TECHNICAL MEMO

TETRA TECH

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To:	Michelle Klaben, YG Project Manager	**Date:**	March 31, 2023
cc:	Hamlet of Mount Lorne	**Memo No.:**	002
From:	Jason Ku, E.I.T. David Moschini, P.Eng.	**File:**	704-ENW.GENV03329-01
Subject:	Hydrological Assessment and Preliminary Mitigation Options for Flooding Area, McConnell Lake, Yukon		

1.0 INTRODUCTION

Tetra Tech Canada In. (Tetra Tech) was retained by the Yukon Government (YG) to complete a hydrotechnical assessment and propose potential mitigation options designed to address the flooding issues near McConnell Lake at Annie Lake Road, Yukon. This technical memorandum summarises the analytical work Tetra Tech has completed to better understand the hydrologic/hydraulic response of McConnell Lake and the adjacent floodplain to different hydrologic conditions likely to affect the area. This document also provides recommendations detailing the works likely needed to reduce the extent of the flooding and protect local dwellings. The scope of the study included the following:

- Complete a comprehensive review of the contributing watershed.
- Develop hydrologic models based on available nearby hydrometric stations.
- Build a hydraulic model based on the available lidar surveys.
- Simulate freshet events to assess the extent of flooding under various return periods.
- Identify, develop, and simulate potential mitigation and diversion strategies under the 200-year flood.

2.0 BACKGROUND

The Hamlet of Mount Lorne is located within the Mount Lorne-Southern Lakes Regional District of the Yukon Territory. The Hamlet is located approximately 41 km south of Whitehorse (Figure 2.1). Tetra Tech was provided with the Hamlet of Mount Lorne's "Mt Lorne Area High Water Concerns" letter dated June 2022 in response to recent flooding noted by local residents. This has resulted in property damage, loss of recreational land and trails. Residents reported increasing water levels of the lake over the last thirty (30) years, with the lake overtopping and flooding into the adjacent Annie Lake golf course ten (10) years ago. Since then, residents claimed that the infiltration rates of the land have been insufficient to manage the snow melt and has resulted in permanent water bodies stretching several kilometres. Residents reported that the White Pass Railway helped protect the area east of the railway while acting as a dyke; however, during last year's freshet this "dyke" breached resulting in extensive damage to additional properties by the highway. With climate change potentially exacerbating the flood conditions, the Hamlet is seeking short-term mitigation options to manage the high water around the affected properties and long-term mitigation strategies to manage the water levels within the McConnell Lake and the surrounding floodplain catchment.

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Figure 2.1. Map of McConnell Lake and adjacent floodplain

The annual McConnell Lake peak flow event consistently occurs during the spring/summer freshet. Tetra Tech completed a hydrologic assessment of the McConnell Lake and the adjacent floodplain catchment in order to estimate the magnitude of a 1 in 200-year design freshet event to be used in subsequent hydraulic analysis and floodplain modelling (Section 4.2.1). Our analysis included a review of background information, a review of the existing gauging information near McConnell Lake, and a regional analysis comparing similar proximate watersheds.

3.0 SURFACE AND CLIMATIC DATA

Tetra Tech completed an aerial LiDAR survey of the study area, including McConnell Lake, the areas of frequent flooding to the east, northeast, south of McConnell Lake, and the Watson River immediately to the south and southeast of McConnell Lake. The survey was completed in September 2022 and was combined with data from the High-Resolution Digital Elevation Model (HRDEM) produced by Natural Resources Canada (NRCan) to produce a topographic surface of the catchment that feeds into the floodplains east of McConnell Lake and west of the highway. Tt's LiDAR survey has a resolution of one (1) metre and the HRDEM from NRCan has a resolution of five (5) metres.

Climatic data was collected from Environment Canada weather station 2100115 – Annie Lake Robinson covering daily precipitation from 1976 to 1982 and 1993 to 2006. Climatic data was also collected from weather station 2101303 – Whitehorse Airport covering daily precipitation data from 1942 to 2013. For the mutual years, the total annual precipitation was compared in Figure 3.1 and no direct correlation was observed. Due to the proximity of Annie Lake Robinson's station to McConnell Lake, this station was selected for the analysis.

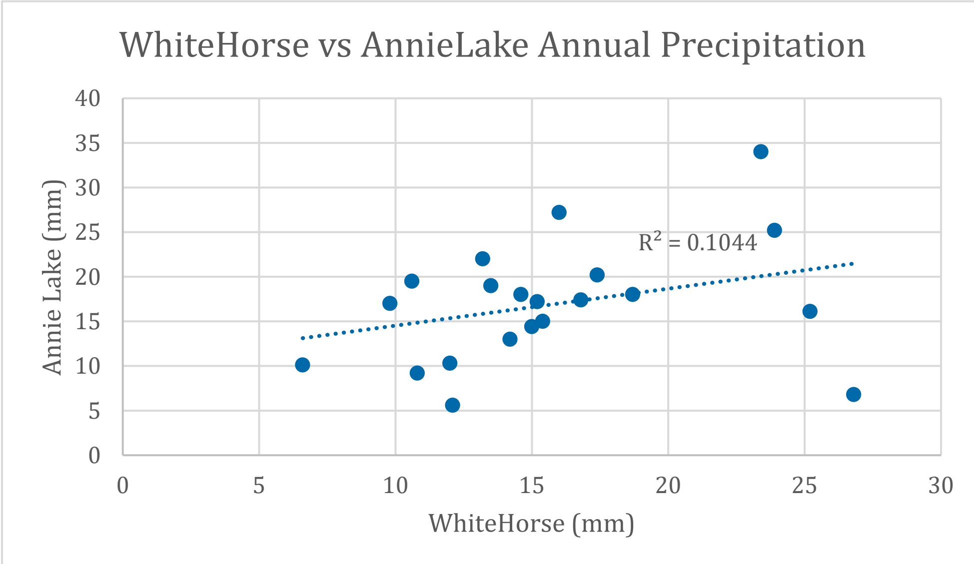

Figure 3.1. Whitehorse vs Annie Lake Station Annual Precipitation

4.0 HYDROLOGIC AND HYDRAULIC MODELLING

As detailed below, Tetra Tech has explored several hydrologic methods in evaluating the hydrologic/hydraulic response of the project area to different hydrologic conditions. Through the process, Tetra Tech was also provided access to infrastructure data allowing for the expansion of the hydrologic/hydraulic analysis to the area east of the highway. As detailed, Tetra Tech has completed the following steps in developing a better understanding of the hydrologic processes affecting the valley:

- Rainfall-Runoff Model
- Regional Analysis (Peak Flow Frequency)
- Regional Analysis (Volume Frequency)

4.1 Rainfall-Runoff Model

4.1.1 Hydrologic Model

Tetra Tech used PCSWMM software to model the hydrology of the catchment feeding into McConnell Lake. The watershed area was delineated and estimated to be approximately 24 km^2, which included part of the mountains west and east of the lake. Impervious area percentages, runoff coefficients, and depression storages were estimated using arial imagery. The terrain model generated from the topographic data is shown in Figure 4.1a, and the refined delineated catchment is shown in Figure 4.1b.

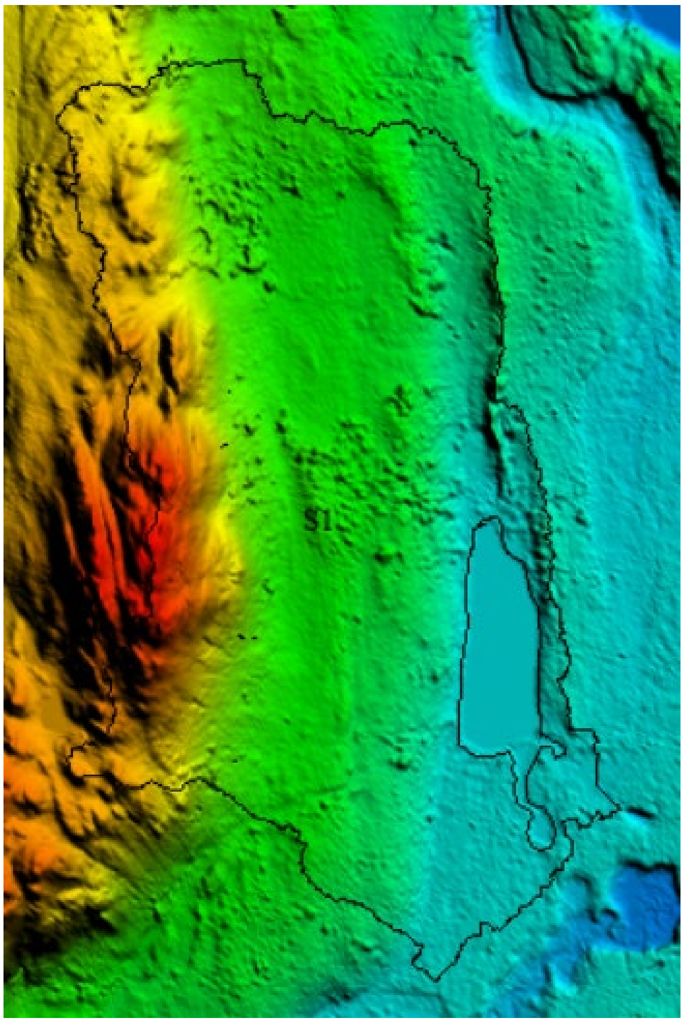

Figure 4.1a. Terrain Model of McConnell Lake

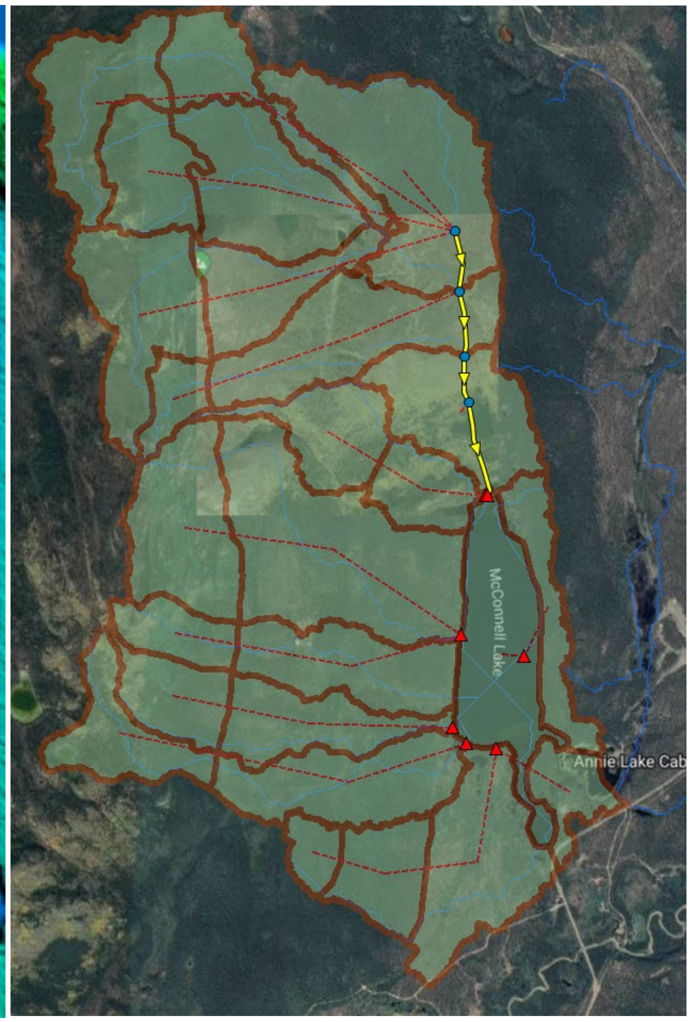

Figure 4.1b. Sub Catchment Delineation of McConnell Lake

SCS Type 1 storms were used to model storm events ranging from 24 hours to 72 hours in duration. The US Soil Conservations Service (SCS) methodology for estimating design peak flows in small watersheds is widely used for design of water management infrastructure and a key component of the methodology is the selection of the appropriate design storm. Four synthetic 24-hour rainfall temporal distributions, or storm types (Type 1, 1A, 2, and 3) have been developed. Although the geographic distribution of the storm types is limited to the USA, McConnell Lake is only 85 kilometres from Alaska, all of which is categorized under Type 1. Tetra Tech reviewed the terrain of Alaska and found that it closely resembled that of the Yukon's southwest corner where McConnell Lake is located. For this reason, Tetra Tech found that the SCS Type 1 storm is a reasonable storm distribution for this exercise. The SCS storms are 24-hour storm distributions based on increments of six (6) minutes. Tetra Tech expanded this design storm by doubling the duration of each increment for the 48-hour storm and tripling the duration of each increment for the 72-hour storm.

The rainfall events over a 24-hour, 48-hour and 72-hour period were derived by summing the daily precipitation of consecutive days. The maximum precipitation for each period and year were entered into a frequency statistical analysis software, HYFRAN, to fit the statistical distributions to the rain data. Several probability distributions were tested, and visual inspection was relied upon to select the best distribution for each station.

It was found that a 72-hour 200-year storm event (approximately 60mm of rainfall over 72 hours) gave the greatest peak flow into the lake. Below, Figure 4.2 displays the rainfall distribution of this event. Its shape represents a long duration storm with a sudden and severe peak, representing a scenario in which the baseflow in the creek is given time to reach a new sustained high during the storm, before a sudden and severe surge is introduced.

