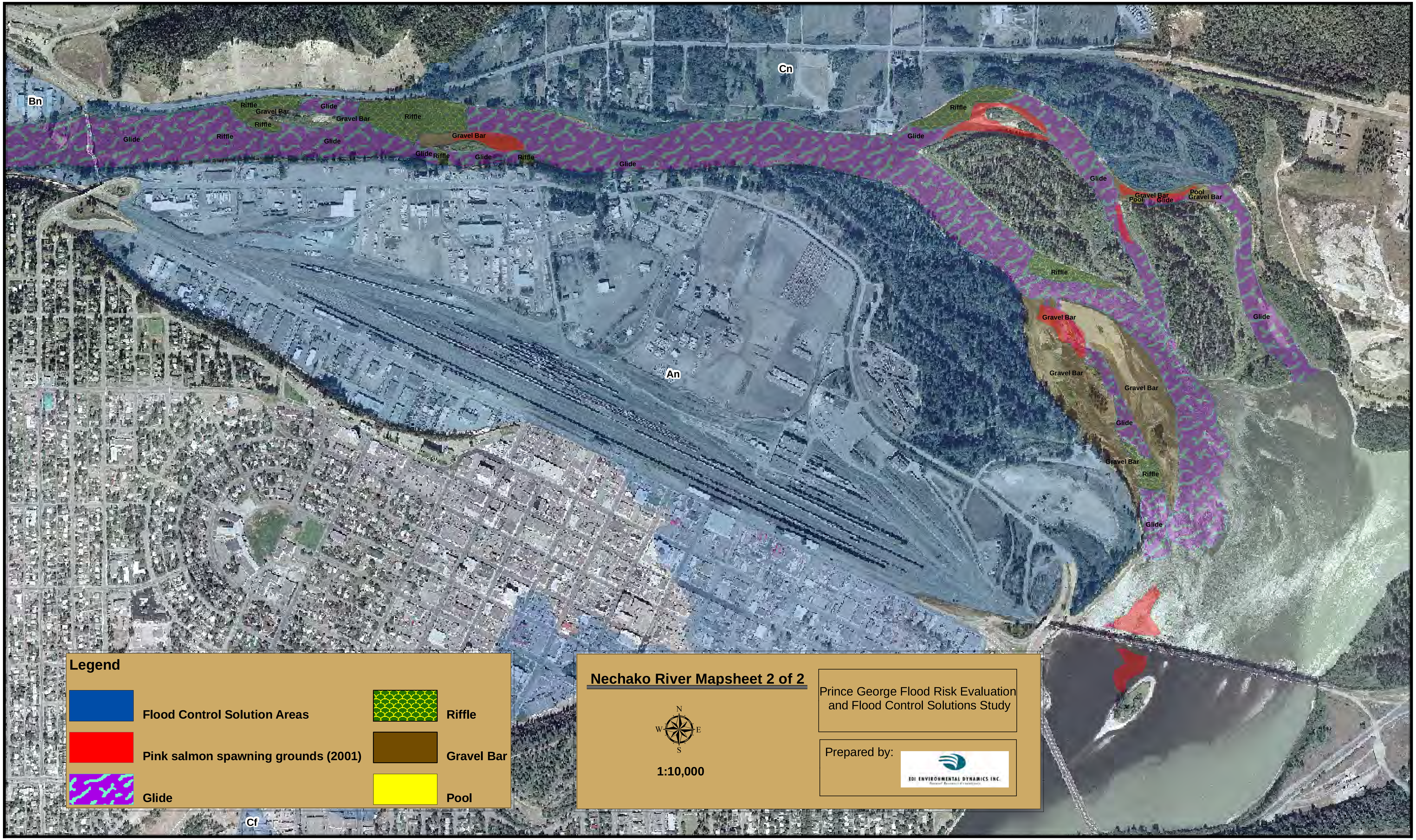


RESULTS OF THE 2008 HABITAT MAPPING

The 2008 habitat assessments ranked each stream section based on three habitat indicators: spawning, overwintering and rearing. Once assessed the data was compiled into a habitat scoring matrix, designed to provide a more precise assessment of the overall habitat ratings.

The habitat ranking (i.e. Low=1, Med=2 and High=3) for a particular site was evaluated based on the ecological importance of known salmonid life history requirements. A score of "1" was assigned where the shoreline habitat retained low productivity or was lacking in habitat features. A score of "2" was assigned where the presence of habitat was observed to have moderately productive habitat features. A score of "3" was assigned where an abundance of suitable habitat criteria was observed (i.e. spawning gravels, rearing habitat and/or overwintering) resulting in highly productive habitat.

Overall, if a site scored "3" in one of the habitat criteria, the entire site was rated as high. If a given site scored a combination of medium and low scores or medium scores for every habitat criteria, it was rated as medium quality habitat. Conversely, if a site received a low (1) score in every habitat criteria, the entire site was given a low rating.

Nechako River Sites	1993 Original Rating	2008 Salmonid Habitat Value Rating	Spawning	Rearing	Overwintering
N1	Low	High	1	3	3
N2	High	Med	2	2	1
N3	High	Med	2	2	1
N4	High	Med	1	2	2
N5	High	High	1	3	1
N6	Med	Med	1	2	2
N7A	Med	Med	1	1	2
N7B		High	2	3	3
N7C		High	2	3	1
N8	High	High	1	3	3
N9A	High	Med	1	2	2
N9B		High	1	3	3
N10A	High	High	3	2	1
N10B		Med	1	2	2
N11	High	High	3	3	2
N12A	High	High	3	3	1
N12B		Med	1	2	1
N12C		Low	1	1	1
N13	Med	Med	1	2	2
N14A	Med	Low	1	1	1
N14B		High	3	3	3
N15A	High	High	1	3	1
N15B		High	2	3	1
N15C		High	3	1	1
N15D		Med	2	2	1
N16	High	High	1	3	3
N17A	Low	High	3	1	1
N17B		High	3	2	1
N18	Med	Med	1	2	2
N19	Low	Low	1	1	1
N20	High	Med	1	2	1
N21	High	Med	1	2	1
N22	Low	Low	1	1	1
N23	Med	Med	2	2	1
N24A	High	High	2	3	2

Nechako River Sites	1993 Original Rating	2008 Salmonid Habitat Value Rating	Spawning	Rearing	Overwinterin g
N25	Med	Med	2	1	2
N26	High	Med	1	2	1
N26A		High	2	3	1
N27	Med	High	1	3	1
N28	High	High	1	3	1
N29	High	High	1	3	2
N30	High	Med	1	2	1
N31	High	Med	2	2	1
N32	High	High	2	3	1
N33	Med	Med	1	2	1
N34A	High	Med	1	2	1
N34B		High	2	3	1
N35	Med	Med	1	2	1
N36	High	High	2	3	1
N37	High	Med	1	2	1
N38	Med	Med	1	2	1
N39	High	High	1	3	2
N40	Low	High	1	3	1
N41	Med	Med	1	1	1
N42	High	Med	1	2	1
N43	High	High	1	3	1
N44	Med	Med	1	2	1
N45	High	High	2	3	2
N46	Low	Low	1	1	1
N47	Med	Med	1	2	1
N48	Med	Med	1	2	1
N49	High	High	1	3	2
N50	Med	Med	1	2	1
N51	High	Low	1	1	1
N52	High	High	3	3	2
N53	Low	Low	1	1	1
N54	Med	Med	1	2	1
N55	High	High	3	2	1
N56	High	High	3	2	1
N57	Low	Low	1	1	1
N57A		High	1	3	1

Nechako River Sites	1993 Original Rating	2008 Salmonid Habitat Value Rating	Spawning	Rearing	Overwintering
N58	Low	Low	1	1	1
N59	High	High	2	3	1
N60	Low	Low	1	1	1
N61	Low	Low	1	1	1
N62	Med	High	2	3	2
N63	Low	High	1	3	2
N64	Low	Low	1	1	1
N65	High	High	1	3	1
N66	Low	Low	1	1	1
N67	Med	Low	1	1	1
N68	Med	High	1	3	1
N69	Low	Low	1	1	1
N70	Med	Med	1	2	1
N71	High	High	1	3	3
N72	High	High	1	3	1
N73	Med	Med	1	2	1
N74	Med	Med	2	2	1
N75	Med	Med	1	2	1
N76	High	High	2	3	1
N77	High	High	1	3	1
N78	High	High	1	3	1
N79	High	High	1	3	1
N80	High	High	1	3	1
N81	High	High	1	3	1
N82	n/a	High	2	3	1
N83	n/a	Med	1	2	1
N84	n/a	Med	2	2	2
N85	n/a	High	3	3	1
N86	n/a	Med	2	2	2
N87	n/a	Med	1	2	1

Fraser River Sites	1993 Original Rating	2008 Salmonid Habitat Value Rating	Spawning	Rearing	Overwinterin g
F17	Med	Med	2	2	2
F18	Low	Low	1	1	1
F19	Low	Med	1	2	2
F20	High	Med	1	2	1
F21	Med	Med	1	2	2
F22	Med	Med	1	2	1
F23	Med	Med	1	2	1
F24	Low	Low	1	1	1
F25	Med	Med	1	2	1
F26	Low	Med	1	2	1
F27	Med	Med	1	2	1
F28	High	High	1	3	3
F29	Med	Low	1	1	1
F31	Low	Low	1	1	1
F32	Med	Med	1	2	1
F33	High	High	1	3	2
F34	Low	Med	2	2	1
F35	Med	High	1	2	3
F36	High	High	1	3	1
F37	High	High	1	3	2
F38	Med	Med	1	2	1
F39	High	Med	1	2	1
F40	Med	Med	2	2	1
F41	Low	Med	1	2	1
F44	Low	Low	1	1	1

APPENDIX C.1

Table 1. Location of 12 white sturgeon radio-tagged in Fall 2007 during radio-telemetry flights in January and May 2008.

Tag Data		Location (May 8, 2008)			Location (January 12, 2008)			Fall 2007 location at time of radio tag application			Comments
Frequency	Code	rkm	Easting	Northing	rkm	Easting	Northing	rkm	Easting	Northing	
148.400	50	~949.2	587559	5979319	948.3	587280	5979410	950.6	588892	5978228	Fall 2007: middle of Grand Canyon, Jan 2008: lower portion of Grand Canyon.
148.400	51	~928	580344	5986313	~925	581082	5987742	949	587222	5979507	Fall 2007: middle of Grand Canyon, Jan 2008: between the Bowron River and Grand Canyon.
148.380	55	Not located			~900	562980	6003637	880.5	551563	6006314	Fall 2007: along North Fraser Road, Jan 2008: McGregor River/Fraser River confluence.
148.420	54	~896.3	563566	6003379	~900	562980	6003637	829.95	530421	5992330	Fall 2007: just downstream of the Willow River confluence with the Fraser River, Jan 2008: McGregor River/Fraser River confluence.
148.420	53	~890.7	558529	6005645	~898	560064	6005012	880.6	551563	6006314	Fall 2007: along North Fraser Road, Jan 2008: ~2 km downstream of the McGregor confluence with the Fraser River.
148.420	51	~950.2	588245	5978910	Not located			949.8	588477	5978821	Originally tagged in Nechako River rkm 110 in 1995, Jan 2008: Not located, but recapture from the Nechako River project so fish may have moved back to known wintering sites near Vanderhoof.
148.420	50	Not located			Not located			948.3	587248	5979562	Fall 2007: Grand Canyon rkm 948 Jan 2008: Not located, may have still been in the canyon.
148.420	52	Not located			Not located			~949	587235	5979523	Originally tagged at rkm 0.1 (Nechako/Fraser confluence) in 1996, Captured again by LTN in 1999 at rkm 826.6 on the Fraser River, Fall 2007 Grand Canyon, Jan 2008: Not located may have still been in the canyon. Alternatively, it may have moved to wintering sites up the Nechako.
148.400	52	~810	522801	5980592	Not located			831.3	531508	5992938	Fall 2007: at rkm 831.3, Jan 2008: Not located.
148.400	54	Not located			Not located			883.6	553994	6006890	Originally tagged at rkm 110 in 1997, Jan 2008: Not located, but recapture from the Nechako River project so fish may have moved back to known wintering sites near Vanderhoof.
148.400	53	~896.3	563566	6003379	Not located			884.1	554197	6007462	Fall 2007: rkm 884.1 along North Fraser road, Jan 2008: Not located.
148.380	53	Not located			Not located			882.3	552441	6006243	Originally tagged downstream of the Grand Canyon at rkm945.8 in 1999, Fall 2007: at rkm 882.3, Jan 2008: Not located, probable that it moved back into canyon area.

