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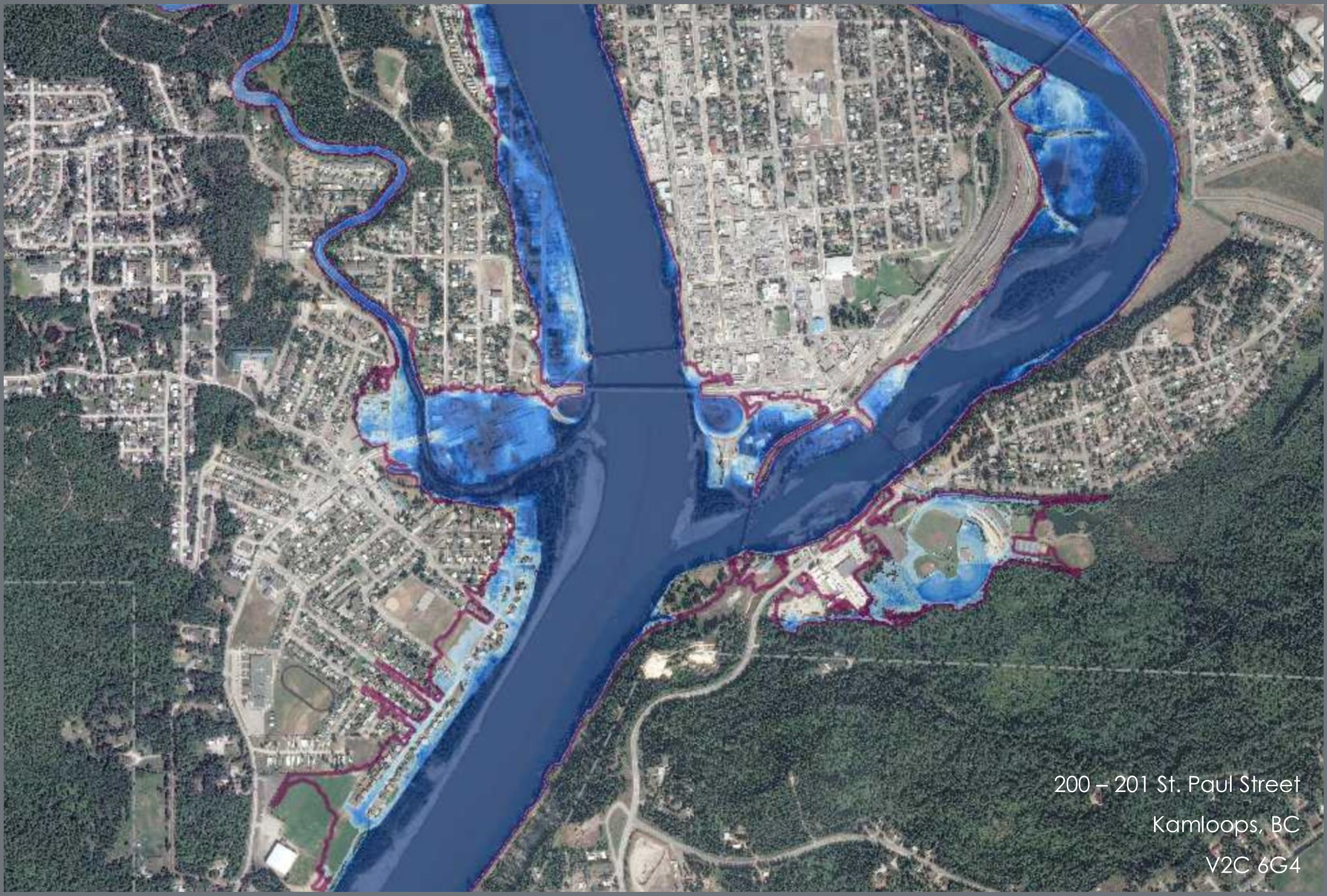
REPORT

PREPARED FOR THE CITY OF QUESNEL

Flood Hazard and Floodplain Mapping



Flood Hazard and Floodplain Mapping

Client: City of Quesnel

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1.0 Introduction

The City of Quesnel (City) experiences inconveniences dealing with the annual high river water level events that cause some flooding of low-lying areas and a disruption to at least one road (Johnston Bridge Loop). Less frequent but higher flow events have impacted private properties and public infrastructure. Every year the City must also monitor and decide what actions to take based on expected river levels.

In 1992 the Province of British Columbia led in developing floodplain mapping for the community to help communicate the extent of a major high water event, noted as a 1 in 200-year return period event, also referred to as an event that has a 0.5% chance of occurring any given year.

Having access to more accurate elevation data and wanting to consider the potential impact of climate change, motivated the City to update the analysis. The City then sought funding to undertake a study to better understand the risks associated with riverine flooding faced by the community and update the floodplain maps which were prepared in 1992.

A grant was received from the National Disaster Mitigation Program (NDMP) to undertake the flood analysis and flood hazard assessment. The purpose of this study is to provide information related to the risks and hazards associated with high flow rates of the Fraser River and Quesnel River in the City of Quesnel. The study includes the following tasks:

- Gather and review available background information in order to better understand the hydrologic and hydraulic conditions in the study area that contribute to flooding;
- Undertake an assessment of the flood hazard faced by the community, with a focus on the extent of public and private property and infrastructure at risk due to flooding;
- Estimate design flow rates for assessing the flood hazard based on historical records;
- Undertake a hydraulic assessment of the river in order to establish water surface elevations during the design flood;
- Assess the effects of potential flood protection works that would protect the community against the identified design flood;
- Assess the potential impacts of future climate conditions on the severity and frequency of the hazard event, and
- Prepare floodplain maps that identify the hazard areas and associated water surface elevations.

2.0 General Description of the Study Area

This floodplain mapping investigation involved a detailed hydrologic model (provided in Appendix A) and a hydraulic analysis (provided in Appendix B) of the Fraser and Quesnel Rivers, Baker Creek and Dragon Creek. The study area comprises a 12.3 km reach of the Fraser River through the City of Quesnel, a 4.4 km reach of the Quesnel River, a 3.9 km reach along Baker Creek and a 1.2 km reach along Dragon Creek. The extent of the study area, including all these river channels, are shown in in Figure 1 of Appendix B.

The Fraser River originates in the Rocky Mountains and, at the City of Quesnel, it flows in a southerly direction and has a drainage area of approximately 100,000 km^2. The Quesnel River flows in a southwesterly direction and discharges into the Fraser River at the south end of the city. Baker Creek is a small tributary of the Fraser River that flows from the west and enters the River just upstream of the Quesnel River confluence. Dragon Creek is a tributary of the Quesnel River draining from the east and entering the River via a 1,200 mm culvert under Johnston Avenue. Drainage basins are shown in Figure 2 of Appendix B.

3.0 History of Flooding

The City of Quesnel is vulnerable to high flood water in the Fraser and Quesnel Rivers, which in turn causes flooding due to backwater along Baker Creek and Dragon Creek.

Baker Creek can have risk of flooding and damage due to debris building and ice jam releases, but those flood mechanisms are different than high river flows. Dragon Creek could have flooding occur due to sediment buildup in the channel or a sudden release of water should temporary damming occur of the channel upstream of properties, which are also not prompted. Those issues are outside the scope of reviewing the floodplain due to high flow rates.

Maximum flows in the Fraser and Quesnel Rivers typically occur in the late spring and early summer as a result of snowmelt. One clear example of snowmelt related flooding was the 1972 flood, which resulted from extreme snow accumulation during the winter followed by warm weather in the spring. A peak flow of 6,510 m^3/s was recorded at the Fraser River near Marguerite hydrometric station (08MC018) located downstream of the City. This corresponded to a 50-year return period flood and resulted in severe flooding, particularly in West Quesnel near the Baker Creek confluence (**Photo 1**) and upstream of the Fraser Bridge Crossing. Flooding on the Quesnel River occurred near the confluence and at the public works yard on the right bank (**Photo 2**).

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Photo 1 - 1972 – Flooding at Lower End of Baker Creek Near Confluence with Fraser River (Source B.C. Ministry of Environment)

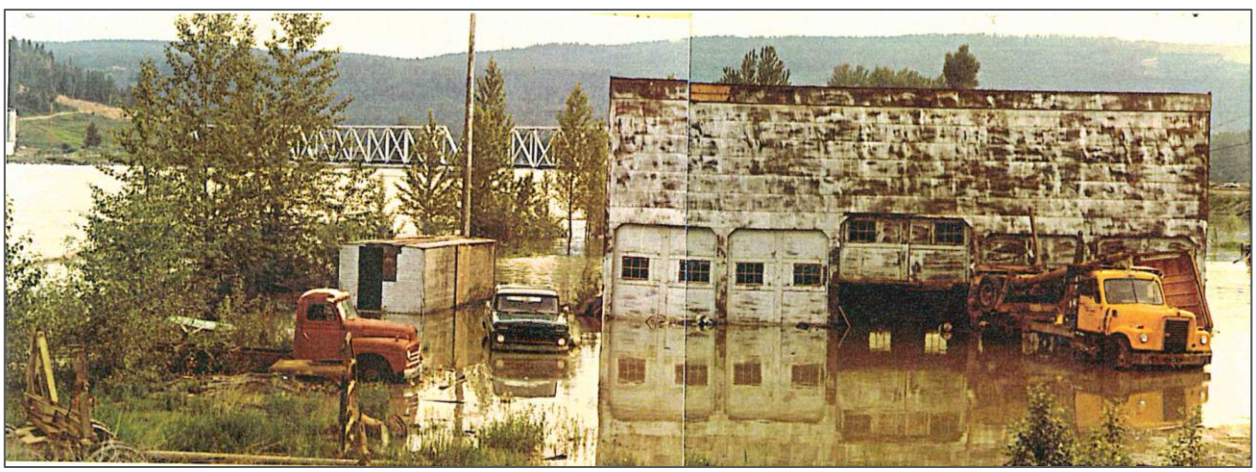


Photo 2 - 1972 – Public Works Yard – 50 Year Return Period Flood (Source: City of Quesnel)

Prior to 1972, there are several recorded flooding events, including in 1967 (with a recorded peak flow of 6,120 m^3/s), and in 1948 flood, which resulted in inundated areas on the left bank of the Fraser River next to the Quesnel River confluence, along the Quesnel River and on in the vicinity of the Baker Creek confluence. **Photo 3** below shows flooding of the Public Works Yard during the 1948 event.

Photo 3 - 1948 – Public Works Yard – 1992 Floodplain Mapping Design Brief Indicates this Flood is Estimated to be the Same Magnitude as the 1972 Flood (From Quesnel Museum - Source: Jack Ives from Branwen Patenaude's Originals)

More recent floods include the 1990 flood, which occurred at the beginning of June, similar to the 1972 event, was the result of sudden warm weather that led to rapid snowmelt. A maximum daily discharge of 5,790 m^3/s was recorded at the Marguerite hydrometric station, which corresponds to approximately a 10-year flood. **Photo 4** shows the extent of flooding near the confluence of the Fraser and Quesnel Rivers and Baker Creek. The Riverfront Walk and a portion of Legion Drive were inundated. Other areas on the west bank of the Fraser River (upstream of the bridges and the underpass of the Moffat Bridge) were also flooded. High water levels lasted for almost seven days.

Photo 4 - June 21, 1990 - Flow Near the Confluence of Fraser River, Quesnel River and Baker Creek (Source: Perry's Picture Place, Quesnel)

In 2007, the City experienced higher water elevations as a more recent occurrence, but not to the extent witnessed in the 1948 or 1972 events. A maximum daily discharge of 5,480 m^3/s was recorded as the 2007 high flow at the Marguerite hydrometric station, which was slightly below the 1990 event. In 2007, ss with the 1990 event, portions of the Rivers Trail and lower areas of road under the Johnston Bridge and Moffatt Bridge (west side) were flooded.

Predictions during Spring 2007 indicated that a higher than usual flood level was expected, which resulted in the City taking pre-emptive measures such as constructing a temporary berm behind West Park Mall and along the lower elevation portion of North Fraser Drive. A severe flooding event did not occur, but it helped the City to understand the efforts required to implement temporary flood measures.

Photo 5 - 2007 – Temporary Flood Protection Along Fraser River Upstream of Bridge Crossings (Source: Urban Systems Ltd.)

Photo 6 - 2007 – Temporary Flood Protection Along Baker Creek Near Confluence of Fraser River (Behind West Park Mall) (Source: Urban Systems Ltd.)

4.0 Peak Flow Estimation

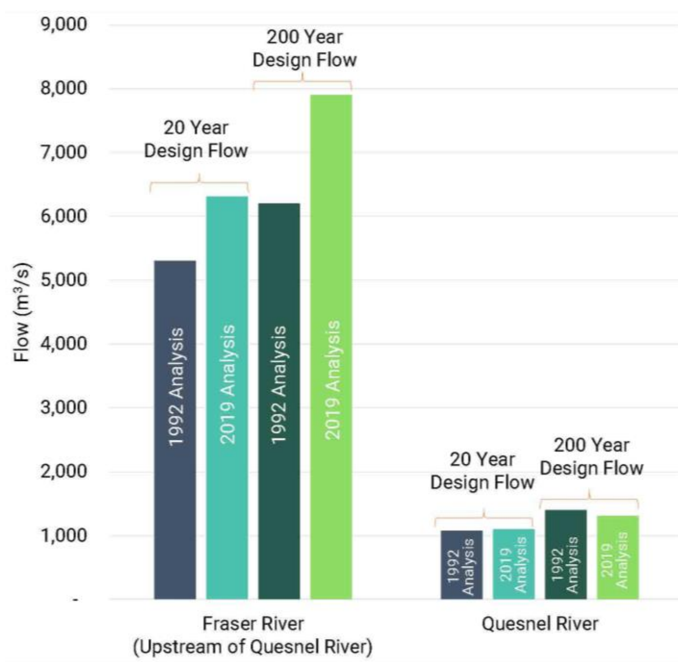
The previous floodplain mapping study that was completed in 1992 (entitled Floodplain Mapping Investigation, Fraser and Quesnel Rivers at Quesnel, Design Brief and prepared by Northwest Hydraulics Consultants Ltd.) was carried out under the Canada-British Columbia Floodplain Mapping Agreement, and contains important information regarding past flooding events, study area hydrology. This report had been used as the basis for the creation of a set of floodplain maps which the City had used as part of the Floodplain Bylaw since their preparation. The existing floodplain maps from that study which are applicable to the current study area are included in Appendix B for information and comparison purposes.

A foundational part of the floodplain mapping process is to review climatic information in order to establish climate conditions in Quesnel and estimate the magnitude of the design flood events. One of the most important factors in predicting flood events is to gain an understanding of the driving factors involved. A flood event may be driven primarily by rain or snowmelt, a combination of the two, or other processes such as debris flows and ice related impacts. To understand the impact of precipitation and snowmelt on flows within the watersheds, streamflow data was reviewed alongside weather data in the area (precipitation, temperature, and snowpack). From this analysis, it was shown that peak flows in these rivers are primarily driven by springtime snowmelt and exacerbated by spring rainfall on the melting snow.

As shown in the adjacent graph, the calculated instantaneous peak flows for the Fraser River and the Quesnel River are 7,903 m^3/s, and 1,306 m^3/s respectively. Appendix A provides a summary of that analysis.

Quesnel River flows went down slightly compared to the 1992 analysis because the last 30 years of flows indicate there have not been as many higher flow events. That brings the average peak down.

The Fraser River flow increased since the 1992 analysis. Records of the 1992 analysis do not give enough detail to determine exactly how it was calculated. A recent, separate Fraser River flow analysis completed by McElhanney Consulting as part of their 2019 bridge pier scour review of Johnston Bridge calculated the river's flow to be almost the same as the 2019 analysis.



Summary of Peak Flows

Based on historical data, peak flows on Baker Creek are independent from flows on the Fraser; on average, peak flows on Baker occur 33 days before the flow peaks on the Fraser. Most often, Baker peaks in the first or second week of May, while the Fraser peaks in the second week of June. As peak flows on Baker Creek are not coincident

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with the two rivers, the average flow on Baker Creek was used during June (when peak flows for the Fraser River are most likely to occur) in the modelling.

In contrast, Fraser River and Quesnel River peak flows often occur very close together. The peaks are within 2 days of each other for 10 of the 16 years for which overlapping flow records are available. Historical flood events with concurrent flows include:

- 1972, the largest flow recorded on the Fraser: peak flow in the Quesnel occurred 2 days later
- 2012 (the 2nd largest recorded flow), 2002, and 2000: Quesnel peaked 1 day after the Fraser.
- 2007, 1999, and 1974: Quesnel and Fraser peaked on the same day
- 1973 and 2009: Quesnel peaked 1 day before the Fraser

Although the peak flows do not coincide every year, the majority of the largest floods historically show the Fraser and Quesnel rivers peaking on the same day (on average). Therefore, it is realistic to assume that the 200-year flows on the Fraser and Quesnel rivers could occur at the same time.

5.0 Potential Future Climate Change Impacts

Consideration of climate change adaptation is becoming an increasingly common aspect of hydrologic analysis. Professional engineers practicing in BC are required by their professional association, EGBC, to consider the issues surrounding climate change so that informed decisions can be made about adaptation. Professional responsibilities are outlined in the EGBC position paper *A Changing Climate in British Columbia – Evolving Responsibilities for APEGBC and APEGBC Registrants*.

EGBC's *Professional Practice Guidelines for Flood Mapping in BC* summarizes the implications of projected climate change with regard to flooding in BC, and the key changes relevant to Quesnel are:

- an increase in frequency and intensity of severe rainstorms and increased snowmelt rates, causing greater peak discharges for a given annual exceedance probability; and
- an increase in the frequency and magnitude of floods due to phenomena such as insect infestations and forest fires.

Climate change is expected to cause different levels of impact on any given region, municipality, or site, depending on characteristics such as topography, watershed size, level of development, and existing infrastructure capacity. Since the social and economic impact of climate change on flood-related events has the potential to be substantial, site-specific evaluation of projected climate change impacts is important for preparedness.

5.1 Climate Change and Freeboard

The analysis of climate change work is summarized in Appendix A. That engineering analysis concluded that an increase in peak flows due to climate change is predicted to be 10%. Discussions then occurred with the City about the degree of uncertainty associated with climate change predictions and how freeboard is typically applied to account for wave action, downstream watercourse blockages that could raise water levels, modelling uncertainties. The practice in British Columbia is to use a 0.3 m freeboard above the 1:200-year return period peak flow when instantaneous peak flow modelling, as what was completed for this study, is used.

Wave action would not be as significant a factor on the rivers compared to more open water. Historically there have been no reported ice jams in these rivers that result in appreciable water level increases and peak flows occur in June when ice jams are not a factor in Quesnel. Therefore, the freeboard in Quesnel would relate more to uncertainties in modelling and a factor of safety related to an uncertainty related to the impact of climate change.

For comparison purposes it was decided that the following two scenarios would be considered for modelling:

1. Applying a 10% peak flow increase due to climate change and a 0.6 m freeboard
2. Applying a 20% peak flow increase due to climate change and a 0.3 m freeboard

Both scenarios apply a factor of safety for emergency planning purposes. If the 10% peak flow increase is too low then the additional freeboard could compensate. Alternatively, if the estimated peak flow is increased to 20% to allow for a degree of additional conservatism then applying the 0.3 m freeboard associated with the peak instantaneous computer modelling is applied.

Section 7 of this report provides a review of the analysis results, with the two scenarios presenting almost the same water levels. Applying a 20% peak flow increase due to climate change and 0.3 m freeboard was therefore selected for the modelling and the risk assessment.

6.0 Channel Stability Assessment

Historic air photos were reviewed for the study area for 1996 and 2018 to help identify changes in the river channels over the 22 year period. That timeframe included some higher flow events, such as the 2007 event, to help identify if there have been changes over time. That timeframe also allows for review of Quesnel River stability after the outer bank of the river underwent erosion protection between the Highway 97 and Johnston bridges. Images along the west side of the Fraser River, where major flooding and channel erosion would have impacts on many properties and transportation routes, where also reviewed, going back as far as 1949. Those images are presented in Appendix C.

Of particular interest, the images show the following:

- The expansion of the community and increasing amounts of community development adjacent to the river over that period of time. Of specific interest, is the development along the west side of the Fraser River that is shown in the floodplain mapping as being under the 200-year return period flood level.
- The west bank of the Fraser River has been relatively stable over time.
- The development of major road and rail transportation routes, however, the majority of that infrastructure is not being impacted by the high water levels.

- Historic lateral movement of the channel thalweg of the main Quesnel River has occurred, especially upstream of the Johnston Bridge, as shown by bank protection measures being installed and shifting of the gravel bars. However, the rivers have not moved in dramatic ways over very long periods of time.

In addition to the historical photos, review of the bridge pier information available from the 1992 study was also compared with more recent channel conditions, as provided by McElhanney Consulting Ltd. in 2019, as summarized in their study entitled Moffatt and Johnston Bridge Scour Assessment. The results indicate that the channels at the bridges are relatively stable, with one pier of the Johnston Bridge being recommended to undergo some additional pier protection due to some scour occurring.

Bathymetric surveys of the Quesnel and Fraser Rivers were completed for the development of both the 1992 and 2020 floodplain delineation models. We completed a comparison of channel cross-sectional geometry from these two surveys based on the information available in the 1992 Floodplain Modelling Report (NHC). This analysis showed little to no bank migration on either the Quesnel or Fraser rivers over the past 27 years. The cross-sectional geometry of the Fraser River appears to be relatively stable. The channel thalweg has shifted slightly in some locations, particularly along the Quesnel River, which sees considerable sediment transport and aggradation. Lateral movement at bridge locations appears to be minimal.

The assessment indicates that the main channel of the Fraser River is relatively stable, and this limited assessment does not indicate that the river's banks within the developed areas of the City are prone to dramatic movement. However, the encroachment of development adjacent to the river can be expected to be at risk of flooding during extreme events as a result of its proximity to the river.

The Quesnel River has experienced bank erosion and, in some areas, investment in erosion protection work by both the City and private entities has been required to protect property and infrastructure. These investments, and the natural migration of the river channel, however are not expected to have an impact on the 200-year return period flood level. The portion of the river channel near the confluence with the Fraser River, which is the area where most of the high water (and backwater effect) of the Quesnel River is experienced, is not viewed as an area of deposition of sediment that would reduce stream cross-sectional area.

It is important to note that, although impacts of river channel migration on 200-year return period water levels may be negligible, erosion of the banks of the Quesnel River should be monitored and mitigated. For example, the Cariboo Pulp and Paper Company completed channel protection in almost 15 years ago to avoid a major impact to their treatment lagoon. Damaging the pulp mill's lagoons with a release to the river could be a significant environmental event. It is important for property owners and the City to remain vigilant in monitoring and mitigating against bank erosion.

Major bank movement due to unstable slopes does occur in the region. For example, just north of the City boundary along the Fraser River, is the Knickerbocker Slide. A major slide could shift a river's direction and a very large slide could have the potential of damming a watercourse. It is noted that the likelihood of a major land movement that could change or temporarily increase river flows may not be high when considering flood levels in the municipality given the size of the Fraser River and Quesnel River channels. It is however outside the scope of this flood hazard assessment to identify the likelihood or hazards that could result from such a catastrophic event. Including freeboard when determining high water levels also provides a degree of conservatism to help mitigate the risk.

7.0 Hydraulic Modelling

A computer model of the river channel was constructed, with specific details about that modelling process and the results being provided in Appendix B.

LiDAR survey information that was gathered during a flight on May 22, 2018 and bathymetric survey of the Fraser River and Quesnel River was gathered on July 3, 2019. Information about bridge structures within the two river channels was also collected from survey information, record drawings and site review. Details of the crossings included channel cross-section information at some structure locations, as well as the size and shape of piers, top of bridge and underside of bridge elevations, and abutment locations and dimensions. Each of the structures was modelled based on the detail that was available. There are no other structures, such as dams or weirs, in the study area.

The calibrated model was then used with the inflow hydrographs with peak flow rates calculated with the application of a 20% increase in flows due to climate change in order to determine the flood extents. The flood extents for the water surface elevation resulting from the 200-year return period event, including a freeboard allowance of 0.3 m, have been mapped to produce updated floodplain maps, which are presented in Appendix B. The floodplain maps assume that no flood protection works have been undertaken.

The calculated water surface elevations (WSE) have been compared to the calculated WSEs from the 1992 study, and the results are presented in Appendix B. The 1992 study incorporates a 0.6 m allowance for freeboard but does not take into account an increase in flow due to climate change. The current study accounts for the possible effects of climate change and applies the 0.3 m freeboard allowance. In all cases, the revised WSEs are greater than the values calculated in the 1992 study, as shown in the examples in the below table, with maps showing cross section locations provided in Appendix B.

Table 7.1: Sample River Cross Sections and Related 200-Year Return Period High Water Elevations

	Urban Model X-Section	1992 NHC WSE Includes 0.6 m freeboard (m)	2020 USL WSE Includes 10% CC + 0.6 m Freeboard (m)	2020 USL WSE Includes 20% CC + 0.3 m Freeboard (m)
Fraser River, Downstream of Quesnel River Confluence	1028	472.10	472.65	472.83
	1041	472.45	473.08	473.15
	1001	472.97	474.07	474.06
Fraser River, Upstream of Quesnel River Confluence	1010.6	473.17	474.37	474.25
	1023	473.44	474.68	474.66
Quesnel River	1012	473.15	473.83	473.82
	1021	473.22	473.85	473.84
	1030	473.43	474.03	474.01
	1051	474.10	474.47	474.25

8.0 Risk Assessment

The EGBC Professional Practice Guideline *Flood Mapping in BC* defines flood risk as the combination of the probability of a flood event and the potential adverse consequences to human health, the environment and economic activity associated with a flood event. The process of risk assessment involves estimating flood hazards and the consequences for each hazard, and combining the results to obtain an overall estimate of the expected risk.

As illustrated in the previous sections, the most significant type of flood hazard identified in Quesnel, that have the potential to put people and property at risk, is surface flooding related to events of varying flood frequencies. Riverbank erosion is also a risk, but it is predicted that neither of the rivers are active enough to represent a significant hazard especially with proactive monitoring by various parties. There may be localized erosion circumstances but in most cases they are of a scale that relate to few properties. The Quesnel River does present some channel instability, but it is assumed that the City, Cariboo Pulp and Paper Company and transportation agencies will continue to monitor for changes in the riverbanks and address any issues proactively.

Engagement sessions occurred with a variety of stakeholders and included discussions with members of emergency services, other government organizations, private companies and the public. That process helped to outline hazards and possible mitigating practices. The engagement included an overview of hydrologic and hydraulic conditions. Data related to flood flow rates, flood extents, ground surface elevations, and flood affected properties were used as a preliminary basis for understanding the scope and scale of a 200-year return period event.

A result of this work is the summarized review of impacts and possible mitigation efforts that could be considered within the scope of the City of Quesnel's roles and responsibilities as a local government.

Another deliverable is the completion of an updated Risk Assessment Information Template (designed for the National Disaster Mitigation Program by Public Service Canada) to help summarize the risks to the community due to a 200-year return period flood event. A copy of the completed Risk Assessment Information Template is provided in Appendix D.

8.1 Summary of Impacts

Impacts are organized in the Risk Assessment Information Template in the following categories:

- People and Societal – displacements, injuries and deaths;
- Local Infrastructure – transportation; health, food and water; energy and utilities; information and communication technology; and safety and security;
- Environmental – damage to or loss of natural assets;
- Economic – local impacts, including property damage, productivity losses, economic disruptions, clean up and restoration costs; and

- Public Sensitivity – public perception of government institutions, and trust and confidence in public institutions, should the identified hazards and vulnerabilities be realized.

This section of the report provides information on the above noted impacts due to a major flooding event in Quesnel to allow the City to identify priorities and direct its efforts in flood risk mitigation.

People and Societal

The impact to people and society from flooding can be significant. Some form of human suffering is almost always associated with damaging floods, through displacement, loss of assets or personal safety. These impacts can be very difficult to quantify.

The magnitude of the risk of loss of life depends largely on whether the flood was predicted and if appropriate warning and evacuation takes place. In Quesnel, it is unlikely that surface flooding will occur with no warning, as the rivers are monitored by the river forecast centre, but it is still a possibility that dikes may fail with little notice or warning, particularly if this happens at night.

A loss of life calculation was completed for assumed worst-case scenarios in order to provide the City with a sense of the magnitude of this risk. This calculation was completed for only the surface flooding scenario using the RCEM - Reclamation Consequence Estimating Methodology (US Department of the Interior Bureau of Reclamation 2015) as a resource. The results of the calculations are presented in Table 8.1.

Table 8.1 – Example Worst-Case Loss of Life Calculation

Hazard Type	Surface Flooding	
Location	Fraser and Quesnel Rivers	
Area at Risk	Residential and Commercial Areas Adjacent to Rivers	
Assumed Population at Risk	500 people	
Assumed Depth	1.5 m	
Assumed Velocity	3 m/s	
Warning Time Category	Adequate warning	Little or no warning
Estimated Fatality Rate	0.001	0.01
Estimated Number of Fatalities	0.5	5

Although these estimated worst-case scenarios indicate a relatively low potential for loss of life when adequate warning is available, the potential is much greater in the event that little or no warning is available, such as a dike breach condition.

Local Infrastructure

Flooding can have a significant impact on a community's infrastructure, including inconvenience from loss of service, and economic impact of replacement cost.

For context, in 2018 a review of the flood area and the BC Assessment value of properties noted that the value of the properties that could be flooded within the 1992 flood area, including 0.6 m freeboard, was in the order of $127 million. The newly modelled flood elevations result in the same order of magnitude of property value within the flooded area. Note however, that these estimates are provided only to outline the scale of impacts. It is noted that some of these properties would likely not be completely lost due to flooding as the water would be more shallow in some areas than others.

It is also noted that community infrastructure impacts and repairs could increase costs, depending on the scale of impact and clean up.

Environmental

Potential environmental risks due to flooding include spills of hazardous materials, oil and fuel spills, and overflows or uncontrolled releases of untreated wastewater. Economic impacts from these types of releases are difficult to quantify.