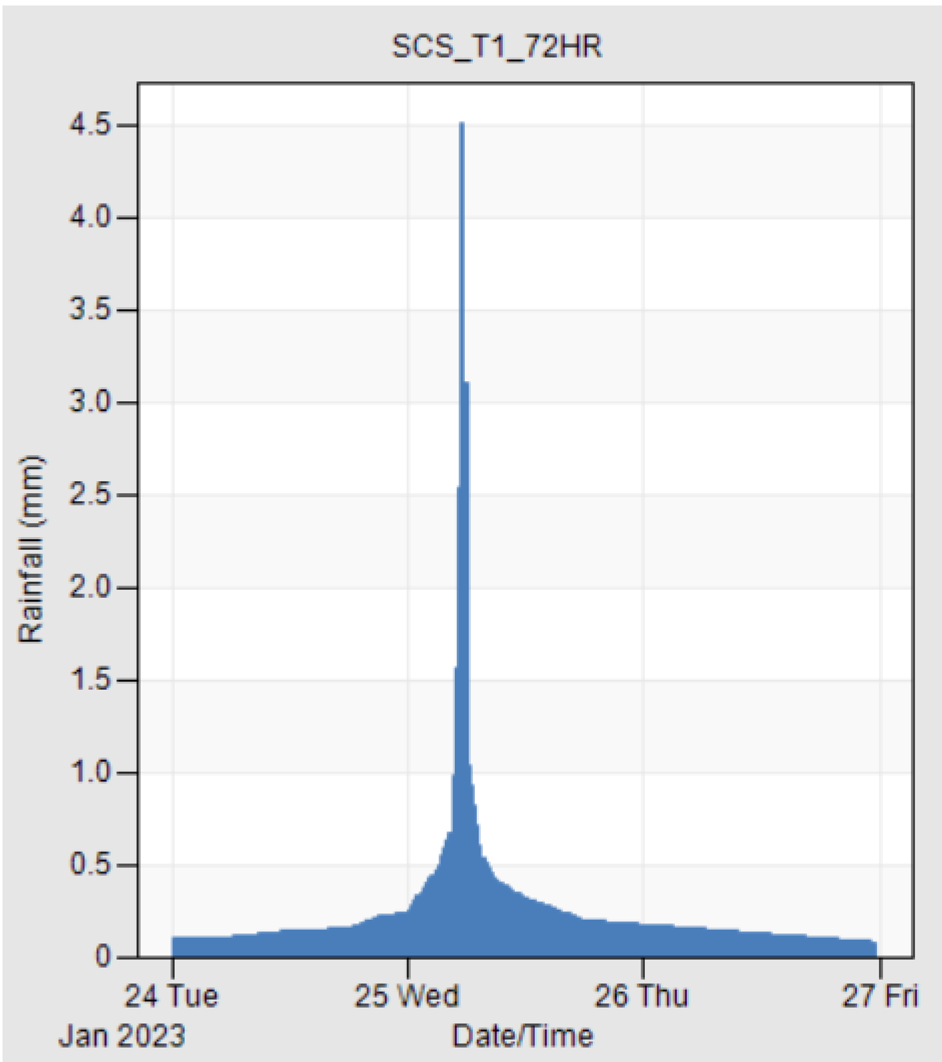

Figure 4.2. SCS Type II 12-hr Rainfall Distribution

4.1.2 Hydraulic Model

The flow response derived from the hydrologic model above was then passed onto the HEC-RAS software for hydraulic modelling of the flow through the valley and floodplain. HEC-RAS was developed by the United States Army Corps of Engineers in 1995 and is often considered an industry standard software for channel flow and floodplain assessment.

A 2D hydraulic model was selected for their flexibility and detailed outputs. By using a computational mesh instead of predefined cross sections as the case in 1D hydraulic models, the underlying terrain is fully utilized to account for water storage and conveyance, and flow movement is calculated in all directions. A computational mesh with variable sized cells was used to spatially discretize the local topography. The computational mesh is preprocessed to develop a detailed elevation-volume relationship for each cell, as well as detailed hydraulic property curves for each cell face. As a result, cells can be used to accurately account for water storage and conveyance. For this assignment, a 30-m cell size was used in flat areas where rapid changes in hydraulics is not expected. A 20-m cell size refinement region was used in the flat floodplains at the outlet of McConnell Lake to the south end. This allowed Tetra Tech to be more conservative by raising the Lake's initial water level and assume freshet occurs when the Lake is already 100% full and about to spillover. Break lines were used for barriers to flow (i.e. embankments) to accurately capture the high ground and to include existing culverts. An example of the computational mesh at the outlet of McConnell Lake and along Klondike Highway is shown in the figure below.

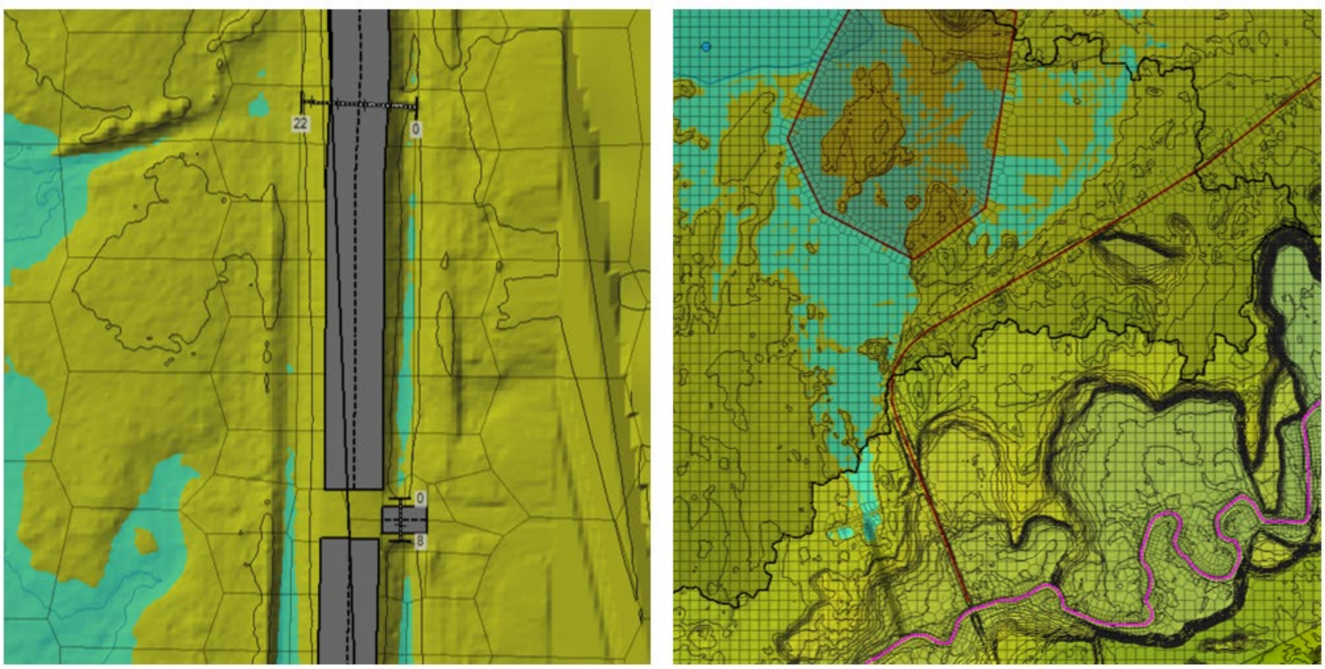

Figure 4.3. Example Computation Mesh with a Refined Channel and Break Lines for Embankments

Manning's roughness coefficients were delineated spatially in HEC-RAS to reflect the resistance to flow from ground cover and vegetation. The extents of the coefficients were assigned based on satellite imagery and site photos. The values of the coefficients were selected based on Open-Channel Hydraulics (Chow, 1959), and previous project experience. Table 4-1 summarizes the values used in the model.

Table 4-1: Manning Roughness Coefficient

Land Cover	Manning's n
Water Surface	0.001
Forest	0.1
Manmade Channel	0.033
Natural River	0.04

The study area is bound by McConnell Lake to the west, Cowley Lake to the north, Watson River to the south, and the ridge of mountains east of Klondike Highway. As illustrated in the figure below, the inflows were introduced into the model at the Lake and the downstream boundary condition for the Lake flooding was set to be along Watson River.

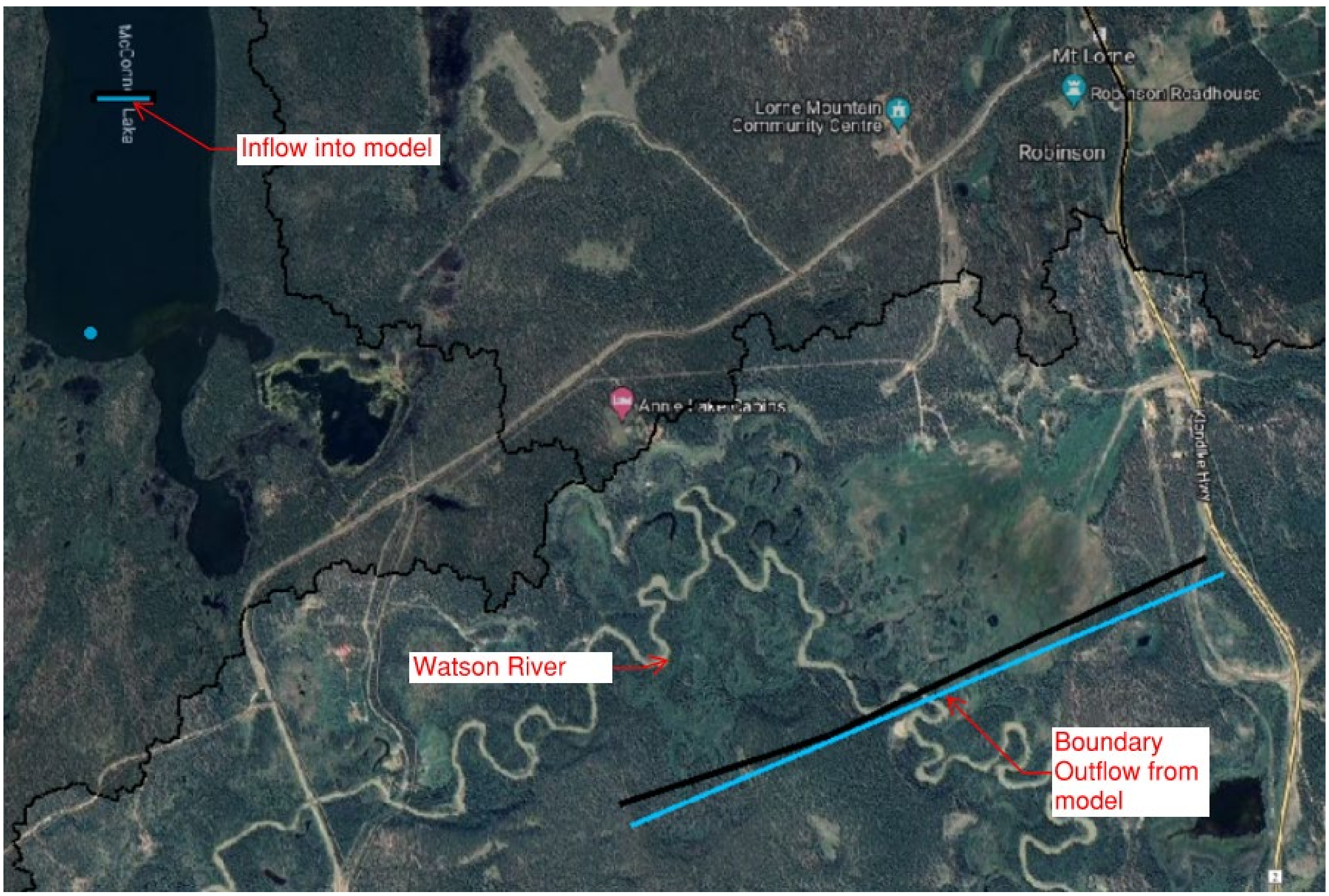

Figure 4.4. Inflow and Outflow Boundaries of Model

Simulations were run for the full 72-hour storm duration, plus a few days at the end of the event to capture any residual effects. Figure 4.5 displays the predicted flooding extents.