Appendix C.2

Scientific Name	English Name	COSEWIC	COSEWIC Comments	BC Status	Identified Wildlife	Prov Wildlife Act	SARA
Acorus americanus	American sweet-flag			Blue			
Anemone virginiana var. *cylindroidea*	riverbank anemone			Red			
Apocynum x *floribundum*	western dogbane			Blue			
Arnica chamissonis ssp. *incana*	meadow arnica			Blue			
Carex rostrata	swollen beaked sedge			Blue			
Carex scoparia	pointed broom sedge			Blue			
Carex sprengelii	Sprengel's sedge			Red			
Carex tenera	tender sedge			Blue			
Carex tonsa var. *tonsa*	bald sedge			Blue			
Draba fladnizensis	Austrian draba			Blue			
Dryopteris cristata	crested wood fern			Blue			
Galium labradoricum	northern bog bedstraw			Blue			
Juncus arcticus ssp. *alaskanus*	arctic rush			Blue			
Juncus stygius	bog rush			Blue			
Malaxis brachypoda	white adder's-mouth orchid			Blue			
Malaxis paludosa	bog adder's-mouth orchid			Blue			
Megalodonta beckii var. *beckii*	water marigold			Blue			
Nymphaea tetragona	pygmy waterlily			Blue			
Oxytropis campestris var. *davisii*	Davis' locoweed			Blue			
Pedicularis parviflora ssp. *parviflora*	small-flowered lousewort			Blue			
Pinus albicaulis	whitebark pine			Blue			
Pyrola elliptica	white wintergreen			Blue			
Senecio plattensis	plains butterweed			Blue			
Sparganium fluctuans	water bur-reed			Blue			
Torreyochloa pallida	Fernald's false manna			Red			

Appendix C.3

Scientific Name	English Name	BC Status	Identified Wildlife
Picea engelmannii x *glauca - Betula papyrifera / Oplopanax horridus*	hybrid white spruce - paper birch / devil's club	Blue	
Picea engelmannii x *glauca / Matteuccia struthiopteris*	hybrid white spruce / ostrich fern	Red	Y (Jun 2006)
Pseudotsuga menziesii / Acer glabrum / Hylocomium splendens	Douglas-fir / Douglas maple / step moss	Red	
Pseudotsuga menziesii - Picea engelmannii x *glauca / Rubus parviflorus*	Douglas-fir - hybrid white spruce / thimbleberry	Blue	
Pseudotsuga menziesii - Pinus contorta / Cladonia spp.	Douglas-fir - lodgepole pine / clad lichens	Blue	

Appendix C.4

Scientific Name	English Name	BC Status	Identified Wildlife
Equisetum fluviatile - Carex utriculata	swamp horsetail - beaked sedge	Blue	
Picea engelmannii x glauca / Spiraea douglasii - Rosa acicularis	hybrid white spruce / hardhack - prickly rose	Blue	
Pinus contorta - Picea mariana / Pleurozium schreberi	lodgepole pine - black spruce / red-stemmed feathermoss	Blue	
Poa secunda ssp. *secunda - Elymus trachycaulus*	Sandberg's bluegrass - slender wheatgrass	Red	
Pseudotsuga menziesii - Pinus contorta / Cladonia spp.	Douglas-fir - lodgepole pine / clad lichens	Blue	
Salix drummondiana / Calamagrostis canadensis	Drummond's willow / bluejoint reedgrass	Blue	
Scheuchzeria palustris / Sphagnum spp.	scheuchzeria / peat-mosses	Blue	

Appendix C.5

Scientific Name	English Name	COSEWIC	COSEWIC Comments	BC Status	Identified Wildlife	Prov Wildlife Act	SARA
Acipenser transmontanus pop. 3	White Sturgeon (Nechako River population)	E (Nov 2003)		Red			1
Acipenser transmontanus pop. 5	White Sturgeon (Upper Fraser River population)	E (Nov 2003)		Red			1
Acipenser transmontanus pop. 6	White Sturgeon (Middle Fraser River Population)	E (Nov 2003)		Red			3
Acroloxus coloradensis	Rocky Mountain Capshell	NAR (Nov 2001)		Blue			
Ardea herodias herodias	Great Blue heron, *herodias* subspecies			Blue	Y (Jun 2006)		
Asio flammeus	Short-eared Owl	SC (Mar 2008)		Blue	Y (May 2004)		3
Botaurus lentiginosus	American Bittern			Blue			
Buteo platypterus	Broad-winged Hawk			Blue			
Colias meadii	Mead's Sulphur			Blue			
Dolichonyx oryzivorus	Bobolink			Blue			
Fossaria parva	Pygmy Fossaria			Blue			
Grus canadensis	Sandhill Crane	NAR (May 1979)	*G. Canadensis tabida* assessed	Blue	Y (Jun 2006)		
Gulo gulo luscus	Wolverine, *luscus* subspecies	SC (May 2003)	Western Population Only	Blue	Y (May 2004)		
Martes pennanti	Fisher			Blue	Y (Jun 2006)		
Myotis septentrionalis	Northern Myotis			Blue			
Numenius americanus	Long-billed Curlew	SC (Nov 2002)		Blue	Y (May 2004)		1
Oeneis jutta chermocki	Jutta Arctic, *chermocki* subspecies			Blue			
Rangifer tarandus pop. 15	Caribou (northern mountain population)	T/SC (May 2002)	Provincial and COSEWIC borders differ therefore there are two listings for this ecotype. The southern portion of the ecotype falls within the northern part of the COSEWIC area that includes the threatened population of southern mountain caribou.	Blue	Y (May 2004)		1
Salvelinus confluentus	Bull Trout			Blue	Y (Jun 2006)		
Somatochlora forcipata	Forcipate Emerald			Blue			
Tympanuchus phasianellus columbianus	Sharp-tailed Grouse, *columbianus* subspecies			Blue	Y (Jun 2006)		
Ursus arctos	Grizzly Bear	SC (May 2002)		Blue	Y (May 2004)		

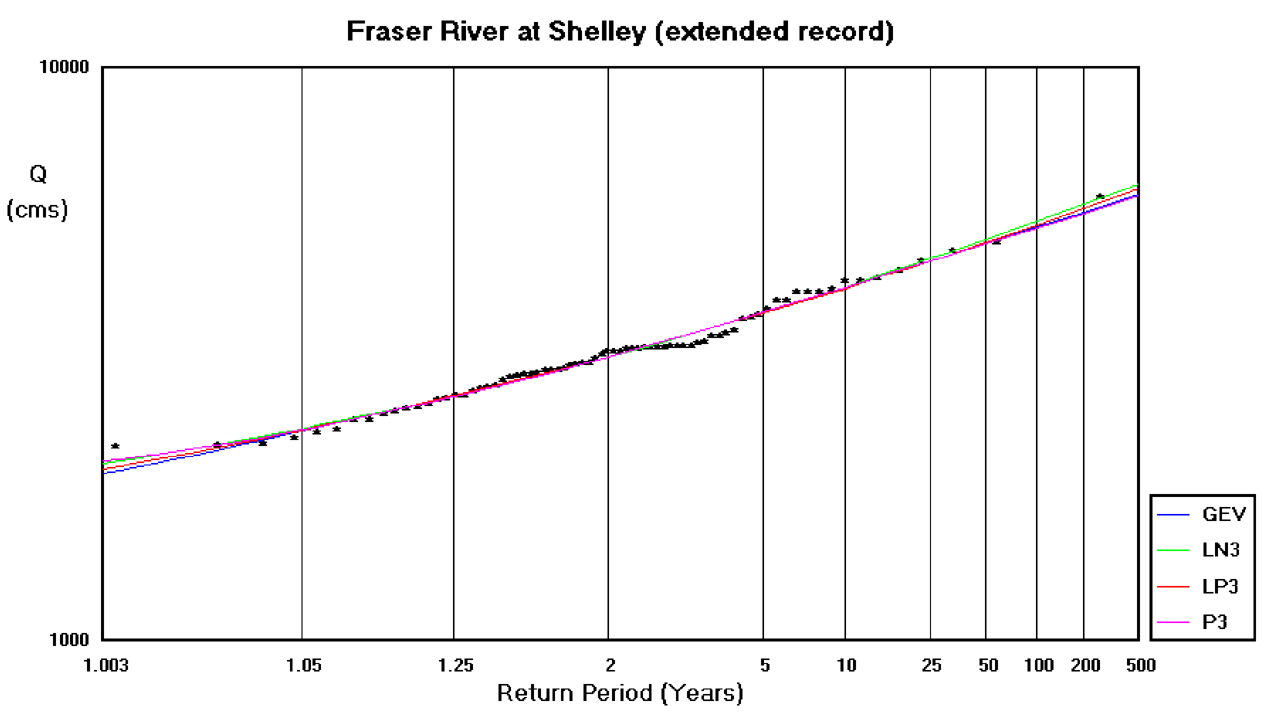
APPENDIX D
FLOOD FREQUENCY ANALYSES

APPENDIX D

Fraser River at Shelley

Year	Max Flow (m^3/s)
1935	3114.83
1936	3934.34
1937	2930.67
1938	2553.14
1939	3441.72
1940	2903.05
1941	2318.34
1942	2801.76
1943	2981.32
1944	2525.52
1945	2981.32
1946	3400.28
1947	3257.56
1948	4611.13
1949	3206.91
1950	3710.00
1951	3000.00
1952	3060.00
1953	2730.00
1954	2970.00
1955	3680.00
1956	3340.00
1957	3400.00
1958	3200.00
1959	3060.00
1960	3230.00
1961	3230.00
1962	3230.00
1963	2920.00
1964	4080.00
1965	3170.00
1966	3260.00
1967	4080.00
1968	3200.00
1969	2430.00
1970	3940.00
1971	3260.00
1972	4980.00
1973	3310.00
1974	3480.00
1975	2490.00
1976	3260.00
1977	2940.00
1978	2210.00
1979	4080.00
1980	2340.00
1981	3050.00
1982	3270.00
1983	2200.00
1984	2690.00
1985	3650.00
1986	4260.00
1987	2860.00
1988	3270.00
1989	2590.00
1990	4800.00
1991	2890.00
1992	2570.00
1993	2690.00
1994	2660.00
1995	2270.00
1996	2640.00
1997	4120.00
1998	2190.00
1999	3800.00
2000	3270.00
2001	3280.00
2002	4260.00
2003	2440.00
2004	2760.00
2005	3030.00
2006	2780.00
2007	4420.00
2008	4310.00

Extend Shelley record based on Big Bar for 1935-1949					
1894 estim=5970 cms			**as historic max for 162 years**		
	Flows	Log of Flows	Hist Wt. Flows		
Mean	3242.96	8.06	3223.17		
St. Dev	708.98	0.21	669.3		
Skew	1.18	0.5	0.97		
RP	GEV	LN3	LP3	P3	
2	3123.61	3114.41	3119.9	3117.9	
5	3721.34	3724.05	3715.2	3730.22	
10	4105.94	4124.59	4100.82	4116.5	
20	4466.74	4506.55	4466.78	4472.72	
25	4579.55	4627.52	4582.52	4583.25	
50	4922.22	5000.45	4939.29	4915.71	
100	5255.21	5372.39	5295.56	5236.95	
200	5580.06	5746.21	5654.62	5549.49	
500	5998.29	6246.51	6137.39	5951.82	
Fit Method	Moments	Max. Like	Moments	Moments	
Location	2925.89	7.45	7.01	3223.17	
Scale	542.46	0.36	0.04	669.3	
Shape	0.03	1389.12	27.67	0.97	

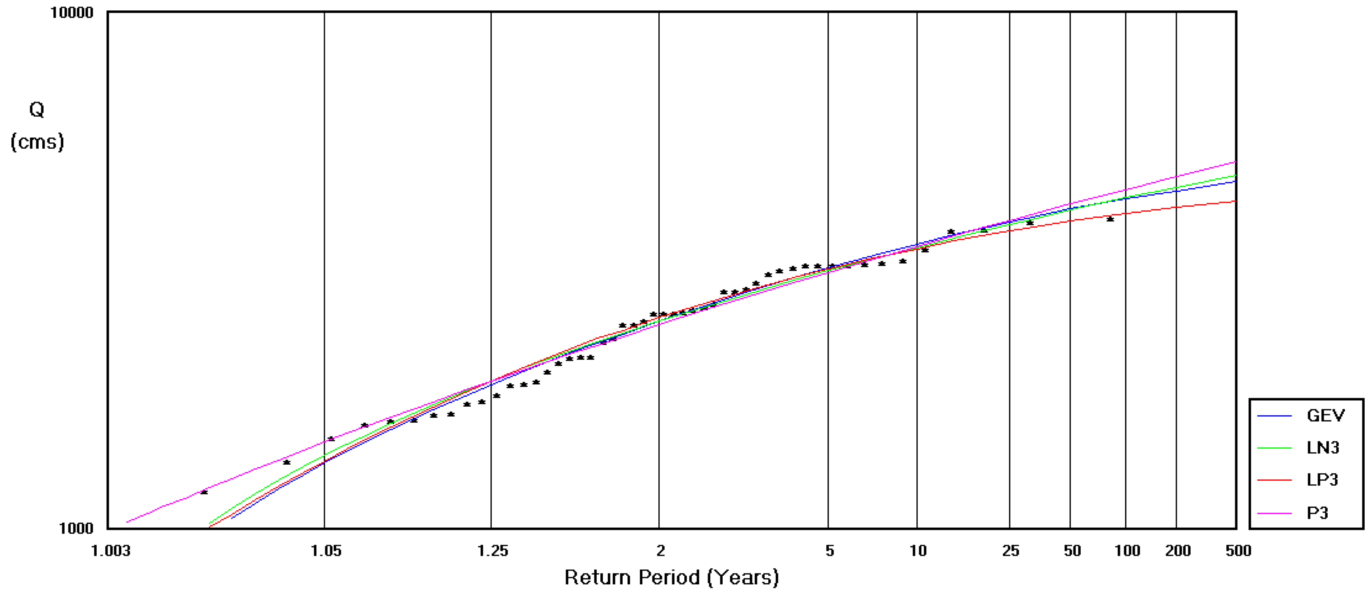


Fraser River at Shelley

(Period: Jun/20 – Jul/20)