For the purposes of this study, arguably the highest environmental risk that the City manages is the discharge of wastewater from the City's sewage collection system. The consequence is that during a flood event, raw wastewater might be pumped into a flooded wastewater collection network and then released directly into the environment. Also, increased sewage flows to the Cariboo Pulp and Paper Company treatment system could have an impact to their operations and discharge volumes. Cariboo Pulp and Paper have noted that the wastewater volumes from the City are in the order of 5% of their facility's total effluent volumes. It is expected that a short duration peak flow event would not overwhelm that treatment system, but it a responsible measure to attempt to protect against directing river flows there.

There could also be chemical releases to the environment due to flooding of properties (e.g. chemicals stored on properties within the floodplain, gas station at West Park Mall) but the City can only provide advice to property owners about the management of their facilities. The construction of flood protection infrastructure to protect multiple properties and infrastructure would be another action that the City could undertake.

It is noted that risk of bank erosion to the Cariboo Pulp and Paper Company property could have devastating environmental impacts. Impacts of high water are not the main risk as the lagoon berms are high enough. It is the risk of river velocity on the banks and berms that should be monitored, with actions to be taken by Cariboo Pulp and Paper Company to protect against that risk.

Economic

Losses to the local economy are difficult to estimate. This could include unemployment, loss of business, and impacts to economic arteries. It is noted that the duration of a major flood event could be short (a couple of days or less, plus the time to conduct clean up) before transportation routes such as Marsh Drive and North Fraser Drive could be re-established to continue the flow of people and goods. Businesses that are flooded would have longer duration impacts during repair or relocation activities. Disruption of power or telecommunications/internet would also impact the economy.

Comprehensive economic analyses to estimate these impacts would be specialized and costly. Qualitatively, the west side of the Fraser River presents the largest risk to the local economy due to damage to properties and disruption of infrastructure.

Public Sensitivity

Public institutions are vulnerable insofar, as a failure to take adequate steps to identify risks and take action to protect the public can lead to a loss of trust and confidence in public institutions should the hazard be realized. The public relies on the various levels of government, including local, provincial, and federal, to put in place measures that reduce the risk to community members who are not knowledgeable about the risks inherent with hazards such as riverine flooding.

8.2 Review of Issues Due to 200-Year Return Period High Water Event

The following are specific impacts that could result should the City experience major flooding due to a 200-year return period flood event. The objective of these hazard assessment summaries is not to itemize every possible hazard and related impact, but rather to help outline representative issues to help understand the scale of the risk and potential mitigative actions.

It is also noted that a flood event in rivers like the Fraser and Quesnel can range from the average annual event to an extreme event. There is the potential to have flood events of a smaller magnitude more frequently than the more extreme design event. The City has a process of monitoring river levels in Quesnel and communicating with Prince George and other government agencies to help predict anticipated water levels. That process also involves triggering specific mitigating actions for smaller high flow events, such as restricting traffic on certain roads, constructing temporary flood protection measures.

Issue Class 1: Damage to Property

Even if flooding is of short duration, even for just an hour or less, the damage can be severe. The following are some examples.

- Residential, Commercial and Institutional Properties
    - There are several homes that are under the flood level on the west side of the Fraser River
    - There are businesses and institutional buildings on both sides of the Fraser River that will be flooded
    - An apparent example shown in the flood level figures is West Park Mall, as the entire mall property may be flooded, including a gas station
    - *Mitigation Options within the City's Purview*
        - *Permanent or temporary flood protection (refer to Section 7 for more details)*
        - *Require that any new development make considerations for flood protection, such as setting the minimum floor elevation above the flood level*

- Quesnel Search and Rescue Building
  - Although not the City's responsibility, this site is worth some attention as its function is to support public safety
  - The building was constructed to the previous floodplain elevation
  - The flood level figures indicate that the Search and Rescue Building will likely incur minimal flooding in an extreme flooding event and shallow flooding to access the building
  - It is recommended that City Emergency Service and Quesnel Search and Rescue make plans to relocate essential equipment from this building if extreme flooding is expected

Magenta line is edge of water during 200 year return period event when 0.3 m freeboard is added

- City Public Works Yard
  - The current Public Works facilities will experience flooding during a significant high water event (in 2007 the flood levels were within ~ 0.5 m of having impacts to the properties. As noted in Section 3, flooding was experienced in 1948 and 1972.
  - *Mitigation Options within the City's Purview*
    - *The City expects to relocate the Public Works functions to a new facility within the next year.*
    - *Once the existing site is vacated by Public Works, the City should only develop the properties in a manner that reduces the risk of flooding (e.g. permanent structures above flood levels)*

Quesnel River Level in 2007 – Public Works (Utilities) Area is in the Foreground

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- West Fraser Timber Park
  - This area would likely only experience flooding of permanent buildings (adjacent to lawn bowling, washroom and office building – see below for pictures of these buildings) during extreme high-water events.
  - *Mitigation Options within the City's Purview*
    - *Blocking the flow of water from the Quesnel River through the Dragon Creek outlet may be an option, but only if there is limited flow from Dragon Creek that could be directed by pumping overland. In a major flood event, the City would likely have more pressing priorities than monitoring and pumping creek flows, even if pumping could be accommodated.*
    - *Completing temporary flood protection around the buildings is likely a more practical option*
    - *Allow sports fields to flood, and complete clean up when priorities allow*

Buildings in West Fraser Timber Park

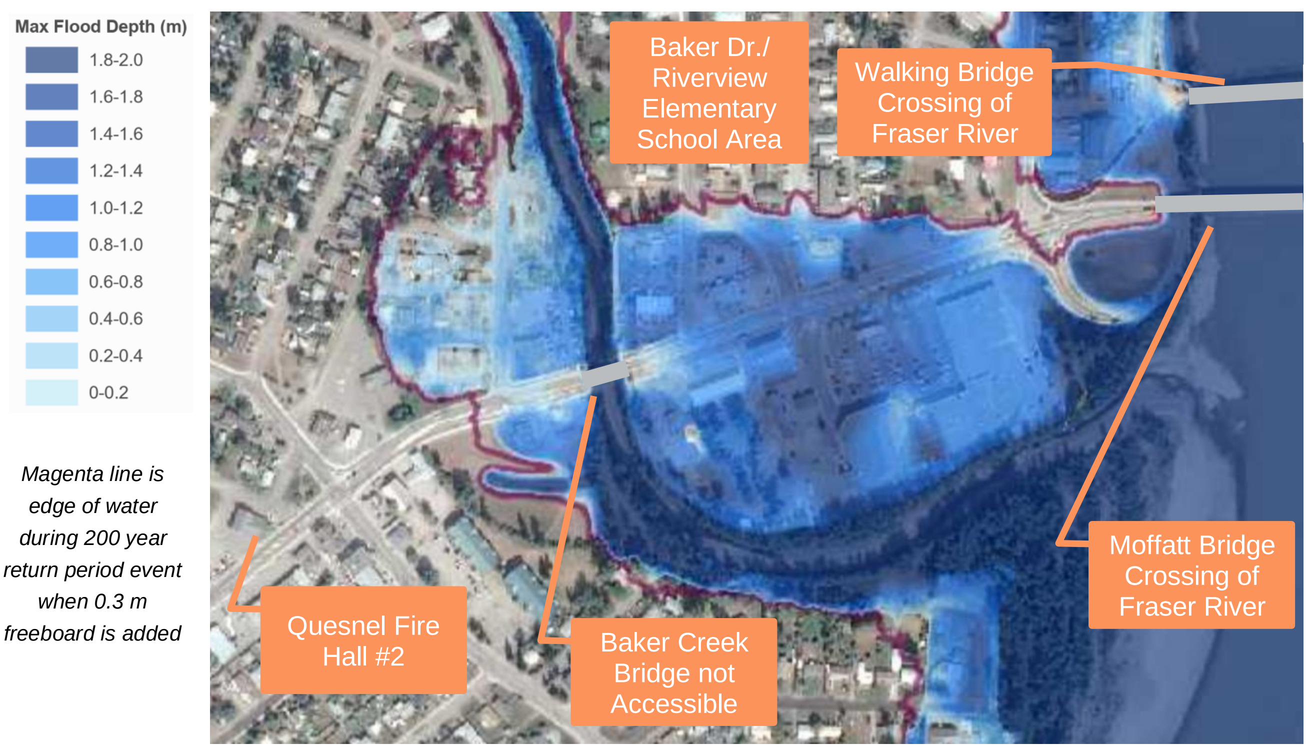
Issue Class 2: Disruption of City-Managed Transportation Routes

The following are key issues related to ensuring that people can access neighbourhoods and that emergency services can be provided. While there are some local roads that will also be impacted, the following are key City roads related to connecting parts of the community.

- Flooding of the Johnston Bridge Loop and adjacent Riverfront Trail is a disruption that occurs almost annually. Having this road flood is not a serious disruption to the City. Thus far the road and trail have not experienced damage due to high-water events.
  - *Mitigation Options within the City's Purview*
    - *Opening the crossing of the CN Rail tracks, blocking the road and notifying the public are steps the City completes in those instances.*
    - *The City may wish to formalize the process and communications for setting up the detour as part of operational procedures.*

- Flooding of the North Fraser Drive southbound lane, under the Moffatt Bridge, occurs at a frequency (approximately every 5 years) that results in the City having a detour route, signage and public notification system. Having this section of North Fraser Drive, under the bridge, is not a serious disruption to the City.
  - *Mitigation Options within the City's Purview*
    - *Continue to manage the detour approach during the high water events, as long as flood levels still allow for access to Marsh Drive via the Elliott Street detour.*
    - *The City may wish to formalize the process and communications for setting up the detour as part of operational procedures.*

- The modelling indicates that during a major flood event, Marsh Drive and the North Fraser Drive area near the Fraser River crossings will experience flooding to the point that it is unlikely traffic can pass. This flooding presents the highest impact to transportation in the City.
    - If Marsh Drive is not passable, then vehicle access across Baker Creek would not be possible.
    - Access to the Baker Drive/Riverview School area would also be blocked to vehicle traffic.
    - Access from North Fraser Drive would also be blocked.
    - It is noted that the 200-year return period flood is likely to not be a long duration event.
    - *Mitigation Options within the City's Purview*
        - *The City has noted the ability to place gravel along Marsh Drive to raise the elevation route as a temporary measure. However, water depths could increase to a level that would make that practice unfeasible. Also the time and cost to complete that temporary access may not be viable. Investment in temporary work would likely be better invested in protecting areas for flooding.*
        - *The City's Fire Hall #2 and some of the fire fighters are located on the west side of Baker Creek. The RCMP have noted the ability to place officers in the west area prior to the occurrence of flooding. Therefore, some emergency services would remain available to the west of the creek.*
        - *Access to the hospital would need to be provided by helicopter in an extreme situation.*
        - *It is noted that, if access to the Baker Drive/Riverview Elementary School area could be provided from Moffatt Bridge, then properties along North Fraser Drive and north of the City could be provided vehicle access through the Bouchie Lake area. Also, the walking bridge across Baker Drive could be accessed to transport emergency patients from west of Baker Creek.*



Magenta line is edge of water during 200 year return period event when 0.3 m freeboard is added

Issue Class 3: Disruption of Transportation Routes Managed by Others

The following are key issues related to ensuring the safe movement of people and goods that have a regional and provincial impact.

- Highway 97
    - Although restrictions of traffic on the highway and related clean up and repairs are not the City's responsibility, the community will be impacted
    - The only portion of Highway 97 at risk of flooding during an extreme flooding event is the underpass of the Moffatt Bridge and surrounding area – detour of this area can be accommodated on Carson Avenue or other City streets
    - The highway bridge deck across the Quesnel River is above the 200-year return period flood level but it is important to protect against disruptions to traffic as impacts could be significant since alternative crossings include Johnston Bridge (that currently restricts heavy vehicle traffic) or significant detours well outside of the community (e.g. at lest 2 hours with a portion on unpaved roads)

- Rail lines – bridges
    - The railway tracks are all above the modelled 200-year return period flood level.
    - It is important to ensure that bridge pier and abutments can handle the high flows to avoid damage

- *Mitigation Options within the City's Purview*
    - *The City is not responsible for this infrastructure, but support may be requested in an emergency.*

Issue Class 4: City Infrastructure – Sanitary

The following are key issues related to minimizing the volume of flood water that enters the sewage collection system, to reduce the risk of the system being overwhelmed and to ensure that sewage lift stations operate and are accessible.

- Toilets get flooded and increase sanitary flows
    - *Mitigation Options within the City's Purview*
        - *There is no apparent solution if the flow cannot be handled. An area that is flooding could be blocked from flowing into the downstream system by isolating/blocking pipes with test balls, but the sewage flow from those areas would then overflow*

- Surface water leaking into manholes
    - Sanitary manholes that are inundated can allow additional water into the collection system
    - *Mitigation Options within the City's Purview*
        - *The City already installs bolts in manhole lifting holes to reduce inflow through lids in areas where stormwater inflow occurs. This practice can be expanded to include all manholes that are at risk of inundation.*
        - *Use of manhole disks could also be considered if they help to further reduce inflow. Placing sandbags over these manholes prior to high-water is also an option.*

Example Manhole Disk Before Manhole Lid is Installed Photo Source: Manhole Rehab Inc. Website

- Protecting Lift Stations from Inundation
  - Rolph Street Lift Station chamber and kiosk are under the 200-year return period flood elevation.
  - The area around the West Quesnel Lift Station will become flooded
  - The area around the Main Lift Station will become flooded.
  - *Mitigation Options within the City's Purview*
    - *Rolph Street Lift Station chamber lid and the electrical kiosk could be raised above the flood level. Alternatively, a dike around the area could be installed. (Note: if the homes along Rolph Street are flooded then it is likely this lift station would not be able to keep up.)*
    - *For the West Quesnel and Main lift stations it is recommended that critical elevations be measured to determine if these facilities will actually flood (both have their main components raised compared to the surroundings), but plans should be established to provide temporary or permanent access during flood periods. (Note: the City has flood protected the West Quesnel Lift Station with temporary measures during previous high water periods.)*

Issue Class 5: City Infrastructure – Potable Water

The following are key issues related to minimizing the risk of water contamination.

- Water System contamination
  - Risk of backflow would increase if some taps are flooded
  - *Mitigation Options within the City's Purview*
    - *Continue to advance the City's cross connection control efforts*

- Wells #3 and #6, along Rolph Street, would be impacted
  - Well #3 is not in use and Well #6 is available only for emergency purposes.
  - Risk of surface water intrusion and contamination of the groundwater might occur in a high-water event
  - *Mitigation Options within the City's Purview*
    - *Power is to be disconnected to these sites during high water*
    - *Risk of contamination of the groundwater will be negated once these wells are properly decommissioned, complete with a surface seal, as part of the City's water system improvement plans.*

Issue Class 6: Non-City Infrastructure – Information and Communication Technology, Natural Gas

The following are key issues related to minimizing disruption of service and safety risks.

- The City does not own or operate this infrastructure, but it's damage could present significant impacts and, in the case of power or natural gas infrastructure, damage could present a safety risk.
  - Overhead wiring may not be at risk as long as currents and debris do not down poles.
  - Underground power and communications wiring may be impacted by flooding, but most buried infrastructure is not susceptible to flooding. Any above-ground kiosks in the flood area would be at risk.
  - *Mitigation Options within the City's Purview*
    - *The City is not responsible for this infrastructure, but support may be requested in an emergency. The City may also need to coordinate with the companies for access and clean up activities*

9.0 Proposed Flood Protection Works

Although there are no set rules, it is common for municipalities to not invest in or manage flood protection works for individual properties. Possible flood protection works outlined in this report relate to investments that would be needed to protect multiple properties and community infrastructure.

There are some areas that would benefit from the construction of permanent flood protection dikes. These would be designed and constructed in accordance with provincial dike design guidelines, and would become flood protection works under the provincial Drainage, Ditch and Dike Act. The City would become the diking authority and would be responsible for the construction and ongoing operation and maintenance of the dikes.

There are also some areas that would justify temporary flood protection which could include temporary berms and/or be in the form of temporary measures such as flood protection products HESCO earth-filled barriers or Tiger Dams. At times these products can be borrowed from Emergency Management BC, but it is noted that the likelihood of securing these items during a major flood event may present an unacceptable risk and delivery times may not be fast enough. If temporary flood protect products are part of the flood protection strategy, the City may wish to consider purchasing and storing some of these items to ensure they are available when needed.

Example Temporary Flood Protection Measure: HESCO Barrier

This product is a relatively lightweight wire mesh basket lined with a geotextile fabric which can be quickly set up and then filled with appropriate sand or granular fill material to create a relatively impermeable barrier to flood waters. They can be stacked. When flood waters have receded the fill material drops out of the bottom when the units are lifted for removal. The barriers themselves can be stored and re-used in the future, while the fill material can be collected and removed. The company also supplies single use barriers.

HESCO Barrier Used Along Dragon Creek in 2012 to Protect Against High Creek Water Levels
Source: Google Streetview

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Example Temporary Flood Protection Measure: Tiger Dam

Tiger Dam is an example of a flexible tube barrier. The units are brough to site, unrolled, filled with water and temporarily secured. They can be reused.

Excerpt from Tiger Dam Product Brochure

https://usfloodcontrol.com/wp-content/uploads/2017/08/TD-BROCHURE.pdf

Comments regarding flexible tube products include:

- Flexible tube systems are easier to install and remove than other flood barriers
- Tubes are not as durable as some other temporary measures
- Although there are larger sizes than shown in the above brochure excerpt, the image does help to communicate that going higher elevations requires multiple tubes to be stacked. Installing a 2 m or higher barrier would require many tubes, space to install in a triangle arrangement and poses a greater risk of damage than some other temporary barriers.
- Flexible tubes might be preferred for where access is limited and the height of barrier is less than 1 m.

It is noted that installing temporary works can be wasteful if they are required repeatedly. They also present a higher risk of failure than properly constructed permanent dikes. Even if the units stay intact, the underlying surface may fail. Permanent dikes are more robust and require little to no preparation when a high-water event occurs. There are also many cases of municipalities securing senior government grants to help subsidize permanent flood protection measures. Temporary measures require emergency actions to obtain and set up, and typically require more monitoring and maintenance during a busy high-water event.

If the City relies on too many temporary measures, they may find there is insufficient time to get all the measures in place. Also, it will place added stress to the annual act of predicting to what extent temporary measures should be installed as the City's investment.

Therefore, the following locations are reviewed with consideration for accommodating permanent flood protection measures. However, opportunities and constraints that may justify temporary measures are also noted. The City must decide to what extent temporary and permanent flood protection measures will be selected as the preferred, long-term strategy. It is also appreciated that using temporary measures may be the only option if high water levels

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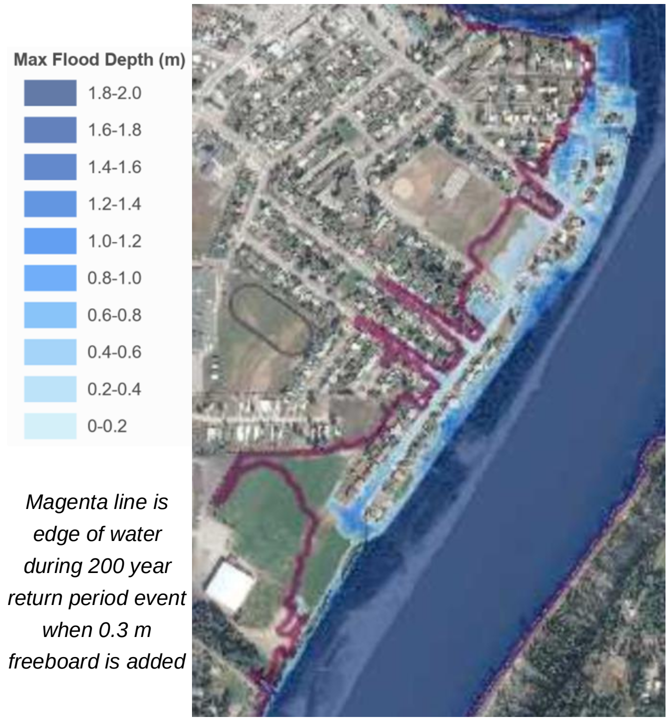
occur before permanent measures can be constructed. Temporary measures also may be the only viable option if there are site constraints (e.g. behind West Park Mall) or in areas where securing a right-of-way is difficult.

9.1 Rolph Street Area

The risks of flooding associated with properties and infrastructure in the Rolph Street area can be mitigated by constructing a flood protection dike. It is understood that previous flood protection along the river in this area, on private properties, raised conflict with property owners that did not want a permanent dike to remain.

A dike built to protect against the 200 year flood elevation would, along certain stretches, vary between 1.5 m and 2 m high if the dike were to be located near the riverbank. The cost to construct that dike would be in the order of $3.4 million, as outlined in the below table.

It is worth noting, however, that many homes within this area are near the top of the elevation of the flood waters prior to the freeboard being added.



Magenta line is edge of water during 200 year return period event when 0.3 m freeboard is added

Rolph St. Area

Rolph Street Flood Protection Dike Estimate of Probable Project Costs				
Description	**Unit**	**Quantity**	**Unit Price**	**Amount**
Tree Clearing and Removals (Excluding Out Buildings)	LS	1	$13,000	$13,000
Stripping and Minor Over-Excavation	m^2	17,900	$8	$143,200
Berm Fill	m^3	22,200	$60	$1,332,000
Toe Drain	m^3	2,000	$80	$160,000
Erosion Protection - Geotextile	m^2	6,300	$20	$126,000
Topsoil and Seed + Other Restoration	m^2	17,900	$25	$447,500
Fencing and Miscellaneous	LS	1	$30,000	$30,000
			Subtotal (rounded)	**$2,250,000**
			Project Contingencies @ 30% (rounded)	$675,000
			Engineering and Regulatory Approvals @ 20% (rounded)	$450,000
			TOTAL	**$3,375,000**

Estimates are in 2020 Canadian Dollars and do not include land or legal costs associated with securing right-of way to facilitate constructing and maintaining a dike. Those costs are difficult to predict and can only be firmly established once negotiations with property owners occur.

Due to proximity of the proposed permanent works to watercourse and riparian areas, it is recommended that options be reviewed with regulatory agencies. Permits will be required. Also, it is advisable to seek the services of a professional archaeologist in locations where there is potential to disturb unknown and/or unrecorded archaeological resources for any areas where excavations are required.

Flood protection works could be in the form of temporary flood protection products such as HESCO earth-filled barriers or Tiger Dams. However, with the flood protection needing to be 2 m high in some places near the riverbank, the risk and practicality of using Tiger Dams makes their use only viable for minor flood elevations. With the HESCO barriers being just over 1 m high, those unit would need to be stacked two high, which could require three times as many units to build stable protection for a major flood.

A compromise between permanent and temporary flood protection would be to build a smaller dike with a height that would accommodate a single row of the HESCO barriers, lock blocks or similar measures to provide the required flood protect height. For some of the length it would require a permanent dike height of 1 m or less. An order of magnitude cost to construct the shorter dike along the route, to facilitate a simpler temporary dike protection approach, is $1.8 million plus the cost of the temporary works during high water events.

If the flood protection works could be placed further from the riverbank, especially in areas where the existing ground is higher, then the need to construct even a small berm will be lessened. However, there would be more impact to properties.

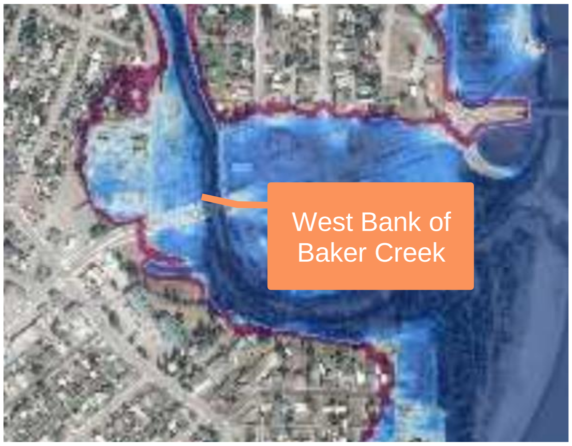
A major factor in accommodating temporary flood protection is having a clear route to install the temporary dike works quickly. This would require:

- An open route in the rear lots of the properties to accommodate the temporary works (fencing that can be easily removed, no trees in the way, no out buildings or other items that are difficult to relocate in the way)
- A response plan to mobilize the equipment and personnel
- Availability of required materials
- Access to complete the works

9.2 West Bank of Baker Creek

The current and the 1992 analysis of flood levels indicate that the west bank of Baker Creek will overtop in the vicinity of Marsh Drive. South of Baker Drive are two private properties and a City-owned lot. The space between the creek and the Elks Hall to the south of Marsh Drive is the lot's parking area. Constructing a dike in that area would take away that parking, but could protect the area from flooding.

North of the bridge is a private lot (Quesnel Toyota) and a City-owned park (Wilma Hanson Park). The City's West Quesnel Sewage Lift Station is in that park.



West Bank of Baker Creek

The current use of the private lots promotes the use of temporary flood protection measures. However, should these lots re-develop the grade of the property should be raised to promote flood protection for the lots and the surrounding area. Wilma Hanson Park could be regraded to provide additional flood protection.

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The City has plans to reconstruct Lewis Drive in the coming years. It would be appealing to raise the grade of that road to help provide some flood protection at least for properties to the west of that road. However, grades of developed private properties and the intersecting Clark Avenue negate raising the road grade too much before overall drainage grades are compromised.

In this area, like most areas that are below the flood elevation, it is recommended that these properties involve investments to reduce the risk of flooding when they are redeveloped.

9.3 North Bank of Baker Creek

This area includes the north bank of Baker Creek, which relates to the West Park Mall and Marsh Drive flooding. A significant factor in constructing a permanent dike along this entire length is that there is limited space behind the Mall to accommodate a berm and allow vehicle traffic. In 2007 the City installed a temporary dike adjacent to the creek, along the Riverfront Trail but it was too narrow to meet permanent dike standards.

After that high water event the City made senior government funding requests to complete a system that would incorporate permanent and temporary flood protection measures in this area. The following page presents the figure included as part of funding submissions.

With the model indicating that flood waters could be in the order of 1 m higher than the 1992 analysis it becomes even more difficult to envision a permanent dike system being installed along the rear of the Mall and through the adjacent

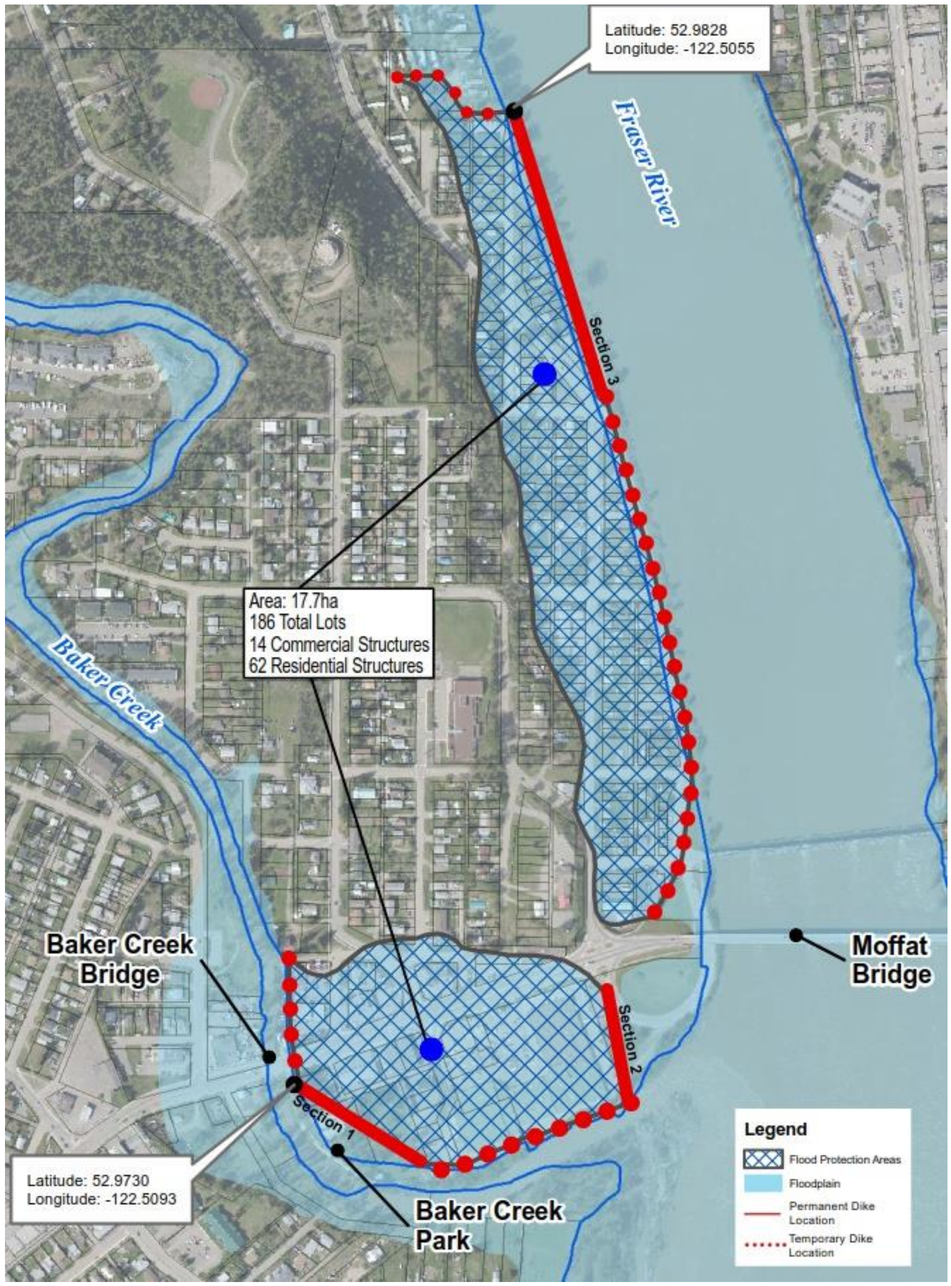

Figure from 2009 Grant Funding Application for Flood Protection Strategy for North Bank of Baker Creek and North Fraser Drive

Baker Creek Park. There is insufficient space behind the Mall and constructing a permanent dike through the park (Section 1 in the above figure) may come with community and political opposition. Also, since the area on both sides of the park would likely have temporary dike infrastructure installed there is less benefit associated with installing a permanent dike, that is slightly over 2 m tall, through the park.

