eDoc 451264 (67 pp)

CITY OF PRINCE GEORGE

FLOOD RISK EVALUATION AND FLOOD CONTROL SOLUTIONS RISK ANALYSIS – PROGRESS REPORT 1

JUNE 2008

nhc northwest hydraulic consultants

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

CITY OF PRINCE GEORGE
FLOOD RISK EVALUATION AND FLOOD CONTROL SOLUTIONS
RISK ANALYSIS – PROGRESS REPORT 1

Prepared for:

City of Prince George
1100 Patricia Boulevard,
Prince George, B.C.
V2L 3V9

Prepared by:

Northwest Hydraulic Consultants Ltd.
30 Gostick Place
North Vancouver, BC
V7M 3G3

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

June 2008
3-4920

DISCLAIMER

This document has been prepared by Northwest Hydraulic Consultants Ltd. (NHC), McElhanney Consulting Services Ltd. (MCSL), Environmental Dynamics Inc. (EDI) and M. Miles and Associates Ltd. (MMA) in accordance with generally accepted engineering and geoscience practices and is intended for the exclusive use and benefit of the client for whom it was prepared and for the particular purpose for which it was prepared. No other warranty, expressed or implied, is made.

Northwest Hydraulic Consultants Ltd. and its officers, directors, employees, agents and sub-consultants (McElhanney Consulting Services Ltd., Environmental Dynamics Inc. and M. Miles and Associates Ltd.) assume no responsibility for the reliance upon this document or any of its contents by any party other than the client for whom the document was prepared. The contents of this document are not to be relied upon or used, in whole or in part, by or for the benefit of others without specific written authorization from Northwest Hydraulic Consultants Ltd. and our client.

Report prepared by:

Bruce Walsh, P.Eng.
NHC – Principal

Bill Cheung, P.Eng.
MCSL – Assistant Branch Manager

Dave Andres, P.Eng.
NHC – Principal

Mike Miles, P.Geo.
MMA - Principal

Monica Mannerström, P.Eng.
NHC - Senior Engineer

Rob Van Schubert, R.P.Bio.
EDI – Vice-President

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF MAPS

LIST OF APPENDICES

1. EXECUTIVE SUMMARY

Flooding in Prince George occurs as a result of either high freshet flows or due to 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. The ice jam flooding in Prince George during the winter of 2007-2008 raised questions about the vulnerability of flood prone areas within the City and resulted in calls for long term solutions to protect properties within the 200-year floodplain.

The City of Prince George retained Northwest Hydraulic Consultants Ltd (**nhc**) along with a team of sub-consultants consisting of McElhanney Consulting Services Ltd (MCSL), Environmental Dynamics Inc (EDI), M. Miles and Associates Ltd (MMA) and Kevin Brown Communications Ltd to carry out a flood risk evaluation and develop flood control solutions for the City. The main goals are to:

- Prepare a comprehensive flood risk evaluation, incorporating a threat and consequence analysis and developing and prioritizing flood relief options.
- Following a public consultation process, select suitable flood control solutions and develop conceptual level designs, including cost estimates and approval requirements.
- Update the existing floodplain maps prepared in 1997.

This report outlines the risk assessment component of the evaluation and summarizes progress to date. Following this initial phase, a detailed technical investigation will be launched.

Historic freshet and ice jam related floods were reviewed and all relevant flow and water level records obtained from Water Survey Canada. The Nechako River flow has been partially regulated since construction of Kenney Dam in 1952. Flow and meteorological records were reviewed to understand the mechanisms behind freshet and ice jam flooding. Both flood conditions give rise not only to high surface water levels but also result in high groundwater levels and local flooding in different parts of the floodplain. Map Panels 1 to 3 show the outline of areas flooded during the freshets of 1948 and 1972 and flooding caused by the 2007-2008 ice jams.

The previous floodplain mapping study completed in 1997 was reviewed and **nhc** confirmed that it needs updating. The new mapping will be based on hydraulic modelling using recent river cross-section surveys, re-estimated design flows and incorporating numeric ice jam evaluations. Map Panels 1 to 3 show the 1997 floodplain boundaries.

A preliminary air photograph analysis was undertaken and showed that primarily industrial development has in-filled many of the secondary Nechako River channels in the confluence area. This may have reduced the flood conveyance area and eliminated alternative flood paths. These relic channels may allow groundwater to flow under roads and any protective dikes during high flows requiring special attention to be given during the design of these works. The air photographs also indicate that former gravel bars and secondary channels have become vegetated. The historical photographs suggest that there may be on-going sediment deposition in both the lower Nechako and in the Fraser River just downstream of the confluence.

A consequence analysis compiling public- and private-owned assets is underway but all necessary input has not been received and the work is yet to be completed.

Based mainly on the flood risk assessment and asset evaluation, areas requiring flood control solutions were identified as shown on Map Panels 1 to 3. Seven flood risk areas were delineated along the Nechako River and another seven along the Fraser River:

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

Fraser River:
Area A_F – West bank at Yellowhead Highway
Area B_F – South Fort George
Area C_F – SFG west of Queensway
Area F_F – Lansdowne south end
Area E_F – West Bank at Island
Area F_F – Northwood Pulpmill Road
Area G_F – Across River from Shelley

Potential preliminary flood relief options were developed for each risk area as listed in Table 4.1 for the Nechako River and Table 4.2 for the Fraser River. The options encompass structural and non-structural solutions and are grouped by area. General Nechako River flood control solutions with potential benefits to several areas are listed as a separate group. The solutions were briefly reviewed in terms of hydraulic, infrastructure, environmental and geomorphic considerations. Based on this review the overall feasibility of the options was assessed.

The identified relief options were also evaluated using a decision-matrix approach. The matrix provided a preliminary evaluation of options and should be considered tentative. However, the matrix indicated that land-use amendments and set-back dikes are generally more favourable than river dikes. River dikes typically require extensive erosion protection which is expensive to install and maintain and they also have greater negative environmental impact on riparian habitat.

It was felt that none of the options should be eliminated through the initially proposed coarse filtering process until more detailed technical investigations have been completed. Ice jam prevention strategies are presented in Table 4.3.

Some additional work, not included in the proposal, was identified and is recommended for the feasibility assessment, the next phase of the project. This work includes additional land and river surveys, two dimensional hydraulic modelling, sediment source and sediment transport analysis, additional sampling for white sturgeon habitat and more extensive public consultation.

2. INTRODUCTION

The City of Prince George (City) retained Northwest Hydraulic Consultants Ltd (**nhc**) along with a team of sub-consultants consisting of McElhanney Consulting Services Ltd (MCSL), Environmental Dynamics Inc (EDI), M. Miles and Associates Ltd (MMA) and Kevin Brown Communications Ltd to carry out a flood risk evaluation and develop flood control solutions for the City. The ice jam flooding in Prince George during the winter of 2007-2008 raised questions about the vulnerability of flood prone areas within the City and resulted in calls for long term solutions to protect properties within the 200-year floodplain. The main study goals are:

- Prepare a comprehensive flood risk evaluation, which incorporates a threat and consequence analysis and develops and prioritizes flood relief options. The evaluation is to include a detailed technical feasibility assessment to evaluate potential options for reducing flood risk to any development in the floodplain, while protecting cultural values as well as aquatic and riparian habitat along the Fraser and Nechako Rivers.
- Following a public consultation process, select suitable flood control solutions and develop conceptual level designs, including cost estimates as well as critical time line and approval requirements.
- Update the existing floodplain maps.

The risk assessment component of the flood risk evaluation is outlined in this report which also forms a progress report of work completed to date. Section 3 provides a detailed flood threat analysis and a consequence analysis is provided in Section 4. Potential flood relief options are presented in Section 5 and Section 6 lists recommendations for the feasibility assessment component of the project. Section 7 summarizes relevant references.

3. THREAT BACKGROUND INFORMATION

Flooding in Prince George occurs as a result of either high freshet flows or due to 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. The study area is shown in Figure 3.1 and encompasses the area within the Prince George city boundaries.

The Fraser River drainage area at Prince George is 32,400 km^2. The considerably larger Nechako River basin of 47,100 km^2 is partially regulated and part of the runoff is diverted to the Kemano power-plant. Nechako River freshet peak flows are only about a quarter of the Fraser annual peak. Generally, reservoir operation delays the Nechako peak flow until after the Fraser River has crested. Since the construction of Kenney Dam in 1952, the operating procedure for the reservoir has gradually changed to accommodate power demands, environmental requirements and flood management.

Nechako flooding due to ice effects occurs typically during freeze-up. In most years, the Nechako ice-cover at Prince George forms due to the accumulation of frazil floes against the ice-cover on the Fraser River. The likelihood of experiencing high ice-related water levels along the Nechako is related to the combined risk of cold temperatures and high Nechako flows during freeze-up. To ensure adequate reservoir capacity in the spring time, relatively large Nechako flows have been discharged in the late fall or early winter, which in combination with natural flows from below the reservoir, can exceed the flow in the Fraser River.

The freshet and ice jam conditions give rise not only to high surface water levels but also result in high groundwater levels and local flooding in different parts of the floodplain. Considering the braided network of channels evident from historic air-photography as outlined in Section 3.3 this is not surprising.

The Lheidli T'enneh 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 1915 when the City of Prince George was founded.

For accurate estimation of design flows it is important to trace historic flood records as far back as possible, so that any unusually large floods can be included in the analysis. Only relatively limited information is available regarding early flooding in the Prince George area. D. Septer (2007) described flooding in Northern British Columbia based on eyewitness accounts and newspaper reports for the period 1820 to 2006. Klohn Crippen (1997) provided some information on flooding in the Prince George area. The Water Survey Canada (WSC) made available relevant unpublished flow and water level records from their archives.

3.1 Historic Freshet Floods

Table 3.1 summarizes significant Fraser River floods, including estimated/recorded water levels and brief descriptions of resulting damage. The largest flood on record occurred in 1894 and according to WSC information dating from 1962, the water level at the CNR Bridge site during the 1894 flood was El. 569.5 m or the same as the 200-year water level computed by Klohn-Crippen (1997), without a freeboard allowance. The WSC historic information was not referenced by Klohn Crippen and this apparent agreement between the flood levels provides some degree of confirmation, considering the 1894 flood is the design flood for the Fraser River downstream of Hope.

Published flow records were obtained for the key WSC stations listed in Table 3.2. The gauge locations and study area are shown in Figure 3.1. Flow histograms showing annual peak flows for *Station 08KB001, Fraser River at Shelley* and *Station 08JC002, Nechako River at Isle Pierre* are shown in Figures 3.2 and 3.3. A water level histogram for *Station 08KE018, Fraser River at South Fort George* is included in Figure 3.4. The South Fort George record was extended to cover the period 1947-1967 based on water level records for *Station 08KE001, Fraser River at Prince George*. An adjustment was made to the Prince George record based on the overlapping period of record from 1968.

Figure 3.5 shows the average timing of peak events and indicates that:

- The Fraser River at Shelley on average peaks around June 10. There does not appear to be a trend towards earlier or later peaks as a result of potential basin changes (eg. pine-beetle devastation) or shifts in the climate.
- The freshet water level at Prince George is mainly a factor of Fraser River flows and water levels at South Fort George typically peak about one day later than at Shelley.
- The Nechako River at Isle Pierre peaks later than the Fraser and over the past fifty years the reservoir operating procedure has delayed the average date of the peak flow by about 15 days.

Monthly average flows for Fraser River at Shelley and Nechako River at Isle Pierre are plotted in Figures 3.6 and 3.7, and average water levels at South Fort George are shown in Figure 3.8. The figures include maximum and minimum values for the period of record to show the range of flows that can be expected in any month.

3.2 Historic Ice Jam Floods

While Prince George is situated at the confluence of two large rivers on which both freeze-up jams and breakup jams can occur, the most serious ice-related flooding appears to occur during freeze-up on the Nechako River. Since the construction of the Nechako Reservoir, thermal processes appear to dominate the breakup thus limiting the severity of breakup on the Nechako River. Freeze-up on the Fraser River occurs at relatively low flows, with peak freeze-up elevations at the mouth of the Nechako River ranging between El. 561.8 and 563.5 m. Breakup on the Fraser River is more spectacular with peak elevations at breakup ranging between El. 564.5 and 566.5 m . However, given the high banks on the Fraser River, and in spite of backing water up the Nechako River during severe breakup events, ice-related flooding from the Fraser does not appear to be a concern.

Campbell (1990) provides the most comprehensive summary of historical freeze-up water levels experienced in Prince George since the 1920's. The City has had a long history of ice jam flooding, particularly at freeze-up with the last major event being in 2007-08. Even though serious flooding had occurred numerous times prior to regulation, local residents are concerned still that the regulation provided by the Kenney Dam and the operation of Skins Lake Spillway by Alcan Smelters and Chemicals Ltd. (Alcan) has increased the severity of flooding within the City. Most of the peak freeze-up levels have been measured at the City Gauge located at the Cameron Street Bridge. Even though the levels have been tabulated for only one location, the levels provide a historical index of the severity of freeze-up stage increases along the Nechako River throughout the City. Table 3.3 summarizes the water levels associated with freeze-up and Figure 3.9 compares the levels to the maximum water level measured in 2007-08.

It is evident that Prince George has been affected by high freeze-up water levels during its entire history. This is most likely due to the Nechako's steep slope and the fact that the natural lake storage upstream contributes to higher flows during the freeze-up period. As far back as the late 1910's, water levels were observed to have exceeded the top of the railway grade and inundated the eastern part of the City on a number of occasions. The part of Prince George located just upstream of the confluence has been affected by flooding most often. This is most likely due to its generally low elevation of the floodplain and because short, ice-supply-limited jams on the Nechako River would have the most effect on water levels closest to the point of lodgement against the Fraser River ice.

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 five times. Undoubtedly, there were other high freeze-up water levels, 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 on four occasions during the period that the gauge operated. The maximum water elevation recorded was 570.7 m in 1959-60.

Since the removal of the gauge, two very severe freeze-up events occurred – in 1996 and 2007. The 1996 event was the seventh highest of record (see Table 3.3) and the 2007 event appears to be the sixth highest on record, and the highest since modern record keeping. It exceeded the 1996 event by about 0.40 m, and was about one metre higher than the next two highest ice events in the modern era.

3.2.1 METEOROLOGICAL CONDITIONS AT FREEZE UP

Ice production and ice jam formation at freeze-up are common processes on northern rivers. On most rivers, the ice covers that develop at freeze-up are a function of the severity of the meteorological conditions and the local hydraulic characteristics, with the former being the main prerequisite for ice cover formation. Although observations and descriptions of these phenomena have been recorded since pre-settlement times, quantitative analysis dates mainly from the 1950's. Key references include Pariset and Hausser (1961), Michel (1971), 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 contained in a compendium edited by Ashton (1986).

Ice production on the Nechako River occurs by (1) shore ice growth, and (2) frazil generation. Generally, shore ice first forms in low-velocity areas adjacent to the banks, then grows outwards and thickens. Once frazil begins to form, it may either contribute to border ice growth or wear it away, depending on hydraulic and thermal conditions.

Frazil generation is the dominant process on most rivers and has a major impact on the subsequent form of the winter ice cover. Warm water enters the Nechako River system from Skins Lake, Fraser Lake, and Stuart Lake. As the flowing water cools to 0°C and heat loss continues, small ice crystals known as frazil form throughout the flow, coalesce into slush accumulations, and float to the surface to form "pans" of pancake-like appearance, each with a solid flat surface and a mass of porous slush suspended underneath.