Year	Max. Flow (m^3/s)
1957	1900.00
1958	1630.00
1959	2890.00
1960	3230.00
1961	1910.00
1962	3230.00
1963	2730.00
1964	3990.00
1965	2490.00
1966	3000.00
1967	3790.00
1968	3200.00
1969	1590.00
1970	2610.00
1971	2310.00
1972	2890.00
1973	3310.00
1974	3480.00
1975	2490.00
1976	3260.00
1977	2620.00
1978	1660.00
1979	2920.00
1980	2340.00
1981	1620.00
1982	3170.00
1983	2150.00
1984	2690.00
1985	2160.00
1986	2610.00
1987	2090.00
1988	2160.00
1989	1750.00
1990	3110.00
1991	2530.00
1992	1930.00
1993	1670.00
1994	2660.00
1995	1500.00
1996	2610.00
1997	3240.00
1998	1180.00
1999	3800.00
2000	3270.00
2001	3240.00
2002	3930.00
2003	1770.00
2004	1810.00
2005	2020.00
2006	1350.00

FREQUENCY ANALYSIS			57-06 (06/20-07/20)	
	Flows	Log of Flows	Hist Wt. Flows	
Mean	2549.80	7.80		
St. Dev	726.86	0.30		
Skew	0.57	-0.40		
RP	GEV	LN3	LP3	P3
2.00	2521.71	2523.25	2563.23	2481.36
5.00	3194.02	3153.42	3185.20	3131.87
10.00	3552.90	3499.25	3484.15	3513.01
20.00	3844.22	3793.45	3710.35	3850.22
25.00	3927.12	3880.65	3772.22	3952.52
50.00	4157.08	4134.16	3938.56	4254.50
100.00	4351.77	4367.10	4073.84	4539.06
200.00	4517.36	4584.45	4185.33	4810.02
500.00	4699.42	4853.31	4304.49	5151.37
Fit Method	L Moments	Max. Like	Max. Like	Moments
Location	2264.60	9.18	8.46	2549.80
Scale	731.10	0.07	-0.15	726.86
Shape	0.23	-7198.57	4.48	0.57

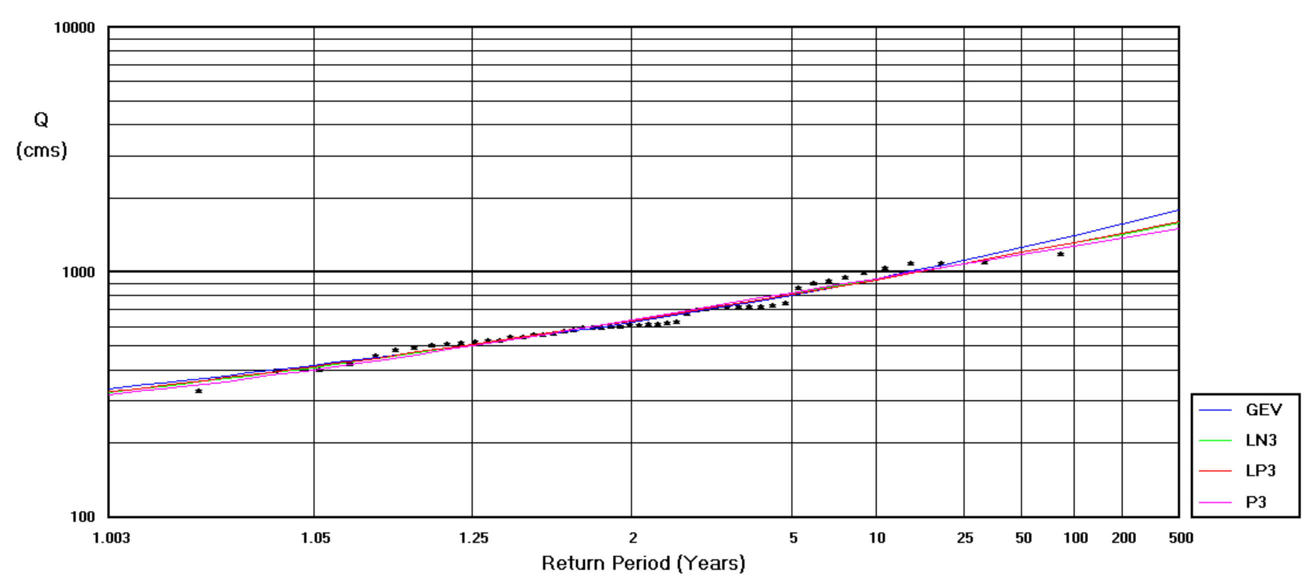


Nechako River at Prince George

(Recorded Values at Isle Pierre + Corrections for Prince George)

Year	Max. Flow (m^3/s)
1957.00	723.23
1958.00	902.32
1959.00	757.27
1960.00	994.82
1961.00	711.47
1962.00	721.11
1963.00	727.16
1964.00	1104.91
1965.00	702.27
1966.00	731.91
1967.00	929.29
1968.00	869.97
1969.00	557.68
1970.00	424.26
1971.00	598.38
1972.00	1101.93
1973.00	544.42
1974.00	956.60
1975.00	401.45
1976.00	1099.07
1977.00	617.55
1978.00	328.00
1979.00	565.21
1980.00	398.65
1981.00	599.95
1982.00	602.79
1983.00	617.01
1984.00	603.40
1985.00	533.00
1986.00	599.41
1987.00	526.85
1988.00	584.02
1989.00	460.58
1990.00	606.99
1991.00	529.90
1992.00	610.75
1993.00	680.81
1994.00	578.51
1995.00	509.00
1996.00	733.73
1997.00	1050.78
1998.00	484.00
1999.00	623.20
2000.00	520.94
2001.00	544.23
2002.00	729.21
2003.00	560.90
2004.00	514.97
2005.00	631.00
2006.00	494.75
2007.00	1194.39

	Flows	Log of Flows	Hist Wt. Flows	
Mean	670.47	6.47		
St. Dev	202.29	0.29		
Skew	0.98	0.31		
RP	GEV	LN3	LP3	P3
2.00	625.63	635.27	634.36	638.33
5.00	806.77	816.22	812.18	823.46
10.00	937.81	936.52	931.98	940.48
20.00	1072.52	1052.12	1048.71	1048.50
25.00	1117.20	1088.89	1086.20	1082.04
50.00	1261.04	1202.70	1203.45	1182.95
100.00	1413.57	1316.82	1322.90	1280.53
200.00	1575.87	1432.10	1445.56	1375.50
500.00	1806.94	1587.19	1613.85	1497.83
Fit Method	L Moments	Max. Like	Max. Like	Moments
Location	571.08	6.18	4.59	670.47
Scale	146.29	0.38	0.04	202.29
Shape	-0.09	152.98	43.92	0.98

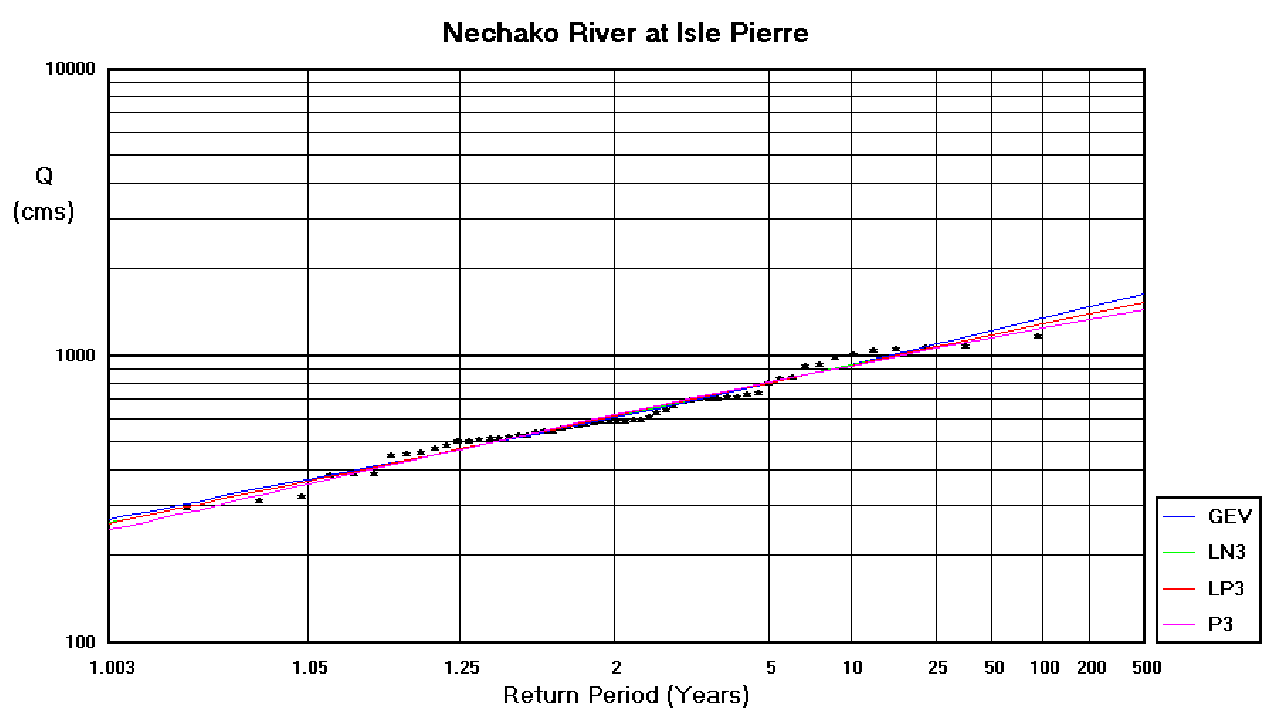


Nechako River at Prince George

(Simulated Flows)

Year	Max Flow (m^3/s)
1957	815
1958	970
1959	1084
1960	984
1961	743
1962	862
1963	551
1964	1143
1965	643
1966	874
1967	967
1968	1058
1969	831
1970	534
1971	959
1972	1342
1973	589
1974	892
1975	724
1976	1228
1977	795
1978	470
1979	596
1980	422
1981	605
1982	615
1983	636
1984	604
1985	501
1986	632
1987	524
1988	626
1989	496
1990	626
1991	569
1992	575
1993	705
1994	605
1995	541
1996	743
1997	1227
1998	500
1999	699
2000	563
2001	602
2002	913
2003	582
2004	530
2005	754
2006	518

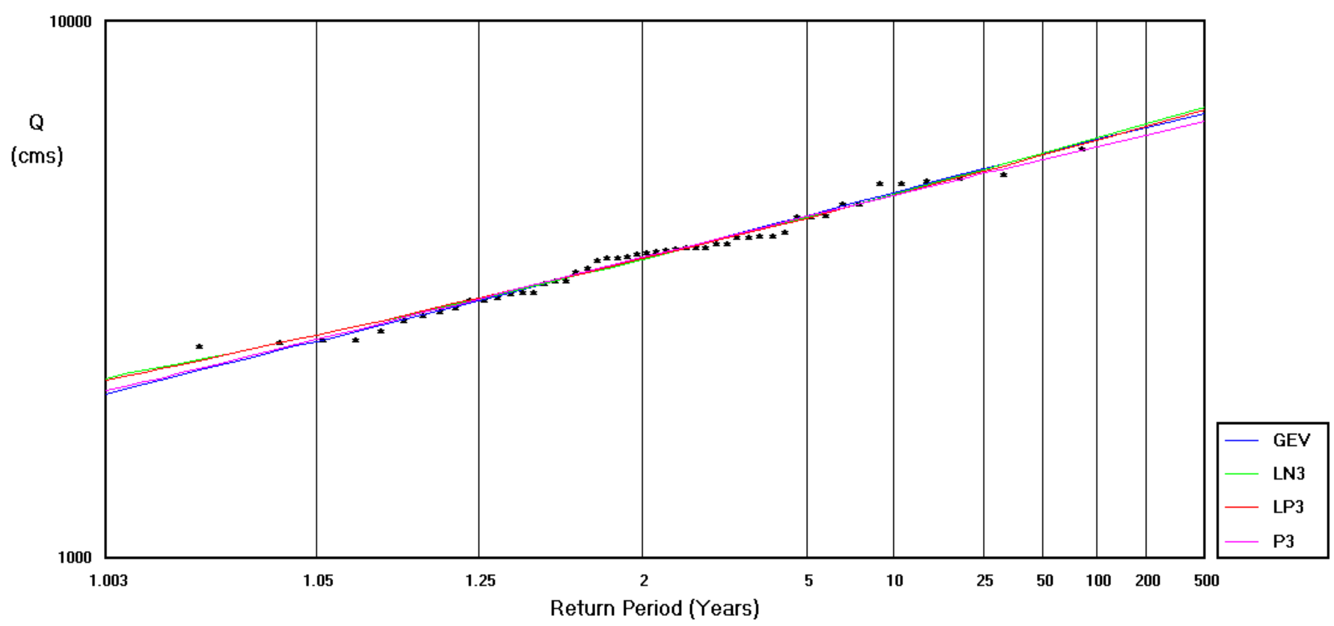
DA's Modified Flows:				
(at Prince George)				
	Flows	Log of Flows	Hist Wt. Flows	
Mean	731.34	6.55		
St. Dev	223.32	0.28		
Skew	1	0.54		
RP	GEV	LN3	LP3	P3
2	676.62	673.22	672.92	695.19
5	877.42	879.59	874.3	899.7
10	1027.73	1036.21	1029.22	1029.42
20	1186.47	1200.09	1194.87	1149.4
25	1240.03	1254.83	1251.17	1186.69
50	1415.45	1431.96	1436.94	1298.99
100	1606.3	1620.8	1641.53	1407.69
200	1814.62	1822.45	1867.89	1513.61
500	2120.15	2110.26	2205.77	1650.15
Fit Method	L Moments	Max. Like	Max. Like	Moments
Location	617.81	5.77	5.91	731.34
Scale	156.64	0.59	0.13	223.32
Shape	-0.13	353.57	5	1



Fraser River Downstream Nechako River
(Flows at Prince George + Flows at Shelley)

