NAHANNI BUTTE DENE BAND

Nahanni Butte Flood Hazard Mapping

Final Report

August 2025 – 23-7137

DILLON CONSULTING

137 Chain Lake Drive
Suite 100
Halifax, Nova Scotia
Canada
B3S 1B3
Telephone
902.450.4000

August 25, 2025

Nahanni Butte Dene Band (Nahanni Butte)
1A Nahanni Mountainview Street
Nahanni Butte, Northwest Territories
X0E 2N0

Attention: Soham Srimani, MBA, PGPM, BEng
Band Manager & Chief Administrative Officer

Nahanni Butte Flood Hazard Mapping – Final Report

Dillon Consulting Limited (Dillon) is pleased to present the following final report as part of the Nahanni Butte Flood Hazard Mapping project.

The attached report outlines the methodology and results of the data collection, hydrologic and hydraulic assessments completed for the development of flood hazard maps for Nahanni Butte. The full-size maps are provided separately due to file size, although compressed versions are appended within this report. This work, made possible through funding acquired from the Flood Hazard Identification and Mapping Program (FHIMP), has been largely completed based on information provided in background documents sourced from both territorial and federal institutions, input from Traditional Knowledge holders, observations from community members and Dillon team members, and the expertise of Dillon's professionals experienced in managing projects of comparable scope and nature. The unique characteristics of the community's specific needs and circumstances are reflected in the approach described herein.

Sincerely,

DILLON CONSULTING LIMITED

Meggie Letman, P.Eng.
Project Manager

Samane Lesani, EIT.
Water Resources Designer

MML:vrh

Our file: 23-7137

Table of Contents

Figures

Tables

Appendices

References

Executive Summary

The Nahanni Butte Dene Band (NBDB) faces increasing flood and erosion risks from climate change. Dillon Consulting Limited (Dillon) was retained by NBDB leadership, in consultation with the Government of the Northwest Territories (GNWT), Environment and Climate Change Canada (ECCC), and Natural Resources Canada (NRCan), to create flood inundation and hazard maps for Nahanni Butte. This project, Phase 2, builds on Phase 1, which focused on understanding risks and mitigation options. Phase 2 aims to produce quality flood hazard maps for land use planning and community safety.

The project used a clear approach, combining local knowledge, data collection, and advanced modeling. Collaboration involved NBDB, GNWT, ECCC, and NRCan to understand local flood mechanisms. As part of Phase 1, a community-led monitoring program was initiated in summer 2024, with residents tracking shoreline conditions and water levels. Dillon also gathered existing geospatial data and conducted a preliminary desktop hydrologic assessment of the Liard and South Nahanni Rivers. In July 2024, the project team visited the community to conduct drone topographic and bathymetric, and to discuss past floods with residents. This data formed the basis for subsequent modeling.

The hydrologic assessment used the Raven hydrologic model to simulate watershed processes under current and future climate conditions, providing robust and defensible peak flow estimates and flow hydrographs. The Raven model, previously developed for the Liard basin, was updated and recalibrated for this study, with a focus on snowmelt parameters. The assessment estimated maximum daily flow rates for both the South Nahanni and Liard Rivers based on the model results. A regional flood frequency analysis (RFFA) was completed for nearby hydrometric stations and compared to a single-station frequency analysis of the Raven model results. The RFFA magnitude, which was greater than the FFA of the Raven results, was chosen to scale the hydrographs for the hydraulic model.

A detailed climate change sensitivity analysis used downscaled climate projections to assess changes in flow characteristics under two climate change scenarios. This analysis determined that "cool/wet" conditions (25^{th} percentile temperature, 75^{th} percentile precipitation) from moderate (SSP2-4.5) and high (SSP5-8.5) emissions scenarios were the most realistic for future peak flows that reflect a potential for increased snowpack in the future. The hydrologic results for the historical and climate change scenarios were used to create inflow hydrographs to be used for the hydraulic assessment.

The hydraulic assessment was conducted using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) Version 6.6 two-dimensional (2-D) modeling software. The hydraulic model incorporated a detailed digital elevation model (DEM) from existing LiDAR, drone survey, and bathymetric survey data. The model was calibrated to the 2012 historical Flood of Record in the Nahanni Butte community (the largest flood in living memory) and validated using observed high-water marks from the 2022 flood event. The calibrated model was used for hydraulic assessment under different flood scenarios.

The project concludes with flood inundation and hazard maps for Nahanni Butte. These include a flood inundation map for the 2012 flood and four flood hazard maps: historical 1% and 0.5% Annual Exceedance Probability (AEP) events, and two climate change scenarios (0.5% AEP for 2022-2050 under SSP2-4.5 and SSP5-8.5 cool/wet conditions). The names and magnitude of these flood events are summarized in **Table E-1**. The maps delineate floodway and flood fringe areas. In Nahanni Butte, the floodway is primarily defined by water depth greater than 1 meter. The maps illustrate the community's varied topography, indicating that few areas are expected to be outside the flood fringe, which is defined by water depth less than 1 meter. The community's existing awareness and proactive measures, such as new construction on higher ground and elevating the first floor of buildings to a minimum height above the ground, demonstrate a realistic approach to flood risk management.

Mapped Scenario	AEP (%)	Maximum Daily Flow Rate (m^3/s)	
		South Nahanni River at the Confluence (36,100 km^2)	Liard River at the Confluence (228,800 km^2)
2012 Historical Flood of Record	-	3,896	15,455
100-Year Open Water Flood	1	4,172	15,139
200-Year Open Water Flood	0.5	4,422	15,709
Scenario 1: Climate Change to 2050, SSP2-4.5	0.5	3,920	16,430
Scenario 2: Climate Change to 2050, SSP5-8.5	0.5	4,020	16,400

1.0 Introduction

Dillon Consulting Limited (Dillon) has been retained by the Nahanni Butte Dene Band (NBDB) community leadership to produce flood hazard maps for the community of Nahanni Butte, in consultation with the Government of the Northwest Territories (GNWT), Environment and Climate Change Canada (ECCC) and Natural Resources Canada (NRCan), through the Federal Flood Hazard Identification and Mapping Program (FHIMP). This project is a complementary phase of the Flood and Erosion Risk Mitigation Project (referred to herein as Phase 1 for simplicity), which is nearing completion and is funded through the funding acquired by the Climate Change Preparedness in the North (CCPN) program. The draft report for Phase 1 was submitted to GNWT for review in March 2025 and is under revision, anticipating finalization in September 2025.

Considering the increasing uncertainty brought about by climate change, community leaders are seeking to enhance their understanding and implement strategies to strengthen the community's resilience against the challenges posed by flooding and erosion. Concurrently, regulators across Canada are seeking to quantify flood risk by producing updated flood inundation and hazard maps through the FHIMP initiatives. The main objective of Phase 1 of this study was to provide insights concerning flood and erosion risks to both community leadership and residents of Nahanni Butte and to offer solutions. The objective of this study, Phase 2, takes the previous objective concerning flood assessment to the flood hazard level to align with FHIMP. The key outcomes of Phase 1 and Phase 2 are as follows:

- **Phase 1:**
  - **Enhance Understanding of Risks:** Provide the community with a better understanding of the risks posed to existing infrastructure from both erosion and flood. This increased understanding will allow residents and leaders to make informed decisions regarding their immediate safety and the preservation of their property.
  - **Identify a List of Potential Mitigation Options:** Present mitigation options to the community to lower the risk that flooding and erosion pose on the community, properties, and infrastructure.
- **Phase 2:**
  - **Develop Flood Hazard Maps:** Develop detailed quality flood hazard maps, authenticated by engineers, in consultation with the GNWT, ECCC, and NRCan to support land use planning and increase the overall safety of the community.

To achieve this, Dillon worked with the community, GNWT, ECCC, and NRCan to understand flood mechanisms. Dillon’s project team also collected available geospatial data to support a desktop hydrologic assessment of the Liard and South Nahanni Rivers. In summer 2024, the project team visited the community to collect topographic and bathymetric information and to discuss flooding and possible mitigation measures with community members. A hydraulic model incorporated the data collected during this site visit, which assisted in the production of flood inundation maps throughout the first phase of the project. Dillon presented these draft flood inundation maps, and a number of potential flood and erosion mitigation and preparedness initiatives, to the community in December 2024. Reporting for this phase is provided under separate cover as the *Nahanni Butte Flood and Erosion Action Plan (Draft, March 2025)*.

In Phase 2, Dillon complemented the first phase of project by conducting hydrologic modelling, climate change sensitivity analysis, and flood hazard mapping. The draft flood hazard maps were shared with NBDB during a June 2025 Focus Group. This report summarizes the background review, data collection, hydrologic and hydraulic analysis, community responses, and flood hazard mapping for Nahanni Butte.

2.0 Background

The community of Nahanni Butte is situated on the South Nahanni River just upstream from the confluence of the South Nahanni and Liard Rivers in the Northwest Territories. Floods in the community are typically driven by heavy rainfall in conjunction with pre-existing high water levels in both the South Nahanni and Liard basins during spring and summer. Water levels on the South Nahanni are influenced by backwater from the Liard River. Recent floods in 2022 increased erosion in sections of the riverbank adjacent to community structures. The background information review compiles data and observations to support future tasks of the assessment, including both publicly available data and data collected from community engagement. The most significant flood in recent memory occurred in 2012 and is considered the Flood of Record, as described below. The study area is shown in **Figure 2-1**.

2.1 Historical Flooding

Based on the information provided in the Historical Flood Events (HFE) documentation available through NRCan (NRCan, 2024), community knowledge ,information published in the "*Historical Flood Review: Fort Simpson, Fort Norman, Fort Good Hope, Fort McPherson, Aklavik, Fort Liard, Nahanni Butte*" (Kriwoken, 1983), and GNWT MACA (Municipal and Community Affairs) Emergency Management Office's historical records (2006), the following historical events caused flooding within the community of Nahanni Butte:

Table 2-1: Chronology of Hydrometric Events

Year/Date	Description	Source
June 1961	Summer flood that inundated school.	Community member recollection (from the Dec 2024 Community Engagement "Focus Group" meeting) and Kriwoken (1983)
July 1972	Summer flood caused by heavy rainfall for the duration of 1 week, which caused bankfull flow within the river.	Community member recollection (from the Dec 2024 Community Engagement "Focus Group" meeting) and Kriwoken (1983)
July 1977	Heavy precipitation and subsequent rapid snowmelt in the headwaters resulted in the worst flooding ever experienced (at the time) in both Nahanni Butte and Fort Liard.	HFE (NRCan), community knowledge, and Kriwoken (1983)
June 2006	Heavy spring snowmelt and rainfall in the Liard River Basin led to flood.	Northern News Network (2006)
May 2009	High water levels as a result of the break-up of a previous ice jam approximately 6 km downstream of Fort Liard led to the community of Nahanni Butte being on flood alert due to the rising Liard River. The community did not eventually flood.	CBC News (2009)

DILLON CONSULTING

Year/Date	Description	Source
June 2012	More than 70 mm of precipitation from a low-pressure weather system combined with spring snowmelt caused widespread flooding in Upper Liard, Yukon; Nahanni Butte, Northwest Territories; and Lower Post, British Columbia. Approximately 20 people from Upper Liard, 80 from Nahanni Butte, and 37 from Lower Post were evacuated. Extensive traffic delays, damage to transport corridors, and ~25 buildings. Floodwaters persisted on June 16; residents returned at the end of June. A high-water mark (HWM) survey identified the HWM as 182.59 m (CGVD28). This is considered the flood of record and is expanded in the following section.	HFE (NRCan) and community knowledge; HWM Survey: Sub-Arctic Surveys, 2012 (as per provided text), and CBC News (2012)
June 2022	High water levels on South Nahanni and Liard Rivers occurred. The communities of Fort Liard and Nahanni Butte were on high alert for flooding and water levels neared bankfull; eventually, no significant flooding occurred.	Event description: HFE (NRCan) and community knowledge

It is evident from the historical floods described above that the community of Nahanni Butte is vulnerable to large rain events that coincide with snow melt resulting in higher runoff rates due to the influence of rain on snow. The community is strongly influenced by backwater conditions in the Liard River, not just the flows on the South Nahanni River itself. This is primarily because Nahanni Butte's proximity to the confluence means it is subject to the Liard's significantly larger discharge volume and its potential to create backwater effects that impede the flow of the South Nahanni River, causing water to rise in the vicinity of the community.

2.1.1 2012 Flood of Record

The June 2012 flood is considered the flood of record due to the specific combination of conditions that caused this high-magnitude flood: abnormally high snowpacks, warm spring temperatures, and an estimated 70 mm of rainfall from a low-pressure system moving through the region. These factors led to an evacuation order for homes in Nahanni Butte starting on June 9, 2012 (Public Safety Canada, 2013; CBC News, 2012).

Table 2-2 summarizes ECCC climate station data relevant to the community of Nahanni Butte for June 6 – 11, 2012. Of the climate stations located within a 200 km radius of the community, only one, Fort Liard, was both upstream of Nahanni Butte and reported daily precipitation data in millimetres for that period.

