FINAL REPORT

# Ebenezer Flats / Kidd Road Flood Mitigation Study

March 12, 2019

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12 March 2019

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Attention: Jason Llewellyn, Director of Planning

Please find attached the Ebenezer Flats / Kidd Road Flood Mitigation Study final report. The final report includes the information that is available to the McElhanney team. The report considered all the comments that RDBN provided on 20 November 2018.

Yours truly,
McELHANNEY CONSULTING SERVICES LTD.

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# EXECUTIVE SUMMARY

Ebenezer Flats is located within Bulkley River floodplain and has been the subject of historical flooding. McElhanney Consulting Services Ltd. (MCSL) has previously assisted the Regional District of Bulkley-Nechako (RDBN) on the investigation of bank erosion due to flood events and development of erosion protection measures. The purpose of this flood mitigation study is to understand the flood risks at Ebenezer Flats and to develop flood mitigation measures.

The study was completed in the following steps:

- Public meeting to identify issues with community members;
- Collection of LiDAR and bathymetric data;
- Estimating the design flood discharges;
- Determining climate change impact on the flows;
- Developing 2D HEC-RAS hydraulic model;
- Completing ice jam modelling;
- Creating flood maps;
- Creating hazard maps and hazard classification;
- Developing flood mitigation options;
- Assessing ice jam mitigation options;
- Developing erosion mitigation option for a reach within Ebenezer Flats; and
- Summarizing conclusions and recommendations.

A public consultation meeting was arranged by RDBN to obtain information and suggestions from the Ebenezer Flats residents prior to the start of the study. MCSL determined the design floods considering climate change. A 2D HEC-RAS hydraulic model was developed. Flood inundation and hazard maps were produced to support an assessment of the flood risk to the area. Following this flood risk assessment, six options were reviewed to mitigate against the identified risk.

The review of potential flood mitigation options considered two levels of flood protection:

- Local flood protection (individual dikes around houses or raising the houses and roads above the flood elevation); and
- Area flood protection (i.e., dikes on the river)

The flood damage and the mitigation options costs were estimated. A Return on Investment (ROI) analysis was completed for each option. However, selection of an option should not be limited to the ROI but on the overall impact factors which cannot be assigned a dollar value. Hence, a Multiple Accounts Evaluation (MAE) was undertaken which included consideration of safety implications, resources required, environmental impacts, downstream impacts, permitting and approval requirements, social issues and overall effectiveness. This evaluation is used to select a preferred flood mitigation option. The following factors were key in the selection of a viable mitigation option:

- Cost of dikes for area flood protection are much higher than individual properties protection.
- Dikes may have geotechnical concerns due to the soil foundation that may result in groundwater infiltration. Groundwater cut-off walls may not be feasible.
- Raising the roads is not an effective flood mitigation option by itself.

No one option was identified as the preferred option by itself. This led to a combined approach for a feasible flood mitigation option. Raising the roads allows for access for emergency vehicles during the flood and delayed evacuations, if required. Raising the house elevations and access to the entrances allows the residents to reduce flood damage and extend evacuation time during the floods. However, it should be noted that the proposed option provides protection up to the 200-year flood event only and floods beyond the 200-year may still require evacuation. In addition, flooding of the areas around the houses may still occur. Basements may not be protected during the floods so additional individual basement protection may be required.

Floodplain maps showing a proposed construction elevation were developed. It is recommended that RDBN should continue to include requirements as part of their planning processes to ensure that any new development is above the identified level.

Ice jam breaking options were considered. In general, the ice breaking is an expensive approach to handle ice jams. It becomes feasible in large rivers passing through areas of high population. There are also extensive permitting requirements, safety concerns and possible environmental impacts. Dikes would be costly and may not be feasible.

Removing the old bridge piers and the island was considered as an ice jam mitigation option. The 2D HEC-RAS model showed that ice jams at the location of the bridge piers would cause local flooding at Ebenezer Flats. Removing the piers would reduce the probability of the ice jams. No information regarding the piers foundation was available to assess the cost. Removing the bridge may slow down the growth of the island due to the accumulated sand bars. Removing the island may not be practical at this point due to the environmental permitting challenges and cost. If the bridge piers are removed, the island and the occurrence of ice jams could be monitored and assessed to determine if removing the island should be further investigated.

A proposed approach to both flood mitigation and ice jams may be achieved in the following steps:

- Confirm that raising the elevation of key roads and the residential properties are RDBN and the residents' preferred options
- Stage the construction of the roads and the dwellings raising (i.e., raising Columbia Road and the adjacent dwellings to the road proceeding 22 Avenue
- Remove the bridge piers and monitor the island and the ice jams occurrence.

In addition to the risk of flooding and ice jams, MCSL assessed erosion protection for the properties in the vicinity of 195 to 661 Viewmount Road North. The river reach is approximately 400m. Riprap is proposed as an erosion mitigation measure. However, for effective erosion protection the river reach that needs to be protected would be extended to 600m. For the 200-year flood, the water depth in the river is estimated at 3.5 m and the scour depth is approximately 1.8m. The cost for using the riprap of the river reach is approximately $1M. Lower levels of protection can be implemented at a lower cost but would provide less protection and may have higher probability of failure.

# DEFINITIONS

Bathymetry – Bathymetry is the measurement of depth of water in oceans, seas, or lakes.

Break-up Period – Break-up period is when river ice surface starts to break, usually at beginning of spring melt.

Catchment – Catchment is the area where precipitation collects and drains to a single outlet.

Coefficient of Determination – The coefficient of determination (denoted by $R^2$) is a statistical measure of how close the data are to the fitted regression line.

Empirical Model – Empirical model is a model in which calculations are based on observed associations between variables.

Flood – Flood is a condition in which a watercourse or body of water overtops its natural or artificial confines and covers land not normally under water.

Flood Hazard Maps – Maps that go beyond inundation maps by providing information on the hazards associated with defined flood events, such as water depth, velocity and duration of flooding.

Flood Risk Maps – Maps that reflect the potential damages that could occur as a result of a range of flood probabilities, by identifying populations, buildings, infrastructure, residences and the environment, cultural and other assets that could be damaged or destroyed.

Freeze-up Period – Freeze-up period is when river surface starts to freeze up, usually at late winter.

Frequency Analysis – Frequency analysis is the study of the number of observations of a random variables.

Hazard – A source of potential harm, or situation with a potential for causing harm, in terms of human injury, damage to health, property, the environment, and other things of value; or some combination of these, as defined by the Canadian Standards Association (CSA 1997)

HEC-RAS – Software developed by US army corps of Engineers which allows the user to perform one-dimensional steady flow, one and two-dimensional unsteady flow calculations, sediment transport/mobile bed computations, and water temperature/water quality modeling.

Hydraulic Model – A hydraulic model is a mathematical model of a water/sewer/storm system and is used to analyze the system's hydraulic behavior.

Hydrograph – A hydrograph is a graph showing the rate of flow (discharge) versus time past a specific point in a river, channel, or conduit carrying flow. The rate of flow is typically expressed in cubic meters or cubic feet per second.

Hydrology – Hydrology is the branch of science concerned with the properties of the earth's water, especially its movement in relation to land.

Hydrometric Station – A station on a river, lake, estuary, or reservoir where water quantity and quality data are collected and recorded.

Instantaneous Peak Flow – Daily mean flow is the average streamflow during a day, and instantaneous peak flow is the highest flow measured during a day. Instantaneous flows can be significantly higher than daily mean flows as a result of phenomena such as intense rainfall or the diurnal cycle of snowmelt.

Inundation Maps – Topographic maps showing the extent of floodwater in plan, under defined flood events.

Isoline – A line on a surface connecting points of equal value.

LiDAR – Light Detection and Ranging, is a remote sensing method used to examine the surface of the Earth.

Return Period – A return period, also known as a recurrence interval (sometimes repeat interval) is an estimate of the likelihood of an event, such as an earthquake, flood, landslide, or a river discharge flow to occur.

ROI – Return on Investment.

TRIM Contours – TRIM stands for Terrain Resource Information Management, TRIM contours are derived from DEM (Digital Elevation Model) data.

# 1. INTRODUCTION

## 1.1. BACKGROUND

In 2008-2009 McElhanney Consulting Services Ltd. (MCSL) assisted the Regional District of Bulkley Nechako (RDBN) with a review of erosion along the banks of the Bulkley River in the Ebenezer Flats area. Approximately 28 properties were involved in that study, which focused solely on bank erosion leading to loss of riverfront property as opposed to flood mitigation.

Although the Erosion Protection Study focused primarily on bank erosion, there was a discussion of historical peak flows in the Bulkley River along with a methodology that used relevant local knowledge to determine an approximate overtopping elevation for the river flows (shown in Figure 1 as the horizontal blue line). At the time, there was not sufficient budget to conduct a full floodplain modelling and mapping exercise. The relevant graph of peak flows, along with the estimated overbank elevation, is shown in Figure 1.

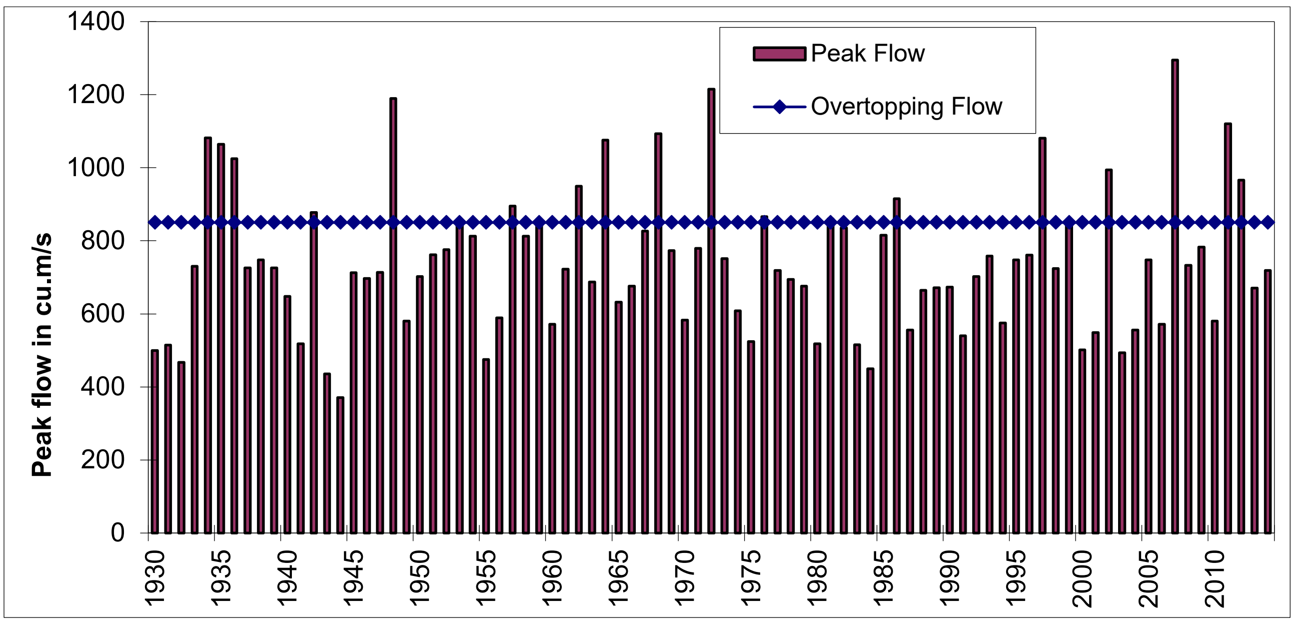



*Figure 1: Historical Peak Flows in the Bulkley River (1930-2014)*

Nearly 10 years has passed since this initial investigation has taken place. Reviewing the updated flow data recorded by the Water Survey of Canada, flows that would have been considered overbank flows also occurred in 2011 and 2015. This is corroborated by actual events. In May 2011 a flood evacuation order was given for the Ebenezer Flats area due to heavy rain and melting snow, with residents having to move pets, livestock, vehicles and other belongings. In December 2015 the Bulkley River overtopped its banks due to the formation of a freeze-up ice jam. The Ebenezer Flats area was affected at that time.

## 1.2. SCOPE

The objectives of this study are to:

- Complete a flood risk assessment;
- Develop flood inundation maps;
- Identify and assess flood mitigation options;
- Identify and assess ice jam mitigation options;
- Assess removal of the old bridge piers and the downstream island on floods and ice jams; and
- Assess erosion protection for selected properties by Bulkley River.

The scope of the current project now includes detailed floodplain modelling that will give a more accurate determination of required flood construction levels in the Ebenezer Flats area for the RDBN. The current project is significantly larger, encompassing more residences and the Ebenezer Canadian Reformed School located on Viewmount Road. Furthermore, flood risks were assessed, and flood mitigation options developed to better manage future floods. The study area is shown in Figure 2.

The following deliverables were prepared as requested by RDBN:

- A report summarizing the information, analysis and the flood and ice jam mitigation options; and
- Floodplain mapping.

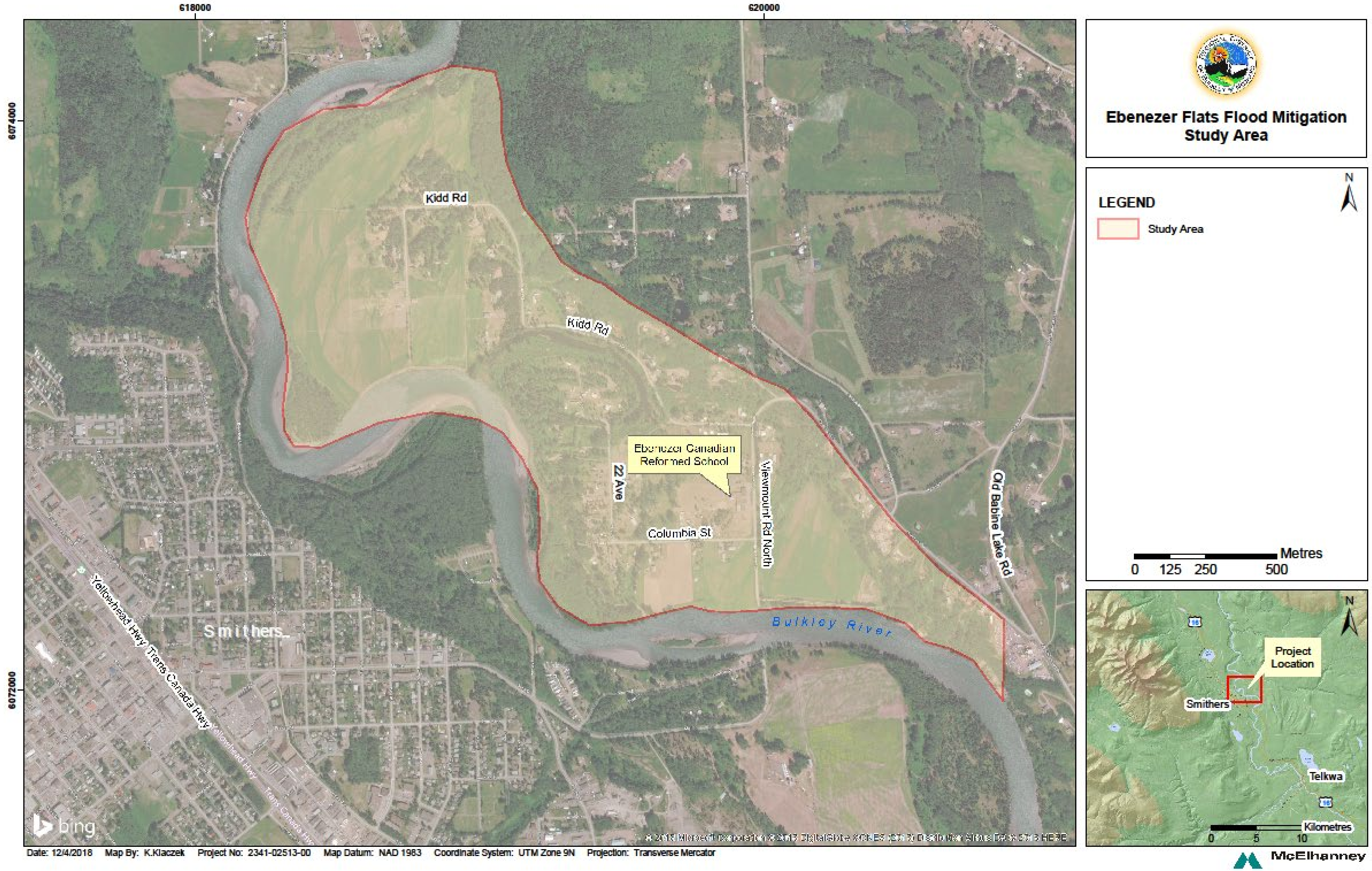



*Figure 2: Study Area*

# 2. METHODOLOGY

The following approach was used to complete this study:

- Public meeting to identify issues with community members;
- Collection of LiDAR and bathymetric data;
- Estimating the design flood discharges;
- Determining climate change impact on the flows;
- Developing 2D HEC-RAS Hydraulic model;
- Completing ice jam modelling;
- Creating flood maps;
- Creating hazard maps and hazard classification;
- Developing flood mitigation options;
- Assessing ice jam mitigation options;
- Developing erosion mitigation option for a reach within Ebenezer Flats; and
- Summarizing conclusions and recommendations.

MCSL attended a public consultation meeting that was arranged by RDBN to obtain information and suggestions from the Ebenezer Flats residents. Information regarding the properties, schools and any critical structures were collected from RDBN and reviewed.

MCSL completed a site survey to obtain the data required for the study area hydraulic modelling. The topography and the nature of the river require two-dimensional (2D) hydraulic modelling. MCSL used a 2D HEC-RAS model. Although this is more complex level of modelling, it can better capture the hydraulic conditions than the one-dimensional (1D) modelling.

The 2D HEC-RAS model was developed. Flood inundation and hazard maps were produced to support an assessment of the flood risk to the area. Flood maps show the depth of the inundated area and hazard maps reflect the risk to the population during the flood event. Flood inundation maps showing a proposed construction elevation were developed.

Following this flood risk assessment, six options were reviewed to mitigate against the identified risk. The review of potential flood mitigation options considered two levels of flood protection:

- Local flood protection (individual dikes around houses or raising the houses and roads above the flood elevation); and
- Area flood protection (i.e., dikes on the river)

Flood mitigation measures were assessed. A ROI analysis was completed for each option. However, selection of an option should not be limited to the ROI but also consider the overall impact factors which cannot be assigned a dollar value. Hence, a Multiple Accounts Evaluation was undertaken which included consideration of safety implications, resources required, environmental impacts, downstream impacts, permitting and approval requirements, social issues and overall effectiveness.

The following ice jam mitigation options were assessed:

- AMPHIBEX;
- Ice Weakening / Drilling;

- Ice Blasting;
- Mechanical Ice Removal (Backhoe Excavator);
- Mechanical Ice Removal (Dragline Crane); and
- Setback Dikes.

Removing the old bridge piers and the island was considered as ice jamming mitigation option. The ice jams at the location of the bridge piers may cause local flooding at Ebenezer Flats. No information regarding the piers foundation was available.

MCSL assessed erosion protection for the properties in the vicinity of 195 to 661 Viewmount Road North. The scour depth was estimated. Riprap sizes and layer thickness were determined and the cost for erosion protection was estimated.

# 3. STUDY AREA SURVEY

MCSL completed LiDAR and bathymetric river surveys. The data from the bathymetric survey and the LiDAR were processed and combined. The information regarding the LiDAR survey data collection, quality control procedures and deliverables are summarized in Appendix D.

Soundings of the Bulkley River at Ebenezer Flats where undertaken on June 12 to 14, 2018. The equipment used for the soundings survey was Trimble dual frequency RTK GPS. This was paired with a Sea Floor Hydrolite eco sounder. Areas of shallow water were surveyed with conventional RTK GPS and chest waders.

Sounder depth was checked with a fixed rod measurement. Additional checks were undertaken against a secondary boat sounder. Further checks were undertaken by sounding over areas of the river bottom that had been surveyed with conventional RTK GPS and chest waders. The RTK GPS was checked against a fixed point before the start of soundings and at the end of sounding each day.

# 4. HYDROTECHNICAL ASSESSMENT

## 4.1. HYDROLOGY

Ebenezer Flats is located on the floodplain of the Bulkley River, east of Smithers. MCSL completed a hydrologic analysis to determine the catchment area and the instantaneous peak flows for a range of return periods up to 200-year. The climate change impacts were considered for snowmelt peak flows by 2060. A 2D HEC-RAS hydraulic model was used to simulate the flood and ice jam conditions. The modelling outputs were used to create flood maps and for developing flood mitigation options.

### 4.1.1. Catchment Area

Figure 3 shows the catchment area of Ebenezer Flats which is approximately 9,000 $km^2$. It is a part of the Bulkley River watershed which originates from Morice Lake and drains a total area of 12,173 $km^2$. The major tributaries to the Bulkley River upstream to the study are Morice River, Little Bulkley River and Telkwa River. The Bulkley River is a tributary to the Skeena River. The confluence of the two rivers is situated just downstream to Hazelton.

The catchment area is delineated based on the Freshwater Atlas drainage basin shapefile available on the Government BC data portal. The delineated catchment was verified against the TRIM contours lines provided by Open Map BC.

### 4.1.2. Regional Hydrometric Stations

The Water Survey of Canada (WSC) operates three hydrometric stations on the Bulkley River. The catchment area and record length of the three hydrometric stations are shown in Table 1. The WSC hydrometric station - Bulkley River near Smithers (08EE005) is located at the Highway 16 bridge approximately 3 km upstream to the study area. The catchment area of the hydrometric station provided by WSC is 8,940 $km^2$.

*Table 1: Regional Hydrometric Stations*

| Station Name | Catchment Area ($km^2$) | Total Years of Records |
|---|---|---|
| Bulkley River near Smithers | 8,940 | 15 |
| Bulkley River at Quick | 7,340 | 85 |
| Bulkley River near Houston | 2,370 | 56 |

The record length for the hydromtetric station at Bulkley River near Smithers (08EE005) is 15 years which is inadequate for the regional frequency analysis. Therefore, a relationship was established between the other two availbale hydrometric stations and the station at Bulkley River near Smithers.

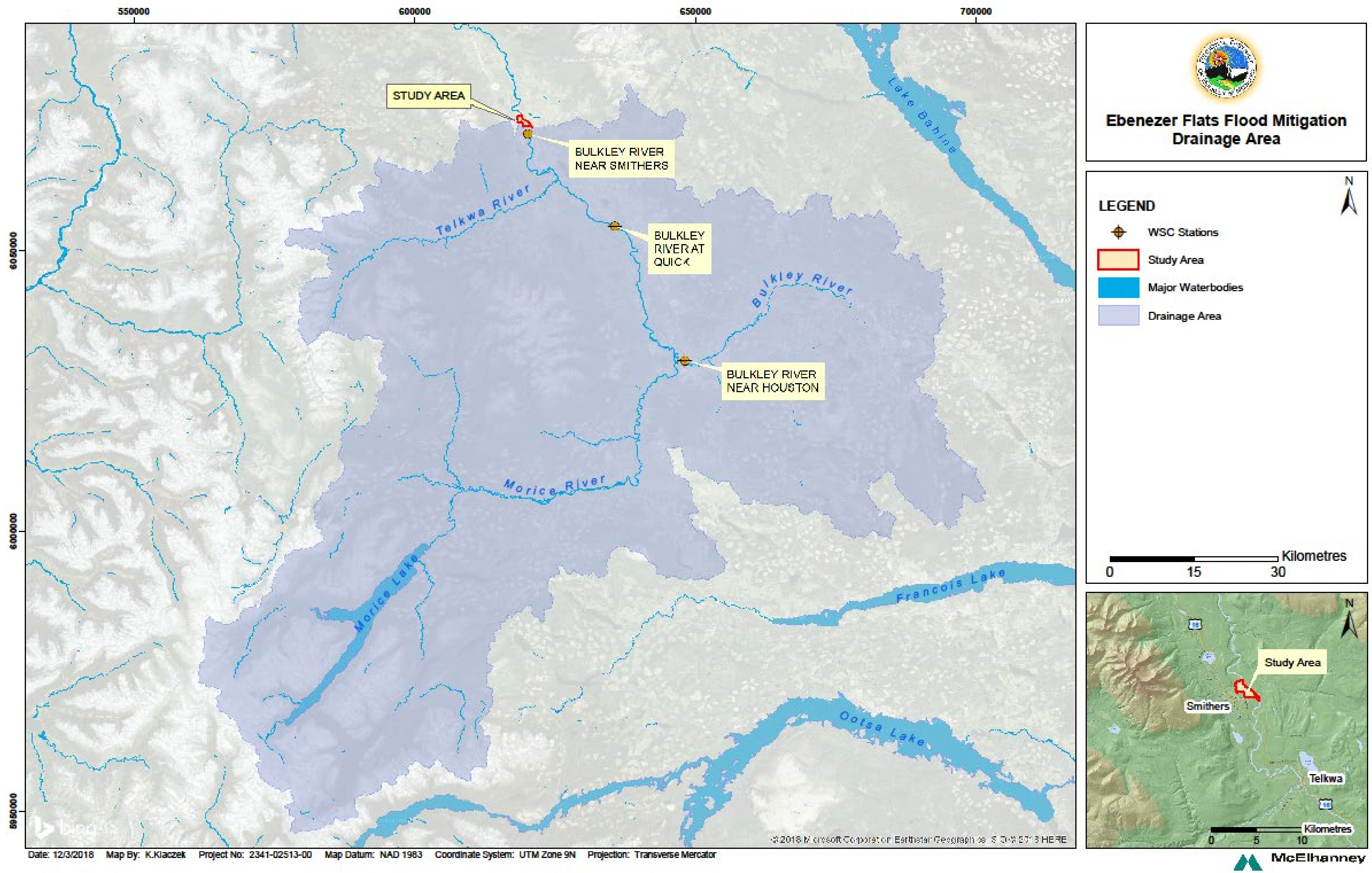



*Figure 3: Catchment Area*

The coefficient of determination ($R^2$), shown in Figure 4, indicates a strong flow correlation between the spring peak flows at Bulkley River near Smithers and spring flows Bulkley River at Quick hydrometric stations (i.e., $R^2$ is close to 1.0). The peak flows at the two hydrometric stations are both snowmelts driven. The correlation of the peak flows between the stations at Bulkley River near Houston and Bulkley River near Smithers is not as strong due to the difference in drainage areas. Hence, the station at Bulkley River near Houston was not used in the hydrologic analysis.