Constructing Section 2 could be accommodated as there is sufficient space and it would be located on City-owned land. That portion or flood protection, by itself would have no value. However, constructing that ~100m length of dike when time is available would reduce the stress of constructing temporary flood protection along that length as part of the other many temporary flood protection works that would be needed to help protect infrastructure and properties.

It is expected that the Section 2 Dike could cost in the order of $150,000, as shown in the following table.

Cost Estimate for Section 2 – From Marsh Dr. to Rivers Trail Access Near Rear of West Park Mall Estimate of Probable Project Costs				
Description	**Unit**	**Quantity**	**Unit Price**	**Amount**
Site Clearing	m^2	0	$5	$0
Stripping and Minor Over-Excavation	m^2	1300	$8	$10,400
Berm Fill	m^3	1530	$40	$61,200
Toe Drain	m^3	150	$80	$12,000
Rip Rap, Geotextile and Filter Rock	m	0	$450	$0
Site Restoration	m^2	1300	$10	$13,000
			Subtotal (rounded)	$96,600
			Project Contingencies @ 30% (rounded)	**$29,000**
			Engineering and Regulatory Approvals @ 20% (rounded)	**$19,000**
			TOTAL (rounded)	**$145,000**

9.4 North Fraser Drive

The previous figure also displays the length along North Fraser Drive that would require flood protection to help reduce the risk of flooding of the property to the west. The figure notes that temporary flood protection measures would be placed from Moffatt Bridge north for the majority of the flood protection length. The logic of that approach was that the is insufficient space to install a dike between the river and North Fraser Drive.

It would be possible to raise the elevation of North Fraser Drive to serve as flood protection along that length, except that having public roads on dikes is not a recommended practice. It is also worth noting that raising the road to the full 200 year flood elevation plus 0.3 m freeboard would result in the road being raising, on average, just over 2 m. That elevation increase would be a major impact on traffic and private property access, to the point where such an increase is likely not practical unless a large-scale elevation increase is undertaken in the North Fraser Dr./Elliott St. area. It would also require the rerouting the sanitary sewer main that runs along the riverbank, replacement of the watermain other major impacts to infrastructure. The cost to complete that work is hard to estimate as it would

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be a combination of public and private infrastructure reconstruction and grade increases. Work just to raise North Fraser Dr. is expected to be more than $6 million. The cost to raise the all the properties and infrastructure, excluding the rebuilding of all private buildings, could be triple that cost or more.

For the time being, the City should plan to provide temporary diking along this segment of the road. As completed in 2007, a temporary berm could be constructed along the road. Flexible tube temporary barriers (e.g. Tiger Dams) would be faster to install if they would be available, however the 2 m height would be challenging to achieve and require significant space and risk of relying on those dams for a 2 m height. Using HESCO barriers may not be a priority in this area since the location and ability to temporarily close North Fraser Drive to traffic between Marsh Dr. and Elliott St. is conducive to heavy construction associated with building a temporary berm.

A northern portion of the proposed flood protection, labelled as Section 3 in the previous figure, could accommodate a permanent dike. North of that the strategy indicates that temporary flood protection should be installed to the north of this section, due to the area being on private property. It is also important to note that Section 3 and the area to the north is more prone to flooding, so having as much of that length having permanent diking is favourable as it would be the first area to flood and direct flow into the lower lands to the south.

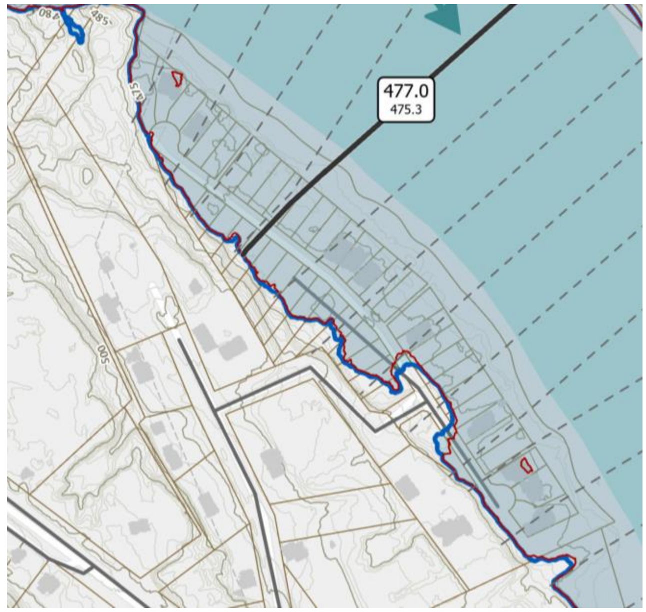
Note there is a sewermain along this route that would need to be outside of the dike area. For the estimate it is assumed that the pipe would need to be shifted west, but that requirement should be confirmed. It may also be that the pipe would need to be shift to an Edkins St./North Fraser Dr. route, which would increase cost.

North Fraser Drive Flood Protection – Section 3 Dike Only Estimate of Probable Project Costs				
Description	**Unit**	**Quantity**	**Unit Price**	**Amount**
Tree Clearing and Removals	LS	1	$5,000	$5,000
New Sewermain (Assuming it can remain behind lots)	m	300	$500	$150,000
Stripping and Minor Over-Excavation	m^2	4200	$8	$33,600
Berm Fill	m^3	5400	$60	$324,000
Toe Drain	m^3	450	$80	$36,000
Erosion Protection - Geotextile	m	1500	$20	$30,000
Site Restoration	m^2	4200	$25	$105,000
Fencing and Miscellaneous	LS	1	$5,000	$5,000
Subtotal (rounded)				$690,000
Project Contingencies @ 30% (rounded)				**$207,000**
Engineering and Regulatory Approvals @ 20% (rounded)				**$138,000**
TOTAL				**$1,040,000**

9.5 Riverfront Walks Strata (1702 Dyke Road)

Although the change in flood elevation does not impact City infrastructure this property will be impacted. With the revised 200 year flood elevation increasing by 2 m in this stretch, existing homes are now within the floodplain. It is understood that the City is currently reviewing options with the owners of property in this area.

The City is able to turn off the lift station, which has its electronics above the 200 year floodplain elevation, to avoid having river inflow overwhelm the sanitary sewer system.



Left image is of the previous floodplain map. Right image is of the updated floodplain map. (477.0 m is the 200 year +0.3 m freeboard water level. 475.3 m is the 20 year + 0.3 m freeboard water level.)

10.0 Proposed Non-Structural Investments

It should be noted that higher risks are likely to be tolerated for existing developments and hazards than for planned or proposed projects, as mitigation against the former may exceed the City's financial capability or be unacceptable to area property owners. There are however some steps to take that do not involve the City constructing flood protection works to help mitigate against the hazards of flooding.

10.1 Restrictions on Further Development in Hazard Areas

The flood hazard maps show the areas most prone to flooding. Where possible and practical, development should not be allowed to occur in the flood prone area.

There are development and redevelopment areas within the floodplain that will see further development in the future. In order to protect those properties from flood hazard and risk, it is typical to require that developers of parcels in these areas raise their proposed buildings and other valuable fixed assets above the flood hazard level or protect their properties with flood protection berms. It is critical to ensure that the flood protection works of one developer does not impact an adjacent property.

It is appreciated that in some locations where there are a series of smaller parcels that could be 1 m or more below the flood level. Developing or redeveloping those parcels could result in grading differences between lots. However, with a long-term view, as parcels are redeveloped eventually the risk of flooding can be avoided for areas.

It is also noted that constructing berms in some areas, such as in the Rolph Street area, would protect some parcels prior to their redevelopment. However, it is still recommended that any new properties incorporate raising buildings and valuable fixed assets to help reduce the long-term risk and reliance on flood protection berms.

10.2 Update Emergency Response Plan

Discussions with City staff indicated that there are a number of actions and communications that take place every year to monitor and prepare for rising floodwaters. City staff has a wealth of knowledge about what actions should take place based on the anticipated river elevation. It was noted however that many of these actions are not outlined in a procedure.

It is recommended that the City's Emergency Response Plan to include specific actions and procedures related to flood protection.

10.3 Additional Planning

In the event of a flood, there are a number of other measures which must be undertaken to protect the areas at risk.

First, there are a number of openings that must be closed to prevent flood waters from entering the areas to be protected. In particular, special attention should be given to storm sewer outfalls and culverts. This infrastructure is normally directly connected to the river, and represents significant sources of potential back flow into the protected areas. The City does complete annual inspection and monitoring of all outfalls to the river that could be subject to flooding, including the maintenance of backwater valves that are on some outlets.

In advance of a flood event, the City has also taken steps to further reduce the risk and rate of flow into the storm system through the use of sandbags at manholes and catchbasins that could bring river water into low lying area.

Similar to culverts and storm sewers, particularly during extreme flood events, sanitary sewers can become a source of back up into buildings or the collection system can be overwhelmed. This can happen because some sanitary sewer manholes are open to the flood waters, which then flow into the sewers and overwhelm the capacity of the sewers to carry the water away. In this case, the manholes can be protected with inflow discs, bolting the lifting holes or sandbags to prevent water from entering the openings. Homeowners can further protect themselves from the possibility of sewer backup into their basements or crawl spaces by installing a back flow preventer, or in an emergency temporarily plugging their main sewer drain with an air filled plug.

In some cases, the ground can become saturated and the groundwater level increased because of the elevated flood waters. As a result, the risk increases for the basements of some houses to become flooded. Sump pumps can be used to keep ground water levels down around houses, but the discharge from sump pumps is often to the ground surface outside the house, and this can often lead to a closed loop of sorts in which the sump pump water is pumped outside only to infiltrate into the ground and affect the building basement again. An alternative, in such cases, is to pump the groundwater to the storm sewer system, if available. In any case, in advance of the flood event, homeowners should be advised to check that their sump pumps are operating properly.

In circumstances when the outlets of storm piping are plugged, it is usually necessary to plan for the provision of pumps to remove water. Furthermore, seepage (groundwater) flows are expected to be a concern during future flood events as they were during the 2007 flood to the west of North Star Road and during some lower flow events. Also, temporary flood protection measures are typically not water tight. Thus, plans must be made to ensure that sufficient pumping capacity is available to remove accumulations of local drainage and seepage flows from these locations, and pump this water over the emergency dike works.

In all of these cases, homeowners should be advised to take the precautionary step of moving all valuables from the portions of their homes that are at risk of flooding to areas that are above the potential height of the flood waters.

Finally, during a high water event, and following the declaration of a state of emergency or a state of local emergency, City of Quesnel staff members, and others appointed by the City, have considerable emergency powers to all reasonable things necessary to protect life and property from the adverse impacts of flood waters. These emergency powers are granted under the *Emergency Program Act*. Familiarity with that act is recommended before exercising any special powers.

10.4 Reduce Inflow into Sanitary Sewer

As noted above, inflows into the sanitary sewer system during flooding events can present significant challenges. Even when river levels are not at extreme high levels the rate of inflow into the sewer system due to leaks in the sanitary collection system put extra strain on the lift stations.

As the adjacent photo shows, groundwater inflow is occurring during high river levels. Taking action to seal as many leaks as is practical is an activity that is planned as part of the City's sewer system improvements.

Groundwater Flowing into Manhole Behind West Park Mall (July 2020)

11.0 Conclusions and Recommendations

11.1 Conclusions

Through this study, the following conclusions have been reached:

1. Some parts of the community are situated in locations which make them extremely vulnerable to the impacts of the flood hazard during those events.
2. There is a risk of property damage and interruption of important municipal services.
3. Climate change has the potential to result in an increase in the frequency and magnitude of extreme flood events, which is expected to create greater risks to the community than in the past.
4. Conditions may change in the future due to changes in the climate, and the construction of flood protection works.

11.2 Recommendations

The floodplain maps provided with this report should be used to define the areas within the City of Quesnel which are subject to risk from riverine flooding, and to establish flood construction levels within those areas, while recognizing that risks still exist due to flood events more extreme than the design flood event.

There are a number of mitigation measures that are recommended in order to protect the community against the risks and hazards associated with flooding due to extreme weather events.

1. Restrict future development in flood prone areas or require flood proofing in conjunction with development.
2. Plan for capital investments in flood protection diking at select locations, including more detailed review of permanent vs. temporary flood protection measures for specific locations and seeking senior government funding.
3. Continued monitoring of banks of the Quesnel River. Some areas, such as along the Cariboo Pulp and Paper Company property or around highway and train bridges, are not the City's responsibility. Since these facilities are of such importance to the community and since could present significant impacts upon failure, the City should maintain an interest in understanding if hazards arise, even if they are not City-responsibility.
4. Update the Emergency Management Plan and operating procedures to outline specific actions tied to expected flood risks and measured river water levels.

Appendix A

Hydrologic Analysis

URBAN SYSTEMS

MEMORANDUM

Date:	July 17, 2020
To:	Tanya Turner, Director of Development Services, City of Quesnel
cc:	Rick Collins, Urban Systems Ltd.; Nic Abarca, Urban Systems Ltd.
From:	Taylor Swailes, Urban Systems Ltd.; Glen Zachary, Urban Systems Ltd.
File:	1190.0184.01
Subject:	Quesnel Frequency Analysis

The purpose of this frequency analysis is to project 200 year river flows and create corresponding design flood hydrographs for Baker Creek, the Quesnel River, and the Fraser River. These hydrographs will then be used in a 2D HEC-RAS model to calculate the floodplain inundation extents.

1. Base Information

Flow projections were created using observed river flows from Water Survey of Canada (WSC):

- 08KE016: Baker Creek, flow from 1963-2013
- 08KH006: Quesnel River near Quesnel, flow from 1939-2016
- 08KE018: Fraser River at South Fort George, flow in 1984, level from 1968-2017
- 08KE002: Fraser River at Quesnel, level from 1941-1994
- 08MC018: Fraser River near Marguerite, flow from 1950-2015

Figure 1 shows the locations of the flow gauges.

Based on National Research Council Canada (NRCC) guidelines (Watt et al., 1989), peak flows can be projected for return periods of up to 4 times the record length; all of these stations have at least 50 years of data, so they can all be used to estimate the 200 year flow. The Baker Creek gauge is directly in Quesnel, on Marsh Drive. The Quesnel gauge is about 30 km upstream, so this was scaled by catchment areas to estimate flow at the mouth before frequency analysis was performed. The Fraser River station in Quesnel only has level, so the flow at Quesnel was estimated by using a watershed scaling factor between South Fort George and Marguerite.

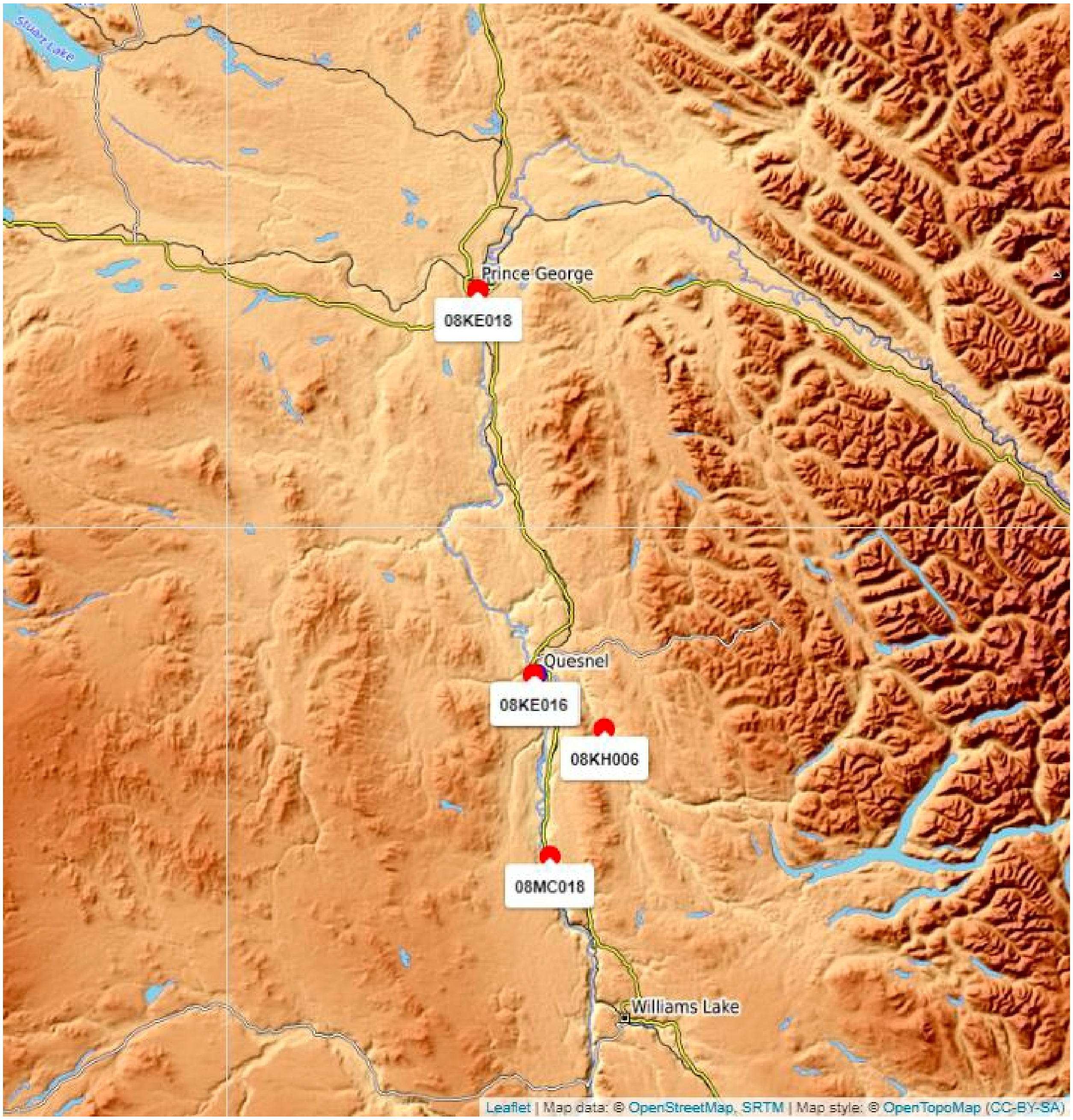


Figure 1: Flow Gauges Used for Hydrologic Analysis

2. Methodology to Project Peak 200 year flow

Guidelines covering the estimation of extreme river flows in BC include:

- *Legislated Flood Assessments in a Changing Climate in BC*; EGBC, 2018
- *Flood Mapping in BC: APEGBC Professional Practice Guidelines*; APEGBC, 2017
- *Federal Hydrologic and Hydraulic Procedures for Floodplain Delineation*; NRCan, 2019
- *Hydrology of Floods in Canada: A Guide to Planning and Design*; NRCC, 1989

The EGBC/APEGBC guidelines inform level of service (LOS) criteria and risk assessment best-practices. They recommend using the 20 year and 200 year floods, with consideration of the 500-2500 year floods if there is high loss potential. The national NRCan and NRCC guidelines leave LOS decisions to the individual provinces, but provide guidance about which statistical methods should be used to project flood return periods. Amalgamating all of these guidelines, the methodology used in this analysis to project the 200 year flow for each station is as follows:

1. Based on observed historical flows, find the annual maximum series (AMS), the highest instantaneous flow that occurred each year. If instantaneous flows are not available, the highest daily average flow is scaled up by the average instantaneous peak to daily average flow ratio. This ratio is calculated using available data.
2. Sort the AMS from smallest to largest, and assign plotting positions (initial estimates of flood return period) based on the method of Cunnane (1978).
3. Test the AMS for independence and stationarity.
4. Fit the AMS to a variety of distributions. Suggested distributions vary between guidelines, so this analysis included most of the commonly-used ones:
    a. Exponential
    b. Generalized Extreme Value (GEV)
    c. Gumbel
    d. Weibull
    e. Normal
    f. Lognormal
    g. 3-Parameter Lognormal
    h. Gamma
    i. Pearson III
    j. Log-Pearson III

    There is no consensus between the guidelines regarding which frequency distribution is most suitable or which fitting method should be used to fit each distribution to the observed data. For this analysis, fitting was performed using maximum likelihood estimation (selecting the distribution parameters which make the observed data most probable) because all of the stations analyzed have relatively long flow records. As a sensitivity check, other fitting methods such as the method of moments (setting population moments equal to sample moments) were also used to fit some of the distributions, but the differences in projected 200 year flow due to fitting methods were small compared to the differences due to distribution type.

5. Select the best fitting distribution based on a combination of:
    a. Akaike Information Criterion (AIC), a model selection "score" that rewards goodness-of-fit, but penalizes increased model complexity to discourage overfitting.
    b. Bayesian Information Criterion (BIC), which is similar to AIC but has a larger penalty term and therefore prefers simple distribution types.
    c. Visual inspection of the best-fit curve compared to the plotting position estimators from step 2.
6. Calculate the 200 year flow based on the selected distribution.

3. Methodology to Create Design Flood Hydrograph

Historically, floodplain delineation was commonly done using 1D steady-state models, which modelled the peak 200 year flow as a constant value (steady-state) and assumed the flow was uniform across the channel and floodplain. With increasing computing power and availability of detailed topographic data, it is becoming more common to create 2D unsteady-state models to provide more details of what could happen during a flood. This approach intrinsically accounts for flood volumes and flood wave timing.

2D models implicitly calculate changes in flow rates and timing during a flood event as a result of floodplain storage, travel time through the floodplain, and lateral movement of water. This means that to generate meaningful results, a full flood hydrograph is needed which includes information about the changes in flow rate before and after the peak.

None of the guidelines above provide recommendations on how to develop a design flood hydrograph once the peak flow has been determined. Therefore, for this analysis, the method of Archer et. al. (2000) was used because it is commonly cited, conceptually simple, and repeatable. This method is summarized as follows:

1. From the observed historical flows, isolate the largest flow events and their hydrographs.
2. From each flood hydrograph, derive the duration before and after the peak for selected percentages of the peak flow. The original paper suggests using 98%, 95%, 90%, 85%, …, 20%.
3. For each percentage, calculate the median duration of all of the flow events. Median is used rather than mean to reduce the influence of outliers.
4. Plot the median durations for each percentage to create a design unit hydrograph (hydrograph with a peak value of 1) and multiply by the peak 200 year flow to calculate the 200 year design hydrograph (Figure 2).

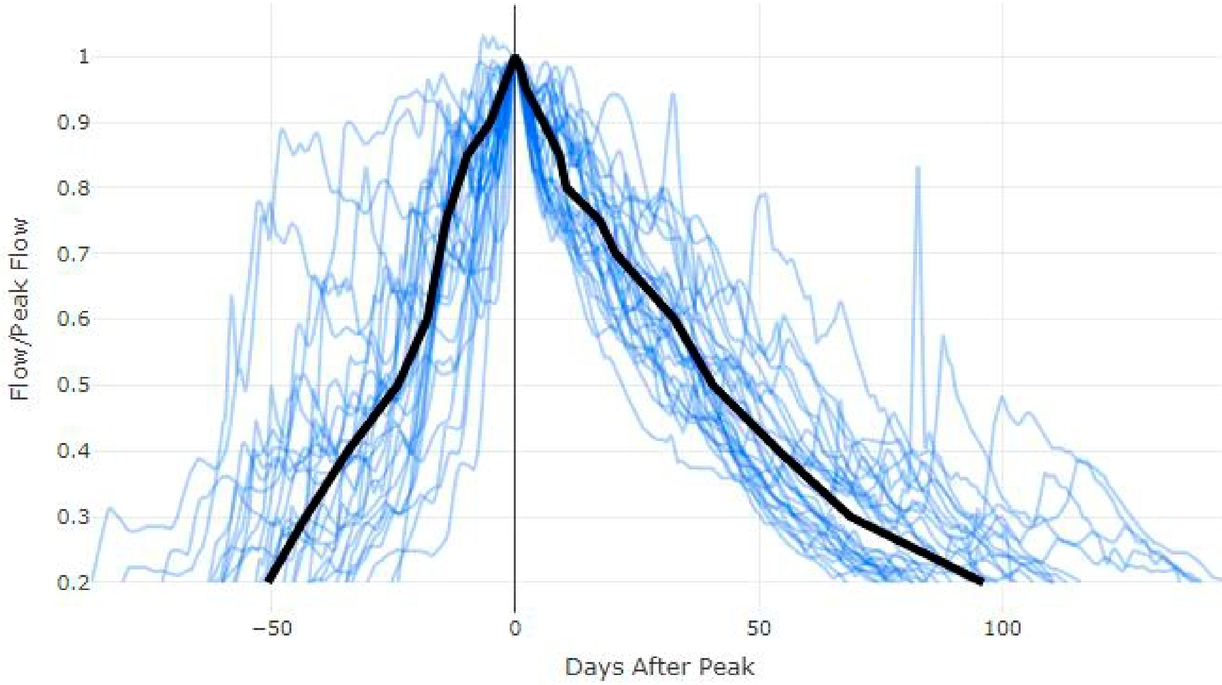


Figure 2: Example Unit Hydrograph for Quesnel River, based on Archer at al. Method. Blue lines are observed flood events normalized by peak flow. Black line is the unit design flood hydrograph, calculated by median duration before and after peak.

4. Peak Flow Timing Between Rivers

The final task to develop the model is to address the timing of peak flows on each of the rivers; i.e. does it make sense to test the 200 year flood occurring on all three rivers simultaneously?

Based on historical data, peak flows on Baker Creek are independent from flows on the Fraser; on average, peak flows on Baker occur 33 days before the flow peaks on the Fraser. Most often, Baker peaks in the first or second week of May, while the Fraser peaks in the second week of June.

In contrast, Fraser River and Quesnel River peak flows often occur very close together. The peaks are within 2 days of eachother for 10 of the 16 years for which overlapping flow records are available. Historical flood events with concurrent flows include:

- 1972, the largest flow recorded on the Fraser: peak flow in the Quesnel occurred 2 days later
- 2012 (the 2nd largest recorded flow), 2002, and 2000: Quesnel peaked 1 day after the Fraser.
- 2007, 1999, and 1974: Quesnel and Fraser peaked on the same day
- 1973 and 2009: Quesnel peaked 1 day before the Fraser

Although the peak flows do not coincide every year, the majority of the largest floods historically show the Fraser and Quesnel rivers peaking on the same day (on average). Therefore, it is realistic to assume that the 200 year flows on the Fraser and Quesnel rivers could occur at the same time. However, peak flows on Baker Creek are clearly not coincident with the two rivers, so for modelling purposes, the average flow on Baker Creek was used during June (when peak flows for the Fraser River are most likely to occur).

5. Resulting Design Hydrographs for Hydraulic Modeling

The projected 200 year peak flow rates are:

- Baker Creek: 165 m^3/s (use 172.8 m^3/s as discussed below)
  - This is slightly lower than the projection from the BC River Forecast Centre (2018), 172.8 m^3/s, and higher than the 1992 flood projection completed by Northwest Hydraulic Consultants ltd. (NHC), 129 m^3/s This is due to small differences in frequency distribution fitting methods, but the projections are overall quite similar. Since the River Forecast Centre estimate is slightly higher, and therefore more conservative, its use is recommended.
- Quesnel River: 1,306 m^3/s
  - This is slightly higher than the BC River Forecast Centre estimate of 1,284 m^3/s; in this case, the River Forecast Centre is estimating flow at the hydrometric station, upstream of the City. Our analysis scaled the flow to account for the catchment area between the gauge and the City, so a higher value is expected. For the Moffat Bridge and Johnson Bridge scour assessment in 2019, McElhanney Ltd. estimated a flow rate of 1,245 m^3/s, but the methodology used was not described. In contrast, NHC (1992) estimated a significantly higher flow of 1400 m^3/s.
- Fraser River: 7,903 m^3/s
  - No estimate for the Fraser River at Quesnel is available from the River Forecast Centre. McElhanney previously estimated 7,696 m^3/s for the scour assessment, which is similar to the value we determined. NHC (1992) estimated a significantly lower value of 6200 m^3/s.

Since the Fraser River analysis required watershed scaling rather than using a single station, it is possible to use the intermediate results from the analysis to estimate the stage-discharge curve in Quesnel. Figure 2 shows the estimated stage discharge in Quesnel in blue, and the known stage-discharge from upstream (expected to be lower) in orange for comparison. This relationship can be checked using the hydraulic model for additional verification of these watershed scaling results.

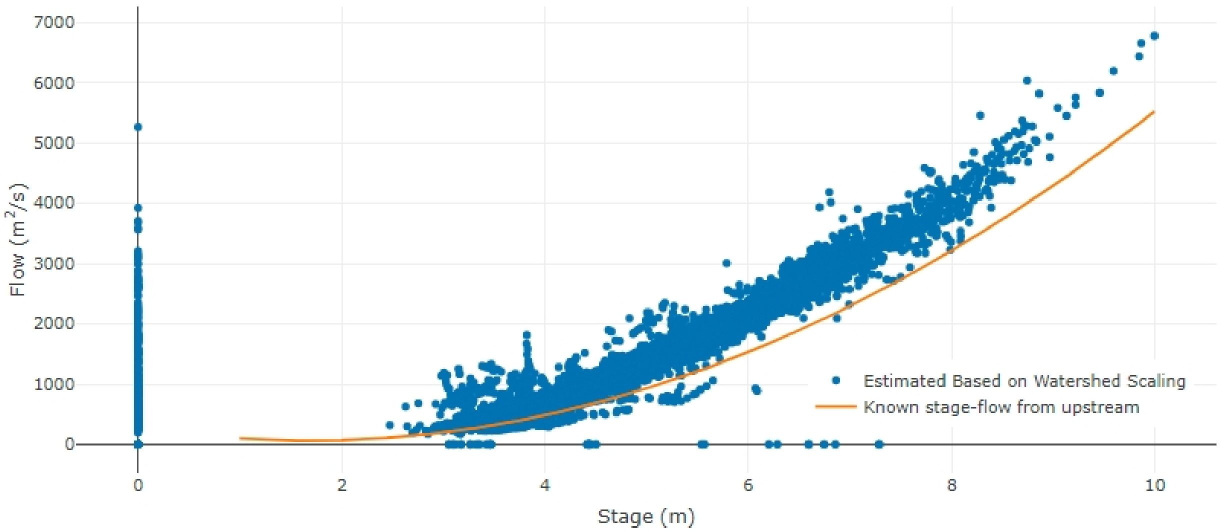


Figure 3: Estimated Stage-Discharge in the Fraser at Quesnel

The resulting design hydrographs recommended to be used in the hydraulic model are given in Figure 4 and tabulated in Appendix A.