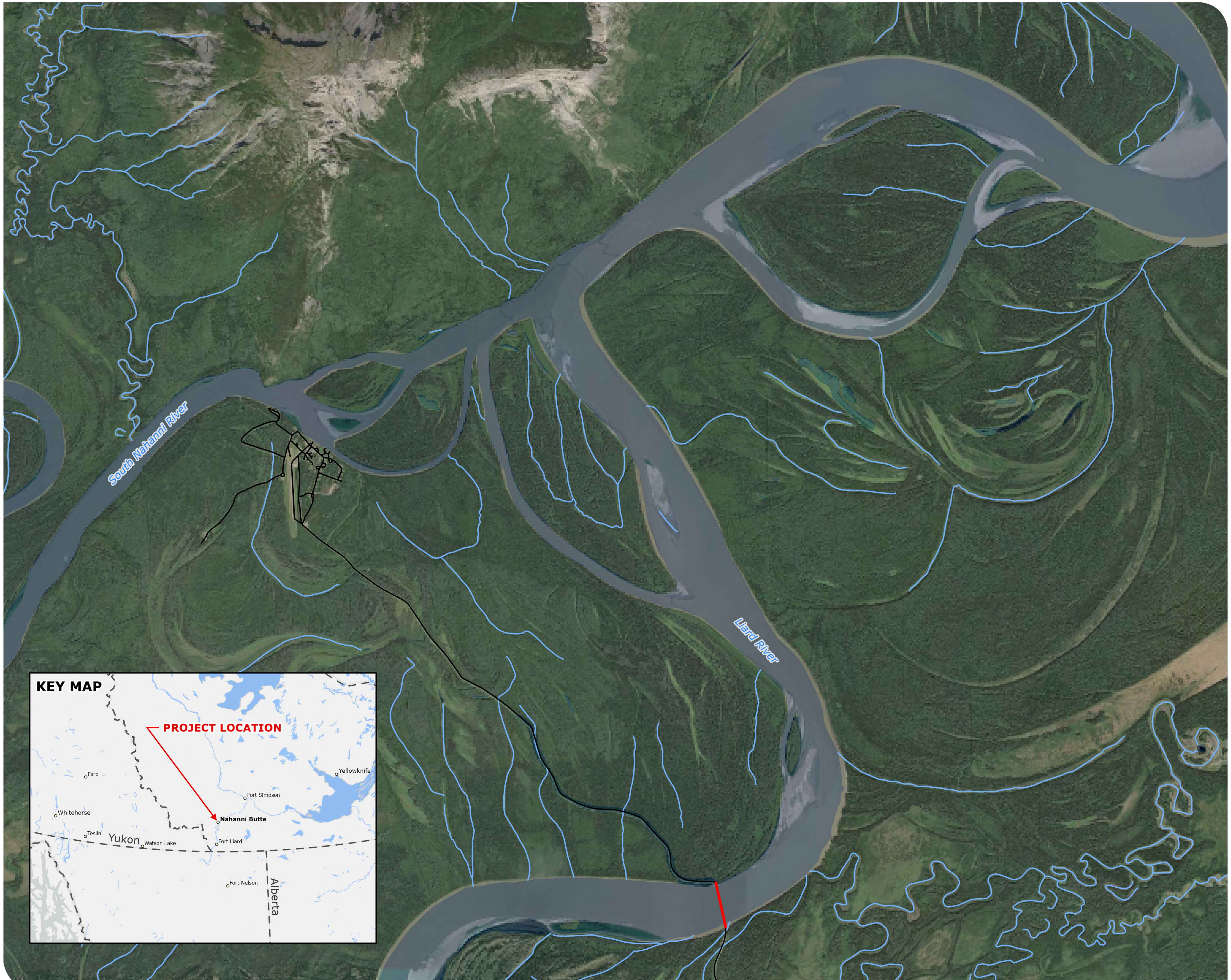
Table 2-2: Relevant Regional Climate Station Precipitation Data (June 6-11, 2012)

Station Name (Climate ID)	Distance from Site (km)	Total Precipitation Amount (mm)						
		June 6	June 7	June 8	June 9	June 10	June 11	Total
Lindberg Landing (220N003)	31	19.5	9.4	0.4	2.1	22.6	25.2	**79.2**
Fort Liard (2201579)	89	32.8	23.6	0.0	10.2	13.8	11.0	**91.4**
Fort Simpson A (2202101)	140	1.0	2.4	0.0	1.4	31.6	11.0	**47.4**

It is clear that precipitation values are variable across the region. The closest climate station to Nahanni Butte reported almost 80 mm of rainfall, while further upstream, the Fort Liard station reported over 90 mm, and downstream near the confluence of the Liard and Mackenzie Rivers, precipitation was less than 50 mm over the same time period. It is highly probable that Nahanni Butte also received significant precipitation over several days in mid-June 2012.

Based on the 1991-2020 climate normals for Fort Liard, the average annual precipitation is 449.2 mm. The average seasonal precipitation is 70.6 mm for spring (March, April, May) and 207.5 mm for summer (June, July, August). The more than 70 mm of precipitation from this single event is therefore comparable to the rainfall expected over three months in the spring and represents approximately 15% of the average annual precipitation (ECCC, 2025).

Community engagement in December 2024 invited community members to share their experiences from this and other floods. These experiences are discussed in **Section 3.0**.



NAHANNI BUTTE FLOOD ASSESSMENT
FLOOD HAZARD MAPPING

STUDY AREA
FIGURE 2-1

River Crossing
Road
Watercourse
Waterbody

SCALE 1:55,000

0 0.5 1 2 Kilometers

N W E S

MAP DRAWING INFORMATION:
DATA PROVIDED BY ESRI Base Imagery, GNWT, NRCAN

MAP CREATED BY: DS
MAP CHECKED BY: ML
MAP PROJECTION: NAD 1983 CSRS UTM Zone 10N

DILLON CONSULTING

PROJECT: 23-7137
STATUS: FINAL
DATE: 2025-08-20

3.0 Community Engagement

Nobody knows these river dynamics as well as the people who live in Nahanni Butte and have lived on its banks for generations. Their personal accounts are a great source of information to aid in understanding the erosion and flooding in the community.

Prior to Dillon's involvement in this project, Chief Steve Vital established a water level monitoring program using a staff gauge in one of the ditches on the river side of Mountain View Street. A staff gauge is a measuring tool used to monitor the water level in water bodies. Chief Vital placed three white poles (staff gauges) in the ground with markings at approximately 10 cm intervals to act as a reference point for an observer. During rain events, water levels are monitored by taking photos of the staff gauges. For example, in the spring of 2022, when water levels began to rise dramatically during spring freshet, it was possible to track the rising water over time as shown in **Figure 3-1**, courtesy of CBC (2022).

Figure 3-1: Water Levels Rising in 2022 (CBC, 2022)

Community engagement has occurred as part of the flood hazard mapping initiative, as summarized in **Table 3-1**. A map summarizing insights from attendees of the Phase 1 Community Engagement Focus Group is included in **Appendix A**.

Table 3-1: Nahanni Butte Community Engagement Summary

Date	Event Description	Attendees	Outcomes and Discussion
December 18, 2024 [1]	Focus Group at the Band Office to discuss community experiences of flooding, potential flood and erosion mitigation measures, and introduce flood hazard mapping	• Dillon • GNWT Department of Environment and Climate Change (ECC) Water Monitoring & Stewardship Division (virtual) • NBDB chief, council, and community leadership • *Total attendees: 19*	Discussed data collection and preliminary hydraulic modelling. GNWT ECC introduced the flood hazard mapping initiative supported by the federal and territorial governments. Community members shared their past experiences of flooding. Dillon presented a variety of structural and non-structural prevention/mitigation and preparedness options. Chief and council expressed preference for structural protection using a dyke or similar structure.
December 18, 2024 [1]	Public open house at the Recreation Center to discuss experiences of flooding and present potential flood and erosion mitigation measures	• Dillon • Nahanni Butte community members • *Total attendees: 12*	Dillon presented results from data collection and community-led monitoring efforts. Dillon invited community members to comment on preliminary flood maps and share their experiences relating to the 2012 flood of record and other floods. Dillon presented a variety of structural and non-structural prevention/mitigation and preparedness options.
June 11, 2025 [2]	Focus Group at the Band Office to discuss flood hazard mapping and present draft maps	• Dillon • GNWT ECC – Water Monitoring & Stewardship Division • GNWT Municipal and Community Affairs, Dehcho Region • NBDB chief, council, and community leadership • *Total attendees: 12*	GNWT ECC presented the purpose of flood hazard mapping. Dillon provided updates on hydrologic and hydraulic modelling and climate change considerations included in the draft flood hazard maps. Attendees were invited to comment on draft hazard maps.

Notes:
[1] This event was part of Phase 1.
[2] This event was part of Phase 2.

Overall, Nahanni Butte community members and leadership have been extremely engaged and helpful throughout this project, and generally possess an optimistic yet realistic attitude to the community's tendency to flood. There is already a minimum building height in place in the community, and new homes are being constructed on the hilltop where flooding does not occur. Furthermore, no new structures are being approved on the water side of Nahanni Mountain View street, in recognition of the erosion risk.

4.0 Data Collection and Review

4.1 Geospatial Data

The following geospatial data were obtained from the following sources and used to support this study:

- Roads, Waterbodies, Watercourses and Building Footprints
  - Natural Resource Canada/CanVec 50K (NRCan, 2017)
- Arctic DEM
  - Polar Geospatial Center (PGC) at the University of Minnesota
- HYDAT Watershed Layer
  - Environment and Climate Change Canada, 2024
- Nahanni Butte Digital Terrain Model (DTM) (2020)
  - McElhanney, 2020; Provided by Government of Northwest Territories
- Light Detection and Ranging (LiDAR) Data (2020)
  - McElhanney, 2020; Provided by Government of Northwest Territories
- 1980 Flood Risk Map Layers (used as a reference)
  - Government of Northwest Territories (email communication and Administration of the Territorial Lands Act System (ATLAS), 2024)

All Geographic Information System (GIS) data were assessed for consistency with the Canadian Geodetic Vertical Datum of 2013 (CGVD2013) and all elevations are reported in CGVD2013, unless otherwise indicated.

4.2 On-site Data Collection

During Dillon's visit to the community from July 9-12, 2024, Dillon personnel performed several tasks to support the flood assessment. The topographic and bathymetric data described below were incorporated into the hydraulic model as a single surface as described in **Section 6.1**:

- **Drone Survey:** A drone survey was conducted to map the topography within the community, including the collection of topographic data, aerial imagery, and video footage. The banks and nearshore areas were also captured using the drone—a DJI Mavic 3T with RTK module, paired with a GNSS base receiver. This adjustment to the scope was made shortly before the July 2024 site visit, which proved beneficial, as water levels were unusually low at the time. As a result, the bathymetric survey alone would not have adequately captured the nearshore areas. The drone was able to survey portions of the riverbed that had become exposed and were therefore not possible to survey using bathymetric methods;