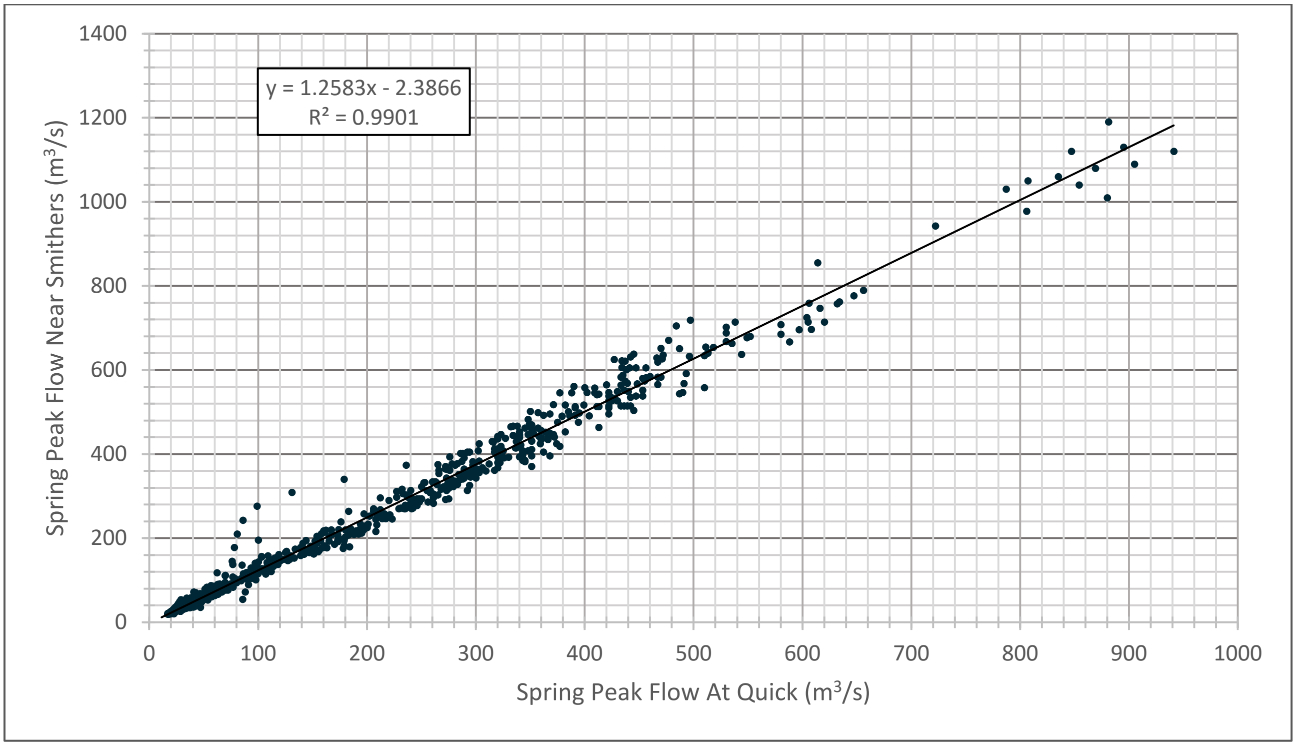



*Figure 4: Spring Runoff Correlation between Hydrometric Stations*

### 4.1.3. Synthetic Flow Hydrograph

A synthetic hydrograph, shown in Figure 5, was generated based on the catchment area ratio between the two hydrometric stations at Bulkley River near Smithers and Bulkley River at Quick. The synthetic hydrograph was created to fill the flow data gaps. The hydrograph in Figure 5 shows that the watershed usually experiences one major runoff which occurs between late spring and early summer. There are rainfall related runoffs recorded between early June and late October. The baseflow in fall and winter is usually around 30 to 200 $m^3/s$.

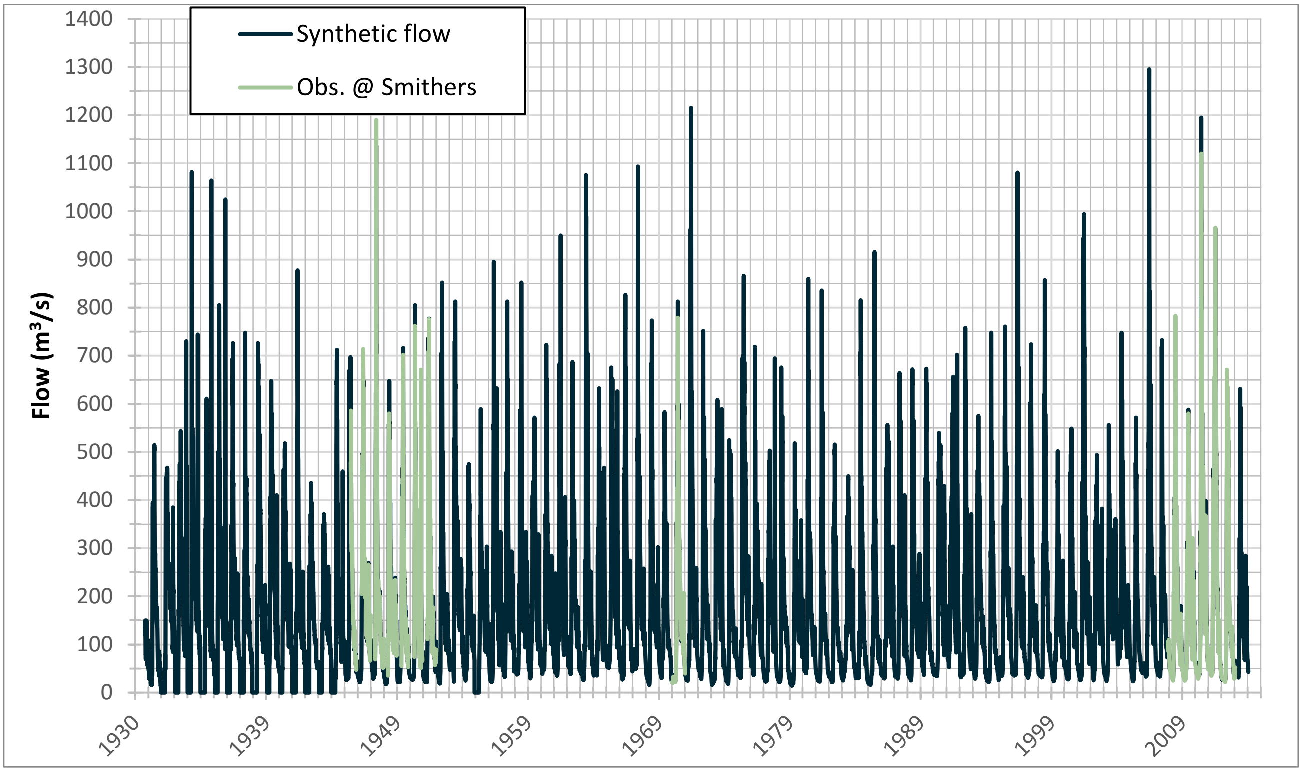



*Figure 5: Synthetic Flow Hydrograph near Smithers*

### 4.1.4. Regional Frequency Analysis

Historical maximum flow data is available from WSC hydrometric station at Bulkley River near Smithers. The flow data is summarized in Table 2. For the years with concurrent maximum daily flows and instantaneous peak flows, the ratio was calculated. The instantaneous peak flows are approximately higher than maximum daily flows by 2% to 5%. The instantaneous peak flow for the missing years of record will be estimated by multiplying the maximum daily flow by a factor of 1.05.

*Table 2: Annual Maximum Daily and Instantaneous Peak Flows at Bulkley River near Smithers*

| Date | Instantaneous Peak Flow ($m^3/s$) | Maximum Annual Daily Flow ($m^3/s$) | Instantaneous Peak/Max Annual Daily |
|---|---|---|---|
| 1947-05-31 | | 714 | |
| 1948-05-29 | | 1,190 | |
| 1949-05-24 | | 580 | |
| 1950-06-18 | | 702 | |
| 1951-05-13 | | 762 | |
| 1952-06-12 | | 776 | |
| 1971-06-09 | | 779 | |
| 2009-06-06 | 796 | 783 | 1.02 |
| 2010-06-03 | 590 | 580 | 1.02 |
| 2011-05-28 | 1,140 | 1,120 | 1.02 |
| 2012-06-25 | 1,010 | 966 | 1.05 |
| 2013-05-13 | 691 | 671 | 1.03 |
| 2014-05-19 | 744 | 719 | 1.03 |
| 2015-05-17 | 1,010 | | |
| 2016-04-25 | 546 | | |

A frequency analysis was completed to determine the instantaneous peak flows for various return periods. The highest instantaneous flows were selected from each year and ranked based on non-exceedance probabilities (Figure 6). The flows and corresponding probabilities were then plotted. Ten probability distribution types were used to fit the dataset and three numerical goodness-of-fit tests were applied to determine the overall highest-ranking distribution type. The overall highest-ranking distribution type is Lognormal. The selected frequency distribution is shown in Figure 6. The bounding lines show the 95% confidence interval.

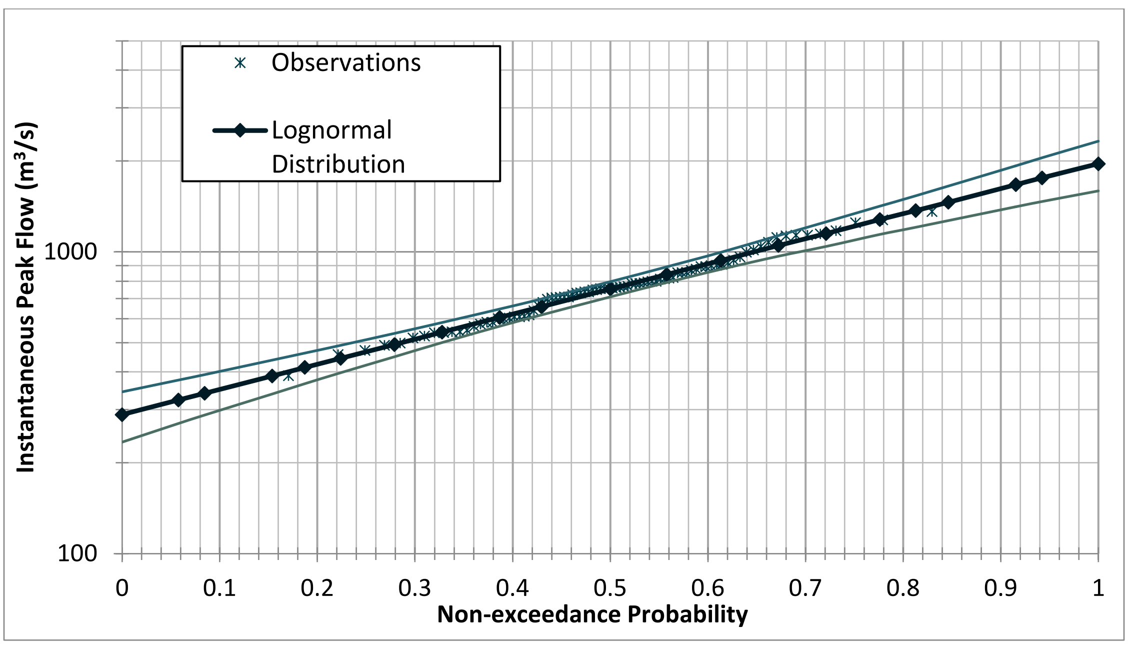



*Figure 6: Discharge - Probability Frequency Curve with Lognormal Distribution*

Table 3 shows that the instantaneous peak flow for the 200-year return period is 1,460 $m^3/s$. The instantaneous peak flow for the 100-year return period is 1,370 $m^3/s$.

*Table 3: Instantaneous Peak Flows*

| Return Period | Instantaneous Peak Flow ($m^3/s$) |
|---|---|
| 200 | 1,460 |
| 100 | 1,370 |
| 50 | 1,280 |
| 20 | 1,150 |
| 10 | 1,050 |
| 5 | 936 |
| 2 | 753 |

The 100-year instantaneous peak flow estimated from the BC 100 Year Peak Flow Isoline is 1,701 $m^3/s$. The Peak Flow Isoline is based on BC streamflow inventory dated back to 1998. The hydrometric data used to compute the isolines is outdated but it is still valid for checking the magnitude of the flood (BC Streamflow Inventory). The estimated flows from the regional analysis will be used for flood modelling and mapping.

## 4.2. CLIMATE CHANGE

The Pacific Climate Impacts Consortium (PCIC) is a regional climate service center at the University of Victoria that conducts climate change impact studies in the Pacific and Yukon region. Its work has been widely accepted by government agencies and engineering associations in Western Canada. MCSL used both PCIC’s climate and hydrologic data to carry out climate change impact analysis. Because the project area does not fall within the extent of the hydrologic model outputs provided by PCIC, an empirical degree-day snowmelt model was developed to determine the relationship between the hydrologic parameters and snowmelt driven runoff in the study area.

### 4.2.1. Snowmelt Runoff Model

There are four major hydrologic parameters included in the snowmelt runoff model:

- Total degree-days during snowmelt;
- Total rain on snow during snowmelt;
- Total Snow Water Equivalent (SWE); and
- Antecedent soil moisture condition.

The total degree-days were calculated as the sum of temperatures above threshold (0 Degree Celsius) during the spring runoff period. The total rain on snow is another key parameter for snowmelt driven runoffs in Northern BC. It was calculated as the total rainfall during the spring runoff period when temperature is above

0 Degree Celsius. Total SWE was calculated as the total snowfall accumulated prior to the melt. The fall precipitation is used to represent the antecedent soil moisture condition.

An empirical snowmelt model was developed to capture the relationships between the hydrologic parameters and the maximum annual daily flows. The model was calibrated using maximum annual daily flows extracted from the synthetic hydrographs for the study area. A total of 64 years of peak flow and climate data were used to calibrate the model. Global Circulation Model (GCM) outputs such as precipitation and temperatures from 2018 to 2100 were used to estimate the trend for snow driven peaks in the study area.

### 4.2.2. Climate Trend Analysis

The snowmelt runoff model results are shown in Figure 7. The circles in the gragh represent the modeled annual maximum flows, the crosses denote the WSC observed annual maximum flows and the triangles indicate the annual maximum flows predicted by the emperical model.

As indicated by the linear trendline in Figure 7, the modeled annual maximum flows generally increased across the 150 years simulation period. The estimated increase by the end of 2060 is about 10%.

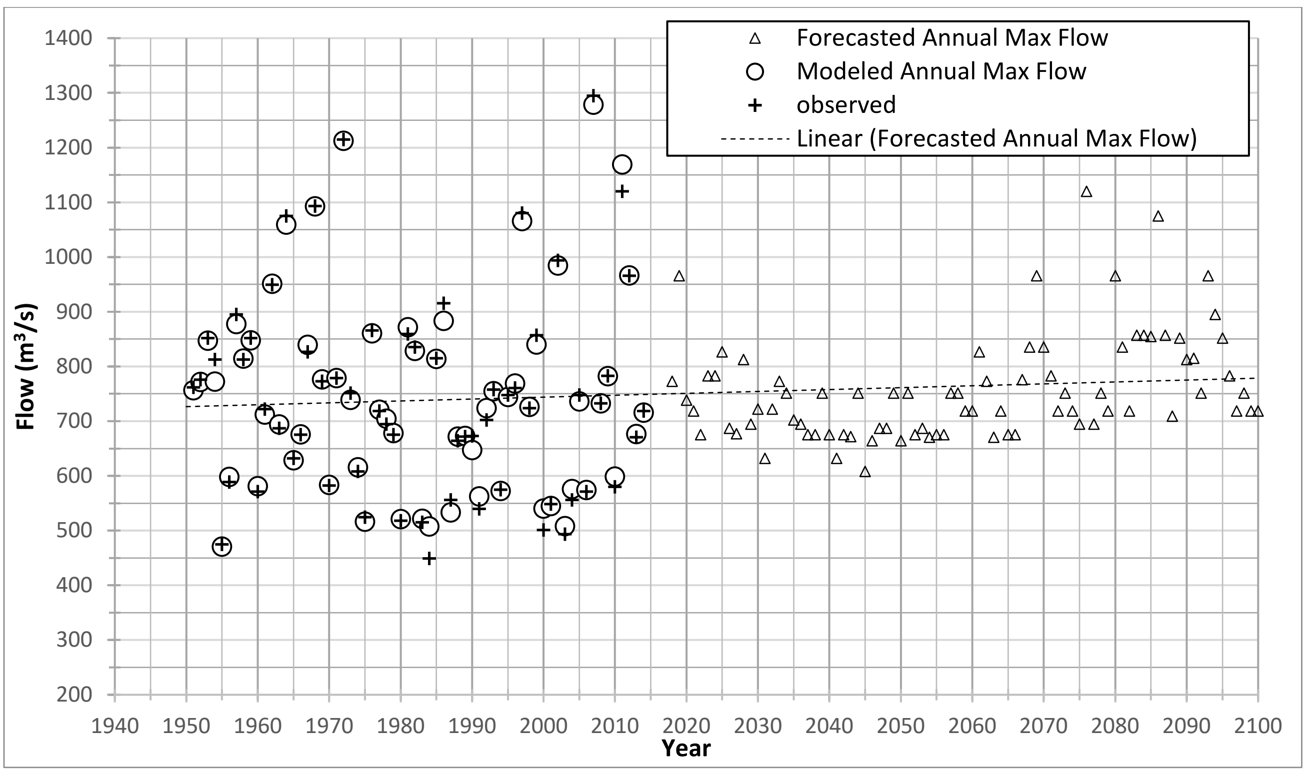



*Figure 7: Annual Maximum Daily Flow Trend Analysis*

### 4.2.3. Climate Change Impact on Peak Flows

A summary of the climate change impacts on peak flows is included in Table 4. The estimated instantaneous flow includes 10% additional flow to account for climate change.

*Table 4: Impact of Climate Change on Instantaneous Peak Flows*

| Return Period | Instantaneous Peak Flow ($m^3/s$) |
|---|---|
| 200 | 1,606 |
| 100 | 1,507 |
| 50 | 1,408 |
| 20 | 1,265 |
| 10 | 1,155 |
| 5 | 1,030 |
| 2 | 828 |

## 4.3. HYDRAULIC MODELLING

A two-dimensional (2D) HEC-RAS (V4.3) hydraulic model was developed to simulate the movement of flood water in the study area. The 2D HEC-RAS model was developed because of the flat topography, the wide floodplain and the river geometry in the project area. Bathymetry and LiDAR data were imported to HEC-RAS model for detailed hydraulic analysis.

Land cover usage was considered to estimate surface roughness. Recorded flows and levels from the hydrometric station at the Bulkley River near Smithers (08EE 005) were used for calibration. Estimated water depths were exported from HEC-RAS to GIS for mapping. Flood inundation maps and hazard maps were created from the model outputs and presented in the following sections.

The results of the hydraulic modelling and the application of flood mitigation options are subject to uncertainty. Uncertainty may result from the accuracy of survey, flow estimation, climate change and the limitations of the hydraulic model. The hydraulic model results should be handled with caution and used for planning purposes. The actual flood limits and depths may vary from the model output.

## 4.4. ICE JAM FLOODING

Ice Jams were modeled and evaluated based on the available information of the historical events. Ice jams can form during freeze-up (November to early January), or break-up (late March to April).

There are four historical events identified from the City of Smithers' online archive and local newspapers. The probable ice jam dates and the associated Bulkley River flows, are listed in Table 5. Based on the date of the occurrence, two were freeze-up jams (2005, 2016) and two were break-up jams (1966, 2009). Possible ice jam dates and flows are summarized in Table 5.

*Table 5: Possible Ice Jam Dates and Flows*

| Ice Jam Date | Flow ($m^3/s$) |
|---|---|
| 2016-01-07 | 35.5 |
| 1966-04-08 | 88 |
| 2009-04-22 | 205 |
| 2005-01-13 | 60 |

An ice jam event occurred on April 22, 2009. The Bulkley River flow near Smithers increased from approximately 30 $m^3/s$ (an average winter flow) to approximately 200 $m^3/s$ over a few days. According to the City of Smithers council's archive, several partial ice jams formed and broke free in the Bulkley River between Quick and Smithers. The mobile ice floes eventually formed a full ice jam adjacent to Ebenezer Flats and caused water level to rise rapidly. Reports stated that "up to 6 ft" of water was flowing through the residential area and "persons were rescued from the roof of a car, rooftop and a tree". Depending on the location of the jam and the topography of the adjacent river banks, water may escape at several locations and cause different levels of damage.

Three probable ice jam locations, shown in Figure 8, were identified based on the anecdotal information provided by the RDBN and residents. Ice jams are highly site specific, influenced by air temperature, flow and river morphology.

Probable Ice Jam Location 1 is immediately upstream of the river bend and the mouth of the Oxbow Lake. An ice jam is likely to occur since the river channel narrows, then encounters a sharp (>90 degree) bend with a shallow riffle immediately downstream. Sand bars and river bends also influence the formation of ice jams at Location 2 and Location 3.

The three probable ice jam locations were modeled to investigate the potential overland flooding that may result (Figure 8). The recorded daily flow on April 22, 2009 (200 $m^3/s$) was selected to simulate a typical flow during a break-up ice jam event. It was assumed the ice jams obstruct flow across the entire river at these locations. A weir structure was used to simulate the ice jam in the 2D HEC-RAS model. The height of the weir is equal to the adjacent river bank and the weir is assumed 10 m long. The effects of the ice jams are shown in Figure 9 to Figure 11.

Figure 9 shows the flooding resulting from an ice jam at Location 1. At a flow of 200 $m^3/s$, water flowed into the Oxbow Lake near Kidd Road and the back channel near 22 Ave. eventually through the two culverts on 22$^{nd}$ Ave and driveway on Kidd Road. Residences at the north end of 22 Ave and Kidd Road are affected by flood water under this scenario. The rest of the study area is not affected.

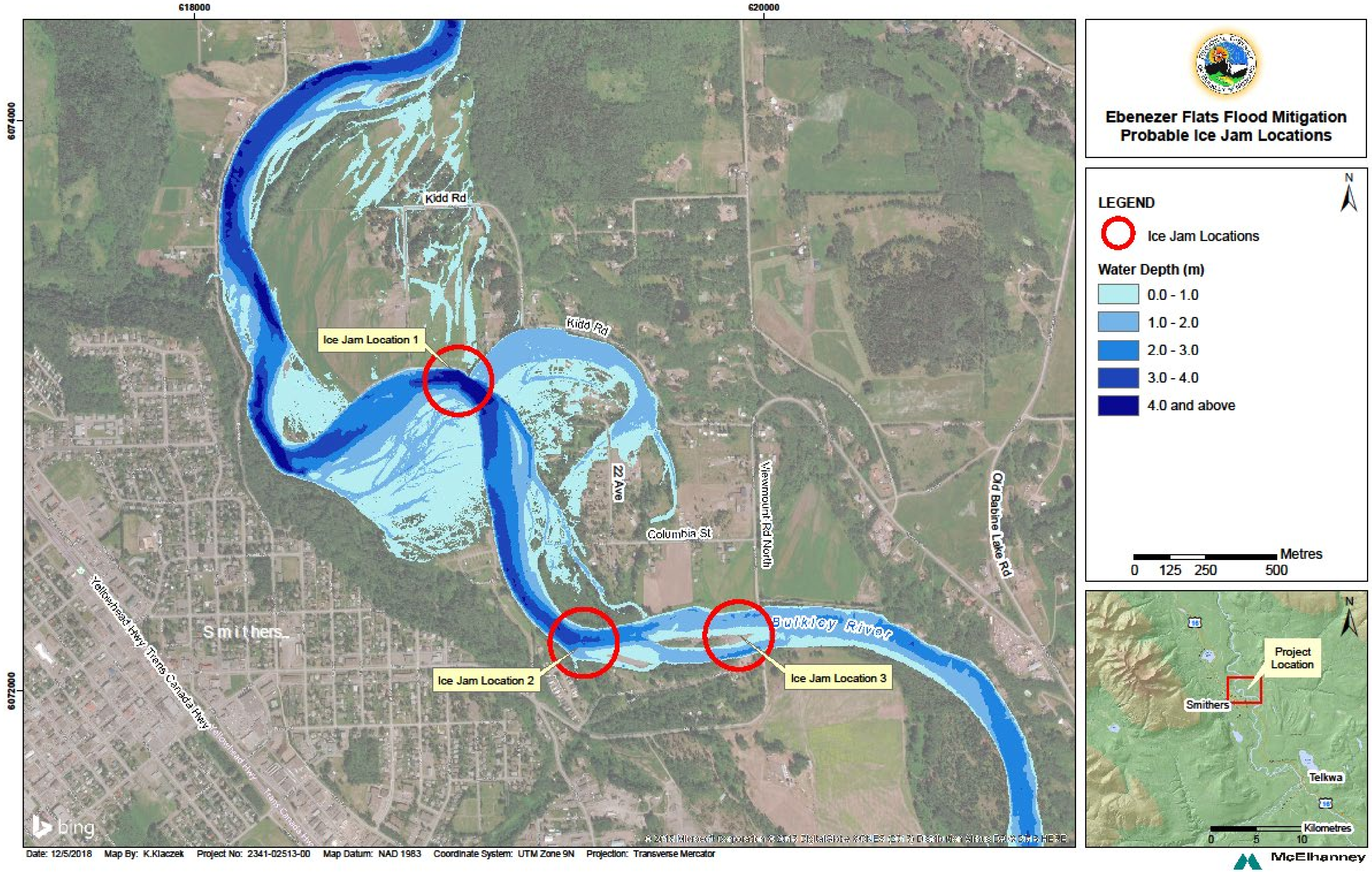



*Figure 8: Probable Ice Jam Locations*

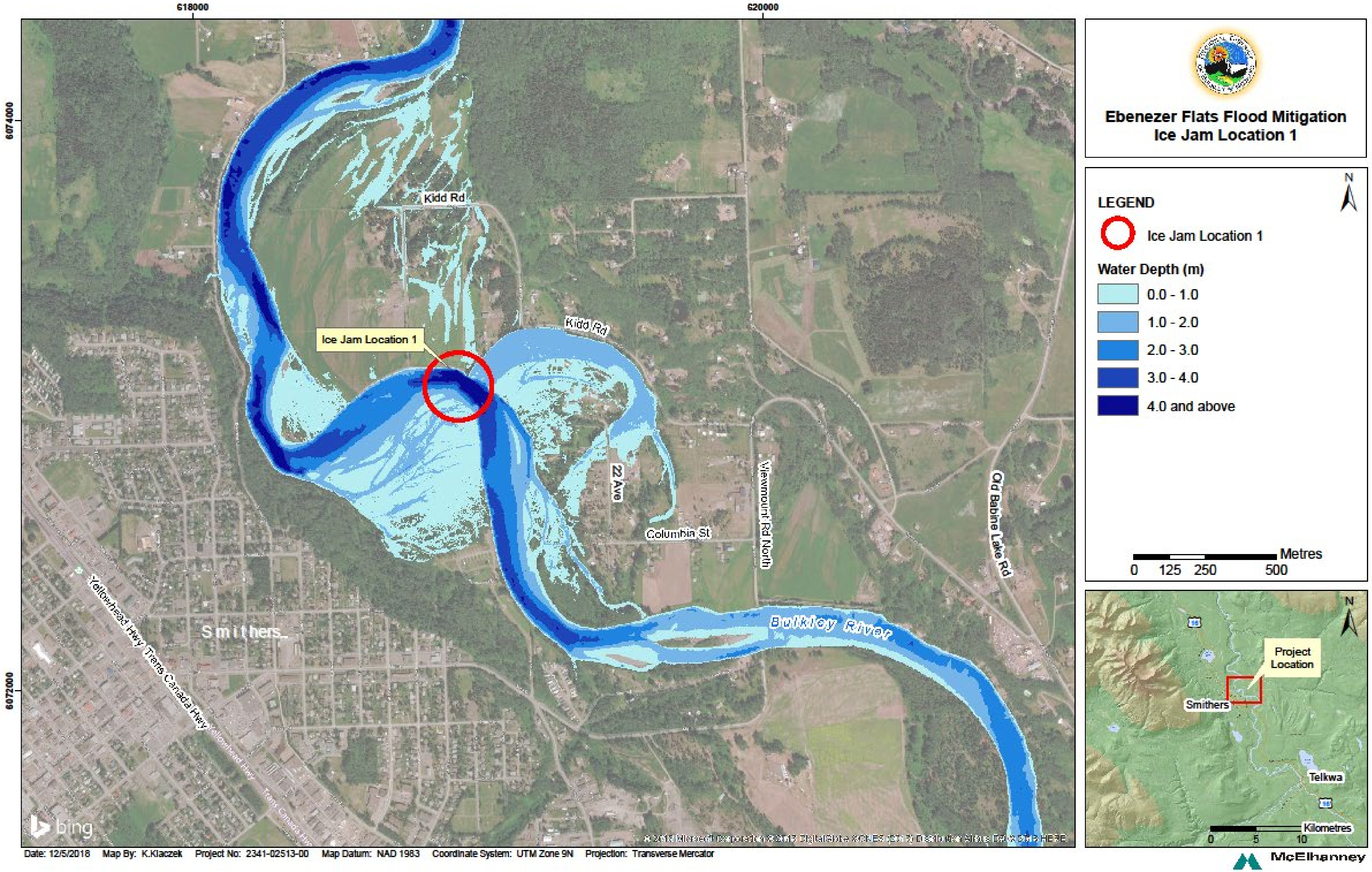



*Figure 9: Ice Jam Location 1*

Figure 10 illustrates the effects of an ice jam at Location 2. With the channel blocked, water escapes through the back channel and overtops the north bank. Location 2 will impact residents between Kidd Road and 22 Ave.