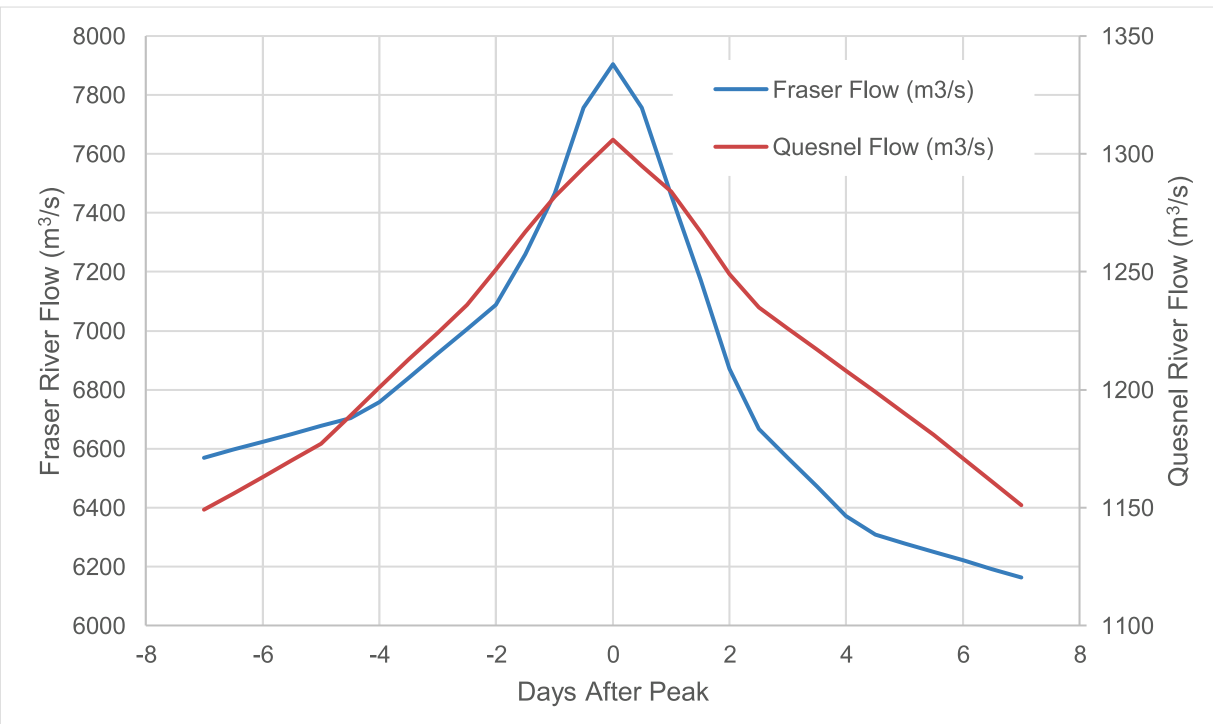


Figure 4: Design Hydrographs for Hydraulic Modelling

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6. Additional Considerations

As noted above, the current estimates (the analysis presented here, the scour assessment completed by McElhanney, and the BC River Forecast Centre projections) all present generally similar flow rates. However, there are significant differences between the rates estimated in this analysis and the rates used for the previous floodplain delineation (NHC, 1992). The rates are compared in Table 1.

Table 1: Peak Flow Estimates, m^3/s

	20 year		200 year		With Climate Change	
					20 year	200 year
	NHC, 1992	USL, 2019	NHC, 1992	USL, 2019	USL, 2019	USL, 2019
Fraser R	5300	6306	6200	7903	6937	8693
Quesnel R	1080	1103	1400	1306	1213	1437
Baker Creek	77	111	129	173	122	190

On reason for this difference is the extra data collected since 1988 (the cut-off for data used in the 1992 study). For example, the largest flows on the Quesnel River occurred in 1948, 1955, and 1972; recent years have had consistently lower flows and therefore the estimated 200 year flow rate using more recent data shows an apparent decrease.

Additionally, although the methodology to estimate peak flows is similar between this analysis and the 1992 study, curve-fitting methods have improved due to increased availability of software tools. Current best-practice is to test a larger number of distributions, and in this analysis it was found that a gamma distribution, which was not one of the distributions tested at the time, provided the best fit. Overall, the present analysis shows a well-fitting regression backed with a longer record length, and is therefore a reliable estimate of flood flows.

The difference between the estimates demonstrates the uncertainties which are inherent in projecting design flood hydrographs to an extreme return period. Therefore, it is recommended to run "sensitivity check" models to assess how the floodplain changes under varying flow rates, rather than relying on a single estimate. A valuable additional check is to model flooded area under steady state flows (i.e. the peak flow applied for the entire modelling period). This is an extremely conservative assumption since it does not account for any peak flow attenuation provided by floodplain storage. It provides, however, an indication of how sensitive the floodplain delineation is to the shape of the flood hydrograph, which can inform additional factors of safety recommended for development in or adjacent to the floodplain.

7. Climate Change Considerations

Climate Change impacts were considered using the projected hydrologic output available from the Pacific Climate Impacts Consortium (PCIC), a climate services centre at the University of Victoria. PCIC used the Variable Infiltration Capacity (VIC) model with climate output from eight statistically downscaled global climate model (GCMs) to generate daily stream flows out to 2098. The modeled flows from hydrometric stations 08KH006 (Quesnel River near Quesnel) and 08KE002 (Fraser River at Quesnel) were downloaded and analyzed to determine the expected future change in peak stream flows.

For the purpose of this study, the following scenarios were considered:

- Emissions Scenario: A2, which assumes greenhouse gas emissions will continue to rise at current rates.
- Climate Model: Median and 90th percentile of the eight bias corrected models
- Time Periods: 50 year time periods were used to provide robust estimates. The climate models project flows to the year 2100, so the furthest future time period is 2050-2100.
  - 1970-2020 (baseline)
  - 2020-2070 (near future)
  - 2050-2100 (far future)

The projected changes in average annual peak flows (index floods) based on the VIC are summarized below for the Fraser and the Quesnel Rivers.

Table 2: Fraser River Projected Changes from Baseline (1970-2020)

Time Period	Median Increase	90th Percentile Increase
2020-2070	0%	11%
2050-2100	0%	19%

Table 3: Quesnel River Projected Changes from Baseline (1970-2020)

Time Period	Median Increase	90th Percentile Increase
2020-2070	-3%	8%
2050-2100	-6%	8%

Tables 2 and 3 show that there is an increase of up to 19% in peak flow rate expected on the Fraser River as a result of climate change; the Quesnel River shows a smaller change, with some models projecting a slight decrease, but the “high” models showing an 8% increase.

As a point of comparison, previous work completed by PCIC and referenced by McElhanney in the scour assessment, recommended using a global 10% increase across the entire watershed. This is a similar magnitude of change to the “near future” 90th percentile numbers presented above, and may be easier to implement in design guidelines.

8. Conclusion

This analysis presents the recommended 200 year flow rates and design flood hydrographs for use in hydraulic analysis for the City of Quesnel floodplain delineation. The instantaneous peak flows for Baker Creek, the Fraser River, and the Quesnel River are 172.8 m^3/s, 7,903 m^3/s, and 1,306 m^3/s respectively.

Additionally, we recommend that the above peak flows be increased by a minimum of 10% to account for potential future climate change. This allowance is based on analysis of hydrologic modeling work completed by PCIC, and considers select GCMs, time periods, and emissions scenarios. Different assumptions would likely result in differences to floodplain delineation, and therefore risk management strategies, such as sensitivity analysis, should be used. It is important to reiterate that climate change projection is an evolving science, and it may be valuable for the City to review and update projections every 5 years or so.

We look forward to your questions and comments.

Sincerely,

URBAN SYSTEMS LTD.

Reviewed By:

PROFESSIONAL PROVINCE OF A. G. ZACHARY BRITISH COLUMBIA ENGINEER

2020-07-17

Taylor Swailes, E.I.T.
Water Resources Analyst

Glen Zachary, M.A.Sc., P.Eng.
Senior Hydrology and Hydraulics Engineer

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9. Appendix: Recommended Design Hydrographs

Table 4: Recommended Design Hydrographs

Days to Peak	Fraser Flow (m^3/s)	Quesnel Flow (m^3/s)	Baker Flow (m^3/s)
-7.0	6570	1149	8.04
-6.5	6597	1156	8.04
-6.0	6624	1163	8.04
-5.5	6650	1170	8.04
-5.0	6677	1177	8.04
-4.5	6704	1189	8.04
-4.0	6759	1201	8.04
-3.5	6841	1213	8.04
-3.0	6924	1224	8.04
-2.5	7006	1236	8.04
-2.0	7089	1251	8.04
-1.5	7259	1267	8.04
-1.0	7465	1282	8.04
-0.5	7757	1294	8.04
0.0	7903	1306	8.04
0.5	7757	1295	8.04
1.0	7460	1284	8.04
1.5	7173	1267	8.04
2.0	6871	1249	8.04
2.5	6668	1235	8.04
3.0	6569	1226	8.04
3.5	6471	1217	8.04
4.0	6372	1208	8.04
4.5	6308	1199	8.04
5.0	6279	1190	8.04
5.5	6250	1181	8.04
6.0	6221	1171	8.04
6.5	6191	1161	8.04
7.0	6162	1151	8.04

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10. Bibliography

AECOM, 2016. National Principles, Best Practices and Guidelines -- Flood Mapping. Natural Resources Canada.

Akaike, H., 1974. A New Look at the Statistical Model Identification. IEEE Transactions on Automatic Control AC-19, 716–723.

APEGBC, 2017. Flood Mapping in BC: APEGBC Professional Practice Guidelines v1.0. Association of Professional Engineers and Geoscientists of BC.

Archer, D., Foster, M., Faulkner, D., Mawdsley, J., 2000. The Synthesis of Design Flood Hydrographs, in: Proceedings of a CIWEM/ICE Conference on Flooding - Risks and Reactions.

Cunnane, C., 1978. Unbiased plotting positions – A review. Journal of Hydrology, Volume 37, Issues 3-4, 205-222.

EGBC, 2018. Legislated Flood Assessments in a Changing Climate in BC. Engineers and Geoscientists British Colubia.

Fathalla, A., 2019. Moffat and Johnston Bridge Scour Assessment (Memorandum). McElhanney Limited.

Khaliq, M.N., Fergusson, S., 2016. Flood Hazard Mapping: A Review of International and National Hydrology and Hydraulic Guidelines (Technical Report No. OCRE-TR-2015-028), Marine Infrastructure Energy & Water Resources. National Research Council Canada, Ottawa, Ontario, Canada.

Luo, C., 2018. Flood Frequency Analysis for the CLEVER Model. BC River Forecast Centre.

Natural Resources Canada, Public Safety Canada, 2019. Federal hydrologic and hydraulic procedures for floodplain delineation (No. 113e). https://doi.org/10.4095/299808

Natural Resources Canada, Public Safety Canada, 2018a. Bibliography of best practices and references for flood mitigation (No. 115e). https://doi.org/10.4095/308380

Natural Resources Canada, Public Safety Canada, 2018b. Federal airborne LiDAR data acquisition guideline (No. 117e). https://doi.org/10.4095/308382

Natural Resources Canada, Public Safety Canada, 2018c. Federal Floodplain Mapping Framework (No. 112e). https://doi.org/10.4095/308128

Northwest Hydraulic Consultants, 1992. Floodplain Mapping Investigation: Fraser and Quesnel Rivers at Quesnel Design Brief. B.C. Ministry of Environment, Land, and Parks.

Watt, W.E., Lathem, K.W., Neill, C.R., Richards, T.L., Rousselle, J., 1989. Hydrology of Floods in Canada; A Guide to Planning and Design. National Research Council Canada, Associate Committee on Hydrology, Ottawa, Ontario, Canada.

Appendix B

Hydraulic Analysis

MEMORANDUM

Date:	March 30, 2020
To:	Tanya Turner, Director of Development Services, City of Quesnel
cc:	Rick Collins, Urban Systems Ltd.; Brendan Pauls, Urban Systems Ltd.
From:	Nicolas Abarca, Urban Systems Ltd.
File:	1190.0184.01
Subject:	Quesnel Hydraulic Modelling and Floodplain Mapping

1.0 INTRODUCTION

The purpose of this memo is to provide information on the methodology and criteria used for the development of a hydraulic model of the Fraser River, the Quesnel River, Baker Creek and Dragon Creek, in the City of Quesnel, BC.

It is important to note that there are risks of the banks of Dragon Creek to overtop further upstream along the creek where there is no influence from high river levels. Those Dragon Creek flood risks have historically been due to sedimentation buildup in the channel, upstream bank failure that could release a larger flow if a temporary blockage occurs, and creek channel migration. Risk of flooding in those upstream areas is not included in this modelling exercise.

It is also noted that there is a risk of flooding and damage due to the release of ice jams within the Baker Creek watershed and risk of flow being blocked at the Marsh Drive bridge. Those ice jam flows and flooding are also not the subject of this modelling.

The hydraulic model was used for updating the City's Floodplain Mapping developed by Northwest Hydraulic Consultants Ltd. (NHC) in 1992.

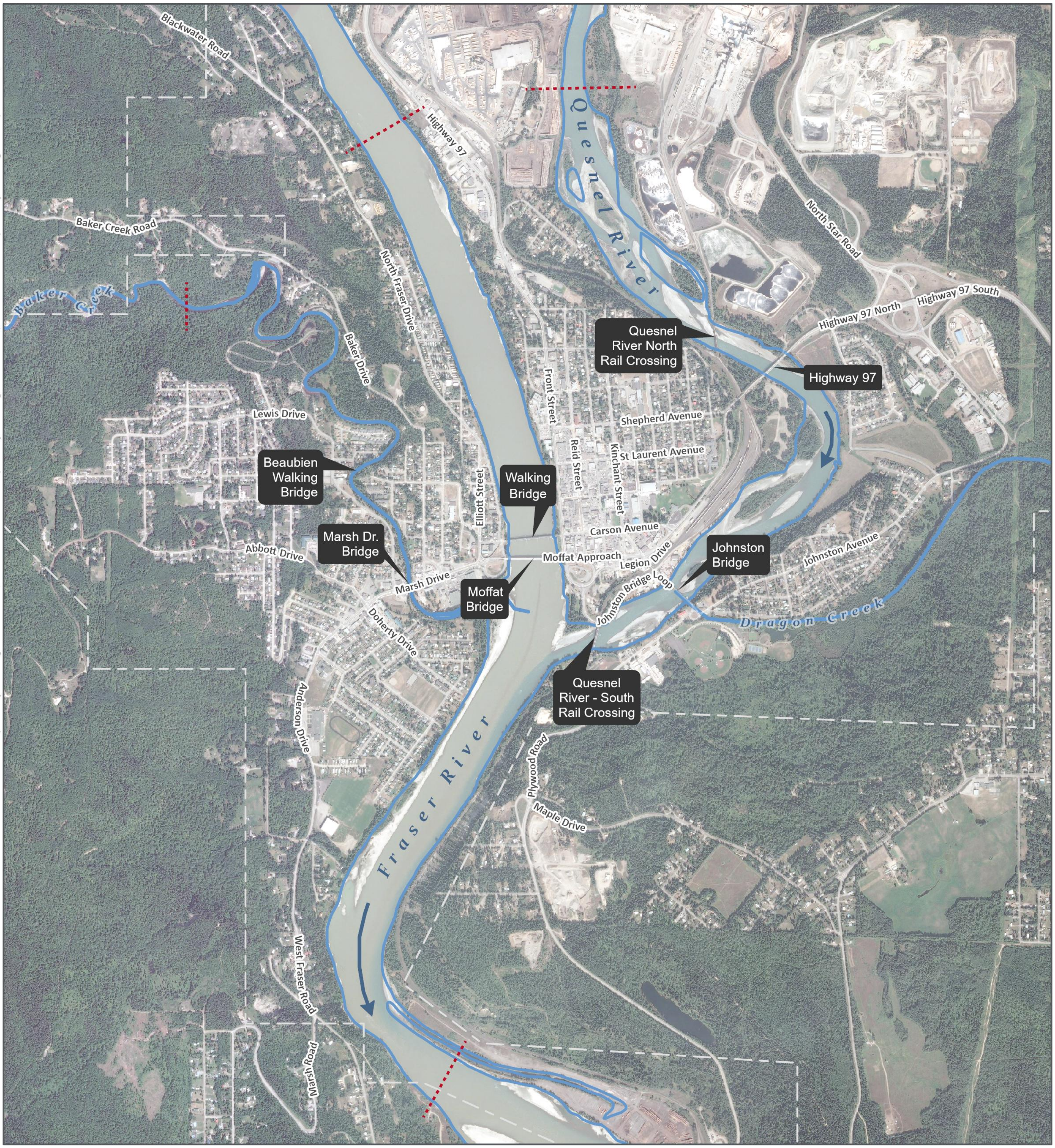
This updated hydraulic model will allow the City of Quesnel to:

- Understand existing flood hazards and risks to existing development and property;
- Assess future development plans and land use intensification near these watercourses to reduce flood hazards and avoid creating new problems;
- Establish a range of suitable, efficient, and cost-effective measures for dealing with flood hazards;
- Understand how infrastructure assets may affect flooding potential in the City, particularly highway bridge crossings;
- Develop a long-term capital improvement plan aimed at upgrading the performance of the existing drainage system, where possible and practical, over time; and
- Identify non-structural mitigation plans, such as a bylaw aimed at flood hazard protection through municipal regulations.

2.0 GENERAL DESCRIPTION OF THE STUDY AREA

This floodplain mapping investigation involved a detailed hydraulic analysis of the Fraser and Quesnel Rivers, Baker Creek and Dragon Creek. The study area comprises a 12.3 km reach of the Fraser River through the City of Quesnel, a 4.4 km reach of the Quesnel River, a 3.9 km reach along Baker Creek and a 1.2 km reach along Dragon Creek. The extent of the study area, including all these river channels, are shown in in **Figure 1.**

The Fraser River originates in the Rocky Mountains and, at the City of Quesnel, it flows in a southerly direction and has a drainage area of approximately 100,000 km^2. The Quesnel River flows in a southwesterly direction and discharges into the Fraser River at the south end of the city. Baker Creek is a small tributary of the Fraser River that flows from the west and enters the River just upstream of the Quesnel River confluence. Dragon Creek is a tributary of the Quesnel River draining from the east and entering the River via a 1,200 mm culvert under Johnston Avenue. Drainage basins are shown in **Figure 2**.



CITY OF
Quesnel

Location Plan

FIGURE 1

Model Limits
Creek
River
City Boundary

0 250 500 750
Meters

N

Coordinate System:
NAD 1983 CSRS UTM Zone 10N

Scale:
1:26,500
(When plotted at 8.5"x11")

Data Sources:
- Data provided by
City of Quesnel
Data BC
Urban Systems Ltd.

Project #: 1190.0184.01
Author: BB
Checked: NA
Status: Draft
Revision: A
Date: 2020 / 3 / 18

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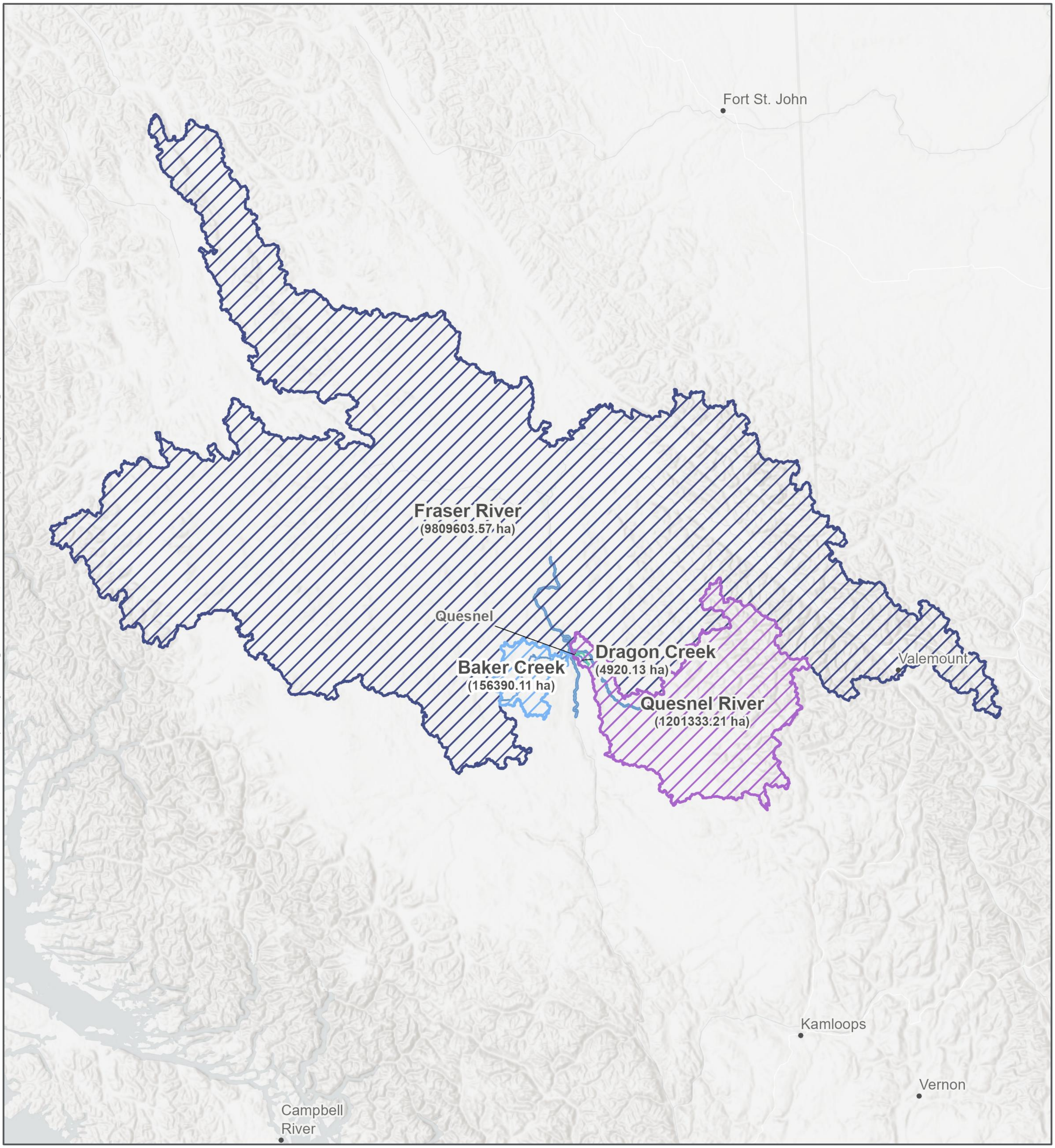
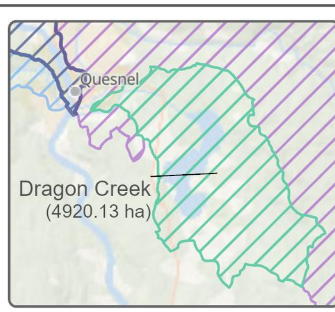


CITY OF Quesnel

Legend:
- Creek
- Fraser River
- Baker Creek
- Dragon Creek
- Quesnel River

Drainage Basins

FIGURE 2



0 25 50 75

Kilometers

Coordinate System: NAD 1983 CSRS UTM Zone 10N

Scale: 1:3,500,000 (When plotted at 8.5"x11")

N

Data Sources:
- Data provided by City of Quesnel
Data BC
Urban Systems Ltd.

Project #:	1190.0184.01
Author:	BB
Checked:	NA
Status:	Draft
Revision:	A
Date:	2020 / 3 / 18

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The accuracy & completeness of information shown on this drawing is not guaranteed. It will be the responsibility of the user of the information shown on this drawing to locate & establish the precise location of all existing information whether shown or not.

3.0 HISTORY OF FLOODING – THIS SECTION MOVED TO MAIN REPORT – DELETE FROM HERE

The City of Quesnel is vulnerable to high flood water in the Fraser and Quesnel Rivers, which in turn causes flooding due to backwater along Baker Creek and Dragon Creek. While extreme events of this sort might be seen as rare, they can and sometimes do occur more frequently than expected by the public and community leaders.

Maximum flows in the Fraser and Quesnel Rivers typically occur in the late spring and early summer as a result of snowmelt. One clear example of snowmelt related flooding was the 1972 flood, which resulted from extreme snow accumulation during the winter followed by warm weather in the spring. A peak flow of 6,510 m^3/s was recorded at the Fraser River near Marguerite hydrometric station (08MC018) located downstream of the City. This corresponded to a 50-year return period flood and resulted in severe flooding, particularly in West Quesnel near the Baker Creek confluence (**Photo 1**) and upstream of the Fraser Bridge Crossing. Flooding on the Quesnel River occurred near the confluence and at the public works yard on the right bank (**Photo 2**).

Photo 1 - 1972 – Flooding at Lower End of Baker Creek Near Confluence with Fraser River (Source B.C. Ministry of Environment)

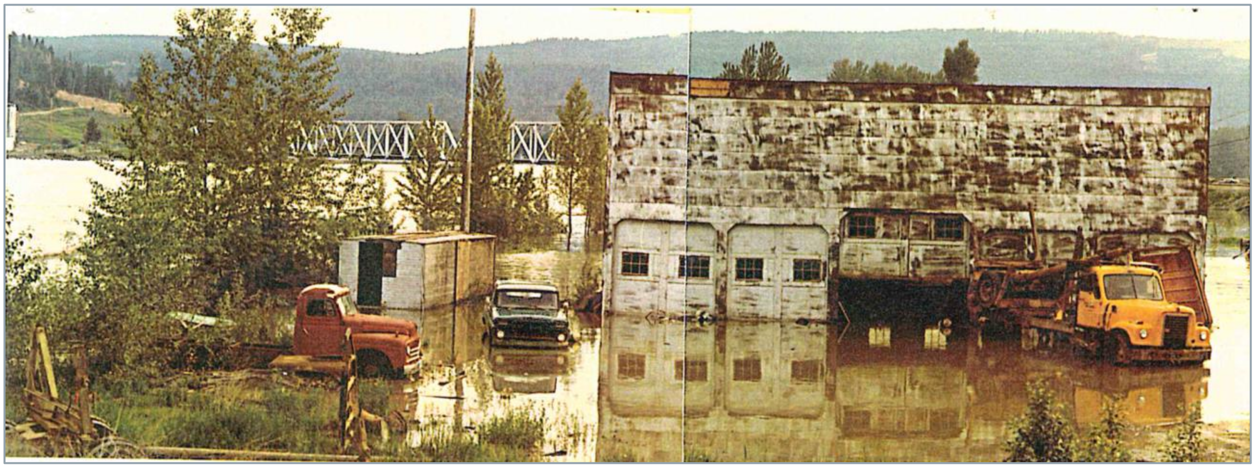

Photo 2 - 1972 – Public Works Yard – 50 Year Return Period Flood (Source: City of Quesnel)

Prior to 1972, there are several recorded flooding events, including in 1967 (with a recorded peak flow of 6, 120 m^3/s), and in 1948 flood, which resulted in inundated areas on the left bank of the Fraser River next to the Quesnel River confluence, along the Quesnel River and on in the vicinity of the Baker Creek confluence. **Photo 3** below shows flooding of the Public Works Yard during the 1948 event.

Photo 3 - 1948 – Public Works Yard – 1992 Floodplain Mapping Design Brief Indicates this Flood is Estimated to be the Same Magnitude as the 1972 Flood (Source: Jack Ives from Branwen Patenaude's Originals)

More recent floods include the 1990 flood, which occurred at the beginning of June, similar to the 1972 event, was the result of sudden warm weather that led to rapid snowmelt. A maximum daily discharge of 5,790 m^3/s was recorded at the Marguerite hydrometric station, which corresponds to approximately a 10-year flood. **Photo 4** below shows the extent of flooding near the confluence of the Fraser and Quesnel Rivers and Baker Creek. The Riverfront Walk and a Portion of Legion Drive were inundated, and other areas on the west bank of the Fraser River (upstream of the bridges and the underpass of the Moffat Bridge) were also flooded. High water levels lasted for almost seven days.

Photo 4 -June 21, 1990 - Flow Near the Confluence of Fraser River, Quesnel River and Baker Creek (Source: Perry's Picture Place, Quesnel)

In 2007, the City has experienced higher water elevations more recently, but not to the extent witnessed in the 1948 or 1972 events. A maximum daily discharge of 5,480 m^3/s was recorded at the Marguerite hydrometric station, which was slightly below the 1990 event. As with the 1990 event, portions of the Rivers Trail and lower areas of road under the Johnston Bridge and Moffatt Bridge (west side) were flooded.

Predictions during Spring 2007 indicated that a higher than usual flood level was expected, which resulted in the City taking pre-emptive measures such as constructing a temporary berm behind West Park Mall and along the lower elevation portion of North Fraser Drive. A severe flooding event did not occur, but it helped the City to understand the efforts required to implement temporary flood measures.

Photo 5 - 2007 – Temporary Flood Protection Along Fraser River Upstream of Bridge Crossings (Source: Urban Systems Ltd.)

Photo 6 - 2007 – Temporary Flood Protection Along Baker Creek Near Confluence of Fraser River (Behind West Park Mall) (Source: Urban Systems Ltd.)

4.0 PAST STUDIES

The existing floodplain mapping for the City of Quesnel was developed in 1992 by NHC, making use of peak flow data that was available at that time. Backwater computations were conducted for the Fraser River, the Quesnel River and Baker Creek in HEC-2, an open-channel, one-dimensional modelling software developed by the US Army Corps of Engineers[1]. NHC conducted cross-sectional surveys of the modelled reaches and extended the cross-sections across and beyond the floodplain using 1:5,000 scale, 2m contour interval topographic mapping provided by the Ministry of the Environment (MOE).