On all but very low-velocity streams, upstream progression of the ice cover starts when frazil pans lodge against a solid ice cover formed by shore ice growth at special low-velocity locations such as deep pools or the head of a lake or reservoir - or when they lodge at a contracted section or sharp bend. In the absence of actual observations it is difficult to estimate where lodgment or bridging may occur, as a generally recognized theory is not available. At Prince George, it appears that when the Fraser River freezes over first, the ice in the Nechako River lodges against the Fraser River ice, and the ice cover forms on the Nechako River by juxtaposing against the ice cover on the Fraser River.

Once lodgement has occurred, the ice cover progresses upstream by the accumulation of ice floes. Two different types of cover - "juxtaposed" or "consolidated" - may develop, depending on hydraulic and meteorologic conditions. If the velocity is low enough, a "juxtaposed" cover forms by accumulation of a single layer of frazil floes. The head of the ice cover advances upstream at a rate determined by the stream velocity and the surface concentration of ice floes. The slush beneath the floes is generally removed by the shear of the flow and is re-distributed downstream under the new cover. The strength and thickness of the juxtaposed cover tend to increase by downward freezing.

As the head of the juxtaposed cover progresses upstream, downstream forces due to its weight and by hydraulic shear on its underside increase in proportion to the length of new cover. These forces are resisted externally by the solid cover at the original lodgment point, and by friction or freezing at the banks, and internally by cohesion, friction and freezing. If the downstream forces exceed the internal resistance at any point, the cover will collapse and shove to form a "consolidated" cover. This process normally occurs abruptly, so that the thickened accumulation is not significantly strengthened by freezing. The ice cover develops a thickness determined by the internal friction of an essentially granular mass of ice floes. This form of cover can be analyzed by a stability equation first proposed by Pariset et al. (1966), to determine an equilibrium thickness for given ice properties and hydraulic conditions. Typically, the higher the discharge during freeze-up, the greater the shear force on the underside of the ice; hence the development of a thicker ice cover and higher water levels.

In some situations, if the channel geometry, temperature, or discharge change dramatically as the ice cover progresses upstream, the type of ice cover can also change substantially over a few kilometres of channel length. Thus, both types of ice cover (consolidated and juxtaposed) are evident. Furthermore, depending on the sequence of events, the type of ice cover can change at one location suddenly over periods of less than one day, or over a longer period of up to two or more weeks. In some cases, open water can re-develop as the head of the advancing ice cover retreats downstream.

The timing of freeze-up on the Fraser River, and thus the time at which an ice cover could form on the Nechako River is a function of the flow and severity of the weather. Analysis of the Fraser freeze-up dates is underway. On the Nechako River, there is a potential for an ice cover to form immediately after the ice cover forms on the Fraser provided ice is being produced on the Nechako River. Given that there would be some length of open water on the Nechako River upstream of Prince George (likely as far upstream as the mouth of the Stuart River during the years when Nechako flows would be high and the potential for severe ice-related water levels to form also high), the supply of ice and the characteristics of the ice floes are determined by the ambient air temperature. Anecdotal evidence suggests that air temperatures less than about $-15\,^{0}$C would be required to produce large enough ice floes with enough integrity to juxtapose against the Fraser River ice cover (not be entrained beneath the Fraser River ice and transported downstream) and form an ice cover on the Nechako River.

Once the ice cover begins to advance upstream, the supply of ice needs to be large enough to offset the transport of ice (as cover load) along the underside of the formed ice cover to allow the cover to maintain its thickness and/or advance upstream. Very little data on the atmospheric conditions are available for years when flows are low, but for high flow years when high ice-related levels are a possibility it is evident that about 5 to 8 freezing or -15 ^{0}C-days would be required for every kilometre advance of the ice cover (Figure 3.10).

3.2.2 FUTURE NECHAKO FLOWS

The Nechako River has been regulated since 1952 and will continue to be regulated in the foreseeable future. Early on in the regulation period, when powerhouse flows were lower due to a reduced generation capacity and inflows were relatively high during a prolonged wet period, winter releases (high Skins Lake outflows in early winter or early spring) were often used to reduce expected adverse reservoir levels in the coming year. Thus, some portion of the high ice-related water levels at freeze-up could be attributed to reservoir operations.

However, since the 1980's, greater powerhouse flows, greater summer flows to enhance the fishery and for other biological purposes, and more sensitivity about the effects of winter flows on ice conditions has changed the operating procedures. This change has affected a reduction in winter flows (particularly at freeze-up) and produced a general reduction in ice-related water levels. Thus, while inflows to the reservoir in the future will likely not be significantly different than those in the past (and are in fact the best representation of what may be expected in the future), the outflows at Skins Lake will be significantly different. To this end, the historical flow record (which reflects very much reservoir operations in the past) has been adjusted to account for the increased powerhouse flows, the increased summer flows, and the reduced winter flows. The result is a record of daily flows that reflects the current regulatory and reservoir operations framework. It should be noted that this work is in progress, and the assumptions used in reservoir operations are currently being vetted by Alcan and the Province of British Columbia.

The end result will be a somewhat reduced risk of ice-related flood levels at Prince George. An ice cover will still form whenever the hydrometeorological conditions dictate and severe ice-related levels could still occur due to high natural inflows, but the historical levels will no longer form the basis for a statistical comparison because the flow regime in the future will not be the same as it has been in the past.

3.3 PREVIOUS FLOODPLAIN MAPPING

Floodplain maps for Prince George were prepared by BC Ministry of Environment (MOE) in 1983. This mapping was subsequently updated by Klohn Crippen in 1997 with the issuance of twelve maps and a design brief. The preparation of the updated maps followed MOE standard procedures and the study findings were reviewed by MOE.

In view of the 2007 ice jam flooding, recent relatively high freshet flows and apparent channel changes, particularly within the confluence area, City of Prince George determined a need to review and update the 1997 floodplain maps.

The hydraulic modelling for the 1997 maps was based on river cross-sections surveyed in 1979 and 1995. Unfortunately, the potentially less stable river reaches in the lower Nechako River and at the confluence with the Fraser used the older 1979 cross-sections while the more stable reaches had 1995 coverage. The survey coverage is summarized below, with the cross-section numbering as shown on the 1997 mapping and summarized in Figure 1.1:

Cross-Sections Surveyed in 1979	Cross-Sections Surveyed in 1995
Fraser XS 9-20	Fraser XS 1-8
Fraser XS 22-33	Fraser XS 21
Nechako XS 1-17	Fraser XS 34-61
	Nechako XS 18-34

There was no overlap of 1979 and 1995 cross-sections and potential channel changes taking place during the intermittent years could not be identified.

The 1997 model was calibrated to high water marks from 1972 and 1990. Ideally, cross-section surveys and recorded high water marks should be from roughly the same time period, unless the channels are known to be stable. Manning's roughness coefficients of 0.029 for Fraser River and 0.028 for Nechako River were derived. However, a re-run of the model suggested that a coefficient of 0.020 for the Nechako produced a better fit with recorded water levels.

The Klohn Crippen Design Brief (1997) described the evaluation of the 20- and 200-year design flows. For the Fraser River above Nechako, a frequency analysis was carried out using flows for Fraser River at Shelley for the period 1956 – 1994, without including historic large floods. A 200-year design flow of 5,560 m^3/s was estimated. For Fraser River below Nechako, coincident and pro-rated Isle Pierre flows were added to give a 200-year design flow of 6,200 m^3/s. In order to establish Nechako River design flows, reservoir routing based on simplified operating assumptions was carried out and the synthesized reservoir outflows were combined with unregulated flows between the reservoir spillway and Prince George. A 200-year flow of 1,365 m^3/s was derived, but instead a flow of 850 m^3/s, as estimated in 1981 by MOE, was used. This flow has been exceeded six times in the past fifty years and during last year the WSC preliminary peak flow was 1,170 m^3/s or 320 m^3/s higher than the 200-year flood used for mapping. Three memoranda prepared by Nichols (1981a), Nichols (1981b) and Wyman (1981) were reviewed to obtain background on the previous hydrologic investigations.

Ice jam modelling was not carried out as part of the 1997 study. Water levels associated with Fraser ice jams were stated to be 3 m lower than open water flood levels at South Fort

George. It was recognized that ice jamming on the Nechako River could cause higher flood levels than the freshet conditions. However, since ice jam modelling was not part of the study scope, a contingency for ice conditions was provided by increasing the standard freeboard allowance of 0.6 m to 1.8 m upstream of Cross-Section 7 (roughly 750 m below Cameron Street Bridge). This 1.2 m increase was based primarily on water levels observed during the 1996 jam. Downstream of Cross-Section 7, where freshet conditions were determined to generate more severe conditions, a freeboard of 0.6 m was adopted.

Based on the above brief review, **nhc** confirms that updating the existing floodplain maps is required; the river surveys in the reaches most likely subject to change are thirty years old; the model calibration appears to have some inconsistencies; the adopted Nechako River design flow appears not to be representative; and, ice-jam modelling needs to be undertaken to more accurately estimate flood levels corresponding to ice conditions.

3.4 Channel Geomorphology Review

Channel conditions along Lower Nechako River have been substantially affected by local land development and by the construction of Kenney Dam in 1952.

Historical air photograph analysis (M. Miles and Associates Ltd., 2008a) indicates that primarily industrial development has infilled many of the secondary or distributary channels and areas of flood plain which formerly occurred at the mouth of Nechako River. This has reduced the flood conveyance area and eliminated alternative paths by which flow could enter Fraser River during periods of high water or ice accumulations on Nechako River. Relic channels may also be providing permeable pathways which allow groundwater to flow under protective dykes during periods of high water level on Nechako River.

The air photograph analysis also indicates that former gravel bars on lower Nechako River have become vegetated islands and that many secondary channels have become vegetated. This type of channel evolution is commonly observed on regulated streams as reduced peak flows allow vegetation to develop on areas which would have been frequently flooded under a natural hydrograph. This loss of former channel area will also reduce the flood conveyance capacity of lower Nechako River.

The historical series of air photographs suggests that there may be on-going sediment deposition on both lower Nechako River and on Fraser River immediately downstream of the Nechako River confluence. Air photo and field studies (M. Miles and Associates Ltd 2008b) indicate that there are numerous localized sediment sources in nearby sections of both Nechako and Fraser Rivers. These sites commonly consist of high glacio-fluvial terraces which contribute sand and gravel to the river. Most of these sites are not amenable to stabilization and gravel production will therefore continue. This implies there would be a need for on-going channel excavation, should sediment transport and ice jam analyses indicate sediment accumulation is a significant factor which affects flooding in the vicinity of Prince George.

The initial geomorphology studies indicate that flood risk in the vicinity of Prince George is the result of development on areas which are subject to a long-standing flood hazard. This risk may have been increased by infilling secondary channels or flood plain areas, channel changes resulting from river regulation and possibly sediment deposition due to river regulation, flood history and possible affects relating to climate change in the upstream watersheds.

3.5 ENVIRONMENTAL CONSIDERATIONS

As part of the feasibility analysis stage of the flood risk evaluation, an environmental "baseline" will be determined to which potential effects of construction and operation of flood control works can be compared. The first phase of establishing a baseline, determining the "state of the baseline", has been completed by performing a literature search for existing information in the study area; this work serves to prevent duplication of field data collection efforts and identify gaps in environmental information.

Appendix B summarizes the environmental state of the baseline, briefly identifying any information gaps and providing a field sampling plan that will fill these gaps and complete the environmental baseline (during the remainder of the project). It also includes the methodology used to complete the environmental section of the decision-matrix (which forms the priority assessment of the potential flood relief options as discussed in Section 5).

Table 3.1: Historic Freshet Flooding

Year	Gauge Height (Old Datum)	Gauge Height (New Datum)	PG WL (m) GSC	SFG WL (m) GSC	General Comparison	Description of Damage
1875					9.9 m above Low Water at Quesnel or higher than ever known before (since 1860?).	Several buildings flooded. Year was likely 1876.
1894		11.5	569.5	569.3	Estimated water level from WSC file (1962).(Design flood - Fraser River downstream of Hope).	Severe flooding throughout BC.
1911	25 ? ft		568.6 ?			City flooded.
1920					Water at "danger point".	
1936	21.8 ft ? 1867.5 ft approx		569.2		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			East End Flats flooded.First Avenue flooded in one location. Sloughs filled to capacity.
1948	26.36 ft 1866.7 ft		568.98			Refer to inundation boundaries.
1954	24.92 ft		568.53			
1964			568.33			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

City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*

City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*

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	Stage
08KE018	Fraser River at South Fort George	79,500	1968-2008	41	Stage

Table 3.3 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)	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	310	Cameron Street Bridge
Mar 7, 1960	570.7	210	Cameron Street Bridge
Feb 5, 1961	569.6	140	Cameron Street Bridge
Jan 22, 1963	569.4	145	Cameron Street Bridge
Dec 15, 1964	568.9	170	Cameron Street Bridge
Jan 3, 1968	568.9	140	Cameron Street Bridge
Dec 27, 1968	568.8	220	Cameron Street Bridge
Jan 26, 1970	>570.4	235	Cameron Street Bridge
Dec 10, 1970	569.6	145	Cameron Street Bridge
Dec 22, 1971	569.1	195	Cameron Street Bridge
Apr 3, 1972	567.5	205	Cameron Street Bridge
Dec 18, 1972	570.0	180	Cameron Street Bridge
Jan 22, 1974	569.0	110	Cameron Street Bridge
Jan 15, 1975	569.0	140	Cameron Street Bridge
Jan 12, 1976	569.8	160	Cameron Street Bridge
Nov 28, 1996	570.9	230 to 280	Cameron Street Bridge
Dec 22, 2007	571.3	280 to 300	Cameron Street Bridge