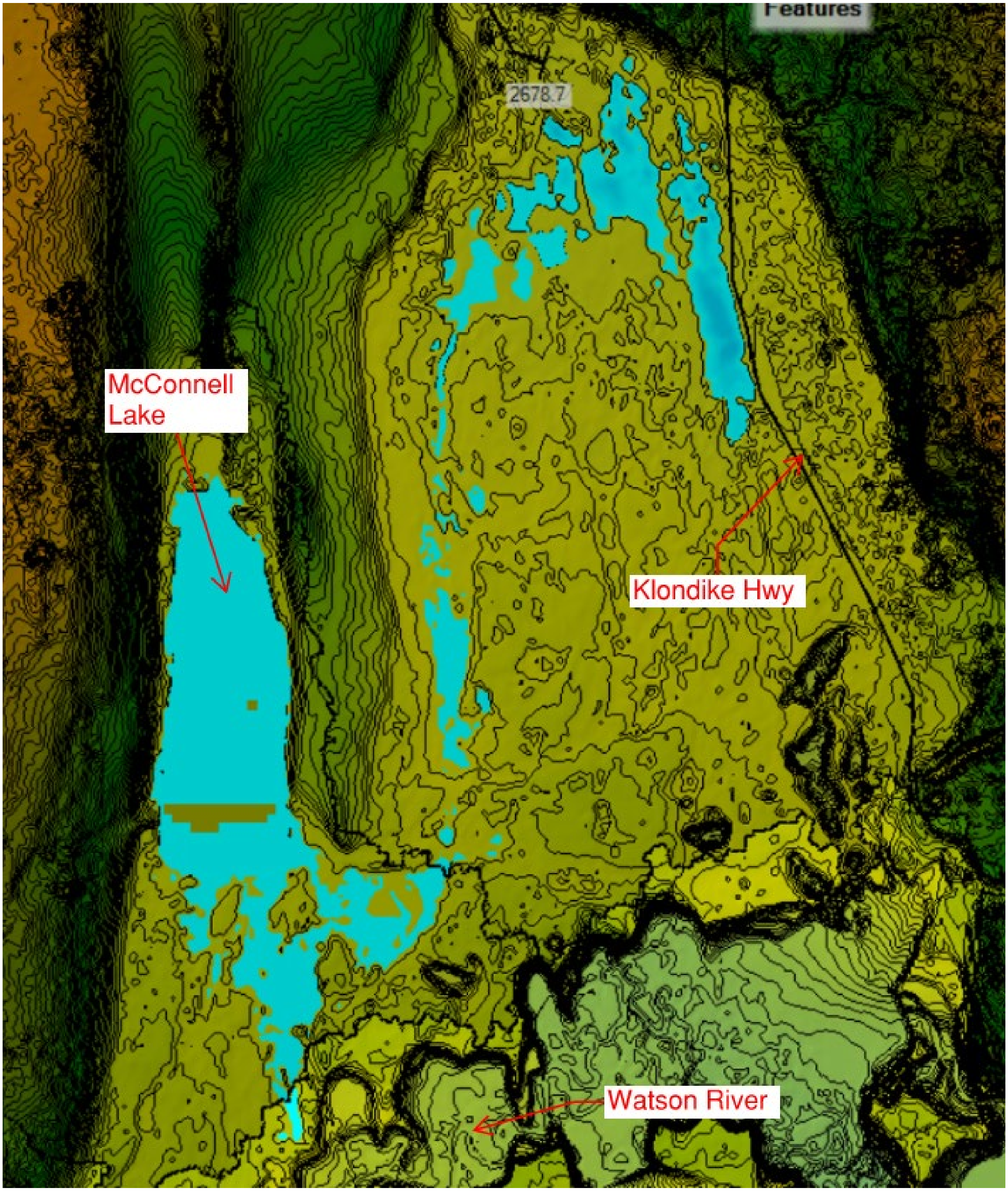

Figure 4.5. Flood Extents from 72-hour Storm Event

Using the SCS Type I 72-hour storm event, it was found that the flood path and extents closely resembles the extent of flooding reported by residents of the Hamlet (Figure 4.6). However, it is important to note that Tetra Tech's model is based on a precipitation event. Given the nature of the events, Tetra Tech explored other viable methods to simulate the freshet events.

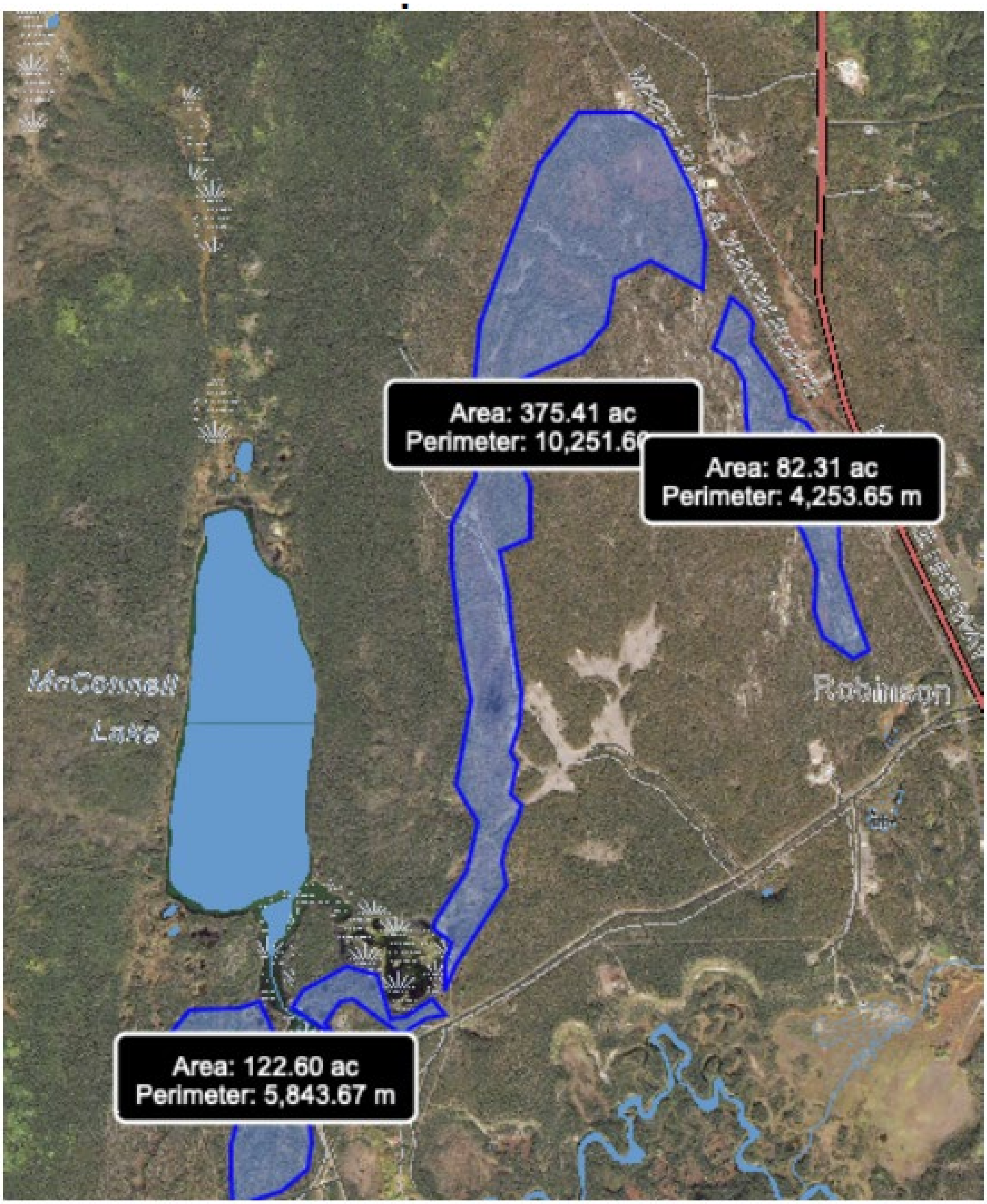

Figure 4.6. Flooding Extents as Reported from the Hamlet of Mount Lorne Letter

4.2 Regional Analysis (Peak Flow Frequency)

After reviewing results from the Rainfall-Runoff model, Tetra Tech proceeded with the development of a regional analysis for the McConnell Lake and adjacent floodplain watershed. Regional analysis is a technique used to estimate flow in ungauged watersheds by correlating measured flows in nearby gauged watersheds with similar physiographic characteristics.

4.2.1 Hydrology based on Peak Flow

Tetra Tech referenced the open database on GeoYukon for records of culverts along the ditches of Klondike highway and crossing the highway. Through this infrastructure, Tetra Tech confirmed the extent of the catchments contributing to the flooding witnessed within the project area. As detailed in Figure 4.7 the contributing catchment is comprised of the mountains east of the Klondike highway, the floodplain west of the highway, and McConnell Lake's catchment described above. All these catchments contribute to the flooding observed by the residents in the floodplain.

Figure 4.7. Expanded Sub Catchment Delineation Including Floodplain and East Ridge

Water Survey Canada (WSC) hydrometric stations in the vicinity of the project site were reviewed to find gauged watercourses with similar watershed characteristics to McConnell Lake and a sufficiently long period of record needed to develop a meaningful statistical analysis. Three (3) stations were selected for the analysis. Station Information is included below in Table 4-2. A map showing the location of each station is provided in Figure 4.8 below.

Table 4-2: McConnell Lake Regional WSC Stations Summary

Station ID	Station Name	Watershed Area (km^2)	Status	Period of Record	Years of Data Available
09AA012	Wheaton River near Carcross	864	Active	1955-2023	68
09AA011	Tagish Creek near Carcross	76.9	Discontinued	1955-1971	16
	Wolf Creek Research Basin	184	Discontinued	1993-2014	21

Figure 4.8. Map with locations of historical WSC stations included in regional analysis.

A flood frequency analysis was conducted using annual peak instantaneous flows for each station. In years where a station had an annual maximum daily flow reported, but no annual maximum instantaneous flow, a maximum instantaneous flow was synthesized from the maximum daily value based on a linear regression analysis of years where both values were available.

The flood frequency statistical analysis software, HYFRAN, was used to fit the statistical distributions to the flow data. Several probability distributions were tested, and visual inspection was relied upon to select the best distribution for each station.

A chart of the GEV fitting used for Station 09AA012 (Wheaton River near Carcross) is shown below (See Figure 4.9).

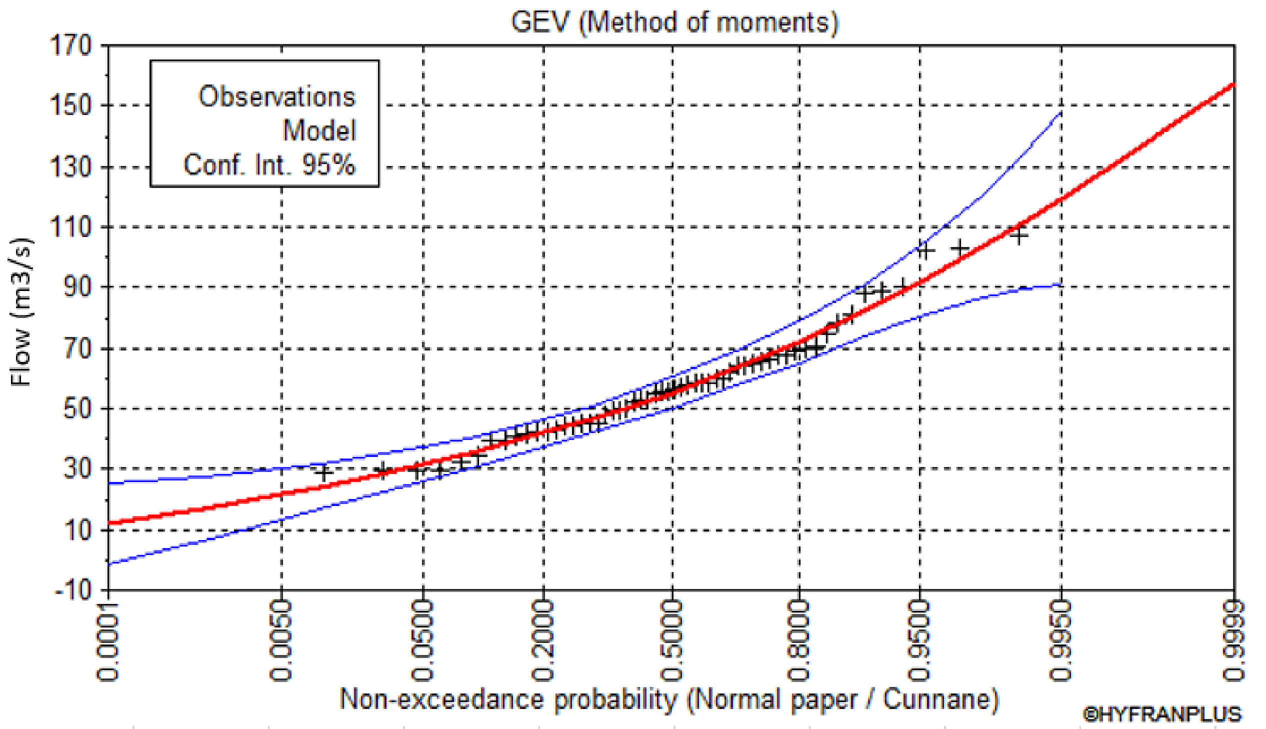

Figure 4.9. GEV Fitting for Station 09AA012

A chart of the GEV fitting used for Station 09AA011 (Tagish Creek near Carcross) is shown below (See Figure 4.10).