DILLON CONSULTING

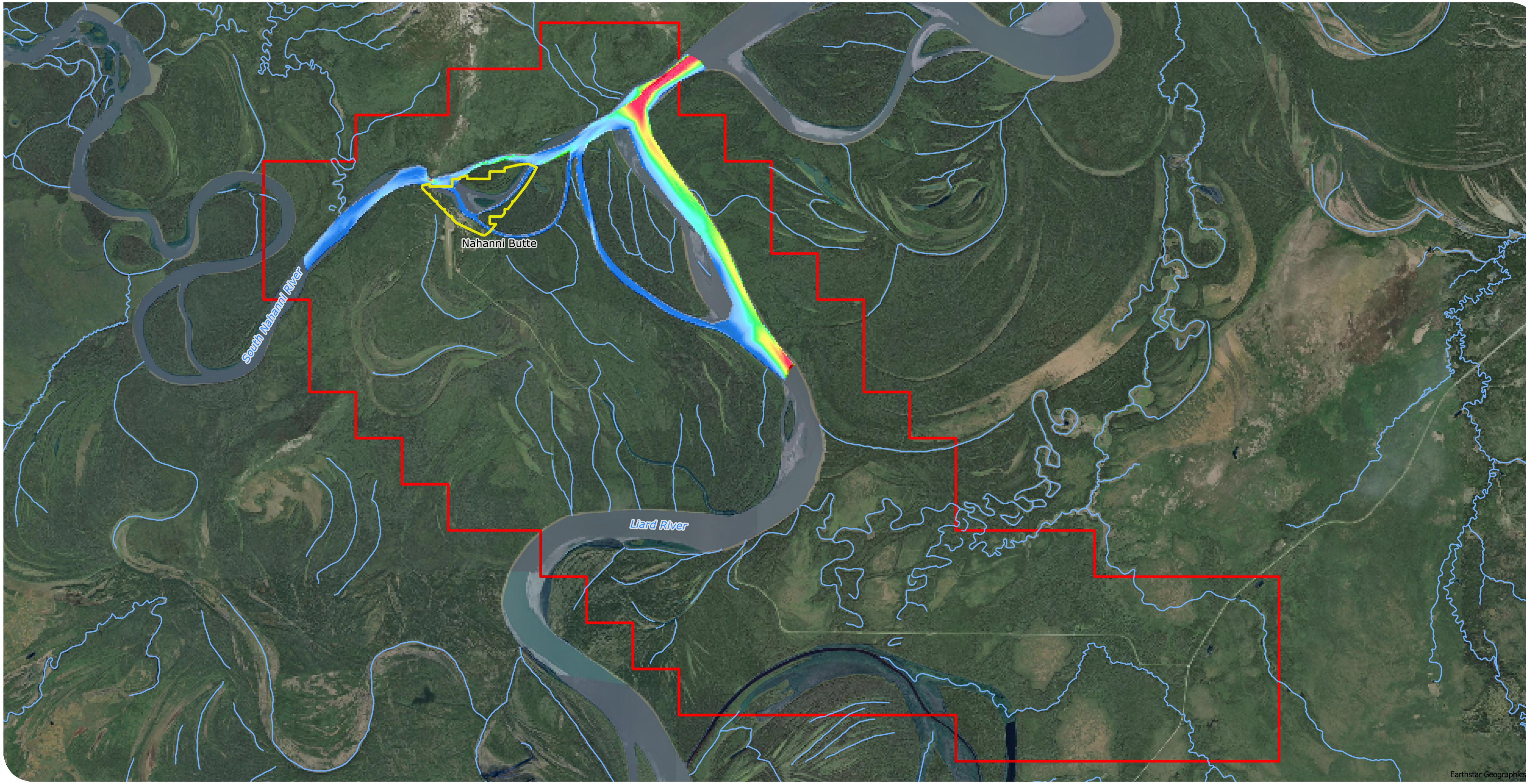
- **Bathymetric Survey:** Dillon collaborated with the band office to commission a personal watercraft to use with Dillon's depth sounder—a Seafloor Hydrolite-Plus Single Frequency Echo Sounder paired with a GNSS receiver—to complete bathymetric mapping of the South Nahanni and Liard Rivers. The extent of the bathymetric survey is shown in **Figure 4-1**. A single ping survey collected bottom elevation at two-second intervals while traversing slowly from shore to shore in a zig-zag pattern. There are no hydraulic structures in the area that would necessitate detailed cross-sections, so the bathymetric survey focused on capturing the braided channels. The survey was conducted along approximately 15 km of the Liard River including 2 km downstream of the confluence with the South Nahanni River and 5 km of a parallel channel of the Liard River, as well as approximately 10 km of the South Nahanni River upstream from the confluence. During the survey, geolocated photos were collected to document representative shoreline and overbank conditions. The water surface elevation in front of the Band Office at this time was approximately 175.5-175.8 m; it fluctuated during the assessment, likely as a result of heavy rains in the headwaters; and
- **Historical Flooding:** Although formal community engagement was scheduled for later in the year, during the July 2024 field trip, Dillon staff spoke with community members and staff about flooding in the community. Through the week, people would comment and bring photos of the 2012 flood. Dillon staff then surveyed the approximate water levels shown in the photos—provided in **Appendix A** — to assist in calibrating the hydraulic model.

4.3 Hydrometric Data

Nahanni Butte is situated approximately 4 km upstream from the confluence of the South Nahanni and Liard Rivers. The South Nahanni River is a significant tributary to the Liard River and flow is characteristic of an alpine catchment regime, where high gradients and low storage capacity result in rapid runoff. To support the hydrologic and hydraulic modelling required for a flood assessment, representative hydrometric data (i.e., water level and flow) were obtained.

An initial screening of Water Survey of Canada (WSC) hydrometric gauges was conducted within a 150 km radius of the Nahanni Butte community (Latitude: 61° 2' 8.7288" N, Longitude: 123° 23' 34.3212" W). Following the screening, ten stations within the predefined radius were identified, namely 10BD001, 10DA001, 10DB001, 10EA003, 10EB001, 10EC001, 10EC002, 10EC003, 10ED001, and 10ED002. Characteristics of the watershed including drainage area, location, land use, and development attributes linked to each hydrometric station were subsequently reviewed. To assess the relevance of these stations to the study area, these characteristics were compared to those of the drainage area to Nahanni Butte. For each of the stations, a single station flood frequency analysis was completed as discussed in **Section 5.0** using the statistical software HYFRAN-Plus. The results of these analyses are provided in *Appendix C* of the Phase 1 report. Historical 1% Annual Exceedance Probability (AEP) (corresponding to a 1 in 100-year return period) unit runoff rates were calculated for each station based on the 1% AEP instantaneous peak flow rates and linked tributary drainage areas. The best fitted distribution for each station is provided in **Table 4-1**.

Four hydrometric stations in the region (Flat River (10EA003), South Nahanni River (10EB001 and 10EC001), and Liard River (10ED001)) were found to be most representative of the watershed in the study. Details of these WSC stations are provided in **Table 4-1**.



175.03 m
158.18 m

2024 Drone Extent (Dillon)
2020 LiDAR Extent (McElhanney)
Watercourse
Waterbody

NAHANNI BUTTE FLOOD ASSESSMENT

Flood Hazard Mapping

BATHYMETRIC AND AERIAL SURVEY COVERAGE

FIGURE 4-1

DILLON CONSULTING

MAP DRAWING INFORMATION:
DATA PROVIDED BY ESRI Base Imagery, GWNT, Dillon Consulting Limited

MAP CREATED BY: DS
MAP CHECKED BY: ML
MAP PROJECTION: NAD 1983 CSRS UTM Zone 10N

SCALE 1:80,000

0 0.75 1.5 3 Kilometers

N W E S

PROJECT: 237137 STATUS: FINAL DATE: 2025-08-20

FILE LOCATION: K:\2023\237137\Product\Client\NahanniButte_2025\NahanniButte_2025.aprx; LAYOUT: Figure_4-1_Extent of Bathymetric & Aerial Survey

Table 4-1: Relevant Regional Hydrometric Station Summary

Station Name	Station Number	Distance from Site (km)	Drainage Area (1,000 km^2)	Watershed Land Use	Instantaneous Peak Flow - 1% AEP Unit Runoff Rate (m^3/s/km^2)	Best Fitted Distribution
Flat River Near the Mouth	10EA003	121	8.56	Forested, with varying vegetation densities, and rocky terrain.	195.09	Log-normal
South Nahanni River Above Virginia Falls	10EB001	144	14.50	Forested, with varying vegetation densities, rocky terrain, and areas devoid of vegetation.	158.62	Normal
South Nahanni River Above Clausen Creek	10EC001	44	31.10	Forested, with varying vegetation densities, rocky terrain, and areas devoid of vegetation.	138.91	Log-normal
Liard River at Fort Liard	10ED001	88	222.00	Forested, with varying vegetation densities, rocky terrain, and areas devoid of vegetation.	66.67	Normal

Data for the four WSC stations were obtained from the HYDAT database for instantaneous peak discharge rates using the R software package 'tidyhydat' (Albers, 2017). The periods of record for each of the stations were initially assessed for any gaps in the data. The span of available records varies among the stations as shown in **Table 4-2**.

Table 4-2: Period of Recorded Daily Flow and Instantaneous Annual Peak Flow for Relevant Hydrometric Stations

Station Name	Station Number	Drainage Area (1000 km^2)	Period of Recorded Flow	Complete Years[1]	Period of Annual Instantaneous Peak Flow	Years with Peak Flow Reported
Flat River Near the Mouth	10EA003	8.56	1960-2023	44	1961-2023	47
South Nahanni River Above Virginia Falls	10EB001	14.50	1962-2019	46	1963-2019	46
South Nahanni River Above Clausen Creek	10EC001	31.10	1969-1995	23	1969-1995	23
Liard River at Fort Liard	10ED001	222.00	1942-2021	53	1966-2019	49

Note:
[1] Complete years defined as years with no missing daily flows.

The datasets presented in **Table 4-2** represent the most current data available at the time of reporting. Hydrometric data is currently undergoing quality checks with the Water Survey of Canada and the datasets are anticipated to be published to the end of 2024 for 10EA003, 10EB001, and 10ED001 by the end of 2025 (Personal communication, 2025). A recently established hydrometric gauge immediately upstream of Nahanni Butte on the South Nahanni River, 10EC004, was installed in fall 2024 and just over three months of level data are published to the end of 2024. This gauge was not used in this analysis but will be useful in future years to reflect conditions in the community.

The Historical Flood Review of Nahanni Butte (Kriwoken, 1983) reported that no past flooding incidents caused by the spring break-up of the Liard River at the South Nahanni River had been reported at Nahanni Butte. Rather, summer flooding in June/July has occurred due to the late break-up of the South Nahanni River and extreme summer storm events. The instantaneous peak flow data for the selected hydrometric gauges generally align with the information presented in the Historical Flood Review of Nahanni Butte. Most of the annual instantaneous peak flows occur in late May to late July. This is illustrated in **Figure 4-2**, which compares the peak annual instantaneous discharges for selected hydrometric stations, normalized by watershed area to represent the relative timing of annual peaks.

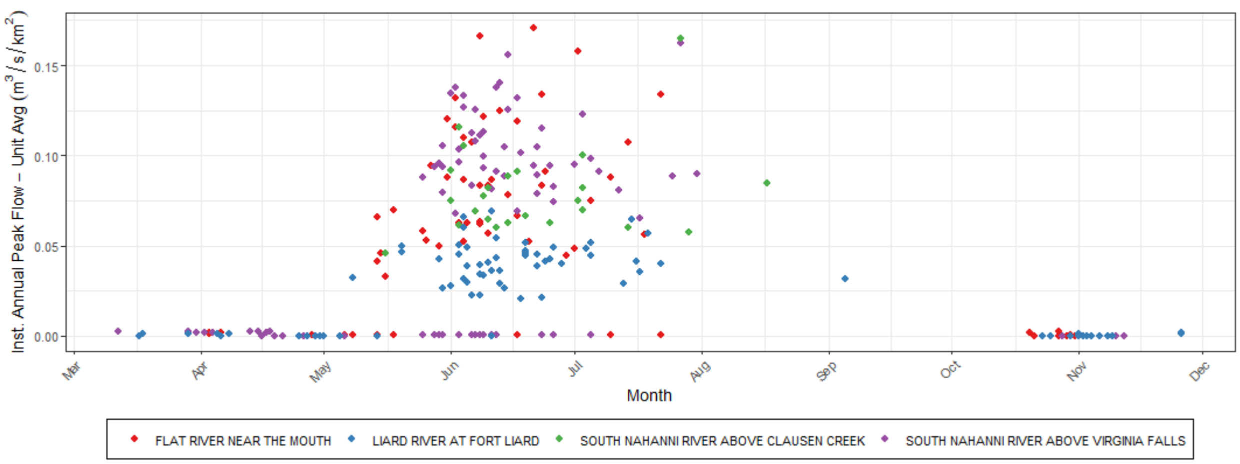


Figure 4-2: Peak Annual Instantaneous Discharge for Selected Hydrometric Stations

From this analysis, it is evident that the hydrologic regime of the South Nahanni and Liard Rivers is primarily governed by spring snow melt that typically occurs in late May to early July. During this time, the watershed can be further impacted from rain on snow during the freshet.

5.0 Hydrologic Assessment

The primary objective of the hydrologic assessment is to estimate peak flow rates for the South Nahanni and Liard Rivers to be used as boundary conditions in the hydraulic model. Hydrologic modelling was completed using a published Raven hydrologic model developed and calibrated for the South Nahanni River and Liard River basins (Brown and Craig, 2020), which was updated to specifically reflect conditions at the confluence of the two rivers.

To estimate historical flood magnitudes, two statistical approaches were used to determine annual exceedance probabilities (AEPs) as described in **Section 5.3**:

- A Regional Flood Frequency Analysis (RFFA) used historical records from nearby hydrometric stations, and
- A single-station flood frequency analysis (FFA) was applied to simulated 1988-2022 model results.

The RFFA and FFA results were compared to select the appropriate magnitude for historical floods. The statistical assessment of the climate change results is also presented in **Section 5.3**. The generation of hydrographs, described in **Section 5.4**, enabled the assessment of future flow rates in various climate change scenarios and were subsequently used in the hydraulic modelling (**Section 6.0**) to produce water levels for flood inundation and hazard mapping.