An ice jam at Location 3 is presented in Figure 11. Occurring immediately downstream of Viewmount Road, the water eventually overtops the north river bank and floods the area between Columbia Street and Kidd Road. The north bank is lower than the south bank at this location. Hence, any ice jam formed between Viewmount Road (old bridge location) and the next downstream river bend will result in flooding to the residential area.

The results of the three modeled scenarios suggest that ice jams between Locations 2 and 3 would flood residential areas in Ebenezer Flats, with flooded depths reaching up to 1.8 m.

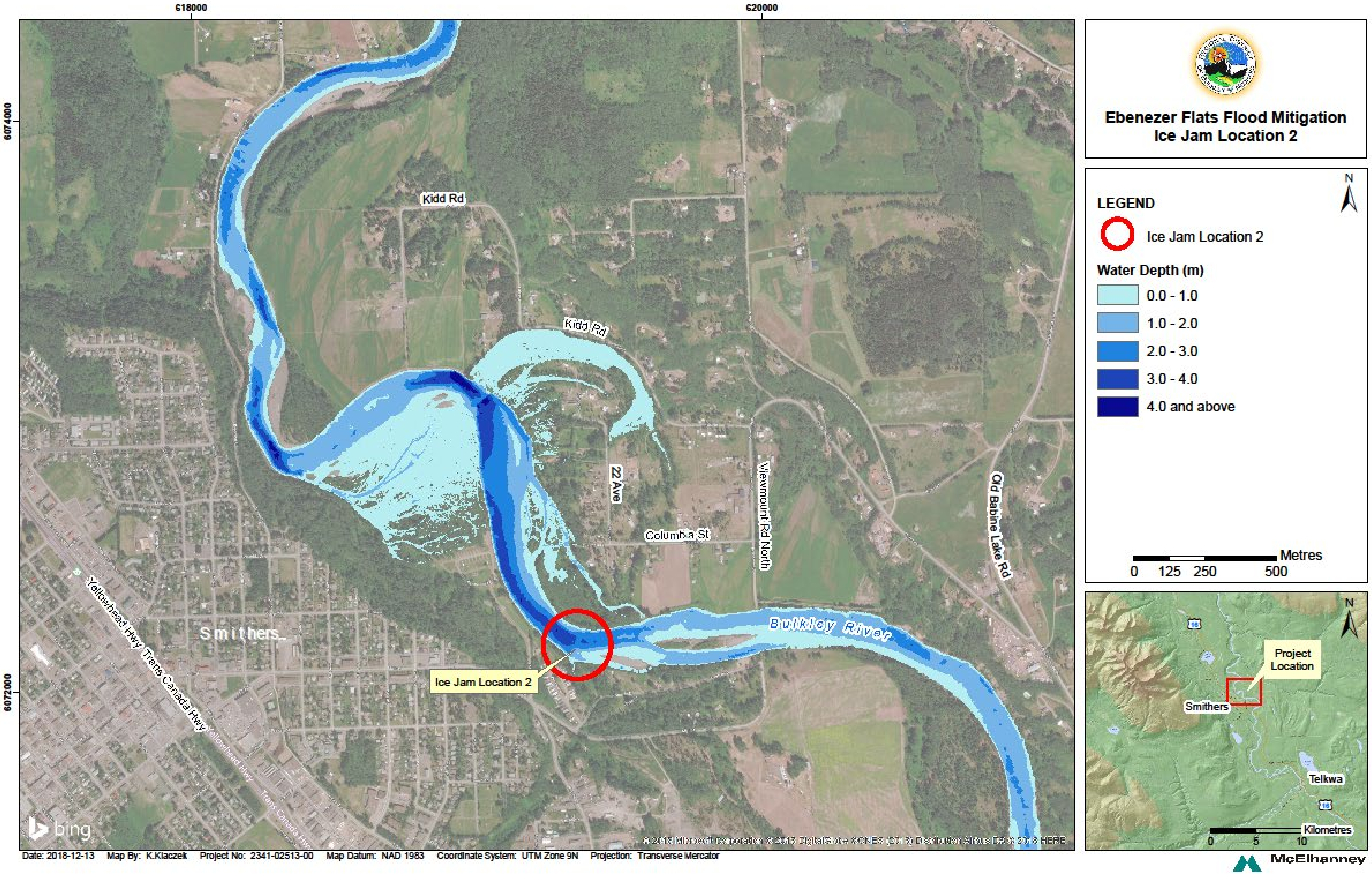



*Figure 10: Jam Location 2*

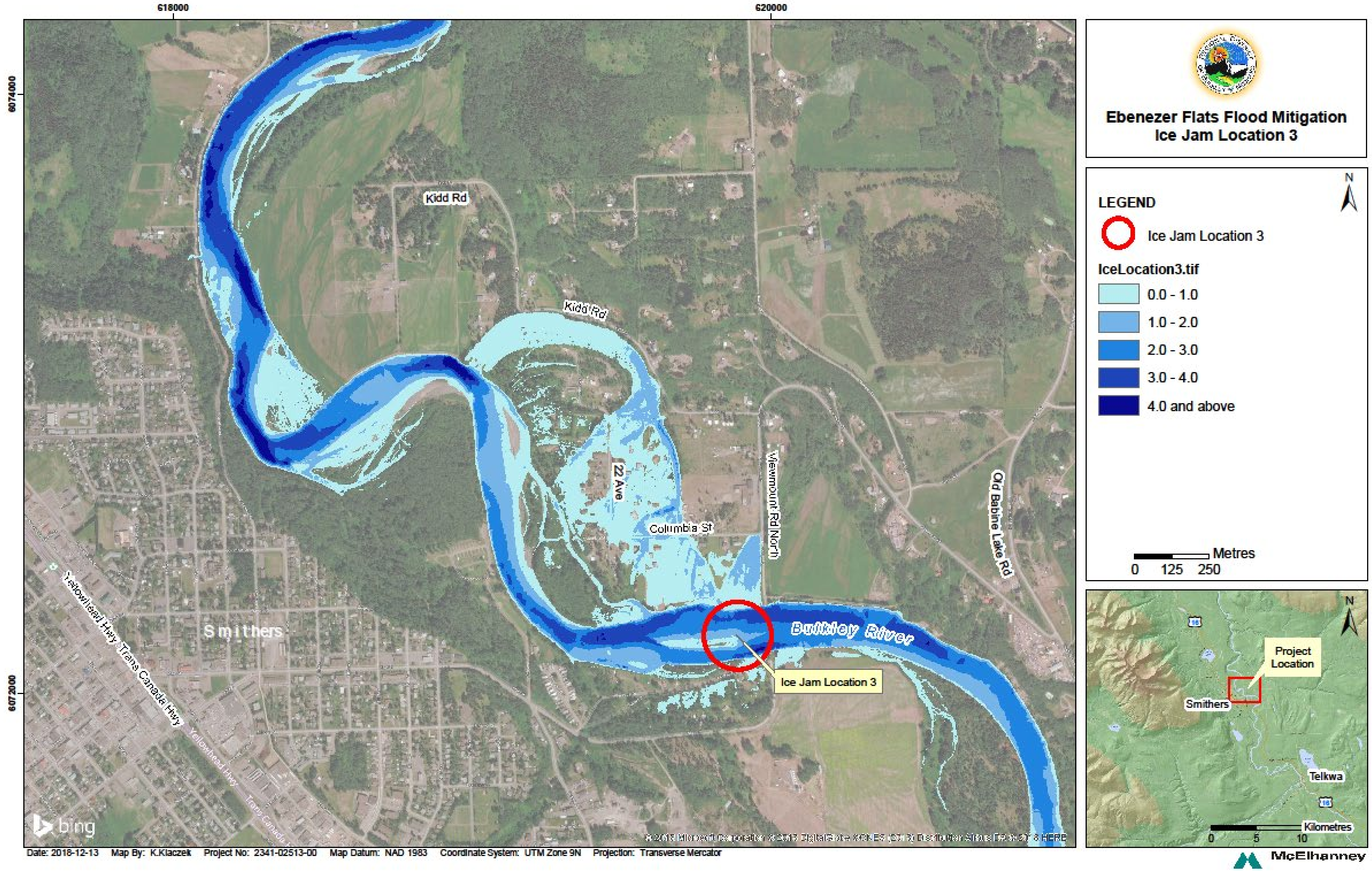



*Figure 11: Ice Jam Location 3*

# 5. FLOOD MAPPING

## 5.1. FLOOD MAPPING TYPES

The Engineers and Geoscientists British Columbia (EGBC) guidelines on Flood Mapping in BC define Inundation Maps as "Topographic maps showing the extent of floodwater in plan, under defined flood events". Flood Hazard Maps are defined as "Maps that go beyond inundation maps by providing information on the hazards associated with defined flood events, such as water depth, velocity and duration of flooding". Flood Risk Maps are defined as "Maps that reflect the potential damages that could occur as a result of a range of flood probabilities, by identifying populations, buildings, infrastructure, residences and the environment, cultural and other assets that could be damaged or destroyed". For the purposes of this report, the vulnerability maps that were produced that identify the flood hazard and the inventory of elements at risk are a form of simplified Flood Risk Map.

## 5.2. FLOODPLAIN MAPPING

An important factor when determining the potential extent of flooding is to identify a return period to model. In most of BC, the design floods for traditional floodplain maps have been those with return periods of 20 and 200 years. The 20-year flood levels have been used to apply Health Act requirements for septic systems, while the 200-year flood levels have been used to establish design elevations for flood mitigation works and Flood Construction Level (FCLs). However, for the Ebenezer Flats area the residents have expressed an interest in addressing the lower order events. While these lower order events may not be as significant in terms of flood extents or depths, when they happen on a more regular basis, the impact on social wellbeing of the local community is significant. We have therefore modelled the 5-year and the 200-year flood events and these have formed the basis for the assessment.

The hydraulic modelling identified the extent of flooding for the 5-year and 200-year event. A floodplain map for the 200-year flood was developed. A freeboard of 1.0m was assumed for the construction elevation. Figure 12 shows the floodplain map with the proposed construction elevation.

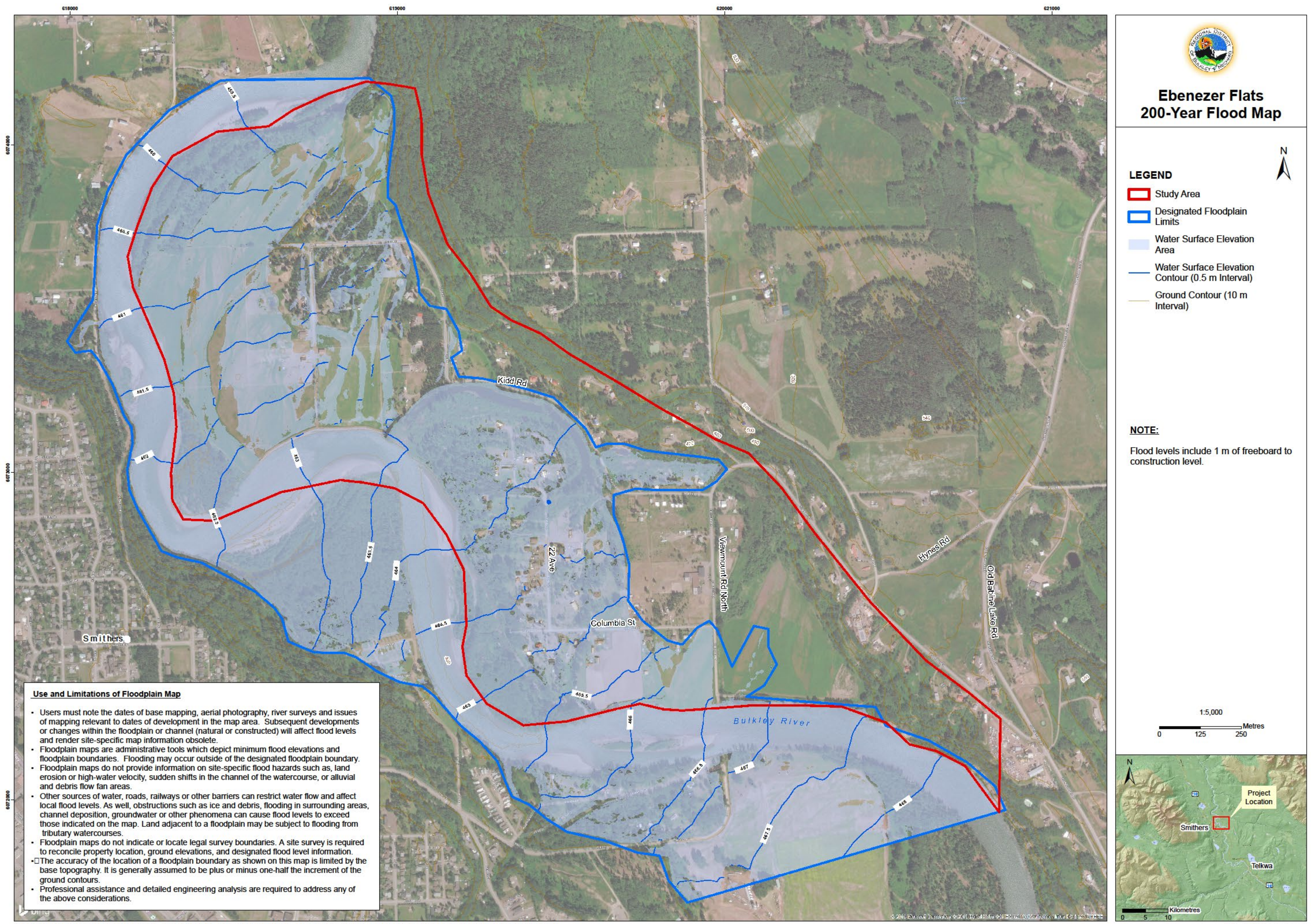



*Figure 12: 200-Year Flood Map*

## 5.3. FLOOD HAZARD CLASSIFICATION AND FLOOD HAZARD MAPS

The flood hazard assessment characterizes the flood process and determines the flood intensity characteristics. The EGBC Professional Practice Guidelines on flood mapping in BC explain that there are several ways to characterize flood hazards. Maps can be prepared to show variations in water depths and water velocities for a given event. Flood hazard maps for the 5-year and the 200-year events are included in Appendix A.

Although there are no hazard classifications for flood hazard ratings specific to Canada, the EGBC guidelines provide the ratings combining both water depth and water velocity developed in the UK. This rating system characterizes hazard intensity as a function of inundation depth, water velocity and the potential for floating debris, primarily based on the consideration of the direct risks to people exposed to floodwaters.

For the purposes of this study we have used this UK classification, as provided by EGBC. The formula is:

$$HR = d \times (v + 0.5) + DF$$

where, HR = (flood) hazard rating;

d = depth of flooding (m);

v = velocity of flood water (m/s); and

DF = debris factor

(DF =0, 0.5, 1 depending on probability that debris will lead to a significantly greater hazard).

Given that the risk to the people within the Ebenezer Flats area comes from the impact of the water itself, rather than the debris, the debris factor has been set at 0. This hazard rating classification framework provides a proxy for physical hazard to persons directly exposed to inundation, with the classifications as set out in Table 6.

*Table 6: Hazard to People Classification*

| Hazard Rating (HR) | Hazard to People Classification |
|---|---|
| < 0.75 | Very Low Hazard (Caution) |
| 0.75 – 1.25 | Danger for Some (includes children, the elderly, and the infirm) |
| 1.25 – 2.00 | Danger for Most (includes the general public) |
| > 2.00 | Danger for All (includes emergency services) |

This hazard classification has been applied to the flooding experienced in the Ebenezer Flats area. Flood Hazard Maps were then produced using the algorithm developed in the UK, which translates the predicted water depth and water velocity into a hazard rating. This classification can be used by RDBN to inform emergency planning procedures and identify areas where resources may be needed in the event of a flooding situation.

The Flood Hazard Maps were further developed to Flood Risk Maps to include the impact on buildings within the study area. The building outlines were obtained from BC Assessment and LiDAR and were used to assess the risk to the properties within the study area. These Flood Risk Maps are used to calculate the potential damages caused by the flooding presented. Flood Risk Maps are shown in Figure 13 and Figure 14.

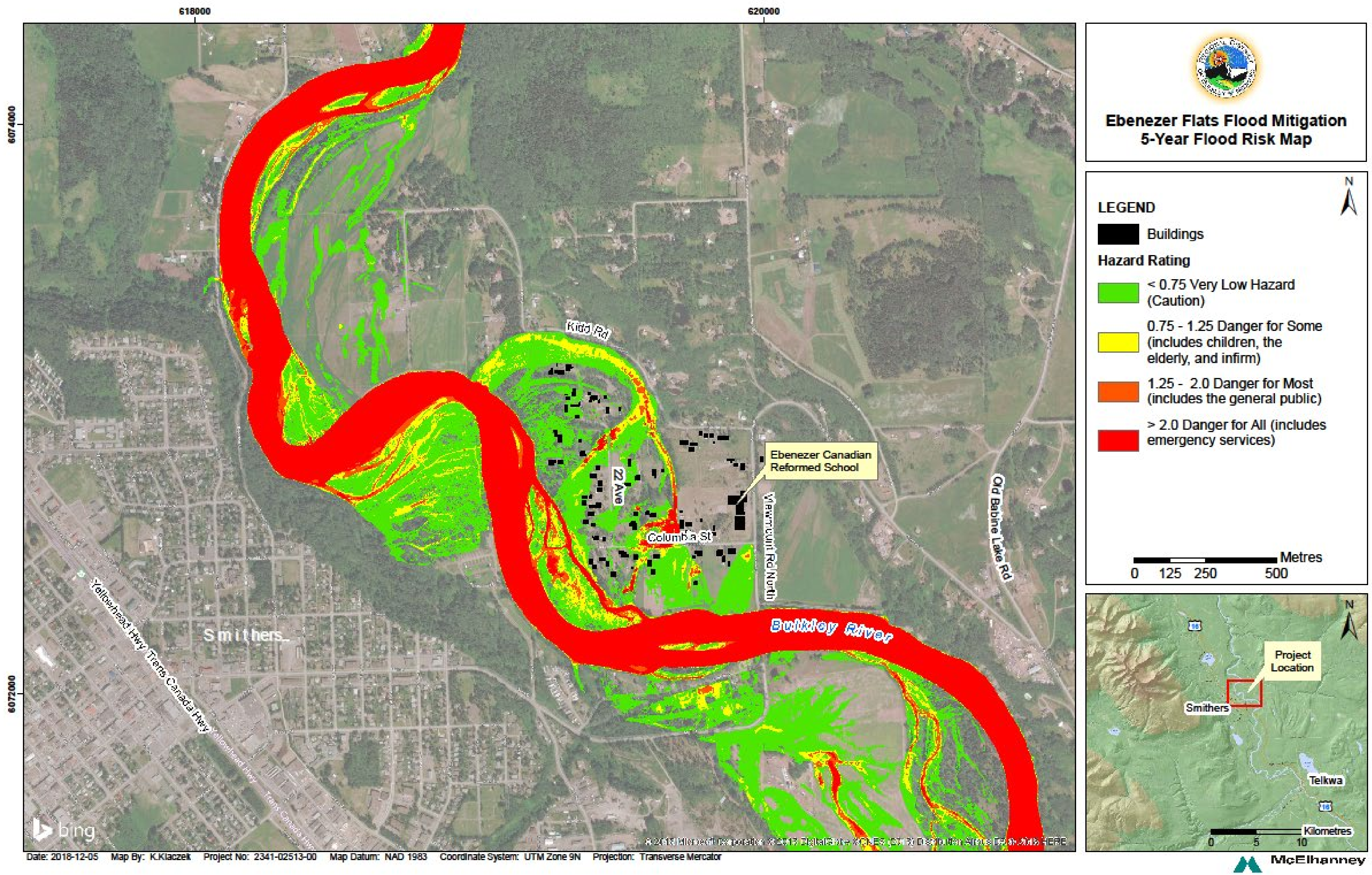



*Figure 13: 5-Year Flood Risk Map*

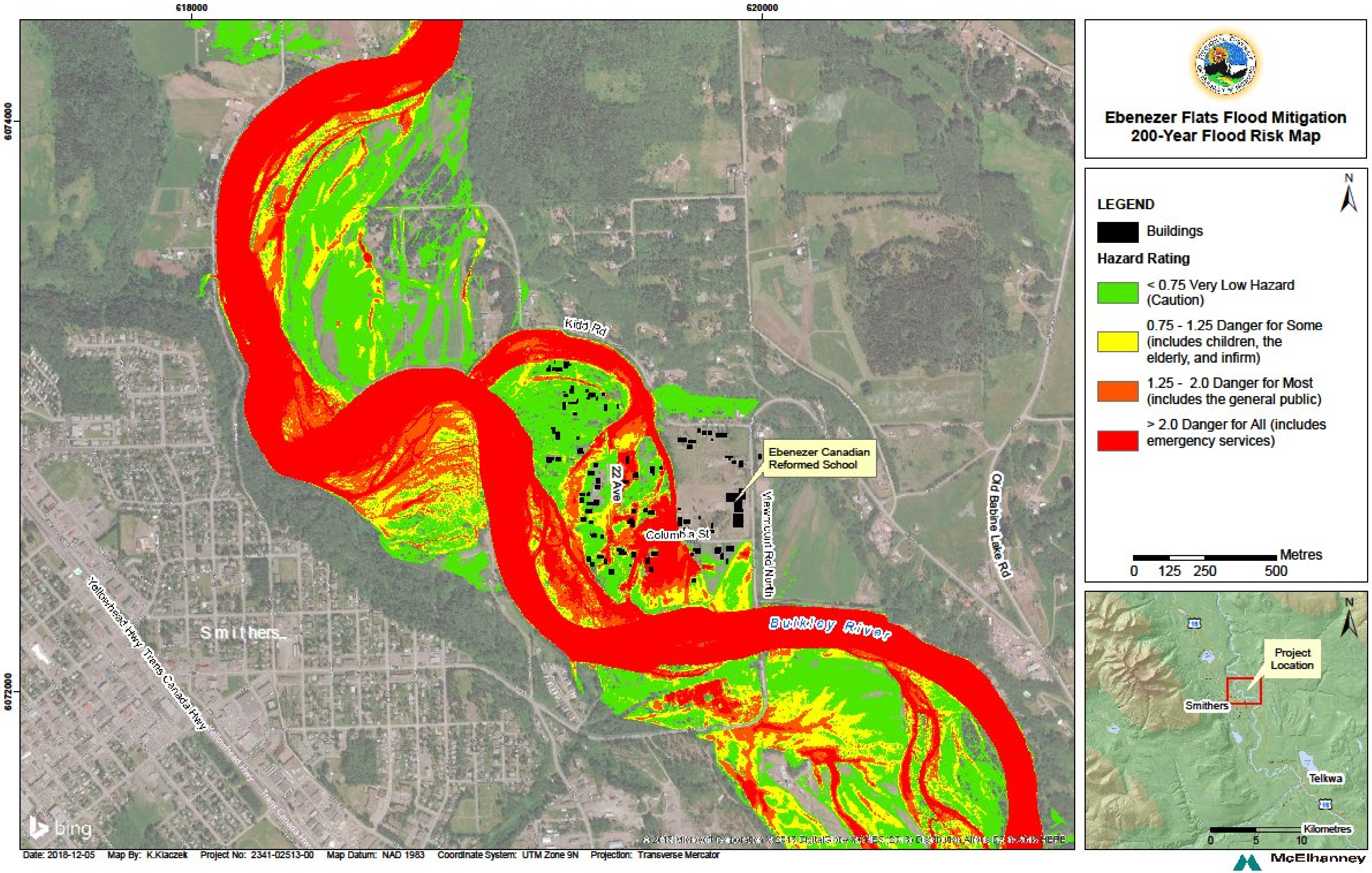



*Figure 14: 200-Year Flood Risk Map*

# 6. FLOOD RISK ASSESSMENT

## 6.1. RISK THRESHOLD

This section reviews the type of flood risk to the Ebenezer Flats area. Flooding results from one of two main processes:

- Freshet flooding that occurs in the spring and is the result of runoff generated from snowmelt and rainfall within watershed; or
- Rapid localized increase in water levels immediately upstream of an ice jam that obstructs flow in the Bulkley River.