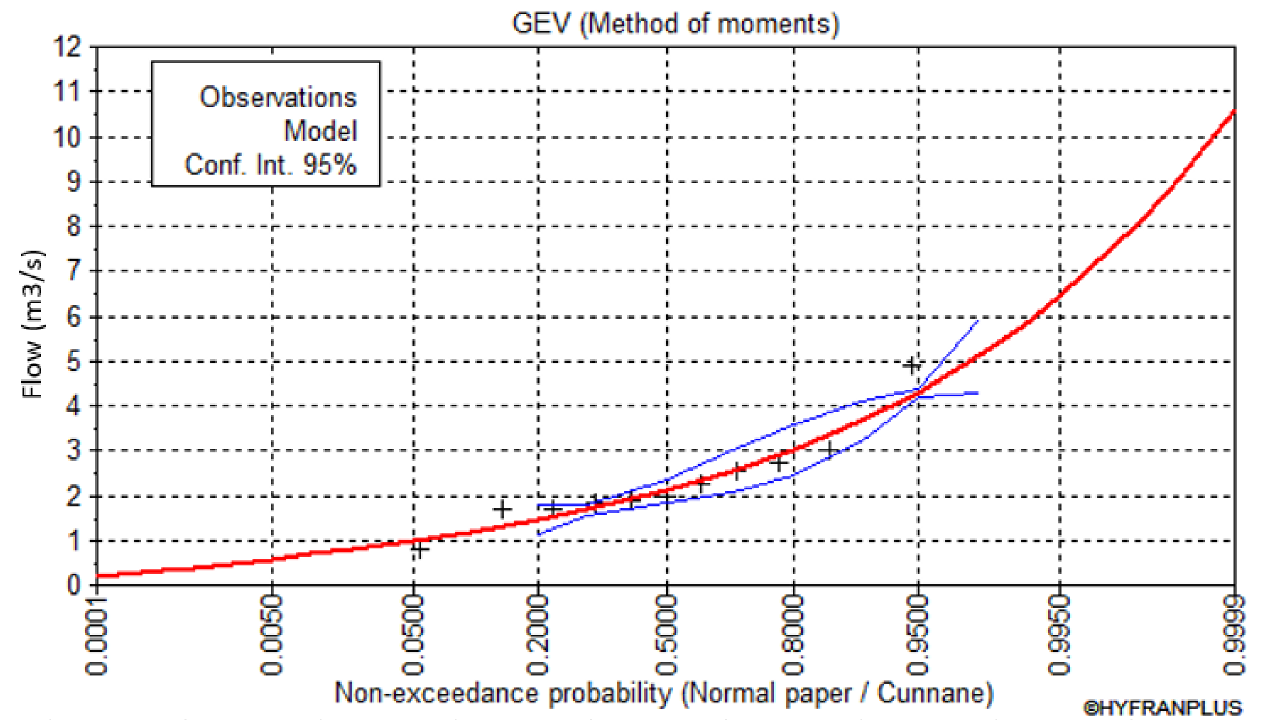

Figure 4.10. GEV Fitting for Station 09AA011

A chart of the GEV fitting used for Wolf Creek Research Basin is shown below (See Figure 4.11).

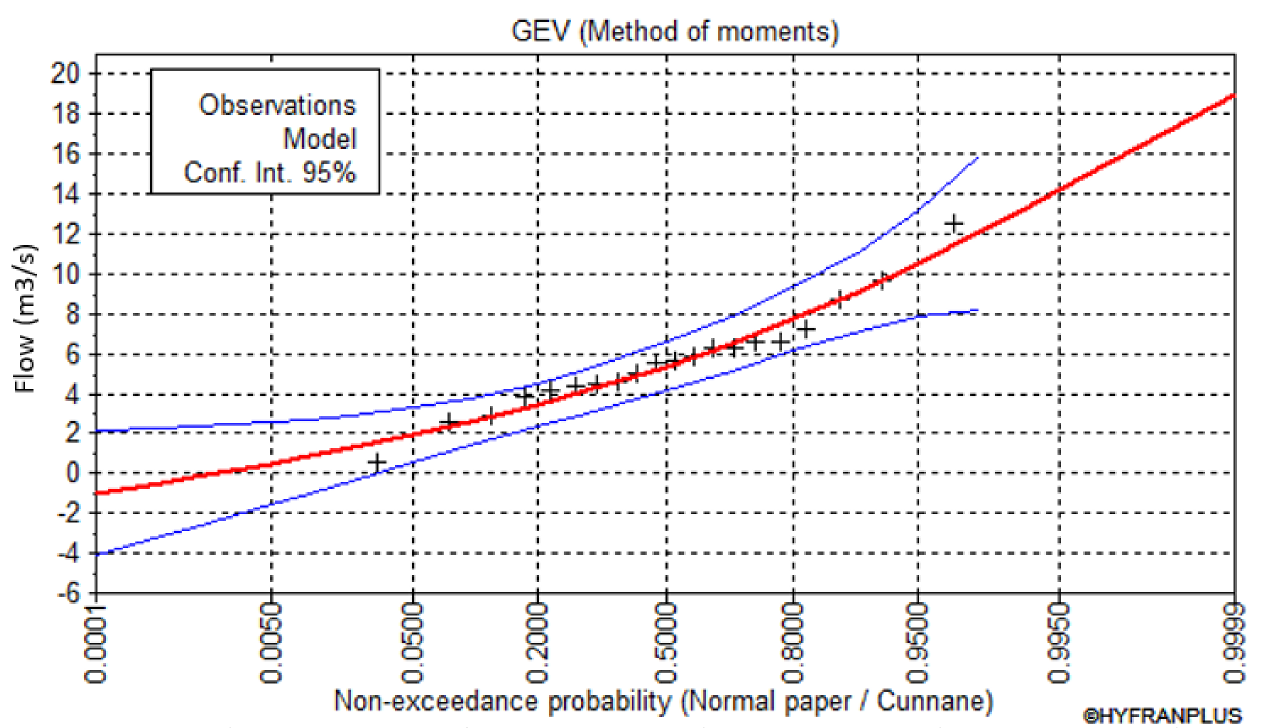

Figure 4.11. GEV Fitting for Wolf Creek Research Basin

Table 4-3 includes the results of the flood frequency analysis for each station.

Table 4-3: McConnell Lake Regional WSC Stations Summary

Station Name	Wheaton River near Carcross		Tagish Creek near Carcross		Wolf Creek Research Basin	
Station ID	09AA012		09AA011			
Watershed Area (km^2)	864		76.9		184	
Return Period	Flows (m^3/s)	Unit Flows (m^3/s/km^2)	Flows (m^3/s)	Unit Flows (m^3/s/km^2)	Flows (m^3/s)	Unit Flows (m^3/s/km^2)
200	120	0.1389	6.43	0.0836	14.2	0.0772
100	112	0.1296	5.76	0.0749	13.2	0.0717
50	103	0.1192	5.11	0.0664	12.1	0.0658
10	82.4	0.0954	3.65	0.0475	9.18	0.0499
2	55.2	0.0639	2.11	0.0274	5.36	0.0291

Water Survey Canada's gauges on Wheaton River, Wolf Creek, and Tagish Creek provide an observed period of record of 68, 21, and 16 years respectively. It should be noted that this included several incomplete years from Wolf Creek and Tagish Creek; thereby resulting in the omission of one (1) year and five (5) years for Wolf Creek and Tagish Creek respectively. To develop a reasonable and accurate flood estimate for upper year return periods such as the 100-year and 200-year events, it is preferable to draw upon a longer period of record. As such, Tetra Tech sought to infer McConnell Lake and floodplain freshet flow estimates from the Wheaton River station.

To develop this period of record, a multiple regression analysis was used to formulate a relationship between Wheaton River and the analogous watercourse. In Northwest Hydraulic Consultant (NHC)'s report "British Columbia Extreme Flood Project – Regional Flood Frequency Analysis-Technical development report and manual to complete a regional flood frequency analysis", the multiple regression analysis provides a fitted model from basin scale predictor variables on a regional level, which follow the form:

$$Q = 10^A * Area^B * MAP^C * MedianZ^D$$

Where Q is the estimated peak flow of the desired return period, Area is the basin area (km^2), MAP is the mean annual precipitation for the basin (mm), and MedianZ is the median basin elevation (m). The variables A, B, C, and D are empirical values derived from delineated ecozones sharing similar characteristics and responses. While this report and study was primarily intended for predicting flood frequency flows in British Columbia, the formula is also applicable for the headwaters in southern Yukon territory. For a 200-year freshet event and ecozone 12, the flows for McConnell Lake and adjacent floodplains were estimated as follows:

Table 4-4: McConnell Lakes flows estimated from Multiple Regression

Area	McConnell Lake	Floodplain	East Ridge
A		-6.4092	
B		0.9849	
C		0.4918	
D		1.3563	
Area (km^2)	23.92	15.89	31.67
MAP (mm)		266.83	
Median Z (m)	832	763.972	957.148
Q (m^3/s)	1.266	0.754	2.019

To establish a comparable baseline relative to the Hamlet of Mount Lorne's resident observations, Tetra Tech sought to estimate the two (2) year return period flows. Given that the above equation only applies for 10-year, 100-year and 200-year flows, Tetra Tech adopted NHC's Drainage Area Scaling Equation. Area based scaling from one or more proxy gauges with similar characteristics is a common method for estimating peak flows in an ungauged basin and follows the form:

$$Q_{ungauged} = Q_{gauged} * (\frac{Area_{ungauged}}{Area_{gauged}})^b$$

Where Q_{gauged} is a flow (of a particular return period) of a gauged site, and $Area_{gauged}$ and $Area_{ungauged}$ are basin areas for gauged and ungauged basins. The scaling exponent b is derived from ecozones and used based on the assumption that flows scale according to a power law form. Using Wolf Creek and Tagish Creek, the gauged watersheds are scaled down to the McConnell Lake and adjacent floodplain catchments as described in table 4-5 below:

Table 4-5: McConnell Lake peak flows estimated from Area Scaling

Reference Station:	Wheaton River	Wolf Creek	Tagish Creek
Q.gauged (2-year)	55.2	5.38	2.11
Area.gauged (km^2)	864	184	76.9
b	1	1	1
McConnell Lake (23.92 km^2)	1.5282	0.6994	0.6563
Floodplain (15.89 km^2)	1.0152	0.4646	0.4360
East Ridge (31.67 km^2)	2.0234	0.9259	0.8690

While Wolf Creek and Tagish Creek exhibited similar estimated flows when scaled to McConnell Lake's catchments, Wheaton River demonstrated a large variance in estimated flows by comparison. The large variance from Wheaton River compared to Wolf Creek and Tagish Creek is likely due to the large catchment area of Wheaton River, which also may exhibit different behaviors caused by detention systems (natural lakes), time of concentration, and other factors. Consequently, although the Wheaton River hydrometric station contained the most years of collective data, it was abandoned as a hydrometric station for consideration.

From the above frequency analysis, Tetra Tech selected an annual hydrograph representative of the 2-year flow for a given hydrometric station. For Wolf Creek hydrometric station, the two-year return period peak flow from the GEV fitting of the frequency analysis above is 5.36m^3/s. This is represented by the 2006 freshet event with a peak flow of 5.68 m^3/s. The daily flows are unitized and scaled relative to the peak flow of the Wolf Creek station. The hydrograph applied to McConnell Lake, floodplain, and east ridge are shown in the figure below:

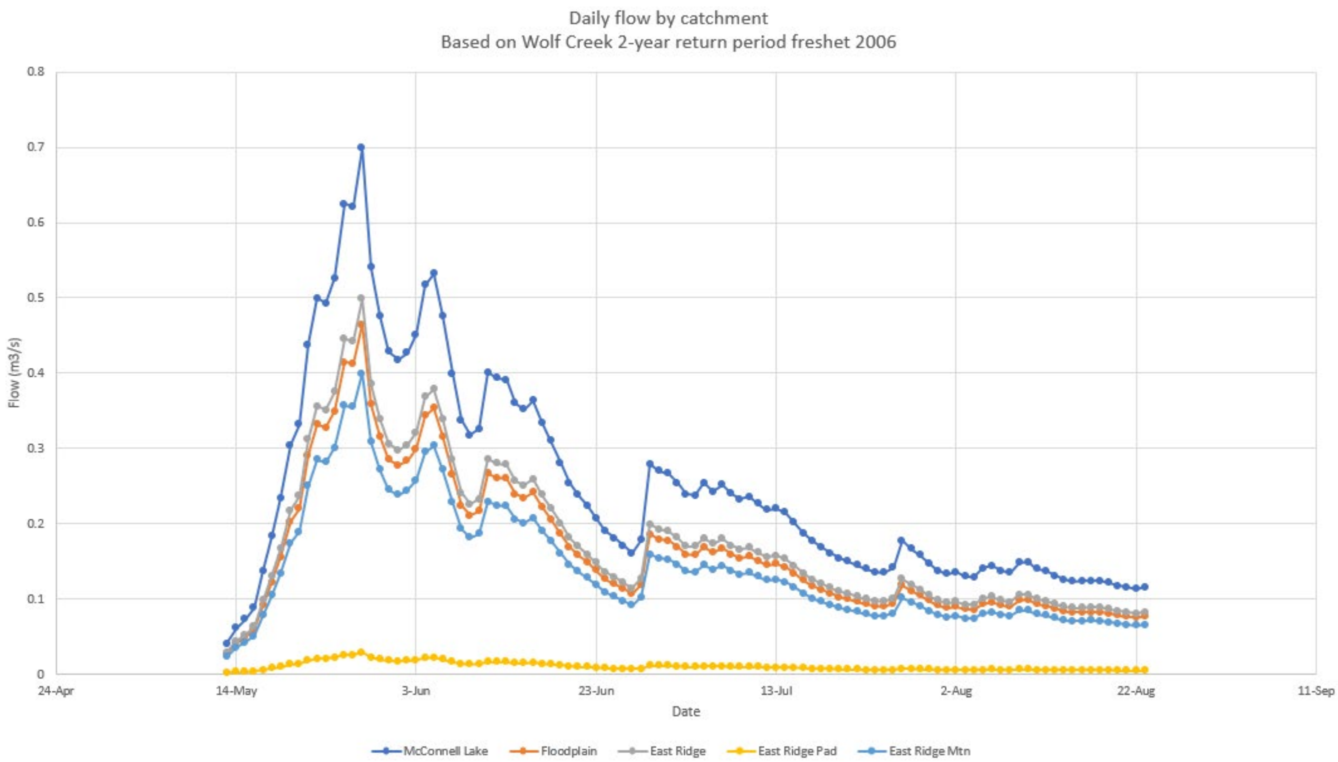

Figure 4.12. Hydrograph applied to Project area based on Wolf Creek 2006 2-year return period freshet.