1. Measured water level was adjusted upward to reflect the stage at the Cameron Street Bridge.

City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*

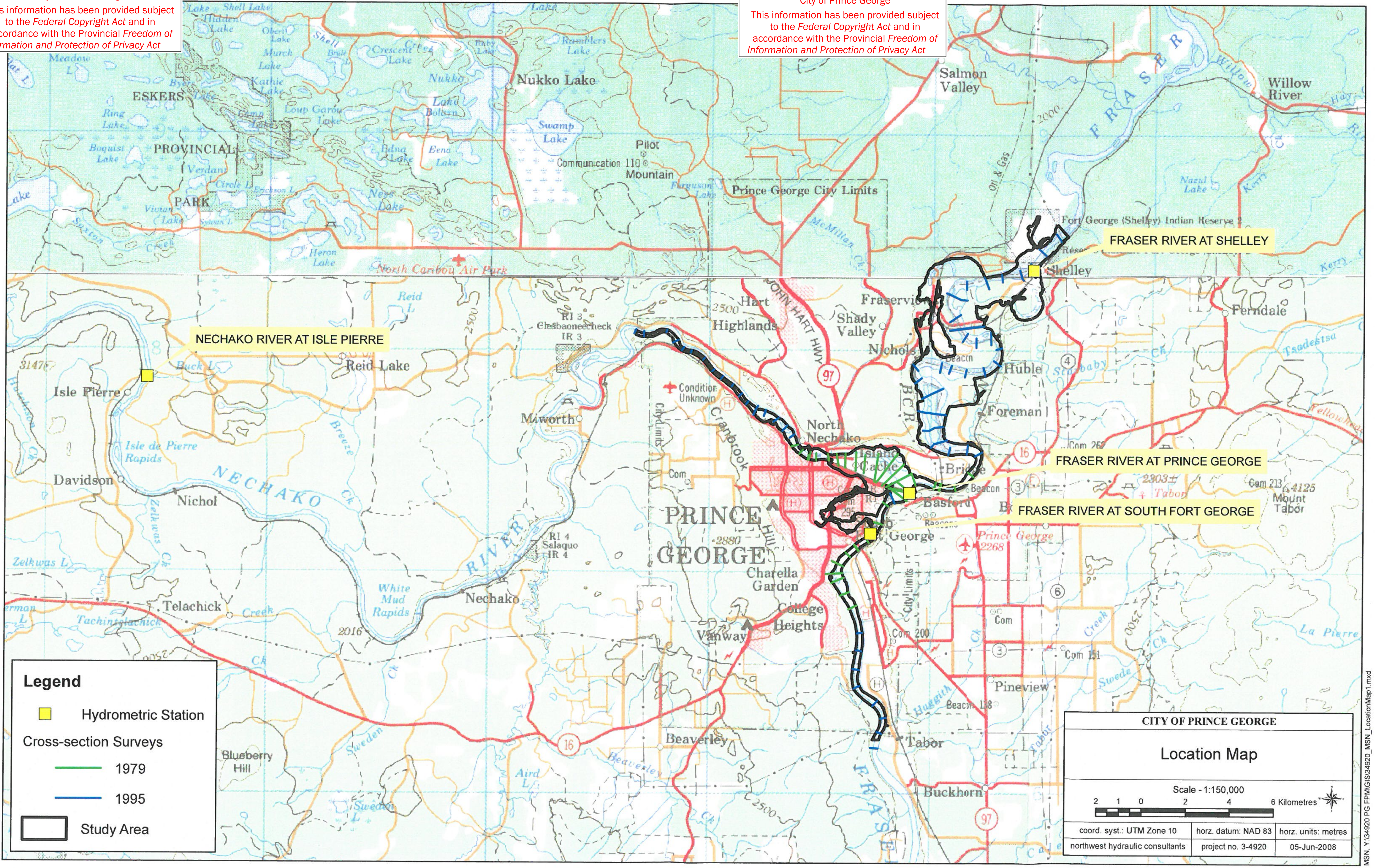
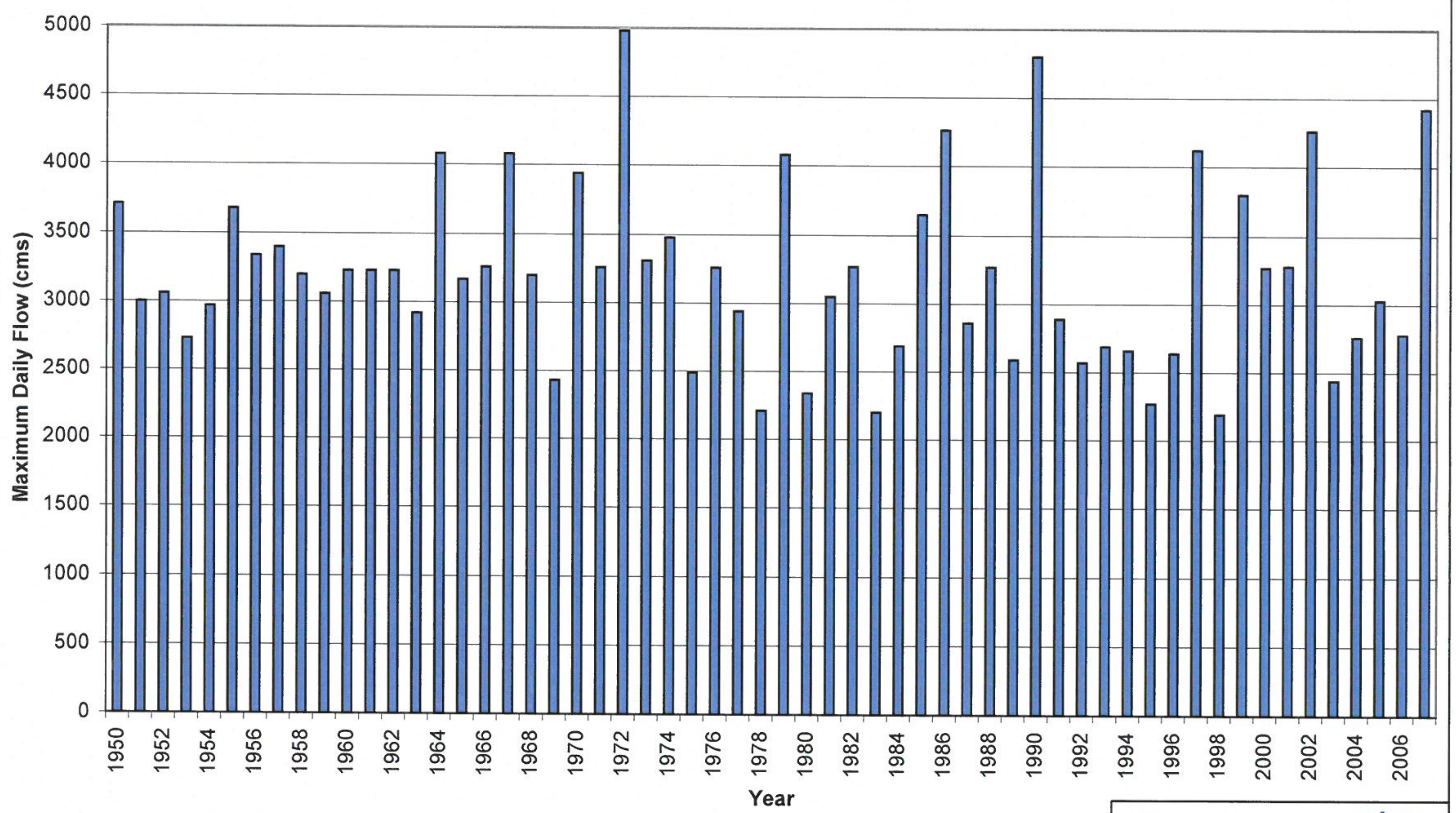
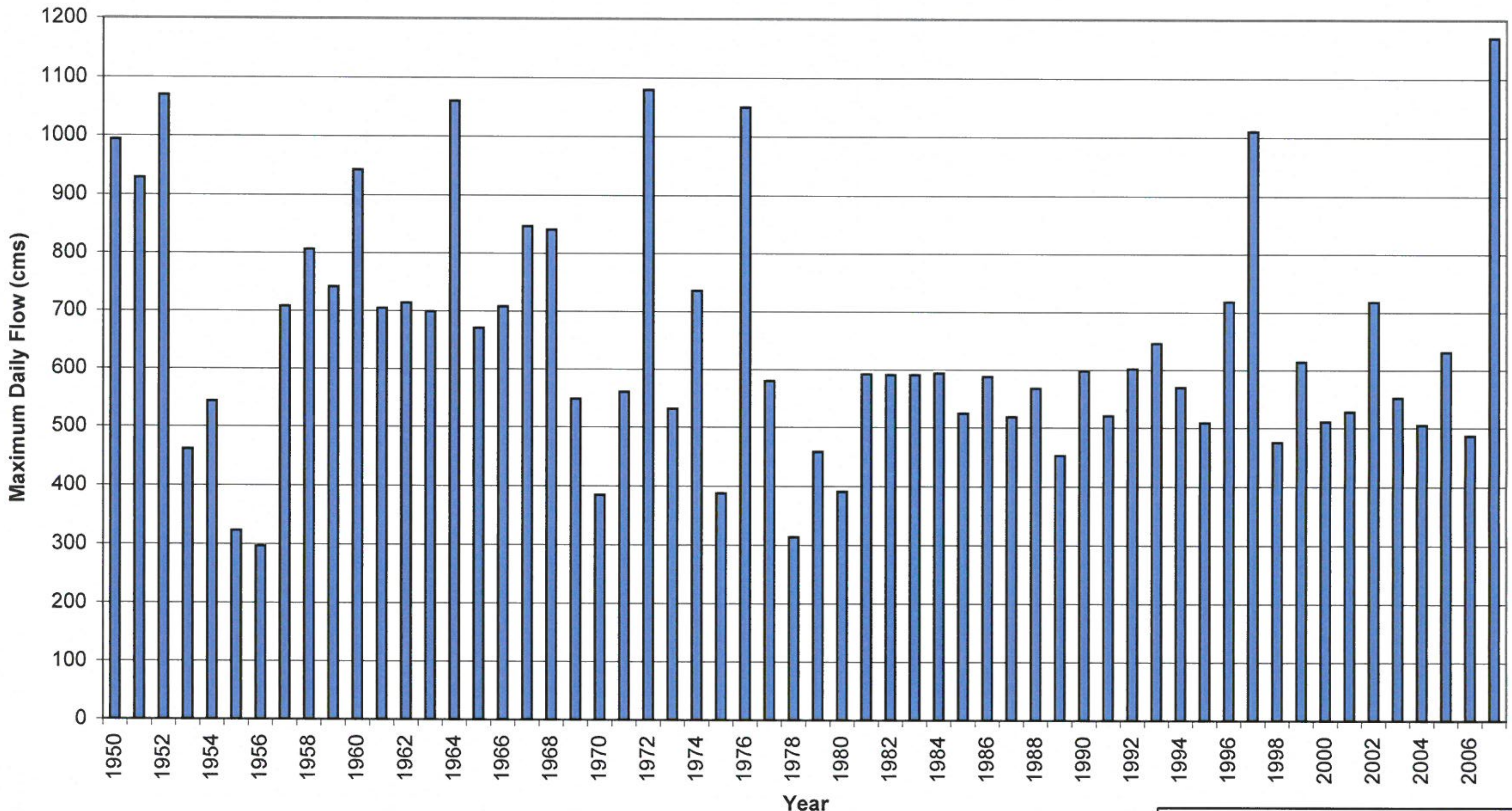


Figure 3.1



City of Prince George **nhc**	
Fraser River at Shelley Annual Peak Flows 1950-2007	
June 2008	Figure 3.2

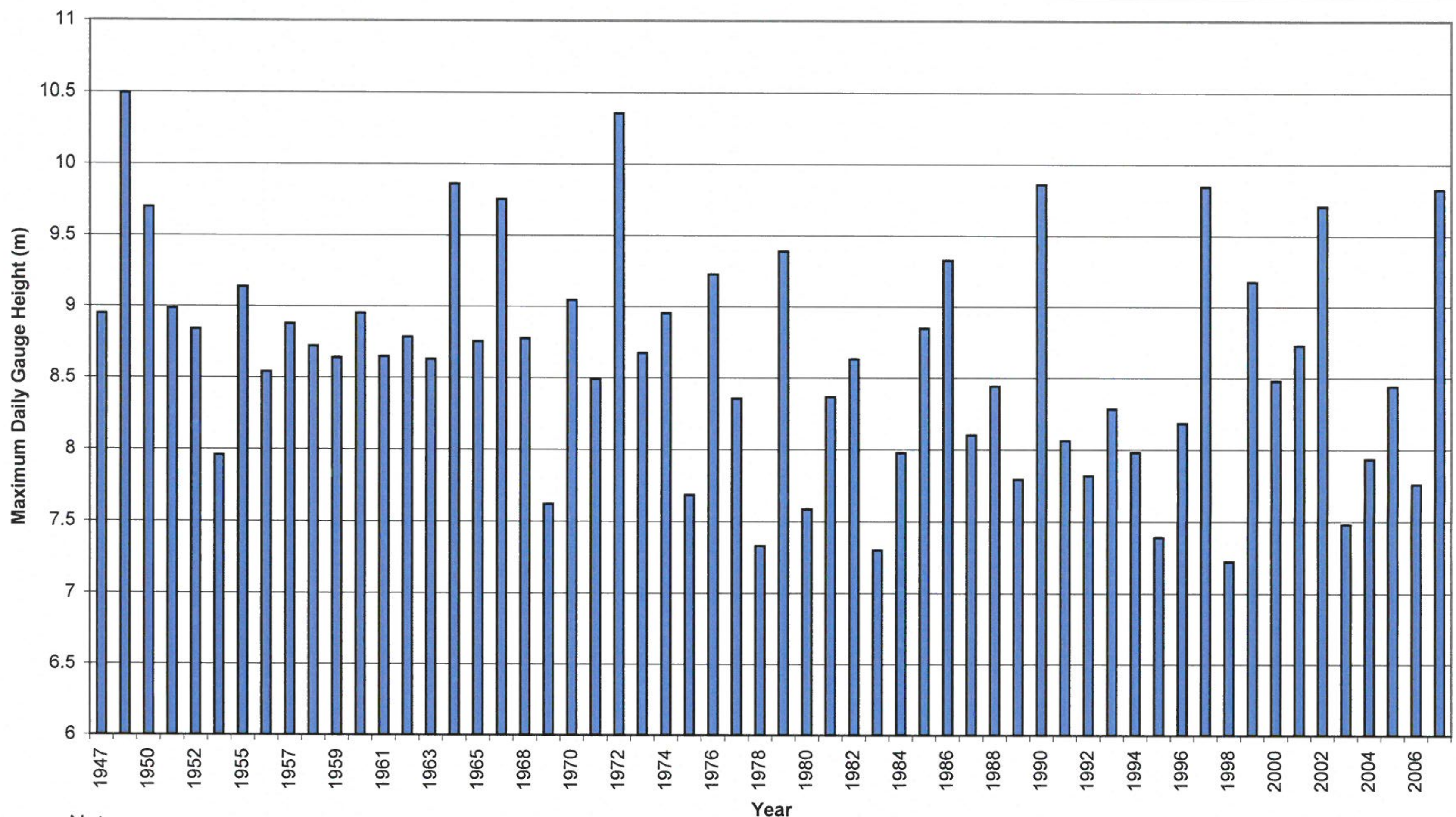


City of Prince George **nhc**

Nechako River at Isle Pierre
Annual Peak Flows 1950-2007

June 2007	Figure 3.3

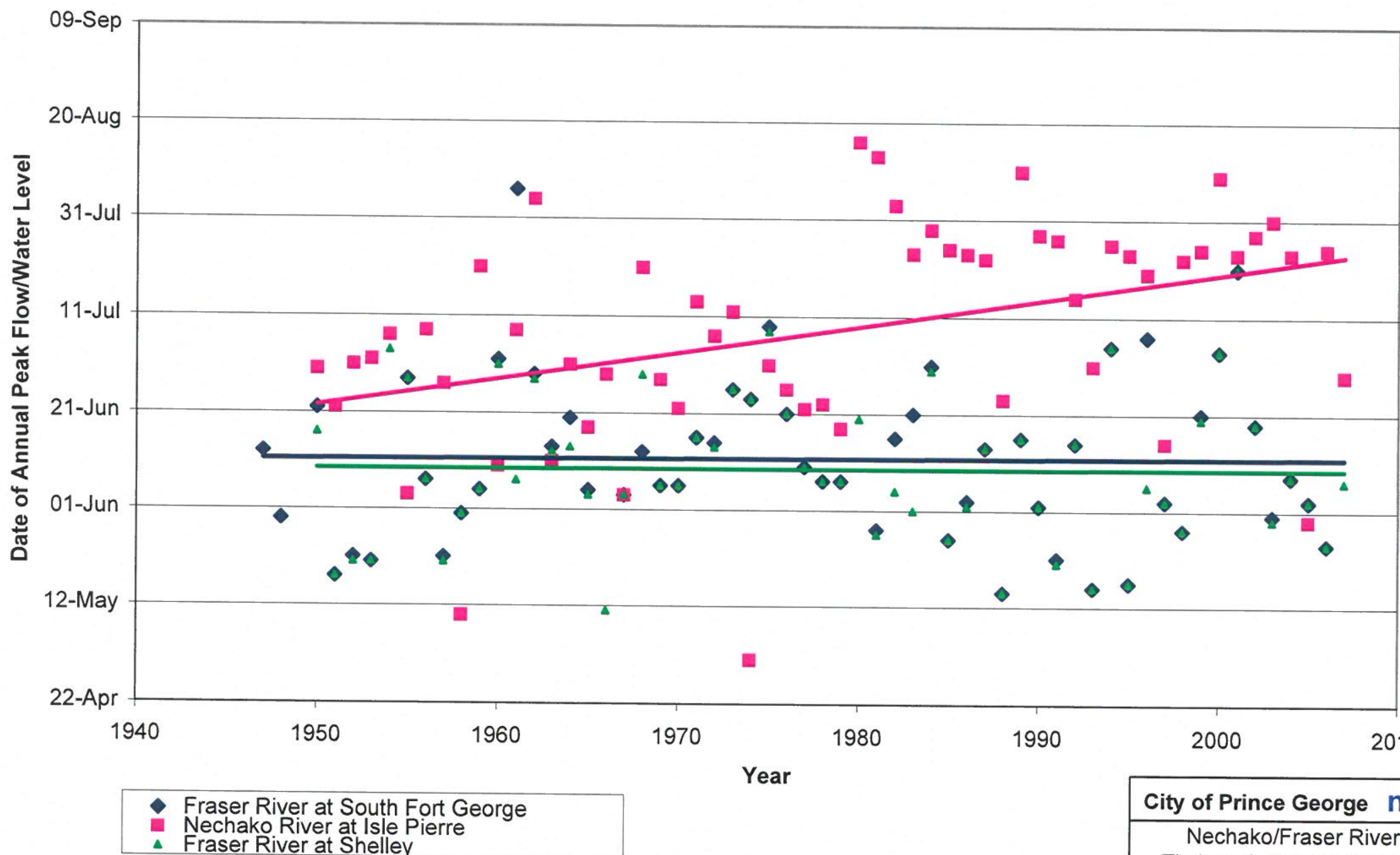
City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*