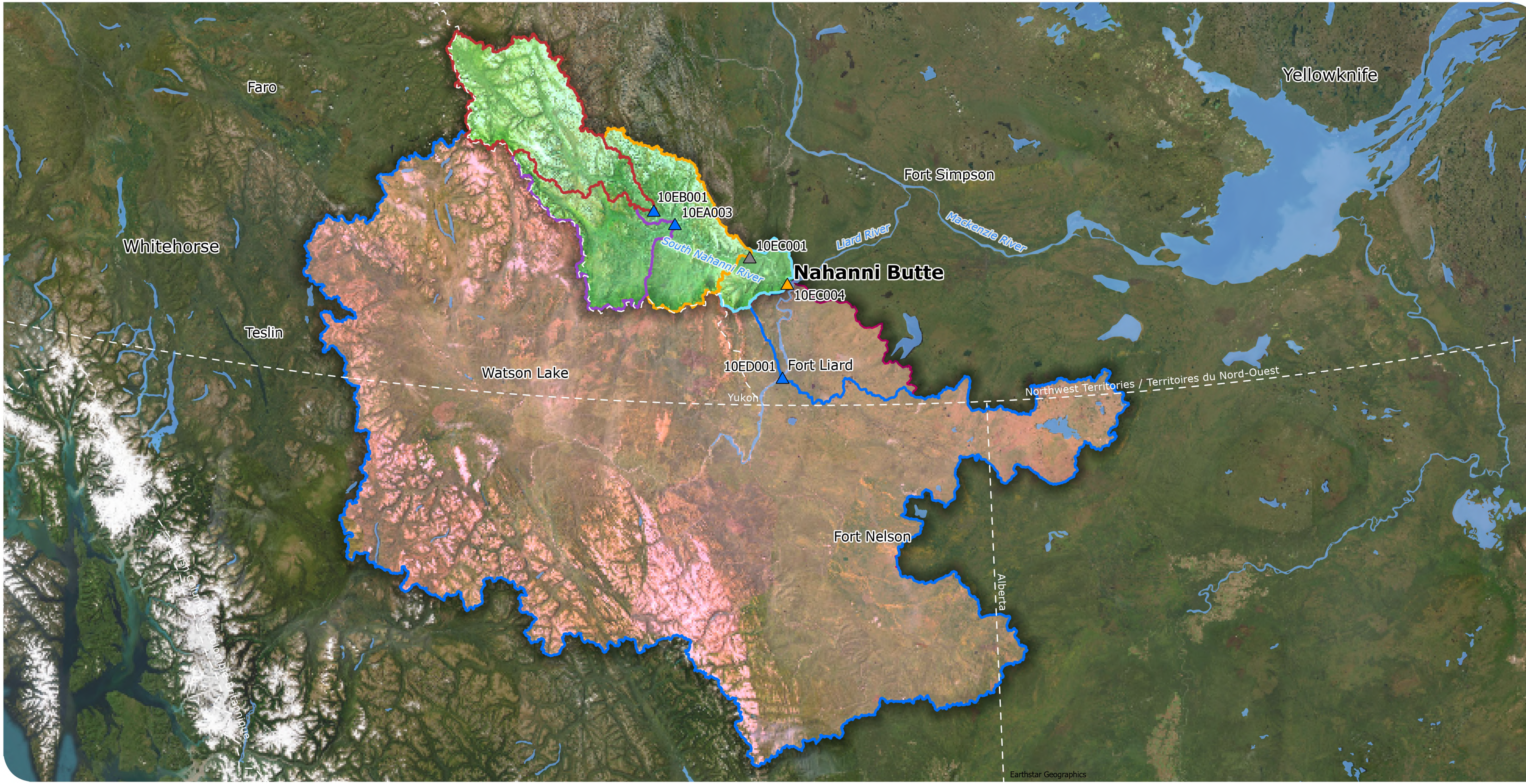
5.1 Drainage Area Delineation

The drainage area was manually delineated using ArcMap, with the aid of available LiDAR data for the surrounding area. An 800-m Arctic Digital Elevation model (ArcticDEM) for Northwest Territories was used to generate 25 m elevation contours within ArcMap, facilitating the delineation of the watershed contributing to the study area.

To support the delineation process, the Northwest Territories Inland Waters data (NWT Inland Water) was employed in ArcMap to identify the locations of watercourses. The NWT Inland Water database, managed by the NWT Centre for Geomatics, provides high-quality geometric descriptions and a set of basic attributes related to Northwest Territories' inland surface waters, including lakes, rivers, streams, and other watercourses. The database is accessible through various formats, including Web Map Services (WMS) and KMZ files, facilitating integration into GIS applications. The drainage area of the closest gauges to the study area including 10EC001 on the South Nahanni River (drainage area 31,100 km^2) and 10ED001 on the Liard River (drainage area 222,000 km^2) were extracted from this database and used as a starting point. Then, the boundary of the watersheds contributing to the Nahanni Butte community location (approximately at the confluence of the South Nahanni and Liard Rivers) was delineated using the contours derived from ArcticDEM.

The published Raven model includes subbasins throughout the overall watershed areas that correspond to suitable drainage basins as determined by Brown and Craig (2020). The subbasins were updated for this assessment by dividing the subbasins at the confluence of the South Nahanni and Liard rivers, which was necessary in order to obtain boundary condition hydrographs for the hydraulic modelling. The total drainage area in the Raven model—268,700 km^2—differs slightly from that delineated using ArcticDEM. The delineation performed in Brown and Craig (2020) used the 2013 Canadian Digital Elevation Model, leading to a slightly different drainage boundary, which is nonetheless similar to the boundary derived in this study.

The total drainage area contributing to the community is approximately 264,900 km^2 at the confluence of the South Nahanni (36,100 km^2) and Liard (228,800 km^2) Rivers, as depicted in **Figure 5-1**.



NAHANNI BUTTE FLOOD ASSESSMENT
Flood Hazard Mapping

South Nahanni Watershed ($36,100\ km^2$)
Liard Watershed ($228,800\ km^2$)

Hydrometric Station
Active Hydrometric Station (Installed September 2024)
Historical Hydrometric Station
Active Hydrometric Station

Hydrometric Station Basin
10ED001
10EC004
10EC001
10EA003
10EB001

WATERSHED AREAS
FIGURE 5-1

DILLON CONSULTING

MAP DRAWING COMPONENTS DATA SOURCES:
Base Imagery: ESRI
Watershed Polygons: GNWT
Labelling: Dillon and NRCan

MAP CREATED BY: DS
MAP CHECKED BY: ML
MAP PROJECTION: NAD 1983 CSRS UTM Zone 10N

SCALE 1:3,500,000
0 35 70 140 km
N W E S

PROJECT: 237137 STATUS: FINAL DATE: 2025-08-20

FILE LOCATION: K:\2023\237137\Product\Client\NahanniButte_2025\NahanniButte_2025.aprx; LAYOUT: Figure_5-1_Watershed Areas and Station watershed

5.2 Hydrologic Modelling Methodology

A hydrologic model for the Liard River basin was updated for this study. The primary goals of these modifications were to extend the model's data series, introduce a new outlet for the hydraulic model, and improve its performance for the new data period. The changes made and the subsequent recalibration are summarized below. All simulated results from the Raven model are at a daily timestep.

5.2.1 Model Updates and Recalibration

The Raven Hydrologic Model is an open-source, object-oriented framework for hydrological modeling developed at the University of Waterloo. Its core strength lies in its flexibility, allowing users to build customized hydrological models by selecting from over 100 available process algorithms and various options for spatial discretization, interpolation, and forcing function generation. This adaptability means Raven can mimic existing hydrological models (in this case, Hydrologiska Byråns Vattenbalansavdelning – Environment Canada (HBV-EC)), facilitate the testing of different model structures, assess structural uncertainty, and explore key research questions related to hydrological processes and their representation. The Liard River basin, including the South Nahanni River, was the subject of a Raven model that was developed and calibrated as reported in Brown and Craig (2020). This published model was the foundation of the hydrologic assessment for this project.

The published Liard River basin model structure is a variant of the HBV-EC model (Hamilton et al., 2000), which is a rainfall-runoff model that includes routines for key hydrologic processes such as evaporation and baseflow, and also includes modules for simulating glacial melt, which is applied within the Liard River model. The hydrologic model structure also contains some modifications made to improve the HBV-EC model for this region, for example, depressional storage in 'wetland'-like hydrologic response units (HRUs), and conditional application of some hydrologic processes for specific regions in the model (e.g., the South Nahanni River sub-basin is treated differently from the rest of the model). The published model is semi-distributed and was built and initially calibrated to a daily timestep. The model is best described as "conceptual", where the algorithms reflect how the hydrologic cycle conceptually operates. For example, snow melt follows a degree day method with an allowance for snow to refreeze. Infiltration is tied to the ratio of soil water content, which is reflective of physical concepts without the rigour of solving Richard's equation. The storage units and parameters in the model have a physically interpretable meaning, but are conceptually abstracted to the HRU or subbasin scale and generally cannot be physically measured in the field.

The published hydrologic model was updated for this study by updating the delineation for a new outlet of interest, updating the timeseries to include recent data, and recalibrating the model using the latest time series. These updates are described in detail below.

1. The first step was to update the delineation manually to introduce a new outlet of interest in the Nahanni Butte area (i.e., splitting subbasin 12 at the confluence), allowing for output hydrographs at

this location to be used as upstream boundary conditions in the hydraulic model. The HRU properties were also updated accordingly. It is noted that only subbasin shapefiles are available for this project as the original published methodology abstracted the HRU locations during an HRU simplification step, which merges small HRUs into larger ones (Brown and Craig, 2020). This means that the HRUs are represented in the model within each subbasin, but specific HRU boundaries within the subbasin are not mapped.

2. The next step was to extend the streamflow and meteorological data time series to the most recent available data. This allowed the model to simulate the 2022 flood event, as described in **Table 2-1** (**Section 2.1**). (initially the model was only set to run until October 1, 2005). Some meteorological stations were excluded from the updated version due to a lack of available data in the 2005-2022 timespan (see **Table 5-1** for relevant data periods in the model). The meteorological data was processed and quality-controlled for this time, including interpolating to fill missing data and correcting some gauge issues (e.g., minimum temperature reported as greater than the maximum temperature). Interpolation of meteorological data was performed using the `rvn_met_interpolate` function from the RavenR package (Chlumsky et al., 2022), which uses an inverse distance weighting approach with data from nearby stations with available data. Streamflow data was interpolated at key stations for later use in assimilation using a linear interpolation method (`na.approx` in R) within each time series individually.
3. Finally, the model was recalibrated at this stage. This was due to the introduction of new meteorological data than the initial calibration period, warranting a need to account for both a new period of data as well as the shifting stations that are included in the model.

Table 5-1: Data Periods for Streamflow Stations, Meteorological Stations, and Model Simulations

Station Name and Description	Start Date	End Date
Meteorological Stations		
Dease Lake	1985-01-01	2025-02-26
Fort Nelson A	1985-01-01	2025-02-26
Tetsa River	1985-01-01	2025-02-26
Muncho Lake	1985-01-01	2025-02-26
Hour Lake (removed from model)	1982-01-01	2017-09-27
Tuchita (removed from model)	1970-01-01	2017-09-27
Watson Lake A	1985-01-01	2025-02-26
Fort Simpson A	1985-01-01	2025-02-26
Wrigley A	1985-01-01	2020-08-02
Keg River	1985-01-01	2021-12-11
Key Streamflow Stations		
LIARD RIVER AT FORT LIARD (10ED001, subbasin 32)	1942-10-01	2022-01-01
SOUTH NAHANNI RIVER ABOVE VIRGINIA FALLS (10EB001, subbasin 3)	1962-01-01	2019-11-11
FLAT RIVER NEAR THE MOUTH (10EA003, subbasin 8)	1960-06-01	2022-09-30

Station Name and Description	Start Date	End Date
Model Periods		
Published full period	1985-10-01	2005-09-30
Published calibration period	1986-10-01	1996-09-30
Published validation period	1996-10-01	2005-09-30
Re-calibration period	1986-10-01	2022-09-30

The calibration was limited in scope to aim for a high performance under the adjustments made in the model but without performing a complete recalibration of the entire model, nor updating any model algorithms or structural components. Thus, the calibration was focused primarily on snowmelt parameters, which are listed in **Table 5-2**. Additional parameters exist in the model that were not re-calibrated in this exercise. The snowmelt factors are applied individually for HRUs classes, though the calibration focused on FOREST-type HRUs, as these constitute approximately 70% of the model.

Table 5-2: Hydrologic Model Parameters used in Model Calibration

Raven Parameter	Description	Units	Calibrated Value	Low Value	High Value	Details
REFREEZE_FACTOR	Factor dictating rate of snow refreezing	mm/d/dC	0.19	0	5	
MIN_MELT_FACTOR	Factor dictating the minimum melt factor of a snowpack	mm/d/dC	1.02	1	3	
MELT_FACTOR	Factor dictating the maximum snow melt rate of a snowpack	mm/d/dC	3.71	1	6	Setup as a tied parameter to ensure it is >= MIN_MELT_FACTOR
HBV_MELT_ASP_CORR	Correction factor for melt by aspect	[0..1]	0.46	0.05	1	
HBV_MELT_FOR_CORR	Correction factor for melt in forested areas	[0..1]	0.33	0.05	1	
RAIN_ICEPT_PCT	Percentage of rain to be intercepted by the canopy	[0..1]	0.10	0	0.2	
SNOW_ICEPT_PCT	Percentage of snow to be intercepted by the canopy	[0..1]	0.12	0	0.3	
RAINSNOW_TEMP	Temperature at which precipitation fractionation begins to split snow into rain	dC	2.45	-3	3	
RAINSNOW_DELTA	Difference in precipitation fractionation from precip being all snow or all rain	dC	2.84	0.5	4	
TOC_MULTIPLIER	Multiplier on the time of concentration (globally)	-	2.00	0.5	3	Manually set to 2.0 as a more reasonable value without diminishing results

The model recalibration setup the objective function on an improvement in Kling Gupta Efficiency (KGE) scores at key watershed locations for this project (i.e., subbasins 3, 8, and 32). The resulting hydrographs were similar to the original model but with a small improvement in volume bias. A summary of the KGE improvements at key model locations is provided in **Table 5-3**.