4.2.2 Hydraulics based on Peak Flow

The more conservative direct-routing inflow scenario was then passed onto the HEC-RAS 2D software for hydraulic modelling of the flow through the floodplain.

The inflow was introduced into the model at five (5) upstream boundary conditions: McConnell Lake, the middle of the flood plain, and three (3) locations along the base of the ridge east of the highway as shown in the Figure 4.13 below. The downstream boundary condition for the floodplain was set to be at the valley connecting the floodplain with Cowley Lake in the north. An infiltration parameter of Curve Number 70 was applied to all the catchments. A Curve Number of 70 is defined by the Natural Resources Conservation Service (NRCS) with woody land cover and soil hydrologic group C. This soil hydrologic group can be described as “soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine textures”. Based on the borehole data obtained by Tetra Tech in a November 2022 study, this soil group best matches the findings described as shallow sand about 3-5 metres in depth overlying clay to more than 15 metres in depth. The continuous, thick clay prevents shallow water from infiltrating deeper into the ground and hence, reasonably contributes to the flooding issue. Simulations were run for 3.5 months to capture the entire freshet cycle. Figure 4.14 displays the predicted flooding extents based on the above hydraulic parameters and freshet.

Figure 4.13. Inflow and Outflow Boundaries

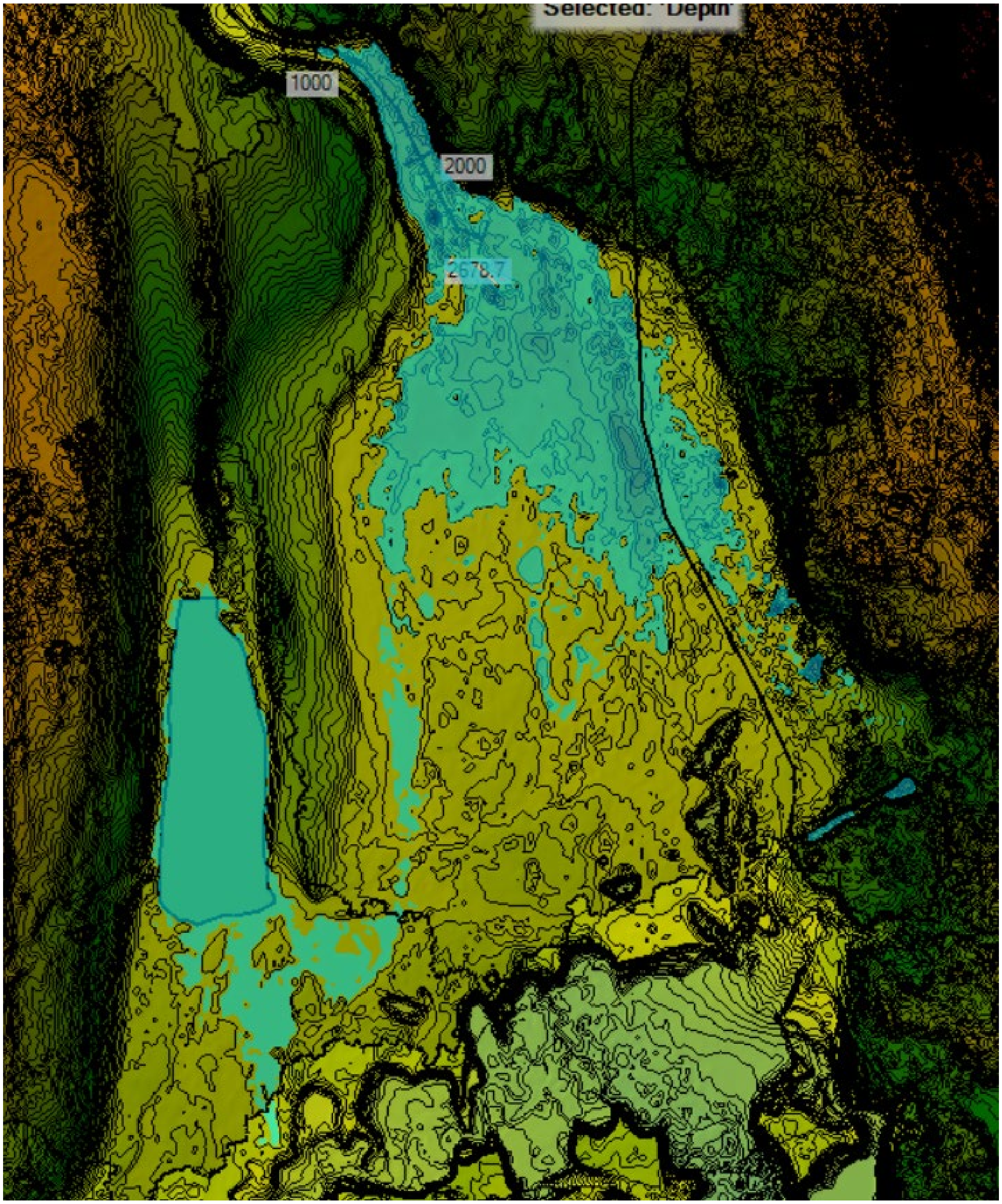

Figure 4.14. Flooding Extent of Project Area Scaled from Wolf Creek 2-Year Freshet

4.3 Regional Analysis (Volume Frequency)

In addition to completing a frequency analysis using peak flows, Tetra Tech has also completed a frequency analysis utilizing historical volume estimates. Rather than concentrate on the peak of the event, the total volume of runoff associated to the event was analyzed through a frequency analysis.

4.3.1 Hydrology based on Peak Volume

A flood frequency analysis was also conducted using volume over a three (3) month period for Wolf Creek and Tagish Creek hydrometric stations. The volume was calculated based on the daily average flow over the day and each day summed over three (3) months. HYFRAN was again used to fit the statistical distributions to the volume data. Several probability distributions were tested, and visual inspection was relied upon to select the best distribution for each station.

A chart of the GEV fitting used for Station 09AA011 (Tagish Creek near Carcross) is shown below (Figure 4.15).

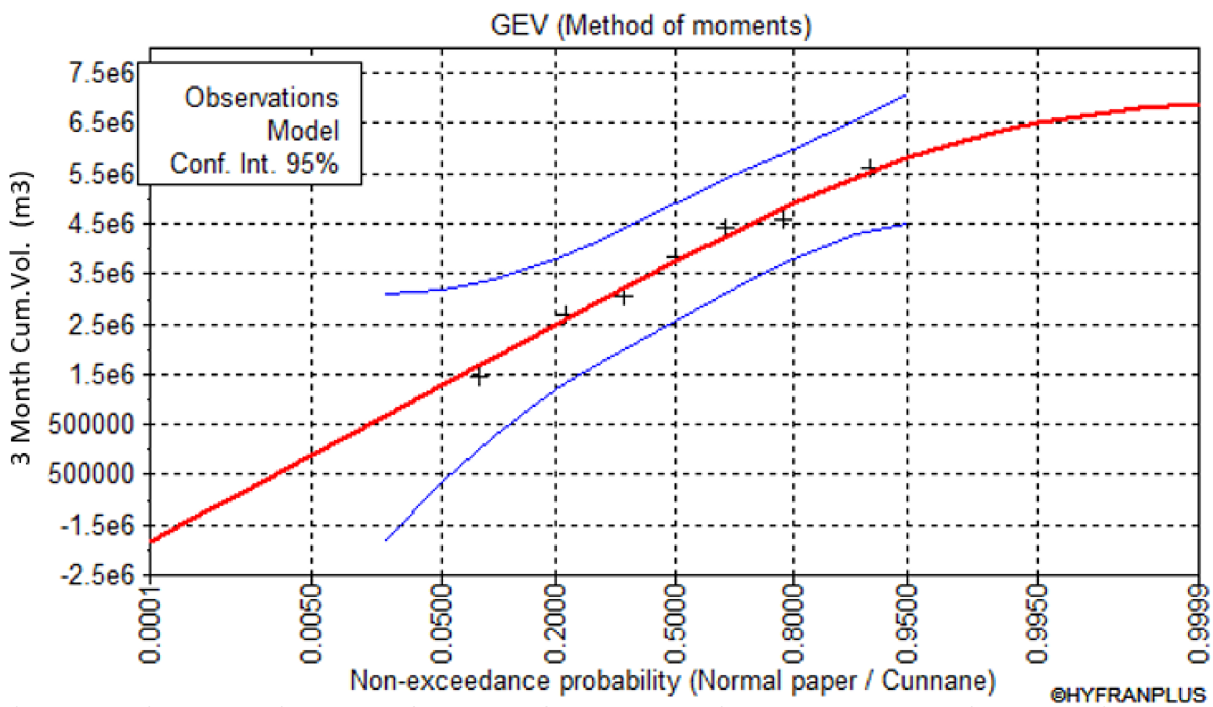

Figure 4.15. GEV Fitting for Station 09AA011

A chart of the GEV fitting used for Wolf Creek Research Basin is shown below (Figure 4.16)

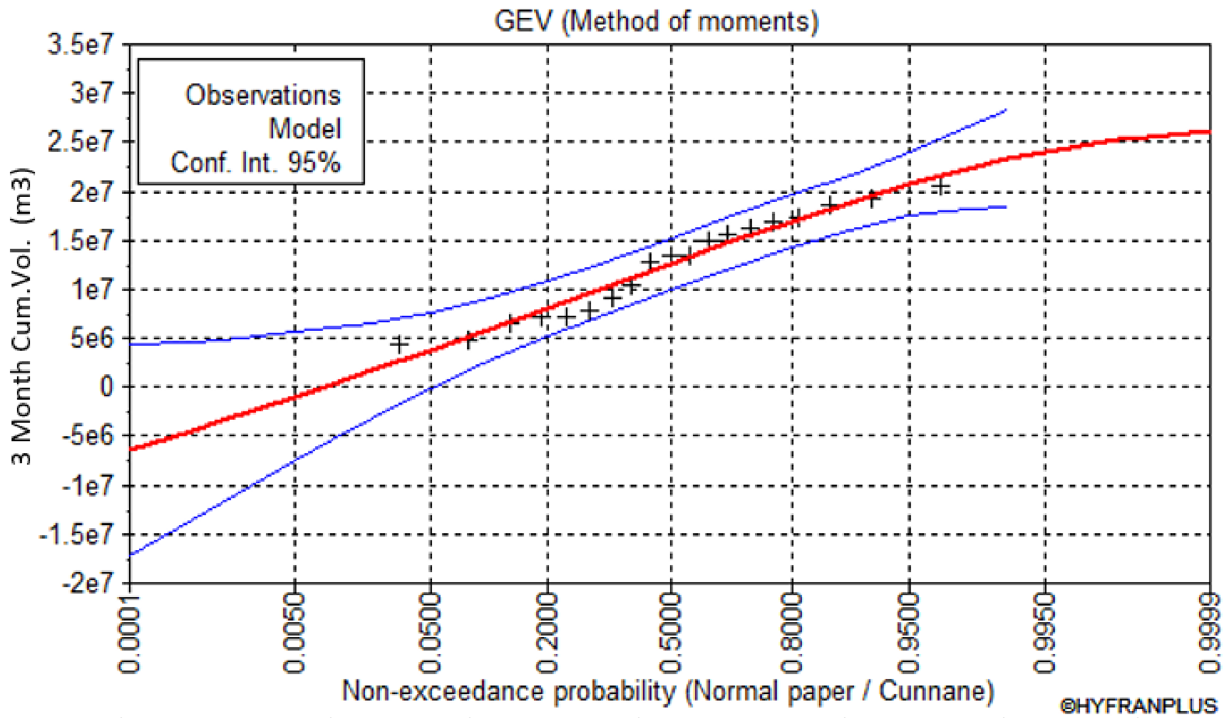

Figure 4.16. GEV Fitting for Wolf Creek Research Basin

Table 4-6 includes the results of the flood frequency analysis for each station.