This risk of flooding has been experienced in flood events when water levels in the Bulkley River rise. These high-water levels frequently result in evacuation alerts for the area, forcing residents to leave their homes and seek refuge elsewhere.

At this time, BC has not developed formal Flood Risk tolerance criteria and risk tolerance must be viewed over varying spatial scales. For example, significant flood damage to a single home in an extreme flood may be tolerable to society, as this constitutes hardship mainly to the owner and may not have a significant effect on society at large. However, if many homes are impacted, losses are increasingly deferred to taxpayers. The 5-year and 200-year flood events have been used as a basis for modelling and hence risk assessment as part of this study. However, RDBN is encouraged to consider establishing a tolerable limit for flood safety (which would be standard-based and/or Risk based) for future development in the area.

The hydraulic modelling indicates that properties are at risk of flooding from the 5-year flood event and upwards, with 10 residential properties showing as experiencing flooding of depths greater than 5cm in the 5-year flood event and 25 residential properties showing as experiencing flooding of depths greater than 5cm in the 200-year flood event.

## 6.2. IMPACTS / CONSEQUENCES ASSESSMENT

The affected area considered for this risk assessment covers an area of approximately 215 ha within the Ebenezer Flats area. Only residential development is affected; there are no commercial, agricultural or industrial buildings within the risk area shown from the hydraulic modelling. A school is located to the east of the affected area, and the results of the hydraulic modelling indicate that it is not at risk of flooding up to the 200-year flood event. In addition, the main access to the school is not affected. Hence, any impact to the school during flood events will be limited to students travelling from the flooded area.

Figure 13 and Figure 14 represent the inundation area and flood hazard rating in areas to be inundated by a 5-year and 200-year return period at the Bulkley River under future climate conditions. The figures also identify the residential area that would be at risk during these scenarios.

The flood depths for the 5-year event within the residential properties ranges from 0 to 0.5m. For the 200-year event, the flood depths range from 0 to 0.8m. The depth of flooding within the buildings assumed that the base of the buildings is at ground elevation. However, flood depths of less than 5cm outside the building were not included in the calculation of total damages within the buildings to account for building thresholds and any anomalies in the modelling process.

The risk assessment included a review of the following impact categories within 5 impact classes as presented by the National Disaster Mitigation Plan:

- People and Societal Impacts
    - Fatalities
    - Injuries
    - Displacement
- Environmental Impacts
- Local Economic Impacts
- Local Infrastructure Impacts
    - Transportation
    - Energy and Utilities
    - Information and Communications Technology
    - Health, Food, and Water
    - Safety and Security
- Public Sensitivity Impacts

### 6.2.1. People and Societal Impacts

It is a priority at the municipal, provincial and federal levels to protect the health and safety of Canadians. Impacts on people are therefore considered pertinent in the assessment process given that natural hazards, such as the flooding experienced at Ebenezer Flats can result in societal disruptions such as evacuations as well as injuries.

The area at risk is made up of only residential properties, with the study area comprising buildings and associated infrastructure (parking, out buildings, access roads, etc.) for residential use. The population of the area is estimated to be approximately 200 based on 75 houses each has an average of 2.5 persons.

Within the study area considered for the risk assessment there is a school. The school is shown not to be at risk of flooding from the Bulkley River up to a 200-year flood event. Ice jam modelling also shows the school is not at risk of flooding from an ice jam event.

The risk of fatalities is low. Some areas have a hazard rating greater than 2.0 for the 200-year event, indicating a danger for all, including emergency services. Injuries could therefore occur before, during and after the flood and may be a direct result of the waters, such as drowning, or otherwise induced by the event, such as an accident during cleanup activities or post-flood depression and sleep disorders. It is therefore recommended that residents are encouraged to make their own specific emergency response plans and an information session is provided to the residents on the specific dangers associated with flooding.

We have assumed that all of the local population will be affected under more frequent flooding events, even if individual properties are not flooded. While the inundation extents are less, residents would seek assistance to protect their properties and access roads such as Columbia Street and 22 Avenue would be disrupted and access for emergency vehicles is likely to be difficult, which poses a risk in terms of emergency response.

The US Federal Emergency Management Agency (FEMA) estimate a recovery time equating to 45 days per 30cm of water. This recovery time includes the time taken for building restoration and repairs. Given that within some areas for the 200-year event the flood depth for the above event is up to 0.8m, this could equate to potential recovery times of 3 months to repair the building damage.

### 6.2.2. Environmental Impacts

Another priority for municipal, provincial and federal governments is to protect Canada's natural environment for current and future generations. Therefore, environmental impacts are included in the assessment to measure the risk event in relation to the degree of damage and predicted scope of clean up and restoration needed following an event.

The Bulkley River has one of the largest wild Steelhead runs in the world. Flooding of the buildings within the residential area can contaminate flood water which would ultimately flow into the Bulkley River and cause potential pollution of this key waterway. In addition, flooding of on-site sewage disposal systems could also result in contamination of flood waters and there may be a particular concern for properties that have outside buildings that are affected, as these buildings may be used to store machinery, fuel or other chemicals. Flooding of the area could result in the mobilization of these potential pollutants. These pollutants can harm fish, wildlife, and vegetation. They can also impact downstream users' drinking water supply or recreational uses of the river. Additionally, flood waters may act as a trigger, releasing and carrying pollutants that were previously present in the environment.

### 6.2.3. Local Economic Impacts

The NDMP identifies that there may be local economic impacts as a result of the flood risk occurring. This is therefore included as an item in the risk assessment to capture the damage or losses to locally economic productive assets, as well as disruptions to the normal functioning of the community's local economic system.

Local residents are likely to experience significant negative economic impacts. These impacts would increase under more severe flooding events. Each flood event results in damages that need repair, time off work to manage flooding and post flood cleanup, as well as disruption of local services due to flooding over roads.

In addition to the time and costs related to building restoration and repairs, there are likely to be local economic impacts relating to responding to the flood during the flood event. This would include requirements for RCMP to provide security if buildings are evacuated as well as support for evacuees and government response, all of which could have impacts on local taxation.

An economic appraisal was undertaken to asses the potential damages caused by the assessed flood risk events. Further information is provided below.

### 6.2.4. Local Infrastructure Impacts

It is recognized that there are several local infrastructure components, that are fundamental to the viability and sustainability of a community. The NDMP therefore includes local infrastructure in the assessment process to identify components that may be at risk that would have a wider impact on the community. The area includes infrastructure such as roads, storm water infrastructure, and sanitary system infrastructure. The infrastructure at risk is limited to local infrastructure and would have a significant impact on the local area.

Columbia Street and 22 Avenue are at risk of flooding during the 5-year and 200-year flood events. Access to local properties will be disrupted. This includes access for emergency vehicles which may pose a health and safety risk. During a 200-year event, flooding is predicted at the southern end of Kidd Road, which would disrupt access to the properties along Kidd Road. The main access route into the area is Viewmount Road North, to the east of the study area. This road remains is outside of the predicted 200-year flooding extent.

During flood events there may be energy and utility disruption to the individual properties if property service connections become flooded, although these impacts are likely to be restricted to the properties directly affected by the flooding, as there is no key energy or utility infrastructure in the area that impacts a wider area. In addition, IT and communications disruptions may occur at the property level, as individual property services become flooded, although this is also is likely restricted to the individual properties that are flooded.

Impact on health, food and water is likely to be significant to the properties that are directly affected by the flooding, as food and health supplies are likely to be damaged during flooding within residential properties or potentially in storage in out buildings etc. In addition, if onsite sewage disposal systems become flooded residents may be unable to use toilets. This is in addition to the direct health impacts of the flooding listed above. As previously discussed, there have been instances when the local area has been placed under evacuation due to potential flooding. This constant threat of flooding in times of heavy rainfall poses a risk to the mental health of the local population.

No intelligence or defence assets are identified within the study area, hence there is considered to be no risk to safety and security on a regional level, although there is a direct risk to the properties that are affected as houses are left unoccupied during times of evacuation.

### 6.2.5. Public Sensitivity Impacts

Although the direct impact of flooding may be restricted to a local level of the properties directly affected, the public sensitivity impacts extend beyond just the residents experiencing flooding. This area is known to be at flood risk and public perception is that action is required to reduce the risk.

## 6.3. DETERMINING POTENTIAL DAMAGES

The Canadian Guidelines of Flood Vulnerability Functions (The Guidelines) provides an accepted method for translating flood stage (depth) to estimated economic damage. These guidelines were applied to the Ebenezer Flats study area. It must be recognized that these damages represent damage to the residential properties only, and do not include specific damages to out buildings etc., as there are no current guidelines on how to assess damage to buildings on residential land that are not residential, commercial or industrial.

Rural residential properties are classified as Class B Residential 2-story buildings per The Guidelines. Class B residential consist of average quality dwellings generally built from stock plans as tract or speculative housing for mid-market consumers from the 1950s onward. The houses are typified by conventional design, and medium quality materials, finishes and workmanship, with some basement finishing and detached garages. This classification represents an average for the residential properties based on data available from BC Assessment at a property level.

No damage was assumed to occur when the flood elevation was below the ground elevation (i.e., the residence was not surrounded by water). We recognize that there is a potential for seepage into basements if the surrounding ground is saturated, however this was not assumed to be the case.

### 6.3.6. Direct and Indirect Losses

In addition to the direct damage to property, a variety of secondary economic, social and environmental impacts are often experienced during flood events. These are considered as indirect losses and include items such as costs of evacuation, employment losses, administrative costs, net loss of normal profit and earning to capital, management and labour and general inconvenience.

The Guidelines further explains that disruption from flooding may occur due to evacuations, road closures or loss of utility services. FEMA estimate a recovery time equating to 45 days per 30cm of water.

The benefit-cost approach to disaster mitigation assessments theoretically requires a complete enumeration of all gains/benefits and losses/costs associated with a project. In practice, however, it is not possible to even identify all potential impacts much less quantify and monetize them, therefore determining a “total cost” of flooding is not possible.

The Guidelines provides an estimate of 15-20% of the cost of direct damages to be used to estimate the potential indirect damages for commercial/industrial development, but no such allowance exists for residential development. A full evaluation of all potential indirect costs through field review, productivity assessment and stakeholder discussion is outside the scope of this assessment. Hence, a value of 10% of the direct losses (damage to the residential properties) has been used to estimate the indirect losses for the Ebenezer Flats area.

### 6.3.7. Damages to other Infrastructure

The affected area includes local access roads of Columbia Street, 22 Ave and Kidd Road. The disruption caused by flooding of this infrastructure would have high local economic impact, with residents unable to travel to work due to access issues or needing to leave work to ensure access is available to their properties. However, the roads that are affected are restricted to local access roads. Hence, it is unlikely that there would be a wider financial impact from traffic disruption.

Given the complexities and unknown factors in determining potential economic impacts of flooding to other infrastructure, including the roads, the damage assessment has been limited to the potential damages to the residential buildings within the area for the purposes of assessing cost-benefit of the potential options to reduce flooding with an allowance of 10% for indirect losses as explained above, although it is recognized that any option that reduces the risk of flooding would have economic benefits for the other infrastructure.

### 6.3.8. Ebenezer Flats Damages

Table 7 to Table 9 provide an assessment of the potential damages that could be experienced for the study area for a variety of flooding scenarios of the Bulkley River. The potential damages are based on the stage damage curves provided in The Guidelines. These Guidelines are currently in draft form, and the depth damage curves will be reviewed as more data on flooding becomes available. The curves are based on national and international information on flooding that has been experienced in a variety of locations. However, it is recognized that the majority of locations used to develop the curves are heavily urbanized areas that may result in higher financial damages than would be experienced at Ebenezer Flats.

In addition, The Guidelines explain that in many flooding situations the actual damages incurred are less than the potential damages because sufficient warning has been provided to the community such that mitigative measures, such as removal of valuables, or the relocation of valuable items to a higher level in the structure results in a reduction of the damages. Contingency measures including warning, flood fighting and individual adjustments with the buildings can result in reductions of up to 30% of damages. The damages presented below should therefore be understood as a conservative approach and actual damages experienced during flooding may be lower.

*Table 7: Depth- Damage for Residential Mobile Homes (No Basement)*

| Depth Relative to Main Floor | Main Floor Contents | Main Floor Structure | Main Total | Basement Contents | Basement Structure | Basement Total |
|---|---|---|---|---|---|---|
| (m) | ($/m²) | ($/m²) | ($/m²) | ($/m²) | ($/m²) | ($/m²) |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.1 | 243 | 362 | 605 | 0 | 0 | 0 |
| 0.3 | 379 | 405 | 784 | 0 | 0 | 0 |
| 0.6 | 426 | 405 | 831 | 0 | 0 | 0 |
| 0.9 | 481 | 470 | 951 | 0 | 0 | 0 |
| 1.2 | 483 | 470 | 953 | 0 | 0 | 0 |
| 2.7 | 483 | 470 | 953 | 0 | 0 | 0 |

*Table 8: Depth- Damage for Class B 2-Story Residential Homes (With Basement)*

| Depth Relative to Main Floor | Main Floor Contents | Main Floor Structure | Main Total | Basement Contents | Basement Structure | Basement Total |
|---|---|---|---|---|---|---|
| (m) | ($/m²) | ($/m²) | ($/m²) | ($/m²) | ($/m²) | ($/m²) |
| 0 | 0 | 0 | 0 | 427 | 490 | 917 |
| 0.1 | 235 | 524 | 759 | 427 | 490 | 917 |
| 0.3 | 342 | 536 | 878 | 427 | 490 | 917 |
| 0.6 | 422 | 625 | 1047 | 427 | 490 | 917 |
| 0.9 | 481 | 792 | 1273 | 427 | 490 | 917 |
| 1.2 | 508 | 792 | 1300 | 427 | 490 | 917 |
| 2.7 | 512 | 792 | 1304 | 427 | 490 | 917 |

*Table 9: Indicative Potential Damages to Residential Properties within the Study Area*

| | 5 Year Return Period | 200 Year Return Period |
|---|---|---|
| Number of residential properties | 10 | 25 |
| Potential damages for residential property only | $0.9M | $2.7M |
| Potential damages including allowance for indirect losses (10%) | $1.0M | $3.0M |

Note that for the purposes of data protection, and individual assessment of each property is not provided in this report and the results presented in Table 9 are for the study area as a whole.

It is important to note that the potential damages shown in Table 9 relate to the potential damages to the residential buildings only, and do not include an allowance for any out buildings, garages or other building on the property as there are currently no guidelines on depth damage data available for this.

Caution should be exercised when reviewing the damage data presented in Table 9 as it relates to the monetary value of damage to the residential properties only, and although a 10% allowance has been added for indirect losses. As the damages caused by flooding cannot be fully represented in terms of monetary value alone, there should be a consideration for the social impacts of flooding as well as other impacts as identified above when considering potential mitigation measures.

# 7. FLOOD MITIGATION PLANNING

The risk mitigation plan for the Ebenezer Flats Area should prioritize the construction of flood protection infrastructure in areas that are more vulnerable to flooding during lower order events. The flood damage assessment revealed that the 5-year and 200-year flood event result in financial damages of $1.0M and $3.0M, respectively. Financial damages do not capture all of the impacts of the flooding that would be experienced in the area.

Potential mitigation options were evaluated using a number of factors, including the reduction in economic impacts versus the cost of providing flood mitigation.

The following flood mitigation options were considered and evaluated as part of this study:

- Construction of a dike on the Bulkley River;
- Installation of a flood gates at a property level, combined with construction of a local dike to protect individual properties;
- Raising residential properties above the flood level; and
- Raising access roads in the area above the flood level.

Further detail on these options is provided in the following sections.

## 7.1. DIKE CONSTRUCTION

The construction of a dike at the river or property level was considered as part of the evaluation of the options listed above. Figure 15 and Figure 16 show sketches of how these dikes could be constructed. Each of the options that included a dike at the river or at a property level have been assessed for the 5-year and 200-year flood event separately to review the cost implications of differing levels of protection. Further information is provided in the following sections. The river dikes are assumed to provide access to the river front and allow for ongoing maintenance.

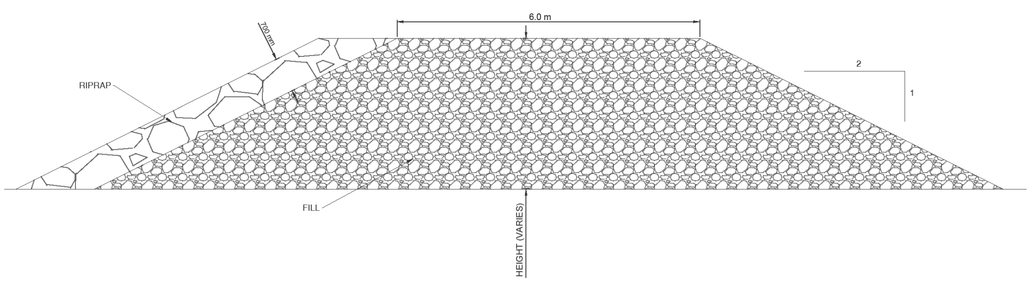



*Figure 15: Potential River Dike Section*

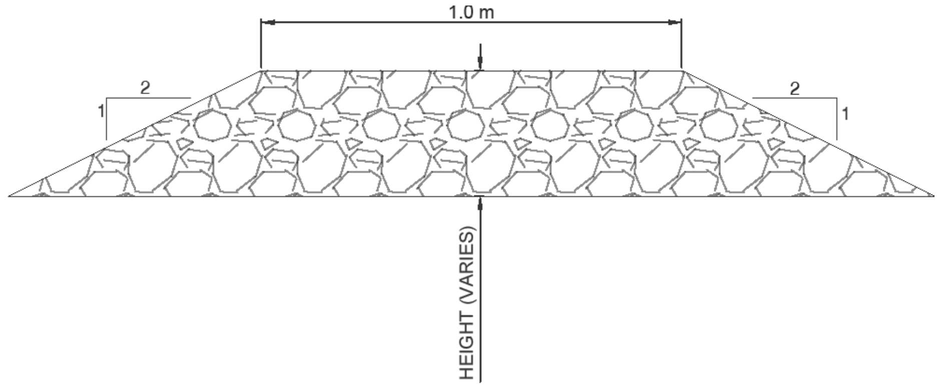



*Figure 16: Section of Potential Dike to Provide Property-level Protection*

The options that included dikes were modeled in HEC-RAS. For both 5-year and 200-year flood events, diking options were considered and modeled to determine the minimum dike elevation required.

## 7.2. GEOTECHNICAL CONSIDERATIONS FOR DIKE FOUNDATION AND GROUNDWATER

A desktop geology study was completed which consisted of review of available geology mapping and BC Water Well Database. Published surficial geology mapping was limited for the study area. However, mapping that was available indicated that Quaternary deposits in the study area are likely to be alluvium, till and gravel (Geology Survey, Open File 352, June 1976).

A review of the available water wells records in the study area indicates that subsurface soils consist of varying thickness of generally clay and gravel. Water wells are shown in Figure 17 and summarized in Table 10. Bedrock was recorded in one water well record at 47.2 m depth. Groundwater levels were reported generally between 3.0 to 6.1 m depth. Shallow groundwater tables are anticipated closer to the river. Groundwater levels vary seasonally and annually depending on many factors including surface and subsurface drainage, precipitations, and the hydrogeology of the area. Fluctuations in the groundwater levels would be anticipated.

Based on the publicly available geology mapping and water well records, the subgrade conditions in the area could be variable comprising glacial deposits (including clay) or gravel. Following discussion with the RDBN, MCSL understands that soil conditions in the area are known to be granular and groundwater table fluctuates. If granular soils are in the foundation area of the dike, a cutoff trench or similar should be considered in design given the potential for groundwater infiltration under the dike. The effectiveness of the dike and potential cut-off trench requirements is unknown without detailed subsurface testing to assess the subsurface conditions in the footprint of the proposed dike (i.e., test pitting).

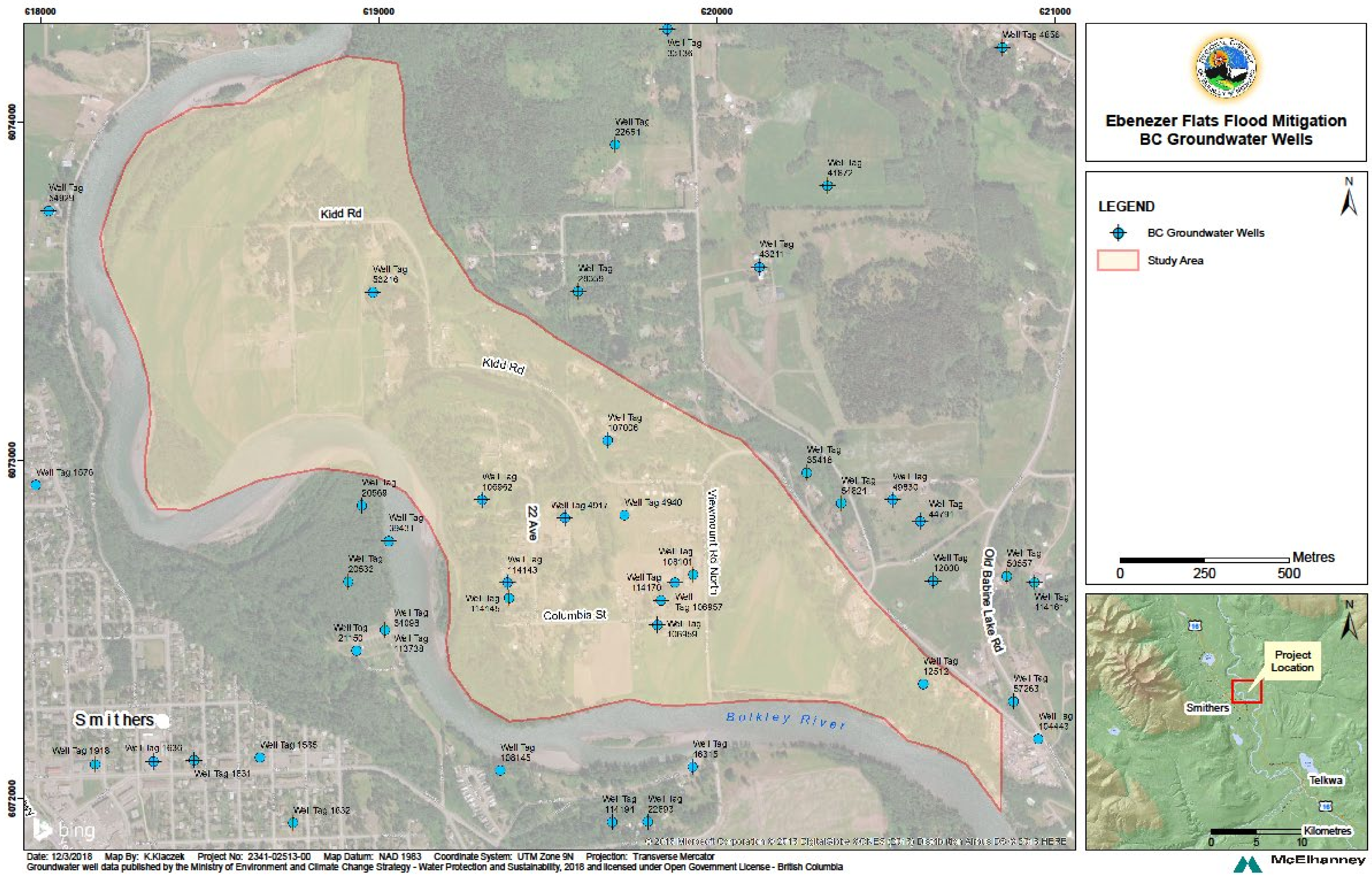



*Figure 17: Water Wells Located in Study Area*

*Table 10: Summary of Water Well Records*

| Water Well Tag | Location | Well Depth | Static Water Level (Construction Date, YYYY-MM-DD) | Lithology[1] |
|---|---|---|---|---|
| 53216 | Kidd Road | 23.8 m | N/A | 0 to 4.3 m: Sand<br>0.9 to 21.3 m: Clay<br>21.3. to 23.8 m: Sand and Gravel |
| 107006 | Kidd Road | 28.0 m | 15.2 m (2011-09-20) | 0 to 11.0 m: Clay<br>11.0 to 12.5 m: Gravel<br>12.5 to 17.1 m: Clay<br>17.1 to 18.9 m: Gravel<br>18.9 to 26.2 m: Clay<br>26.2 to 28.0 m" Gravel |
| 106962 | 22nd Ave | 20.1 m | 3.0 m (2011-07-23) | 0 to 5.8: Silty Clay/Sand<br>5.8 to 18.9 Silty Clay/Clay<br>18.9 to 20.1 Gravel |
| 4917 | 22nd Ave | 6.1 m | 4.9 m (1950-01-010 | 0 to 6.1 m: Clay |
| 114143 | 22nd Ave | 19.8 m | 6.1 m (1997-09-02) | 0 to 4.6 m: Gravel<br>4.6 to 17.1 m: Clay/Silt<br>17.2 to 19.8 m: Gravel |
| 114145 | 22nd Ave | 20.2 m | 3.0 m (1997-08-31) | 0 to 4.7 m: Gravel<br>4.7 to 17.4 m: Clay<br>17.4 to 20.2 m Gravel |
| 28359 | 23rd Ave | 51.2 m | N/A | 0 to 47.2 m: Clay<br>47.2 51.2 m: Bedrock |
| 106959 | Columbia St | 20.1 m | 5.2 m (2011-05-23) | 0 to 3.0 m: Sandy Loam/Gravel<br>3.0 to 10.7 m: Clay<br>10.7 to 18.6 m: Silt/Sand/Clay<br>18.6 to 20.1 m: Gravel |
| 114170 | Columbia St | 18.9 m | 4.3 m (1999-09-14) | 0 to 4.3 m: Gravel<br>4.3 to 16.8 m: Clay<br>16.8 to 18.9 m: Silt to Sand to Gravel |
| 106957 | Viewmount Road | 20.9 m | 6.1 m (2011-05-23) | 0 to 4.6 m" Sand Loam/Gravel<br>4.6 to 17.1 m: Clay<br>17.1 to 20.9 m: Sand to Gravel |

Notes:

[1] Obtained from water well record, typically, as per water well drillers observations.

## 7.3. OPTION.1: RIVER DIKE (5-YEAR RETURN PERIOD FLOOD)

This option includes the construction of a dike at the river level to provide protection up to the 5-year return period. In this option, dike was modeled along the back channel and extended both upstream and downstream to prevent water from flooding the houses in the study area. As shown in Figure 18, water is constrained mostly in the channel and majority of the study area is not flooded. There are a few houses still affected by flooding further downstream to the dike. From a cost benefit point of view, individual ring dikes are recommended for these houses.