Channel roughness coefficients were calibrated against two sets of recorded profiles: high water marks surveyed by the MOE corresponding to the 1990 peak flows, and water surface levels at the time of the survey in July 1990. The agreement between the computed and recorded water surface elevations (WSE) was considered acceptable for the Quesnel River and Baker Creek. However, a review of recorded water levels on the Fraser River at Quesnel showed large variations in the stage-discharge relation. As a result, roughness values were increased by approximately 20% for the model to match the high envelope rating curve at Quesnel.

It is important to note that, even though flood levels may be affected by ice jams, these were not accounted for in NHC's study. According to the 1992 document, residents report that the Fraser River may only freeze over completely once every three years and that flooding due to ice jams has not occurred. Similarly, even though ice jams have been known to occur in the Quesnel River, the study mentions that no damage to structures due to ice have been reported.

Floodplain mapping was developed as part of the 1992 study at a scale of 1:5,000, and contour intervals of 2m were prepared to show the outline of the 200-year floodplain. The 1992 floodplain mapping is included in **Attachment A.**

5.0 UPDATED HYDROLOGY

There are now an additional 28 years of data available, since the previous flood mapping study, to update the peak flow estimates for the Fraser and Quesnel Rivers and Baker Creek at the City of Quesnel. Furthermore, the potential impacts of climate change on peak flow estimates are now much better, although not fully, understood and need to be taken into consideration when developing a flood hazard plan.

Urban conducted an updated hydrologic analysis based on this more extensive record and recommended 200-year flow rates and design flood hydrographs for use in hydraulic analysis. As summarized in the Urban Systems memo entitled "Quesnel Frequency Analysis", the instantaneous peak flows for Baker Creek, the Fraser River, and the Quesnel River were established at 172.8 m^3/s, 7,903 m^3/s, and 1,306 m^3/s, respectively.

[1] HEC-2 has, in recent years, evolved into the HEC-RAS software, which has improved computational capabilities, which include, among other things, unsteady flow and 2-dimensional modelling.

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Additionally, in order to account for potential future climate change, an analysis of hydrologic modelling work completed by PCIC was conducted, and considered select General Circulation Models (GCMs), time periods, and emissions scenarios. The projected increases in annual peak flows on the Fraser and Quesnel rivers were estimated to range between 8% and 19%. Based on subsequent discussions with the City, it was decided to take a conservative approach and apply a 20% increase on peak flood flows for both major rivers. Note that using a 20% increase due to Climate Change appears to be generally consistent with the approach adopted in many locations throughout the Province. Details on the hydrologic analysis conducted by Urban are included in the November 15, 2019 memorandum entitled “Quesnel Frequency Analysis”. The following table summarizes peak flow estimates from the 2019 hydrologic analysis compared to the 1992 estimates:

Table 1 - Comparison of Peak Flow Estimates (m^3/s)

					With Climate Change	
	20 year		**200 year**		**20 year**	**200 year**
	NHC (1992)	**USL (2019)**	**NHC (1992)**	**USL (2019)**	**USL (2019)**	**USL (2019)**
Fraser River	5,300	6,306	6,200	7,903	7,567	9,483
Quesnel River	1,080	1,103	1,400	1,306	1,323	1,567
Baker Creek	77	111	129	173	133	208

The above flows were used for all unsteady flow hydraulic computations. It is important to note that, historically, the majority of the largest floods show the Fraser and the Quesnel Rivers peaking on the same day. As such, it is realistic to assume that the 200-year flows on both rivers could occur at the same time. However, peak flows on Baker Creek have historically never coincided with peaks on the two main rivers. As a result, mean annual flows on Baker Creek were used for all simulations.

The design hydrographs for the Fraser and Quesnel Rivers resulting form the 2019 hydrologic analysis (not including climate change) and used for hydraulic modelling are shown in **Figure 3**.

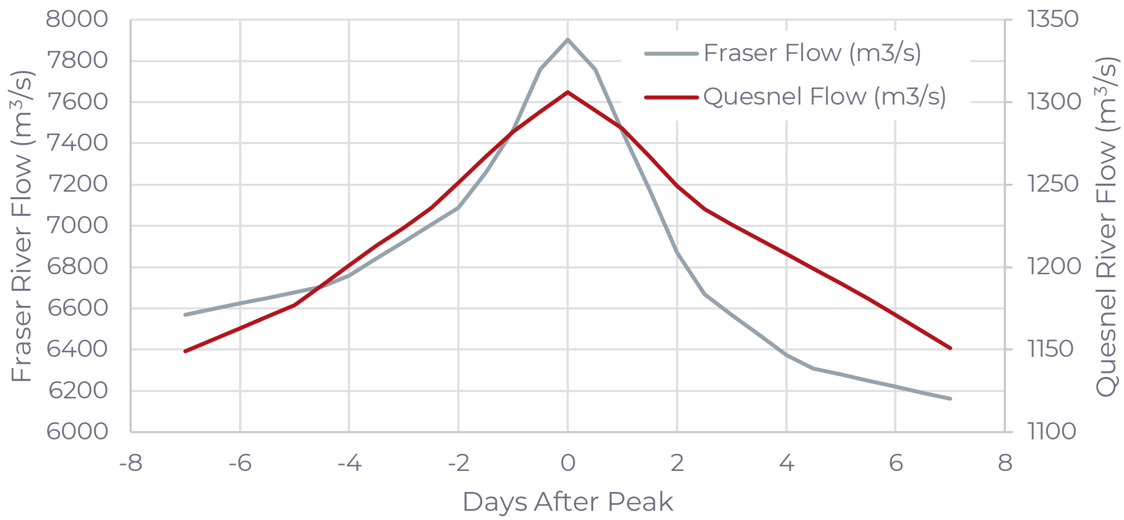


Figure 3 - Fraser River and Quesnel Hydrographs

6.0 HYDRAULIC MODELLING

A computer model of the Fraser River, the Quesnel River, Baker Creek and Dragon Creek was constructed using the hydraulic modelling program GeoHEC-RAS. This program was selected because it allows for the construction of a combined 1-D model for the main river channels and 2-D flow meshes for the floodplain areas, which was deemed to be desirable for this study area because of the expected interaction between the rivers and the adjacent lands upon which overland flow was known to have occurred during past flooding events. The 2-D component allows for more representative flooding analysis, including the effects of floodplain storage, which have the potential to affect the calculated water surface elevations for a specific single value flow rate. The effect is typically a lowering of the water surface elevations compared to 1-D models.

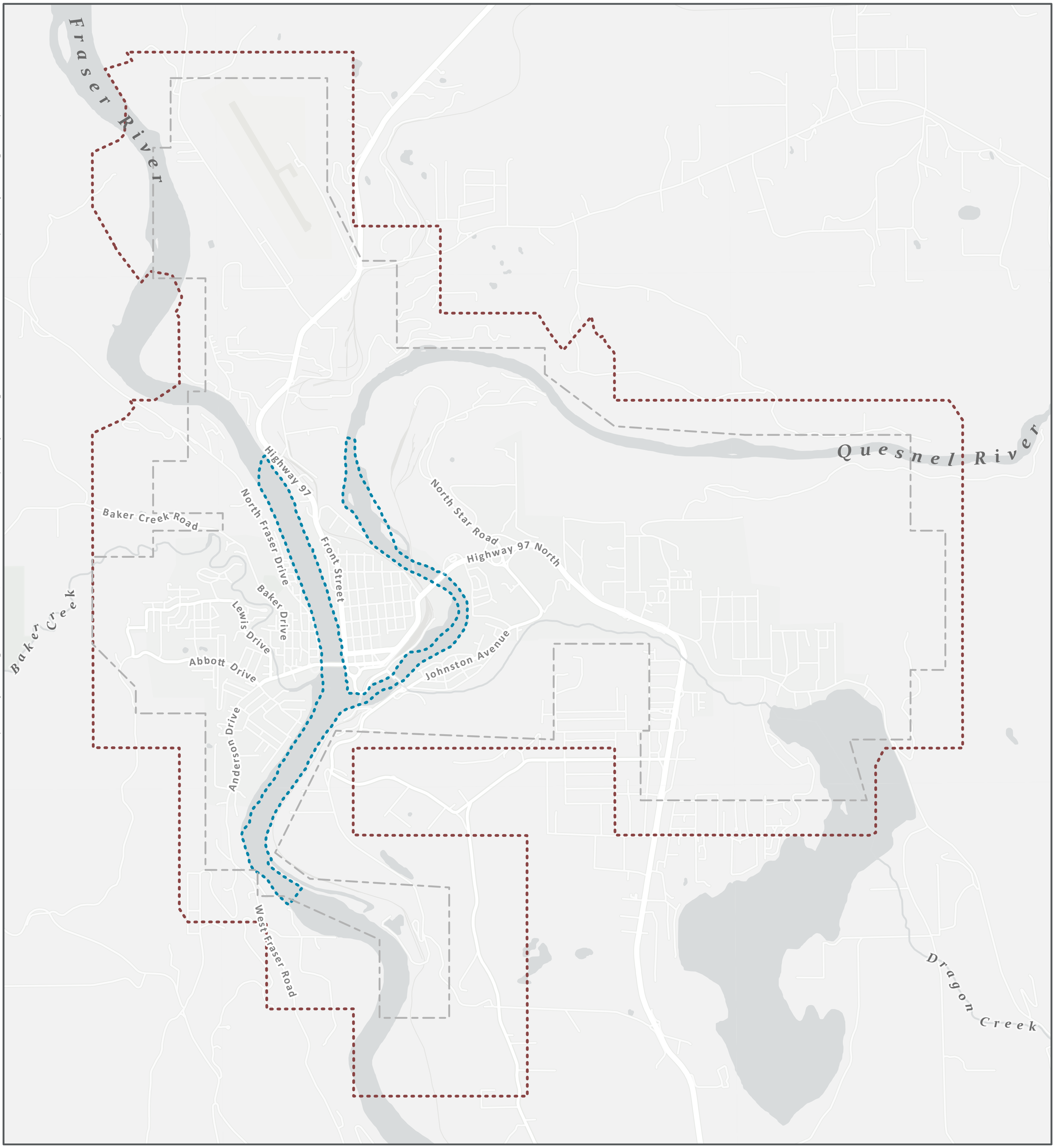
Baker Creek and Dragon Creek outflows amount for a very small percentage of the Fraser and Quesnel River flows, respectively. As a result, they essentially have no effect on water levels of the main rivers during a major flooding event. However, because of the history of flooding along these two water courses, resulting from backwater from the Fraser and Quesnel Rivers, they were included in the model as part of the 2-D flow overflow areas. Note that, while mean annual flows were included for Baker Creek, flows along Dragon Creek were reviewed but considered too small during high river level periods and thus negligible.

6.1. MODEL GEOMETRY

Development of the model began with the acquisition of LiDAR data from the City, complemented with a bathymetric survey of the Fraser and Quesnel Rivers, was carried out by McElhanney Engineering in the summer of 2019. The extents of both the LiDAR data and the bathymetric survey are shown in **Figure 4**. The primary purpose of the bathymetric survey is to provide an accurate representation of the channel bottom, below the water surface elevation at the time the LiDAR was flown, as LiDAR technology cannot obtain ground information beyond the surface of the water. The LiDAR and the bathymetry Digital Elevation Model (DEM) were merged together to create a continuous surface between the channel and the surrounding land.

The bathymetric survey limits did not extend along the Fraser as far as the City's north and south boundaries. In order to extend the model to the City limits, the upper 1.4 km and lower 1.1 km of the modelled reach of the Fraser River were interpolated based on the average slope along the river profile, using upstream and downstream cross-section geometries.

There are five bridges along the modeled reaches of the Fraser and Quesnel Rivers and two additional bridges exist along Baker Creek. However, because only backwater is the main concern along Baker Creek, and the Creek is being modelled as a 2-D overflow area, these two structures were not included in the model. Information about bridge structures within the Fraser and Quesnel Rivers was collected and used to create the model geometry. Details of the crossings included the location, size and shape of piers, top of bridge and underside of bridge elevations, and abutment locations and dimensions. There are no other structures, such as dams or weirs, in the study area.



CITY OF Quesnel

City Boundary
LiDAR Extent
Bathymetric Survey Extent

LiDAR and Bathymetric Survey Extents

FIGURE 4

0 250 500 750
Meters

N

Coordinate System:
NAD 1983 CSRS UTM Zone 10N

Scale:
1:60,000
(When plotted at 8.5"x11")

Data Sources:
- Data provided by
City of Quesnel
Data BC
Urban Systems Ltd.

Project #: 1190.0184.01
Author: BB
Checked: NA
Status: Draft
Revision: A
Date: 2020 / 3 / 17

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The accuracy & completeness of information shown on this drawing is not guaranteed. It will be the responsibility of the user of the information shown on this drawing to locate & establish the precise location of all existing information whether shown or not.

The overbanks were modelled as 2-D overflow areas, connected to the main channels via lateral structures in the form of zero-elevation overflow weirs. The 2-D mesh was defined as a 20m x 20m uniform mesh, with a 10m x 10m resolution along defined break lines, used to define major changes in ground slope, such as road embankments of creek top-of-banks.

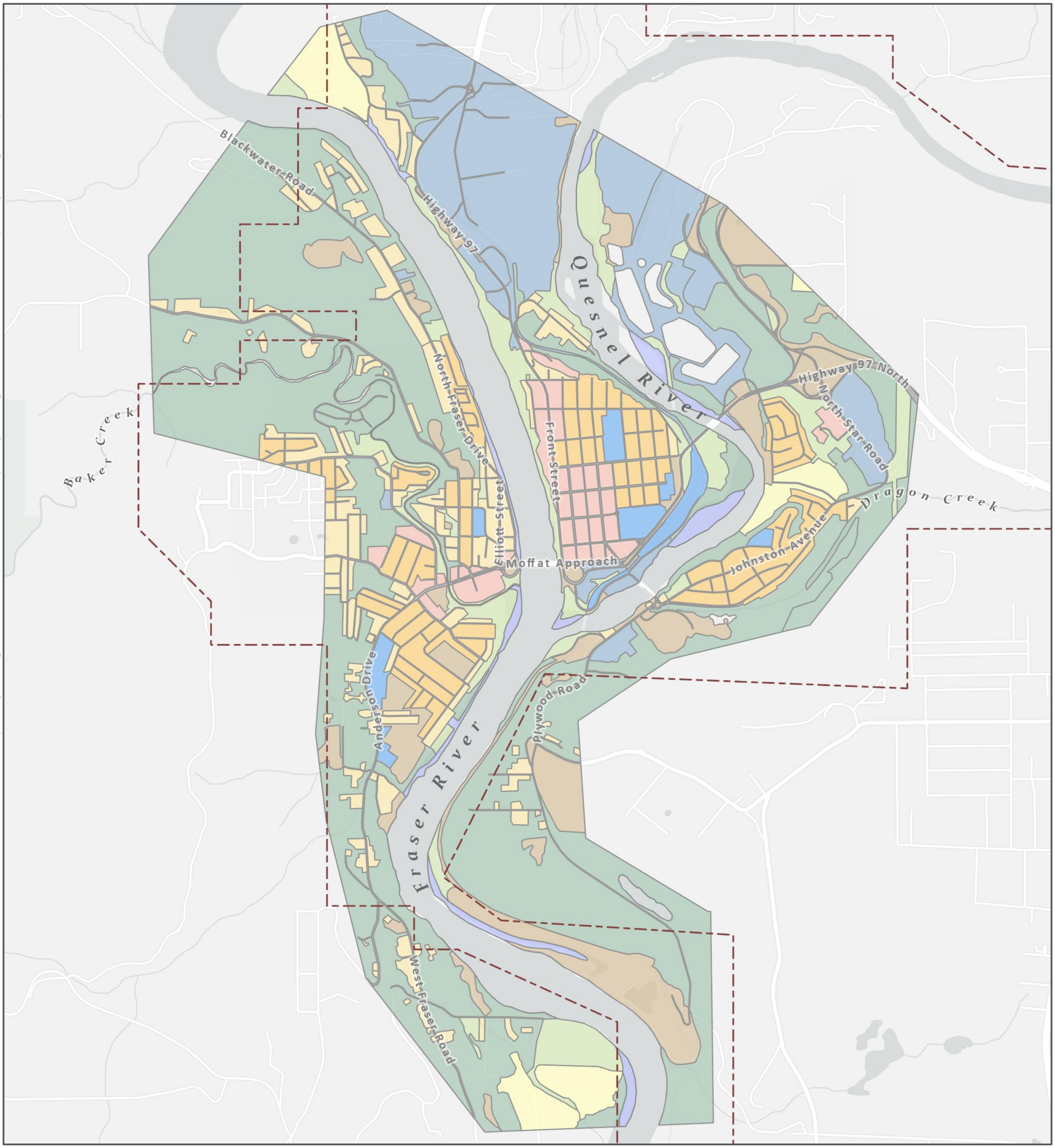
6.2. LAND COVER (OVERBANK MANNING'S ROUGHNESS COEFFICIENTS)

Land cover was digitized based on Bing imagery orthophotos, captured between August 2018 – June 2019. A map showing the land cover used for modelling purposes is included in **Figure 5**. The land cover was used to determine Manning's roughness coefficients for all overbank areas in the model, using the "Modified Channel Method" (USGS, 1992[2]). The following Table provides a summary of Manning's roughness coefficients by land use. Detailed calculations using the Modified Channel Method are included in **Attachment B**.

Table 2 - Land Cover (Overbank Manning's Roughness Coefficients)

Land Cover	Manning's 'n'
Water	0.045
Roads	0.02
Industrial	0.15
Agricultural	0.043
Open Space	0.04
Low Density Residential	0.05
Lightly Forested	0.14
Dense Forest	0.16
Wetland	0.14
High Density Residential	0.064
Commercial	0.15
Institutional	0.06

[2] United States Geological Survey. (1992). "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains", Water Supply Paper 2339.



CITY OF Quesnel

Land Cover

FIGURE 5

City Boundary

Land Cover Type (Manning's n values)

- Agricultural (0.043)
- Commercial (0.15)
- Dense Forest (0.16)
- High Density Residential (0.064)
- Industrial (0.15)
- Institutional (0.06)
- Lightly Forested (0.14)
- Low Density Residential (0.05)
- Open Space (0.04)
- Roads (0.02)
- Wetland (0.14)

0 250 500 750

Meters

N

Coordinate System:
NAD 1983 CSRS UTM Zone 10N

Scale:
1:36,000
(When plotted at 8.5"x11")

Data Sources:
- Data provided by City of Quesnel
Data BC
Urban Systems Ltd.

Project #: 1190.0184.01
Author: BB
Checked: NA
Status: Draft
Revision: A
Date: 2020 / 3 / 18

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6.3. MAIN CHANNEL ROUGHNESS COEFFICIENTS (MODEL CALIBRATION)

Initial Manning's 'n' values for the main channel were estimated using the modified channel method but calibrated based on known water surface elevations. Unfortunately, the only available information on known water surface elevations comes from the 1992 floodplain mapping investigation report (NHC), which includes high water marks from a June 1990 event, and from the time the survey was conducted (July 1990). The high-water marks for the June event corresponded to peaks that did not occur simultaneously, but rather 10 days from each other. As a result, this event was not considered appropriate for calibration.

The flows from the time of the survey and the surveyed water levels were used for calibration of Manning's n. The following were the peak flows used:

- Fraser River above the Quesnel River Confluence = 2,630 m^3/s (July 4, 1990)
- Quesnel River = 763 m^3/s (July 4, 1990)
- Baker Creek = 13.8 m^3/s (July 4, 1990)

The results of the calibration are shown in **Tables 3 and 4** below:

Table 3 - Main Channel Manning's Roughness Coefficient Calibration Results (Fraser River)

NHC X-Section	Urban Model X-Section	1992 NHC Manning's 'n'	2020 USL Manning's. 'n'	Recorded WSE (m)	Modelled WSE (m)	Difference (m)
7	1028	0.030	0.027	467.31	467.34	0.03
8	1041	0.030	0.027	467.74	467.73	-0.01
9	1001	0.030	0.020	468.12	468.23	0.11
11	1011	0.028	0.020	468.61	468.52	-0.09
15	1014	0.027	0.031	468.62	468.57	-0.05
16	1023	0.028	0.031	468.91	468.87	-0.04
17	1037	0.028	0.031	469.4	469.38	-0.02

Table 4 - Main Channel Manning's Roughness Coefficient Calibration Results (Quesnel River)

NHC X-Section	Urban Model X-Section	1992 NHC Manning's 'n'	2020 USL Manning's. 'n'	Recorded	Modelled	Difference
3	1009.1	0.036	0.039	468.59	468.38	-0.21
9	1018	0.036	0.030	468.97	469.07	0.1
10	1021	0.036	0.037	469.25	469.2	-0.05
12	1041	0.037	0.037	471.64	471.56	-0.08
15	1053	0.030	0.020	471.89	472.00	0.11
19	1061	0.030	0.020	472.35	472.68	0.33
22	1069	0.030	0.033	473.53	473.58	0.05

As seen in the above tables, the calibrated Manning's 'n' values are generally lower than those used in the 1992 study. It is important to note however, that the 1992 study included calibration of Manning's 'n' values to multiple events over a longer reach for both the Quesnel and the Fraser Rivers. Additionally, based on a review of recorded Fraser River water levels at Quesnel, roughness values for the 1992 study were increased artificially by 20% for the model to match the high envelope rating curve at Quesnel.

Because of the lack of more recently recorded water levels, it was determined that artificially increasing Manning's 'n' values was unjustifiable, particularly given that flood flows are already being artificially increased to account for climate change. As a result, it was decided to use the calibrated Manning's 'n' values as shown in **Tables 3 and 4** for all simulations. Since the calibration results show good correlation with observed water levels, this makes the chosen values defendable.

6.4. MODEL RESULTS AND FLOODPLAIN MAPPING

Based on discussions with the City, it was decided that for the purposes of mapping the floodplain, Urban would use the calculated WSE for the 200-year and 20-year instantaneous floods, including a 20% increase to account for climate change and an allowance for freeboard of 0.3 m. This approach differs from that of the 1992 study, which used to the 200-year and 20-year maximum daily floods (with no account for climate change) plus 0.6 m of freeboard. Note that NHC adopted this approach because it consistently yielded higher WSEs than using the instantaneous flood plus 0.3 m of freeboard. However, for the present study, that approach would be overly conservative, as the 20% increase to instantaneous peak flows from climate change already accounts for a significant factor of safety.

Tables 5 to 8 show the differences between the 1992 WSE and the present study's WSEs used for the purposes of floodplain mapping. It is important to note that the 1992 report does not include these elevations in tabular form, and as such, they were approximated from the profiles included at the end of that document.

Table 5 – 200-year Water Surface Elevation Comparison (Fraser River)

Reach	NHC X-Section	Urban Model X-Section	1992 NHC WSE (m)*	2020 USL WSE (m)***	Difference (m)
D/S of Quesnel R. Confluence	6	1012	471.68	472.17	0.49
	7	1028	472.10	472.83	0.73
	8	1041	472.45	473.15	0.70
	9	1001	472.97	474.06	1.09
U/S of Quesnel R. Confluence	10	1010.6	473.17	474.25	1.08
	11	1011	473.17	474.25	1.08
	13	1012.3	473.20	474.24	1.04
	14	1013.4	473.23	474.17	0.94
	15	1014	473.20	474.34	1.14
	16	1023	473.44	474.66	1.22
	17	1037	473.96	475.18	1.22

Reach	NHC X-Section	Urban Model X-Section	1992 NHC WSE (m)*	2020 USL WSE (m)***	Difference (m)
	18	1052	474.26	475.57	1.31
	19	1058.32**	474.70	476	1.30
	20	1058.88**	475.09	476.64	1.55

*Approximated from 1992 Report Profiles (NHC) – Includes 0.6 m of freeboard.
**Interpolated cross-sections
***Includes 20% Climate Change flow increase and 0.3 m of freeboard

Table 6 – 20-year Water Surface Elevation Comparison (Fraser River)

Reach	NHC X-Section	Urban Model X-Section	1992 NHC WSE (m)*	2020 USL WSE (m)***	Difference (m)
D/S of Quesnel R. Confluence	6	1012	470.84	470.98	0.14
	7	1028	471.23	471.68	0.45
	8	1041	471.67	472.01	0.34
	9	1001	472.16	472.85	0.69
U/S of Quesnel R. Confluence	10	1010.6	472.35	473.1	0.75
	11	1011	472.36	473.08	0.72
	13	1012.3	472.39	473.09	0.7
	14	1013.4	472.48	473.03	0.55
	15	1014	472.47	473.1	0.63
	16	1023	472.64	473.38	0.74
	17	1037	473.27	473.95	0.68
	18	1052	473.54	474.36	0.82
	19	1058.32**	473.90	474.84	0.94
	20	1058.88**	474.30	475.58	1.28

*Approximated from 1992 Report Profiles (NHC) – Includes 0.6 m of freeboard.
**Interpolated cross-sections
***Includes 20% Climate Change flow increase and 0.3 m of freeboard

Table 7 – 200 year-Water Surface Elevation Comparison (Quesnel River)

Reach	NHC X-Section	Urban Model X-Section	1992 NHC WSE (m)*	2020 USL WSE (m)***	Difference (m)
Quesnel River	1	1003.6	473.04	473.58	0.54
	2	1008	473.03	473.69	0.66
	3	1009.1	473.04	473.7	0.66
	4	1009.3	473.03	473.73	0.7
	5	1009.5	473.07	473.72	0.65
	6	1012	473.15	473.82	0.67
	7	1014	473.15	473.81	0.66

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Reach	NHC X-Section	Urban Model X-Section	1992 NHC WSE (m)*	2020 USL WSE (m)***	Difference (m)
	8	1017.6	473.15	473.79	0.64
	9	1018	473.15	473.81	0.66
	10	1021	473.22	473.84	0.62
	11	1030	473.43	474.01	0.58
	12	1043	473.79	474.19	0.4
	13	1051	474.10	474.25	0.15
	14	1052	474.15	474.35	0.2
	15	1053	474.14	474.41	0.27
	16	1054	474.18	474.43	0.25
	17	1059	474.43	474.54	0.11
	18	1060	474.42	474.49	0.07
	19	1061	474.38	474.79	0.41
	20	1061.4	474.66	475	0.34
	21	1064	475.03	475.16	0.13
	22	1071	475.51	475.37	-0.14
	23	1080	476.06	475.75	-0.31

*Approximated from 1992 Report Profiles (NHC) – Includes 0.6 m of freeboard.
**Interpolated cross-sections
***Includes 20% Climate Change flow increase and 0.3 m of freeboard

Table 8 – 20 year-Water Surface Elevation Comparison (Quesnel River)

Reach	NHC X-Section	Urban Model X-Section	1992 NHC WSE (m)*	2020 USL WSE (m)***	Difference (m)
Quesnel River	1	1003.6	472.10	472.36	0.26
	2	1008	472.10	472.45	0.35
	3	1009.1	472.14	472.48	0.34
	4	1009.3	472.14	472.5	0.36
	5	1009.5	472.14	472.51	0.37
	6	1012	472.22	472.61	0.39
	7	1014	472.22	472.61	0.39
	8	1017.6	472.26	472.59	0.33
	9	1018	472.26	472.61	0.35
	10	1021	472.30	472.63	0.33
	11	1030	472.60	472.88	0.28
	12	1043	473.15	473.26	0.11
	13	1051	473.55	473.45	-0.1
	14	1052	473.59	473.56	-0.03

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Reach	NHC X-Section	Urban Model X-Section	1992 NHC WSE (m)*	2020 USL WSE (m)***	Difference (m)
	15	1053	473.63	473.62	-0.01
	16	1054	473.70	473.63	-0.07
	17	1059	473.95	472.36	0.26
	18	1060	473.99	472.45	0.35
	19	1061	473.99	472.48	0.34
	20	1061.4	474.22	472.5	0.36
	21	1064	474.54	472.51	0.37
	22	1071	475.02	472.61	0.39
	23	1080	475.65	472.61	0.39

*Approximated from 1992 Report Profiles (NHC) – Includes 0.6 m of freeboard.
**Interpolated cross-sections
***Includes 20% Climate Change flow increase and 0.3 m of freeboard

URBAN SYSTEMS LTD.

Nicolas Abarca, M.Sc., P.Eng.
Water Resources Engineer

cc: Rick Collins, Brendan Pauls – Urban Systems Ltd.

/na

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Floodplain Mapping

200 Year Instantaneous Flood (Including 20% Climate Change and 0.3 m of Freeboard)

LIMITATIONS OF FLOODPLAIN MAPS:

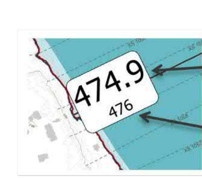
1. The flood hazard maps are based on river surveys conducted in 2019, and LiDAR surveys from 2018. The maps depict flood conditions at the time of the surveys. Changes to the channel, flood plain, or climate will affect the flood levels and render the site-specific map information obsolete.
2. Flood hazard maps are administrative tools that show the minimum designated flood elevation and flood plain boundaries. Flooding may occur outside the designated boundaries. Urban Systems Ltd. (USL) do not assume any liability by reason of the designation or failure to designate areas on the map.
3. Flood hazard maps do not provide information on site-specific hazards such as land erosion or sudden shifts in the water courses.
4. Other sources of water, roads, railways or other barriers can restrict water flow and affect flood levels locally. Channel obstructions, local storm water inflows, groundwater or other land drainage can cause flood levels to exceed those indicated on the map. Land adjacent to a flood plain may be subjected to flooding from tributary streams that are not indicated on the maps.
5. The accuracy of the location of a flood plain boundary as shown on this map is limited by the accuracy of the LiDAR data used for generating base contour mapping.
6. Professional assistance and detailed site-specific engineering analysis are required to address any of the above issues.