Table 5-3: Summary of Recalibration Metric Improvements at Key Stations

Station	KGE original	KGE recalibrated	Improvement
10EA003 (Subbasin 8)	0.699	0.737	0.038
10EB001 (Subbasin 3)	0.629	0.701	0.072
10ED001 (Subbasin 32)	0.832	0.855	0.023
10ED002 (Subbasin 63)	0.802	0.856	0.053

Validation was not performed in this project as the model structure had been previously validated by Brown and Craig (2020), and the objective here was to ensure high performance for applied use. As such, the advice of Shen et al. (2022) was followed, which is to use all available data in calibration rather than to reserve data for validation.

The recalibrated model was used to simulate the desired flood scenarios under both existing and future climate conditions. To simulate historical floods as accurately as possible, the model used real measured streamflow data from upstream gauge stations (where available) to override the streamflow in the model at key locations. This historical data was adjusted (interpolated) to fill missing values and was then inserted directly into the model at specific locations. With this approach, the model did not need to simulate streamflow throughout the entire upstream watershed—reducing uncertainty and improving reliability in the results. Additional details of the flood scenarios established for this assessment are provided in the following section.

5.2.2 Flood Scenarios

The selection of scenarios for flood simulation involves consideration of joint probabilities between peak flows of both the South Nahanni and Liard Rivers, key mechanisms of streamflow flood events such as distinguishing between rain on snow and rain-driven events, initial conditions in snowpack and antecedent soil moisture. The precise conditions and annual exceedance probabilities (AEPs) to consider in the flood scenarios have been developed through consideration of the Federal Flood Mapping Guidelines and in consultation with project team partners at GNWT, ECCC, and NRCan.

The flow dynamics at the confluence of the South Nahanni and Liard Rivers are a driving force in flooding in the community. Rather than separating major events on the two rivers, the flood scenarios assumed that peak flows corresponding to the chosen AEPs are concurrent; e.g., the 1% AEP peak flow on the Liard River occurs in the same year and on the same day as the 1% AEP flow on the South Nahanni River. This is generally considered a conservative assumption, though given the relatively long peaks in this system, this is a reasonable assumption. Maximum daily flows corresponding to the flood scenarios were extracted from the continuous model.

Unlike other riverine communities in the NWT, Nahanni Butte experiences open water flooding rather than ice jam-driven flooding, thus the AEPs were chosen according to GNWT recommendations for open water flooding: the 1% AEP (1 in 100-year) and 0.5% AEP (1 in 200-year) flood flows were considered for the historical conditions, and were compared to RFFA as described in **Section 5.3**.

A climate change sensitivity analysis was conducted to evaluate the hydrologic response of the South Nahanni and Liard River basins to changing climate and provide insights to select the climate change flood scenarios for the future. Two future scenarios were selected in collaboration with the project team partners through the sensitivity analysis.

5.2.3 Climate Change Sensitivity Analysis

Climate change can significantly influence the community's flood risks through changes in the timing, intensity, duration, amount, and phase (rain/snow) of precipitation events. A detailed climate change sensitivity analysis was completed for the South Nahanni and Liard River basins considering various future climate scenarios. In absence of NWT-specific guidelines to incorporate climate change in flood mapping, the climate change scenarios have been established based on consultation with GNWT, NRCan, and ECCC and in accordance with the Federal Flood Mapping Guidelines. The considerations included climate change datasets, global climate model, time horizon, and emissions scenarios as described below.

5.2.3.1 Datasets

For the climate change sensitivity analysis, the Sixth Coupled Model Intercomparison Project (CMIP6) climate projections statically downscaled by Environment and Climate Change Canada (ECCC)'s Climate Research Division (CRD) and the Pacific Climate Impacts Consortium (PCIC) was used. This dataset has the required precipitation and temperature projections available at a 10 km spatial resolution for the time frame of 1950-2100. The downscaled datasets are available for 26 Global Climate Models (GCMs) and Ensemble of Models under three Shared Socioeconomic Pathways (SSPs) (Riahi et al., 2017) from CMIP6 (Eyring et al., 2016) using two distinct downscaling methods including CanDCS-U6 (univariate downscaling) and CanDCS-M6 (multivariate downscaling).

For the purpose of this assessment, CanDCS-M6 was used as outlined in the technical notes of the dataset that the univariate scaling, "can omit or poorly represent important phenomena that are characterized by combinations of temperature and precipitation" (Government of Canada, 2025).

5.2.3.2 Global Climate Model

As recommended in the Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation (NRCan, 2023), the ensemble of models was used due to inherent uncertainties of GCMs and interdependencies among models (Jeong, D. I., & Cannon, A. J. 2023). For the model ensemble, percentiles from statistics are used to summarize the range of results from the multi-model ensemble. In this study, the commonly used percentiles including median (50th percentile), 25th and 75th percentiles (outlined by Canadian Centre for Climate Services) were considered for temperature and precipitation (EBNFLO Environmental AquaResourc Inc., 2010).

The median percentiles can be interpreted as the "expected" projection, and the combination of 25th percentile temperature and 75th percentile precipitation may be viewed as a more conservative set of possibilities that would likely lead to greater peak flows during future flood events (i.e., lower winter temperatures leading to greater snowpack buildup with higher rain on snow volumes during the spring freshet) (Ouranos Consortium, 2023). These scenarios were used to encompass a range of possible future climate scenarios while determining appropriate flow rates to use in this flood hazard study. A more conservative combination of percentiles, i.e., 5th percentile temperature and 95th percentile precipitation, was not selected, as these represent a much more substantial decoupling of variables from the underlying climate modelling and was deemed to represent an overly conservative scenario.

5.2.3.3 Time Horizon

Climate change impacts are expected to intensify over time, and near-term climate model projections are generally more certain. When planning for the future, other Canadian jurisdictions, such as British Columbia Ministry of Environment (Ausenco Sandwell, 2011), City of Surrey (Northwest Hydraulic Consultants, 2017), and City of Moncton (City of Moncton, 2013), often select a planning horizon (like the year 2050) for infrastructure planning or land use decisions. In this study, the calibrated hydrologic model was run continuously from 2022 to 2100. This approach enabled analysis across multiple time periods within the simulation window, providing a more comprehensive understanding of future conditions. The results and assessment are discussed in **Section 5.3.3**.

5.2.3.4 Emissions Scenarios

Two commonly used emissions scenarios, moderate- and high-emission scenarios (SSP2-4.5 and SSP5-8.5, respectively) were selected to be used in the sensitivity analysis. A summary of the proposed scenarios to perform the climate change assessment is provided in **Table 5-2**.

The scenarios are based on the Shared Socio-economic Pathways (SSPs). SSPs are narratives that describe a range of possible future global developments, including population, economic growth, and technological change (ClimateData.ca, n.d.). The number following the SSP (e.g., -4.5) represents the estimated radiative forcing in the year 2100, measured in watts per square metre (W/m^2). Radiative forcing is a measure of the change in the Earth's energy balance due to a climate driver, such as greenhouse gases, with a positive value indicating a warming effect.

- SSP2-4.5, or the "Middle of the Road" scenario, describes a future where social, economic, and technological trends do not significantly deviate from historical patterns. It represents moderate challenges to both climate change mitigation and adaptation, with a projected radiative forcing of 4.5 W/m² by 2100.
- SSP5-8.5, or "Fossil-Fueled Development," is a scenario characterized by rapid economic growth and high energy demand—primarily met by fossil fuels—and presents significant mitigation challenges, with a projected radiative forcing of 8.5 W/m² by 2100.

Figure 5-2 depicts the SSP scenarios and their five families, showing illustrative temperature levels relative to pre-industrial levels. It shows historical temperatures, current temperatures (as of 2020), and the projected branching of the scenarios over the 21st century. The small black horizontal bars on the 2100 pillars for each SSP indicate the illustrative temperature levels for the range of scenarios available from the Integrated Assessment Model (IAM) community when the baseline SSP scenarios were created. The source for this figure is Meinshausen et al. (2020).

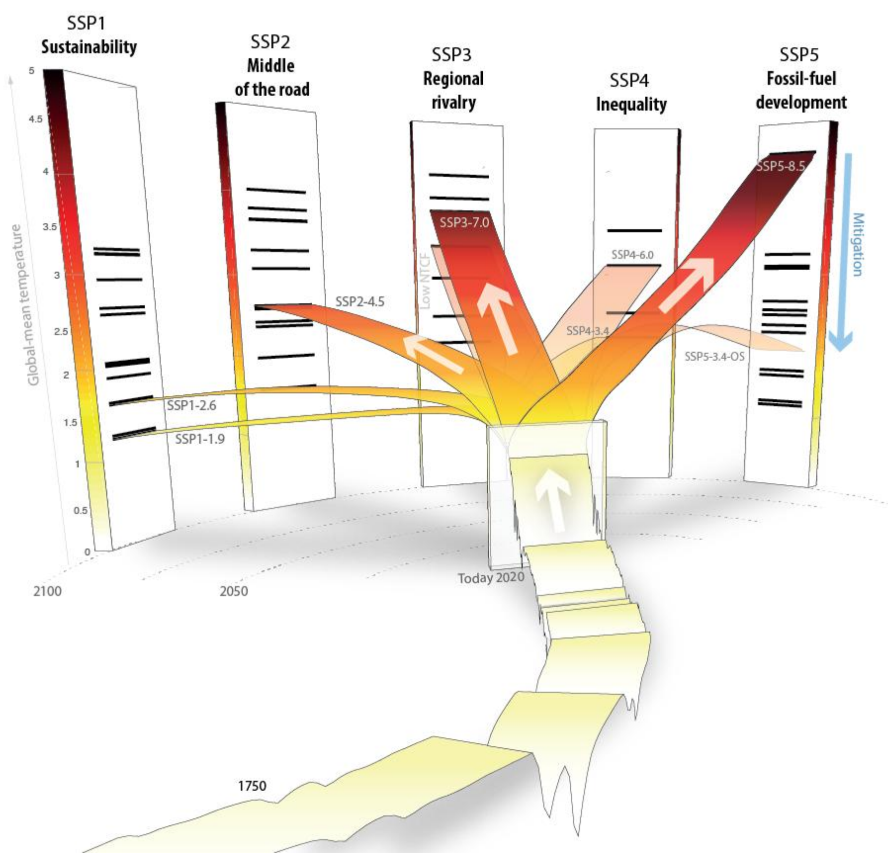


Figure 5-2: Shared Socio-economic Pathways (SSPs) and Illustrative Temperature Levels

Table 5-4: Proposed Scenarios for Climate Change Sensitivity Analysis

Climate Change Scenario Name	Emission Pathway Scenario	Model	Modelling Period	Temperature Percentile	Precipitation Percentile
Moderate Emission-Median Condition	SSP2-4.5	Ensemble	2022-2100	50th	50th
Moderate Emission-Cool/ Wet Conditions	SSP2-4.5	Ensemble	2022-2100	25th	75th
High Emission-Median Conditions	SSP5-8.5	Ensemble	2022-2100	50th	50th
High Emission-Cool/ Wet Conditions	SSP5-8.5	Ensemble	2022-2100	25th	75th

Sensitivity analysis results for the above climate change scenarios are provided in **Section 5.3.3**. Note that the time horizon for the hydraulic modelling can be selected from any period within the extended timeframe of 2022 to 2100.

5.3 Statistical Assessment

The flow data from the hydrometric stations (as described in **Section 4.3**) and the continuous hydrologic model results (described in **Section 5.2**) must be understood in terms of annual exceedance probability (AEP) using statistical relationships. This section outlines the statistical assessment methodologies employed in this study to conduct regional flood frequency analysis on hydrometric data and single-station flood frequency analysis on the hydrologic model results to deepen our understanding of the South Nahanni and Liard Rivers.

5.3.1 Data Assumptions for Flood Frequency Analysis

The Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation (NRCan, 2023) identifies several key assumptions that must be checked before a flood frequency analysis (FFA) can be undertaken. That is, the data must be independent, homogeneous, and stationary. To do this, Dillon used three different probability tests to assess the applicability of the data series:

- **Wald-Wolfowitz Test of Independence:** non-parametric statistical test that checks a randomness hypothesis for a two-valued data sequence. In other words, it can evaluate whether the elements of a sequence are occurring randomly and independently of each other;
- **Kendall Stationarity Test:** non-parametric statistical test is used to detect any prominent trends in time-series data. The main objective of Kendall's stationarity test is to evaluate whether the variability of the time-series data remains constant over time; and
- **Wilcoxon Homogeneity Test (at annual scale):** non-parametric statistical test that compares two related samples to assess whether their population mean ranks differ. It is a paired difference test and an alternative to the paired student's t-test when the population cannot be assumed to be normally distributed.

For ease of interpretation, p-values (or probability values) can range from 0 to 1. Values close to 0 would indicate a significant result, whereas values close to 1 would signify a result that is very unlikely to be significant. The current analysis uses the 5% threshold to assess statistically significant; therefore, if a p-value falls below 0.05 it would be identified as significant, whereas values greater than 0.05 would not be statistically significant.