The required flood protection infrastructure along the eastern bank of the Bulkley River would be 1.1 km long and shall have an average dike height of 1.2 m. This will provide a 1m freeboard over the 5-year flood elevation. Top of dike was assumed to be 6m. A riprap layer will be used for erosion protection.

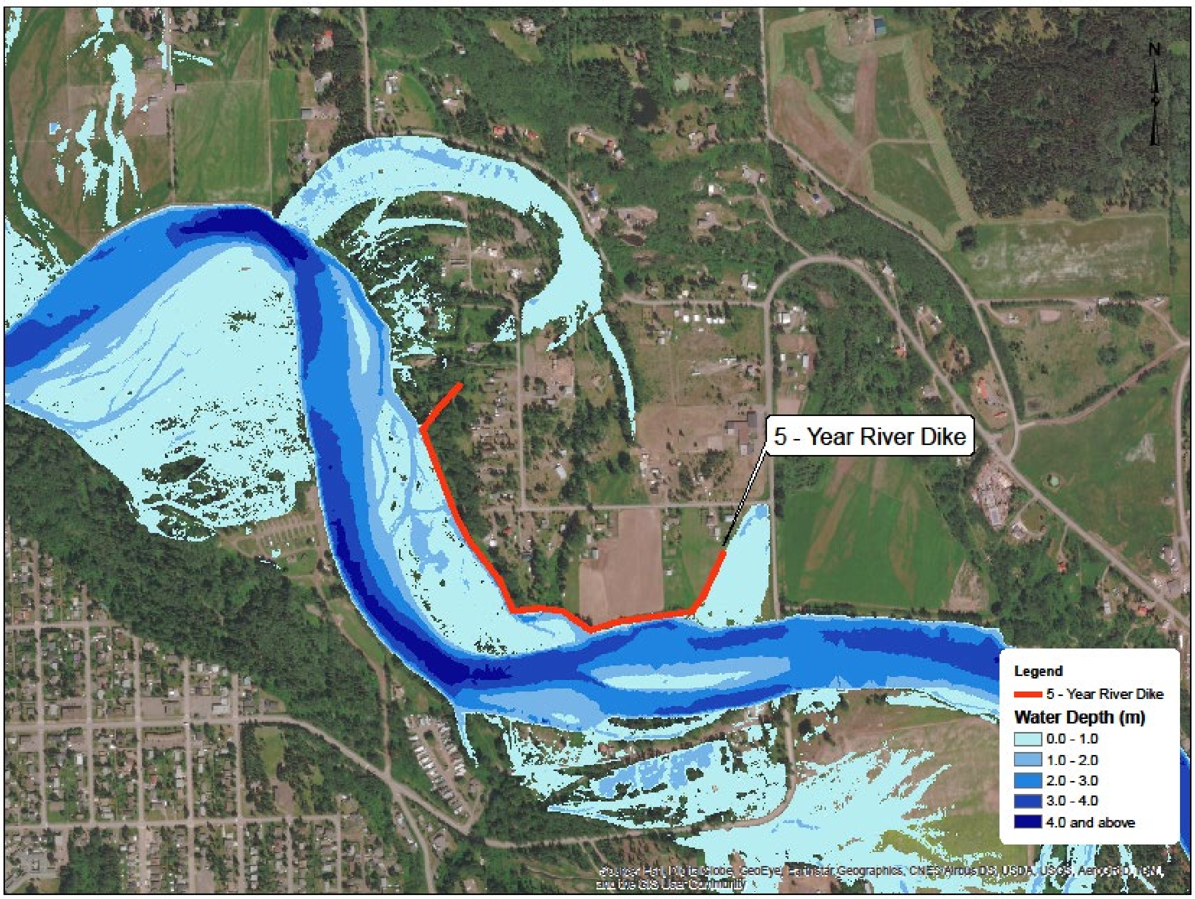



*Figure 18: River Dike Option 1, 5-Year Flood*

## 7.4. OPTION.2: INDIVIDUAL DIKING (5-YEAR RETURN PERIOD FLOOD )

In this option, individual earthfill dikes are constructed for all houses in the study area that are shown to be at risk during the 5-year return period (10 properties in total). The dikes would be constructed around the residential properties with break in the dike to allow at-grade access to the property during non-flood events, and flood barriers similar to those shown in Figure 19 would be deployed during times of flooding to seal the access point, preventing water egress into the residential properties. This option does not reduce the overall extent of flooding but provides protection at an individual property level to reduce the impact of flooding.

*Figure 19: Example Flood Barrier (Constructed in a Wall)*

## 7.5. OPTION.3: RIVER DIKE (200-YEAR RETURN PERIOD FLOOD )

This option includes the construction of a dike at the river level to provide protection up to the 200-year return period. In this option, the dike was modeled along the back channel and extended all the way to the downstream oxbow lake. In addition to the dike, two flap gates were added to the existing culverts on 22 Ave and the driveway on Kidd Road (Figure 20). The flap gates allow water flowing in one direction to prevent water from flooding the area, meanwhile provide necessary drainage.

The required flood protection infrastructure along the eastern bank of the Bulkley River will be 1.6 km long and shall have an average dike height of 1.7 m. This will provide a 1m freeboard over the 200-year flood elevation. Top of dike was assumed to be 6m. A riprap layer would be used for erosion protection.

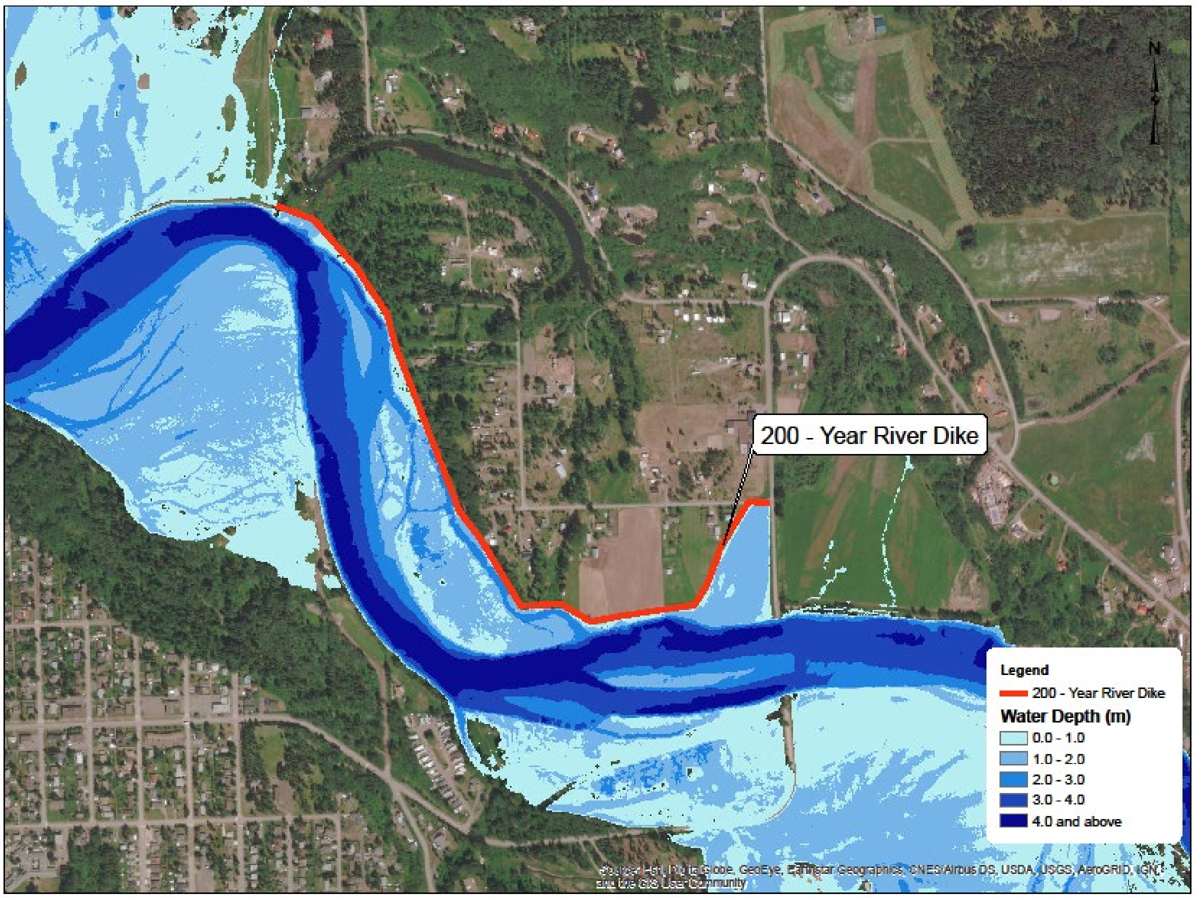



*Figure 20: River Dike Option 3, 200-Year Flood*

## 7.6. OPTION.4: INDIVIDUAL DIKING (200-YEAR RETURN PERIOD FLOOD )

This is the same as option 2 but includes constructing dikes and flood barriers for all residential properties affected during the 200-year return period. Individual earthfill dikes are constructed for all houses in the study area that are shown to be at risk during the 200-year return period (25 properties in total). The dikes would be constructed around the residential properties with break in the dike to allow at-grade access to the property during non-flood events, and flood barriers would be deployed during times of flooding to seal the access point, preventing water egress into the residential properties. This option does not reduce the overall extent of flooding but provides protection at an individual property level to reduce the impact of flooding.

## 7.7. OPTION.5: ELEVATION OF EXISTING DWELLINGS

In this option individual houses are raised to an elevation above the modelled flood level. If a house is below the flood level or does not have adequate freeboard, the house can be elevated to achieve the minimum construction elevation. This option does not reduce the overall extent of flooding but raises the properties above the flood level and hence reduces the risk of internal flooding at an individual property level. House raises are up to 1.0m. Before each house can be raised it must be prepared by:

- Removing attachments to the foundation;
- Removing drywall below the level which will be lifted;
- Removing asbestos which will be disturbed by the lifting process;
- Removing brickwork/ chimneys and additions that are not to be moved; and
- Disconnecting all services such as hydro, gas, water supply, sewer/ septic, and furnace/ boiler.

Following these preparatory steps, the house can be raised using hydraulic jacks, blocks, and beams. The house should be raised 0.3m above its final elevation and be supported by cribbing while foundation works are completed. Foundation works should include:

- Form erection;
- Rebar installation;
- Concrete placement;
- Form stripping, and
- Used material disposal.

Once the new foundation has developed sufficient strength the house will be lowered onto it. At this point services can be reconnected and miscellaneous works such as stair/ brickwork reinstatement can begin.

## 7.8. OPTION.6: ROADS RAISING AND DRIVEWAYS RECONSTRUCTION

Elevating the roads does not add protection to the flood impacted areas as the flood direction is not cut off. However, the raised roads would provide access to emergency vehicles, extend evacuation opportunities to the residents, and reduce the need for mandatory evacuation resulting from safety concerns. This option is shown in Figure 21.

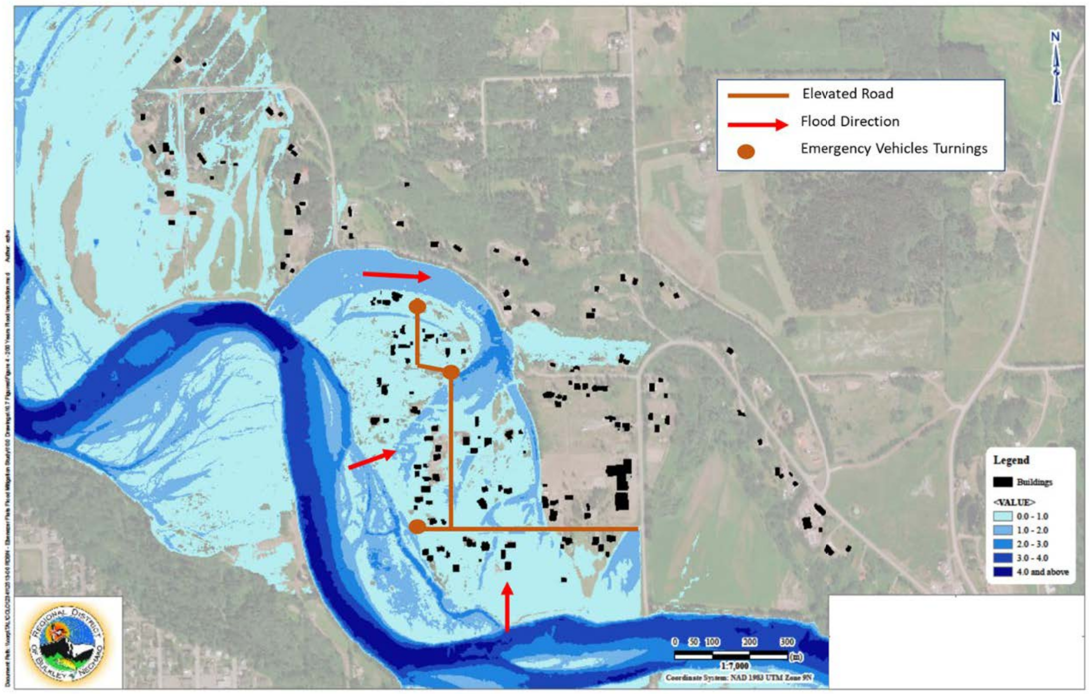



*Figure 21: Road Reconstruction*

The roads include Columbia Street and 22 Avenue. The length of the roads is approximately 1.3 km. The proposed road raise is 0.6 m for access to protect against the 5-year flood and 1.0 m for the 200-year flood. However, it should be noted that during ice jams Columbia Street may need to be raised to 1.0 m to avoid flooding during these events. Typical road raise cross section is shown in Figure 22.

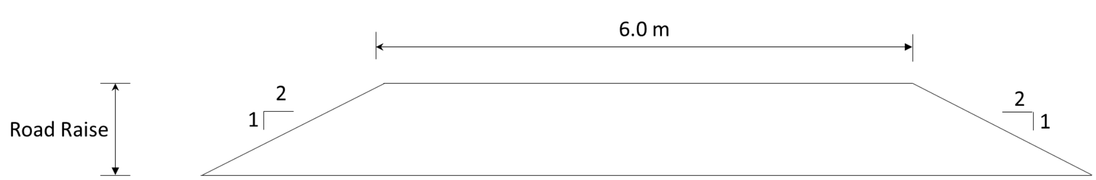



*Figure 22: Typical Road Raise Cross Section*

Roads in the rural area come under the jurisdiction of the MOTI, hence if the road is to be raised by 0.6m, a new 0.615m pavement structure should be constructed on-top of the existing road after the removal of existing pavement, as per B.C Supplement to TAC Geometric Design Guide. If the road is to be raised by 1.0m, a 0.4m layer of fill should be placed on-top of the existing road after the removal of existing pavement, then building the 0.615m pavement structure on-top of the fill layer. Ditch reconstruction will be required along the raised roads to facilitate drainage.

Driveways will be reconstructed to align with the raised roads. We have assumed a driveway width of 6m; lengths and grades will vary depending on how high roads are being raised:

- A 0.6m roadway raise results in approximately 13m long driveways with 5% grade.
- A 1.0m roadway raise results in approximately 15m long driveways with 7% grade.

Culverts are required for all reconstructed driveways and will vary in length from 9m to 11m respective to a 0.6m or 1.0m raise of roads.

During construction, MCSL suggests having a minimum of 1.0 m gravel widening of the existing roadway to keep at least one lane open for access and egress. Traffic control measures such as signage, delineators, and traffic control persons will be implemented as required by the Traffic Management Plan.

The 3rd party utilities that are affected by roadway construction may require relocation. It is assumed no streetlighting, signage, or pavement markings will be installed, relocated, or reinstated.

For roads raise of 0.6 m, the estimated cost would be $2.0M. For a road raise of 1.0m, the estimated cost would be $3.4M. Additional cost for moving utilities or land acquisition should be added, if required. A Class D cost estimate is included in Appendix C.

It should be recognized that although the options presented above provide protection against the flooding discussed for each return period, there are residual risks and pros and cons for each option as discussed in the following sections.

## 7.9. COST ESTIMATES

Table 11 provides the preliminary costing for the proposed flood mitigation alternatives.

The costing completed is based on previous projects completed in the area. The ROI is calculated using the following formula:

$$\%ROI = 100\, x \frac{\$\, Losses\ Avoided}{\$\, Project\ Cost}$$

Where the losses avoided represents the total damage that will be avoided because of the proposed flood mitigation at a strictly residential-property level

*Table 11: Return on Investment (ROI) Analysis*

| Flood Mitigation Alternative | Project Cost | Potential Damages Avoided for each Flood Event | ROI | Comments |
|---|---|---|---|---|
| Option 1 – River dike protecting to the 5-year event | $1.3M | $1.0M | 75% | Soil conditions may increase cost significantly or make the option impractical to construct |
| Option 2 – Property level dike and flood barrier for 10 properties shown to be at risk during the 5-year event | $0.6M | $1.0M | 165% | Limited flood protection |
| Option 3 – River dike protecting to the 200-year event | $2.6M | $3.0M | 115% | Soil conditions may increase cost significantly or make the option impractical to construct |
| Option 4 – Property level dike and flood barrier for 25 properties shown to be at risk during the 200-year event | $1.5M | $3.0M | 200% | Requires residents to place and remove the flood gates. Also requires long-term maintenance. |
| Option 5 – Elevation of 25 properties shown to be at risk during the 200-year event | $1.7M | $2.4M | 140% | Basements are still at risk of flooding. No long-term maintenance |
| Option 6 – Road reconstruction (0.6 m and 1.0 m raise) | $2.0M-$3.4M | n/a | n/a | Provides only enhanced emergency access not flood protection |

Note: Project costs are Class D with 40% contingency included in the cost estimate. Cost estimate is based on the available information when the study was completed. Site investigations and detailed design are required to refine the cost estimates.

We note that the ROI analysis does not reflect all associated costs. The estimated costs are to be used for planning purposes. Constructing dikes will require land acquisition or rights of way acquisition over private property and the installation of control valves and/or pump stations to accommodate local stormwater drainage. The operation and maintenance cost should be considered for the selected mitigation option.

## 7.10. COMPARISON OF FLOOD MITIGATION OPTIONS

Each of the options presented provides different benefits. The pros and cons for each option are presented below. A Multiple Accounts Evaluation (MAE) was completed for the options presented. The MAE considers the following criteria:

- Construction safety rating;
- Resources required;
- Environmental and downstream impacts;
- Permitting and approval requirements;
- Social issues;
- Effectiveness; and
- Advantages and disadvantages.

### 7.10.1. Options 1 and 3 – River Dike

**Pros**

- “Passive” flood defense – does not require members of the public to do anything to provide protection
- Maintenance responsibility is clear (RDBN and benefitting taxpayers)
- Provides protection for everything outside of river – including roads and all buildings
- Allows for access and egress to area in times of flooding
- Less disruption to residents during construction than property level dike and flood gates

**Cons**

- More expensive than property level dikes and flood gates
- Larger construction required than property level dikes and flood gates
- River dikes can result in increases in adjacent and upstream levels in the main watercourse
- Requires land acquisition or rights of way acquisition
- Potential issues with groundwater infiltration
- Geotechnical concerns regarding dike foundation and groundwater
- Construction and maintenance costs must be assumed by the benefitting property owners

### 7.10.2. Options 2 and 4 – Property Level Dike and Flood Gates

**Pros**

- Cheaper than a river dike
- Encourages residents to take an active role in flood protection and can be used as part of an awareness campaign
- Smaller construction required than a river dike
- Smaller impact on downstream levels than a river dike

**Cons**

- “Active” flood defense –requires members of the public to ensure that flood gates are closed in times of flooding
- When residents are on vacation or away from home they are likely to close flood gates in case of flooding – security risk as it makes it clear that residents are not home
- Only provides protection to immediate property – roads and outbuildings etc. would still be flooded
- Access and egress to properties unavailable during times of flooding when gates are closed
- More disruption to residents during construction than a river dike
- Individual property owners would be the end owner of the dike and flood gate and would therefore be responsible for maintenance

### 7.10.3. Options 5– Raising Property Levels

**Pros**

- “Passive” flood defense – does not require members of the public to do anything to provide protection
- No change in maintenance requirements from current situation
- Minimal downstream impacts
- Clear ownership
- No risk of structure breach as with dikes.
- No ongoing structure to monitor

**Cons**

- Disruption to residents during property raising
- May negatively impact on the aesthetic value of the property
- Unclear on impact on property value
- Does not provide safe access or egress to the properties during flood events from local roads unless roads are raised

### 7.10.4. Options 6– Raising Access Road Levels

**Pros**

- “Passive” flood defense – does not require members of the public to do anything to provide protection
- No change in maintenance requirements from current situation
- Minimal downstream impacts
- Clear ownership
- No risk of structure breach as with dikes.
- No ongoing structure to monitor
- Provides safe access or egress to the properties during flood events

**Cons**

- Disruption to residents during construction
- Does not provide protection to residents at a property level

The results of the MAE are summarized in Table 12. The MAE analysis was combined with cost and ROI for each option in a weighted matrix to determine the best option. The ranking of options is presented in Table 13.

The options assessment and ranking show the following:

- River dikes has a lower ROI than individual properties protection. They also require high long-term maintenance cost.
- Individual property dikes may not provide full protection of the land but have a more attractive ROI and overall ranking as the costs are lower.
- Raising individual properties elevation ranks highest based on the overall assessment criteria.
- Raising the road level does not provide a viable solution to mitigate against the risk of flooding by itself. When combined with raising property elevations, it provides a solution that not only protects individual property but also ensures safe access and egress is available to properties during flooding events.

The options were then each scored on a scale of 1-4 with 1 being that the option meets the criteria the least and 4 meeting the criteria the most. Where options met the criteria equally, the same score was assigned. Each of the criteria were than assigned a different weighting depending on the priority of this criteria and a total weighted score calculated. The options were then ranked based on this total score, with a ranking of 1 identified as the highest score, to 3 with the lowest score.

Based on discussions with RDBN, maintaining road access to the flooded area is a high concern. An integrated option combining raising the houses and the roads provides a great advantage to property protection, emergency access and opportunities for delayed evacuations. This combined option can also be constructed in stages as funds become available to the Ministry of Transportation and Infrastructure (MOTI). A Class D cost estimate for the selected option is included in Appendix C.

*Table 12: Flood Mitigation Options Assessment*

| Flood Mitigation Option | Safety Rating | Resources Required | Environmental Impacts | Downstream Impacts | Permitting and Approval Requirements | Social Issues | Effectiveness | Advantages | Disadvantages |
|---|---|---|---|---|---|---|---|---|---|
| Option 1/ Option 3 - River dike | Construction near to watercourse, minimal safety implications once constructed | Could be constructed by local construction company | Dependent on location. Potential impacts from general erosion and sediment cause by construction. | Potential changes/ increase in flooding/ erosion downstream. Must be investigated in a subsequent study | Typically require extensive permitting from environmental and Dike perspectives. | Provides peace of mind to residents as no action needed by them during a flooding situation, provides a "passive protection" | Provides a full protection as water is confined within the river area and prevents flooding in the area. Reduces the chances of evacuation. | No action required during flood events other than ongoing maintenance. Provides a full protection and prevents flooding of the area. | Cost and large-scale construction |
| Option 2/ Option 4 - Property level dike and flood gates | Heavy machinery near to residential properties during construction. Once construction is complete there are safety implications as safe access and egress to the properties is impacted during flooding | Dikes could be constructed by local construction company, flood gates likely to be imported from another country | Dependent on location. Potential impacts from general erosion and sediment cause by construction. | Likely none, but potential impacts from general erosion and sedimentation cause by construction. | Works not within 30m of a watercourse and hence no permitting considerations identified. | Residents required to activate flood gates themselves during flooding events, could be issues if the residents are away | Does not prevent overall flooding but does provide protection at a property level, although does not allow for safe access and egress to properties to the surrounding area. May not work if groundwater rises. Properties would likely still require evacuation to ensure safety of residents | Lower cost and construction implications that river dike | Issues with safe access and egress to properties during flooding event. Requires action from the residents during a flood event to provide protection. |
| Option 5 - Raising property elevation | Heavy machinery near to residential properties during the period of raising the properties. Minimal safety implications once properties are raised | Specialist contractor required | Dependent on location. Potential impacts from general erosion and sediment cause by construction. | Likely none, but potential impacts from general erosion and sedimentation cause by construction. | Works not within 30m of a watercourse and hence no permitting considerations identified. | Impact to residents during raising but once raised, provides a "passive protection" with no ongoing action required from residents | Does not prevent overall flooding but does provide protection at a property level, although does not allow for safe access and egress from properties to the surrounding area as roads would still be flooded. Properties would likely still require evacuation to ensure safety of residents | Removes properties from the flooding and reduces effect of flooding at a property level | Disruption to residents during the property raising process and does not ensure safe access and egress from the properties to the surrounding area during flood events. |
| Option 6 - Raising road levels | Minimal safety implications during construction other than ensuring safe access and egress to properties during construction phase. Once constructed provides safe access and egress to properties during flooding. | Could be constructed by local construction company | Dependent on location. Potential impacts from general erosion and sediment cause by construction. | Likely none, but potential impacts from general erosion and sedimentation cause by construction. | Works not within 30m of a watercourse and hence no permitting considerations identified. | Provides peace of mind to residents as no action needed by them during a flooding situation, provides a "passive protection" | Does not prevent overall flooding but provides access and egress is available during flooding from properties to the surrounding area. Would be most effective when used in conjunction with property level protection through property level dikes or raising property levels. | Provides safe access and egress to properties during flooding. | Does not provide protection to properties, would be most effective when used in conjunction with Option 2, 4 or 5. |

*Table 13: Flood Mitigation Options Weighted Score and Ranking*

| Flood Mitigation Option | Safety Rating | Resources Required | Environmental Impacts | Downstream Impacts | Permitting and Approval Requirements | Social Issues | Effectiveness | ROI | Weighted Score | Overall Ranking |
|---|---|---|---|---|---|---|---|---|---|---|
| **Weighting** | **10%** | **5%** | **20%** | **5%** | **10%** | **10%** | **20%** | **20%** | | |
| Option 1/ Option 3 - River dike | 1 | 1 | 4 | 1 | 1 | 5 | 5 | 1 | 2.8 | 3 |
| Option 2/ Option 4 - Property level dike and flood gates | 4 | 3 | 5 | 4 | 3 | 1 | 1 | 5 | 3.4 | 2 |
| Option 5 - Raising property levels | 3 | 2 | 5 | 4 | 3 | 3 | 3 | 4 | 3.6 | 1 |
| Option 6 - Raising road levels | 4 | 2 | 5 | 3 | 2 | 3 | n/a | n/a | n/a | n/a |

## 7.11. ICE JAM MITIGATION OPTIONS

Ice jam mitigation measures fall into three general categories: preventative measures; ice removal and breaching (reactive); and damage reduction. The different ice jam mitigation options were evaluated based on criteria such as safety, environmental impacts, permitting, downstream impacts, social implications, effectiveness and cost. Several mitigation options were looked at based on anticipated flow, water depth, and water velocity conditions at the time of probable occurrence. Seven options are highlighted and discussed.