Year	Max. Flow (m^3/s)
1957.00	3987.20
1958.00	3763.00
1959.00	3642.08
1960.00	3993.70
1961.00	3774.74
1962.00	3801.65
1963.00	3638.14
1964.00	5069.27
1965.00	3866.94
1966.00	3853.82
1967.00	5009.29
1968.00	3972.57
1969.00	2841.34
1970.00	4335.48
1971.00	3708.34
1972.00	5799.71
1973.00	3792.61
1974.00	4059.00
1975.00	2878.33
1976.00	4329.37
1977.00	3424.70
1978.00	2520.18
1979.00	4586.43
1980.00	2560.02
1981.00	3468.07
1982.00	3745.77
1983.00	2479.96
1984.00	3127.84
1985.00	3963.55
1986.00	4584.45
1987.00	3263.65
1988.00	3599.04
1989.00	2933.92
1990.00	5199.05
1991.00	3297.93
1992.00	3030.02
1993.00	3034.15
1994.00	3129.08
1995.00	2658.46
1996.00	3283.60
1997.00	5110.26
1998.00	2552.08
1999.00	4360.16
2000.00	3687.47
2001.00	3798.10
2002.00	4986.57
2003.00	2773.24
2004.00	3117.46
2005.00	3621.00
2006.00	3065.74

	Flows	Log of Flows	Hist Wt. Flows	
Mean	3701.57	8.20		
St. Dev	777.66	0.21		
Skew	0.58	0.10		
RP	GEV	LN3	LP3	P3
2.00	3605.57	3597.79	3602.83	3626.90
5.00	4339.38	4308.12	4298.83	4323.48
10.00	4786.94	4752.06	4731.13	4732.49
20.00	5189.67	5162.13	5129.79	5094.82
25.00	5312.25	5289.61	5253.71	5204.82
50.00	5674.91	5676.24	5629.67	5529.71
100.00	6013.63	6053.09	5996.61	5836.09
200.00	6331.27	6424.07	6358.53	6128.03
500.00	6722.01	6909.73	6833.73	6496.07
Fit Method	L Moments	Max. Like	Max. Like	Moments
Location	3352.39	7.89	5.83	3701.57
Scale	701.84	0.28	0.02	777.66
Shape	0.09	922.83	133.33	0.58



APPENDIX E
DETAILED ICE ANALYSES

The freeze-up processes in the Fraser and Nechako Rivers are complex and this Appendix provides more technical detail on some aspects of the analysis, omitted from the main text. Some of the tables and figures of the main report are referenced.

E.1 – FRASER RIVER ICE-RELATED WATER LEVELS

Approximate open water and ice-related rating curves at the confluence were shown in **Figure 4.6**. The curves were determined from water level data at the South Fort George gauge and adjusted by 0.75 m to reflect the difference in water levels between the South Fort George gauge and the discontinued Prince George gauge located near the confluence at the CN railway bridge.

The peak freeze-up levels are also shown in **Figure 4.6**, relative to the open water rating curve. The water level increases by between 0.4 and 3.3 m at freeze-up due to the effects of the ice cover. The lower range of the increase is associated with either a thermal ice cover (due to shore ice growth) or a juxtaposed ice cover composed of an ice thickness that would be equivalent to the thermal thickness of the frazil floes. The solid-ice rating curve reflects an adopted ice thickness of 0.40 m and a Manning ice roughness coefficient (n_i) of 0.020. The upper range of the data reflects an ice cover thickness that would be representative of an equilibrium ice jam. The ice jam rating curve that defines the upper bounds of the freeze-up data was simulated using a Manning ice roughness coefficient (n_i) of 0.050 and a coefficient of internal friction of the ice accumulation of 1.0. The value chosen for the coefficient of internal friction is typical of what has been used on other rivers to analyze freeze-up ice accumulations and breakup jams.

The freeze-up level on the Fraser River at the confluence varies from about El. 563 to 565 m GSC. From consideration of the channel cross section on the Nechako River at the confluence (**Figure E.1**) the velocity on the Nechako River would vary from 0.5 to 1.2 m/s for flows between 100 and 250 m^3/s at the minimum freeze-up level and from 0.07 to 0.20 m/s for the corresponding flows at the maximum freeze-up level. The approach flow Froude number would vary between 0.05 and 0.11 at the low freeze-up level and it would vary from 0.03 to 0.08 at the high freeze-up levels for Nechako River flows of 100 and 250 m^3/s respectively.

E.2 – NECHAKO RIVER ICE VOLUMES

On the basis of observed shear wall thicknesses (**Figure 4.2**) and equilibrium ice-jam thickness calculations, the thickness of a typical ice accumulation is estimated to be about 2 m. Assuming a frazil ice porosity of 0.5 and a river width of 120 m, the estimated volume of ice trapped in the upstream-advancing accumulation is then 130 m x 120 m x 2 m x 0.5, or roughly 16,000 m^3 per degree-day of freezing. So, for an air temperature of minus 10 ^{0}C, the ice discharge contributing to ice accumulation would be 160,000 m^3/day or about 1.9 m^3/s. Adding 0.6 m^3/s to account for the frazil ice transported beneath the cover, the total rate of ice generation is estimated as 2.5 m^3/s within the upstream ice generation zone.

E.3 – NECHAKO RIVER ICE FREQUENCY ANALYSIS

The following procedure was used to derive frequency curves of freeze-up water levels at various locations along the Nechako River.

1. A record length of 58 years (1950-51 to 2007-08) representing regulated conditions was adopted. Those ice-related water levels in **Table 4.2** that could be ascribed to freeze-up represent the 13 highest freeze-up events in that period.

2. An *empirical frequency curve* of historical peak freeze-up levels at Cameron Street Bridge (**Figure 4.14**) was derived by assigning the highest event since regulation in 1950-51 a return period of 58 years, the second-highest a return period of 29 years, and the lowest a return period of about 5 years.

3. A *simulated frequency curve* of annual peak freeze-up levels at Cameron St Bridge was based on Monte Carlo analysis of a 1000-year time period that combined the annual probability of experiencing a given discharge (**Figure 4.13**) with (1) the annual probability of experiencing 100 ^{0}C-days of freezing after lodgement at South Fort George (70% from **Table 4.2**) and (2) the annual probability of experiencing a fully developed equilibrium freeze-up accumulation. For years when an equilibrium ice accumulation would have developed at Cameron St Bridge, the peak freeze-up water level was calculated from the ice jam rating curve in **Figure 4.10**, using the discharge for that year as determined from a Monte Carlo simulation. For the other years, the freeze-up water level was calculated from the solid-ice rating curve shown in **Figure 4.10**. Finally, a frequency plot of the 1000-year series of freeze-up levels that resulted from the analysis was obtained.

4. The probability of experiencing an equilibrium ice accumulation at Cameron St Bridge was determined by trial and error until the simulated frequency curve more or less matched the empirical frequency curve based on historical data. A value of 25% produced the most reasonable fit (**Figure 4.14**). The Monte Carlo computation of the 1000-year series of freeze-up discharges was based on a lognormal distribution of known flows averaged over a 10-day period after freeze-up – those had a mean of 150 m^3/s and a standard deviation of 80 m^3/s. Both the 70% probability of experiencing the required amount of ice production and the 25% probability of developing an ice cover thickness equivalent to a fully-developed equilibrium accumulation were defined by Bernoulli distributions.

5. Frequency curves for other locations along the Nechako River were calculated using the same annual probability of an equilibrium freeze-up accumulation as for Cameron St Bridge, but substituting the annual probability for that particular location of experiencing sufficient degree-days of freezing to ensure an ice accumulation, as shown in **Table 4.3**.

6. Given the more or less uniform channel characteristics within the study area, the shape of the rating curves for both an equilibrium ice accumulation and a solid ice cover should be similar, but with the actual levels offset vertically according to the slope of the river. On this basis, peak water levels at other locations were offset vertically from the level at Cameron St Bridge according to differences measured in 1996 (**Figure 4.8**), as follows:

- Winton Global - 2.9 m
- John Hart Bridge 1.1 m
- Foothills Bridge 4.9 m
- Morning Place 8.4 m

The simulated frequency curves are shown in **Figure 4.14.** Ice-related water levels for various return periods, including 0.6 m of freeboard, are summarized in **Table 4.4**. For Cameron St Bridge, the 100-year ice-related flood level is 571.4 m, or 572.0 m including freeboard. The reported maximum level at Cameron St Bridge during the winter of 2007-08 was 571.3 m, or only 0.1 m lower than the simulated 100-year level. This event is estimated to have had a return period of approximately 90 years.

E.4 – Gravel Removals and Ice Lodgement Process

The propensity for juxtapostion decreases with increasing Froude numbers (increasing velocity) and the transport of frazil slush increases with increasing velocity. In other words, higher velocities result in a delay in the formation of an ice cover.

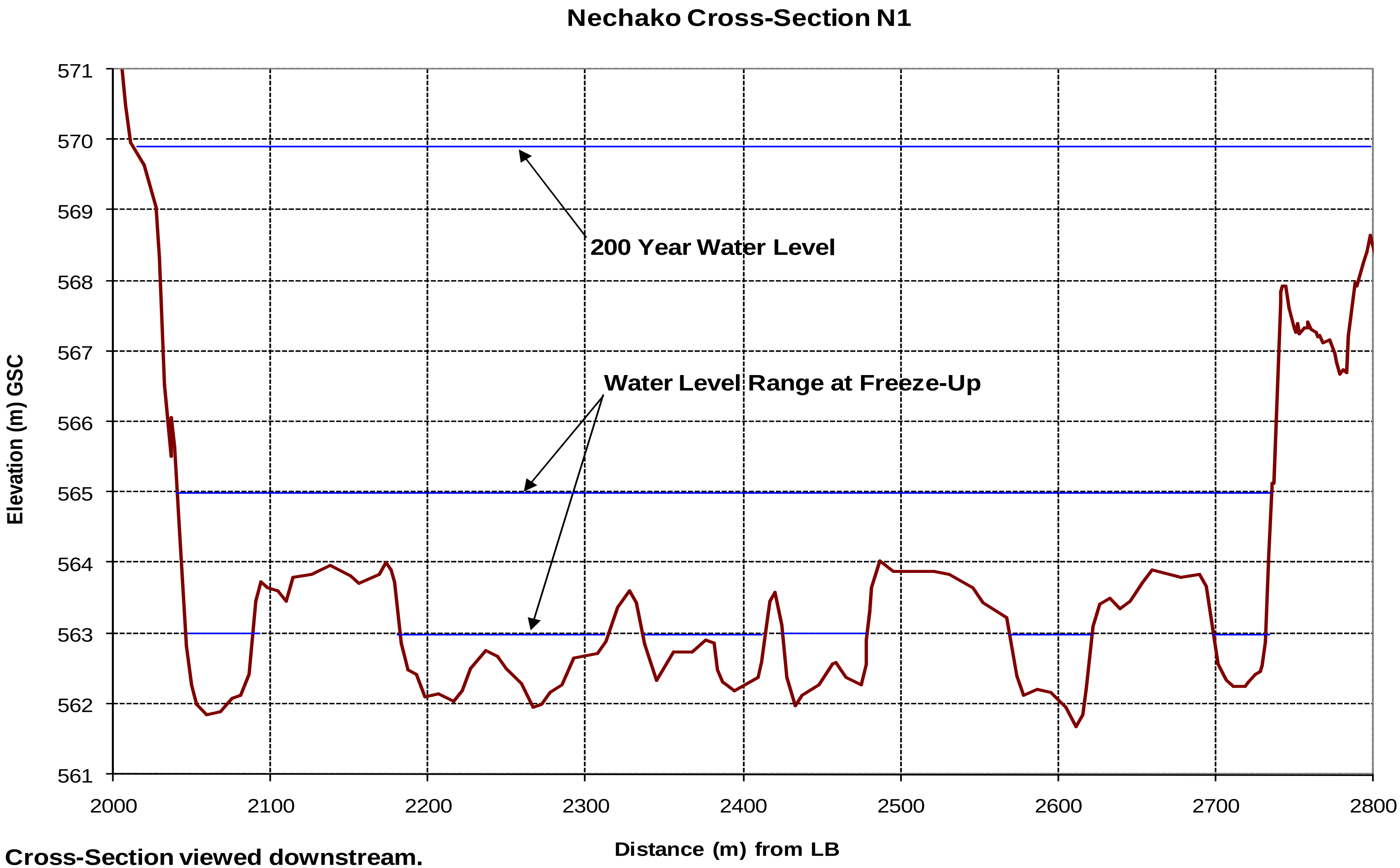
Any gravel removal in the Nechako River channel would increase the flow area, lower velocities, reduce the Froude number and enhance the juxtapostion processes, allowing a stable ice cover to form sooner, ultimately contributing to a more rapid advance of the ice cover upstream. For example, at a Nechako River flow of 100 m^3/s and a low Fraser River freeze-up level, removing gravel from the channel by an average of one metre would reduce the Froude number from 0.05 to 0.01. At a Nechako River flow of 250 m^3/s, the gravel removal would reduce the Froude number from 0.11 to 0.03. For the high Fraser River freeze-up level, the Froude number reduction would be from 0.03 to 0.01 and from 0.08 to 0.03 for Nechako River flows of 100 and 250 m^3/s respectively. With juxtapostion a near certainty at Froude numbers below 0.08, it is clear that removing gravel would assist the formation of an ice cover and not reduce the likelihood or delay the formation of an ice cover at the confluence.