The results of the probability tests for the instantaneous peak flow, and maximum daily flow rate, for the regional stations introduced in **Section 4.3** are presented in **Table 5-5**.

Table 5-5: Probability Test Results of Chosen Gauge Stations

Dataset	Results for Instantaneous Peak Flow			Results for Maximum Daily Flow		
	Wald-Wolfowitz p-value	Kendall p-value	Wilcoxon p-value	Wald-Wolfowitz p-value	Kendall p-value	Wilcoxon p-value
Flat River Near the Mouth	0.494	0.536	0.689	0.242	0.842	0.795
South Nahanni River Above Virginia Falls	0.694	1	0.451	0.470	0.883	0.658
South Nahanni River Above Clausen Creek	0.630	0.967	0.660	0.857	0.505	0.610
Liard River at Fort Liard	0.786	0.368	0.527	0.505	0.238	0.775

We therefore accept that the instantaneous peak flow and maximum daily flow results are independent, stationary, and homogeneous.

The following extreme value statistical probability distributions were subsequently assessed for goodness-of-fit using the HYdrological FREquency ANalysis-Plus (HYFRAN-Plus) software package (INRS, 2008). HYFRAN-Plus is a specialized tool developed by Institute National de la Recherche Scientifique, Canada (INRS):

- Normal;
- Lognormal;
- Gamma;
- Gumbel;
- Log-Pearson type III;
- Pearson type III; and
- Weibull.

Distributional parameter estimates were estimated using the method of maximum likelihood (ML) where possible and the method of moments where ML estimates could not be attained. Comparative goodness-of-fit was initially assessed using probability plots of the aforementioned statistical distributions. Those displaying an adequate fit, particularly in the upper tail (where the fit of extreme value distribution is most critical when considering low frequency, high magnitude events) were comparatively assessed using the minimum Akaike Information Criterion (AIC), which is a measure of model fit and additionally addresses potential overfitting of a prospective statistical model.

5.3.2 Regional Flood Frequency Analysis

A Regional Flood Frequency Analysis (RFFA) was completed using available hydrometric data in the vicinity of Nahanni Butte as described in **Section 4.3**. RFFA is a method used in hydrology to estimate flood risks and characteristics across a specific geographic region. This technique describes regional watershed characteristics, especially in areas with limited local data, by drawing on extensive datasets from nearby stations as described in **Section 4.3**. Unlike approaches that rely solely on local or simulated data, RFFA leverages historical flood data from multiple monitoring sites within a region. This approach was used to estimate the magnitude of the historical annual exceedance probabilities of 1% and 0.5%. This was done on two datasets: the first is the timeseries of annual instantaneous peak flowrates, which is expected to generally be greater than the second dataset, a timeseries of annual maximum daily flow rates.

The temporal resolution of the hydrologic model is daily, therefore, a daily flow rate was required to scale the hydrograph for each mapped scenario, which is discussed in more detail in **Section 5.4**. One limitation of this approach is that the maximum daily flow rate is generally expected to be less than the instantaneous peak flow. Instantaneous peak flows are provided for the regional stations described in **Section 4.3**.

The RFFA was then completed using the four WSC hydrometric stations detailed above, with resultant R^2 values of 0.999 for both the 100-year and 200-year return periods for the instantaneous peak flow timeseries. The results of the regression analysis are shown in **Figure 5-3**.

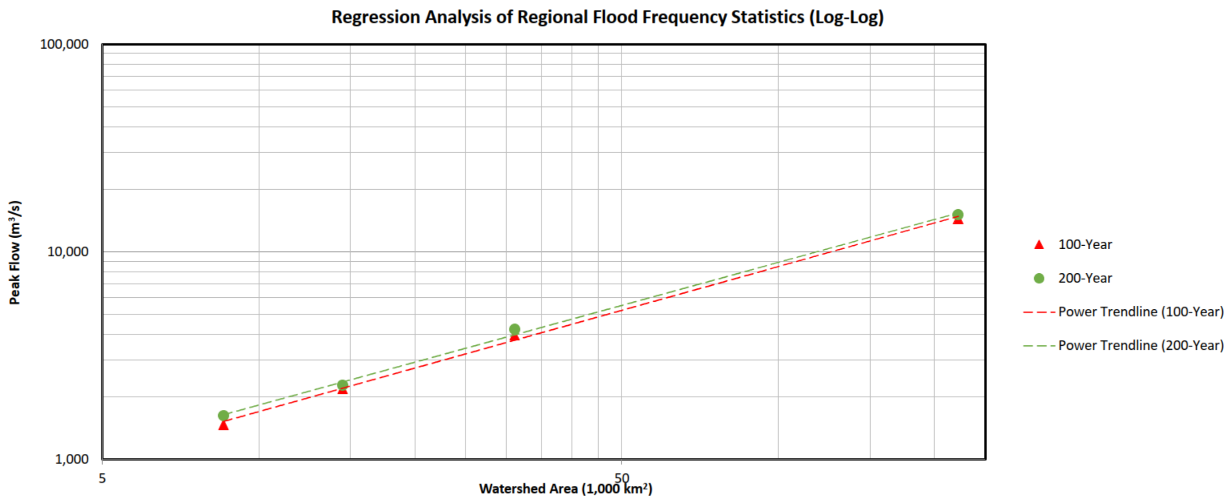


Figure 5-3: Regression Analysis of Regional Flood Frequency Statistics (Log-Log)

The statistically derived RFFA flow rate for the South Nahanni and Liard Rivers was prorated by drainage area (36,100 km^2 and 228,800 km^2, respectively) to approximate instantaneous peak flows and maximum daily flows for each return period. The results of the frequency analysis are shown in **Table 5-6**.

Table 5-6: Estimated Historical Flows by Return Period Based on Regional Frequency Analysis

AEP (%)	South Nahanni River at the Confluence		Liard River at the Confluence	
	Instantaneous Peak Flow Rate (m^3/s)	Maximum Daily Flow Rate (m^3/s)	Instantaneous Peak Flow Rate (m^3/s)	Maximum Daily Flow Rate (m^3/s)
1	4,440	4,172	15,430	15,139
0.5	4,716	4,422	16,084	15,709

This comparison of instantaneous and daily maxima highlights an important distinction in the anticipated flood magnitude. Instantaneous peak flows represent the absolute highest flow rate at a specific moment during a flood. This data can be difficult to collect, and since the hydrometric gauge in Nahanni Butte has been in place for less than a year, it is not available for this specific area. Maximum daily flows, which represent the highest average flow over a 24-hour period, are more readily available but tend to underestimate the true flood magnitude, especially during flash flood events. This is because the daily average smooths out the peak, leading to a lower value.

As expected, **Table 5-6** shows that the maximum daily flow rate for each AEP in each river is slightly less than the instantaneous peak flow rate, by approximately six percent for the South Nahanni River and two percent for the Liard River. With this consideration, we understand that the daily flow rates discussed in the following section may be expected to slightly underestimate the maximum flood intensity compared to the instantaneous peak flow. Community engagement and hydrologic model results indicate that Nahanni Butte is not subject to flash flooding; the level in the South Nahanni and Liard Rivers rise gradually. Therefore, a daily maximum flow rate may adequately capture flood trends. The following sections describe the modeled maximum daily flows for the historical and climate change scenarios.

5.3.3 Raven Output – Historical Flood Frequency Analysis

A single-station FFA was performed on the results from the Raven model, which covered the period from 1985 to 2022. All results from the Raven model for this assessment are presented at a daily time step. This analysis aimed to estimate the magnitude of the 1% and 0.5% AEPs for the South Nahanni River and the Liard River at the Confluence. The comparison presented in **Table 5-7** presents the results of the FFA and compares them to the results of the RFFA described above.

Table 5-7: Comparison of Historical RFFA Peak Flows vs. FFA Peak Flows Using Simulation Results

AEP (%)	Maximum Daily Flow Rate, Daily (m^3/s)			
	FFA using Raven Historical Simulated Flow (1985-2022)		RFFA (Maximum Daily Flow Rate)	
	South Nahanni River at the Confluence	Liard River at the Confluence	South Nahanni River at the Confluence	Liard River at the Confluence
1	3,610	13,007	4,172	15,139
0.5	3,720	13,716	4,422	15,709

The results in **Table 5-7** consistently show that the peak flow estimates from the RFFA are greater than those from the single-station FFA for both the South Nahanni and Liard Rivers. Therefore, the regional approach was selected to represent the flood magnitude at a daily scale. The underestimation of the instantaneous peak flow is balanced by the choice of the greater of the values compared in **Table 5-7**.

5.3.4 Raven Output – Climate Change Frequency Analysis and Sensitivity Analysis Results

With the climate change assessment and expected changes in patterns of precipitation and temperature, the dataset resulting from the hydrologic simulation is likely to be non-stationary in nature. Therefore, the FFA for the climate change scenarios considers climate change non-stationarity.

As outlined earlier, design flows with annual exceedance probabilities (AEPs) of 0.5% and 1% (i.e., 200- and 100-year return period) are considered in this assessment. The maximum daily flows obtained from hydrologic modelling based on climate change scenarios were used to conduct Flood Frequency Analysis (FFA) and obtain climate change-adjusted annual exceedance probabilities including 1% and 0.5 % AEP.

In this study, for the purpose of comparison in sensitivity analysis, future simulated flows in three representative climate periods, 2022-2050, 2051-2075, and 2076-2100 were considered.

DILLON CONSULTING

- The 2022-2050 climate period may provide more detailed insights into climate change impacts in the near-term, leading to a clearer understanding of changes in flood frequency and allow for more targeted planning; and
- The climate period to 2075 and to 2100 may also yield useful insights for a longer horizon and highlight the expected extremes in a changing climate.

Flood frequency analysis was completed for the three above-mentioned climate periods to estimate 0.5% and 1% AEP. The results are presented in **Appendix B**. The sensitivity analysis results comparing the climate change scenario results for three future periods to the historical scenario (RFFA) are presented for each AEP in **Table 5-8** and **Table 5-9** for the Liard River and South Nahanni River, respectively.

Table 5-8: Climate Change Sensitivity Analysis Results Comparing Historical and Future Conditions Maximum Daily Flows for Liard River

	Simulated Maximum Daily Flows (m^3/s)				Change in Future Flow Compared to the Baseline (%)		
Scenario Name	**Historical (RFFA)**	**Moderate Emission-Median Condition SSP2-4.5_T50P50**					
Time Period	-	2022-2050	2051-2075	2076-2100	2022-2050	2051-2075	2076-2100
1% AEP	15,139	3,280	3,500	3,350	-78.3	-76.9	-77.9
0.5% AEP	15,709	3,350	3,600	3,430	-78.7	-77.1	-78.2
Scenario Name	**Historical (RFFA)**	**Moderate Emission-Cool/Wet Conditions SSP2-4.5_T25P75**					
Time Period	-	2022-2050	2051-2075	2076-2100	2022-2050	2051-2075	2076-2100
1% AEP	15,139	16,240	16,190	17,220	7.3	6.9	13.7
0.5% AEP	15,709	16,430	16,390	17,610	4.6	4.3	12.1
Scenario Name	**Historical (RFFA)**	**High Emission-Median Condition SSP5-8.5_T50P50**					
Time Period	-	2022-2050	2051-2075	2076-2100	2022-2050	2051-2075	2076-2100
1% AEP	15,139	3,710	2,990	3,240	-75.5	-80.2	-78.6
0.5% AEP	15,709	3,890	3,020	3,330	-75.2	-80.8	-78.8
Scenario Name	**Historical (RFFA)**	**High Emission-Cool/Wet Conditions SSP5-8.5_T25P75**					
Time Period	-	2022-2050	2051-2075	2076-2100	2022-2050	2051-2075	2076-2100
1% AEP	15,139	16,200	16,900	16,700	7.0	11.6	10.3
0.5% AEP	15,709	16,400	17,100	16,900	4.4	8.9	7.6

Table 5-9: Climate Change Sensitivity Analysis Results Comparing Historical and Future Conditions Maximum Daily Flows for South Nahanni River

	Simulated Maximum Daily Flows (m³/s)				Change in Future Flow Compared to the Baseline (%)		
Scenario Name	**Historical (RFFA)**	**Moderate Emission-Median Condition SSP2-4.5_T50P50**					
Time Period	-	2022-2050	2051-2075	2076-2100	2022-2050	2051-2075	2076-2100
1% AEP	4,172	1,350	1,300	1,330	-67.6	-68.8	-68.1
0.5% AEP	4,422	1,370	1,320	1,360	-69.0	-70.1	-69.2
Scenario Name	**Historical (RFFA)**	**Moderate Emission-Cool/Wet Conditions SSP2-4.5_T25P75**					
Time Period	-	2022-2050	2051-2075	2076-2100	2022-2050	2051-2075	2076-2100
1% AEP	4,172	3,880	4,030	3,940	-7.0	-3.4	-5.6
0.5% AEP	4,422	3,920	4,100	3,960	-11.4	-7.3	-10.4
Scenario Name	**Historical (RFFA)**	**High Emission-Median Condition SSP5-8.5_T50P50**					
Time Period	-	2022-2050	2051-2075	2076-2100	2022-2050	2051-2075	2076-2100
1% AEP	4,172	1,500	1,260	1,380	-64.0	-69.8	-66.9
0.5% AEP	4,422	1,560	1,270	1,410	-64.7	-71.3	-68.1
Scenario Name	**Historical (RFFA)**	**High Emission-Cool/Wet Conditions SSP5-8.5_T25P75**					
Time Period	-	2022-2050	2051-2075	2076-2100	2022-2050	2051-2075	2076-2100
1% AEP	4,172	3,980	4,160	4,180	-4.6	-0.3	0.2
0.5% AEP	4,422	4,020	4,200	4,150	-9.1	-5.0	-6.2

The sensitivity analysis results show that estimated maximum daily flows considering median percentiles (50th) are significantly lower than anticipated, with peaks of around 3000 m^3/s on the Liard River and 1000 m^3/s on the South Nahanni River for the whole future period (2021-2100). The estimated 1% AEP and 0.5% AEP using RFFA are 4172 m^3/s and 4422 m^3/s for the South Nahanni River, and 15,139 m^3/s and 15,709 m^3/s for the Liard River, respectively, indicating a large discrepancy in the results under median scenarios.