**Option 1: AMPHIBEX**

AMPHIBEX is an amphibious excavator developed in Quebec by Normrock Industries Inc. It has been successfully used for ice-breaking on rivers such as Red River in Manitoba and Rideau River in Ontario. This equipment can work on shallow water, hard-to-reach sites and ice-bound waterways. The modes of locomotion include crawling, sliding, floating and propulsion. Figure 23 shows the AMPHIBEX operating on the Red River.

Figure 23: An AMPHIBEX Icebreaker Operates on the Red River North of Selkirk on Tuesday, February 17, 2015. (CHRISD.CA)

Compared to other ice-breaker boats, the advantage of using this equipment is that it can float on shallow water and may cause minimum impact to environment. The two stabilizers on the sides can help AMPHIBEX counter unbalancing forces caused by stream current. However, the limitation of the AMPHIBEX is that it can only work in relatively slow-moving water and is only effective cutting up to 4 ft of ice. Fast moving water current may cause the AMPHIBEX to drift and to be trapped at downstream water infrastructure. This may potentially endanger the operator and the equipment. Another drawback of using AMPHIBEX is the cost. Equipment and operators need to be brought in from outside the province, the cost of mobilization and demobilization is relatively high.

**Option 2: Ice Weakening / Drilling**

The ice weakening / drilling option refers to the weakening of the structure of a solid ice sheet by drilling or auguring (Figure 24). This option requires a specialist with knowledge of the local ice condition and operators with hand-held ice drilling equipment. The effectiveness of this option is highly dependent on the ice conditions and how the drilling holes are arranged on the ice cover. The initial cost for hiring an ice specialist is high but can be reduced over time if a local, site specific, methodology is developed. From a safety perspective, the operators should check the ice thickness before stepping on the ice cover, wear proper ice/water safety gears and follow ice/water safety guidelines. Safety inspectors should be on site at all time. The advantage of this mitigation option is it requires minimum resources and has minimum environmental impacts. The disadvantage is its effectiveness is highly dependent on local ice conditions and it involves crew working on ice cover. Ice weakening/ drilling is as a pre-emptive measure and intended to weaken existing ice cover to prevent stable ice cover from causing and ice jam.

Figure 24: U.S. Marines Drilling on Ice with Alaskan Natives (U.S. Marine Forces Reserve Website)

**Option 3:  Ice Blasting**

Ice jam commonly occur where mobile ice encounters existing stable, competent ice cover. Ice blasting is a preventative mitigation measure to break up a floating sheet ice cover by placing explosive charges in the water underneath the ice cover, or with a much greater size of charges, placed on or within the ice. Ice blasting is rarely effective as large fragment of ice sheet may shift downstream and cause flooding in area already inundated or not previously flooded. Charges must be set precisely to minimize percussion to area other than the ice. In addition, the cost to hire expert contractor and obtain environmental permits is high. Figure 25 shows ice blasting on the Rideau River.

*Figure 25: Ice Blasting on the Rideau River, March 08, 2014 (Ottawa Citizen)*

**Option 4 & 5:  Mechanical Ice Removal (Backhoe Excavator/ Dragline Crane)**

Both backhoe excavator and dragline crane mitigation options fall into the mechanical ice removal category. Mechanical ice removal refers to taking ice from a river using construction equipment. Bulldozers, backhoes, draglines and clamshells are often used. The objective of this type of mitigation measures is to create a channel that allow free flow of ice and water. In general, mechanical ice removal is a short-term solution to ice jam on a small stream. The use of construction of equipment to move an ice jam becomes unfeasible when there’s a large amount of ice to be removed (long ice jam or a wide river), ice blocks are too large or too heavy to be handled with existing equipment, elevated upstream water level, and increased flow. It should be mentioned using an excavator close to river bank and fast-moving water imposes potential danger to the operator(s) and equipment. It is also dangerous if the wire of the dragline crane gets caught underneath the sheet ice cover. This may cause damage to the crane and the people in the surrounding area. The efficiency of using construction equipment to remove ice cover can be estimated by dividing the total amount of ice that needs to be removed by the estimated volume of ice removed per hour.  For example, a rough estimation shows a 110-ton dragline crane with 1-yard bucket can remove approximately 150 cubic yards of ice from the river per hour. Assuming 0.5 m thick, 50 m wide and 500 m long ice sheet, the total hours required to remove all the ice from the river is approximately 65 hours. Figure 26 shows a dragline crane removing ice.

*Figure 26: Dragline Crane Removing Ice from Catfish Creek in Port Bruce (Aylmer Express)*

**Option 6: Setback Dike**

The setback dike provides relief to ice jam flooding by increasing the flow area. During an ice jam event, the additional flow area on-top of the river bank would allow water to bypass the ice jam area and reenter the river channel downstream to the ice jam. The minimum setback distance would be 10m to 15m away from the existing river bank. The height and length of the setback dike is assumed to be similar to a 5-years flood dike. The advantage of the setback dike is that it would have minimum environmental impacts and it can be constructed away from the water. Hence, it is safer than other mitigation options. However, the drawback is that the construction cost is high (approximately $1M) and it requires additional land acquisition. Figure 27 shows a typical setback dike cross section.

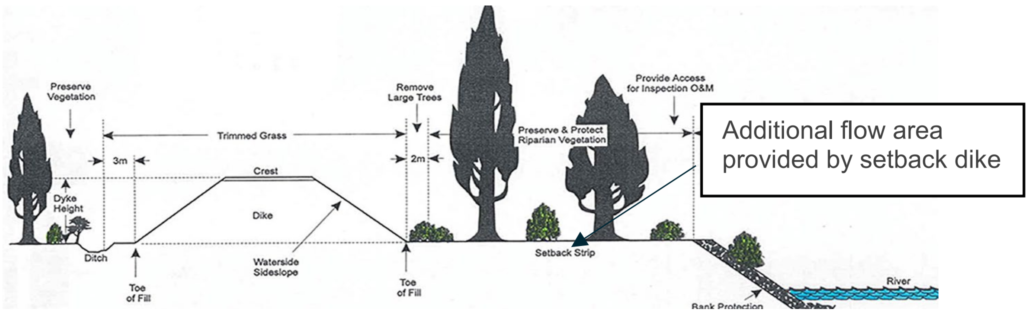



*Figure 27: Typical Setback Dike Cross-Section (Dike Design & Construction Guidelines, Government of BC)*

**Option 7: Raising Property Elevation**

Raising the elevation of properties would significantly reduce the damage caused by ice jam flooding. However, the formation of ice jam is highly dependent on the flow and weather condition. As discussed in Section 4.4, an ice jam could occur at different locations along the river, hence the flood extent and depth are also different. The cost estimate would be inaccurate without knowing which houses are affected and the flood depth at the house location. Due to the uncertainties mentioned above, this option is not included in the MAE for ice jam mitigation (Table 14 and Table 15). The pros and cons for this option can be found in Table 12, section 7.10.

Table 14 summarizes the ice jam mitigation options assessment. The mitigation options were assessed based on safety, environmental impacts, permitting, downstream impacts, social implications, effectiveness and cost. It should be noted a mitigation measure is only appropriate when there is sufficient storage area for the ice removed and enough clearance at downstream for the ice to pass through. Option 1, 2 and 3 are only effective as pre-emptive measures when deployed prior to ice breakup. Option 4 and 5 can be deoplyed either as pre-emptive or responsive measure. However, option 4 and 5 are not effective when the volume/mass of the ice jams is too large.  It may be more beneficial to invest in improving the overall flood protection than direct ice mitigation options. Flood mitigation options discussed earlier provide also a better level of ice jam protection.

As shown in Table 15, the ice jam mitigation options were ranked based on criteria mentioned above. Each options are marked on the scale of one to five. The highest the score the most the option meets the criteria. A weighting factor was applied to place higher importance on criteria that are identified as significant for this project.: envriomental impact, effectivenes and costs are weighted 20%, which is higher that the remaining criteria. The six options were ranked from highest to the lowest. Based on the scoring matrix, the highest ranking mitigation option is Option 6 -Setback dikes, primarily because of its effectiveness in providing flood protection regardless of ice conditions. The principal drawback of this option is it requires large amout of budget up in front and maintance across its service life.

*Table 14: Ice Jam Mitigation Options Assessment*

| Ice-Jam Mitigation Option | Safety Rating | Resources Required | Environmental Impacts | Downstream Impacts | Permitting and Approval Requirements | Social Issues | Effectiveness | Cost Per Ice Jam | Advantages | Disadvantages |
|---|---|---|---|---|---|---|---|---|---|---|
| Option 1 - AMPHIBEX | Certified by WCB | Contractor comes from out of province | Virtually no environmental impact | Need enough river clearance for ice to pass through at downstream | Any work below the high-water-mark will require some level of permitting. | Minimal disruption to local community, provides an active response | Preventative measure, effective pre-breakup | \$130,000 ~ \$200,000 | Causes little damage | Trouble with currents in river, operating constraints include thickness of ice, water velocity and depth of water |
| Option 2 - Ice weakening/ drilling/ augering | Operators need to take safety precautions working on ice | Operators | Virtually no environmental impact | Need enough river clearance for ice to pass through at the downstream | Any work below the high-water-mark will require some level of permitting. | Minimal disruption to local community but may provide a less effective result that may impact the local community | Highly dependent on ice conditions, effective pre-breakup | \$30,000 ~ \$50,000 | No environmental impacts, reduced probability of ice jam initiation | . Highly dependent on ice conditions (requires pre-assessment) to determine efficacy. |
| Option 3 - Ice blasting | Very dangerous for workers placing the charges | Contractor | Danger to fish habitat | May cause large sheet of ice moving downstream | Will require DFO and FLNRORD Approval. DFO has very stringent rules surrounding blasting in/near water and sets limits on acoustic levels. | Noise disruption to local community. Limited effectiveness may cause negative impact on community's perception of action being taken | Rarely effective. Need experts to set up charges correctly, effective pre-breakup | \$100,000 ~ \$300,000 | Preemptive ice blasting can reduce ice jams | Ice blasting is rarely effective. Explosives must be set precisely to minimize blast percussion to areas other than the ice. Successful charges may fragment the ice but will likely shift large portions causing worse flooding in areas already inundated or in areas not previously flooded. |
| Option 4 - Backhoe/ clamshell excavator | Not very safe working close to river and current | Contractor, machine and operator(s) | Damage to river bank is likely to occur. | Need enough river clearance for ice to pass through at downstream | Will require DFO and FLNRORD permitting. | Minimal disruption to local community but may provide a less effective result which may impact on local community. Damage to river bank may impact on community's use of river for recreational purposes during non-ice-jam conditions | Not effective when large amounts of ice to be removed or ice blocks are too heavy/large | \$85,000 ~ \$110,000 | Relatively easy to operate | Excavating ice near river bank may damage river bank or create erosion concerns. This could be very ineffective as the excavator's reach will be limiting, and ice is thickest on the edges of the river. |
| Option 5 - Dragline ice removal | Relatively safe workers out of the water | Contractor, machine and operator(s) | Low impact if dragging only the Ice. Sediment disturbance if dragging river bottom | Potential sedimentation if dragline is near the substrate. | Will require DFO and FLNRORD permitting. | Some disruption to local community as multiple set ups may be required. | Not effective when large amount of ice to be removed | \$130,000 ~ \$170,000 | If used for dredging of river bottom could potentially help eliminate ice from jamming at the confluence. | Multiple set ups likely required. Not easy to operate. Must remove ice from shore once it is removed from the river |
| Option 6 - Setback dikes | Medium to high | Contractor, machine and operator(s) | Low, but dependent on location. | Low impact, setback dike provides additional flow area, allow water to bypass the ice jam area | Significant permitting required from environmental and Dike perspectives. | More disruption to local community during dike construction | Effective in protect properties from ice jams flooding | \$60,000 ~ \$90,000 | Little damage to habitat easy to construct | Require additional land to construct dikes. Require continuous maintenance. |

**Assumptions:**

Cost estimate in Table 14 is high-level budget based on past project experience and/or quotes provided by contractors. The cost for each option is broken down to per ice jam occurance. The location of the ice jam is assumed betweeen probable location 2 and 3 (Figure 8). The river depth is assumed at 0.5 ~1 m – sufficient for the amphibious excavators to operate on.The ice thickness for option 4 and 5 is assumed at 0.5 m pre-breakup. The area of ice cover is assumed 25,000 $m^2$. The quote the demolition/blasting contractor provided assumed ice cover thick enough for drilling and placing the charges within it, the actual cost for placing the charge underneath the ice cover may vary. The service life for Option 6 is assumed at 50 years. The cost estimated is based on \$1M construction cost and 1 in 2 years ice jam occurrence or 1 in 3 years ice jam occurrence.

*Table 15:Ice Jam Mitigation Options Ranking*

| Ice-Jam Mitigation Option | Safety Rating | Resources Required | Environmental Impacts | Downstream Impacts | Permitting and Approval Requirements | Social implications | Effectiveness | Cost | Score | Overall Ranking |
|---|---|---|---|---|---|---|---|---|---|---|
| **Weighting** | **10%** | **5%** | **20%** | **5%** | **10%** | **10%** | **20%** | **20%** | | |
| Option 1 - AMPHIBEX | 3 | 2 | 5 | 3 | 3 | 5 | 2 | 2 | 3.2 | 3 |
| Option 2 - Ice weakening/ drilling/ augering | 3 | 4 | 5 | 3 | 5 | 4 | 2 | 4 | 3.8 | 2 |
| Option 3 - Ice blasting | 1 | 2 | 0 | 2 | 0 | 2 | 2 | 3 | 1.5 | 6 |
| Option 4 - Backhoe/ clamshell excavator | 2 | 3 | 3 | 3 | 3 | 4 | 2 | 3 | 2.8 | 5 |
| Option 5 - Dragline ice removal | 3 | 3 | 4 | 3 | 3 | 3 | 2 | 3 | 3.0 | 4 |
| Option 6 - Setback dikes | 5 | 3 | 4 | 5 | 3 | 2 | 5 | 3 | 3.8 | 1 |

Score Range:  1-5 (Poor, Fair, Good, Better, Best)

## 7.12. REMOVING PIER FOUNDATION AND ISLAND

MCSL carried out a flood mitigation and ice jam analysis for removing the gravel bar and the old bridge piers as shown in Figure 28. In 1966, an ice jam destroyed the old Bulkley River bridge (Figure 29). Removing the gravel bar and the remaining bridge piles may improve the hydraulic capacity at this stretch of the river. Its effect on ice jams through this reach is less clear. From an ecological perspective, dredging the river can have significant impacts upon river ecosystem and its wildlife. This would require DFO and FLNRORD approvals. The geomorphic effects of dredging the river is also complex. Dredging the river bottom or removing the gravel bar in the center of the river will lead to temporary channel instability. MCSL notes that the river in this reach has become wider as a result of the piers and gravel bar.

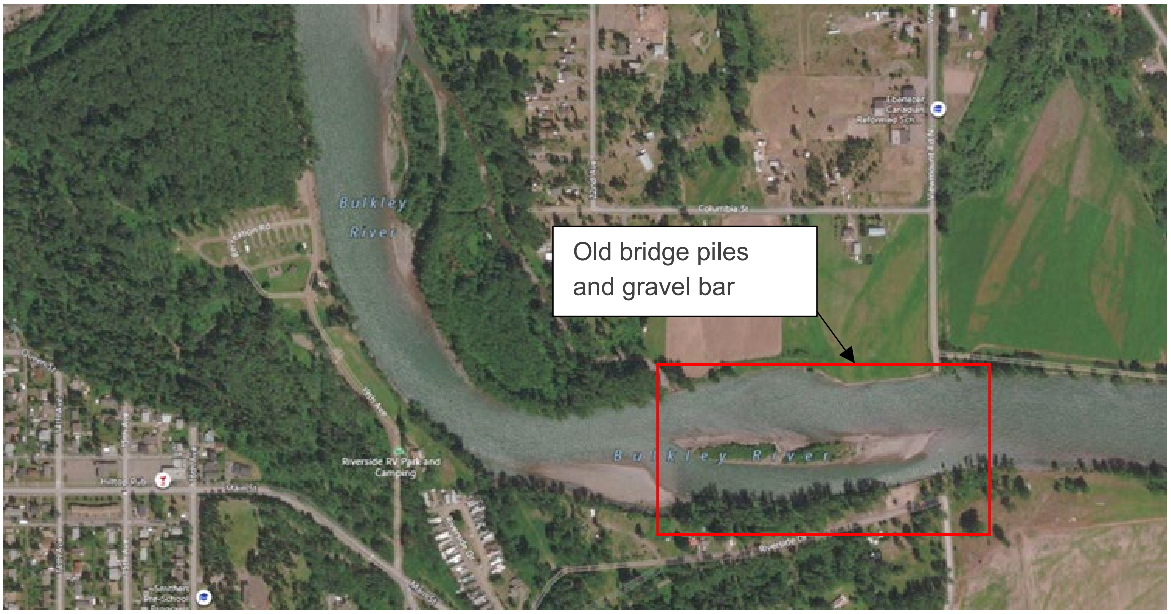
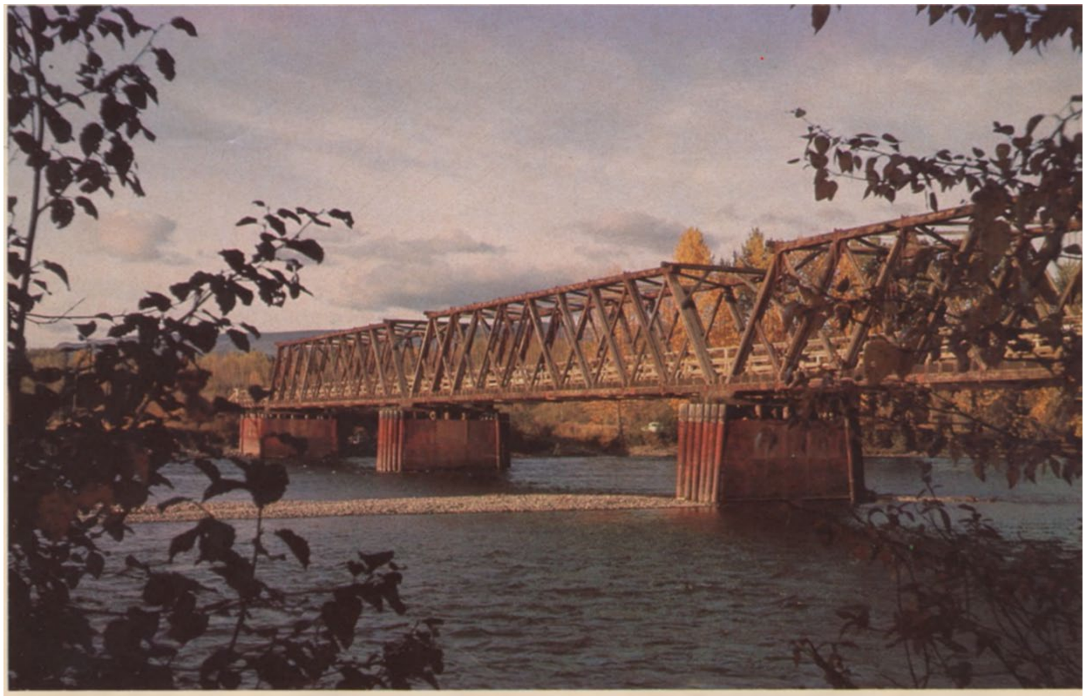



*Figure 28: Current Photo at the Old Bridge Location (Bing Maps)*

Dredging the channel at this location may provide temporary, localized flood relieve. MCSL anticipates that the river will aggrade at specific locations within the reach, however we anticipate that the channel will narrow to its existing width over time as it restablishes a balance between coveyance, bedload transport, and geometry. The cost to remove the gravel bar and cut the old bridge piles could be high. Based on a high-level cost estimate, to remove a total volume of approximately 30,000 m$^3$ it may cost up to $0.9M not including disposing the removed material. No information was available for the bridge piles. From the available bridge photo, the piers may have been constructed of deep piles. To remove the sections above the river bed may require underwater cutting of the structure. This work is specialized and must be carried out by commercial divers. The cost is likely to be high but cannot be estimated without further investigation to determine the size of structure to be removed.



The old Bulkley River bridge. It served Smithers for many years but was demolished in a massive ice jam in 1966.

*Figure 29: Historical Photo of the Bridge*

## 7.13. EROSION MITIGATION OPTION

MCSL completed erosion assessment and developed erosion mitigation option for the properties in the vicinity of 195 to 661 Viewmount Road North (Figure 30). Scour assessment was carried out to estimate the depth of scour that may be anticipated with the implementation of the erosion protection. Riprap is proposed for erosion protection. A cost estimate is provided for planning purposes. Actual cost may vary depending on the detailed design and actual site conditions.


*Figure 30: Potential Scour Location*

### 7.13.5. Scour Assessment

A scour assessment was performed to guide the design of erosion protection measures. The bank erosion area is located on an outer bend in the river. As shown in Figure 31 , the water velocity adjacent to the river bank is predicted to be 2.5 to 3 m/s. The water velocity is higher in the river main channel than near the river bank. The LiDAR and river bathymetry data indicates potential scour location near bend apex.

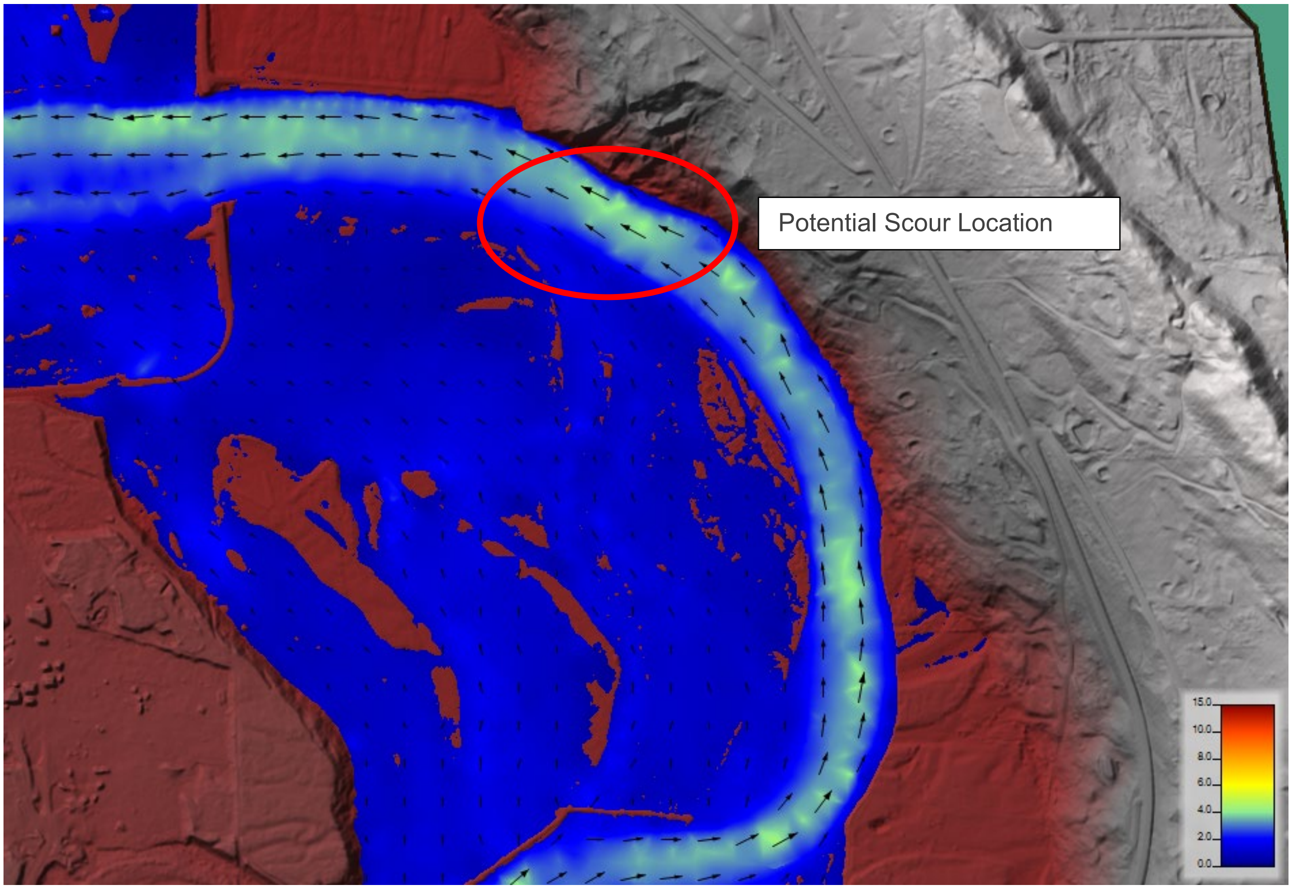


*Figure 31: Velocity Vector and Magnitude for 200-Year Flood*

The scour assessment was performed using Blench's Regime formula for natural scour outlined in section 4.4.6 in TAC (2001).

## Blench's Regime Formula for Natural Scour

Blench's formula is given by:

$y_r=(q^2/F_{b0})^{1/3}$

Where:

$y_r$ is the mean depth of the scoured channel in meters

q is the discharge intensity (Q/W) for a given cross section

Q is the discharge in $m^3/s$

W is the top width of the flow in meters

$F_{b0}$ is a factor based on the median grain size of the material ($D_{50}$) in mm and is taken from a chart provided in Figure 4.24 of TAC (2001). Given an estimated $D_{50}$ of 30 mm, $F_{b0}$ is 1.5.

$y_s$ is determined by $y_s = y_r - y_o$

$y_s$ is the mean scour depth in meters

$y_o$ is the average depth through the cross section prior to scour

The values used are summarized below in Table 16.

*Table 16: Blench's Natural Scour Parameters*

| Q $m^3/s$ | W m | q $m^2/s$ | q2 | Fbo | yr m | yo m | ys m |
|---|---|---|---|---|---|---|---|
| 1606 | 130 | 12.35 | 152.62 | 1.5 | 4.67 | 3.5 | 1.17 |

The above formula gives the average scour depth through the channel. To determine the maximum scour depth, a factor is used to account for channel alignment. The channel is a moderate bend reach and results in a factor of 1.5. This results in a maximum scour depth of 1.75 m.