As slush arrives at the confluence, it will be transported into the Fraser River if the local velocity is large enough. If not, it will accumulate underneath the ice cover at the confluence until the local velocity is increased sufficiently (by the overall reduction in the flow area) to transport the incoming slush. Applying a critical Shields Number of 0.040 for the threshold of ice transport just upstream of the Nechako/Fraser confluence, the threshold velocity below which there would be no cover load transport is about 0.3 m/s. For velocities less than this, the frazil would keep accumulating, reducing the flow area and gradually increasing velocities until they reached the threshold value of 0.3 m/s. The frazil would then be transported into the Fraser and no additional deposition would occur.

At Fraser River freeze-up levels less than about El. 563.5 m GSC (**Figure E.1**), the velocity at the confluence would be greater than 0.3 m/s for any flow that would likely be evident at freeze-up on the Nechako River. Thus, the entire incoming cover load would be swept out into the Fraser River. At freeze-up levels between El. 563.5 and El. 565.0 m

GSC, between 0.1 and 1.7 m of frazil deposition (the thickness of the deposition increasing with increasing water levels and decreasing with increasing Nechako River flows) would occur until the critical velocity of 0.3 m was reached.

If the main channel in the vicinity of Cottonwood Island (or even in the Fraser River downstream of the Nechako River) was to be dredged, the local velocity would be reduced. This would make it easier for the ice cover to form, thereby most likely promoting a more rapid advance of the ice cover within the section of the river that is dredged. Once the ice cover advanced upstream of the dredged area, the rate of advance would return to that which is currently being experienced. The under-ice velocities in the dredged section would be less than upstream and the cover load arriving from upstream would deposit in the dredged area. Since the water level is controlled by backwater conditions on the Fraser River, the frazil slush would continue to deposit until the thickness of the deposit increased to the point where the under-ice velocity would be large enough to re-establish the required transport rate to transport the incoming cover load without additional deposition.



Cross-Section viewed downstream.

City of Prince George	nhc
Fraser River Freeze-Up Levels	
January 2009	Figure E.1

APPENDIX F

INITIAL FLOOD CONTROL SOLUTIONS - PROGRESS REPORT 1

Table E.1: Flood Control Solutions - Nechako River

Mitigation Options	Mitigation Sub-Options	Alternate Designs	Hydraulic Considerations	Infrastructure Considerations	Environmental Considerations	Geomorphology Considerations	General Evaluation	EVALUATION CRITERIA 1 = low, 3 = high								WEIGHTING FACTOR 1 = less important 3 = more important								Total Weight Factor	Area Ranking
								Risk after Implementing	Constr./Maintenance	Access Problems	Drainage Problems	Environmental Impact	River Instability Risk	Direct Cost	Social Cost	Risk after Implementing	Constr./Maintenance	Access Problems	Drainage Problems	Environmental Impact	River Instability Risk	Direct Cost	Social Cost		
																3	2	1	1	3	2	3	3		
Area A_N (Southbank at confluence)																									
No permanent protection, provide temporary works as required			On-going flood risk.	Emergency response on call.	No new environmental impacts expected in absence of permanent protection. Potential environmental considerations associated with temporary works depends on design of those works. For example, release of deleterious substances is possible with use of amphibex and warm water release.	The effects of ongoing sediment deposition must be considered.	Not acceptable in the long term.	3	3	3	2	1	3	1	3	9	6	3	2	3	6	3	9	41	9
Diking	Next to river and along Cottonwood Island back channel		Need erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, seal old channel entrances, pump&treat internal flows.	Access limited for construction and maintenance.	Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review will be triggered.**	Reduced flood conveyance area. Sub-surface flow will continue to cause flooding hazard.	Significant environmental, river encroachment and access issues.	2	3	1	2	3	3	2	1	6	6	1	2	9	6	6	3	39	8
	Permanently raise River Road	Do nothing for development outside road	Some erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, seal old channel entrances, pump&treat internal flows.	Continued flood risk outside road.	Potential minor riparian habitat encroachment.	Maintains exising flood conveyance area.	Feasible but still need to deal with groundwater problems.	2	3	1	2	2	2	2	2	6	6	1	2	6	4	6	6	37	6
		Extend dike locally to protect development outside dike	Need erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, seal old channel entrances, pump&treat internal flows.	Access limited for construction and maintenance.	Potential riparian habitat encroachment. **Federal review potentially triggered.**	Reduces flood conveyance area. Sub-surface flow is still an issue.	Feasible but still need to deal with groundwater problems.	1	2	1	2	3	2	2	1	3	4	1	2	9	4	6	3	32	4
		Land-use change outside dike	Some erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, seal old channel entrances, pump&treat internal flows.	Business access issues.	Potential minor riparian habitat encroachment.	Maintains or increases conveyance area	Feasible but still need to deal with groundwater problems.	1	1	1	2	2	1	2	2	3	2	1	2	6	2	6	6	28	1
		Raise development outside dike	Need erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, seal old channel entrances, pump&treat internal flows.	Business access issues.	Potential minor riparian habitat encroachment.	Modest reduction in conveyance area	Feasible but still need to deal with groundwater problems.	2	2	2	2	2	2	2	1	6	4	2	2	6	4	6	3	33	5
	Build setback dike along railway.	Individually ring dike some development outside dike	Provide seepage cut-off, seal old channel entrances, pump&treat any internal flows.	Business access issues.	Potential minor riparian habitat encroachment.	Maintains conveyance area	Good from river engineering perspective but expensive.	2	1	3	2	2	2	2	3	6	2	3	2	6	4	6	9	38	7
		Land-use change outside dike	Provide seepage cut-off, seal old channel entrances, pump&treat any internal flows.		Potential minor riparian habitat encroachment.	Restores former conveyance area	Good from river engineering, environmental and geomorphological perspective but expensive.	1	1	1	1	2	1	3	2	3	2	1	1	6	2	9	6	30	2
Land-use change over entire floodplain				Unlikely to include railroad and downtown area.	Restores functional floodplain areas	Restores former conveyance area	Unlikely to include downtown area.	1	1	1	1	1	1	3	3	3	2	2	1	3	2	9	9	31	3
Improve internal drainage.	Deep groundwater pumping		Groundwater governed by river levels, not effective without diking.	Large pump capacity required	Potential for existing groundwater contamination in industrial areas. Testing and treatment may need to be considered.	It could be difficult to significantly lower ground water levels	Expensive. Expected to be difficult to reduce groundwater levels during flood. Would be undertaken as part of a diking option.	2	1	3	1	2	1	3	2	6	2	3	1	6	2	9	6	35	n/a
	Ditch and pump.		Groundwater governed by river levels, not effective without diking.	Complex ditch network. Difficult to fit in with in with existing infrastructure.	Potential for ditch water contamination in industrial areas. Testing and treatment may need to be considered.	Large deep ditches might improve drainage.	Expensive. Expected to be difficult to reduce groundwater levels during flood. Would be undertaken as part of a diking option.	2	1	2	1	2	1	3	2	6	2	2	1	6	2	9	6	34	n/a
Area B_N (Northbank east of JH Brdg)																									
No permanent protection, provide temporary works as required					No new environmental impacts expected in absence of permanent protection. Potential environmental considerations associated with temporary works depends on design of those works. For example, release of deleterious substances is possible with use of amphibex and warm water release.	Status quo - check rates of local sediment accumulation	Not acceptable in the long term.	3	3	2	2	1	1	1	2	9	6	2	2	3	2	3	6	33	2
Land-use change over entire floodplain					nil	No significant change but reduces future flood protection requirements	Unlikely.	1	1	1	1	1	1	3	3	3	2	1	1	3	2	9	9	30	1
Diking	Next to river		Need erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.	Access issues	Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	No significant change - but reduces flood storage area	Environmental and access issues.	2	3	1	3	3	2	3	1	6	6	1	3	9	4	9	3	41	7
	Raise Mcaloney and Ongman Roads	Land-used change outside road	Install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.	Access issues	Potential minor riparian habitat encroachment.	No significant change - but reduces flood storage area	Feasible but expensive.	1	2	1	2	2	1	3	2	3	4	1	2	6	2	9	6	33	2
		Do nothing for development outside road	Install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.	Access issues	Potential minor riparian habitat encroachment.	Maintains flood storage area	Feasible	2	3	2	2	2	2	2	2	6	6	2	2	6	4	6	6	38	6
	Low dike providing base for temporary high water protection	Same sub-options as for full height dike	Temporarily raise dike as needed using gabions or lock blocks.	Emergency response on call.	Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	No significant change - but reduces flood storage area	Feasible	2	2	1	3	3	2	2	1	6	4	1	3	9	4	6	3	36	4
Individually raise/flood proof any essential development/basements					Potential minor riparian habitat encroachment.		Feasible but expensive.	2	2	3	2	2	2	2	2	6	4	3	2	6	4	6	6	37	5

Table E.1: Flood Control Solutions - Nechako River

								EVALUATION CRITERIA 1 = low, 3 = high								WEIGHTING FACTOR 1 = less important 3 = more important									
Mitigation Options	**Mitigation Sub-Options**	**Alternate Designs**	**Hydraulic Considerations**	**Infrastructure Considerations**	**Environmental Considerations**	**Geomorphology Considerations**	**General Evaluation**	Risk after Implementing	Constr./Maintenance	Access Problems	Drainage Problems	Environmental Impact	River Instability Risk	Direct Cost	Social Cost	Risk after Implementing	Constr./Maintenance	Access Problems	Drainage Problems	Environmental Impact	River Instability Risk	Direct Cost	Social Cost	**Total Weight Factor**	**Area Ranking**
																3	2	1	1	3	2	3	3		
Area C_N (Northbank near confluence)																									
No permanent protection, provide temporary works as required			PG Pulpmill Road shown as dike on provincial dike mapping.		No new environmental impacts expected in absence of permanent protection. Potential environmental considerations associated with temporary works depends on design of those works. For example, release of deleterious substances is possible with use of amphibex and warm water release.	On-going sediment deposition would increase flood hazard	Not acceptable in the llong term.	3	3	3	3	1	2	1	3	9	6	3	3	3	4	3	9	40	7
Land-use change over entire floodplain					Restores functional floodplain areas	Some conveyance increase.	Good from river engineering, environmental and geomorphological perspective but expensive.	1	1	1	1	1	1	3	2	3	2	1	1	3	2	9	6	27	1
Diking	Next to river		Need erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.	Maintenance issues	Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	Decrease flood conveyance/storage area	Not advisable.	3	3	2	2	3	3	3	2	9	6	2	2	9	6	9	6	49	9
	Raise PG Pulpmill Road if necessary and install seepage prevention to ensure dike meets standards or build new standard dike along road	Do nothing for development outside road	Install flapgates on culverts and prevent seepage, raise as necessary.	Access issues	If a new dike is built along road: Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered**	Road is away from river, little geomorphological impact	Groundwater problems north of road.	2	2	2	2	3	2	2	2	6	4	2	2	9	4	6	6	39	5
		Build local dikes to protect development outside road	Install flapgates on culverts and prevent seepage. Install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.	Access issues	Potential riparian habitat encroachment. **Federal review potentially triggered.**	Minor reduction in flood conveyance or storage area	Groundwater problems north of road. May not be practical.	1	3	2	2	3	2	3	1	3	6	2	2	9	4	9	3	38	4
		Land-use change outside road	Install flapgates on culverts and prevent seepage, raise as necessary.	Access issues	Potential minor riparian habitat encroachment (associated with raising the road).	Minor increase in flood conveyance or storage area	Feasible but groundwater problems north of road.	1	2	1	2	2	1	3	2	3	4	1	2	6	2	9	6	33	2
		Raise/flood proof development outside road	Install flapgates on culverts and prevent seepage, raise as necessary.	Access issues	Potential minor riparian habitat encroachment.	Road is away from river, little geomorphological impact	Feasible but groundwater problems north of road.	1	2	2	2	2	2	3	2	3	4	2	2	6	4	9	6	36	3
		Individually ring dike some development, land-use change for remaining properties	Install flapgates on culverts and prevent seepage. Install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.	Access issues	Potential riparian habitat encroachment (i.e. if ring dikes are next to river). **Federal review potentially triggered.**	Minor reduction in flood conveyance or storage area	Feasible but groundwater problems north of road.	1	2	2	2	3	2	3	2	3	4	2	2	9	4	9	6	39	5
Individually raise/flood proof any essential development, land-use change for remaining properties				Most impact if north side of dike bought out	Potential minor riparian habitat encroachment.	Reduces need for future flood protection in hazardous location	Feasible but expensive.	2	2	3	2	2	2	3	2	6	4	3	2	6	4	9	6	40	7
Groundwater control pumping (North of road)			Groundwater governed by river levels, not effective without diking.	Large pump capacity required	Potential for existing groundwater contamination in industrial areas. Testing and treatment may need to be considered.	May be difficult to significantly reduce groundwater levels	Expensive. Expected to be difficult to reduce groundwater levels during flood. Would be undertaken as part of a diking option.	3	1	3	1	2	1	3	1	9	2	3	1	6	2	9	3	35	n/a
Area D_N (Northbank west of JH Brdg)																									
No permanent protection, provide temporary works as required				Emergency response on call.	No new environmental impacts expected in absence of permanent protection. Potential environmental considerations associated with temporary works depends on design of those works. For example, release of deleterious substances is possible with use of amphibex and warm water release.	Status quo	Not acceptable in the long term.	3	3	2	2	1	1	1	2	9	6	2	2	3	2	3	6	33	2
Land-use change over entire floodplain					Restores functional floodplain areas	Reduces need for future flood protection in hazardous location	Good from river engineering perspective but expensive and politically difficult.	1	1	1	1	1	1	3	3	3	2	1	1	3	2	9	9	30	1
Diking	Next to river		Need erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.		Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	Decrease flood conveyance/storage area	May not be practical	2	3	1	2	3	3	3	1	6	6	1	2	9	6	9	3	42	7
	Raise Preston Road	Land-use change outside road	Install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.		Potential minor riparian habitat encroachment.	Could possibly affect left bank side channel/island	Feasible but groundwater problems north of road.	1	2	1	2	2	1	3	2	3	4	1	2	6	2	9	6	33	2
		Flood proof development outside road			Potential minor riparian habitat encroachment.	Minor reduction in flood storage area	Feasible but groundwater problems north of road.	2	3	2	2	2	2	2	2	6	6	2	2	6	4	6	6	38	6
	Low dike providing base for temporary high water protection	Same sub-options as for full height dike	Temporarily raise dike as needed using gabions or lock blocks.	Emergency response on call.	Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	No significant change - but reduces flood storage area	Feasible	2	2	1	2	3	2	2	1	6	4	1	2	9	4	6	3	35	4
Individually raise/flood proof any essential development/basements, land-use change for remaining properties					Potential minor riparian habitat encroachment.	Minimises loss in flood storage area. Reduces need for future flood protection in hazardous location	Feasible.	2	2	3	2	2	2	2	2	6	4	3	2	6	4	6	6	37	5