Further assessment of the meteorological forcings under the median scenario indicated that the downscaled daily maximum precipitation was approximately ten times less than the meteorological gauge data, suggesting that the downscaled climate results under the median precipitation scenario underestimates the variability and possibly the overall amount of precipitation in the basin. To verify that the processing approach was applied correctly, the downscaled products were also assessed in the historical period (2001-2020) in which gauge data is available. It was found that the same general characteristics for annual peak flows and precipitation variability existed in the historic period, confirming that this was a bias of the downscaled products that was consistent from 2001-2100. Accordingly, the median conditions for forcing inputs were excluded from scenario selection.

While the work plan focused on the median and cool/wet (25th percentile temperature/75th percentile precipitation), following the underestimation of peak flows under the median scenario, a more extreme climate scenario was assessed using 5th percentile of temperature and 95th percentile precipitation in order to better understand the variability in the downscaled climate products. The results indicate that using 5th temperature and 95th precipitation percentiles produce overly conservative maximum flows in order of 1.5 to 3 times higher than anticipated. In addition, the 5th temperature and 95th precipitation percentiles scenario was evaluated in the historical period from 2001 to 2020 to verify the consistency in results, which was confirmed.

5.3.4.1 Climate Change Scenario Selection

The climate change sensitivity analysis demonstrated that the cool/wet climate change scenarios (i.e., 25th percentile precipitation and 75th percentile temperature) were most reflective of reasonable maximum daily flows for both rivers. Two combinations of the following conditions were selected from the sensitivity analysis to represent the climate change scenarios:

- Annual Exceedance Probability (e.g., 1% or 0.5%);
- Emissions scenario (e.g., SSP5.45 or SSP5.85);
- Time period (e.g. 2022-2050, 2051-2075, or 2076-2100).

The relative magnitude of the peak flow from each of the cool/wet scenarios are presented in **Figure 5-4** and **Figure 5-5** for South Nahanni River and Liard River, respectively. Note that the vertical axis has been modified to demonstrate the variability between scenarios.

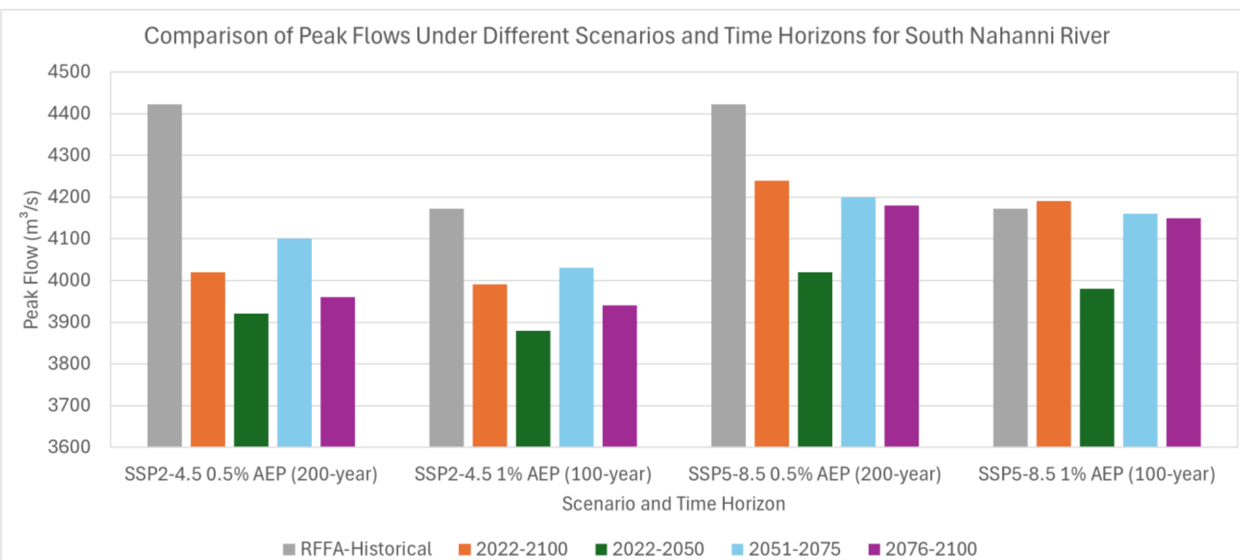


Figure 5-4: Sensitivity Analysis Results for Cool/Wet Climate Conditions (South Nahanni River)

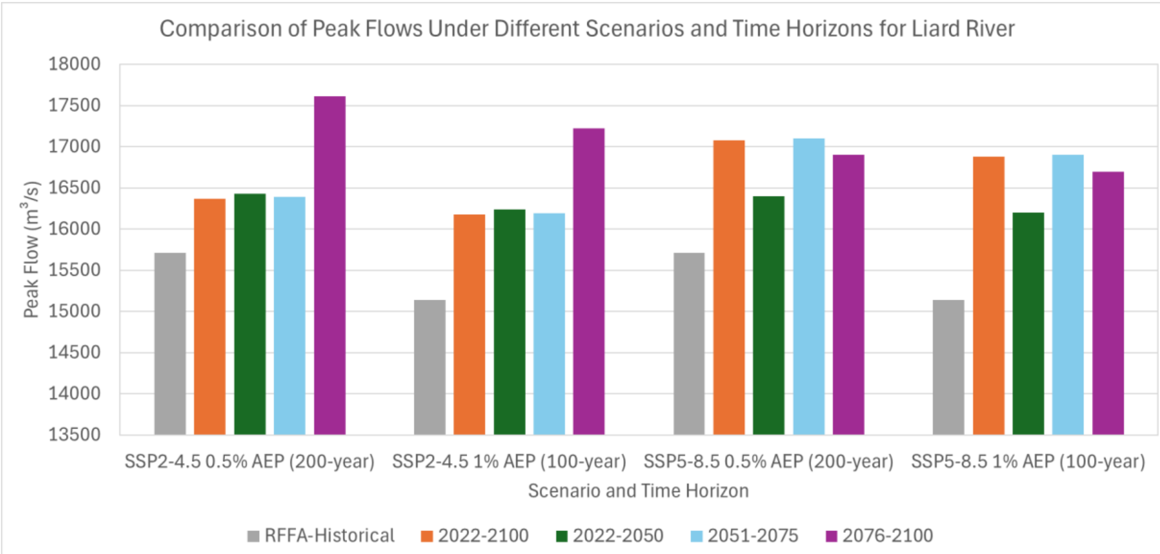


Figure 5-5: Sensitivity Analysis Results for Cool/Wet Climate Conditions (Liard River)

The figures present the historical maximum daily flows from the RFFA and the FFA results for the climate change sensitivity analysis. In the Liard River, maximum daily flows appear to increase as climate change progresses, while the South Nahanni River flows appear to stabilize or decrease in response to climate change.

The two climate change scenarios were selected in consultation with GNWT, ECCC, and NRCAN, and based on the following considerations:

- **Annual Exceedance Probability:** The hydraulic assessment of historical conditions indicated that full flooding will happen during both 1% and 0.5% AEP historical flood events, and the difference between the extent of the two events was minor. As such, the 0.5% AEP was selected for the climate change scenario.
- **Emission scenarios**: SSP2-5.5 and SSP5-8.5 were selected for climate change scenarios to represent one moderate and one extreme emission scenario.
- **Time period:** the near future from 2022 to 2050 was selected to create flood hazard mapping under climate change scenarios as it is more useful in the short term for planning considerations.

The two selected scenarios to be used in flood mapping under climate change are summarized in **Table 5-10**. For the purpose of clarity, they will be referred to by the appropriate emission pathway scenario, which is what differentiates the two, in the following sections.

Table 5-10: Selected Climate Change Scenarios for Flood Hazard Mapping

Flood Scenario ID	AEP (%)	Climate Change Scenario Name	Emission Pathway Scenario	Model	Modelling Period	Temperature/ Precipitation Percentile
Scenario 1: Climate Change to 2050, SSP2-4.5	0.5	Moderate Emission-Cool/ Wet Conditions	SSP2-4.5	Ensemble	2022-2050	$25^{th}/75^{th}$
Scenario 2: Climate Change to 2050, SSP5-8.5	0.5	High Emission-Cool/ Wet Conditions	SSP5-8.5	Ensemble	2022-2050	$25^{th}/75^{th}$

The peak flows for the selected scenarios for the South Nahanni and Liard Rivers are summarized in **Table 5-11**.

Table 5-11: Estimated Future Maximum Daily Flows Under Selected Climate Change Scenarios

Flood Scenario ID	AEP (%)	Maximum Daily Flow Rate (m^3/s)	
		South Nahanni River at the Confluence (36,100 km^2)	Liard River at the Confluence (228,800 km^2)
Scenario 1: Climate Change to 2050, SSP2-4.5	0.5	3,920	16,430
Scenario 2: Climate Change to 2050, SSP5-8.5	0.5	4,020	16,400

5.3.4.2 Snowpack under Future Climate Scenarios

The simulated snowpack under future climate scenarios is an important part of understanding what is driving future flood conditions. The Snow Water Equivalent (SWE) is a common measure of snowpack, measured in millimetres as the equivalent amount of water in a snowpack if it were melted to a fully liquid state. This simulated variable is shown for the SSP2-4.5 and SSP5-8.5 emissions scenarios under the cool/wet climate change scenarios until the year 2100 in **Figure 5-6**.

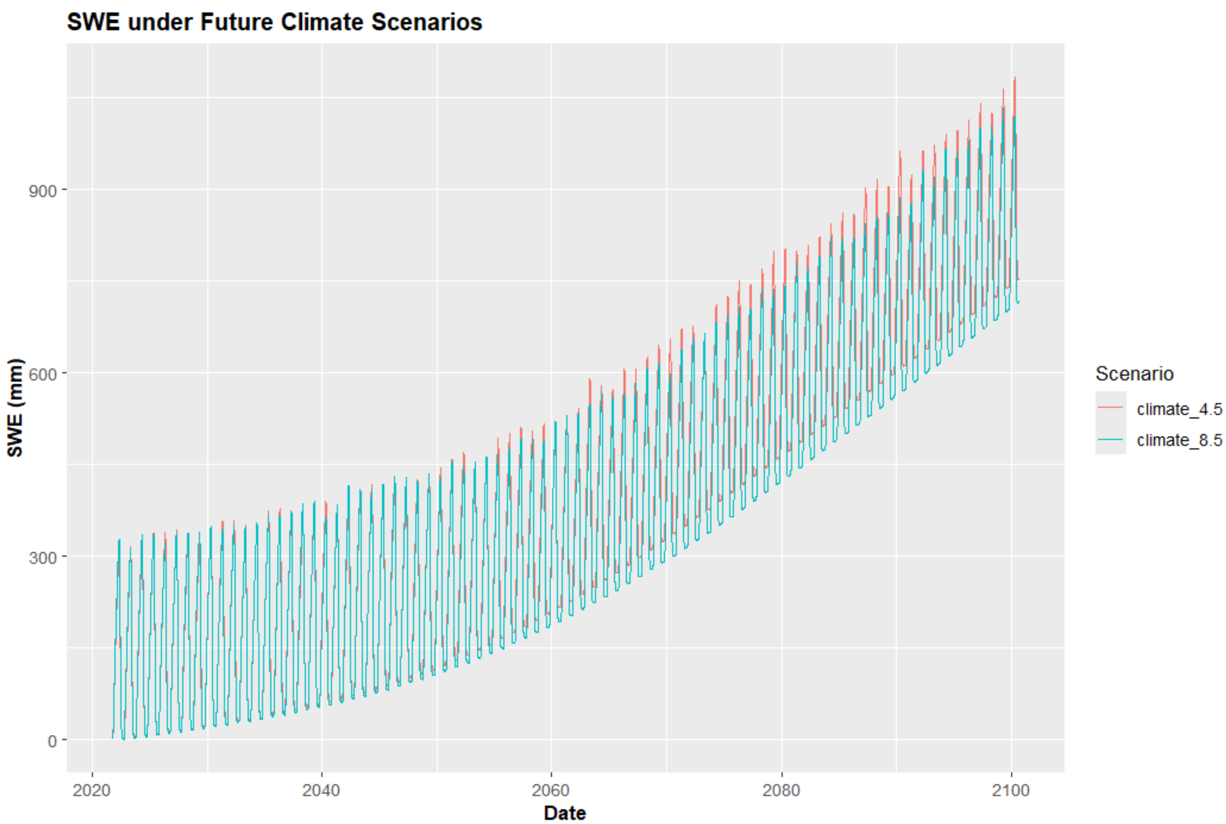


Figure 5-6: Snow Water Equivalent (SWE) of Snowpacks On-Average Across the Watershed Under SSP2-4.5 and SSP5-8.5 Emissions Scenarios from the Year 2022 to 2100

The plot shows that under this climate scenario, with lower temperatures and higher precipitation, the snowpacks increase gradually from the baseline annual maximum until about 2050, and then continue to increase the annual maximum snowpack at a greater rate until the year 2100. The annual maximum snowpack amounts are similar in the two climate scenarios initially, but the lower emissions SSP2-4.5 scenario produces higher annual maximum snowpacks than the SSP5-8.5 scenario from around the year 2060 and onwards. This is likely due to the higher average temperatures in the SSP5-8.5 scenario than the SSP2-4.5 scenario, eventually leading to a smaller buildup of the snowpack, which seems to overcome likely additional or more extreme precipitation in the SSP5-8.5 scenario. While the buildup of snowpack to such levels may be conservative as temperatures may follow a greater increase than the 25^{th} percentile scenario, this nonetheless indicates the possibility of higher annual maximum snowpacks and consequentially higher maximum annual flows in the watershed depending on future climate conditions.