### 7.13.6. Erosion Protection

Riprap is recommended to be installed on the streambed and embankment. The nominal ($D_{50}$) riprap size, as per the Riprap Design Chart in Appendix B, is 565 mm and an equivalent mass of 250 kg with a maximum allowable velocity of 4.5 m/s assuming 2:1 bank slope. The riprap sizes are shown in Table 17. The rock shape should be angular. The minimum thickness of the riprap layer is 1000 mm. The riprap revetment should be installed from toe of the bank to the top of the bank. The minimum length of apron is 4m. The top of the riprap should be at minimum 0.6m above the 200-year flood level. The erosion protection should extend beyond both the tangent points of both upstream and downstream as indicated in Figure 32. The estimated length of the ripraps is approximately 600m.


*Figure 32: Recommended Erosion Protection Extent*

Non-woven geotextile or granular filter is required to avoid loss of bank material. Based on the recommended $D_{50}$ size of 565 mm for rock riprap, the filter rock material size should fit in the range shown in Table 17. The filter layer thickness should be greater than 250 mm.

*Table 17: Riprap and Filter Sizes*

| | Riprap (mm) | Filter (mm) | |
|---|---|---|---|
| $D_{15}$ | 195 | 7.8 | 39.0 |
| $D_{50}$ | 565 | 22.6 | 113.0 |
| $D_{85}$ | 600 | 40.0 | 97.5 |

The typical cross section details for erosion protection are shown in Figure 33.

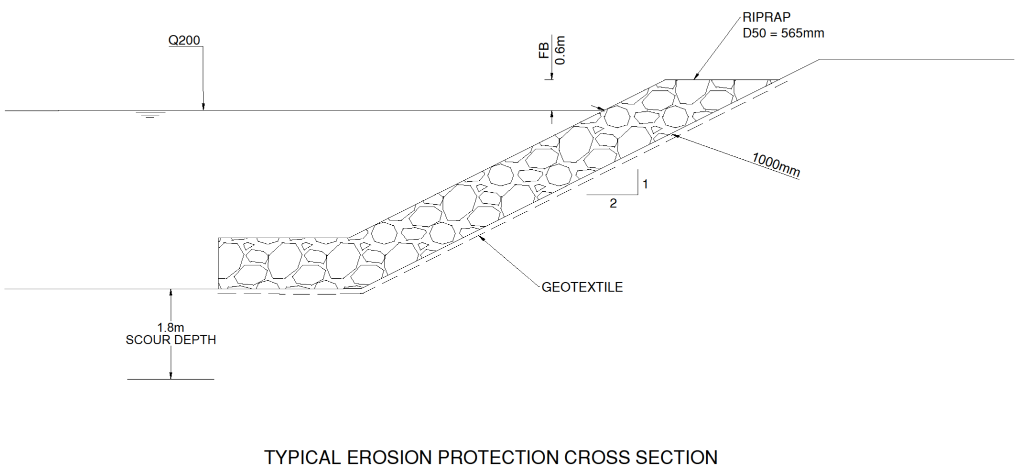



*Figure 33: Erosion Protection Typical Section*

The estimated cost for erosion mitigation is approximately $1M. Most of the cost is for the riprap purchase and installation.

# 8. CONCLUSIONS AND RECOMMENDATIONS

Flooding in Ebenezer Flats is the result of extreme rainfall or freshet flows in the Bulkley River or of ice jams that block the river, obstructing the flow and causing backwater and flooding upstream of the ice jam. MCSL investigated a 5-year return period flood and a 200-year return period flood to assess the potential flood inundation and hazard presented by each event.

The results of the analysis indicate that the 5-year flood event results in flooding of ten properties resulting in water depth up to 0.5m at the houses. The 200-year flood results in flooding of 25 properties resulting in water depth up to 0.8m at the houses. Information regarding the house floor elevation was not available for this study.

To mitigate against flooding to the Ebenezer Flats area, MCSL investigated six potential flood mitigation options Mitigation categories included:

- Local flood protection (individual dikes around houses or raising the houses and roads above the flood elevation); and
- Area flood protection (i.e., dikes on the river)

A MAE was undertaken to evaluate the options. The results of this evaluation are presented in Table 18.

*Table 18: Results of MAE for Flood Mitigation Options*

| Flood Mitigation Option | Weighted Score | Overall Ranking |
|---|---|---|
| Option 1/ Option 3<br>River Dike | 2.8 | 3 |
| Option 2/ Option 4<br>Property Level Dike and flood gates | 3.4 | 2 |
| Option 5<br>Raising property levels | 3.6 | 1 |
| Option 6<br>Raising road levels | n/a | n/a |

Raising the roads allows for access by emergency vehicles during the floods and delayed evacuations but it does not provide flood protection. Raising the house elevations and access to the entrances allows the residents to reduce flood damage and gain more response time during the floods. However, it should be noted that the proposed option provides protection up to the 200-year flood event only and floods beyond the 200-year may still require evacuation. This is the case with other mitigation options as planning for mitigation measures beyond the 200-year flood may not be practical. In addition, for this mitigation option flooding of the areas around the houses may still occur. Basements may not be protected during the floods so additional individual basement protection may be required.

Although the areas around the houses may be flooded, the passive nature of this option, which requires no input or action from residents once the properties are raised, along with the continuous access to the residents, the avoidance of evacuation and protecting the dwellings make it an attractive option. This flood mitigation option can be implemented in stages over several years as funds becomes available.

The following steps and considerations are recommended for the selected option:

- Detailed design and cost estimate;
- Review of land ownership;
- Review planning implications for future development in the area (setting minimum construction level, areas to avoid development etc.); and
- Seeking funding and resources to implement the selected option.

Three locations of previous ice jams in the Bulkley River that resulting in flooding of Ebenezer Flats were assessed. The ice jams may result in water depths less than 1.0m except for a very small reach on Columbia Road that may reach up to 1.8 m. Ice jam breaking options were considered. In general, the ice breaking is an expensive approach to handle ice jams. It becomes feasible in large rivers passing through areas of high population. There are also extensive permitting requirements, safety concerns and possible environmental impacts. Dikes would be costly and may not be feasible. However, the proposed flood mitigation options may also reduce the flood impacts from ice jams.

Removing the old bridge piers and the island was considered as an ice jam mitigation option. The 2D HEC-RAS model showed that ice jams at the location of the bridge piers would cause local flooding at Ebenezer Flats. Removing the piers would reduce the probability of the flood jams. No information regarding the piers foundation was available to assess the cost. Removing the bridge piers may slow down the growth of the island due to the accumulated sand bars. Removing the island may not be practical at this point due to the environmental permitting challenges and cost. If the bridge piers are removed, the island and the occurrence of ice jams could be monitored and assessed to determine if removing the island should be further investigated.

A proposed approach to both flood mitigation and ice jams may be achieved in the following steps:

- Confirm that raising the elevation of key roads and the residential properties are RDBN and the residents' preferred option
- Stage the construction of the roads and the dwellings raising (i.e., raising Columbia Road and the adjacent dwellings to the road then raise 22 Avenue)
- Remove the bridge piers and monitor the island and the ice jams occurrence.

MCSL assessed erosion protection for the properties in the vicinity of 195 to 661 Viewmount Road North. The river reach is approximately 400m. Riprap is proposed as an erosion mitigation measure. However, for effective erosion protection the river reach that needs to be protected would be extended to 600m. For the 200-year flood, the water depth in the river is estimated at 3.5 m and the scour depth is approximately 1.8m. The cost for using the riprap of the river reach is approximately $1M. Lower levels of protection can be implemented at a lower cost but would provide less protection and may have higher probability of failure.

In addition to the construction of the structural mitigation options measures identified in this report, consideration should be given to undertaking a flood awareness campaign to ensure that all residents are aware of what to do in the event of an emergency. This would include review and communication of Emergency Response Plans, identification of muster points and providing emergency contact lists as well as encouraging residents to prepare their own flood response plan for their property.

# 9. LIMITATIONS AND CLOSURE

This is a strategic assessment only and does not replace site specific flood risk assessments for individual site development, which would be subject to the requirements of local planning and EGBC Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC. This assessment is risk from river flooding only, no modelling has been undertaken of surface water flooding.

The hydraulic model results may have uncertainties due to the modelling limitations and the information used in the model such as the survey, flow estimation and climate change. The results should be used with caution as a planning tool. Actual flood depths and velocities may differ from the model output. Results from the model were used to create flood and hazard maps. Flood maps were created taking into account 1.0m of freeboard to establish the construction elevation. Any new developments should be higher than the construction elevation. It is recommended that RDBN should continue to include requirements as part of their planning processes to ensure that any new development is above the identified construction level.

The assessment has been prepared by McElhanney Consulting Services Ltd. (MCSL) for the benefit of the RDBN. The information and data contained herein represent MCSL's best professional judgement considering the knowledge and information available to MCSL at the time of preparation.

MCSL denies any liability whatsoever to other parties who may obtain access to this report for any injury, loss or damage suffered by such parties arising from their use of, or reliance upon, this document or any of its contents without the express written consent of MCSL and the RDBN.

We thank you for the opportunity to work on this project. Please do not hesitate to contact us if you have any questions.

Yours truly,

McElhanney Consulting Services Ltd.

Eric Zhu P.Eng.

Hydrotechnical Engineer

Clare Share, P.Eng.

Project Engineer


2019-03-12

Amr Fathalla, M.Sc., P.Eng.

Senior Water Resources Engineer

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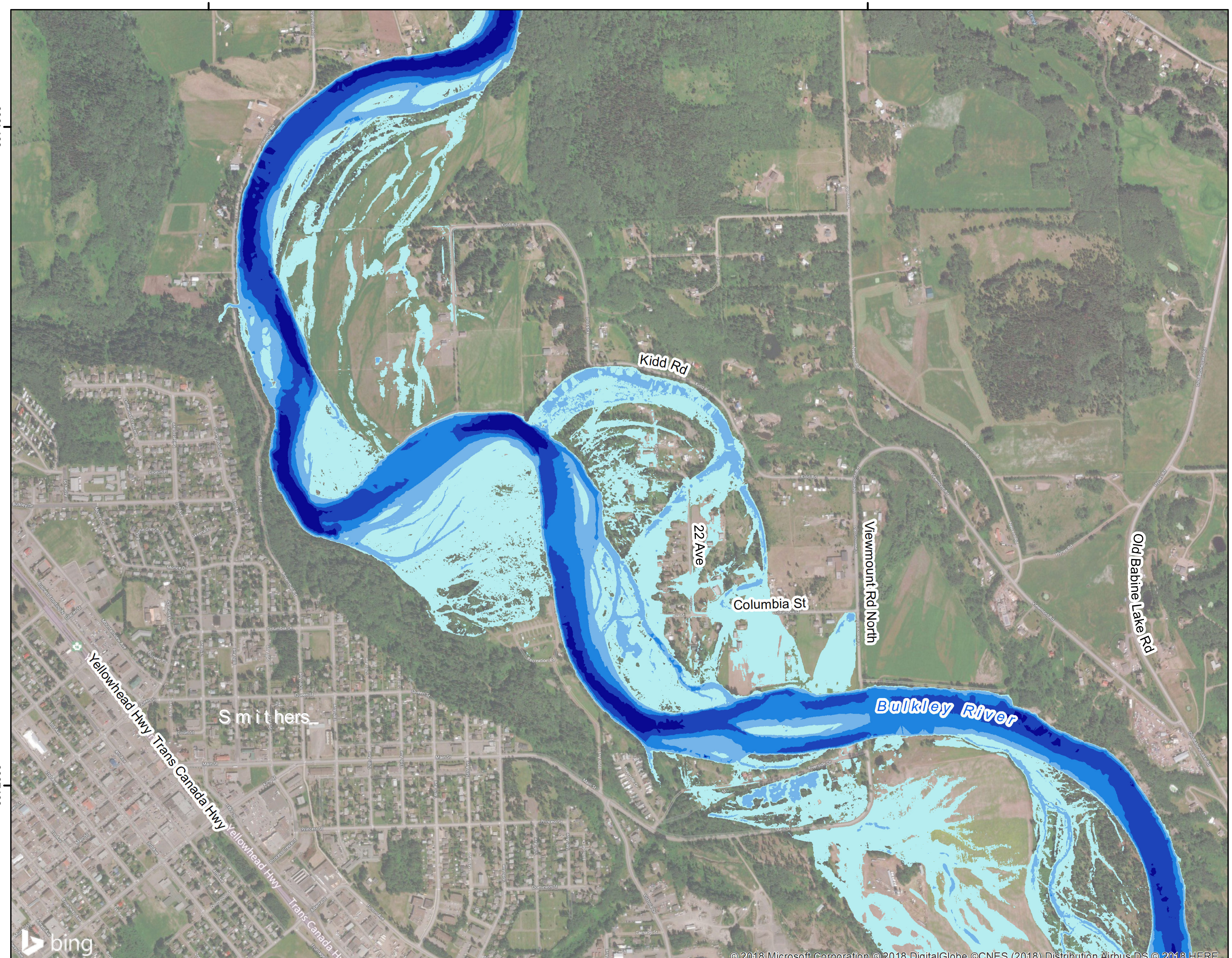
# APPENDIX A
# FLOOD HAZARD MAPS

**Ebenezer Flats Flood Mitigation**
**5-Year Flood Inundation Map**
**December**



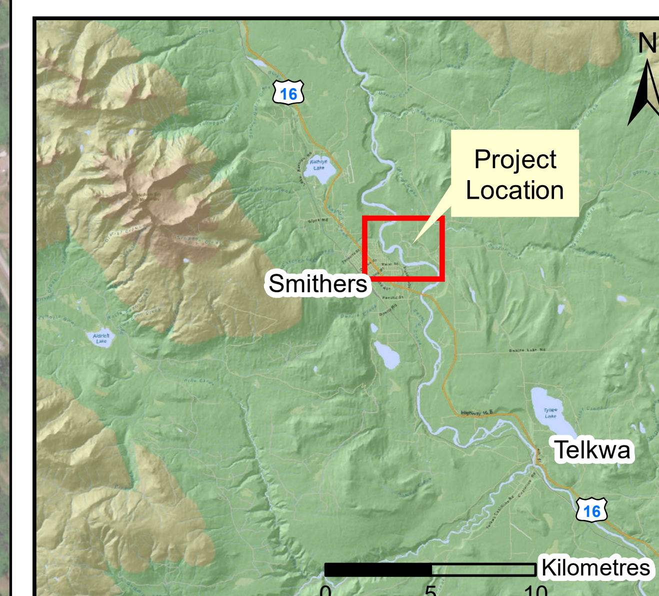

**LEGEND**

**Water Depth (m)**

- 0.0 - 1.0
- 1.0 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 and above

N

Metres
0 125 250 500




Date: 12/4/2018 Map By: K.Klaczek Project No: 2341-02513-00 Map Datum: NAD 1983 Coordinate System: UTM Zone 9N Projection: Transverse Mercator

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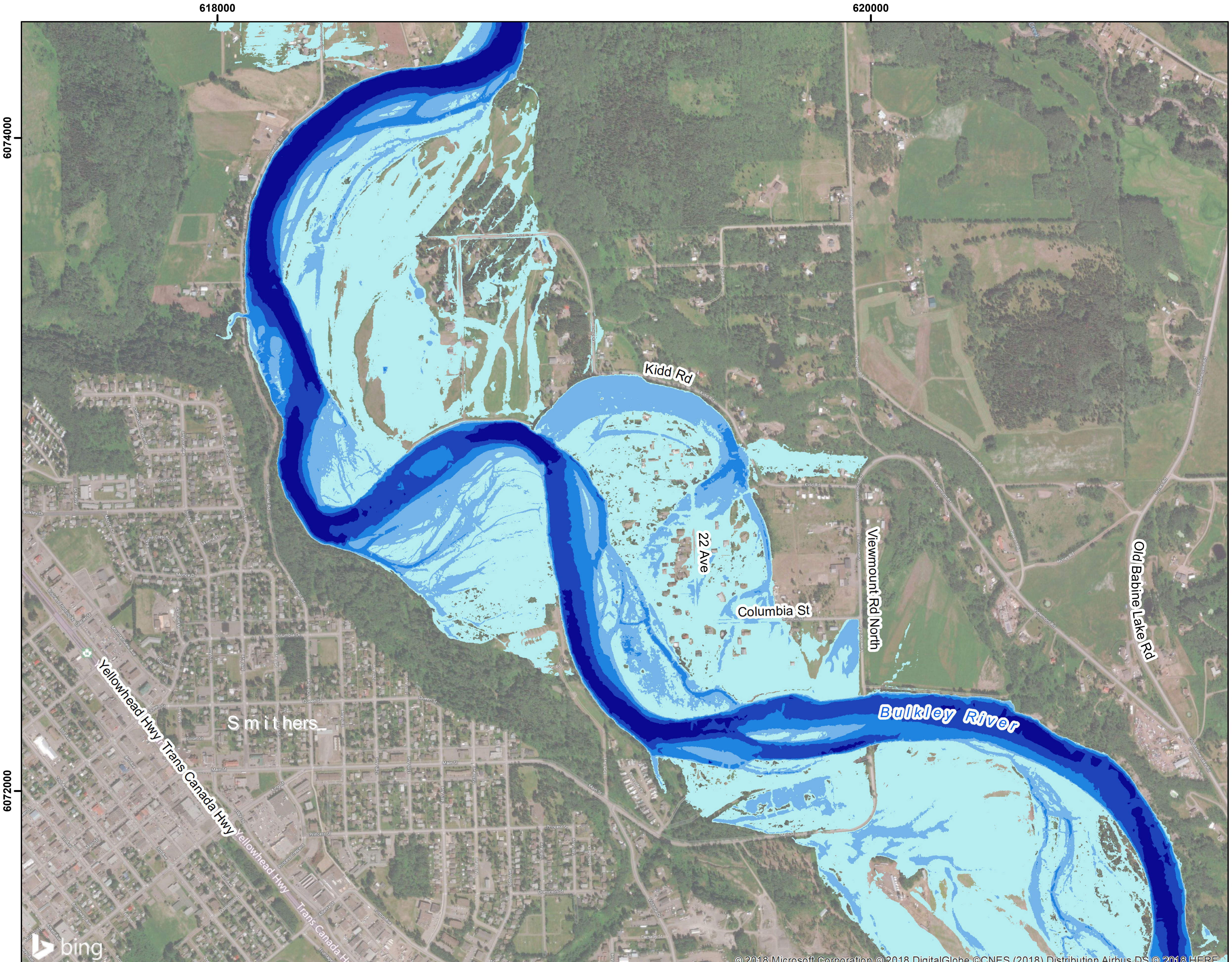



**Ebenezer Flats Flood Mitigation**
**200-Year Flood Inundation Map**
**December**

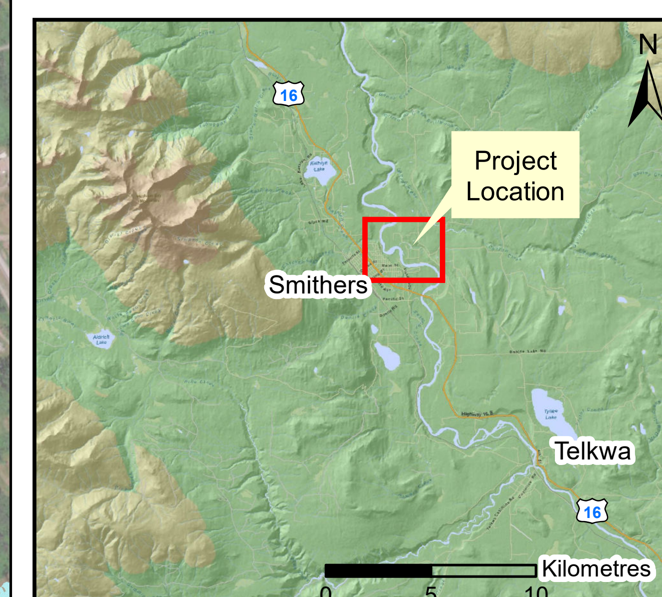
**LEGEND**

**Water Depth (m)**

- 0.0 - 1.0
- 1.0 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 and above

N

Metres
0 125 250 500




Date: 12/4/2018 Map By: K.Klaczek Project No: 2341-02513-00 Map Datum: NAD 1983 Coordinate System: UTM Zone 9N Projection: Transverse Mercator

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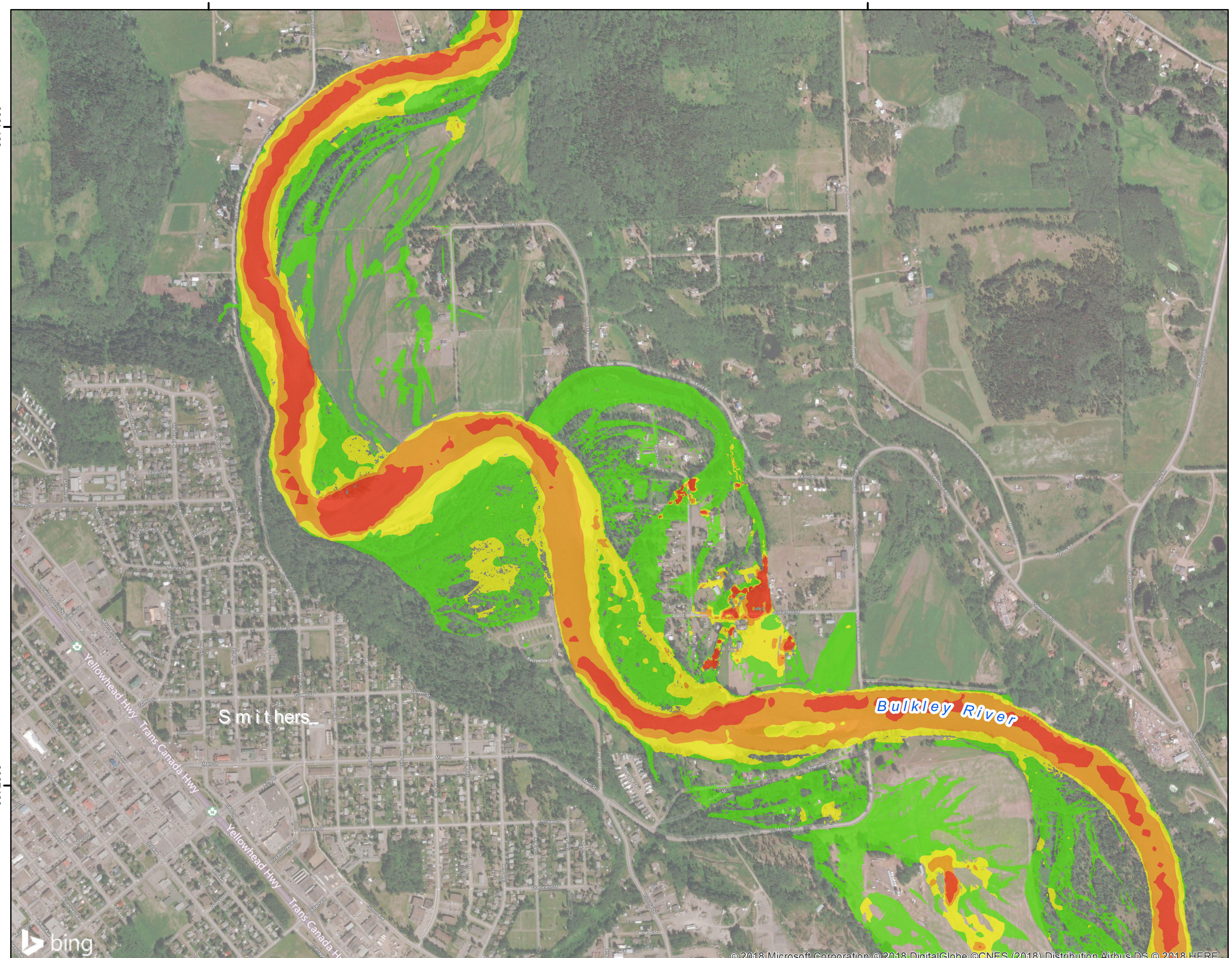
# Ebenezer Flats Flood Mitigation 5-Year Velocity Map

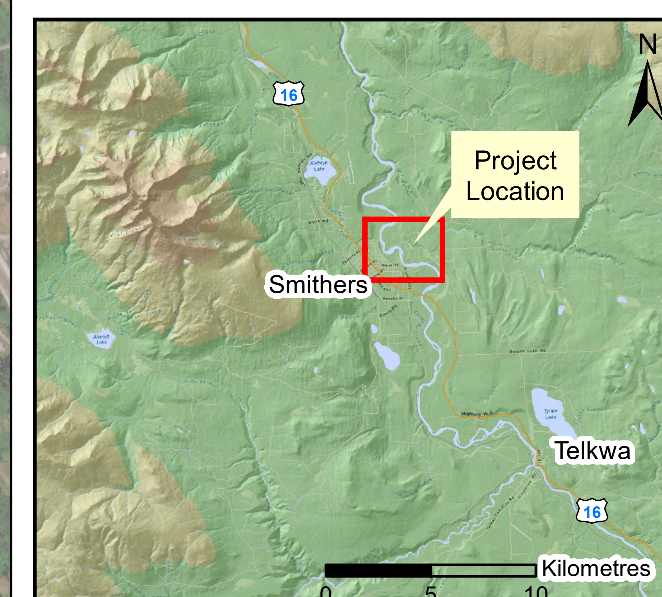



**LEGEND**

**Water Velocity (m/s)**

- <1 m/s
- 1 m/s - 2 m/s
- 2 m/s - 3 m/s
- > 3 m/s

Metres: 0 125 250 500




Date: 12/5/2018 Map By: K.Klaczek Project No: 2341-02513-00 Map Datum: NAD 1983 Coordinate System: UTM Zone 9N Projection: Transverse Mercator