Table 4-6: McConnell Lake Regional WSC Stations Summary

Station Name	**Tagish Creek near Carcross**	**Wolf Creek Research Basin**
Station ID	09AA011	
Watershed Area (km²)	76.9	184
Return Period	**3 Month Cumulative Volume (m³)**	**3 Month Cumulative Volume (m3)**
200	6.51E+06	2.40E+07
100	6.36E+06	2.33E+07
50	6.17E+06	2.24E+07
10	5.42E+06	1.91E+07
2	3.74E+06	1.25E+07

The area scaling equation in the above section was used to scale the volumes down to the McConnell Lake and adjacent floodplain catchments as described in Table 4-7 below:

Table 4-7: McConnell Lake Freshet Volume estimated from Area Scaling

Reference Station:	Tagish Creek	Wolf Creek
V.gauged (2-year)	3,750,000	12,500,000
Area.gauged (km^2)	76.9	184
b	1	1
McConnell Lake (23.92 km^2)	1,166,450	1,624,902
Floodplain (15.89 km^2)	774,870	1,079,419
East Ridge (31.67 km^2)	1545,284	2,152,630
Total	**3,486,604**	**4,856,951**

From the above frequency analysis, Tetra Tech selected an annual hydrograph representative of the 2-year volume for the given hydrometric station. For Wolf Creek hydrometric station, the two-year return period has a freshet volume of 12,500,000 m^3 from the above GEV fitting of the frequency analysis. This is represented by the 2008 freshet event with a volume of 12,695,230 m^3. For Tagish Creek, the two-year return period has a freshet volume of 3,750,000 m^3 from the above GEV fitting of the frequency analysis. This is represented by the 1967 freshet event with a volume of 3,856,982 m^3. The daily volumes are unitized and scaled relative to the volume of Wolf Creek station and Tagish Creek station. The hydrographs applied to McConnell Lake, floodplain and east ridge are shown in the figures below.

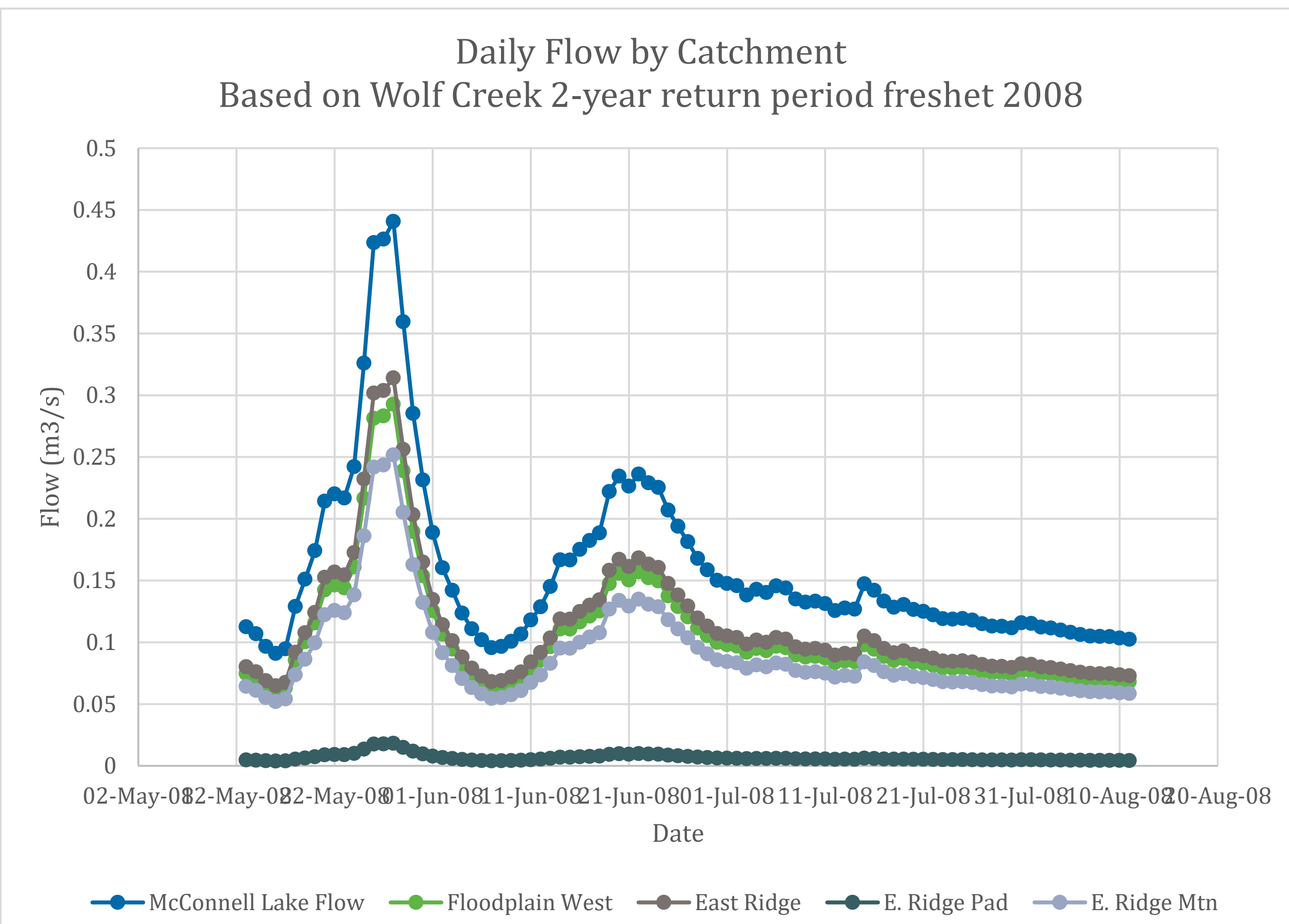

Figure 4.17. Hydrograph Applied to Project Area Based on Wolf Creek 2008 2-year Return Period Freshet.

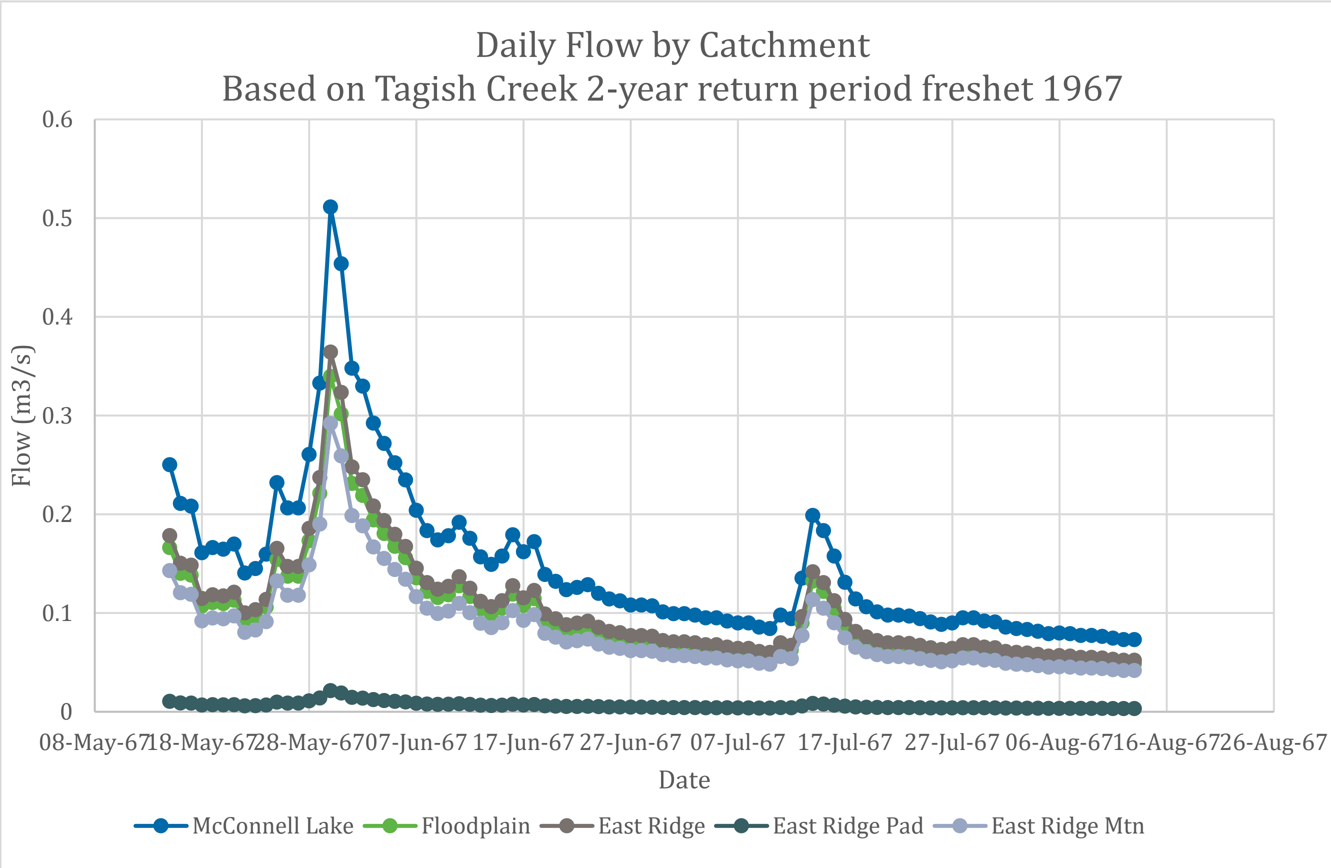

Figure 4.18. Hydrograph applied to Project area based on Tagish Creek 1967 2-year return period freshet.

4.3.2 Hydraulics based on Volume

The above hydrographs were again integrated into HEC-RAS to model the hydraulic response of the system. Given that the two-year event in the peak flow model above extensively inundated the floodplain and did not match resident reports, Tetra Tech opted to increase the infiltration parameter to a Curve Number of 55 for Wolf Creek. A Curve Number of 55 is defined by NRCS with woody land cover and soil hydrologic group B. This soil hydrologic group can be described as "soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, and moderately well to well-drained soils. Tetra Tech suspected that the 3-5 metres of sand was more efficient at draining the soils than anticipated in the model above. Figure 4.19 illustrates the predicted flooding extent based on this set of hydraulic parameters and freshet hydrograph.

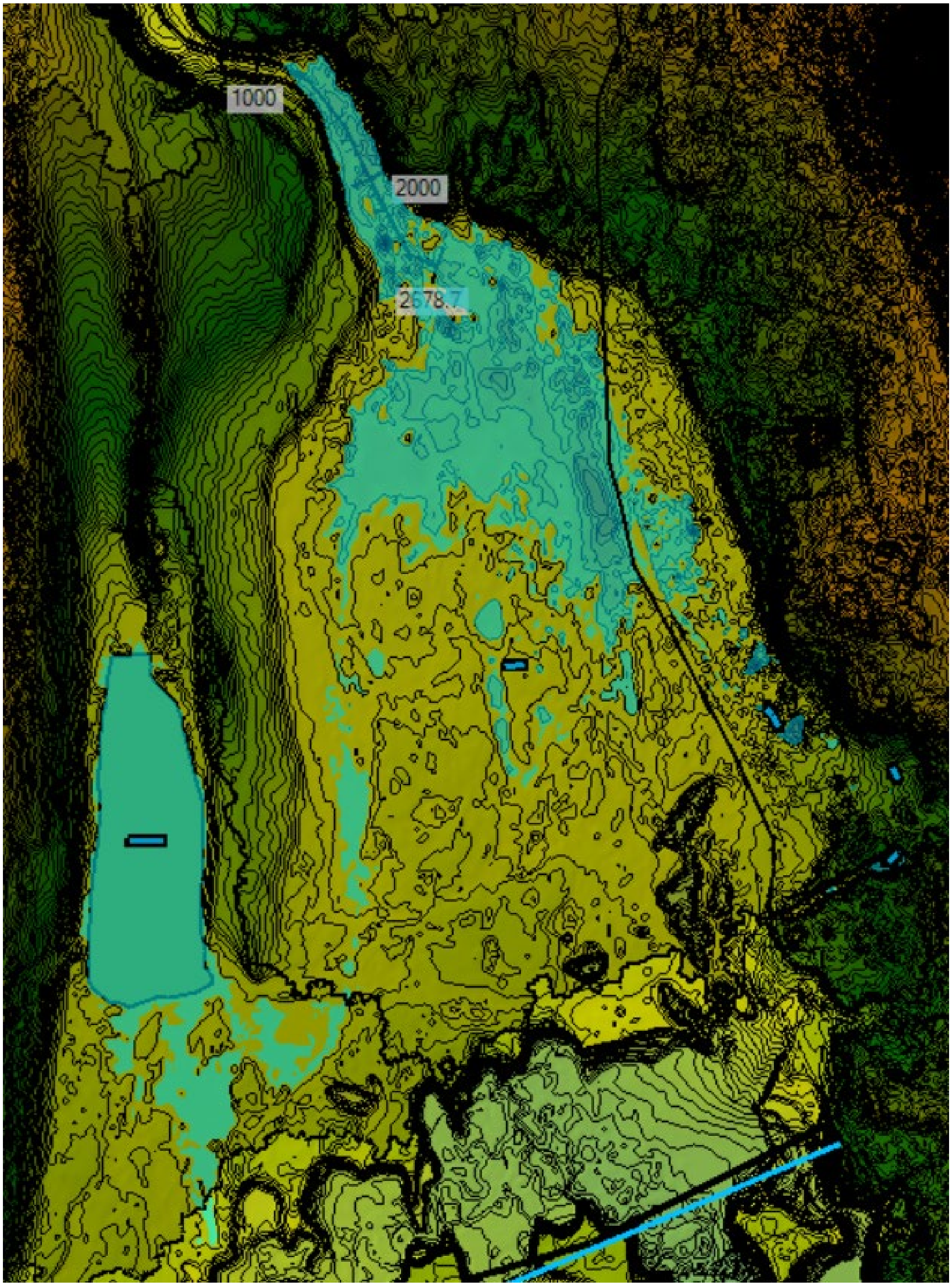

Figure 4.19. Flooding Extent of Project Area Scaled From Wolf Creek 2-Year Freshet

In the above scenario, extensive inundation of the northeast section of the floodplain is still observed based on the Wolf Creek 2-year return period freshet scaled by volume. Tetra Tech finally increased the infiltration rate Curve

Number to 36 and tested the response. A Curve Number of 36 is defined by NRCS with woody land cover and soil hydrologic group A. This soil hydrologic group can be described as “low runoff potential. Soils have high infiltration rates even when thoroughly wetted and consisting chiefly of week, well to excessively drained sands or gravels”. Tetra Tech believes this scenario does not accurately represent the soils characterized by the boreholes. Instead, this final scenario aims to test if the model is based on insufficient, omitted, or unreliable data. Figure 4.20 displays the predicted flooding extents based on the above hydraulic parameters and freshet.