NOTES TO USERS:

1. The Designated Flood has a statistical return period of 200-years. (There is one in 200 chance that the Designated Flood could be equaled or exceeded in any one year.)
2. Freshet flood levels were computed using a coupled 1D/2D hydraulic model in GeoHEC-RAS, version 2.7.0.24476. The main channels, the structures, and some overbank areas were modelled as 1-dimensional. Most overbank areas were modelled as 2-dimensional.
3. Flood Construction Levels (FCL's) were computed at the 200-year flood level and are shown on the maps.
4. Flood levels corresponding to the 20-year flood level are also indicated.
5. Flood inundation boundaries are delineated for the 200-year flood and the 200-year flood +0.3m of freeboard
6. The flood boundaries are not established on the ground by legal survey and are not delineated for side streams, local drainage or storm water runoff.
7. The required setback of the buildings from natural boundaries or water courses is not shown. For setback restrictions and other guidelines refer to City of Quesnel Flood Plain regulation Bylaw No. 1187.
8. These maps are available from the City of Quesnel. The City of Quesnel does not provide any warranty or guaranty of merchantability of fitness to a particular purpose. The city is not liable for any damages or losses that my result from the use of the information in this document.

LEGEND

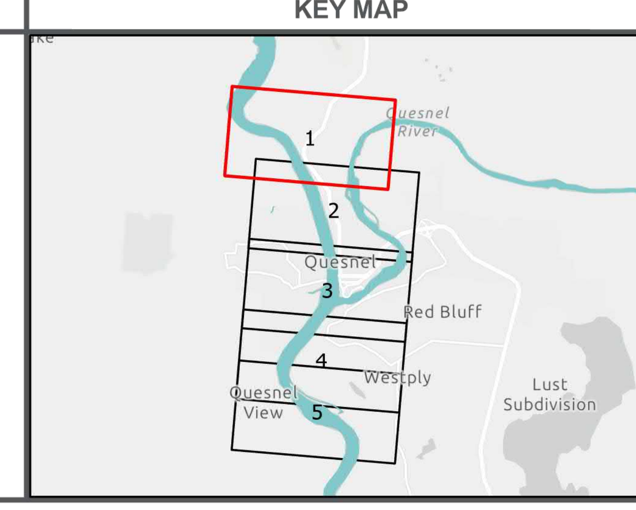
- River Flow Arrows
- Study Limits
- 1D Modelled Cross Sections
- 2019 Contours - 1m Intervals
- 2019 Contours - 5m Intervals
- Map Sheet Match Line
- City Boundary
- Parcel Boundary
- Building Footprint
- Flood Construction Level Isoline
- 1 in 200 yr Flood Limit, including 0.3m freeboard (FCL)
- 1 in 200 yr Flood Limit



Flood Construction Level (FCL) – 200yr + 0.3m Freeboard

1 in 20yr Flood Level + 0.3m Freeboard

KEY MAP



The accuracy & completeness of information shown on this drawing is not guaranteed. It will be the responsibility of the user of the information shown on this drawing to locate & establish the precise location of all existing information whether shown or not.

Data Sources:

Data provided by the
- City of Quesnel
- Urban Systems Ltd
- Base map provided by ESRI

Project #:	1190.0184.01
Date:	2020 / 6 / 3

Coordinate System:

NAD 1983 CSRS UTM Zone 10N
All elevations shown in meters, using Canadian Geodetic Vertical Datum of 2013 (CGVD2013)

Author:	BB
Checked:	BP
Status:	FINAL
Revision:	A

Floodplain Mapping and Risk Assessment

MAP 1 of 5

Fraser and Quesnel Rivers at Quesnel

Scale: 1:4,000

0 50 100 150 200 250
Meters

(When plotted at 24"x36")

CITY OF Quesnel

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\\usl.urban-systems.com\projects\Projects_KAM\1190\0184\01\D-Design\GIS\Projects\Pro_Projects\Pro_Projects.aprx\Official Floodplain Mapping Figures

Last updated by bbourdages on June 3, 2020 at 11:02 AM
Last exported by bbourdages on June 3, 2020 11:02 AM

LIMITATIONS OF FLOODPLAIN MAPS:

1. The flood hazard maps are based on river surveys conducted in 2019, and LiDAR surveys from 2018. The maps depict flood conditions at the time of the surveys. Changes to the channel, flood plain, or climate will affect the flood levels and render the site-specific map information obsolete.
2. Flood hazard maps are administrative tools that show the minimum designated flood elevation and flood plain boundaries. Flooding may occur outside the designated boundaries. Urban Systems Ltd. (USL) do not assume any liability by reason of the designation or failure to designate areas on the map.
3. Flood hazard maps do not provide information on site-specific hazards such as land erosion or sudden shifts in the water courses.
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6. Professional assistance and detailed site-specific engineering analysis are required to address any of the above issues.

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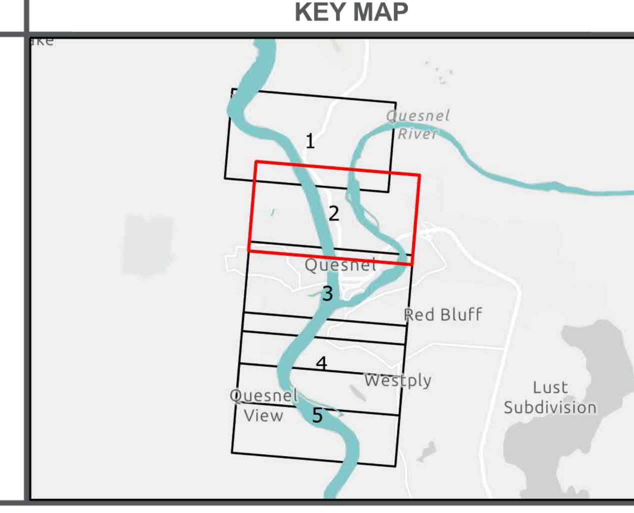
LEGEND

- River Flow Arrows
- Study Limits
- 1D Modelled Cross Sections
- 2019 Contours - 1m Intervals
- 2019 Contours - 5m Intervals
- Map Sheet Match Line
- City Boundary
- Parcel Boundary
- Building Footprint
- Flood Construction Level Isoline
- 1 in 200 yr Flood Limit, including 0.3m freeboard (FCL)
- 1 in 200 yr Flood Limit

474.9 — Flood Construction Level (FCL) – 200yr + 0.3m Freeboard
476 — 1 in 20yr Flood Level + 0.3m Freeboard

KEY MAP



The accuracy & completeness of information shown on this drawing is not guaranteed. It will be the responsibility of the user of the information shown on this drawing to locate & establish the precise location of all existing information whether shown or not.

Data Sources:

Data provided by the
- City of Quesnel
- Urban Systems Ltd
- Base map provided by ESRI

Project #: 1190.0184.01
Date: 2020 / 6 / 3
Coordinate System:
NAD 1983 CSRS UTM Zone 10N
All elevations shown in meters, using Canadian Geodetic Vertical Datum of 2013 (CGVD2013)

Author: BB
Checked: BP
Status: FINAL
Revision: A

Floodplain Mapping and Risk Assessment

MAP 2 of 5

Fraser and Quesnel Rivers at Quesnel

Scale: 1:4,000

0 50 100 150 200 250 Meters

(When plotted at 24"x36")

CITY OF Quesnel

URBAN systems

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Last updated by bbourdages on June 3, 2020 at 11:03 AM
Last exported by bbourdages on June 3, 2020 11:02 AM

LIMITATIONS OF FLOODPLAIN MAPS:

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- Parcel Boundary
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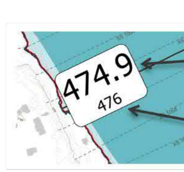
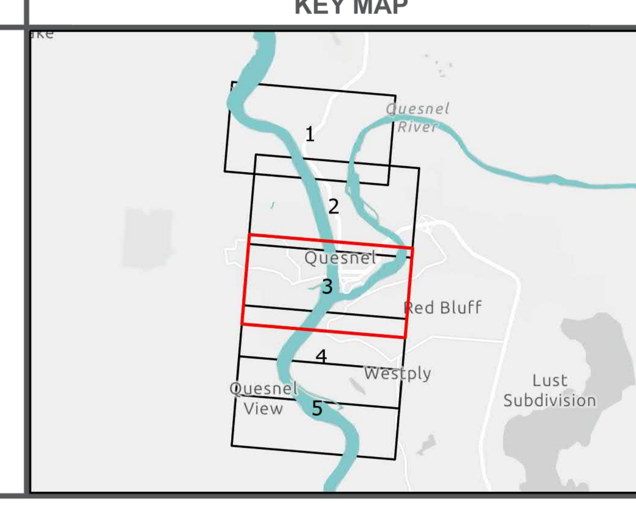
- Flood Construction Level Isoline
- 1 in 200 yr Flood Limit, including 0.3m freeboard (FCL)
- 1 in 200 yr Flood Limit



Flood Construction Level (FCL) – 200yr + 0.3m Freeboard

1 in 20yr Flood Level + 0.3m Freeboard

KEY MAP



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Project #:	1190.0184.01
Date:	2020 / 6 / 3

Coordinate System:

NAD 1983 CSRS UTM Zone 10N
All elevations shown in meters, using Canadian Geodetic Vertical Datum of 2013 (CGVD2013)

Author:	BB
Checked:	BP
Status:	FINAL
Revision:	A

Floodplain Mapping and Risk Assessment

MAP 3 of 5

Fraser and Quesnel Rivers at Quesnel

N
W E
S

Scale: 1:4,000

0 50 100 150 200 250
Meters

(When plotted at 24"x36")

CITY OF Quesnel

URBAN systems

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- Map Sheet Match Line
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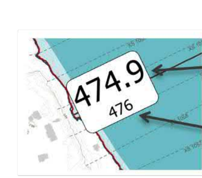
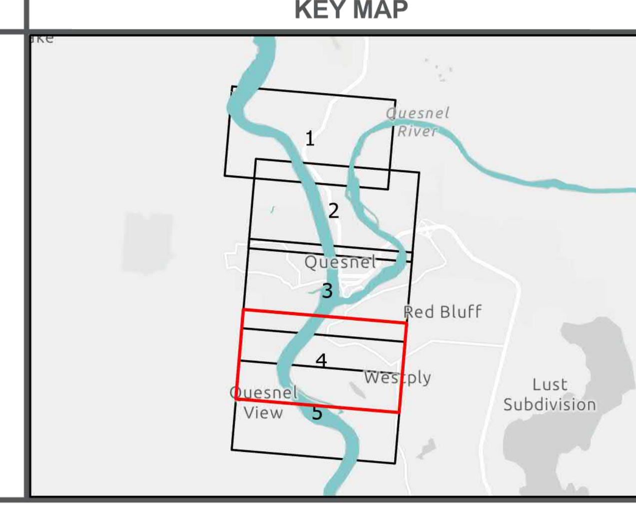
- Parcel Boundary
- Building Footprint
- Flood Construction Level Isoline
- 1 in 200 yr Flood Limit, including 0.3m freeboard (FCL)
- 1 in 200 yr Flood Limit



Flood Construction Level (FCL) – 200yr + 0.3m Freeboard

1 in 20yr Flood Level + 0.3m Freeboard

KEY MAP



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Data Sources:

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- Base map provided by ESRI

Project #: 1190.0184.01
Date: 2020 / 6 / 3
Coordinate System:
NAD 1983 CSRS UTM Zone 10N
All elevations shown in meters, using Canadian Geodetic Vertical Datum of 2013 (CGVD2013)

Author: BB
Checked: BP
Status: FINAL
Revision: A

Floodplain Mapping and Risk Assessment

MAP 4 of 5

Fraser and Quesnel Rivers at Quesnel

N W E S

Scale: 1:4,000

0 50 100 150 200 250
Meters

(When plotted at 24"x36")

CITY OF Quesnel

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Last updated by bbourdages on June 3, 2020 at 11:05 AM
Last exported by bbourdages on June 3, 2020 11:02 AM

LIMITATIONS OF FLOODPLAIN MAPS:

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LEGEND

- River Flow Arrows
- Study Limits
- 1D Modelled Cross Sections
- 2019 Contours - 1m Intervals
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- Map Sheet Match Line
- City Boundary
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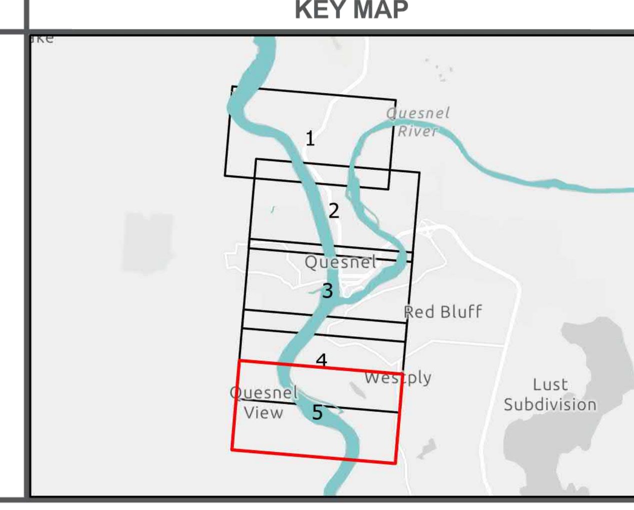
474.9 — Flood Construction Level (FCL) – 200yr + 0.3m Freeboard
476 — 1 in 20yr Flood Level + 0.3m Freeboard

KEY MAP



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Data Sources:

Data provided by the
- City of Quesnel
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Project #:	1190.0184.01
Date:	2020 / 6 / 3

Coordinate System:
NAD 1983 CSRS UTM Zone 10N
All elevations shown in meters, using Canadian Geodetic Vertical Datum of 2013 (CGVD2013)

Author:	BB
Checked:	BP
Status:	FINAL
Revision:	A

Floodplain Mapping and Risk Assessment

MAP 5 of 5

Fraser and Quesnel Rivers at Quesnel

Scale: 1:4,000

0 50 100 150 200 250 Meters

(When plotted at 24"x36")

CITY OF Quesnel

URBAN systems

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Last updated by bbourdages on June 3, 2020 at 11:06 AM
Last exported by bbourdages on June 3, 2020 11:02 AM

Attachment A

1992 Floodplain Mapping (NHC)

Use and Limitations of Floodplain Maps

- Users must note the dates of base mapping, aerial photography, river surveys and issue of mapping relevant to dates of development in the map area. Subsequent developments or changes within the floodplain or channel (natural or constructed) will affect flood levels and render site-specific map information obsolete.
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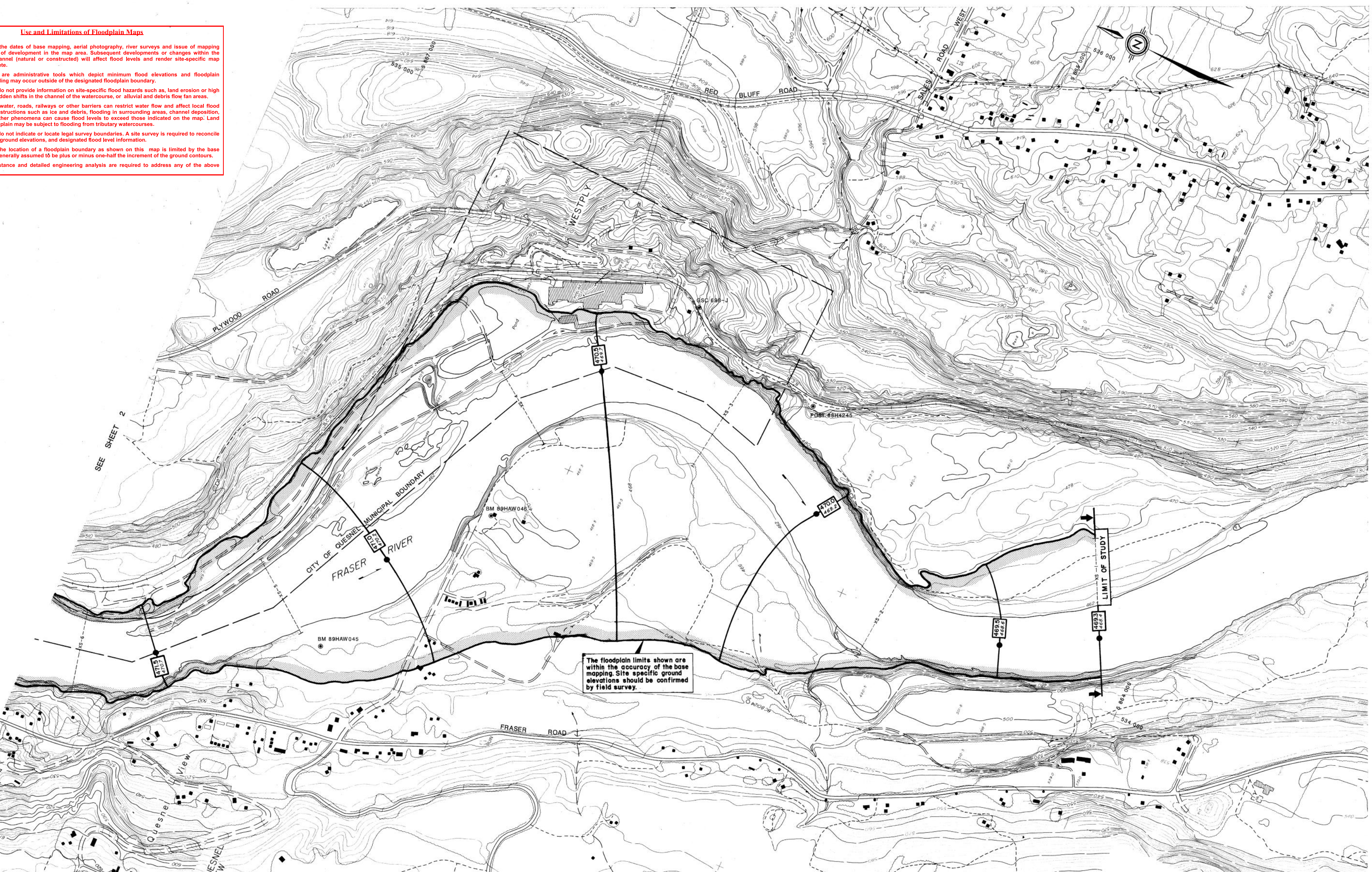

NOTES

Produced by: British Columbia Water Management Branch, Special Projects Section, Floodplain Mapping Program.

Survey: River survey done by Surveys Section, Water Management Branch, Project 89 12 F027. July, 1989.
a) Horizontal control based on provincial network.
b) Elevations are in metres and are referred to Geodetic Survey of Canada datum. (◉ indicates Survey Monument).

Mapping: Base mapping done by Map Production Division, Surveys and Resource Mapping Branch, Project 81-028T, 1980 Air Photography.
a) Contour interval 2 metre and greater; spot elevatons shown to 0.1 metres, with accuracy to ± 0.5 metres, except where noted.
b) Grid origin referred to U.T.M. Projection Zone 10 .

FLOODPLAIN DATA

1. The floodplain areas as depicted on this map have been interim designated pursuant to the Canada/British Columbia Floodplain Mapping Agreement (1988) by the Minister of the Environment for Canada and the Minister of Environment, Lands and Parks for British Columbia.

   Flooding may still occur outside of the interim designated floodplain areas. The Ministers do not assume any liability by reason of the interim designation or failure to interim designate areas on this map.
2. The Designated Flood has a statistical frequency of occurrence of once every 200 years.
3. The flood levels were computed using a standard step method modelling technique, assuming open water flow conditions.
4. The floodplain limits assume the absence of all dykes.
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9. MAPS AVAILABLE FROM SURVEYS AND RESOURCE MAPPING BRANCH, MAPS B.C., MAP AND AIR PHOTO SALES, VICTORIA, B.C.

LEGEND

DESIGNATED FLOODPLAIN LIMIT

FLOOD LEVEL

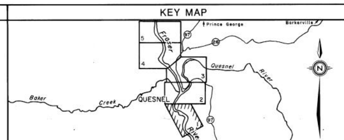
RIVER

200 Year Frequency

20 Year Frequency

(METRES G.S.C. DATUM)

KEY MAP



Scale 1:250 000

REVISIONS

No.	DESCRIPTION	DATE

northwest hydraulic consultants ltd.

ISSUE OF MAPPING DATE Sept. 30, 1992

ENVIRONMENT CANADA INLAND WATERS / ENVIRONNEMENT CANADA EAUX INTÉRIEURES

BRITISH COLUMBIA MINISTRY OF ENVIRONMENT / COLOMBIE-BRITANNIQUE MINISTÈRE DE L'ENVIRONNEMENT

CANADA BRITISH COLUMBIA FLOODPLAIN MAPPING AGREEMENT / L'ACCORD CANADA COLOMBIE-BRITANNIQUE SUR LA CARTOGRAPHIE DES PLAINES D'INONDATION

DRAWN M.W.

CHECKED CN.

RIVER SURVEY M. P.

DESIGNED

FLOODPLAIN MAPPING

FRASER AND QUESNEL RIVERS AT QUESNEL

100m 0 100 200 300 400 500m

Scale in metres

ENGINEER N.J. Galay RECOMMENDED F. Woods APPROVED

FILE No. 100-0000-Q

N.T.S.MAP No. 93B/15, 16

SCALE 1 : 5 000

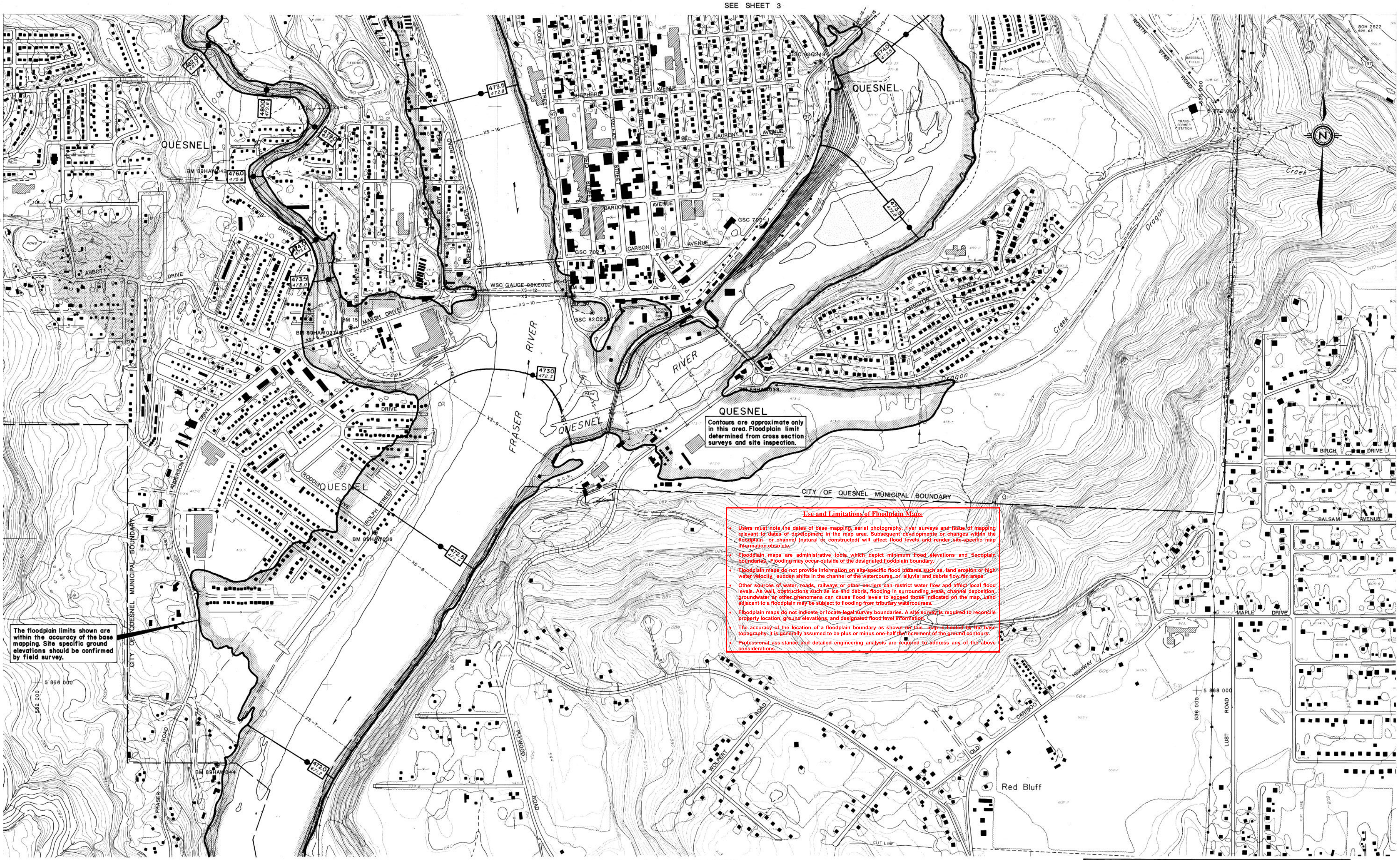
NEGATIVE No.

DRAWING No. 89-43-1 REV.

SHEET 1 of 5

DDflmg

SEE SHEET 3



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SEE SHEET 1

NOTES

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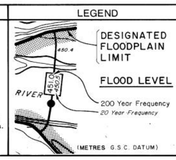
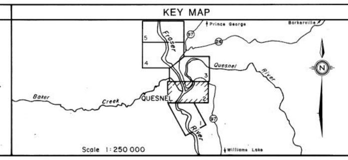


KEY MAP



REVISIONS

No.	DESCRIPTION	DATE
1.	Extends, revises and replaces Dwg. 87-17, Sheet 1 dated May 1987 and interim designated Sept. 30, 1988.	Sept.30,1992

ISSUE OF MAPPING DATE Sept. 30, 1992

DRAWN M.W.

CHECKED CN.

RIVER SURVEY M. P.

DESIGNED

ENGINEER

RECOMMENDED

APPROVED

northwest hydraulic consultants ltd.

ENVIRONMENT CANADA INLAND WATERS / ENVIRONNEMENT CANADA EAUX INTÉRIEURES

BRITISH COLUMBIA MINISTRY OF ENVIRONMENT / COLOMBIE-BRITANNIQUE MINISTÈRE DE L'ENVIRONNEMENT

CANADA BRITISH COLUMBIA FLOODPLAIN MAPPING AGREEMENT / L'ACCORD CANADA COLOMBIE-BRITANNIQUE SUR LA CARTOGRAPHIE DES PLAINES D'INONDATION

FLOODPLAIN MAPPING
FRASER AND QUESNEL RIVERS AT QUESNEL

100m 0 100 200 300 400 500m

Scale in metres

FILE No. 100-0000-Q

N.T.S.MAP No. 93B/15, 16

SCALE 1 : 5 000

NEGATIVE No.

DRAWING No. 89-43-2 REV.

SHEET 2 of 5

DDflmg

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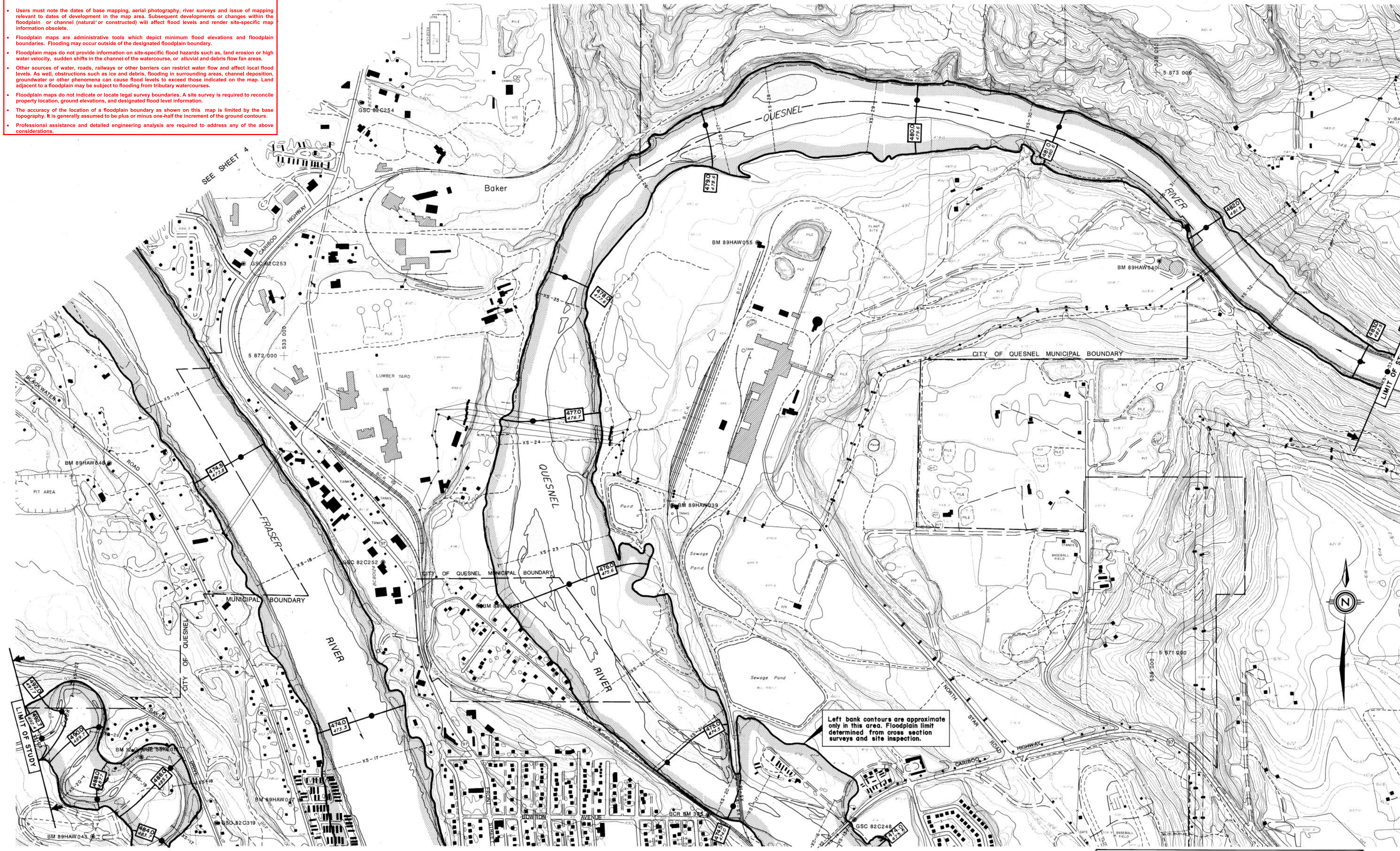
- Floodplain maps do not indicate or locate legal survey boundaries. A site survey is required to reconcile property location, ground elevations, and designated flood level information.
- The accuracy of the location of a floodplain boundary as shown on this map is limited by the base topography. It is generally assumed to be plus or minus one-half the increment of the ground contours.
- Professional assistance and detailed engineering analysis are required to address any of the above considerations.