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

City of Prince George **nhc**	
Fraser River at SFG Annual Peak WL's 1947- 2007	
June 2008	Figure 3.4

City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*

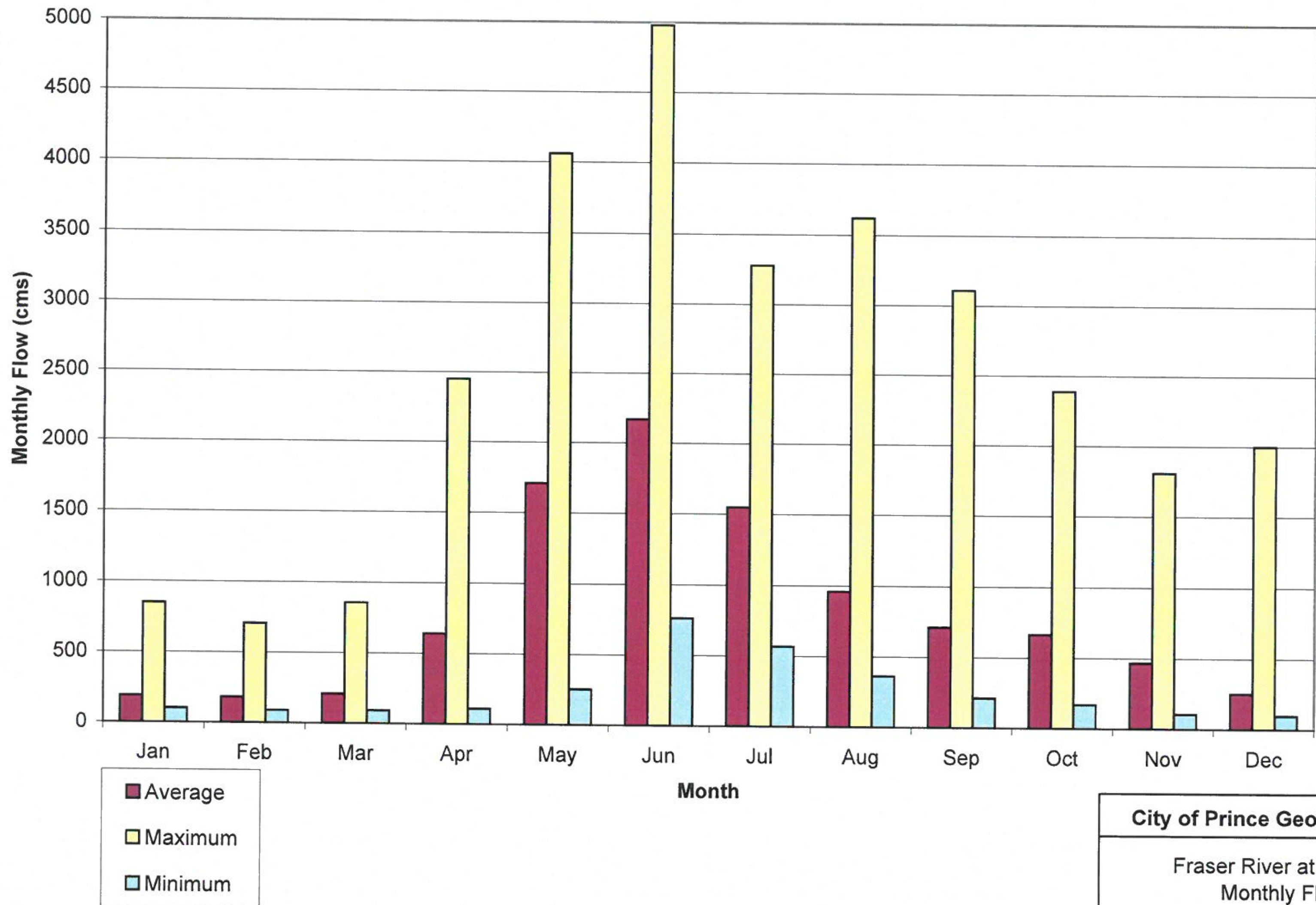


City of Prince George nhc

Nechako/Fraser River Timing of Freshet Peak

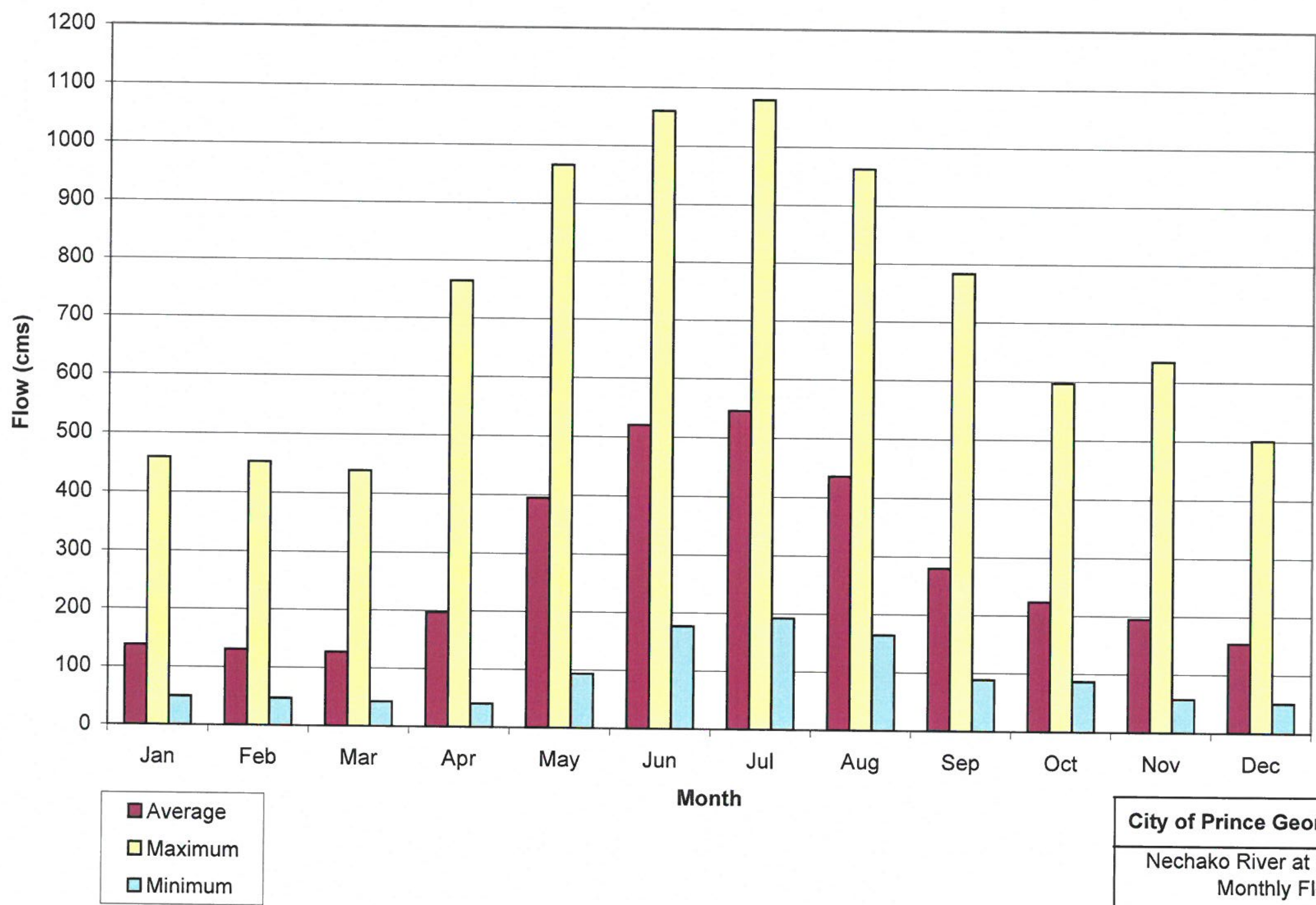
June 2008	Figure 3.5

City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*



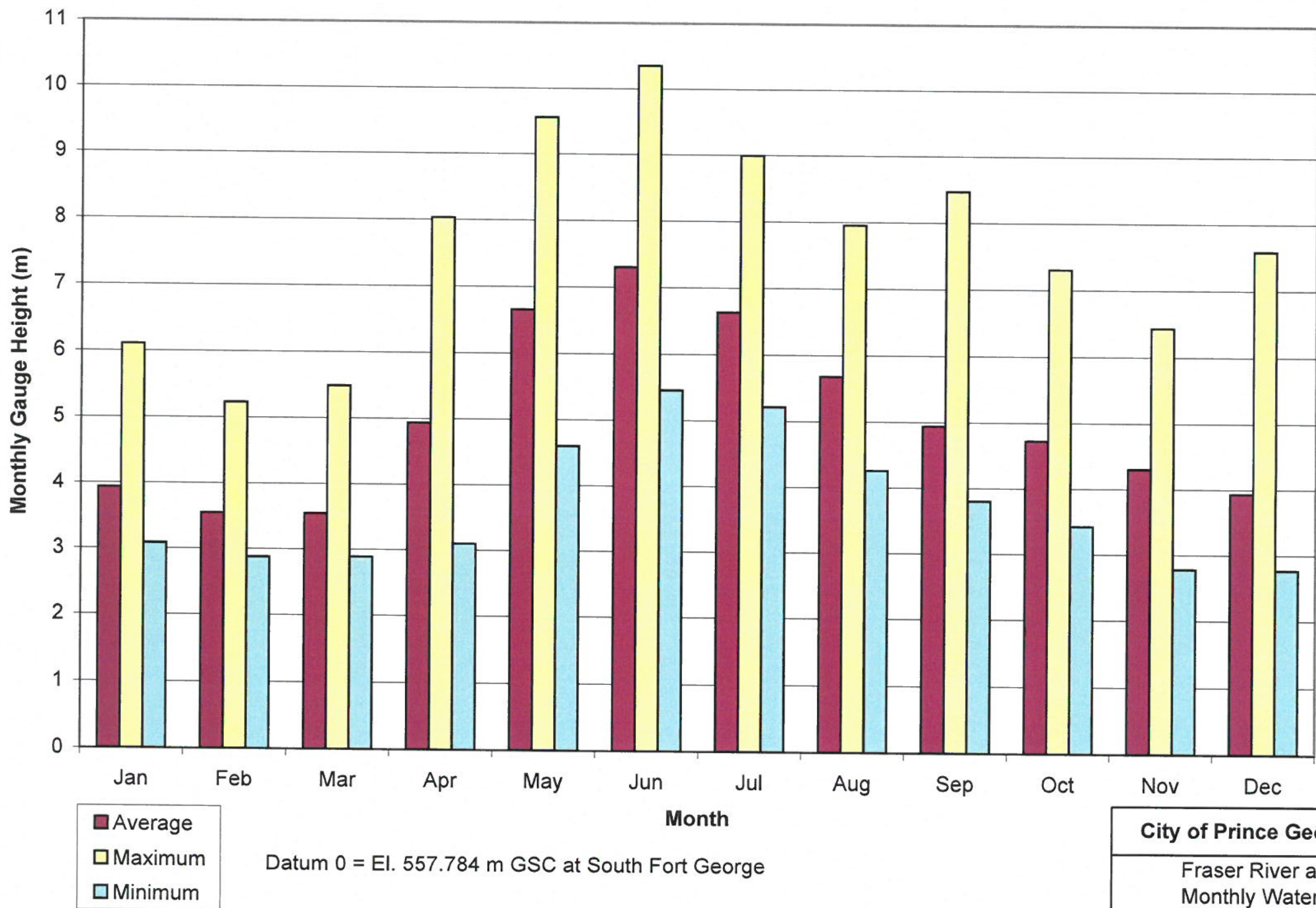
City of Prince George nhc	
Fraser River at Shelley Monthly Flows	
June 2008	Figure 3.6

City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*



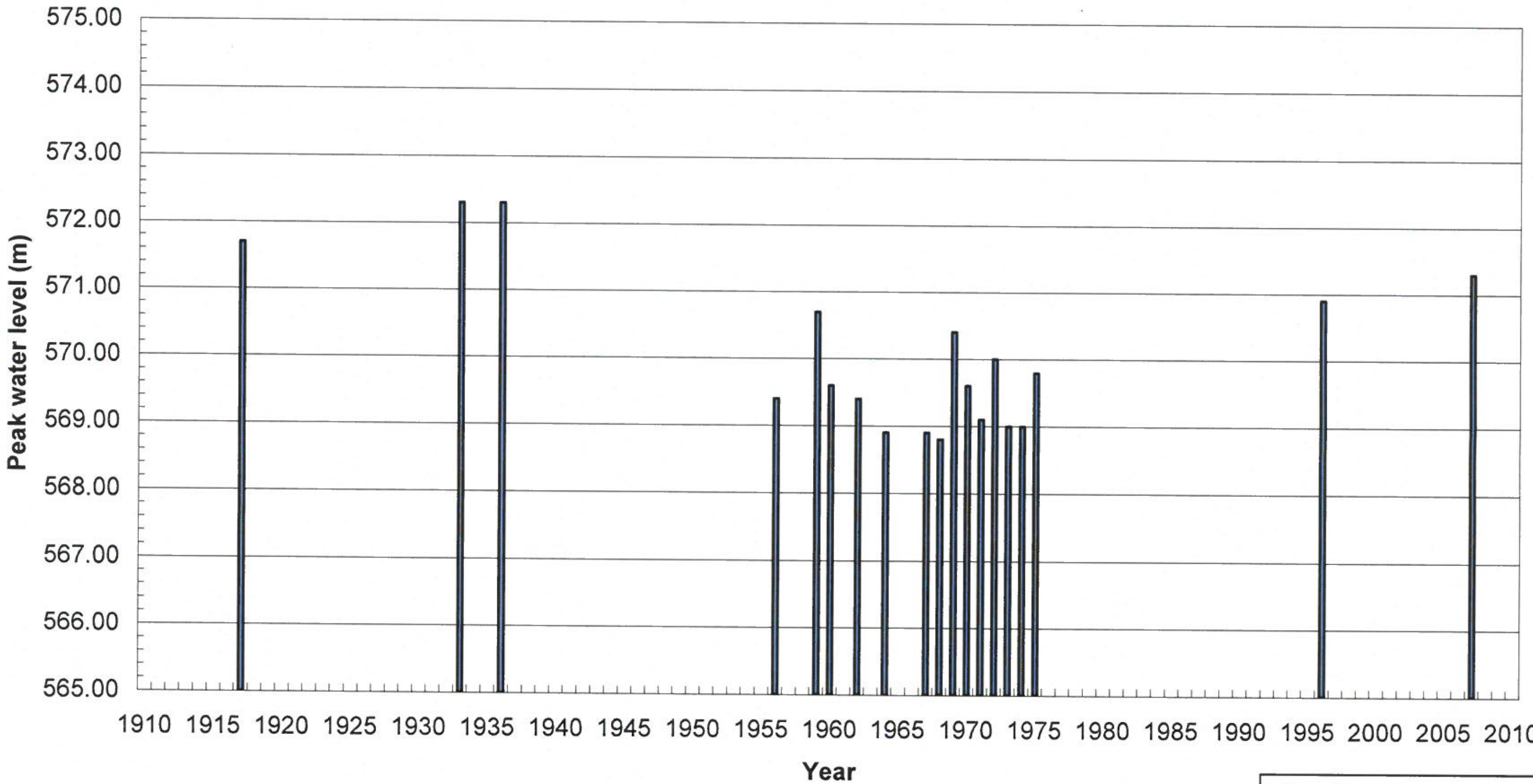
City of Prince George nhc	
Nechako River at Isle Pierre Monthly Flows	
June 2008	Figure 3.7