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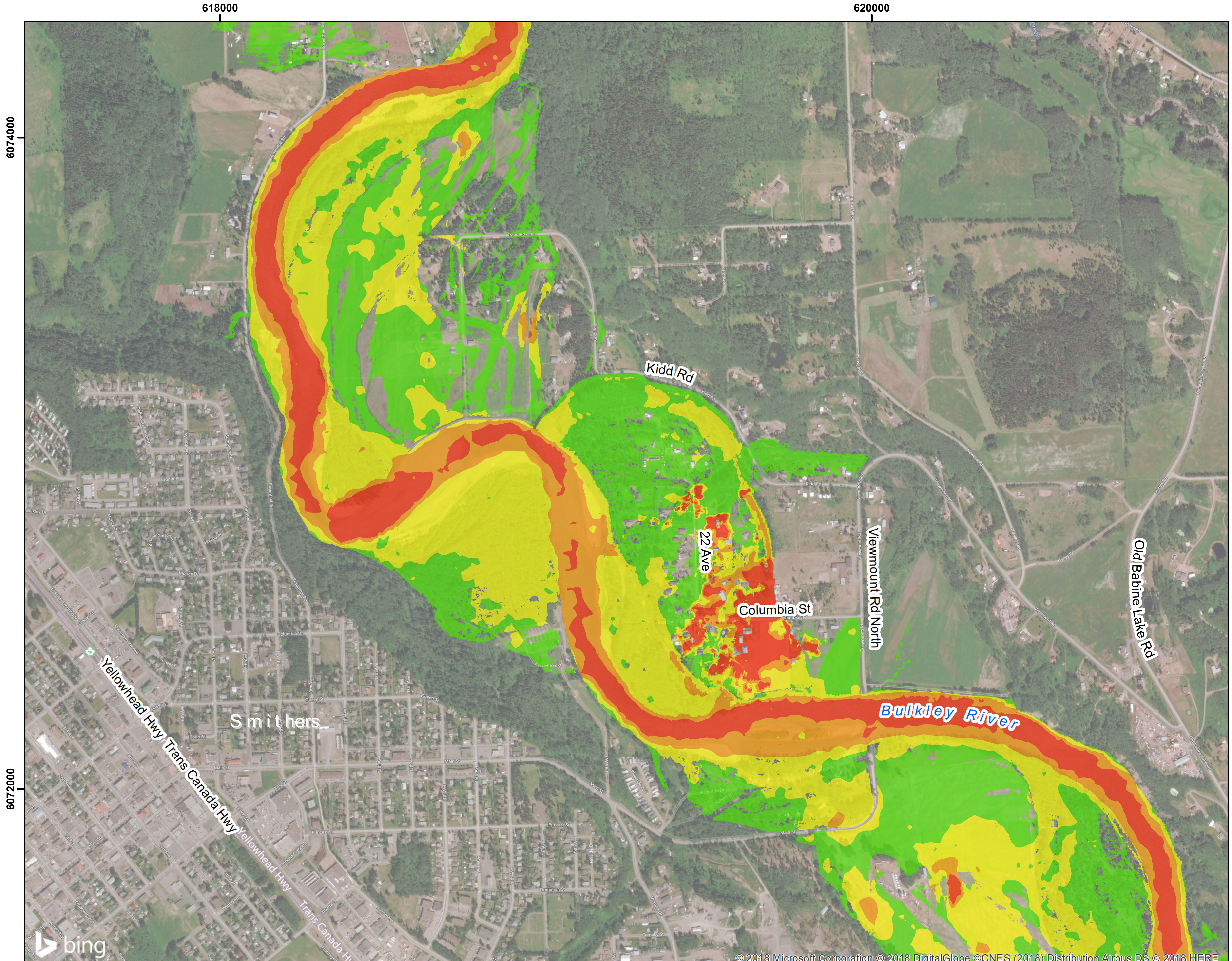



**Ebenezer Flats Flood Mitigation**
**200-Year Velocity Map**

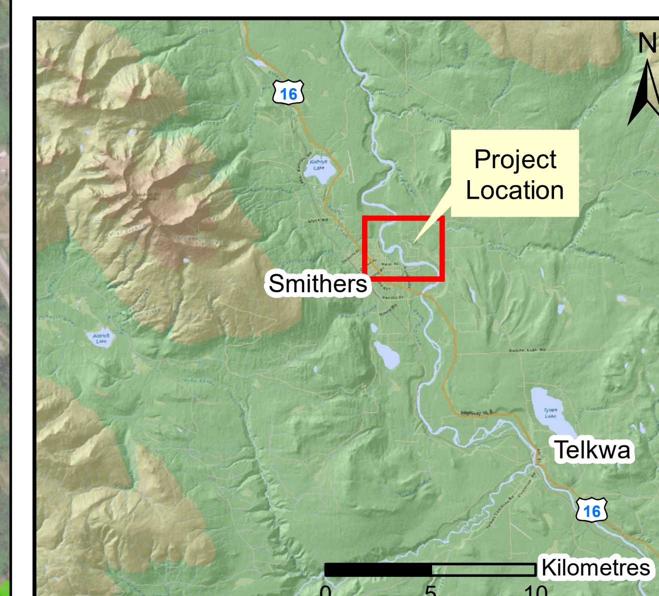
N

**LEGEND**

**Water Velocity (m/s)**

- <1 m/s
- 1 m/s - 2 m/s
- 2 m/s - 3 m/s
- > 3 m/s

Metres
0 125 250 500




Date: 12/4/2018 Map By: K.Klaczek Project No: 2341-02513-00 Map Datum: NAD 1983 Coordinate System: UTM Zone 9N Projection: Transverse Mercator

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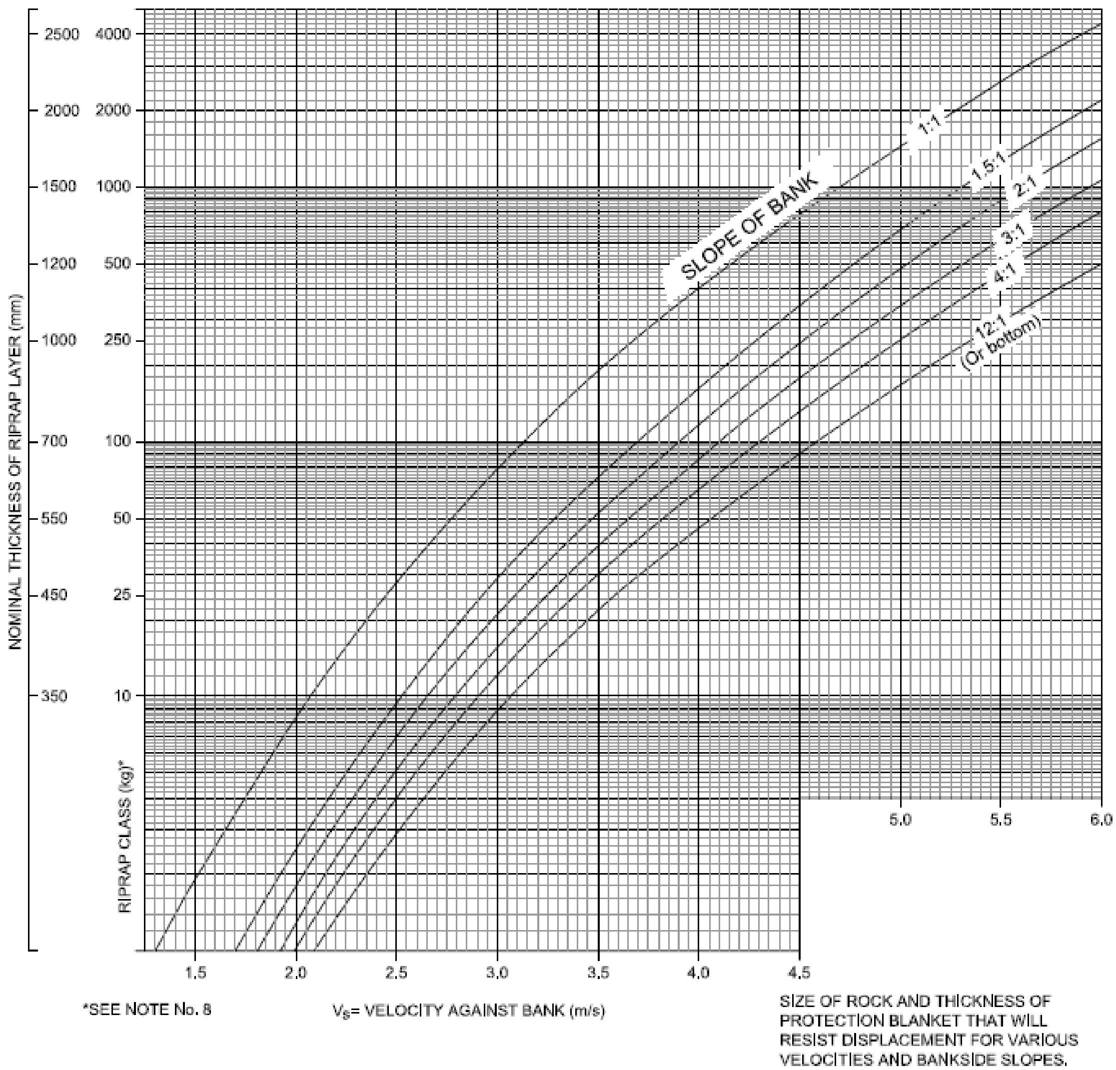
# APPENDIX B
# RIPRAP DESIGN CHART

Figure 1030.A Riprap Design Chart



# APPENDIX C

# CLASS D COST ESTIMATE (RAISING THE HOUSES AND THE ROADS)

## CLASS D COST ESTIMATE - ROADS AND DRIVEWAYS (0.6m RAISE)

# EBENEZER FLATS FLOOD PROTECTION

# SMITHERS, BC

**29-Nov-18**

| DESCRIPTION | | TOTAL AMOUNT |
|---|---|---|
| ROADS AND DRIVEWAYS | | $1,309,200 |
| 3RD PARTY UTILITY RELOCATIONS | | $50,000 |
| PROJECT RECORD DRAWINGS | | $10,000 |
| **SUB-TOTAL** | | **$1,369,200** |
| ENVIRONMENTAL MITIGATION | 2% | $27,400 |
| ENGINEERING & CONSTRUCTION SERVICES | 6% | $82,200 |
| CONTINGENCY | 40% | $547,700 |
| **PROJECT TOTAL (ROUNDED)** | | **$2,027,000** |

## McElhanney Consulting Services Ltd.

### Ebenezar Flats Flood Mitigation Cost Estimate

### Roads and Driveways - 0.6m Raise

**Date:** 2018-11-29

### Project Information

**Client:** Regional District of Bulkley Nechako

**Project No:**

**Site Address:** Site includes Columbia Street, 22nd Avenue and 25 driveways in the Ebenezar flats area. Please see Proposal for addresses.

### COST ESTIMATE

| Item# | Description of Work | Unit of Measure | Approx. Quantity | Unit Price | Extended Amount |
|---|---|---|---|---|---|
| **01.** | **General** | | | | |
| | Traffic Management Plan | L.S. | 1 | $5,000.00 | $5,000.00 |
| | Traffic Control | L.S. | 1 | $100,000.00 | $100,000.00 |
| | | | | | |
| | | | | | |
| | | | | | |
| **02.** | **Site Preparation** | | | | |
| | Erosion and Sediment Control | L.S. | 1 | $20,000.00 | $20,000.00 |
| | Clearing and Grubbing | Hectare | 1 | $38,000.00 | $38,000.00 |
| | Removal and Disposal | Cubic Metre | 85 | $15.00 | $1,275.00 |
| | Common Excavation and Off-site Disposal | Cubic Metre | 1840 | $25.00 | $46,000.00 |
| | Imported Embankment Fill | Tonnes | 4050 | $65.00 | $263,250.00 |
| | | | | | |
| **03.** | **Roadway Construction** | | | | |
| | Paving | | | | |
| | *Asphalt* | Tonnes | 1350 | $150.00 | $202,500.00 |
| | *Crushed Base Course (CBC)* | Cubic Metre | 650 | $65.00 | $42,250.00 |
| | *Select Granular Sub-Base (SGSB)* | Cubic Metre | 4680 | $65.00 | $304,200.00 |
| | Drainage | | | | |
| | *Ditching* | Metre | 2600 | $35.00 | $91,000.00 |
| | | | | | |
| **04.** | **Driveway Construction** | | | | |
| | Paving | | | | |
| | *Asphalt* | Tonnes | 310 | $150.00 | $46,500.00 |
| | *Crushed Base Course (CBC)* | Cubic Metre | 25 | $65.00 | $1,625.00 |
| | *Select Granular Sub-Base (SGSB)* | Cubic Metre | 540 | $65.00 | $35,100.00 |
| | Drainage | | | | |
| | *Culverts* | Metre | 225 | $500.00 | $112,500.00 |
| | | | | | |
| | | | | **TOTAL** | **$1,309,200.00** |

**Assumptions:**

**1. Total roadway length=1300m.**

**2. Road will be raised by removing existing pavement and placing new 0.615m thick pavement strucuture on-top of existing granulars.**

**3. Ditches will be reconstructed on either side of the roadway.**

**4. All driveways will be reconstructed and will have approximately 5% grade. Dimensions are assumed to be 6m wide by 12.3m long.**

**5. Culverts will be installed at all reconstructed driveways.**

**6. Traffic control cost accounts for a 60 day construction window during which the flow of traffic will be accommodated by a gravel widening of the existing 1.3km of road which will be 1m wide and 0.3m deep.**

**7. No streetlighting, signage, or pavement marking installations, reinstatements or relocations.**

## CLASS D COST ESTIMATE - ROADS AND DRIVEWAYS (1.0m RAISE)

# EBENEZER FLATS FLOOD PROTECTION

# SMITHERS, BC

**29-Nov-18**

| DESCRIPTION | | TOTAL AMOUNT |
|---|---|---|
| ROADS AND DRIVEWAYS | | $2,231,875 |
| 3RD PARTY UTILITY RELOCATIONS | | $50,000 |
| PROJECT RECORD DRAWINGS | | $10,000 |
| **SUB-TOTAL** | | **$2,291,900** |
| ENVIRONMENTAL MITIGATION | 2% | $45,800 |
| ENGINEERING & CONSTRUCTION SERVICES | 6% | $137,500 |
| CONTINGENCY | 40% | $916,800 |
| **PROJECT TOTAL (ROUNDED)** | | **$3,392,000** |

## McElhanney Consulting Services Ltd.

**Ebenezar Flats Flood Mitigation Cost Estimate**

**Roads and Driveways - 1.0m Raise**

**Date:** 2018-11-29

**Project Information**

**Client:** Regional District of Bulkley Nechako

**Project No:**

**Site Address:** Site includes Columbia Street, 22nd Avenue and 25 driveways in the Ebenezar flats area. Please see Proposal for addresses.

**COST ESTIMATE**

| Item# | Description of Work | Unit of Measure | Approx. Quantity | Unit Price | Extended Amount |
|---|---|---|---|---|---|
| **01.** | **General** | | | | |
| | Traffic Management Plan | L.S. | 1 | $5,000.00 | $5,000.00 |
| | Traffic Control | L.S. | 1 | $115,000.00 | $115,000.00 |
| | | | | | |
| | | | | | |
| | | | | | |
| **02.** | **Site Preparation** | | | | |
| | Erosion and Sediment Control | L.S. | 1 | $20,000.00 | $20,000.00 |
| | Clearing and Grubbing | Hectare | 1.5 | $38,000.00 | $57,000.00 |
| | Removal and Disposal | Cubic Metre | 85 | $15.00 | $1,275.00 |
| | Common Excavation and Off-site Disposal | Cubic Metre | 2300 | $25.00 | $57,500.00 |
| | Imported Embankment Fill | Tonnes | 17200 | $65.00 | $1,118,000.00 |
| | | | | | |
| **03.** | **Roadway Construction** | | | | |
| | Paving | | | | |
| | *Asphalt* | Tonnes | 1350 | $150.00 | $202,500.00 |
| | *Crushed Base Course (CBC)* | Cubic Metre | 650 | $65.00 | $42,250.00 |
| | *Select Granular Sub-Base (SGSB)* | Cubic Metre | 4680 | $65.00 | $304,200.00 |
| | Drainage | | | | |
| | *Ditching* | Metre | 2600 | $35.00 | $91,000.00 |
| | | | | | |
| **04.** | **Driveway Construction** | | | | |
| | Paving | | | | |
| | *Asphalt* | Tonnes | 360 | $150.00 | $54,000.00 |
| | *Crushed Base Course (CBC)* | Cubic Metre | 20 | $65.00 | $1,300.00 |
| | *Select Granular Sub-Base (SGSB)* | Cubic Metre | 390 | $65.00 | $25,350.00 |
| | Drainage | | | | |
| | *Culverts* | Metre | 275 | $500.00 | $137,500.00 |
| | | | | | |
| | | | | **TOTAL** | **$2,231,875.00** |

**Assumptions:**

**1. Total roadway length=1300m.**

**2. Road will be raised by removing existing pavement, placing 0.4m of fill, then building new 0.615m thick pavement strucuture on-top of existing granulars.**

**3. Ditches will be reconstructed on either side of the roadway.**

**4. All driveways will be reconstructed and will have approximately 7% grade. Dimensions are assumed to be 6m wide by 14.5m long.**

**5. Culverts will be installed at all reconstructed driveways.**

**6. Traffic control cost accounts for a 60 day construction window during which the flow of traffic will be accommodated by a gravel widening of the existing 1.3km of road which will be 1m wide and 0.3m deep.**

**7. No streetlighting, signage, or pavement marking installations, reinstatements or relocations.**

# CLASS D COST ESTIMATE - HOUSES

# EBENEZER FLATS FLOOD PROTECTION

# SMITHERS, BC

29-Nov-18

| DESCRIPTION | | TOTAL AMOUNT |
|---|---|---|
| MOBILIZATION | | $10,000 |
| SMALL HOUSES (8 ASSUMED) | | $360,000 |
| MEDIUM HOUSES (10 ASSUMED) | | $450,000 |
| LARGE HOUSES (7 ASSUMED) | | $315,000 |
| PROJECT RECORD DRAWINGS | | $10,000 |
| **SUB-TOTAL** | | **$1,145,000** |
| ENGINEERING & CONSTRUCTION SERVICES | 6% | $68,700 |
| CONTINGENCY | 40% | $458,000 |
| **PROJECT TOTAL (ROUNDED)** | | **$1,672,000** |

## McElhanney Consulting Services Ltd.

### Ebenezar Flats Flood Mitigation Cost Estimate

### House Raising - Small House

**Date:** 2018-11-29

### Project Information

**Client:** Regional District of Bulkley Nechako

**Project No:**

**Site Address:** 8 houses in the Ebenezar Flats area of Smithers, BC. Please see Proposal for addresses.

### COST ESTIMATE

| Item# | Description of Work | Unit of Measure | Approx. Quantity | Unit Price | Extended Amount |
|---|---|---|---|---|---|
| **01.** | **General** | | | | |
| | Building Permit | Each | 8 | $1,000.00 | $8,000.00 |
| | | | | | |
| **02.** | **Site Preparation** | | | | |
| | Removal of foundation attachments | Each | 8 | $1,000.00 | $8,000.00 |
| | Removal of drywall | Each | 8 | $1,500.00 | $12,000.00 |
| | Asbestos abatement | Each | 8 | $2,500.00 | $20,000.00 |
| | Disconnect services | Each | 8 | $1,000.00 | $8,000.00 |
| | *Hydro* | | | | |
| | *Gas* | | | | |
| | *Water supply* | | | | |
| | *Sewer* | | | | |
| | *Septic Tank connection* | | | | |
| | *Furnace/ boiler* | | | | |
| | | | | | |
| **03.** | **House Raising and Foundation Works** | | | | |
| | Raise house | Each | 8 | $13,000.00 | $104,000.00 |
| | Foundation Works | Each | 8 | $20,000.00 | $160,000.00 |
| | | | | | |
| **04.** | **Restoration of Existing Conditions** | | | | |
| | Reconnect services | Each | 8 | $1,000.00 | $8,000.00 |
| | *Hydro* | | | | |
| | *Gas* | | | | |
| | *Water supply* | | | | |
| | *Sewer* | | | | |
| | *Septic Tank connection* | | | | |
| | *Furnace/ boiler* | | | | |
| | Miscellaneous (stairs, chimney etc.) | Each | 8 | $4,000.00 | $32,000.00 |
| | | | | | |
| | | | | **TOTAL** | **$360,000.00** |

**Assumptions:**

**1. Assumed house dimensions:**

**Small House=1000 ft$^2$**
**Length=2 x Width; L=44.8 ft; W=22.4 ft**
**Foundation length=1.5 x Perimeter=61.4m**

**Medium House=2000 ft$^2$**
**Length=2 x Width; L=63.2 ft; W=31.6 ft**
**Foundation length=1.5 x Perimeter=86.7m**

**Large House=2500 ft$^2$**
**Length=2 x Width; L=70.8 ft; W=35.4 ft**
**Foundation length=1.5 x Perimeter=97.1m**

## McElhanney Consulting Services Ltd.

### Ebenezar Flats Flood Mitigation Cost Estimate

### House Raising - Medium Houses

**Date:** 2018-11-29

### Project Information

**Client:** Regional District of Bulkley Nechako

**Project No:**

**Site Address:** 10 houses in the Ebenezar Flats area of Smithers, BC. Please see Proposal for addresses.

### COST ESTIMATE

| Item# | Description of Work | Unit of Measure | Approx. Quantity | Unit Price | Extended Amount |
|---|---|---|---|---|---|
| **01.** | **General** | | | | |
| | Building Permit | Each | 10 | $1,000.00 | $10,000.00 |
| | | | | | |
| **02.** | **Site Preparation** | | | | |
| | Removal of foundation attachments | Each | 10 | $1,000.00 | $10,000.00 |
| | Removal of drywall | Each | 10 | $1,500.00 | $15,000.00 |
| | Asbestos abatement | Each | 10 | $2,500.00 | $25,000.00 |
| | Disconnect services | Each | 10 | $1,000.00 | $10,000.00 |
| | *Hydro* | | | | |
| | *Gas* | | | | |
| | *Water supply* | | | | |
| | *Sewer* | | | | |
| | *Septic Tank connection* | | | | |
| | *Furnace/ boiler* | | | | |
| | | | | | |
| **03.** | **House Raising and Foundation Works** | | | | |
| | Raise house | Each | 10 | $13,000.00 | $130,000.00 |
| | Foundation Works | Each | 10 | $20,000.00 | $200,000.00 |
| | | | | | |
| **04.** | **Restoration of Existing Conditions** | | | | |
| | Reconnect services | Each | 10 | $1,000.00 | $10,000.00 |
| | *Hydro* | | | | |
| | *Gas* | | | | |
| | *Water supply* | | | | |
| | *Sewer* | | | | |
| | *Septic Tank connection* | | | | |
| | *Furnace/ boiler* | | | | |
| | Miscellaneous (stairs, chimney etc.) | Each | 10 | $4,000.00 | $40,000.00 |
| | | | | | |
| | | | | **TOTAL** | **$450,000.00** |

**Assumptions:**

**1. Assumed house dimensions:**

**Small House=1000 $ft^2$**

**Length=2 x Width; L=44.8 ft; W=22.4 ft**

**Foundation length=1.5 x Perimeter=61.4m**

**Medium House=2000 $ft^2$**

**Length=2 x Width; L=63.2 ft; W=31.6 ft**

**Foundation length=1.5 x Perimeter=86.7m**

**Large House=2500 $ft^2$**

**Length=2 x Width; L=70.8 ft; W=35.4 ft**

**Foundation length=1.5 x Perimeter=97.1m**

## McElhanney Consulting Services Ltd.

### Ebenezar Flats Flood Mitigation Cost Estimate

### House Raising - Large Houses

**Date:** 2018-11-29

### Project Information

**Client:** Regional District of Bulkley Nechako

**Project No:**

**Site Address:** 7 houses in the Ebenezar Flats area of Smithers, BC. Please see Proposal for addresses.

### COST ESTIMATE

| Item# | Description of Work | Unit of Measure | Approx. Quantity | Unit Price | Extended Amount |
|---|---|---|---|---|---|
| **01.** | **General** | | | | |
| | Building Permit | Each | 7 | $1,000.00 | $7,000.00 |
| | | | | | |
| **02.** | **Site Preparation** | | | | |
| | Removal of foundation attachments | Each | 7 | $1,000.00 | $7,000.00 |
| | Removal of drywall | Each | 7 | $1,500.00 | $10,500.00 |
| | Asbestos abatement | Each | 7 | $2,500.00 | $17,500.00 |
| | Disconnect services | Each | 7 | $1,000.00 | $7,000.00 |
| | *Hydro* | | | | |
| | *Gas* | | | | |
| | *Water supply* | | | | |
| | *Sewer* | | | | |
| | *Septic Tank connection* | | | | |
| | *Furnace/ boiler* | | | | |
| | | | | | |
| **03.** | **House Raising and Foundation Works** | | | | |
| | Raise house | Each | 7 | $13,000.00 | $91,000.00 |
| | Foundation Works | Each | 7 | $20,000.00 | $140,000.00 |
| | | | | | |
| **04.** | **Restoration of Existing Conditions** | | | | |
| | Reconnect services | Each | 7 | $1,000.00 | $7,000.00 |
| | *Hydro* | | | | |
| | *Gas* | | | | |
| | *Water supply* | | | | |
| | *Sewer* | | | | |
| | *Septic Tank connection* | | | | |
| | *Furnace/ boiler* | | | | |
| | Miscellaneous (stairs, chimney etc.) | Each | 7 | $4,000.00 | $28,000.00 |
| | | | | | |
| | | | | **TOTAL** | **$315,000.00** |

**Assumptions:**

**1. Assumed house dimensions:**

**Small House=1000 $ft^2$**
**Length=2 x Width; L=44.8 ft; W=22.4 ft**
**Foundation length=1.5 x Perimeter=61.4m**

**Medium House=2000 $ft^2$**
**Length=2 x Width; L=63.2 ft; W=31.6 ft**
**Foundation length=1.5 x Perimeter=86.7m**

**Large House=2500 $ft^2$**
**Length=2 x Width; L=70.8 ft; W=35.4 ft**
**Foundation length=1.5 x Perimeter=97.1m**

# APPENDIX D
# LIDAR SURVEY

**LIDAR SURVEY**

**Project Name:** Ebenezer Flats

**Area:** approximately 17.5 $Km^2$

**Mission Date:** 2018-06-23

**Location:** Ebenezer Flats, Smithers, BC

**System:** Optech Galaxy T1000

http://www.teledyneoptech.com/index.php/product/optech-altm-galaxy/

The Galaxy was mounted on Piper Apache fixed wing Aircraft.

**Quality Control:**

The LiDAR data consistencies have been checked between the flight lines using Terrascan software.

Comparison of Bare Earth LiDAR data with Ground Survey Values.

dz**:** elevation difference between “Check” points and LiDAR points. We have a total of 372 check points (kinematics GPS ground survey points) for the project area.

**Statistical analysis:**

| | |
|---|---|
| Average dz | +0.016 m |
| Minimum dz | -0.530 m |
| Maximum dz | +0.550 m |
| Average magnitude | 0.070 m |
| Root Mean Square | 0.120 m |
| Std Deviation | 0.119 m |

**Measured Point density:**

Full Feature Point Density is 14.36 pt/$m^2$

Bare Earth Point Density is 3.43 pt/$m^2$

**LiDAR Survey Deliverables**

Final output data is provided in NAD83 CSRS UTM09 and the elevations are based on CGVD13 geoid model. The deliverables include:

- Classified LiDAR bare earth and non-bare earth in LAS
- Model key Points in XYZ
- 20 Cm Orthophoto image in TIFF format