SEE SHEET 2

NOTES

Produced by: British Columbia Water Management Branch, Special Projects Section, Floodplain Mapping Program.

Survey: River survey done by Surveys Section, Water Management Branch, Project 89 12 F027. July, 1989.
a) Horizontal control based on provincial network.
b) Elevations are in metres and are referred to Geodetic Survey of Canada datum. (◉ indicates Survey Monument).

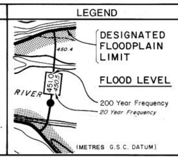
Mapping: Base mapping done by Map Production Division, Surveys and Resource Mapping Branch, Project 81-028T, 1980 Air Photography.
a) Contour interval 2 metre and greater; spot elevatons shown to 0.1 metres, with accuracy to ± 0.5 metres, except where noted.
b) Grid origin referred to U.T.M. Projection Zone 10 .

FLOODPLAIN DATA

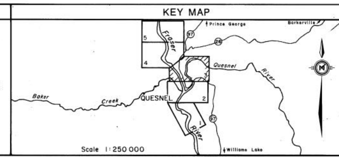
1. The floodplain areas as depicted on this map have been interim designated pursuant to the Canada/British Columbia Floodplain Mapping Agreement (1988) by the Minister of the Environment for Canada and the Minister of Environment, Lands and Parks for British Columbia.

   Flooding may still occur outside of the interim designated floodplain areas. The Ministers do not assume any liability by reason of the interim designation or failure to interim designate areas on this map.
2. The Designated Flood has a statistical frequency of occurrence of once every 200 years.
3. The flood levels were computed using a standard step method modelling technique, assuming open water flow conditions.
4. The floodplain limits assume the absence of all dykes.
5. The floodplain limits and flood levels include an allowance for freeboard.
6. The floodplain limits are not established on the ground by legal survey.
7. The floodplain limits are not delineated for side streams and tributaries.
8. The required setback of buildings from the natural boundaries of lakes and watercourses to allow for the passage of floodwaters and possible bank erosion is not shown. This information is available either through local municipalities or the Ministry of Environment, Lands and Parks.
9. MAPS AVAILABLE FROM SURVEYS AND RESOURCE MAPPING BRANCH, MAPS B.C., MAP AND AIR PHOTO SALES, VICTORIA, B.C.

LEGEND



KEY MAP



REVISIONS

No.	DESCRIPTION	DATE
1.	Extends, revises and replaces Dwg. 87-17, Sheet 1 dated May 1987 and interim designated Sept. 30, 1988.	Sept.30,1992

ISSUE OF MAPPING DATE: Sept. 30, 1992

DRAWN: M.W.
CHECKED: C.N.
RIVER SURVEY: M. P.
DESIGNED:

northwest hydraulic consultants ltd.

ENVIRONMENT CANADA INLAND WATERS / ENVIRONNEMENT CANADA EAUX INTÉRIEURES
BRITISH COLUMBIA MINISTRY OF ENVIRONMENT / COLOMBIE-BRITANNIQUE MINISTÈRE DE L'ENVIRONNEMENT
CANADA BRITISH COLUMBIA FLOODPLAIN MAPPING AGREEMENT / L'ACCORD CANADA COLOMBIE-BRITANNIQUE SUR LA CARTOGRAPHIE DES PLAINES D'INONDATION

FLOODPLAIN MAPPING
FRASER AND QUESNEL RIVERS AT QUESNEL

100m 0 100 200 300 400 500m
Scale in metres

ENGINEER: [signature] RECOMMENDED: [signature] APPROVED: [signature]

FILE No. 100-0000-Q
N.T.S.MAP No. 93B/15,16, 93G/1,2
SCALE 1 : 5 000
NEGATIVE No.
DRAWING No. 89-43-3 REV.
SHEET 3 of 5

DDfImg

Attachment B

Calculation of Manning's 'n' Values (Overbanks)

URBAN SYSTEMS

FLOODPLAIN MANNING'S N (Modified Channel Method) - For Building Floodplain

COMPONENT (See Table 3 image on the far right for more detail)	SELECTED VALUE	COMMENT
Base n Value (nb)	1	Buildings
Degree of Irregularity (n1)	0.02	Very irregular - Buildings rise at 90 deg to ground
Variation in Flood Plain X-Sect (n2)	0	Not Applicable
Effect of Obstruction (n3)	0.03	The buildings are obstruction
Amount of Vegetation (n4)	0.2	Used highest value since we are dealing with buildings here
Sinuosity of floodplain (m)	1	Not Applicable
Channel Manning's 'n'	**1.250**	

FLOODPLAIN MANNING'S N (Modified Channel Method) - For Field Floodplain

COMPONENT (See Table 3 image on the far right for more detail)	SELECTED VALUE	COMMENT
Base n Value (nb)	0.03	Firm Soil
Degree of Irregularity (n1)	0.005	"Minor" - a few rises and dips or sloughs
Variation in Flood Plain X-Sect (n2)	0	Not Applicable
Effect of Obstruction (n3)	0.003	Few scattered obstructions, occupy < 5% of cross sectional area
Amount of Vegetation (n4)	0.025	Large, on the low end, field crops or tall grasses
Sinuosity of floodplain (m)	1	Not Applicable
Channel Manning's 'n'	**0.063**	

FLOODPLAIN MANNING'S N (Modified Channel Method) - For Lawn Floodplain

COMPONENT (See Table 3 image on the far right for more detail)	SELECTED VALUE	COMMENT
Base n Value (nb)	0.025	Firm Soil
Degree of Irregularity (n1)	0.001	"Minor" - a few rises and dips or sloughs. Lowest end of Minor
Variation in Flood Plain X-Sect (n2)	0	Not Applicable
Effect of Obstruction (n3)	0.001	Negligible - Obstructions occupy less than 5 % of cross sectional area
Amount of Vegetation (n4)	0.002	Small - Dense growth of flexible turf grass
Sinuosity of floodplain (m)	1	Not Applicable
Channel Manning's 'n'	**0.029**	

FLOODPLAIN MANNING'S N (Modified Channel Method) - For Road Floodplain

COMPONENT (See Table 3 image on the far right for more detail)	SELECTED VALUE	COMMENT
Base n Value (nb)	0.015	Concrete
Degree of Irregularity (n1)	0	"Minor" - some irregularities such as ditches and roads
Variation in Flood Plain X-Sect (n2)	0	Not Applicable
Effect of Obstruction (n3)	0	None
Amount of Vegetation (n4)	0	None
Sinuosity of floodplain (m)	1	Not Applicable
Channel Manning's 'n'	**0.015**	

FLOODPLAIN MANNING'S N (Modified Channel Method) - For Tree Floodplain

COMPONENT (See Table 3 image on the far right for more detail)	SELECTED VALUE	COMMENT
Base n Value (nb)	0.03	Firm soil
Degree of Irregularity (n1)	0.005	"Minor" - some irregularities such as ditches and roads
Variation in Flood Plain X-Sect (n2)	0	Not Applicable
Effect of Obstruction (n3)	0.02	Appreciable obstructions such as houses and trees, covering 15-50% of area
Amount of Vegetation (n4)	0.05	"Very Large" - Treed areas. Some variation in undergrowth, but all heavily treed.
Sinuosity of floodplain (m)	1	Not Applicable
Channel Manning's 'n'	**0.105**	

FLOODPLAIN MANNING'S N (Modified Channel Method) - For Water Floodplain

COMPONENT (See Table 3 image on the far right for more detail)	SELECTED VALUE	COMMENT
Base n Value (nb)	0.015	Treating water like smooth concrete
Degree of Irregularity (n1)	0	"Minor" - some irregularities such as ditches and roads
Variation in Flood Plain X-Sect (n2)	0	Not Applicable
Effect of Obstruction (n3)	0	None
Amount of Vegetation (n4)	0.01	Small
Sinuosity of floodplain (m)	1	Not Applicable
Channel Manning's 'n'	**0.025**	

URBAN SYSTEMS

FLOODPLAIN MANNING'S N (Modified Channel Method) - For Shrub Floodplain

COMPONENT (See Table 3 image on the far right for more detail)	SELECTED VALUE	COMMENT
Base n Value (nb)	0.03	Firm soil
Degree of Irregularity (n1)	0.003	"Minor" - some irregularities such as ditches and roads
Variation in Flood Plain X-Sect (n2)	0	Not Applicable
Effect of Obstruction (n3)	0.02	Appreciable obstructions such as houses and trees, covering 15-50% of area
Amount of Vegetation (n4)	0.05	"Very Large" - high underbrush and short trees
Sinuosity of floodplain (m)	1	Not Applicable
Channel Manning's 'n'	**0.103**	

FLOODPLAIN MANNING'S N (Modified Channel Method) - For Yard Floodplain

COMPONENT (See Table 3 image on the far right for more detail)	SELECTED VALUE	COMMENT
Base n Value (nb)	0.02	Mixture of concrete and firm soils
Degree of Irregularity (n1)	0.003	"Minor" - some irregularities such as ditches and roads
Variation in Flood Plain X-Sect (n2)	0	Not Applicable
Effect of Obstruction (n3)	0.03	Appreciable obstructions such as houses and trees, fences, and yard furniture, covering 15-50% of area
Amount of Vegetation (n4)	0.02	Medium vegetation - grass on lawns and scattered trees, gardens, shrubs
Sinuosity of floodplain (m)	1	Not Applicable
Channel Manning's 'n'	**0.073**	

FLOODPLAIN MANNING'S N (Modified Channel Method) - For Rock Floodplain

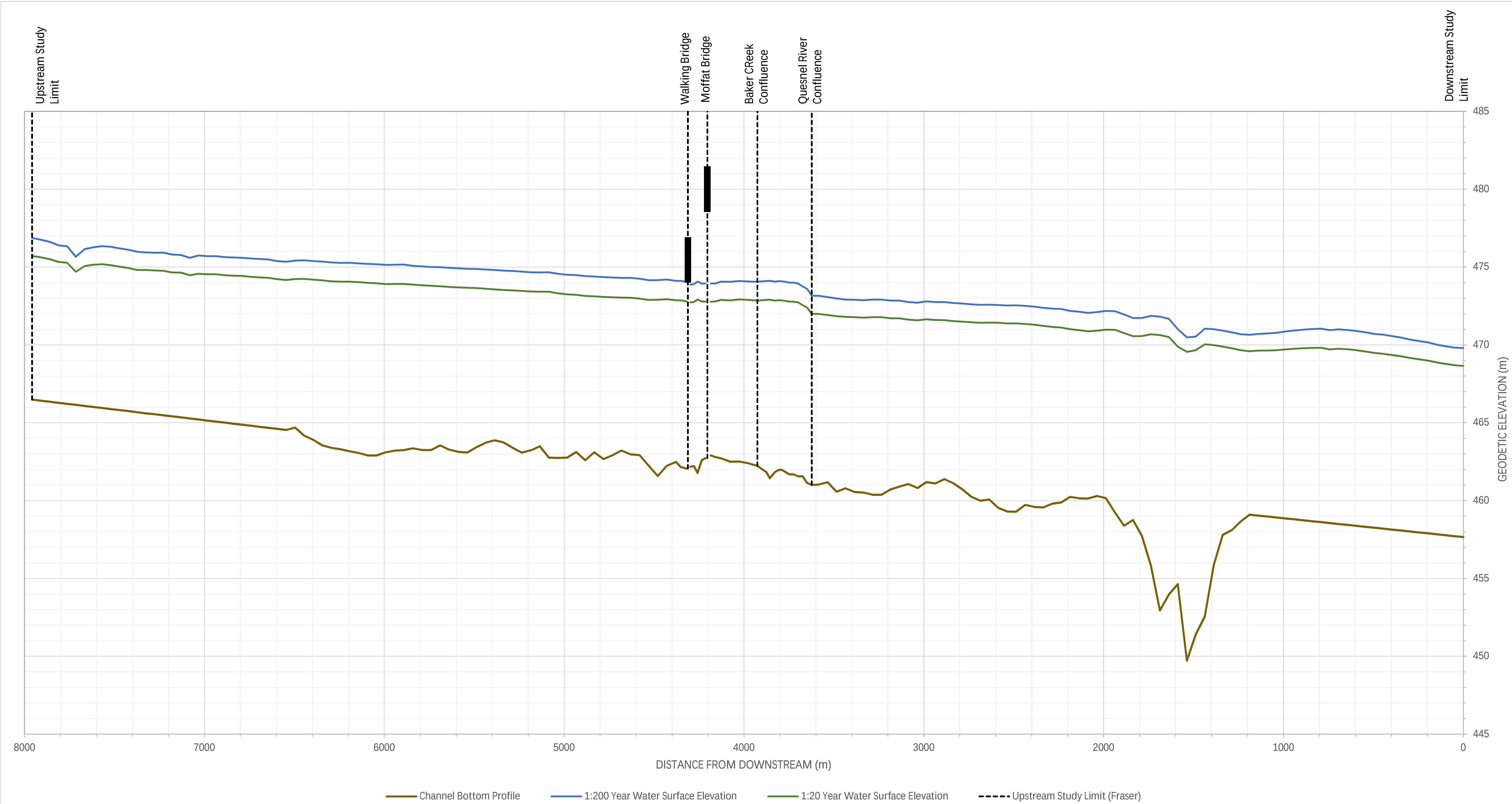
COMPONENT (See Table 3 image on the far right for more detail)	SELECTED VALUE	COMMENT
Base n Value (nb)	0.025	Rock cut
Degree of Irregularity (n1)	0.004	"Minor" - some irregularities in rocks
Variation in Flood Plain X-Sect (n2)	0	Not Applicable
Effect of Obstruction (n3)	0.004	Negligible obstructions covering < 5% of area
Amount of Vegetation (n4)	0	None
Sinuosity of floodplain (m)	1	Not Applicable
Channel Manning's 'n'	**0.033**	

Table 3. Adjustment values for factors that affect roughness of flood plains
[Modified from Aldridge and Garrett, 1973, table 2]

Flood-plain conditions		*n* value adjustment	Example
Degree of irregularity (n_1)	Smooth	0.000	Compares to the smoothest, flattest flood plain attainable in a given bed material.
	Minor	0.001–0.005	Is a flood plain slightly irregular in shape. A few rises and dips or sloughs may be visible on the flood plain.
	Moderate	0.006–0.010	Has more rises and dips. Sloughs and hummocks may occur.
	Severe	0.011–0.020	Flood plain very irregular in shape. Many rises and dips or sloughs are visible. Irregular ground surfaces in pastureland and furrows perpendicular to the flow are also included.
Variation of flood-plain cross section (n_2)		0.0	Not applicable.
Effect of obstructions (n_3)	Negligible	0.000–0.004	Few scattered obstructions, which include debris deposits, stumps, exposed roots, logs, or isolated boulders, occupy less than 5 percent of the cross-sectional area.
	Minor	0.005–0.019	Obstructions occupy less than 15 percent of the cross-sectional area.
	Appreciable	0.020–0.030	Obstructions occupy from 15 to 50 percent of the cross-sectional area.
Amount of vegetation (n_4)	Small	0.001–0.010	Dense growth of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation, or supple tree seedlings such as willow, cottonwood, arrowweed, or saltcedar growing where the average depth of flow is at least three times the height of the vegetation.
	Medium	0.011–0.025	Turf grass growing where the average depth of flow is from one to two times the height of the vegetation, or moderately dense stemmy grass, weeds, or tree seedlings growing where the average depth of flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to 1- to 2-year-old willow trees in the dormant season.
	Large	0.025–0.050	Turf grass growing where the average depth of flow is about equal to the height of the vegetation, or 8- to 10-year-old willow or cottonwood trees intergrown with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 2 ft, or mature row crops such as small vegetables, or mature field crops where depth of flow is at least twice the height of the vegetation.
	Very large	0.050–0.100	Turf grass growing where the average depth of flow is less than half the height of the vegetation, or moderate to dense brush, or heavy stand of timber with few down trees and little undergrowth where depth of flow is below branches, or mature field crops where depth of flow is less than the height of the vegetation.
	Extreme	0.100–0.200	Dense bushy willow, mesquite, and saltcedar (all vegetation in full foliage), or heavy stand of timber, few down trees, depth of flow reaching branches.
Degree of meander (m)		1.0	Not applicable.

Attachment C

Fraser River Flood Profiles



CITY OF QUESNEL

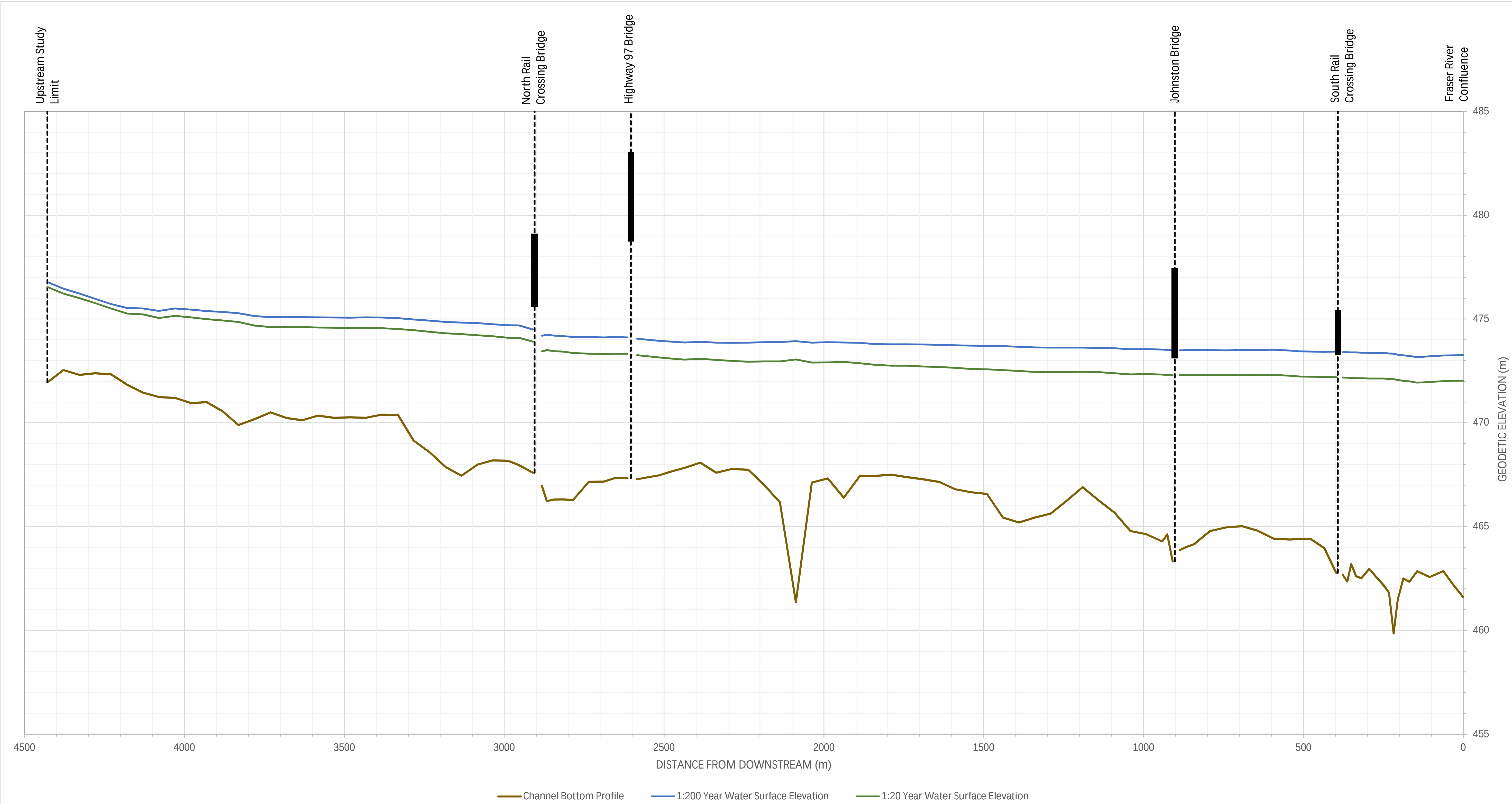
HYDRAULIC MODELLING AND FLOODPLAIN MAPPING

Fraser River Flood Profiles

URBAN SYSTEMS

Attachment D

Quesnel River Flood Profiles



CITY OF QUESNEL

HYDRAULIC MODELLING AND FLOODPLAIN MAPPING

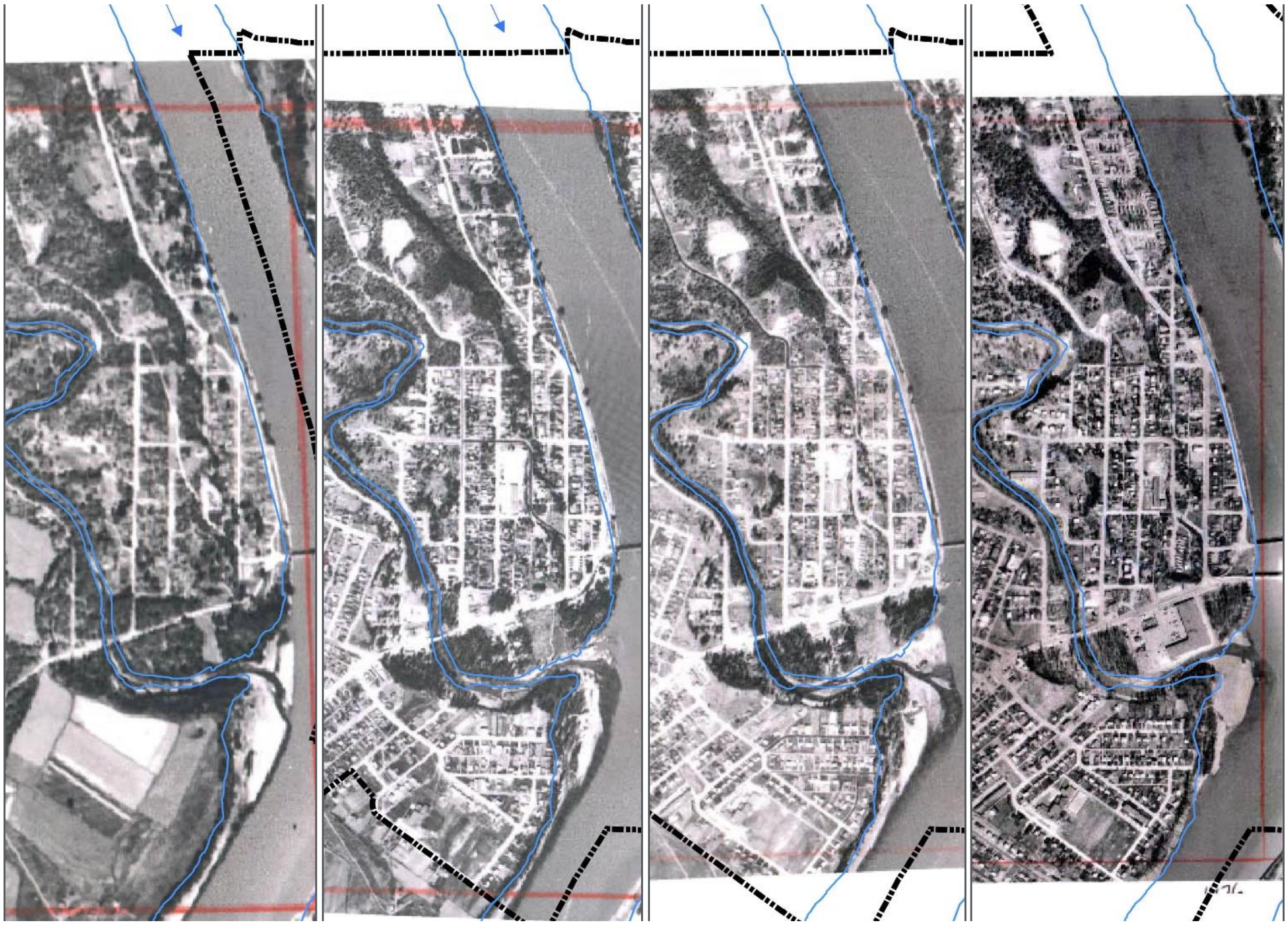
Quesnel River Flood Profiles

URBAN SYSTEMS

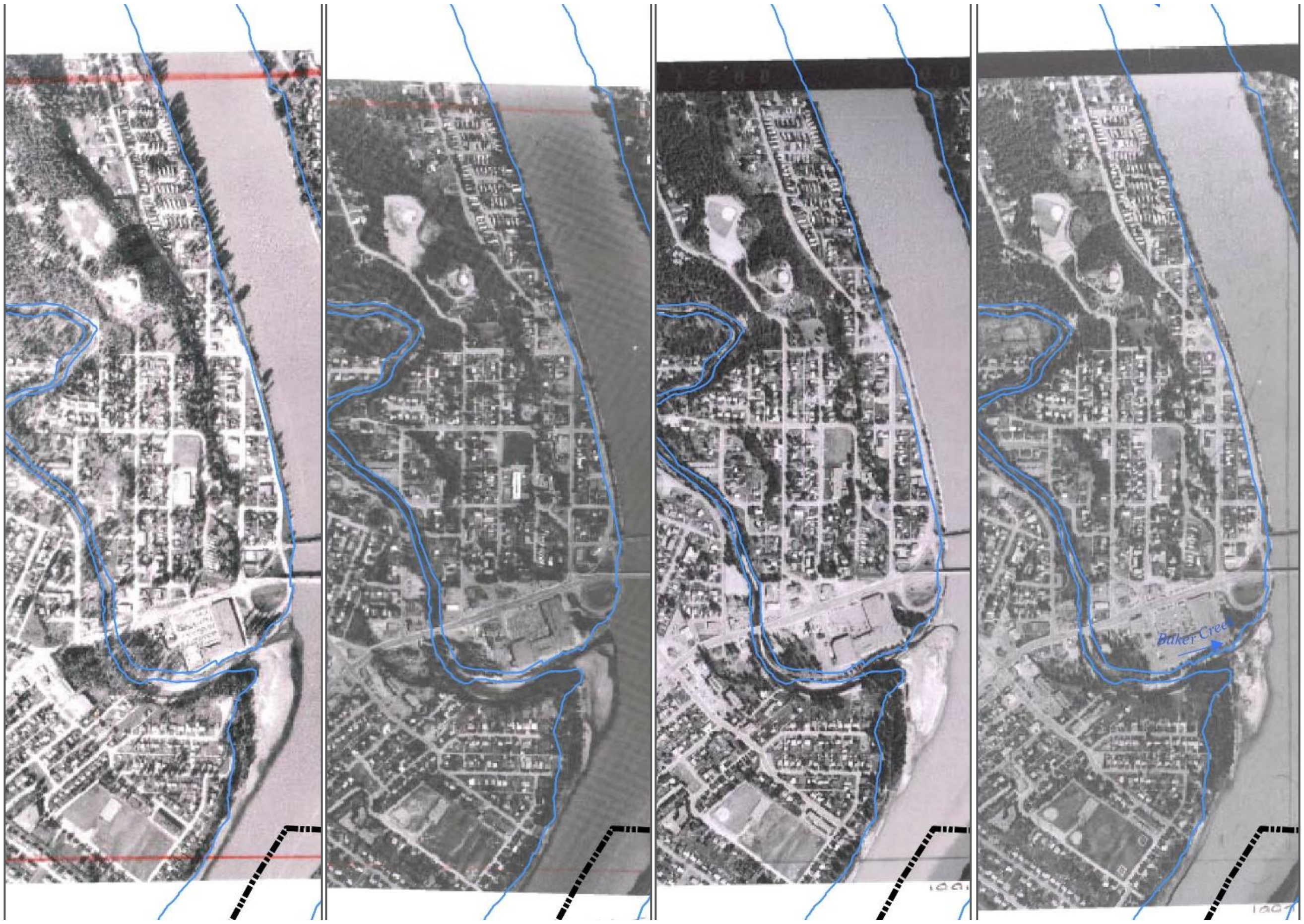
Appendix C

Channel Stability Assessment Figures

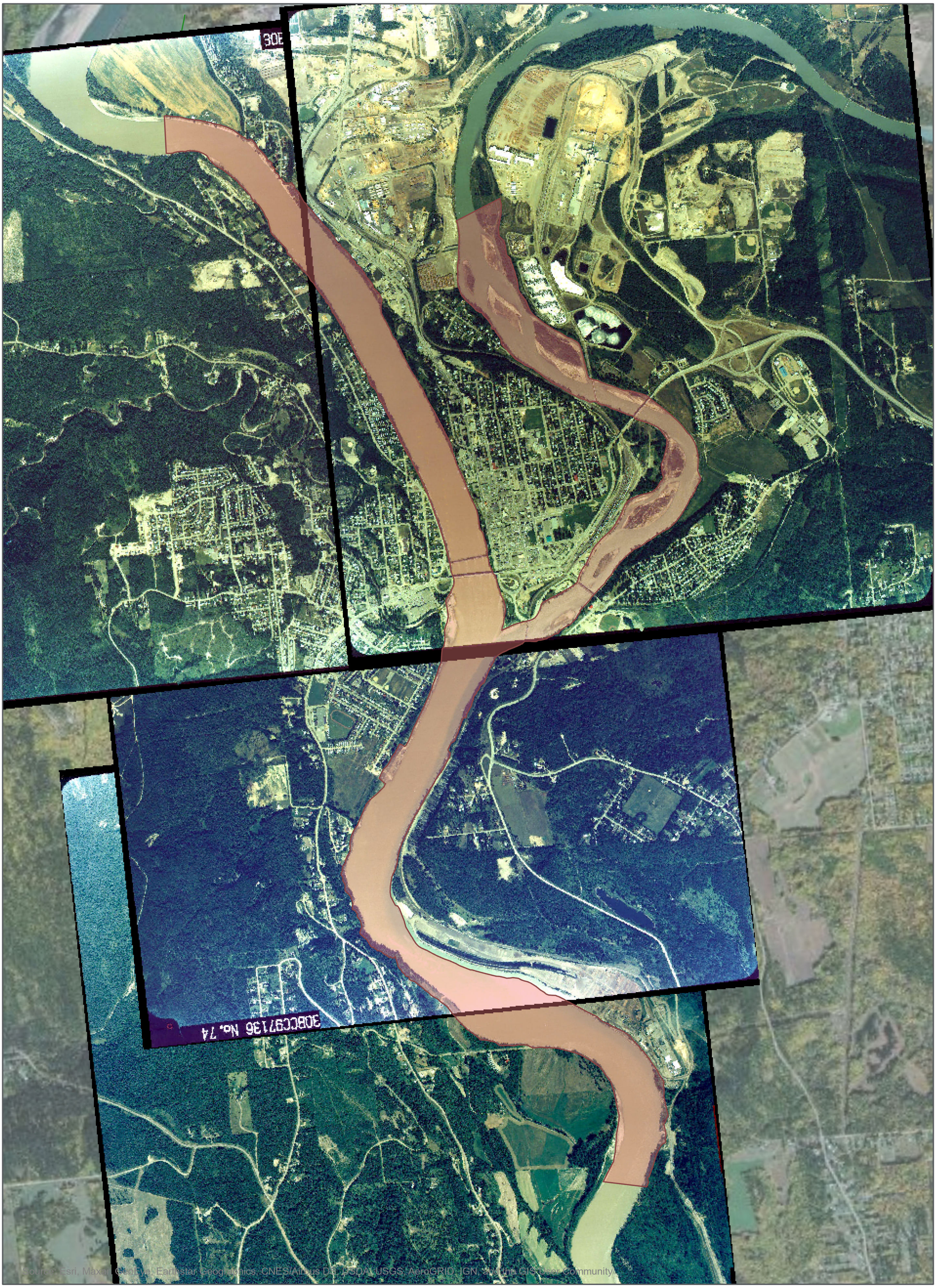
URBAN SYSTEMS



1949 1963 1969 1976



1982 1985 1991 1997



URBAN systems

Project #:	1190.0184.01
Author:	BB
Checked:	
Status:	
Revision:	A
Date:	2020 / 6 / 30

0 100 200 300
Meters

N

Coordinate System:
NAD 1983 CSRS UTM Zone 10N

Scale: 1:23,265
(When plotted at 11"x17")

Data Sources:
- Data provided by
Urban Systems Ltd.
Data BC

The accuracy & completeness of information shown on his drawing is not guaranteed. It will be the responsibility of the user of the information shown on this drawing to locate & establish the precise location of all existing information whether shown or not.