Table E.1: Flood Control Solutions - Nechako River

Mitigation Options	Mitigation Sub-Options	Alternate Designs	Hydraulic Considerations	Infrastructure Considerations	Environmental Considerations	Geomorphology Considerations	General Evaluation	EVALUATION CRITERIA (1 = low, 3 = high): Risk after Implementing	Constr./Maintenance	Access Problems	Drainage Problems	Environmental Impact	River Instability Risk	Direct Cost	Social Cost	WEIGHTING FACTOR (1 = less important, 3 = more important): Risk after Implementing	Constr./Maintenance	Access Problems	Drainage Problems	Environmental Impact	River Instability Risk	Direct Cost	Social Cost	Total Weight Factor	Area Ranking
																3	2	1	1	3	2	3	3		
Area E_N (Morning Place)																									
No permanent protection, provide temporary works as required				Emergency response on call.	No new environmental impacts expected in absence of permanent protection. Potential environmental considerations associated with temporary works depends on design of those works. For example, release of deleterious substances is possible with use of amphibex and warm water release.	Status quo	Not acceptable in the long term.	3	3	2	3	1	2	1	3	9	6	2	3	3	4	3	9	39	4
Diking	Next to river		Need erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.	Maintenance issues	Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	Could destabilize downstream left bank terrace	Not advisable	3	3	2	2	3	2	3	2	9	6	2	2	9	4	9	6	47	5
	Low dike providing base for temporary high water protection		Temporarily raise dike as needed using gabions or lock blocks.	Emergency response on call.	Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	No significant change - but reduces flood storage area	Feasible	2	3	2	2	3	2	2	1	6	6	2	2	9	4	6	3	38	3
Individually raise/flood proof any essential development					Potential minor riparian habitat encroachment.	Minor reduction in flood storage area	Feasible	2	2	2	1	2	2	2	1	6	4	2	1	6	4	6	3	32	2
Land-use change over entire floodplain					Restores functional floodplain areas	Little benefit, but reduces need for future flood protection in hazardous location.	Feasible	1	1	1	1	1	1	3	3	3	2	1	1	3	2	9	9	30	1
Area F_N (Southbank at Foot Hills Br)																									
Prevent future development and flood proof existing development if necessary			No hydraulic impact	Limited existing development.	Potential minor riparian habitat encroachment.	Investigate sidechannel to see if any infilling can be removed.	Feasible	1	1	2	1	2	1	1	1	3	2	2	1	6	2	3	3	22	1
Area G_N (Southbank U/S of JH Br)																									
Prevent future development and flood proof existing development if necessary			No hydraulic impact.	Limited existing development.	Potential minor riparian habitat encroachment.	Reduces need for future flood protection in hazardous location. Can a flood channel be created here?	Feasible	1	1	2	1	2	1	1	1	3	2	2	1	6	2	3	3	22	1
General Lower Nechako Area																									
Floodways	Enlarge Cottonwood Island back channel		May need erosion protection and series of bridges.	Potential ice jam relief. Ongoing maintenance. Only possible with landuse changes	Stream morphology change to entire back channel. Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review will be triggered.**	Would partially restore historic conveyance area	Feasible but not a solution by itself. Effects on Areas A&C to be evaluated in model.	*3*	*3*	*2*	*2*	*3*	*3*	*2*	*2*	9	6	2	2	9	6	6	6	46	
	Open up/straighten historic channel along RR		May need erosion protection and series of bridges.	Potential ice jam relief. Ongoing maintenance. Only possible with landuse changes	Stream morphology change. Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review will be triggered.**	Would partially restore historic conveyance area	Feasible but not a solution by itself. Effects on Areas A&C to be evaluated in model.	3	3	3	2	3	3	3	3	9	6	3	2	9	6	9	9	53	
	Channel through Area C_N, south of road				Stream morphology change. Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review will be triggered.**	Can this be made self-scouring or would maintenance dredging be needed?	Feasible but not a solution by itself.	3	3	2	2	3	3	2	2	9	6	2	2	9	6	6	6	46	
Improve drainage	Modify 1st Avenue storm drains				nil		Feasible but not a solution by itself. Effects on Areas A&C to be evaluated in model.	3	3	2	2	1	1	2	1	9	6	2	2	3	2	6	3	33	
Enlarge main river channel by dredging	Bar scalping		Monitoring and maintenance required.		Disturbance of river bed, likely HADD. **Federal review will be triggered.**	Maintenance excavation could be needed due to ongoing sediment deposition. Ice jam initiation may still occur on Fraser River	Feasible but not a solution by itself. Effects on Areas A&C to be evaluated in model.	3	3	2	3	3	3	2	2	9	6	2	3	9	6	6	6	47	
	Bar scalping and instream excavation		Monitoring and maintenance required.		Disturbance of river bed, likely HADD. **Federal review will be triggered.**	Maintenance excavation could be needed due to ongoing sediment deposition. Ice jam initiation may still occur on Fraser River	Feasible but not a solution by itself. Effects on Areas A&C to be evaluated in model.	3	3	2	3	2	3	2	2	9	6	2	3	6	6	6	6	44	
Flow regulation	Enlarge storage behind Kenney Dam				Detailed and complex provincial and **federal reviews required**. Multi-year environmental studies likely required for permitting.	Larger riparian/shoreline impacts	Expensive. Not a solution by itself.	3	3	3	3	3	3	3	1	9	6	3	3	9	6	9	3	48	
	Build new storage				Detailed and complex provincial and **federal reviews required**. Multi-year environmental studies likely required for permitting.	Larger riparian/shoreline impacts	Expensive. Not a solution by itself.	3	3	3	3	3	3	3	1	9	6	3	3	9	6	9	3	48	
	Revise operating procedure				Detailed and complex provincial and **federal reviews required**. Multi-year environmental studies likely required for permitting.	Complex issue including effects on water temperature, sediment transport, bank stability. Might be tied into proposed water release facility at Kenney Dam.	Feasible.	3	3	3	3	3	3	2	1	9	6	3	3	9	6	6	3	45	

Note! Direct comparison of Lower Nechako general options is not valid.

Table E.2: Flood Control Solutions - Fraser River

Mitigation Options	Hydraulic Considerations	Infrastructure Considerations	Environmental Considerations	Geomorphology Considerations	General Evaluation
Area A_F (Yellowhead Br)					
No permanent protection, provide temporary works as required		Emergency response on call	No new environmental impacts expected in absence of permanent protection. Potential environmental considerations associated with temporary works depends on design of those works. For example, release of deleterious substances is possible with use of amphibex and warm water release.		
Diking next to river	Need erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.	D/S tie-in may be difficult	Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	Area next to bridge abutment, no measurable impact. Minor loss in flood storage area.	Feasible
Low dike next to river	Low dike providing base for temporary high water protection	Emergency response on call	Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**		
Land-use changes			Restores functional floodplain areas		Feasible
Raise/flood proof any development			Potential minor riparian habitat encroachment.		Feasible
Area B_F (South Fort George)					
No permanent protection, provide temporary works as required		Emergency response on call	No new environmental impacts expected in absence of permanent protection. Potential environmental considerations associated with temporary works depends on design of those works. For example, release of deleterious substances is possible with use of amphibex and warm water release.		Not acceptable in the long term.
Diking-next to river/slough	Need erosion protection, install lockblock/sheetpile walls where insufficient space, provide seepage cut-off, pump internal flows.		Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	Drains or pumps may be needed to prevent water being trapped behind dyke. Reduces flood storage area and cuts off a possible flood drainage channel.	May not be feasible
Individually raise/flood proof any essential development, buy out rest		Emergency response on call	Potential minor riparian habitat encroachment.	Could reactivate sizeable flood relief channel	Feasible
Land-use changes			Restores functional floodplain areas	Could reactivate sizeable flood relief channel	Flooding occurs frequently, this may be best option.
Area C_F (SFG west of Queensway)					
No permanent protection, provide temporary works as required		Emergency response on call	No new environmental impacts expected in absence of permanent protection. Potential environmental considerations associated with temporary works depends on design of those works. For example, release of deleterious substances is possible with use of amphibex and warm water release.		Area protected by road/dike. Determine if any additional protection is required.
Land-use changes			Restores functional floodplain areas		Unlikely.
Upgrade to standard dike, provide seepage cut-off and internal pumping			Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	Drains or pumps may be needed to prevent water being trapped behind dyke. Reduces flood storage area and cuts off a possible flood drainage channel.	May not be required.
Individually raise/flood proof any essential development/basements			Potential minor riparian habitat encroachment.	Impacts will be determined by the number of sites	May not be required.

Mitigation Options	EVALUATION CRITERIA 1 = low, 3 =high								WEIGHTING FACTOR 1 = less important 3 = more important								Total Weight Factor	Area Ranking
	Risk after Implementing	Constr./Maintenance	Access Problems	Drainage Problems	Environmental Impact	River Instability Risk	Direct Cost	Social Cost	Risk after Implementing	Constr./Maintenance	Access Problems	Drainage Problems	Environmental Impact	River Instability Risk	Direct Cost	Social Cost		
									3	2	1	1	3	2	3	3		
Area A_F (Yellowhead Br)																		
No permanent protection, provide temporary works as required	3	3	3	2	1	1	1	3	9	6	3	2	3	2	3	9	37	3
Diking next to river	2	3	1	2	3	1	2	2	6	6	1	2	9	2	6	6	38	4
Low dike next to river	3	3	2	2	3	1	2	1	9	6	2	2	9	2	6	3	39	5
Land-use changes	1	1	1	1	1	1	3	2	3	2	1	1	3	2	9	6	27	1
Raise/flood proof any development	1	2	2	2	2	1	2	2	3	4	2	2	6	2	6	6	31	2
Area B_F (South Fort George)																		
No permanent protection, provide temporary works as required	3	3	3	3	1	2	1	3	9	6	3	3	3	4	3	9	40	3
Diking-next to river/slough	2	3	2	3	3	2	3	2	6	6	2	3	9	4	9	6	45	4
Individually raise/flood proof any essential development, buy out rest	2	2	2	3	2	1	3	2	6	4	2	3	6	2	9	6	38	2
Land-use changes	1	1	1	1	1	1	3	3	3	2	1	1	3	2	9	9	30	1
Area C_F (SFG west of Queensway)																		
No permanent protection, provide temporary works as required	3	3	2	3	1	1	1	2	9	6	2	3	3	2	3	6	34	3
Land-use changes	1	1	1	1	1	1	3	2	3	2	1	1	3	2	9	6	27	1
Upgrade to standard dike, provide seepage cut-off and internal pumping	2	3	1	3	3	1	2	1	6	6	1	3	9	2	6	3	36	4
Individually raise/flood proof any essential development/basements	1	1	3	2	2	1	2	1	3	2	3	2	6	2	6	3	27	1