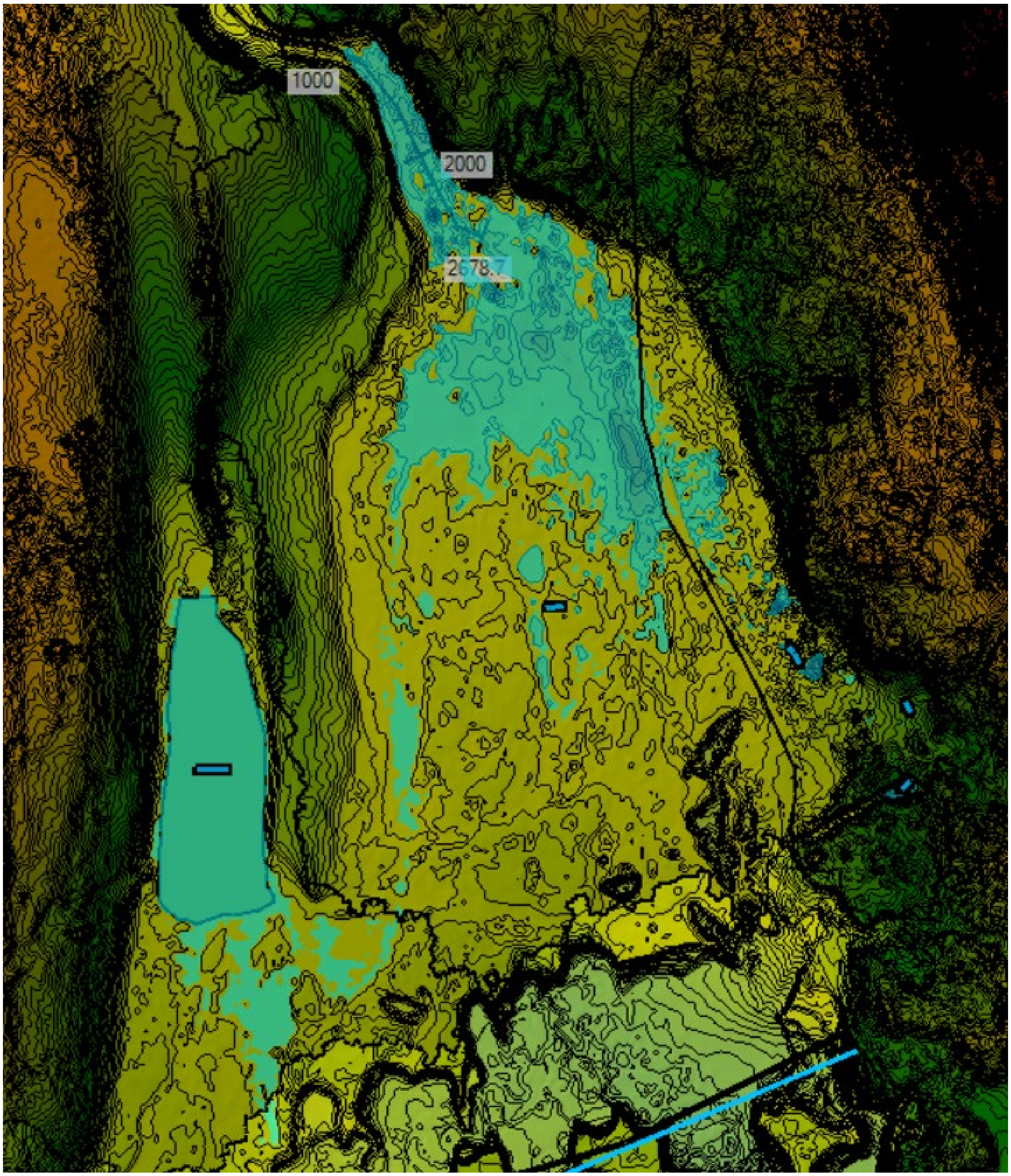

Figure 4.20. Flooding extent of project area scaled from Tagish Creek 2-year freshet

5.0 RESULTS AND RECOMMENDATIONS

5.1 Review of Results and Comparison with Observations

Based on the analysis completed to date, Tetra Tech was able to reproduce a number of events mimicking the extent of the flooding noticed in the field. That said, in each of the scenarios tested above, it was found that the developed models appear to overestimate the extent of the flooding including portions of the highway which, based on anecdotal observations, has never flooded. Residents noted the Klondike Highway was never overtopped during these yearly flood events. Based on the analysis and available LiDAR data the highway should have overtopped consistently over the past few years (see low point in Figure 5.1). Assuming the LiDAR data is correct, the only conclusion which can be derived is that the model developed to date is overestimating flood levels. Recognizing the issue, Tetra Tech has attempted to calibrate the model to match the depth and extent of flooding, but regardless of the method used and regardless of the adjustments made to any of the used parameters, the models developed to date continuously reported deeper depths.

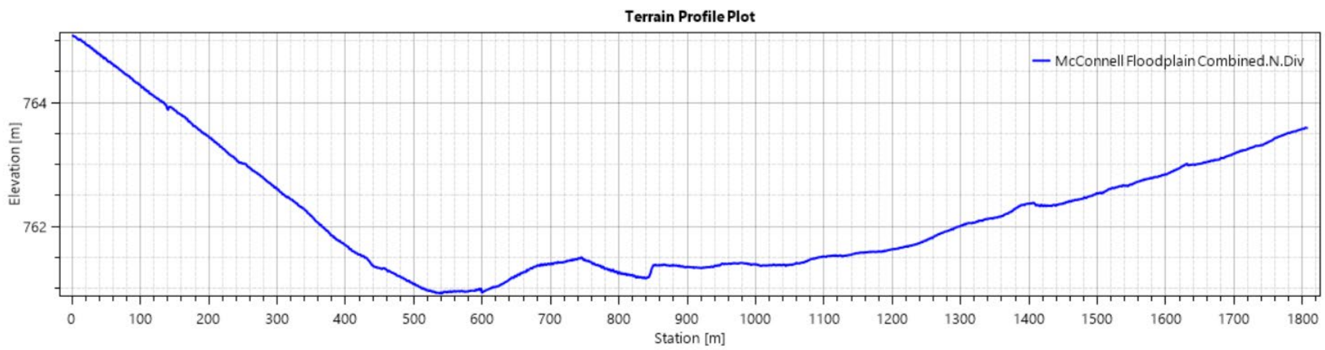

Figure 5.1. Klondike Highway Profile

The flooding depth at STA 0+540 along the highway is summarized in the below table and provides a snapshot comparing the difference in flooding between the scenarios.

Table 5-1: Flooding depth at Low Point of Klondike Highway STA 0+540

Scenario	Reference Hydrometric Station	Type of Scaling	Infiltration Curve Number	Flood Depth at STA 0+540
1	Wolf Creek	Peak Flow	70	1.08m
2	Wolf Creek	Volume	55	0.41m
3	Tagish Creek	Volume	36	0.31m

Tetra Tech has arrived at several possible theories for why the modeled results do not match observations. First, there exists an embankment in the valley between the floodplain and Cowley Lake. Based on the LiDAR, the HEC-RAS model treats this embankment as a solid obstruction. Tetra Tech suspects the embankment is potentially permeable and allows water to freely cross the embankment allowing flood levels to spread over a wider area, reducing the ultimate flood levels. It is also possible that along this embankment culvert crossings may be present allowing water to freely move across the embankment. Furthermore, Tetra Tech speculates Cowley Lake, McConnell Lake, and Watson River are all connected by the underground sand layer. The permanent water bodies at the south end of McConnell Lake, around the perimeter of the floodplain, and the along the valley between the floodplain and Cowley Lake support this hypothesis. From the south end of McConnell Lake, the permanent water bodies appear to stretch south towards Watson River, progressively shrinking in size. The tree density reviewed through Google Maps and the LiDAR contours suggest an obvious flow path during freshet in which McConnell

Lake's water infiltrates under the banks and daylights north of the river (see Figure 5.2). Given the extremely flat topography in this area, the HECRAS model demonstrates similar behavior while being bounded by the topographic ridges captured by the LiDAR data. While the topography is suggesting there is a barrier, the anecdotal information, the vegetation, the geology, and the topographic patterns suggest otherwise.

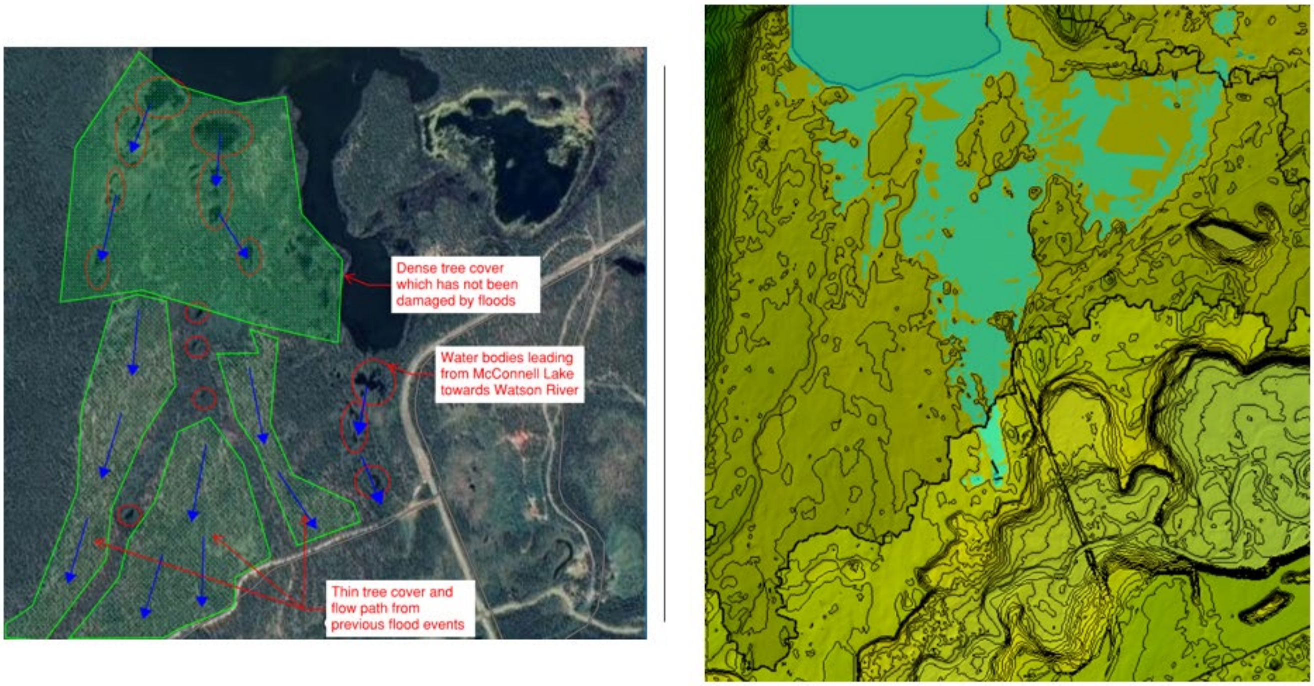

Figure 5.2: Comparison between HECRAS flood results and Google Maps tree cover by McConnell Lake

Along the perimeter and middle of the floodplain, permanent water bodies and thinned tree density support the theory that although the water surface elevation does not reach the same extent as the model suggests, the groundwater inundation exhibits a similar behavior to that shown in the model. A 3-5 metres depth of groundwater is trapped over a layer of clay unable to infiltrate through the deep clay layer. Restricted by the clay barrier, water is forced to spread laterally, drowning tree roots and daylighting along low points of the floodplain as shown in the figure below.