City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*



City of Prince George nhc	
Fraser River at SFG Monthly Water Levels	
June 2008	Figure 3.8

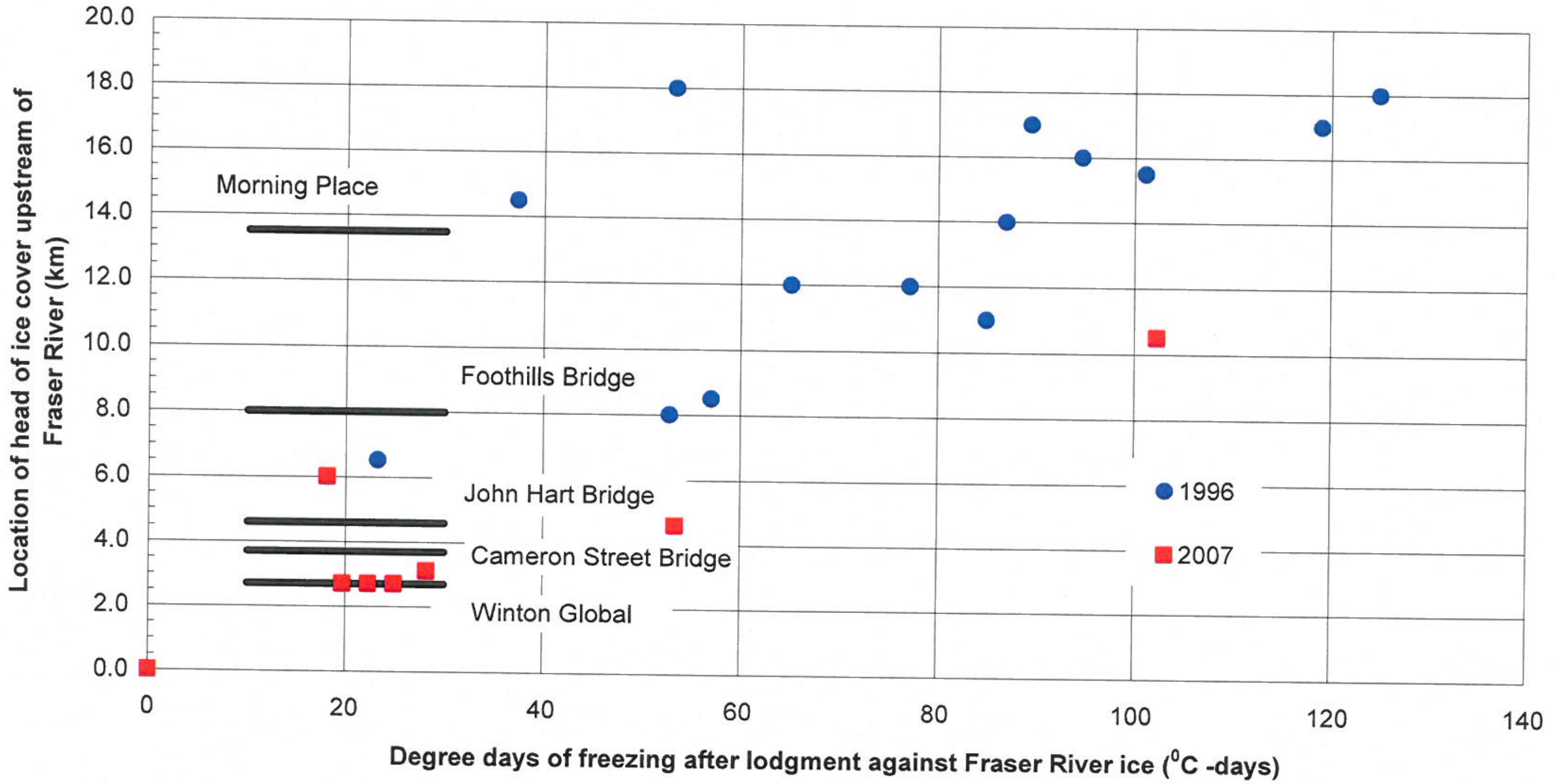
City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*



City of Prince George	**nhc**
High Ice-Related Water Levels at Cameron Street Bridge	
June 2008	Figure 3.9

City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*

City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*



City of Prince George	nhc
Ice Cover Location vs Degree Days	
June 2008	Figure 3.10

Table 4.1: 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 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

City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*

Table 4.1: 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

City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*

Table 4.1: 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 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.

City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*

City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*

Table 4.1: 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 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

City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*

Table 4.1: 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 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

City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*

Table 4.1: Flood Control Solutions - Nechako River

Mitigation Options	Mitigation Sub-Options	Alternate Designs	Hydraulic Considerations	Infrastructure Considerations	Environmental Considerations	Geomorphology Considerations	General Evaluation
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.
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
	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
Individually raise/flood proof any essential development					Potential minor riparian habitat encroachment.	Minor reduction in flood storage area	Feasible
Land-use change over entire floodplain					Restores functional floodplain areas	Little benefit, but reduces need for future flood protection in hazardous location.	Feasible
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
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
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.
	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.
	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.
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.
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.
	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.
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.
	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.
	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.

Mitigation Options / Sub-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 E_N (Morning Place)																		
No permanent protection, provide temporary works as required	3	3	2	3	1	2	1	3	9	6	2	3	3	4	3	9	39	4
Diking – Next to river	3	3	2	2	3	2	3	2	9	6	2	2	9	4	9	6	47	5
Diking – Low dike providing base for temporary high water protection	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	2	2	2	1	2	2	2	1	6	4	2	1	6	4	6	3	32	2
Land-use change over entire floodplain	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	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	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	3	3	2	2	3	3	2	2	9	6	2	2	9	6	6	6	46	
Floodways – Open up/straighten historic channel along RR	3	3	3	2	3	3	3	3	9	6	3	2	9	6	9	9	53	
Floodways – Channel through Area C_N, south of road	3	3	2	2	3	3	2	2	9	6	2	2	9	6	6	6	46	
Improve drainage – Modify 1st Avenue storm drains	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	3	3	2	3	3	3	2	2	9	6	2	3	9	6	6	6	47	
Enlarge main river channel by dredging – Bar scalping and instream excavation	3	3	2	3	2	3	2	2	9	6	2	3	6	6	6	6	44	
Flow regulation – Enlarge storage behind Kenney Dam	3	3	3	3	3	3	3	1	9	6	3	3	9	6	9	3	48	
Flow regulation – Build new storage	3	3	3	3	3	3	3	1	9	6	3	3	9	6	9	3	48	
Flow regulation – Revise operating procedure	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.

City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*

Table 4.2: Flood Control Solutions - Fraser River

Mitigation Options	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_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.			3	3	3	2	1	1	1	3	9	6	3	2	3	2	3	9	37	3
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	2	3	1	2	3	1	2	2	6	6	1	2	9	2	6	6	38	4
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.**			3	3	2	2	3	1	2	1	9	6	2	2	9	2	6	3	39	5
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	1
Raise/flood proof any development			Potential minor riparian habitat encroachment.		Feasible	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		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	2	1	3	9	6	3	3	3	4	3	9	40	3
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	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		Emergency response on call	Potential minor riparian habitat encroachment.	Could reactivate sizeable flood relief channel	Feasible	2	2	2	3	2	1	3	2	6	4	2	3	6	2	9	6	38	2
Land-use changes			Restores functional floodplain areas	Could reactivate sizeable flood relief channel	Flooding occurs frequently, this may be best option.	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		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.	3	3	2	3	1	1	1	2	9	6	2	3	3	2	3	6	34	3
Land-use changes			Restores functional floodplain areas		Unlikely.	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			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.	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			Potential minor riparian habitat encroachment.	Impacts will be determined by the number of sites	May not be required.	1	1	3	2	2	1	2	1	3	2	3	2	6	2	6	3	27	1

City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*

Table 4.2: Flood Control Solutions - Fraser River

Mitigation Options	Hydraulic Considerations	Infrastructure Considerations	Environmental Considerations	Geomorphology Considerations	General Evaluation
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.
Land-use changes			Restores functional floodplain areas		Feasible
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
Individually raise/flood proof any essential development			Potential minor riparian habitat encroachment.	Impacts will be determined by the number of sites	Feasible
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.
Land-use changes			Restores functional floodplain areas		Feasible
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.
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
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.
Ring Diking set-back from river	Provide seepage cut-off, pump internal flows.		Potential minor riparian habitat encroachment.		Feasible but expensive
Individually raise/flood proof any essential development			Potential minor riparian habitat encroachment.	Impacts will be determined by the number of sites	Feasible
At any vulnerable development in floodplain, alter land-use			Restores functional floodplain areas	Maintains flood conveyance storage area	Feasible
Area G_F (Across from Shelley)					
Prevent future development. Flood proof existing development as necessary			Potential minor riparian habitat encroachment.	An appropriate plan	Feasible

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 D_F (Lansdowne south end)																		
No permanent protection, provide temporary works as required	3	3	3	3	1	1	1	2	9	6	3	3	3	2	3	6	35	3
Land-use changes	1	1	1	1	1	1	3	3	3	2	1	1	3	2	9	9	30	1
Provide diking for part of area.	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	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	3	3	3	3	1	1	1	2	9	6	3	3	3	2	3	6	35	3
Land-use changes	1	1	1	1	1	1	3	2	3	2	1	1	3	2	9	6	27	2
Diking	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	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	3	3	3	2	1	2	1	2	9	6	3	2	3	4	3	6	36	4
Ring Diking set-back from river	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	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	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	1	1	1	1	2	1	1	1	3	2	1	1	6	2	3	3	21	1

Table 4.3: 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. May 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.	-

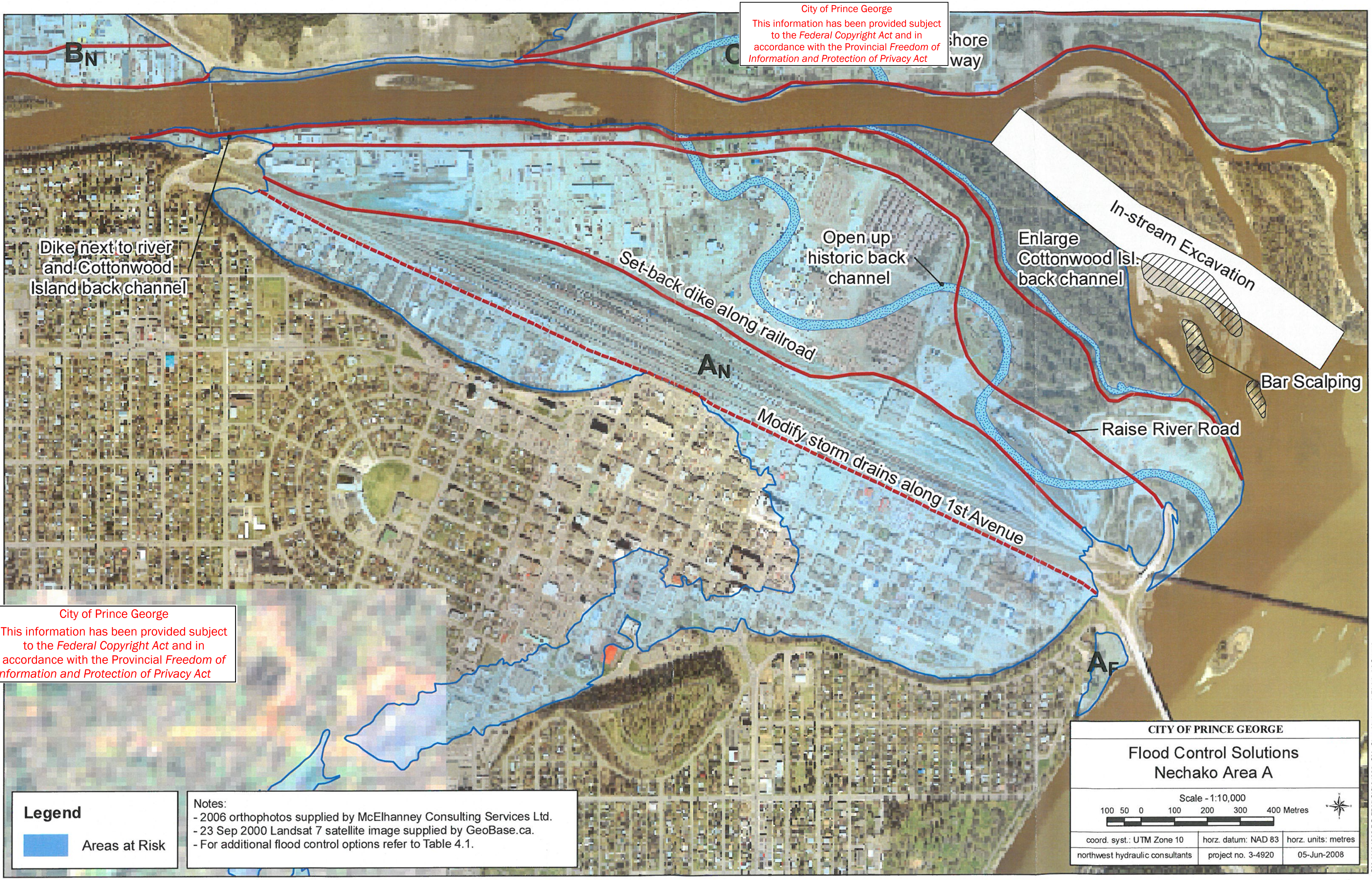

City of Prince George
This information has been provided subject to the Federal Copyright Act and in accordance with the Provincial Freedom of Information and Protection of Privacy Act
BN
Dike next to river and Cottonwood Island back channel
Open up historic back channel
Enlarge Cottonwood Isl. back channel
In-stream Excavation
Set-back dike along railroad
AN
Bar Scalping
Raise River Road
Modify storm drains along 1st Avenue
AF
City of Prince George
This information has been provided subject to the Federal Copyright Act and in accordance with the Provincial Freedom of Information and Protection of Privacy Act
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 4.1.
CITY OF PRINCE GEORGE
Flood Control Solutions
Nechako Area A
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
05-Jun-2008