Table E.2: Flood Control Solutions - Fraser River

						EVALUATION CRITERIA 1 = low, 3 =high								WEIGHTING FACTOR 1 = less important 3 = more important									
Mitigation Options	**Hydraulic Considerations**	**Infrastructure Considerations**	**Environmental Considerations**	**Geomorphology Considerations**	**General Evaluation**	Risk after Implementing	Constr./Maintenance	Access Problems	Drainage Problems	Environmental Impact	River Instability Risk	Direct Cost	Social Cost	Risk after Implementing	Constr./Maintenance	Access Problems	Drainage Problems	Environmental Impact	River Instability Risk	Direct Cost	Social Cost	**Total Weight Factor**	**Area Ranking**
														3	2	1	1	3	2	3	3		
Area D_F (Lansdowne south end)																							
No permanent protection, provide temporary works as required		Emergency response on call	No new environmental impacts expected in absence of permanent protection. Potential environmental considerations associated with temporary works depends on design of those works. For example, release of deleterious substances is possible with use of amphibex and warm water release.		Not acceptable in the long term.	3	3	3	3	1	1	1	2	9	6	3	3	3	2	3	6	35	3
Land-use changes			Restores functional floodplain areas		Feasible	1	1	1	1	1	1	3	3	3	2	1	1	3	2	9	9	30	1
Provide diking for part of area.			Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	Reduces flood conveyance capacity	Feasible but expensive	2	2	2	2	3	1	3	2	6	4	2	2	9	2	9	6	40	4
Individually raise/flood proof any essential development			Potential minor riparian habitat encroachment.	Impacts will be determined by the number of sites	Feasible	1	2	2	3	2	1	2	2	3	4	2	3	6	2	6	6	32	2
Area E_F (Westbank at island)																							
No permanent protection, provide temporary works as required		Emergency response on call	No new environmental impacts expected in absence of permanent protection. Potential environmental considerations associated with temporary works depends on design of those works. For example, release of deleterious substances is possible with use of amphibex and warm water release.		Feasible solution considering limited development.	3	3	3	3	1	1	1	2	9	6	3	3	3	2	3	6	35	3
Land-use changes			Restores functional floodplain areas		Feasible	1	1	1	1	1	1	3	2	3	2	1	1	3	2	9	6	27	2
Diking	May need erosion protection, provide seepage cut-off, pump internal flows.		Riparian habitat encroachment. Potential streambank erosion and streambed scour. **Federal review potentially triggered.**	Minor reduction in flood conveyance capacity	May not be economically justifiable.	1	3	2	2	3	1	3	1	3	6	2	2	9	2	9	3	36	4
Individually raise/flood proof any essential development/basements or move/isolate and land-use changes			Potential minor riparian habitat encroachment.	Impacts will be determined by the number of sites	Feasible	1	1	2	1	2	1	2	1	3	2	2	1	6	2	6	3	25	1
Area F_F (Northwood Pulpmill Rd)																							
No permanent protection, provide temporary works as required		Emergency response on call	No new environmental impacts expected in absence of permanent protection. Potential environmental considerations associated with temporary works depends on design of those works. For example, release of deleterious substances is possible with use of amphibex and warm water release.	Reduction in flood conveyance capacity	Feasible solution considering limited development.	3	3	3	2	1	2	1	2	9	6	3	2	3	4	3	6	36	4
Ring Diking set-back from river	Provide seepage cut-off, pump internal flows.		Potential minor riparian habitat encroachment.		Feasible but expensive	1	2	2	2	2	1	3	1	3	4	2	2	6	2	9	3	31	3
Individually raise/flood proof any essential development			Potential minor riparian habitat encroachment.	Impacts will be determined by the number of sites	Feasible	1	2	3	2	2	1	2	1	3	4	3	2	6	2	6	3	29	2
At any vulnerable development in floodplain, alter land-use			Restores functional floodplain areas	Maintains flood conveyance storage area	Feasible	1	1	1	1	1	1	3	2	3	2	1	1	3	2	9	6	27	1
Area G_F (Across from Shelley)																							
Prevent future development. Flood proof existing development as necessary			Potential minor riparian habitat encroachment.	An appropriate plan	Feasible	1	1	1	1	2	1	1	1	3	2	1	1	6	2	3	3	21	1

Table E.3: Ice Jam Flood Control for Nechako River

Flood Control Method	Purpose	Comments	Additional Investigations to Follow
Diking	Prevents direct flooding from high water caused by ice jams.	Due to filled in back-channels and porous soil conditions in the floodplain, dikes will not provide complete protection unless seepage is prevented and/or groundwater is pumped from developed areas.	Yes
Flow Control	Allows reduction of flows during critical freeze-up conditions.	Existing storage reservoir at Kenney Dam cannot be operated effectively to reduce flows on an as-needed basis. The length of time between action at Skins Lake and flow reductions are Prince George is too long within the context of how much in advance ice conditions can be forecasted for there to be an effective release management system. There are limitations to how much flow can be reduced within the context of natural flows in the system, and the minimal effects that the reduction would have on ice-related water levels.	-
Ice Control Dam	The structure would cause the ice cover to form upstream of the City, preventing the formation of a thick ice cover at and upstream of the confluence with the Fraser River.	A very expensive solution with serious environmental and infrastructure concerns.	-
Ice Booms	Similar to the control dam but usually applied in slow velocity rivers.	Not practical in the relatively fast flowing Nechako.	-
Channel Modification	Ice jams typically form at shallow river sections, gravel bars and surface obstructions. Channel modifications are undertaken to reduce the degree of flow obstruction.	The method may have negative impact on instream and riparian habitat. May not be effective for the Nechako River because the ice levels at the confluence with the Fraser River are determined by the ice levels on the Fraser River, regardless of the Nechako bed levels.	Yes
Side-channel enlargement or introduction of new back-channels	Allows flow passage outside main channel.	Reclamation and expansion of riparian habitat. Limited flood reduction since relief channels are expected to fill with frazil.	Yes
Blasting	Breaks ice cover into floes which can be transported downstream.	Absolutely ineffective during the formation of ice jams during freeze-up, high environmental impact and dangerous. Can only be used once a solid ice cover has formed and then in only localized situations - not on the scale of the Nechako River.	-
Mechanical Removal	Ice is cut, sawn or split into more transportable pieces to open up an ice-free portion of channel.	This was done last winter using an amphibex (excavator on pontoons). Success of method depends on temperature, flow conditions, and an ice-free area downstream to store the dislodged ice. Not practical for long jams or strong river currents. Can only be used after a jam has formed and peak water levels have been attained. My be used to limit the duration of high water levels, but takes a long time to produce significant results without cooperation of the hydrometeorological conditions.	Yes
Hot Water Supply	Supply hot water to melt ice.	Method applied last winter. Produced localized melting only. Environmental concerns if unsuitable or polluted water is discharged. Only effective once an ice cover has formed and high water levels have developed. May be useful for reducing the duration of high water, but takes a long time to produce significant results. May operate more successfully if installed ahead of jamming.	-

APPENDIX G

GROUNDWATER REPORT BY THURBER ENGINEERING LTD.

M E M O R A N D U M

To: Dave Dyer
City of Prince George

Date: September 26, 2008

From: Dave Smith

File: 14-224-0

RIVER ROAD SUBDRAIN AND PUMP CHAMBER SYSTEM

As requested, we have reviewed the reference documents you provided to assess the feasibility of the proposed subdrain and pump system along River Road to prevent flooding of the area to the south due to high groundwater levels. Our assessment is presented below.

1. REFERENCE INFORMATION

The reference information we have utilized in preparing this assessment is as follows, listed in chronological order of preparation:

1 - February 21, 2006 report by AMEC Earth & Environmental entitled *City of Prince George – Groundwater Elevation Study*

2 - November 17, 2006 report by GeoNorth Engineering Ltd. (GeoNorth) entitled *Groundwater Elevation Monitoring Study – 1st Avenue and River Road Area, Prince George, BC*

3 - Figure 4-1946 prepared by M Miles & Associates Ltd. (MMA), at 1:7500 scale and dated May 7, 2008, comprising a mosaic of the study area prepared from 1946 airphotos

4 - May 15, 2008 report by GeoNorth entitled *Groundwater Elevation Monitoring Program – 1st Avenue and River Road Area, Prince George, BC*

5 - Airphotos of the study area marked up by McElhanney Consulting Services (McElhanney) for nhc to show areas affected by flooding due to high groundwater levels and flooding directly from the Nechako River

6 - June 2008 report by northwest hydraulic consultants (nhc) entitled *Flood risk Elevation and Flood Control Solutions – Risk Analysis – Progress Report 1*

7 - Figure 4 – 2008 prepared by MMA at 1:7500 scale and dated September 10, 2008, comprising a recent, coloured airphoto mosaic of the study area

8 - Report prepared for Prince George City Council entitled *River Road Subdrain and Pump Chamber System* dated September 23, 2008

Hereinafter, the documents are referred to by the number

2. SOIL CONDITIONS IN STUDY AREA

Document 1 includes the logs of 15 test holes drilled in the study area for installation of monitoring wells. The holes varied in depth from 4.1 m to 9.1 m but most were 7.6 m deep. Sand or sand and gravel was the predominant soil unit encountered with a thin (1 to 2 m thick) clay layer in several holes and a thick silt layer in one hole (MW 05-06).

No gradation results are presented in the report but the logs generally indicate a trace of silt, which we interpret to be less than 10% silt.

Test hole locations are shown on Attachment 1 taken from Document 4.

3. GROUNDWATER MONITORING RESULTS

Groundwater levels in the 15 monitoring wells were recorded daily between January 2007 and February 2008 using data loggers which were downloaded by GeoNorth for digital elevation modelling of the groundwater surface. Groundwater profiles in Document 4 indicate a downward gradient to the north, thus groundwater flow towards the River for most of the year. When the River level rises, mounding of the groundwater surface occurs adjacent to the River, causing groundwater levels to rise throughout the area of influence.

Attachment 1, taken from Document 4 shows groundwater levels on January 7, 2008 after the second peak high water level in the Nechako River resulting from the ice jam. Attachment 1 information is reproduced in Table 1 in terms of the depth of the groundwater surface over the study area divided into 4 zones.

Allowing for slight inaccuracy in the data logger recordings (to explain groundwater levels above the ground surface), it is evident, that at high River flows and levels, the groundwater surface rises and flooding occurs in the area defined by MWs 05-1, 05-2, 05-7, 05-8, 05-9 and 05-10. These wells are highlighted on Attachment 1. This conclusion is in general agreement with McElhanney's observations except that McElhanney interpreted flooding north of the railway tracks to result from surface flow directly from the Nechako River.

To assess the influence of a historic backwater channel of the River, now backfilled, the channel shown on Document 3 has been added to Attachment 1. It appears that the channel has little if any influence on high groundwater levels.

It is not clear from the data reviewed how quickly groundwater levels respond to a rising River level and how far back mounding of the groundwater occurs. However, it is evident from the groundwater profiles shown for Cross-section B-B' in Document 4 that the gradient reverses for over 500 m from the River, resulting in the high groundwater levels recorded in the monitoring wells.

In comparison, groundwater levels recorded in the monitoring wells on May 23, 2007 before high River levels occur are shown for the same 4 zones in Table 2. This table indicates that except for MWs 4th Scotia and 05-2, the groundwater surface drops to between 2 and 3 m below the ground surface and poses no risk of flooding in the study area.

4. PROPOSED SUBDRAIN AND PUMP CHAMBER SYSTEM

The conceptual scheme shown in Document 8 will undoubtedly assist in lowering the groundwater table at high River level in the vicinity of the subdrain but its influence to the south will be limited by the clean granular soils which underlie the study area. We do not expect that it can possibly affect the groundwater levels south of the railway tracks, to 600 m south of River Road.

Installation of the subdrain to below the groundwater levels recorded in MWs 05-7, 05-8 and 05-10 at low River levels (as shown on Table 2) will assist in lowering the groundwater level until the River level starts to rise. Further analysis of River levels and water levels in these monitoring wells will be required to establish how long this effect will occur.

To effectively maintain a low groundwater surface as the River level requires the control exerted by the River and the mounding which occurs to be eliminated. The cut-off shown schematically in Document 8 will achieve this but we expect that the cut-off will need to be of significant depth, possibly of the order of 10 m or more and, therefore, installed below the water table. Determination of the cut-off depth will require further analysis and a knowledge of the hydraulic conductivity (permeability) of the subsoils.

With regard to the extent of the subdrain system, Table 1 results indicate that the east end of the study area, beyond MW 05-07, does not experience groundwater levels above 3 to 5 m from the ground surface even at peak River levels. Therefore, it seems likely that the subdrain system could be terminated between MWs 05-7 and 05-6. This limit is shown on Attachment 2 prepared from Document 8.

5. CONCLUSION

The discussion presented above is summarized as follows:

- The proposed subdrain scheme is feasible and will have a beneficial effect on groundwater levels, albeit a limited effect that will not extend the entire 600 m width of the 2007 – 2008 problem area
- The efficacy of the system will be enhanced by extending the cut-off, possibly, to 10 m depth or more
- The system need not extend for the entire length of River Road
- Further site investigation and analysis are required for detailed design of the system

We trust this is sufficient for your present needs.

DS/cw

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THURBER ENGINEERING LTD.

Table 1

JANUARY 7, 2008 GROUNDWATER LEVELS (FROM DOCUMENT 4)

Location	Monitoring Well	Depth to Groundwater Surface (m)
Adjacent to Nechako River	05-10	0.29 above ground surface
	05-8	0.27 above ground surface
	05-7	0.58
Near River Road, away from River	05-6	2.68
	05-5	4.91
	3 – River Road	3.90
Near Rail Tracks	05-1	0.32
	05-2	0.29
	05-9	0.20 above ground surface
	Via Rail	2.83
	05-3	2.40
	NR Motors	2.54
South Of Rail Tracks	CKPG	2.62
	4th Scotia	1.17
	05-4	3.30

Note: Groundwater levels of concern are highlighted in yellow.