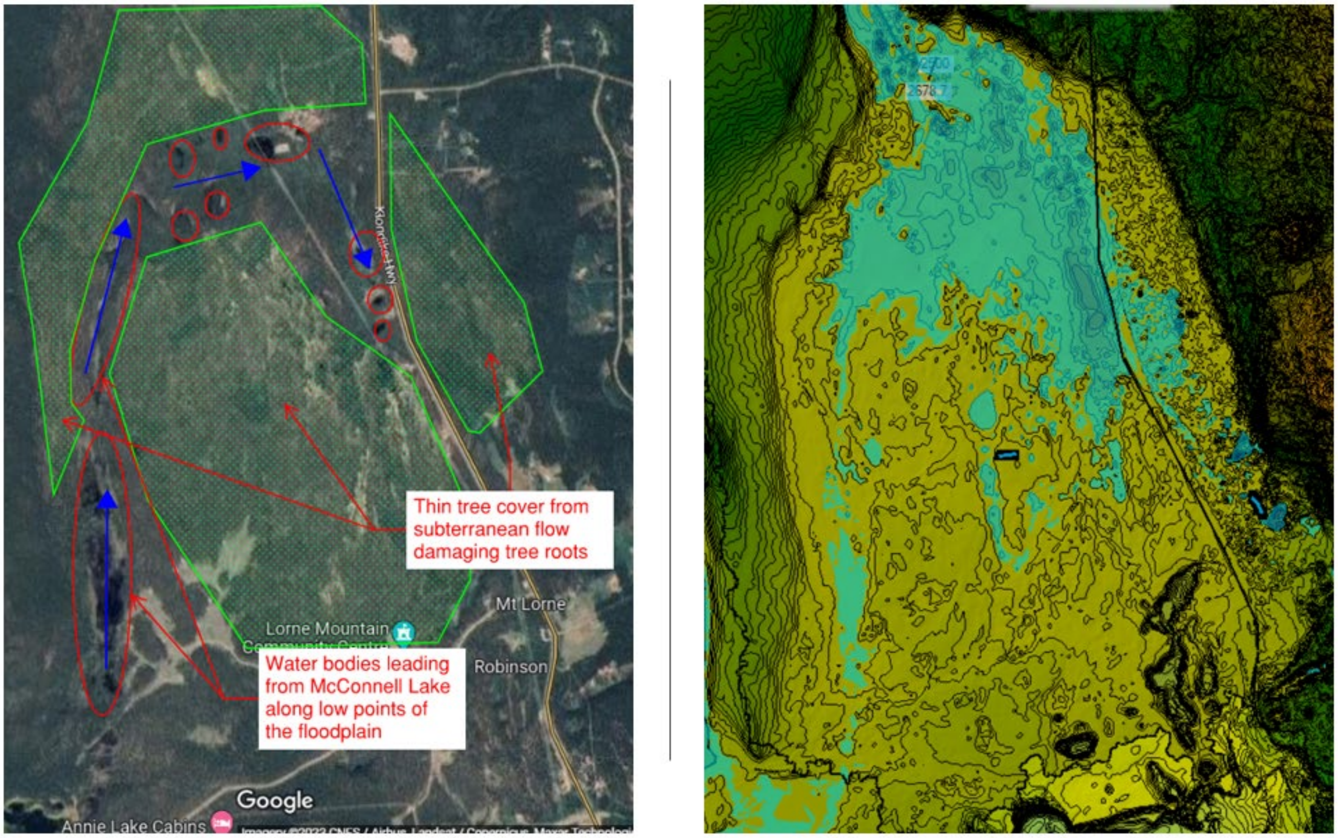

Figure 5.3: Comparison between HECRAS flood results and Google Maps tree cover by floodplain

Finally, Tetra Tech reviewed the tree cover and water bodies in the valley between the floodplain and Cowley Lake. These features strongly suggest a subterranean connection between these two areas. A profile of the valley derived from the LiDAR (see Figure 5.4) confirms the existence of a high point midway down the valley (See Figure 5.5). This high point appears to be largely responsible for the backup of floodwaters in the north and northeast areas of the floodplain .

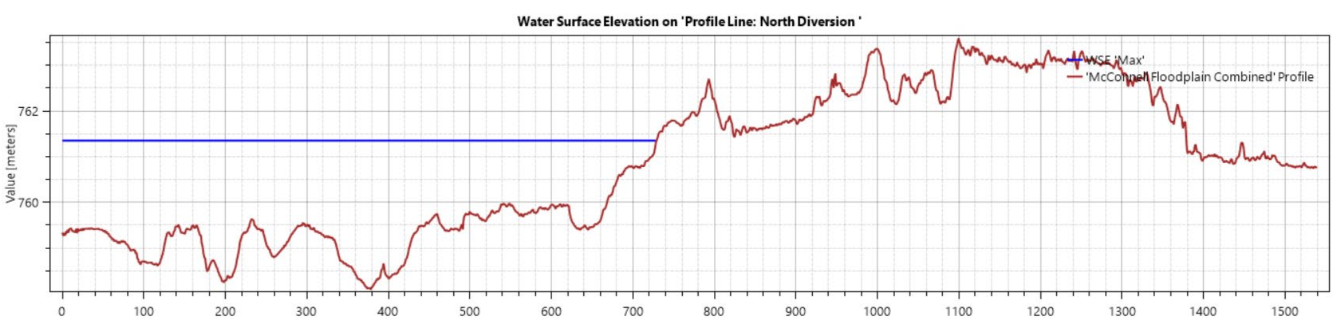

Figure 5.4: Profile of Valley with water surface elevation

As detailed in Figure 5.5, the topography suggests a natural connection to Cowley Lake. If not through the surface, the hydraulic connection is likely taking place though the sand layer connecting the floodplain to the lake. Tetra Tech has explored the possible presence of a topographic connection (See Figure 5.6) and the potential effects of linking the floodplain with Cowley Lake. As soon as the connection was added to the model, water levels dropped.. Furthermore, the floodwaters did not overtop Klondike Highway and more accurately resembles the observations reported by residents. Figure 5.6 below illustrates the flood extents with a diversion channel and compares this to photos taken of the 2021 and 2022 freshet floods.

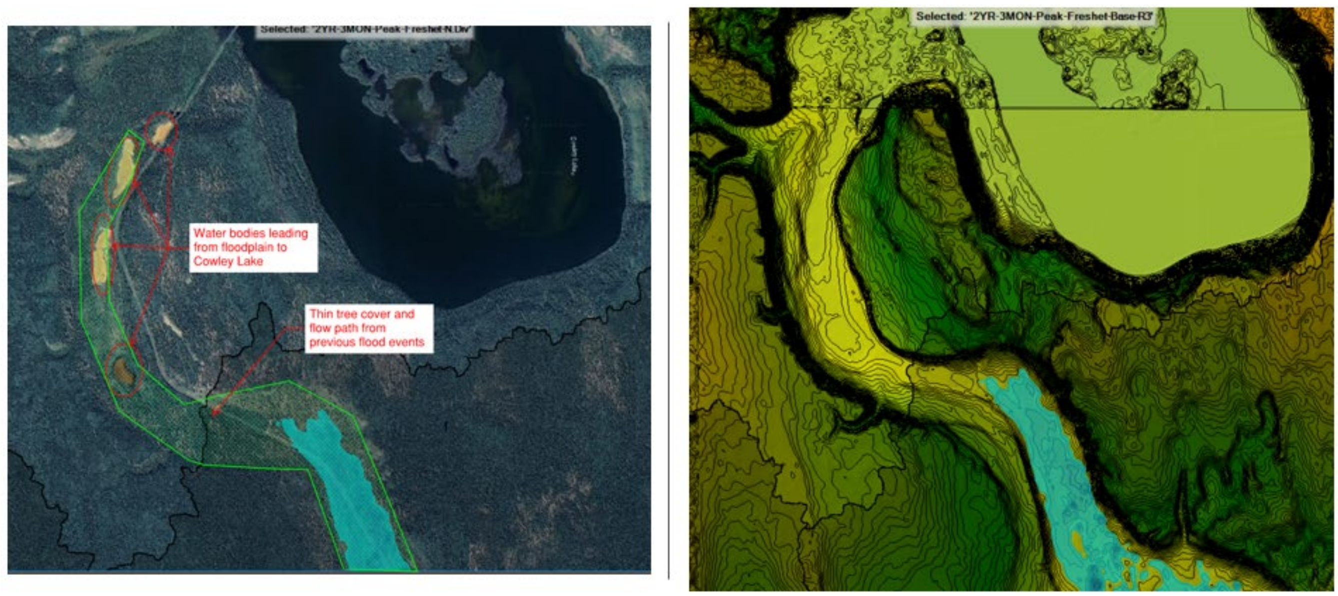

Figure 5.5: Comparison Between HECRAS Flood Results and Google Maps Tree Cover by Valley

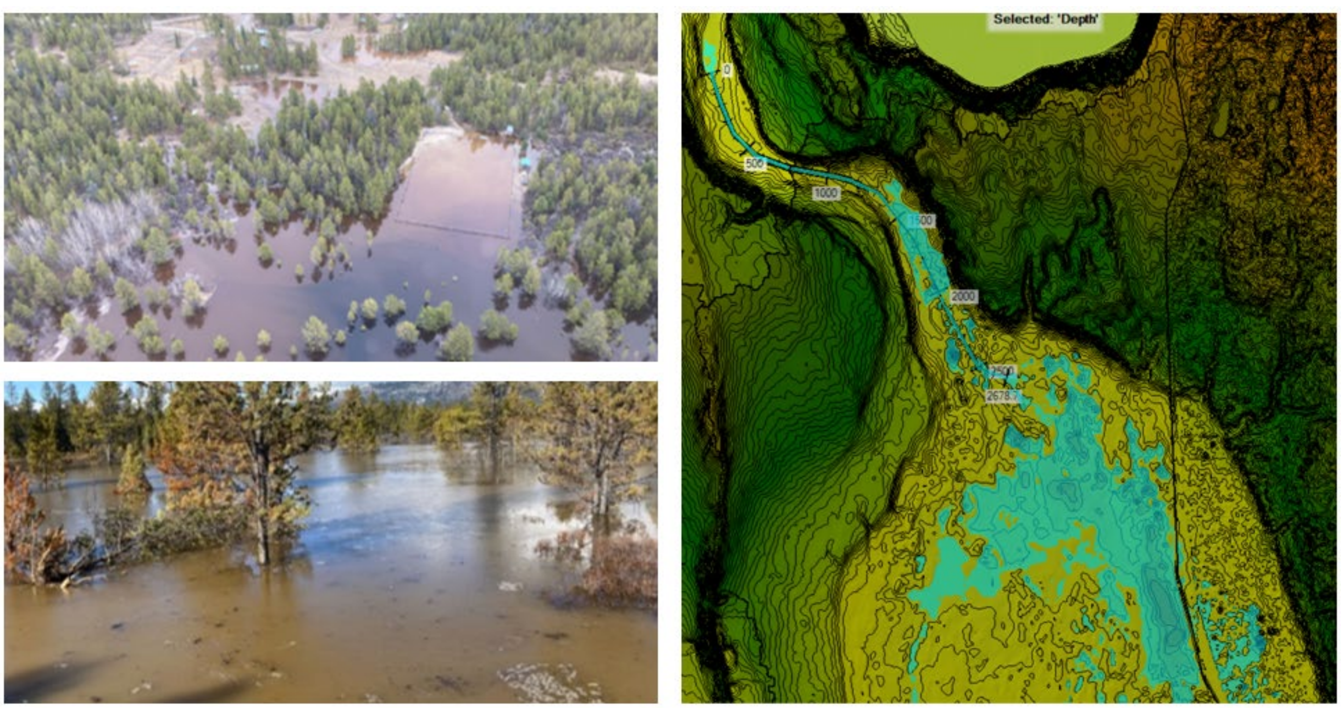

Figure 5.6: Comparison of modelled flood extents with diversion channel and field photos

The similarity between the flood extents between field observations and the model with a diversion channel suggests that although a man-made surface channel may not exist, a subterranean connection may exist. It is also possible that a series of culverts may be present allowing water to freely move towards the Lake. A similar result was observed by modifying the LiDAR and adding a deeper ditch at the south end of McConnell Lake along Two Horse Creek Road and allowing for increased conveyance to the culvert at the intersection of Two Horse Creek Road and Annie Lake Road. However, the effectiveness of this ditch is limited by only redirecting and reducing flows from McConnell Lake. Due to the topography of the floodplain graded toward the north and northeast corner, this ditch and culvert are not able to reduce flooding along the eastern area of the floodplain.

5.2 Recommendations

Evident from the discussion and results above, additional investigation is required to clarify the site conditions. This will allow Tetra Tech to calibrate the models and reproduce the observed water levels. With an accurate model representative of recent freshet events, Tetra Tech would seek to recommend and size diversion structures and mitigation strategies for the 1/200-year freshet event. Groundwater hydrology and upwelling was not considered in this scope. Tetra Tech recommends the following points to form the core of future efforts:

- A geotechnical investigation should be conducted across the southern border of McConnell Lake, the floodplain, the valley towards Cowley Lake, and to some extent, the tributary catchment east of Klondike Highway. This will be vital to rationalizing infiltration parameters used to calibrate the model and develop justified flood mitigation strategies.
- A field review of man-made water management infrastructure should be conducted. The open database GeoYukon provides the locations of culverts crossing and along Klondike Highway and Two Horse Creek Road; however, the invert elevations were not recorded. In this HECRAS model, the inverts were inferred based on the immediate topography. Furthermore, the effective 2-year freshet or precipitation conveyance of each culvert can be estimated by inspecting the rust line within the culvert. Tetra Tech also suspects there exists undocumented or damaged culverts crossing the abandoned rail line or road embankments which could potentially assist with floodwater conveyance.
- A field review during the freshet period to better understand the freshet behavior, overland flow path, flood depth, and flood extent will provide Tetra Tech another source of field observations to justify the model calibration after incorporating the above investigations.

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We trust this technical memo meets your present requirements. If you have any questions or comments, please contact the undersigned.

Respectfully submitted,
Tetra Tech Canada Inc.

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