Figure 4.1

City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*

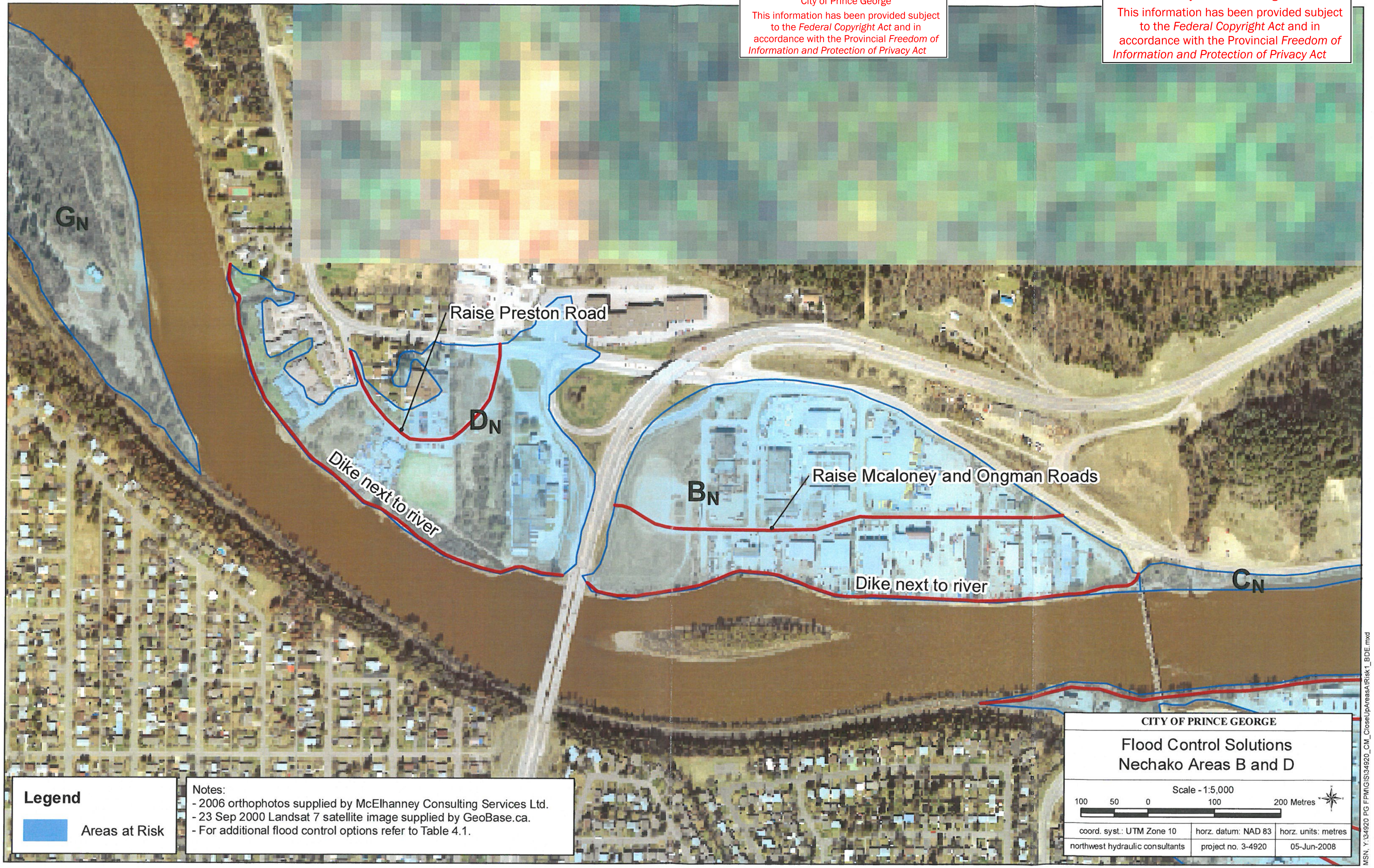
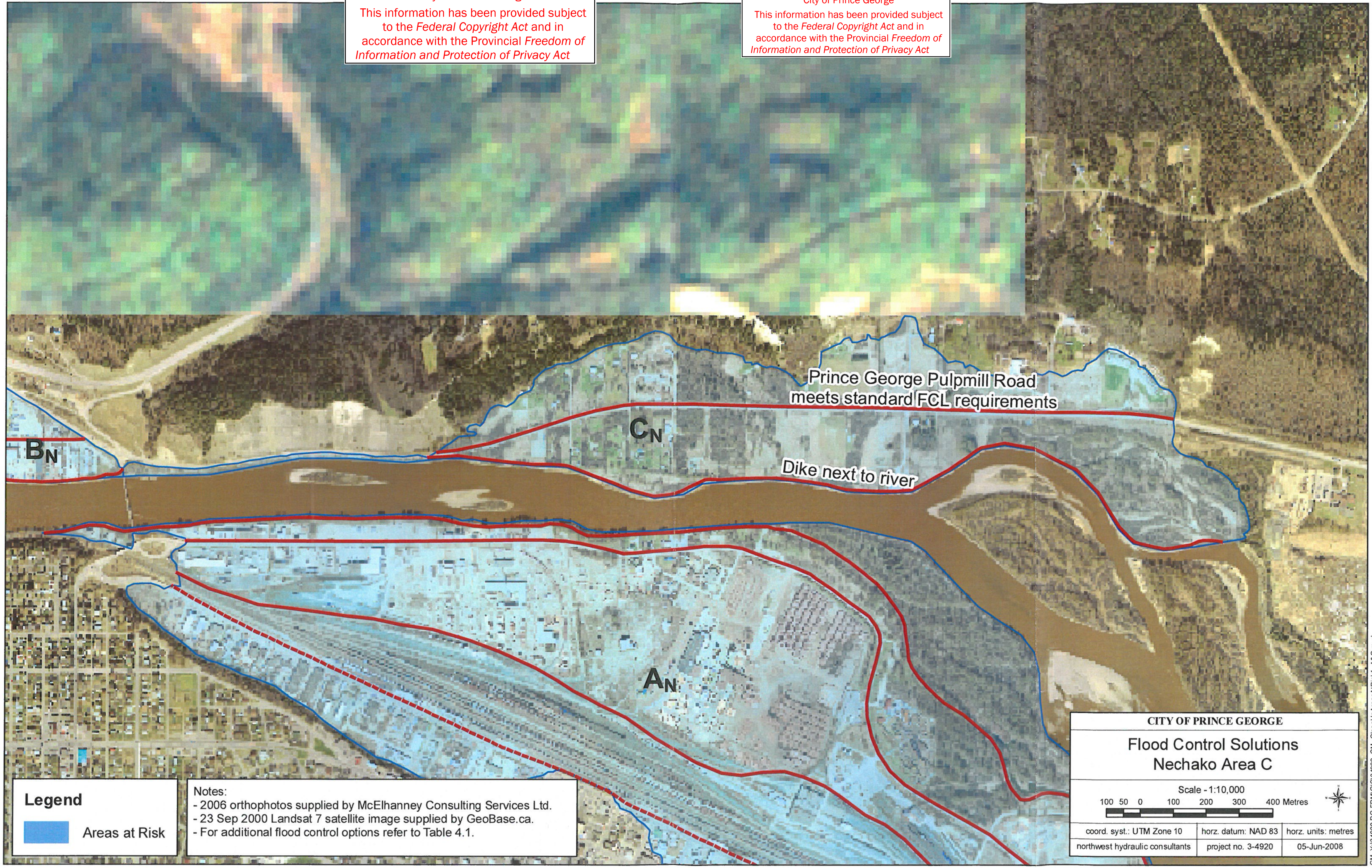


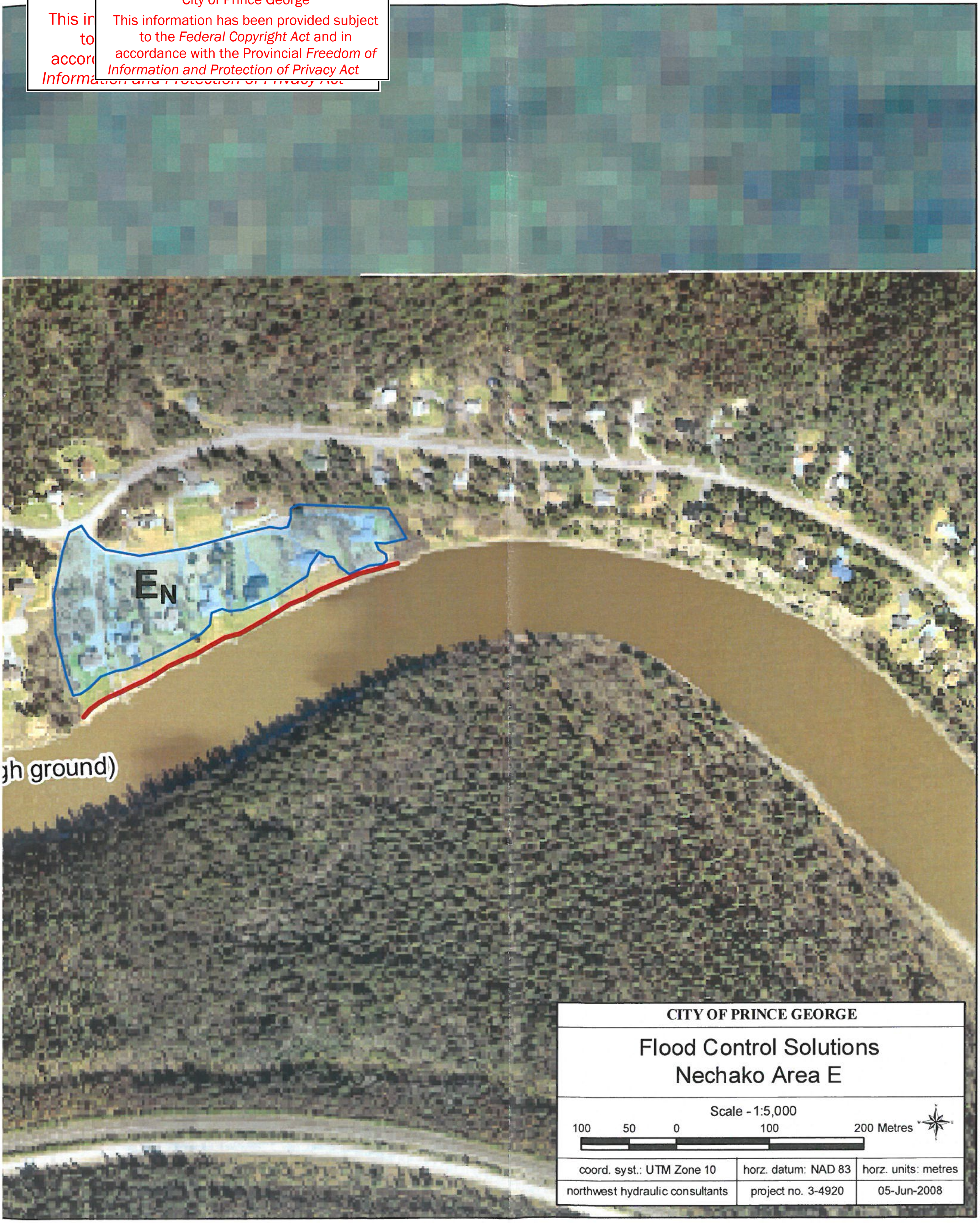
Figure 4.2

City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*



CM, Y:\34920 PG FPM\GIS\34920_CM_CloseUpAreasAtRisk1_A&C.mxd

Figure 4.3



MSN, Y:\34920 PG FPM\GIS\34920_CM_CloseUpAreasAtRisk1_BDE.mxd

Figure 4.4

5. CONSEQUENCE ANALYSIS

5.1 ASSET INVENTORY

5.1.1 PUBLIC-OWNED ASSETS

Protection of public water utilities was a priority during the 2007-2008 ice jam event and so assessing costs or damages to these utilities is difficult, since it is understood that almost every effort would be utilized to protect them in another event. Discussions with the City of Prince George are still being held regarding the manner in which to assess public utilities. Replacement values may not be the best way to assess the potential impact since very little actual damage was seen even in such a large event.

5.1.2 PRIVATE-OWNED ASSETS

An inventory, including replacement values of private-owned utility assets such as those of BC Hydro, Telus, Terasen and Shaw Cable is underway. Along with the inventory, the utility companies are asked to provide information on the vulnerability of these assets during flood events, the importance of their operation during flood events and to provide estimated costs of any damage experienced during the recent ice jam event.

5.1.3 PRIVATE PROPERTY ASSETS

Due to the high priority of addressing Nechako areas A and C, the property values in both these locations were first evaluated. Though not necessarily considered to be market value, property values and improvements from the assessment roll were determined. The total of land assessment values and improvements in Area A_N (north of railroad) is $21,116,000. The total of land assessed values and improvements in Area C_N (PG Pulpmill Road) is $4,082,533 for properties north of the road and $5,155,526 south of the road. The need for a more detailed breakdown of specific properties depending on the various mitigation options is under evaluation.

Part of the consequence review is the impact on business cost due to a flood event. A survey was distributed to business owners in Area A_N and C_N requesting information on the average daily impact to their businesses during a flood event including production loss, wage loss, damages, and costs to protect their property. A number of these responses are still outstanding.

5.2 ASSET RANKING

The assessment and ranking of properties is presently on-going and this information is needed before the analysis can be completed for the identified flood risk areas.

5.2.1 FUNCTIONALITY AND ACCESSIBILITY OF ASSETS

Road access during flood events is invaluable and it should be noted that the Prince George Pulpmill Road proved to be a major staging area during the 2007-2008 ice jam event for evacuating residents, deploying flood pumps and allowing access to the major industrial lands (two pulp mills, a refinery, chemical plants, industrial contractors etc) to the east of the flooded area. A major fire at one of the pulp mills during the ice jam flood could have had disastrous results if access had not been available. Similarly, access along River Road during flood conditions is considered very important by the City and accordingly, vehicular travel is to be maintained during flood events up to the 200-year level.

5.2.2 INITIAL COST EVALUATION

Each of the fourteen flood risk areas identified in Section 4 will be investigated in detail and the flood control solutions proposed for the different areas compared in terms of their life cycle costs. The life cycle costs will be evaluated over a 50-year period based on:

- Assessed property values.
- Capital, operation and maintenance costs of the flood control works.
- 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.

Based on an initial evaluation, the following tentative net present value costs were estimated for four scenarios identified for risk area A_N (south-shore of Nechako River at the confluence):

1. Status Quo – No flood protection or land-use amendments:	$40.3 M
2. Land-use amendment; floodplain access provided:	$27.2 M
3. Set-back dike along River Road; floodplain access provided:	$25.2 M
4. Dike along Nechako River; floodplain access provided:	$34.2 M

Similarly, two scenarios were evaluated for risk area C_N (north-shore of Nechako River at the confluence):

1. Status Quo – No flood protection or land-use amendment: $20.0 M
2. Land-use amendment: $10.2 M

Details regarding each scenario will be provided in the next progress report. It should be emphasized that the above values are preliminary and presented as a sample of the type of analyses that are currently underway. To accurately complete this evaluation the next phase of the project, the technical feasibility assessment, must be carried out.