Existing bank (2018)

Floodplain Mapping and Risk Assessment

Bank Change

Appendix D

Risk Assessment Information Template

Public Safety Canada Sécurité publique Canada

Ottawa, Canada
K1A 0P8

National Disaster Mitigation Program (NDMP)
Risk Assessment Information Template

Risk Event Details			
Start and End Date	Provide the start and end dates of the selected event, based on historical data.	Start Date: 20/07/2020	End Date: 20/07/2020
Severity of the Risk Event	Provide details about the risk, including: • Speed of onset and duration of event; • Level and type of damaged caused; • Insurable and non-insurable losses; and • Other details, as appropriate.	The floodplain mapping in the City of Quesnel municipal boundary was last updated in 2020. In 1972 the City experienced what was deemed a 1:50 year high water event, with some damage and flooding occurring. However, the 200 year flood level would cause more impacts. There exists significant infrastructure in the existing 200 year floodplain, including sanitary sewer infrastructure and major transportation routes. The extents of the 200 year floodplain have adjusted, with some more area being at risk.	
Response During the Risk Event	Provide details on how the defined geographic area continued its essential operations while responding to the event.	The 1972 event resulted in the 1 in 50 year return period high water level for over a week. Reports indicate that several families were evacuated with some homes and an apartment being severely damaged. A 200 year return period flood would cause even more damage, including risks to public and private infrastructure, unless significant investment is made in flood protection.	
Recovery Method for the Risk Event	Provide details on how the defined geographic area recovered.	The City would need to evacuate residents from certain areas unless flood protection works are constructed. If insufficient flood protection is in place, then some main City roads will be cut off.	
Recovery Costs Related to the Risk Event	Provide details on the costs, in dollars, associated with implementing recovery strategies following the event.	Recovering from a 200 year period event would be significant, including private and public investments being needed. Depending on which areas were protected from flooding, the recovery costs from a 200 year period event will riquire a multi-million dollar event.	

Recovery Time Related to the Risk Event	Provide details on the recovery time needed to return to normal operations following the event.	It could take weeks to recover from a 200 year return period flood in order to just return to basic operations. Impacts to buildings could take months to repair, with some buildings likely needing to be demolished.

Risk Event Identification and Overview	
Provide a qualitative description of the defined geographic area, including: • Watershed/community/region name(s); • Province/Territory; • Area type (i.e., city, township, watershed, organization, etc.); • Population size; • Population variances (e.g., significant change in population between summer and winter months); • Main economic areas of interest; • Special consideration areas (e.g., historical, cultural and natural resource areas); and an • Estimate of the annual operating budget of the area.	The Fraser River and Quesnel River are large tributaries, which can result in high watr levels that are sustained for days. The last census identified the population of the City of Quesnel as being 10,007, but the tourism and industrial activities in the area can increase the community's population on a seasonal basis. Economic reviews indicate that the service area of Quesnel has a population of approximately 25,000. The City is home to pulp mills, sawmills and plants responsible for production of plywood and medium density fibreboard (MDF) that supply wood-based material on an international scale. CN Rail maintains a switching yard in the municipality and Highway 97 travels through the heart of the community. It is not possible to estimate the annual operating budget of the area since the privately held major industrial facilities in the area preclude obtaining financial information. However, the financial impact of industry and tourism is understood to be significant relative to the size of the community.
Methodolgies, processes and analyses	
Provide the year in which the following processes/analyses were last completed and state the methodology(ies) used: • Hazard identification; • Vulnerability analysis; • Likelihood assessment; • Impact assessment; • Risk assessment; • Resiliency assessment; and/or • Climate change impact and/or adaptation assessment. Note: It is recognized that many of the processes/analyses mentioned above may be included within one methodology.	The adjacent list of processes/analysis were completed in 1992. The exception is the climate change impact assessment. The work was updated in 2020 to reflect improved topographic information, additional flow records and the expected impact of climate change. In 2001 the City also completed a review of the Public Works Yard, which reiterated the risk of having that essential facility within the the existing floodplain. Some work was also conducted in 2007 by the Forest Practices Board for the Baker Creek watershed due to the impacts of the mountain pine beetle.

Hazard Mapping

To complete this section:

- Obtain a map of the area that clearly indicates general land uses, neighbourhoods, landmarks, etc. For clarity throughout this exercise, it may be beneficial to omit any non-essential information from the map intended for use. Controlled photographs (e.g. aerial photography) can be used in place of or in addition to existing maps to avoid the cost of producing new maps.
- Place a grid over the maps/photographs of the area and assign row and column identifiers. This will help identify the specific area(s) that may be impacted, as well as additional information on the characteristics within and affecting the area.
- Identify where and how flood hazards may affect the defined geographic area.
- Identify the mapped areas that are most likely to be impacted by the identified flood hazard.

Map(s)/photograph(s) can also be used, where appropriate, to visually represent the information/prioritization being provided as part of this template.

Hazard identification and prioritization

List known or likely flood hazards to the defined geographic area in order of proposed priority. For example: (1) dyke breach overland flooding; (2) urban storm surge flooding ; and so on.	(1) high water levels including dike overtopping and subsequent overland flooding of the Flood Hazard and Floodplain Mapping, prepared by Urban Systems Ltd. in 2020 outlines the extent (2) river channel erosion that can damage buildings, railway infrastructure and utilities (3) surpassing capacity of sewer system and lift stations, which will result in discharge of raw sewage to the river
Provide a rationale for each prioritization and the key information sources supporting this rationale.	High water levels are viewed as the first priority given the extent of the impact to City and private operations as well as potential damage to public and private buildings Erosion is viewed as the second priority as some key utilities could be impact by bank erosion at key locations and impacts to public and private property are a concern. The impacts of raw sewage discharge were noted as a third priority because that impact is significant but will likely not result in as high a recovery cost.

Risk Event Title

Identify the name/title of the risk. An example of a risk event name or title is: "A one-in-one hundred year flood following an extreme rain event."	A one-in-two hundred year flood during spring freshet.

Type of Flood Hazard

Identify the type of flood hazard being described (e.g., riverine flooding, coastal inundation, urban run-off, etc.)	Riverine flooding and bank erosion

Secondary hazards	
Describe any secondary effects resulting from the risk event (e.g., flooding that occurs following a hurricane).	- Environmental damage due to raw sewage being discharged to the environment - Health risks should the potable water system be damaged - Road, bridge and building damage that pose health and safety risks
Primary and secondary organizations for response	
Identify the primary organization(s) with a mandate related to a key element of a natural disaster emergency, and any supporting organization(s) that provide general or specialized assistance in response to a natural disaster emergency.	- The City of Quensel would be the initial responders due to proximity and awareness of the risk - Province of BC would also then respond as the City's capacity to address such widespread impact justifies additional support

Risk Event Description	
Description of risk event, including risk statement and cause(s) of the event	
Provide a baseline description of the risk event, including: • Risk statement; • Context of the risk event; • Nature and scale of the risk event; • Lead-up to the risk event, including underlying cause and trigger/stimulus of the risk event; and • Any factors that could affect future events. Note: The description entered here must be plausible in that factual information would support such a risk event.	The risk of river and creek flooding near the confluence of Fraser River, Quesnel River and Baker Creek is real. Floods have been recorded several times with damage occurring. However, the recorded events were not 1 in 200 return period events. As well, the changes in the expected river and creek flows due to climate change are not included in the existing floodplain mapping.

Location	
Provide details regarding the area impacted by the risk event such as: • Province(s)/territory(ies); • Region(s) or watershed(s); • Municipality(ies); • Community(ies); and so on.	The public and private operations within and around Quesnel will be directly impacted. It will also have major consequences to the local heavy industrial operations. The regional transportation network will also be impacted. Southbound traffic on Highway 97 will need to be diverted due to flooding. Flooding on the west side of the Fraser River, near the confluence with Baker Creek, will also impact North Fraser Dr. and Marsh Drive heavy industrial routes. These west side routes also provide access to nearby first nations communities.
Natural environment considerations	
Document relevant physical or environmental characteristics of the defined geographic area.	The 1992 floodplain analysis design brief indicates that the watershed at Quesnel has an area of 100,000 square km. The area is mountainous and directs snowmelt that cause high river levels during spring runoff periods. High water events can be extended for over a week as the contribution area to the river flows is quite large. The area noted in Quesnel as being in the 200 year floodplain is developed with residential, institutional, commercial and industrial sites. The area also includes natural amenities such as salmon spawning ground.
Meteorological conditions	
Identify the relevant meteorological conditions that may influence the outcome of the risk event.	Spring freshet is the cause of the risk event. Because the highest river flows from the Fraser River and Quesnel River watersheds do not always coincide, the full impact of high river flows has been avoided in recent times. Records have shown, however, that the two rivers can peak at the same time (this occurred during the 1972 flood) so such a peak flow alignment would have more significant impacts. Climate changes and changes within the watersheds (e.g. logging, wildfires and impacts from the pine beetle infestation) may adjust the flow rates and the high flow timings.

Seasonal conditions	
Identify the relevant seasonal changes that may influence the outcome of the risk assessment of a particular risk event.	Spring snowmelt period presents the highest flooding risk. Climate change may result in higher river flows. More extreme rain events would also contribute to the flood level risk.
Nature and vulnerability	
Document key elements related to the affected population, including: • Population density; • Vulnerable populations (identify these on the hazard map from step 7); • Degree of urbanization; • Key local infrastructure in the defined geographic area; • Economic and political considerations; and • Other elements, as deemed pertinent to the defined geographic area.	The area of most risk of flooding is the low-lying areas of Quesnel. The mapping and summary provided in Flood Hazard and Floodplain Mapping, prepared by Urban Systems Ltd. in 2020. identifies the floodplain extents. The highest density of population that will have buildings impacted is found along the west bank of the Fraser River. Just to the northeast of the confluence of the Fraser River and the Quesnel River is City's the main sewage lift station that serves all properties that have sewer service within Quesnel (with the exception of South Quensel). Impacts to both sides of the Fraser River can have health, environmental and economic impacts. Rail and major truck routes could be flooded. Operations of the major mills could be impacted if timber supply is interrupted. Overflow of sanitary sewer could enter into homes and public space, thus presenting a health risk.

Asset inventory	
Identify the asset inventory of the defined geographic area, including: • Critical assets; • Cultural or historical assets; • Commercial assets; and • Other area assets, as applicable to the defined geographic area. Key asset-related information should also be provided, including: • Location on the hazard map (from step 7); • Size; • Structure replacement cost; • Content value; • Displacement costs; • Importance rating and rationale; • Vulnerability rating and reason; and • Average daily cost to operate. A total estimated value of physical assets in the area should also be provided.	The entire community's critical assets could be impacted if the risks of high river flows are not mitigated. Water distribution, sewage collection are all managed from the Public Works Yard. BC Assessment data indicates that the value of land improvements in the City, within the area at risk is over $10,000,000. Note that is likely and underestimate as there are significant structures such as West Park Mall and other commercial buildings as well as many residential buildings. The daily operations that will be impacted are significant. Basic municipal functions could be interrupted, resulting in sanitary and clean drinking water concerns. Business operations could also be impacted.
Other assumptions, variability and/or relevant information	
Identify any assumptions made in describing the risk event; define details regarding any areas of uncertainty or unpredictability around the risk event; and supply any supplemental information, as applicable.	The hydrologic study prepared as part ofthe 2020 work makes predictions regarding the impacts of climate change. Those predictions may no reflect the long term reality in the watershed.
Existing Risk Treatment Measures	
Identify existing risk treatment measures that are currently in place within the defined geographic area to mitigate the risk event, and describe the sufficiency of these risk treatment measures.	There does exist some dike infrastructure along the west bank of the Fraser River that does help protect residential properties and a sewage lift station. Note that dike is not built to the existing 200 year flood level. Erosion protection has also been installed along the Fraser River, Quesnel River and Baker Creek. The protection is managing with current flows, but increased flows due to climate change may justify additional works.

<table>
<tr><td colspan="3">Likelihood Assessment</td></tr>
<tr><td colspan="3">Return Period</td></tr>
<tr><td>Identify the time period during which the risk event might occur. For example, the risk event described is expected to occur once every X number of years. Applicants are asked to provide the X value for the risk event.</td><td colspan="2">A 200 year return period flood is the focus of current and proposed mapping. However, impacts to some properties, transportation routes and properties can occur with lower flood levels.</td></tr>
<tr><td colspan="3">Period of interest</td></tr>
<tr><td colspan="3">Applicants are asked to determine and identify the likelihood rating (i.e. period of interest) for the risk event described by using the likelihood rating scale within the table below.</td></tr>
<tr><td>Likelihood Rating</td><td colspan="2">Definition</td></tr>
<tr><td>5</td><td>The event is expected and may be triggered by conditions expected over a 30 year period.</td><td rowspan="5">4</td></tr>
<tr><td>4</td><td>The event is expected and may be triggered by conditions expected over a 30 - 50 year period.</td></tr>
<tr><td>3</td><td>The event is expected and may be triggered by conditions expected over a 50 - 500 year period.</td></tr>
<tr><td>2</td><td>The event is expected and may be triggered by conditions expected over a 500 - 5000 year period.</td></tr>
<tr><td>1</td><td>The event is possible and may be triggered by conditions exceeding a period of 5000 years.</td></tr>
<tr><td>Provide any other relevant information, notes or comments relating to the likelihood assessment, as applicable.</td><td colspan="2">Records of the 1972 flood indicate that some roads and properties were impacted. While the 200 year floodplain mapping indicates that key infrastructure is at risk of flooding, it is likely that a flood level with a shorter return period will also be a concern, as shown in the 20 year return period flood mapping. The risk is further raised when the impacts of climate change, wildfire and the pine beetle epidemic are also considered.

Also note that almost every year there are some impacts of flooding on area roads as certain roads (i.e. Johnston Bridge Loop and North Fraser Drive) are at an elevation that results in flooding with much lower river levels.</td></tr>
</table>

Impacts/Consequences Assessment

There are 12 impacts categories within 5 impact classes rated on a scale of 1 (least impacts) to 5 (greatest impact). Conduct an assessment of the impacts associated with the risk event, and assign one risk rating for each category. Additional information may be provided for each of the categories in the supplemental fields provided.

A) People and societal impacts

	Risk Rating	Definition	Assigned risk rating
Fatalities	5	Could result in more than 50 fatalities	2
	4	Could result in 10 - 49 fatalities	
	3	Could result in 5 - 9 fatalities	
	2	Could result in 1 - 4 fatalities	
	1	Not likely to result in fatalities	
Supplemental information (optional)	Depending on the rate of river level rise and the speed at which a river bank failure could occur, there presents a small risk that a fatality could occur. That risk is present during the high flow event and during the construction activities needed to repair any damage. This risk is also minimized because the City is proactive in managing the high river levels that are experienced every year.		
Injuries	5	Injuries, illness and/or psychological disablements cannot be addressed by local, regional, or provincial/territorial healthcare resources; federal support or intervention is required	2
	4	Injuries, illnesses and/or psychological disablements cannot be addressed by local or regional healthcare resources; provincial/territorial healthcare support or intervention is required.	
	3	Injuries, illnesses and/or psychological disablements cannot be addressed by local or regional healthcare resources additional healthcare support or intervention is required from other regions, and supplementary support could be required from the province/territory	
	2	Injuries, illnesses and/or psychological disablements cannot be addressed by local resources through local facilities; healthcare support is required from other areas such as an adjacent area(ies)/municipality(ies) within the region	
	1	Any injuries, illnesses, and/or psychological disablements can be addressed by local resources through local facilities; available resources can meet the demand for care	
Supplemental information (optional)	The local hospital is well equipped to address any health issues that are expected to be a result of the flooding. However, if the west side of the Fraser River is isolated from the east side then access to the hospital will be cut off. The Fire Department does have Fire Hall #2 on the west wide of the flooding extents for emergency response. A more significant injury may require the use of a helicopter to cross over the flooded area.		

	Risk Rating	Definition	Assigned risk rating

Displacement	Percentage of displaced individuals	5	> 15% of total local population	3
		4	10 - 14.9% of total local population	
		3	5 - 9.9% of total local population	
		2	2 - 4.9% of total local population	
		1	0 - 1.9% of total local population	
	Duration of displacement	5	> 26 weeks (6 months)	4
		4	4 weeks - 26 weeks (6 months)	
		3	1 week - 4 weeks	
		2	72 hours - 168 hours (1 week)	
		1	Less than 72 hours	
Supplemental information (optional)				
B) Environmental impacts				
		5	> 75% of flora or fauna impacted or 1 or more ecosystems significantly impaired; Air quality has significantly deteriorated; Water quality is significantly lower than normal or water level is > 3 meters above highest natural level; Soil quality or quantity is significantly lower (i.e., significant soil loss, evidence of lethal soil contamination) than normal; > 15% of local area is affected	2
		4	40 - 74.9% of flora or fauna impacted or 1 or more ecosystems considerably impaired; Air quality has considerably deteriorated; Water quality is considerably lower than normal or water level is 2 - 2.9 meters above highest natural level; Soil quality or quantity is moderately lower than normal; 10 - 14.9% of local area is affected	
		3	10 - 39.9% of flora or fauna impacted or 1 1 or more ecosystems moderately impaired; Air quality has moderately deteriorated; Water quality is moderately lower than normal or water level is 1 - 2 meters above highest natural level; Soil quality is moderately lower than normal; 6 - 9.9 % of area affected	

	2	< 10 % of flora or fauna impacted or little or no impact to any ecosystems; Little to no impact to air quality and/or soil quality or quantity; Water quality is slightly lower than normal, or water level is less than 0.9 meters above highest natural level and increased for less than 24 hours; 3 - 5.9 % of local area is affected	
	1	Little to no impact to flora or fauna, any ecosystems, air quality, water quality or quantity, or to soil quality or quantity; 0 - 2.9 % of local area is affected	
Supplemental information (optional)			
C) Local economic impacts			
	Risk Rating	**Definition**	**Assigned risk rating**
	5	> 15 % of local economy impacted	3
	4	10 - 14.9 % of local economy impacted	
	3	6 - 9.9 % of local economy impacted	
	2	3 - 5.9 % of local economy impacted	
	1	0 - 2.9 % of local economy impacted	
Supplemental information (optional)			

D) Local infrastructure impacts			
	Risk Rating	**Definition**	**Assigned risk rating**
Transportation	5	Local activity stopped for more than 72 hours; > 20% of local population affected; lost access to local area and/or delivery of crucial service or product; or having an international level impact	5
	4	Local activity stopped for 48 - 71 hours; 10 - 19.9% of local population affected; significantly reduced access to local area and/or delivery of crucial service or product; or having a national level impact	
	3	Local activity stopped for 25 - 47 hours; 5 - 9.9% of local population affected; moderately reduced access to local area and/or delivery of crucial service or product; or having a provincial/territorial level impact	
	2	Local activity stopped for 13 - 24 hours; 2 - 4.9% of local population affected; minor reduction in access to local area and/or delivery of crucial service or product; or having a regional level impact	
	1	Local activity stopped for 0 - 12 hours; 0 - 1.9% of local population affected; little to no reduction in access to local area and/or delivery of crucial service or product	
Supplemental information (optional)			
Energy and Utilities	5	Duration of impacts > 72 hours; > 20% of local population without service or product; or having an international level impact	5
	4	Duration of impact 48 - 71 hours; 10 - 19.9% of local population without service or product; or having a national impact	
	3	Duration of impact 25 - 47 hours; 5 - 9.9% of local population without service or product; or having a provincial/territorial level impact	
	2	Duration of impact 13 - 24 hours; 2 - 4.9% of local population without service or product; or having a regional level impact	
	1	Local activity stopped for 0 - 12 hours; 0 - 1.9% of local population affected; little to no reduction in access to local area and/or delivery of crucial service or product	

Supplemental information (optional)	High water events can last for well over a week in Quesnel, as noted during the 1972 flood. A major impact will be the operation of the sanitary sewer system, which would likely become flooded. There would also be termination of power service to flooded buildings.		
Information and Communications Technology	5	Service unavailable for > 72 hours; > 20 % of local population without service; or having an international level impact	1
	4	Service unavailable for 48 - 71 hours; 10 - 19.9 % of local population without service; or having a national level impact	
	3	Service unavailable for 25 - 47 hours; 5 - 9.9 % of local population without service; or having a provincial/territorial level impact	
	2	Service unavailable for 13 - 24 hours; 2 - 4.9 % of local population without service; or having a regional level impact	
	1	Service unavailable for 0 - 12 hours; 0 - 1.9 % of local population without service	
Supplemental information (optional)	No major service interruption expected, assuming that power poles are not damaged during a high flow event.		
Health, Food, and Water	5	Inability to access potable water, food, sanitation services, or healthcare services for > 72 hours; non - essential services cancelled; > 20 % of local population impacted; or having an international level impact	3
	4	Inability to access potable water, food, sanitation services, or healthcare services for 48 - 72 hours; major delays for nonessential services; 10 - 19.9 % of local population impacted; or having a national level impact	
	3	Inability to access potable water, food, sanitation services, or healthcare services for 25 - 48 hours; moderate delays for nonessential services; 5 - 9.9 % of local population impacted; or having a provincial/territorial level impact	
	2	Inability to access potable water, food, sanitation services, or healthcare services for 13 - 24 hours; minor delays for nonessential; 2 - 4.9 % of local population impacted; or having a regional level impact	
	1	Inability to access potable water, food, sanitation services, or healthcare services for 0 - 12 hours; 0 - 1.9 % of local population impacted	

Supplemental information (optional)	Flooding on the west side of the Fraser River presents isolation from healthcare and other services for a major portion of the community, including some nearby first nations communities. Having Fire Hall #2 on the west side of the flooding area does help to reduce some risk.		
Safety and Security	5	> 20 % of local population impacted; loss of intelligence or defence assets or systems for > 72 hours; or having an international level impact	1
	4	10 - 19.9 % of local population impacted; loss of intelligence or defence assets or systems for 48 – 71 hours; or having a national level impact	
	3	5 - 9.9 % of local population impacted; loss of intelligence or defence assets or systems for 25 – 47 hours; or having a provincial/territorial level impact	
	2	2 - 4.9 % of local population impacted; loss of intelligence or defence assets or systems for 13 – 24 hours; or having a regional level impact	
	1	0 - 1.9 % of local population impacted; loss of intelligence or defence assets or systems for 0 – 12 hours	
Supplemental information (optional)	Intelligence and defence systems will be minimally impacted. However properties on the west side of the Fraser River could be isolated from local police and fire department services, but the City's emergency planning during flooding being updated to ensure that Fire Hall #2 is properly equipped and staff and keeping some police presence on the west side of the flooding will help to reduce the risk somewhat.		

E) Public sensitivity impacts			
	Risk Rating	Definition	Assigned risk rating
	5	Sustained, long term loss in reputation/public perception of public institutions and/or sustained, long term loss of trust and confidence in public institutions; or having an international level impact	3
	4	Significant loss in reputation/public perception of public institutions and/or significant loss of trust and confidence in public institutions; significant resistance; or having a national level impact	
	3	Some loss in reputation/public perception of public institutions and/or some loss of trust and confidence in public institutions; escalating resistance	
	2	Isolated/minor, recoverable set - back in reputation, public perception, trust, and/or confidence of public institutions	
	1	No impact on reputation, public perception, trust, and/or confidence of public institutions	
Supplemental information (optional)	Widespread flooding of Quesnel and/or discharge of raw sewage to the Fraser River will present a lack of confidence as concerns regarding these problems have been mounting as the profile of the impacts of climate change increase. As well tourism could be impacted is visitors become worries about being stranded or of being there when a flood event occurs. Confidence in the availability of reliable transport is essential to the rail operations. The negative public and business relations associated with the trucking routes to the major industrial facilities could have consequences to those businesses.		

Confidence Assessment		
Based on the table below, indicate the level of confidence regarding the information entered in the risk assessment information template in the "Confidence Level Assigned" column. Confidence levels are language - based and range from A to E (A=most confident to E=least confident).		
Confidence Level	**Definition**	**Confidence Level Assigned**
A	Very high degree of confidence Risk assessment used to inform the risk assessment information template was evidence - based on a thorough knowledge of the natural hazard risk event; leveraged a significant quantity of high - quality data that was quantitative and qualitative in nature; leveraged a wide variety of data and information including from historical records, geospatial and other information sources; and the risk assessment and analysis processes were completed by a multidisciplinary team with subject matter experts (i.e., a wide array of experts and knowledgeable individuals on the specific natural hazard and its consequences) Assessment of impacts considered a significant number of existing/known mitigation measures	
B	High degree of confidence Risk assessment used to inform the risk assessment information template was evidence - based on a thorough knowledge of the natural hazard risk event; leveraged a significant quantity of data that was quantitative and qualitative in nature; leveraged a wide variety of data and information including from historical records, geospatial and other information sources; and the risk assessment and analysis processes were completed by a multidisciplinary team with some subject matter expertise (i.e., a wide array of experts and knowledgeable individuals on the specific natural hazard and its consequences) Assessment of impacts considered a significant number of potential mitigation measures	
C	Moderate confidence Risk assessment used to inform the risk assessment information template was moderately evidence - based from a considerable amount of knowledge of the natural hazard risk event; leveraged a considerable quantity of data that was quantitative and/or qualitative in nature; leveraged a considerable amount of data and information including from historical records, geospatial and other information sources; and the risk assessment and analysis processes were completed by a moderately sized multidisciplinary team, incorporating some subject matter experts (i.e., a wide array of experts and knowledgeable individuals on the specific natural hazard and its consequences) Assessment of impacts considered a large number of potential mitigation measures	

D	Low confidence Risk assessment used to inform the risk assessment information template was based on a relatively small amount of knowledge of the natural hazard risk event; leveraged a relatively small quantity of quantitative and/or qualitative data that was largely historical in nature; may have leveraged some geospatial information or information from other sources (i.e., databases, key risk and resilience methodologies); and the risk assessment and analysis processes were completed by a small team that may or may not have incorporated subject matter experts (i.e., did not include a wide array of experts and knowledgeable individuals on the specific natural hazard and its consequences). Assessment of impacts considered a relatively small number of potential mitigation measures	B
E	Very low confidence Risk assessment used to inform the risk assessment information template was not evidence - based; leveraged a small quantity of information and/or data relating to the natural risk hazard and risk event; primary qualitative information used with little to no quantitative data or information; and the risk assessment and analysis processes were completed by an individual or small group of individuals little subject matter expertise (i.e., did not include a wide array of experts and knowledgeable individuals on the specific natural hazard and its consequences). Assessment of impacts did not consider existing or potential mitigation measures	

Rationale for level of confidence

Provide the rationale for the selected confidence level, including any references or sources to support the level assigned.	The 1992 flood assessment that was completed by Northwest Hydraulics Consultants formed the basis of the original floodplain mapping. the 2020 work updated the flood assessment information.

Key Information Sources	
Identify all supporting documentation and information sources for qualitative and quantitative data used to identify risk events, develop the risk event description, and assess impacts and likelihood. This ensures credibility and validity of risk information presented as well as enables referencing back to decision points at any point in time. Clearly identify unclassified and classified information.	Floodplain Mapping Investigation, Fraser and Quesnel Rivers at Quesnel, Design Brief, prepared by Northwest Hydraulics Consultants Ltd. in 1992. The Effect of Mountain Pine Beetle Attack and Salvage Harvesting on Streamflows, prepared by the Forest Practices Board in 2007 regarding the Baker Creek watershed. Flood Hazard and Floodplain Mapping, prepared by Urban Systems Ltd. in 2020.
Description of the risk analysis team	
List and describe the type and level of experience of each individual who was involved with the completion of the risk assessment and risk analysis used to inform the information contained within this risk assessment information template.	Chris Coben, City of Quesnel's Director of Capital Works and Infrastructure with over 17 years of experience working at the City of Quesnel. Rick Collins, P.Eng. with 22 years of engineering consulting experience and has completed a number of utility risk assessments during that period. he has also worked as a consultant to the City for the last 20 years.