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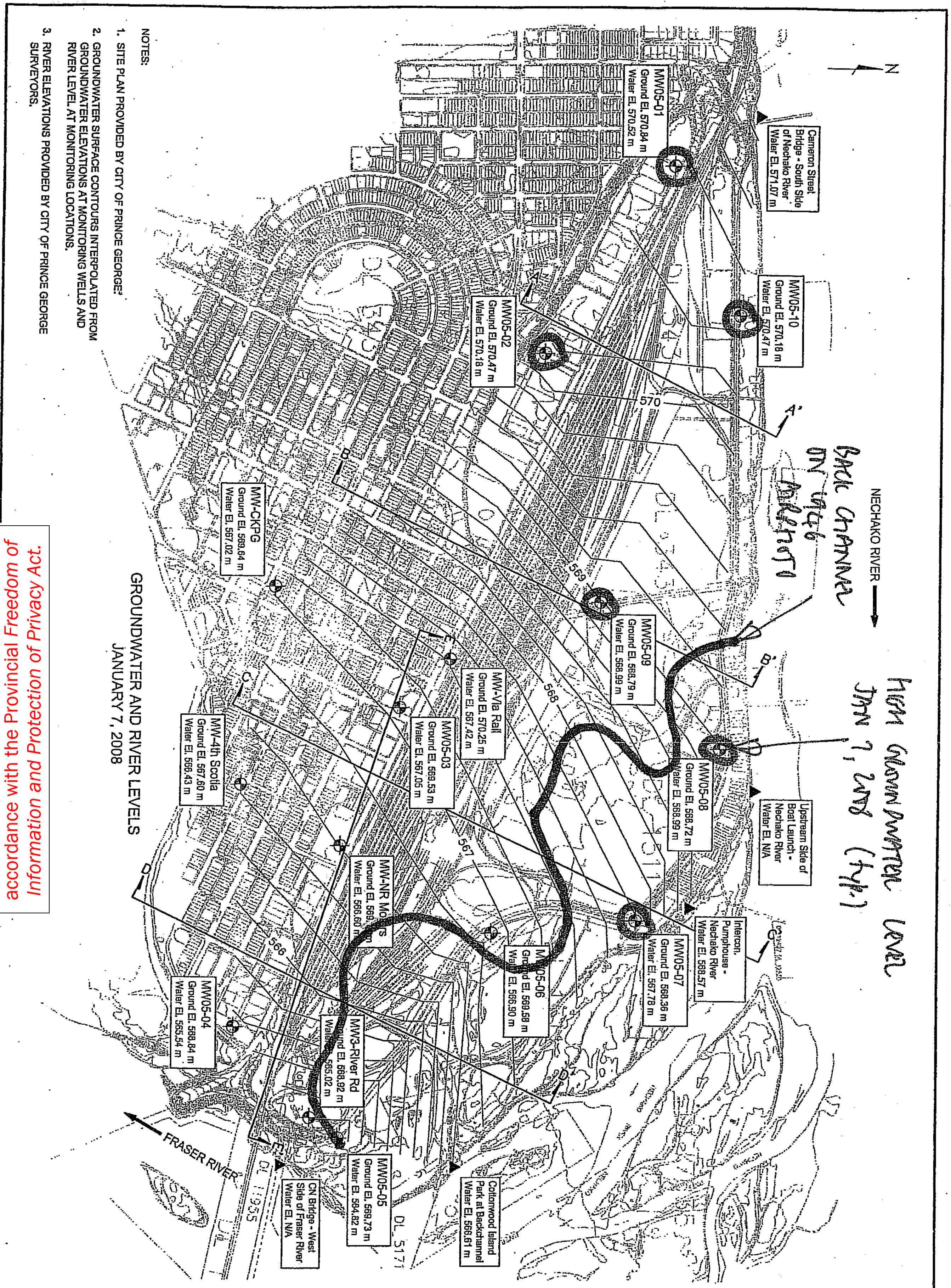
Table 2

MAY 23, 2007 GROUNDWATER LEVELS (FROM DOCUMENT 4)

Location	Monitoring Well	Depth to Groundwater Surface (m)
Adjacent to	05-10	2.38
Nechako River	05-8	2.57
	05-7	2.13
Near River	05-6	3.62
Road	05-5	3.76
away from River	3 – River Road	2.68
	05-1	2.31
Near Rail	05-2	1.80
Tracks	05-9	2.18
	Via Rail	3.90
	05-3	N/A
	NR Motors	3.05
South	CKPG	3.32
Of Rail	4th Scotia	1.56
Tracks	05-4	2.99

Attachment 1



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DATE: 2008/05/15			
DWN BY: LU			
MAP REF: –			
DWG NO. 2284-2008-01-07	REV. – / PROJECT NO: K-2284		

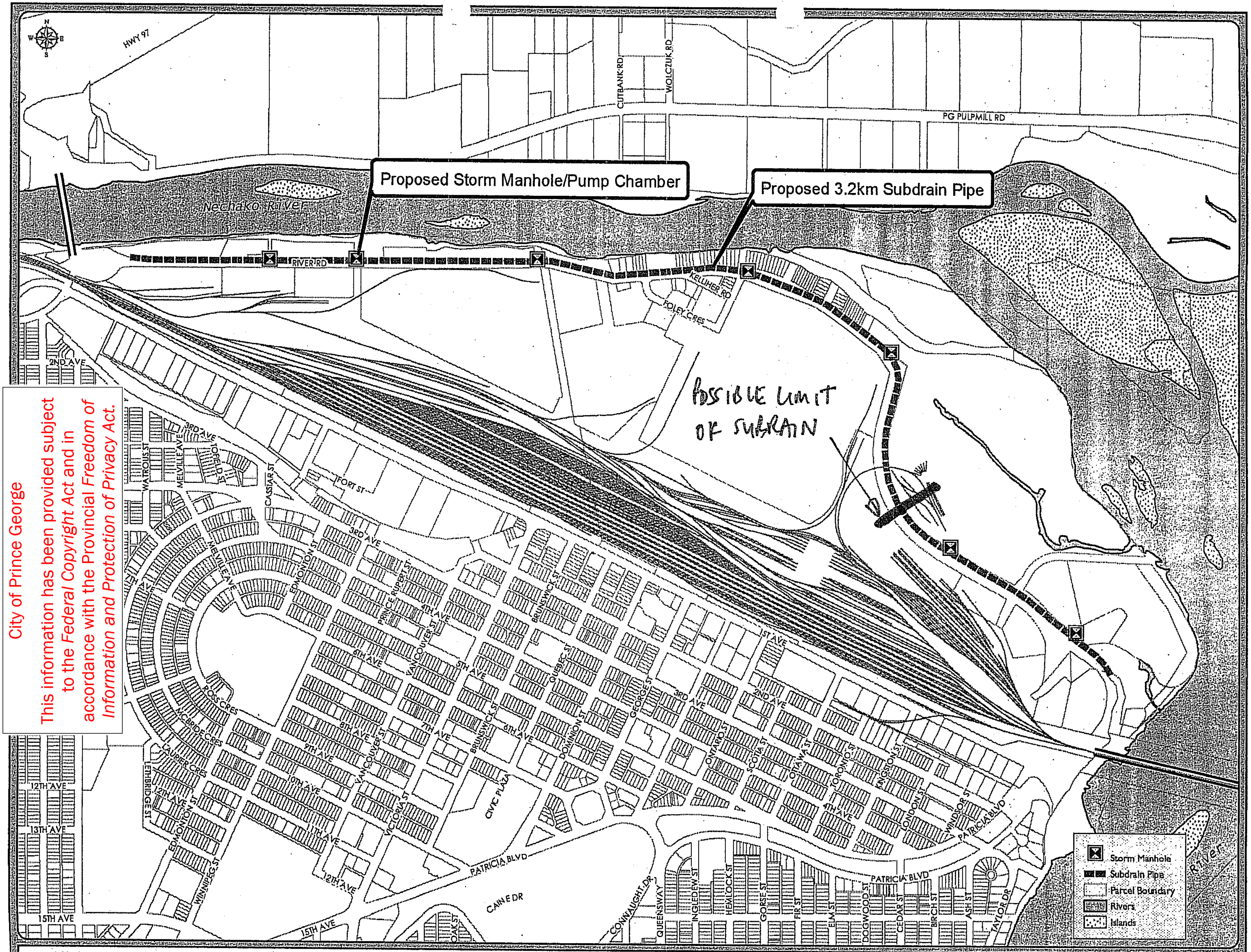

Figure 1. River Road Subdrain

APPENDIX H

DISCUSSION OF GRAVEL REMOVALS AT NECHAKO-FRASER CONFLUENCE

1. INTRODUCTION

Flood control solutions for City of Prince George were developed as outlined in the main report. The report concluded that gravel removals from the confluence area would not reduce design flood levels. This is opposite to the preference held by some stakeholders and this appendix was prepared to clarify the technical basis for the findings by NHC.

2. BACKGROUND

Flooding in Prince George is caused by either high freshet (snowmelt) flows in the Fraser River or ice-related flooding in the Nechako River. According to public perception, gravel has accumulated in the lower Nechako River and some landowners fear that the accumulations may aggravate flood levels. Evidence from historic air photographs supports that some material accumulation has taken place at the confluence. However, the photographs were taken at various flow conditions and it is not possible to quantitatively estimate accumulation volumes.

A comparison of river cross-sections surveyed in 1979 and 2008 indicates substantial lateral shifting of gravel bars but only very minor net build-up within the confluence area and bed lowering in some other areas. The 1979 cross-sections were surveyed about 400 m to 500 m apart and any depositions between the sections would not have been picked up by the surveys. When the hydraulic models with 1979 and 2008 cross-sections were compared (for the same flows, section spacing and channel roughness), the computed 200-year water surface profiles were nearly identical. This suggests that the channel changes from the past 30 years have had little impact on the freshet design profiles.

3. EFFECTS OF DREDGING ON FRESHET FLOOD PROFILES

During the freshet, the Nechako flood levels are controlled by conditions in the Fraser River. The Fraser River below the confluence essentially acts as a bathtub drain and the water levels at the confluence are determined by the capacity of the channel for many kilometres below the confluence. This river reach is relatively straight and steep, containing no major gravel bars, and increasing its flow capacity by removing gravel is not practical.

Dredging or bar scalping within the confluence area would not increase the flow drainage capacity of the downstream Fraser channel. Even if a very large volume of material were to be removed, creating a deep lake at the confluence, it would not reduce flood levels in the Nechako River. This was tested in the 2008 hydraulic model, where a volume of 2,000,000 m^3 was removed, without any significant change to the flood profile. The actual configuration of the excavation does not affect the results.

However, during low flows when the Fraser River does not produce backwater conditions, the Nechako profile is affected by dredging, dropping locally in response to any significant removal.

4. ICE FORMATION IN NECHAKO RIVER

The formation of an ice cover is complex and to understand the process the following basic hydraulic concepts are helpful:

- In any river, the flow rate is the product of the channel cross-sectional area and the flow velocity. If the flow area at a cross-section increases, there must be a corresponding decrease in the velocity. Correspondingly, a decrease in the flow area results in a velocity increase.
- The flow velocity is affected by the roughness of the bed/banks and of the ice cover in the winter. Ice increases the roughness, reducing flow velocities and requiring a much larger flow area (increased depth) to pass a particular flow than during ice-free conditions. This is why there is an increase in the water level when an ice cover forms.
- Icy slush can move along the bottom of the ice cover if the velocity is high enough. The moving slush is known as "cover load". If the velocity is not high enough, the slush will accumulate which will reduce the flow area. As the flow area reduces, the velocity will increase until the velocity becomes high enough to begin moving the slush.

Figures 4.1 and 4.2 (Main Report) schematically illustrate the freeze-up process in the Nechako River. At Prince George, frazil ice that is generated in the Nechako River floats downstream and is carried away by the Fraser River while the Fraser River is open. Lodgement of the ice pans on the Nechako River only begins when an ice cover on the Fraser River forms at the confluence. As the ice cover forms and more ice pans accumulate against the Fraser River ice cover, the water level in the Nechako increases due to the increased roughness, which floats the accumulating ice higher above the bed.

Figure 5.3 (Main Report) shows that ice-related flooding typically occurs when Nechako River flows during the freeze-up period exceed 200 m^3/s and the ten-day average air-temperature is colder than -5^{o}C. The figure suggests that if gravel were removed from the lower Nechako in the 1960's and early 1970's, it did not prevent ice-related flooding. On the other hand, the reason ice-related flooding did not occur from the mid 1970's to mid 1990's was because the flow/climate conditions were non-conducive to ice-flooding, regardless if gravel removals took place.

5. EFFECTS OF DREDGING ON THE ICE FLOOD PROFILE

While dredging has been suggested as a method to reduce ice-related flooding, the following are key reasons why dredging will not help:

- The ice cover on the Fraser River begins by forming downstream of Prince George and eventually progresses upstream to the confluence. The eventual elevation of the ice cover at the confluence is a function of conditions in the Fraser River many kilometers downstream and the river flow. Dredging the Fraser River near the confluence will not change the ice cover elevation and

Nechako frazil will continue to lodge at elevations suggested by the historical record.

- If the ice cover elevation at the confluence is unchanged, dredging the Nechako River will effectively increase the size of the channel. This would reduce the velocity making it more likely for ice pans to lodge at the Fraser. This would in turn make it more likely for a stable ice cover to form sooner and ultimately contribute to a more rapid upstream advance of the ice cover. The elevation of the ice cover would not be lowered by the dredging.
- While dredging the Nechako at the confluence will make it more likely for a stable ice cover to form, it will not change the fundamental flow-related ice thickness and water elevations that would develop further upstream past the boat launch where ice-related flooding governs the design levels.
- Incoming frazil slush can be transported under the ice cover, provided the velocity is large enough. If not, the slush will accumulate under the ice, slowly reducing the flow area until the velocity increases sufficiently to begin transporting the slush. Dredging effectively increases the flow area and will cause slush to accumulate. The shape of the dredged channel does not affect the outcome.
- If first lodgement were to occur on the gravel bars at the confluence, dredging the area could improve the transport of ice into the Fraser. However, this situation has not been observed, nor would the dredging change ice cover conditions in the Fraser River. The Fraser River conditions would still govern the lodgement process.
- Some sediment deposition has occurred between the confluence and the CNR bridge, just downstream. Dredging this material will not change the ice cover level at the confluence since these conditions are governed by river conditions downstream of Prince George.

6. CONCLUSIONS

Considering that gravel removals from the Nechako-Fraser confluence would not reduce freshet or ice-related flood levels we cannot recommend them as a flood control solution at this time. We recommend performing repeat grid surveys in the confluence area to compare against the survey completed in 2008 and more accurately determine the deposition volumes in the confluence to see if future maintenance gravel removals may be warranted.

Numerous fish species are found in the Nechako and Fraser Rivers, including different types of salmon and white sturgeon, an endangered species. If proposed in the future, gravel removals must be approved by provincial and federal regulatory agencies before they can proceed.