6. FEASIBILITY ASSESSMENT RECOMMENDATIONS

The flood risk analysis will be followed by detailed technical investigations to evaluate the feasibility of identified flood control solutions. The project proposal listed the following components for the feasibility assessment:

- Data collection and review
- Geomorphic assessment
- Hydrologic analysis (open-water and ice conditions)
- Soils and geotechnical investigations
- River hydraulics, freshet and ice-related flooding analysis
- Environmental impacts
- Floodplain (internal) drainage considerations
- Property Acquisition

In order to complete the flood risk analysis, some of the technical investigations under the feasibility assessment were undertaken. This work clarified additional data needs and requirements for further work as outlined below:

1. River and Land Surveys - A comparison of 1979/1995 and 2008 river cross-sections showed some channel changes in the lower Nechako River and in the Fraser River at the confluence. Collection of LiDAR data was recommended and the bathymetric survey was expanded to provide grid-coverage rather than a few sections in the confluence area. This information will allow for more detailed hydraulic analyses, better volume estimates of sediment deposition and opportunity to track channel changes over the course of the 2008 freshet.

2. Hydraulic Analyses – Water surface profiles obtained during the bathymetric surveys showed that the flow in the confluence area is highly two dimensional. For more accurate representation, modelling this area using a two dimensional model such as River2D is recommended. This modelling would allow more detailed assessment of different dredging scenarios, flood-ways and dike alignments (see Appendix A).

3. Geomorphic Analyses – The historic air photography analysis suggested that gravel accumulation may be occurring in the confluence area. To further investigate where this material originates from and evaluate the feasibility of stabilizing the source areas a sediment source investigation is recommended. Also, the sediment transport capacity should be determined for lower Nechako River and for Fraser River in the vicinity of the Nechako River confluence. Predicted values associated with unusually high river flows in 2007 should be compared to other values in the post-1950 period. Depending on the results of this analysis, and the on-going river ice studies, it may be warranted to develop a one or two dimensional sediment transport model of the study area. This would be used to evaluate future sediment transport potential and assess the affects of various sediment removal strategies.

4. Environmental Assessments

Although many years of white sturgeon research have been completed on the Nechako and Fraser Rivers, no known study has specifically targeted white sturgeon habitats at the confluence of the Nechako and Fraser Rivers. Due to the potential for critical habitat to be present within this area, some additional sampling effort is recommended to increase understanding of the species' behavior and habitat utilization within the study area. This will allow a more comprehensive assessment of potential impacts from proposed flood control strategies and will likely be necessary for submission for federal review.

5. Public Consultations – As requested by the City, public consultations initially scheduled for after completion of the feasibility assessment have been moved forward and more on-going involvement is now anticipated throughout the project.

A schedule and estimated budget for this work will be provided.

7. REFERENCES

Beltaos, S., 1983. River ice jams: theory, case studies and applications. Journal of Hydraulic Engineering, ASCE., Vol. 109, No. 10, pp. 1338-1359.

Campbell, P., 1990. Nechako River Flooding and Erosion, Appendix A of Nechako River Water Management Plan. British Columbia Ministry of Environment, Lands, and Parks. Prince George.

Doughty-Davies, J. and Morley J.H., 1974. Fraser River Agreement Studies, Task 2, Prince George Diking Costs.

Klohn-Crippen, 1997. Floodplain Mapping Fraser and Nechako Rivers at Prince George. Report prepared for BC Monistry of Environment.

Michel, B., 1971. Winter regime of rivers and lakes. Cold Regions Science and Engineering Monograph III-B1a, US Army Corps of Engineering, Cold Regions Research and Engineering Laboratory.

M. Miles and Associates Ltd. 2008a. Nechako River at Prince George Flood Hazard Study: Compilation and Interpretation of Historical Air Photos. Unpublished report prepared for The City of Prince George. 6 p. plus appendices.

M. Miles and Associates Ltd. 2008b. Nechako River at Prince George Flood Hazard Study: Identification of Local Sediment Sources. Unpublished report prepared for The City of Prince George.

Nichols, R.W., 1981a. Fraser-Nechako Flood Profile at Prince George. BC Ministry of Environment.

Nichols, R.W., 1981b. Fraser-Nechako Flood Profile at Prince George. BC Ministry of Environment.

Pariset, E. and R. Hausser, 1961. Formation and evolution of ice covers in rivers. Transactions of the Engineering Institute of Canada, Vol. 5, No. 1, pp. 40-49.

Pariset, E., R. Hausser, and A. Gagnon, 1966. Formation of ice covers and ice jams in rivers. Journal of the Hydraulics Division, ASCE., Vol. 92, No. HY6, pp. 1-24.

Septer, D. 2007. Flooding and Landslide Events Northern British Columbia 1820-2006. BC Ministry of Environment.

Shen, H.T. and L.A. Chiang, 1984. Simulation of growth and decay of river ice cover. Journal of Hydraulic Engineering, ASCE., Vol. 110, No. 7, pp. 958-971.

Shen, H.T., H. Shen, and S.M. Tsai, 1990. Dynamic transport of river ice. Journal of Hydraulic Research, IAHR, Vol. 28, No. 6, pp. 659-671.

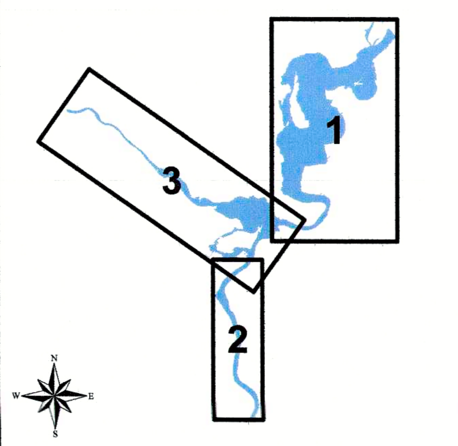
Shen, H.T., D.S. Wang, and A.M.W. Lal, 1993. A river ice simulation model - RICEN. Model formulation and program guide. Report No. 93-7, Department of Civil and Environmental Engineering, Clarkson University, Potsdam, NY, USA.

Wyman, R.R., 1981. Fraser-Nechako 200-Year Discharge estimates. BC Ministry of Environment.

MAPS


City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*
Map Panel Index
1
2
3
CITY OF PRINCE GEORGE
Flood Risk Areas
Fraser River above Nechako,
Map 1
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
10-Jun-2008
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
FRASER RIVER AT SHELLEY
G F
F F
E F
FRASER RIVER AT PRINCE GEORGE
N
E
S
W
Map Panel 1
City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*
MSN, Y:\34920 PG FPM\GIS\34920_MSN_HazardMitigation1_Panel1.m

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 2 and 3

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	10-Jun-2008

MSN, Y:\34920 PG FPM\GIS\34920_MSN_HazardMitigation1_Panels2and3.mxd

City of Prince George
This information has been provided subject to the *Federal Copyright Act* and in accordance with the Provincial *Freedom of Information and Protection of Privacy Act*

APPENDIX A

nhc

SUBMISSION
Flood Control Solutions

Date	June 12, 2008
Topic	Dredging - Flood Control Solutions
Purpose	For decision ☐ For information ☒
Submitted By	Monica Mannerstrom, nhc
Approved By	Bruce Walsh, nhc

Issue

The preliminary geomorphic assessment suggests that sediment deposition has been occurring in the main channel of the Nechako River near the confluence. There is strong public desire to dredge the lower end of the Nechako River in the attempt to reduce flood levels during both the freshet flood and ice jam flooding.

Channel geometry from the 1997 floodplain mapping study was used to develop a HEC-RAS model to make a preliminary assessment of the effect of dredging on freshet and ice jam flood levels.

Background

The preliminary geomorphic assessment of the lower 2 km of the Nechako River at the confluence used available historical airphotos from between 1929 and 2006. In 1926, numerous distributory channels were present prior to industrial development, and there were numerous gravel bars, vegetated islands and active secondary channels within the mainstem channel.

The historical air photos indicate that sediment deposition may be occurring in the main channel near the confluence. These changes are noticeable in the post-1994 period.

Land development has infilled the majority of the distributory channels to the south of the Nechako. Reduced flows following river regulation have also led to greater channel stability with the resulting loss in secondary channels as former gravel bars coalesce into islands. These changes may reduce flood conveyance capacity in the mainstem channel and the ability for the secondary channels to convey flood flows when the main channel is blocked by ice.

The cross-sections used for the 1997 floodplain mapping study were used to develop a HEC-RAS model, which was then used to make a preliminary assessment of the effect of dredging on water levels during freshet and winter floods.

The model was calibrated to water levels recorded on the Fraser and Nechako rivers during the floods of 1972 and 1990. The results of the calibration are shown in Figures A1 and A2. The ground profile refers to the thalweg (deepest portion of the channel) and distance is measured from Cross-Section 1 on the Nechako River (see 1997 floodplain mapping).

Figure A1. Fraser River Calibration, n = 0.029

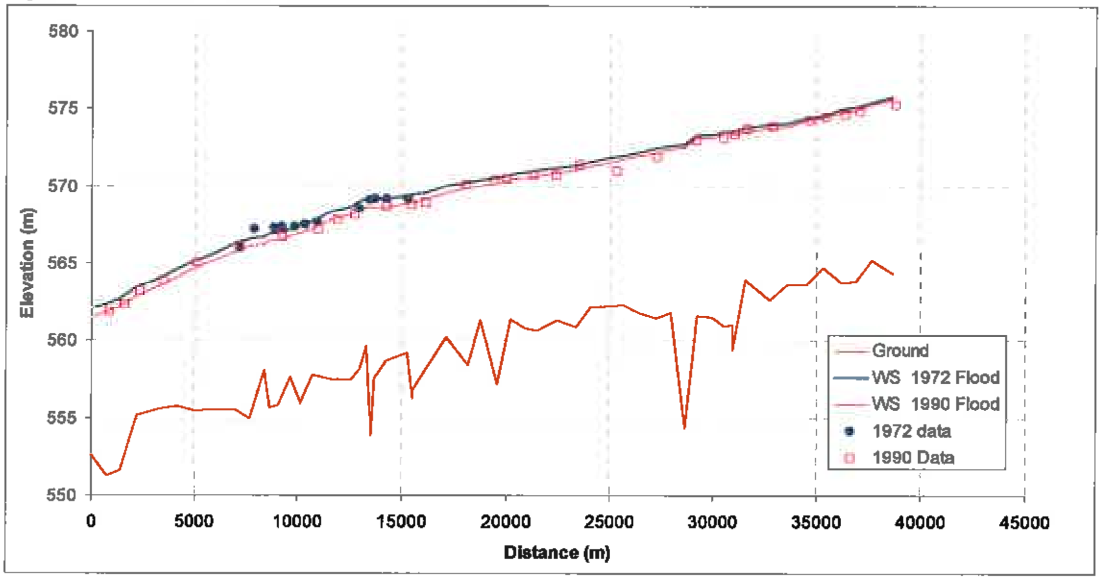
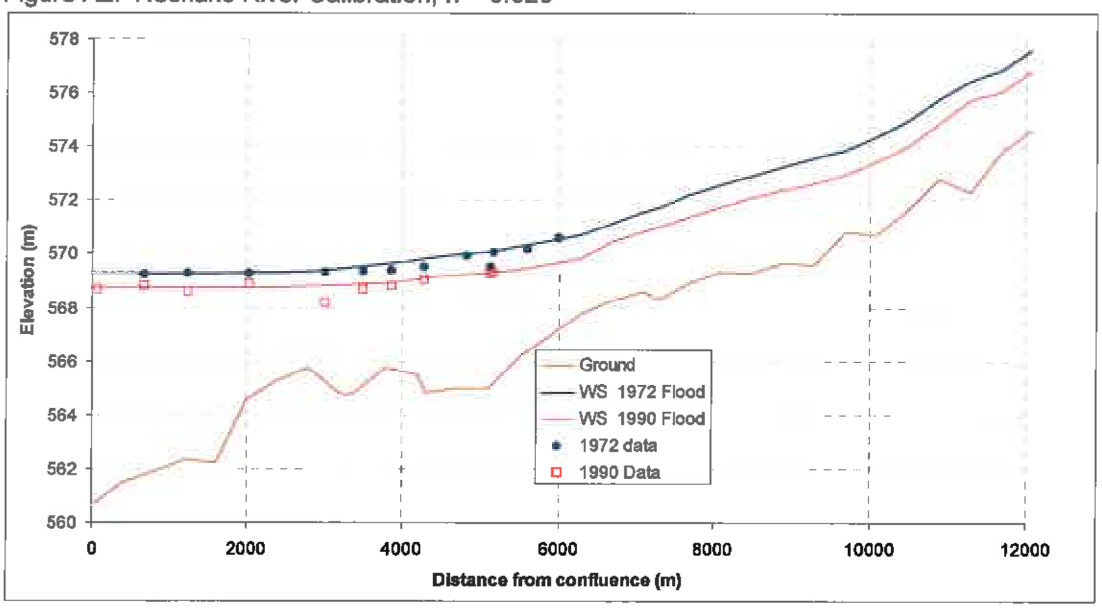


Figure A2. Nechako River Calibration, n = 0.020



The calibrated model was then used to determine the effect of dredging for the 20- and 200-year freshet flood conditions, and for winter flood conditions. The assumed dredged area was 1200 m long, by 80 m wide by 4 to 5 m deep, which represents a volume in the order of 432,000 m^3.

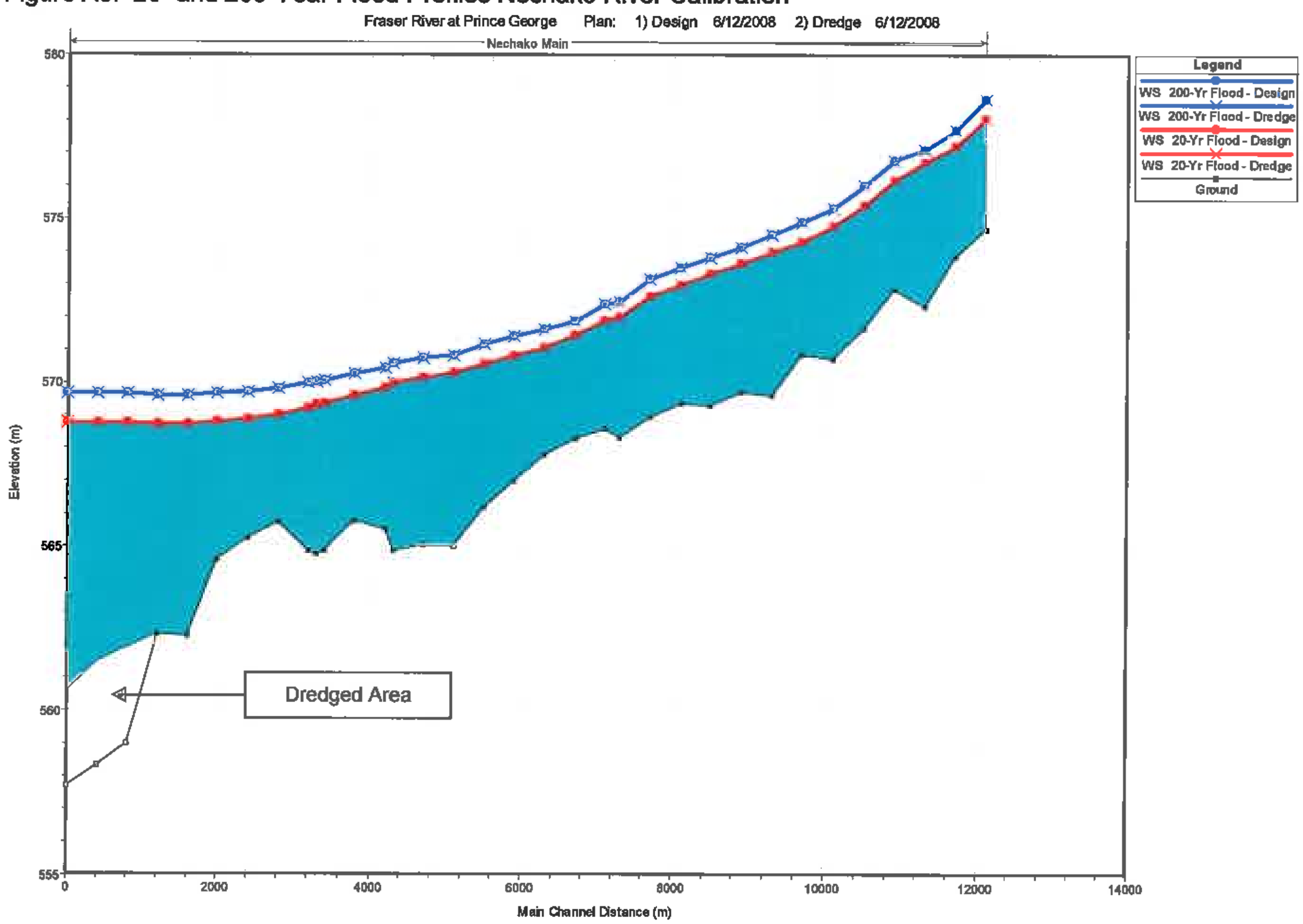
Discussion

Freshet Flooding

The water levels along the lower Nechako River during a freshet flood are controlled by the water level in the Fraser River. As shown in Figure A2, the backwater effect of the Fraser River on the Neckako River extends about 5 km upstream of the confluence to about the John Hart Bridge. This means the bed level in the Neckako River along the lower 5 km do not play much of a role in the water level that occurs along this section of the Nechako River.

Figure A3 shows the resulting water levels if the lower 1200 m of the mainstem of the Nechako River are dredged. As is seen in the figure virtually no difference is observed between the two profiles for either the estimated 20-year and 200-year flood flows.

Figure A3. 20- and 200-Year Flood Profiles Nechako River Calibration



However, it should be noted that the HEC-RAS model is a 1-dimensional model which calculates the average water level at the cross-section. Given the complexity of the flow at the confluence with multiple channels and vegetated bars, it is possible that dredging may affect local hydraulic conditions and that some benefits may be realized. For this reason more detailed 2-dimensional modeling of the confluence is recommended that would identify if local improvements are realized, for this or other dredging options. This modeling would also assist in interpreting the cause and effect of sedimentation at the confluence.

Ice Jam Flooding

The Fraser ice cover provides a lodgment point that stops the Nechako River ice that forms upstream of Prince George from flowing into the Fraser River. Consequently, when the ice accumulates against the Fraser River ice and a cover forms on the Nechako River, the subsequent freeze-up level is a function of the Nechako River discharge and the ice supply. If the ice supply is limited by warm weather, the length of the ice accumulation may be too short to form an equilibrium ice condition and the higher water levels associated with the development of the ice cover would extend only a short distance upstream of the Fraser River. However, if there is a prolonged cold spell and there is sufficient ice supply to form a long ice cover with an equilibrium thickness, the thickness of the ice cover and the ultimate water level associated with the ice cover will be a function of only the local channel geometry, river slope and the discharge. To significantly reduce the ice-related water levels, the slope of the Nechako channel would need to be reduced throughout the Prince George reach to a point well upstream of the City.

At high winter flows with a heavy load of ice, ice-related water levels are more a function of the thickness of the developed ice cover and its attendant underside roughness than due to any particular blockage of flow due to ice accumulated on the bed. However, at lower flows when the developed ice cover may begin to approach the bed, dredging a low water channel down the centre of the existing river channel might produce a water level reduction by conveying more flow than would otherwise be conveyed in the shallower part of the channel. Although, this would be a desirable result, the positive effects of the dredging would only be evident at times when the resulting ice levels for the un-dredged channel would not be a problem anyway.

The effect of a dredged low flow channel along the mainstem will be investigated further in the feasibility assessment phase of the study.

RECOMMENDATIONS

Develop a 2-dimensional model of the Nechako and Fraser rivers at the confluence, and use the model to investigate whether dredging will cause local water level reductions for both freshet and ice jam flooding. A cost and time estimate will be developed for this work.

APPENDIX B

EDI ENVIRONMENTAL DYNAMICS INC.
Natural Resource Consultants

BOX 5, 2011 PG PULPMILL ROAD ▪ PRINCE GEORGE, BC ▪ V2L 4R9 ▪ P: (250) 562-5412 ▪ F: (250) 562-5413

June 2008

Northwest Hydraulic Consultants
30 Gostick Place
North Vancouver, BC
V7M 3G3

EDI Job Number: 08-BC-0034

Attention: Monica Mannerström

Re: City of Prince George Flood Risk Evaluation and Flood Control Solutions project - Environmental State of the Baseline

In February 2008, Environmental Dynamics was retained by northwest hydraulic consultants (nhc) to provide environmental assessments and advice regarding flood control solutions associated with the City of Prince George Flood Risk Evaluation and Flood Control Solutions project. As part of the feasibility analysis of Phase 1 (Flood Risk Evaluation) of the project, an environmental "baseline" will be determined to which potential effects of construction and operation of flood control works can be compared. The first phase of establishing a baseline, determining the "state of the baseline", has been completed by performing a literature search for existing information in the study area; this work serves to prevent duplication of field data collection efforts and identify gaps in environmental information.

This report will summarize the environmental state of the baseline, briefly identify any information gaps and provide the field sampling plan that will fill these gaps and complete the environmental baseline (during the remainder of the project). It also includes the methodology used to complete the environmental section of the nhc-designed decision-matrix (which forms the priority assessment of the potential flood relief options).

Existing Environmental Information

Study Area

The study area covers the Nechako and Fraser Rivers and their tributaries and the associated riparian areas within the city limits of Prince George, BC. Although the study area focuses on the Nechako River from its confluence with the Fraser River (near downtown Prince George) to approximately 15 km upstream (near Miworth), environmental attributes of the mainstem Fraser River within city limits will also be examined.

Within the study area, the Nechako River is characterized by a riffle-pool morphology. Approximately 50% of the mainstem channel banks are characterized by large substrates with enhanced complexity provided by backeddies, riffles and shallow pools (Nowotny and Hickey 1993). Two large island complexes, Cottonwood Island and Fish Trap Island, are found within the study area on the Nechako River. There are also three off-channel sloughs along the Nechako, 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.

The only major tributary to the Nechako River within the study area is McMillan Creek, located approximately 3 km from the confluence (near the Cameron Street bridge). McMillan Creek is fish-bearing although culverts under PG Pulpmill Road may pose a fish barrier during normal flow conditions (likely backwatered during high flow conditions). Major tributaries to the Fraser River include Parkridge Creek, Varsity Creek, and Bittner Creek.

High water channels and floodplains of the Nechako River have been altered since the construction of the Kenney Dam in 1952. Side channels which were historically wetted during periods of high flows are progressively vegetating, as high flows are less frequent due to flow regulation at the dam.

The natural riparian corridors tend to be dominated by a cottonwood overstory, except along the lower reach of the Fraser River below the Simon Fraser Bridge where the river becomes more incised and the riparian areas become dominated by spruce and fir cover. Despite the amount of urban development that has taken place over the last 100 years, there are still large expanses of intact riparian vegetation, particularly along the upper Nechako and the east bank of the Fraser River. However, there is also extensive industrial, agricultural, residential and linear development that has had a considerable effect on riparian habitats within the city limits.

Fisheries

Numerous fish species are found within the confluence of the Nechako and Fraser River(s) including salmonids (sockeye salmon, chinook salmon, coho salmon, pink salmon, and rainbow trout), non-sport fish (prickly sculpin, slimy sculpin, largescale sucker, longnose sucker, white sucker, pacific lamprey, redside shiner, northern pikeminnow, peamouth chub, brassy minnow, longnose dace and leopard dace), mountain whitefish, burbot and two species of concern identified by the British Columbia Conservation Data Center (CDC). These species include the red-listed[1] white sturgeon[2] and the blue-listed bull trout.

---

[1] According to the CDC, a red-listed species is any indigenous species that is considered to be extirpated, endangered or threatened in British Columbia. Blue listed species are indigenous species considered to be of special concern/vulnerable in British Columbia. They possess certain characteristics that make them particularly sensitive to natural events and human activities.

[2] 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.

A comprehensive fish habitat inventory of the Nechako and Fraser Rivers within Prince George city limits was completed by ECL Envirowest Consultants Limited in 1993 (Nowotny and Hickey 1993). The study produced detailed foreshore habitat mapping.

Salmonid Life History within the Study Area

Most anadromous salmonids returning to the Nechako River system from the Fraser River will likely migrate into the Stuart- Takla drainage basin or Nadina-Francois Lake drainage basin to spawn. However, pink salmon have been observed spawning within the vicinity of the confluence (Nutton pers. comm. 2008). Adult salmon migrations begin to arrive in the study area as early as June and terminate in late October to mid November.

Salmon fry outmigrate downstream spending portions of their first and sometimes second year of life in lakes or along river margins. Chinook salmon fry may migrate considerable distances up tributary streams during the summer months. 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 at various times from spring to early fall, depending on the species and natal stream.

Fluvial populations of bull trout certainly utilize the study area as a migration corridor to access spawning or forage areas in the upper Fraser and Nechako watersheds. 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.

Current Status of White Sturgeon – Nechako and Upper Fraser Populations

The Nechako River and Fraser River white sturgeon populations have been studied intensively in recent years. Genetic studies have revealed that the two populations are genetically separate and do not interbreed (Nechako White Sturgeon Recovery Initiative 2008). In 2006, both the Upper Fraser and Nechako River populations were added to Schedule 1 of the federal Species at Risk Act (SARA); SARA designation triggers a requirement to assess population status, critical habitat and provide recovery initiatives.

Research conducted on the Upper Fraser population has focused primarily on presence/absence and population abundance, based on mark-recapture studies (Yarmish and Toth 2000, 2002). With the inclusion of recent (unpublished) data, the Upper Fraser River population is estimated to be around 800 individuals (Yarmish pers. com. 2008). In 1999, RL&L estimated the Nechako River white sturgeon population at 547 individuals. The Nechako River population is predominantly mature individuals ranging from 30 to 50 years of age with low juvenile abundance; suggesting widespread recruitment failure (McAdam et al. 2005).

Critical habitats for both populations include spawning locations, staging areas, immature (larval and juvenile) rearing habitats as well as adult feeding locations (Yarmish et al. 2002, McAdam et al. 2005, Wood 2007). Potential threats to sturgeon habitat most often occur through anthropogenic activities such as dredging, river regulation, development activities within riparian, foreshore and/or floodplain areas, as well as effluent discharge (Wood 2007). To date, little research has been conducted to determine the suitability of the lower Nechako to provide spawning or critical rearing habitat for white sturgeon.

Wildlife

Numerous wildlife species can be found near the confluence of the Nechako and Fraser River(s). In 2003, Golder and Associates conducted a wildlife habitat assessment on Fishtrap Island (as part of the Application for Environmental Assessment Certificate and Draft Comprehensive Study Report: City of Prince George Hart Water Supply Improvements Fishtrap Island Collector Well Project). 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 in abundance throughout all three locations.

The following bird and mammal species are blue-listed by the CDC in the Prince George forest district: great blue heron, short-eared owl, sandhill crane, long-billed curlew, sharp-tailed grouse, wolverine, fisher, bighorn sheep, caribou (southern population and northern mountain population) and grizzly bear.

Information Gaps and Sampling Plan – Fish Habitats

Potential effects on aquatic habitats will be a major consideration in determining the feasibility of any proposed flood control solution. While detailed habitat mapping was conducted in 1993, it is possible that significant morphological changes have occurred over the last 15 years. Existing foreshore habitat mapping will be verified and updated where necessary in the summer of 2008. This information will form the foundation of the environmental assessment and may be used for future environmental permitting applications.

Information Gaps and Sampling Plan – White Sturgeon

Although many years of white sturgeon research have been completed on the Nechako and Fraser Rivers, no known study has specifically targeted white sturgeon habitats at the confluence of the Nechako and Fraser Rivers. Due to the potential for critical habitat to be present within this area, some additional sampling effort is recommended to increase understanding of the species' behavior and habitat utilization within the study area. This will allow a more comprehensive assessment of potential impacts from proposed flood control strategies and will likely be necessary for submission for federal review.

During the 2008 field season, EDI will perform opportunistic sampling for white sturgeon using set lines and/or gill nets.

Decision-matrix – Methodology of Environmental Section

A written description of environmental considerations and a ranking (from "1" to "3") for potential environmental impact was completed for each mitigation option (and mitigation sub-option) on the decision-matrices (one each for the Nechako and Fraser Rivers) provided by nhc. The environmental impact ranking (i.e. Low=1, Med=2 and High=3) for a particular mitigation option was evaluated based on the degree of environmental permitting that would be required. A low ranking of "1" was assigned in cases where no environmental impact from the flood control solution option is anticipated (e.g. no permanent protection works). A moderate ranking of "2" was assigned where some impact to the environment is expected but no major environmental approvals are required. A high ranking of "3" was assigned when a major provincial and/or federal permit is required to approve permanent footprint impacts on habitat. The assumption being that the degree of permitting is correlated roughly to the degree of environmental impact. Consequently, written descriptions of "Environmental Considerations" are also primarily concerned with issues that may require permitting and as such focus on potential effects of design (not construction) and continued operation of mitigation designs.[3]

Yours truly,
EDI ENVIRONMENTAL DYNAMICS INC.

Rob Van Schubert, R.P. Bio.
Senior Fisheries Biologist

Literature Cited

B.C. Conservation Data Center. 2008. BC Conservation Data Center, Species and Ecosystems Explorer. www.srmapps.gov.bc.ca/apps/eswp.html

Fisheries Information Summary System, 2008. www.bcfisheries.gov.bc.ca/fishinv/fiss.html (Accessed May, 2008)

Golder & Associates 2003. Application for Environmental Assessment Certificate and Draft Comprehensive Study Report: City of Prince George Hart Water Supply Improvements Fishtrap Island Collector Well Project, Prince George, BC.

Hatfield, T., S. McAdam and T. Nelson. 2004. Impacts to Abundance and Distribution of Fraser River White Sturgeon.

McAdam, S.O., C.J. Walters and C. Nistor. 2005. Linkages between white sturgeon (*Acipenser transmontanus*) recruitment and altered bed substrates in the Nechako River, Canada. Trans. Am. Fish. Soc. 134: 1448-1456.

Nowotny, C. and D.G. Hickey. 1993. Inventory and Rating of Salmonid Habitats along the Fraser and Nechako Rivers within the City Limits of Prince George, B.C.

[3] Potential effects of construction were not evaluated as they are highly dependent on construction methodology and generally can be mitigated using a variety of techniques.

Nutton, B. 2008. Personal communications May 2008 Department of Fisheries and Oceans Section Head Biologist.

RL&L. Environmental Services Ltd. 2000. Fraser River White Sturgeon Monitoring Program Region 7 (Omineca-Peace) 1999 Data Report. Final report prepared BC MELP Fisheries Branch.

Scott, W.B. and Crossman, W.B. 1973. Freshwater Fishes of Canada. Bulletin 184 Fisheries Research Board of Canada.

Yarmish, J.A. and B.M. Toth. 2002. 2001/2002 Assessment of upper Fraser River white sturgeon. Report produced by Lheidli T'enneh First Nation for Upper Fraser/Nechako Fisheries Council and Fisheries Renewal BC. 37p.

Wood, C. 2007. Recovery Potential Assessment for White Sturgeon. DFO Can. Sci. Advis. Sec. Sci. Advis.Rep.2007/014