5.4 Hydrograph Creation

Flow hydrographs are required for the hydraulic model as inflow boundary conditions for the South Nahanni and Liard Rivers for the 1% AEP and 0.5% AEP for historical conditions, the two selected future climate conditions (refer to **Section 5.2.2**), and the 2012 flood event. The approach used to generate these required hydrographs is described in the following sections.

Flow hydrographs for both historical and future conditions were developed using simulated flow data from the Raven model for the South Nahanni and Liard Rivers as described in **Section 5.2**. To generate a temporally distributed hydrograph, the hydrographs from the 2012 flood of record (as simulated by the updated Raven model) were selected as the representative hydrographs for all frequency-based scenarios provided to the hydraulic model. The 2022 modeled hydrograph was also extracted for use in hydraulic model validation.

For each modelled event, the maximum daily flows described in **Section 5.3** were used to scale each upstream river based on the ratio of the estimated peak to the 2012 peak. For the historical 1% and 0.5% AEP, the estimated peak flows from the RFFA were greater than the ones obtained from FFA using the simulated historical flow, therefore the maximum daily flows from RFFA were used to scale the 2012 hydrograph. For the climate change scenarios, the maximum daily flows from the FFA of the appropriate climate change results were used to scale the hydrograph. All generated hydrographs for the Nahanni Bute and Liard Rivers are presented in **Figure 5-7** and **Figure 5-8**.

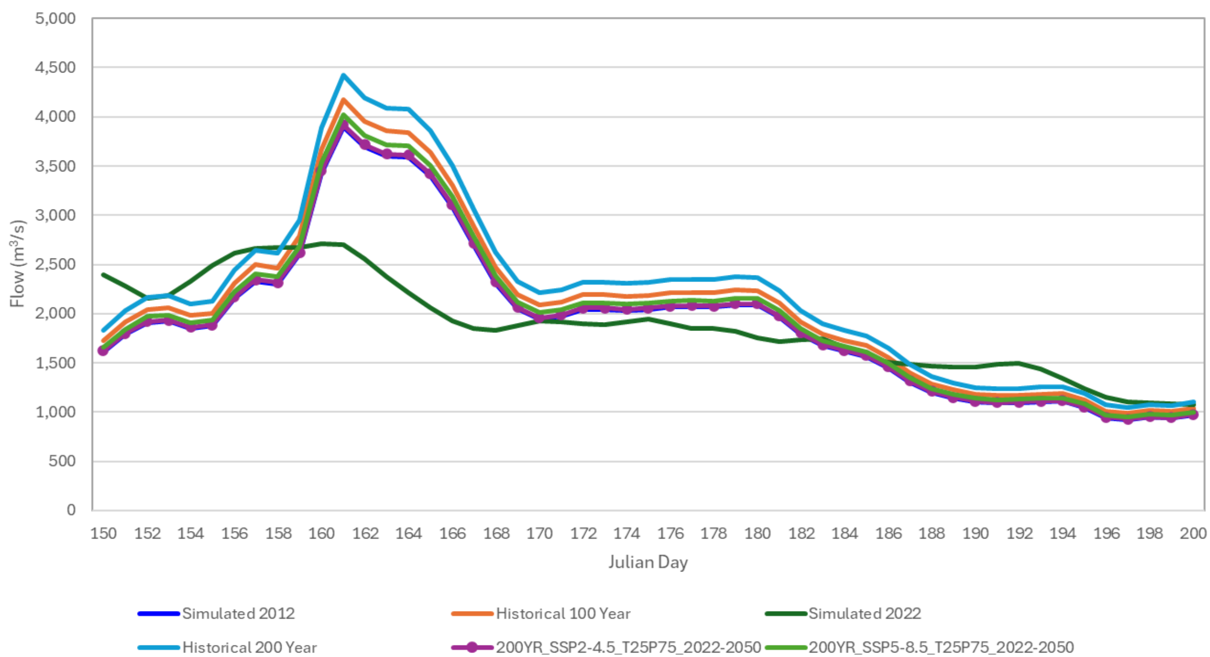


Figure 5-7: The South Nahanni River Hydrographs Under Different Flood Events

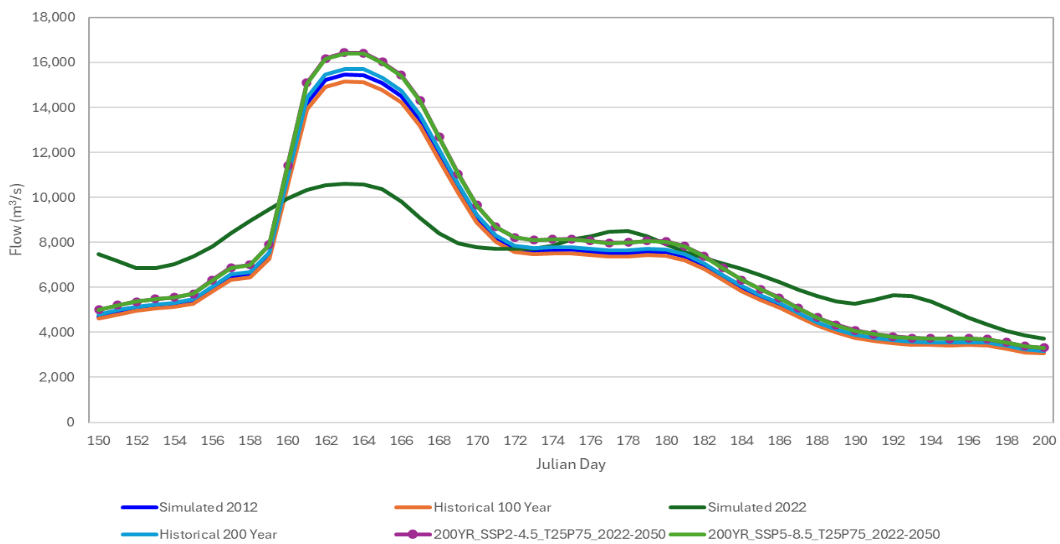


Figure 5-8: The Liard River Hydrograph Under Different Flood Scenarios

It is worth noting that for the Liard River the 2012 hydrograph with peak of 15,455 m^3/s is between the 1% AEP and 0.5% AEP historical hydrographs with peak of 15,139 and 15,709 m^3/s, respectively. The 2012 flow hydrograph, along with the generated 100-year and 200-year hydrographs for both historical and future flood events, are presented in **Appendix C**.

5.5 Hydrologic Results and Mapped Scenarios

Based on the statistical assessment, including both Regional Flood Frequency Analysis and the future climate change sensitivity analysis, four distinct flood hazard mapping scenarios have been chosen. These scenarios include the historical 1% and 0.5% AEPs derived from the baseline conditions, alongside two selected climate change-adjusted 0.5% AEP scenarios (Moderate Emission-Cool/Wet Conditions and High Emission-Cool/Wet Conditions) for the near-future period (2022-2050). **Table 5-12** summarizes the estimated maximum daily flows for each of these historical and future conditions for both the Liard and South Nahanni Rivers at the confluence, providing the critical inputs for the hydraulic model and flood hazard mapping.

Table 5-12: Estimated Maximum Daily Flows

Mapped Scenario	AEP (%)	Peak Maximum Daily Flow Rate (m^3/s)	
		South Nahanni River at the Confluence (36,100 km^2)	Liard River at the Confluence (228,800 km^2)
2012 Historical Flood of Record	-	3,896	15,455
100-Year Open Water Flood	1	4172	15,139
200-Year Open Water Flood	0.5	4,422	15,709
Scenario 1: Climate Change to 2050, SSP2-4.5	0.5	3,920	16,430
Scenario 2: Climate Change to 2050, SSP5-8.5	0.5	4,020	16,400

6.0 Hydraulic Assessment

The hydraulic analysis of the riverine flood areas adjacent to the community of Nahanni Butte was conducted using the Hydrologic Engineering Center's River Analysis System (HEC-RAS) Version 6.6 two-dimensional (2-D) modeling software (U.S. Army Corps of Engineers, Hydrologic Engineering Center). The flow hydrographs generated from the hydrologic assessment for the South Nahanni and Liard Rivers were used as upstream boundary conditions in the hydraulic model. Details of the hydraulic modelling methodology, model calibration, and validation are provided in the following sections. The extent of the flood assessment in the hydraulic model is provided in **Figure 6-1**.

6.1 Hydraulic Modelling Methodology

The appropriate selection of hydraulic modelling tools for the study area is a key aspect of building a robust mathematical model. A primary consideration for the study area was the selection of a one- or two-dimensional (1-D or 2-D) simulation approach. With respect to the flat terrain of the study area and braided nature of the South Nahanni and Liard River, a 2D model was selected for the purposes of this work to better establish the primary floodway and secondary flood fringe through the study area. Additionally, 2D models more accurately capture the complex floodplain dynamics, particularly for the subject study area that is situated adjacent to the confluence of two major rivers, the South Nahanni and Liard Rivers. Accordingly, HEC-RAS 2D was utilized to analyze flood inundation extents and depths by inputting detailed topographic data, boundary conditions, and hydrologic inputs, thereby providing a robust framework for assessing flood risks and informing mitigation strategies.

HEC-RAS is a modelling program designed to simulate steady and unsteady flow for a network of natural and constructed channels. It employs a finite volume approach to solve the shallow water equation, allowing for a detailed representation of complex flow patterns, including those influenced by variable topography, obstructions, and varying boundary conditions. The model supports the integration of high-resolution terrain data and can simulate a range of hydrological events, from steady-state conditions to unsteady flow scenarios. In this study unsteady flow conditions were considered as it accounts for changes in flow rate, velocity, and water depth over time. Unsteady flow analysis provides a dynamic picture of flood inundation, showing not only the maximum flood extent but also the timing, duration and progression of the flood event, yielding more realistic and comprehensive understanding of the rivers system dynamic.

Modelling a 2D unsteady flow conditions requires three primary categories of input data:

- Geometric Data: the digital terrain model (DTM) and two-dimensional flow areas (2D flow areas) consisting of computational mesh that define the physical shape of the river and floodplain.
- Unsteady flow data: the time-varying data that drives the simulation, primarily consisting of boundary conditions and initial conditions.

DILLON CONSULTING

- Hydraulic parameters: notably, the surface roughness coefficients that describes the friction of the channel and floodplain surfaces.

The details of the input data used in this study are provided in the following sections.

6.1.1 Geometric Data: Terrain

The primary input of the 2D model is high-resolution terrain data that captures the elevation of both river channels and the surrounding floodplains. The terrain data is also required in order to do any mapping of the computed results, for the 2D areas of the model. For this purpose, the DEM was derived from a combination of available LiDAR from the GNWT, topographic survey collected by drone, and the bathymetric survey data which are detailed as follows:

- The surface dataset for the hydraulic model was based on the 2020 GNWT Digital Terrain Model (DTM), derived from airborne LiDAR collected by McElhanney. This dataset provided coverage for the wider extents of the study area.
- A 2024 drone-based photogrammetric dataset, collected by Dillon as described in **Section 4.2**, was integrated into the 2020 GNWT DTM to provide higher-accuracy elevation data for the built-up areas of the community and the shorelines immediately adjacent to them.
- Bathymetric data, collected by Dillon in 2024 for the South Nahanni and Liard Rivers, was then integrated into the combined surface to incorporate riverbed topography. ArcticDEM data was not used in the final surface, as the 2020 GNWT DTM provided sufficient coverage and accuracy for the study area.

The integrated DEM was used to create a terrain file within the RAS-mapper application of HEC-RAS, which is the basis for the 2D model. All elevations in the model and those reported in this document are in the CGVD2013 vertical datum.

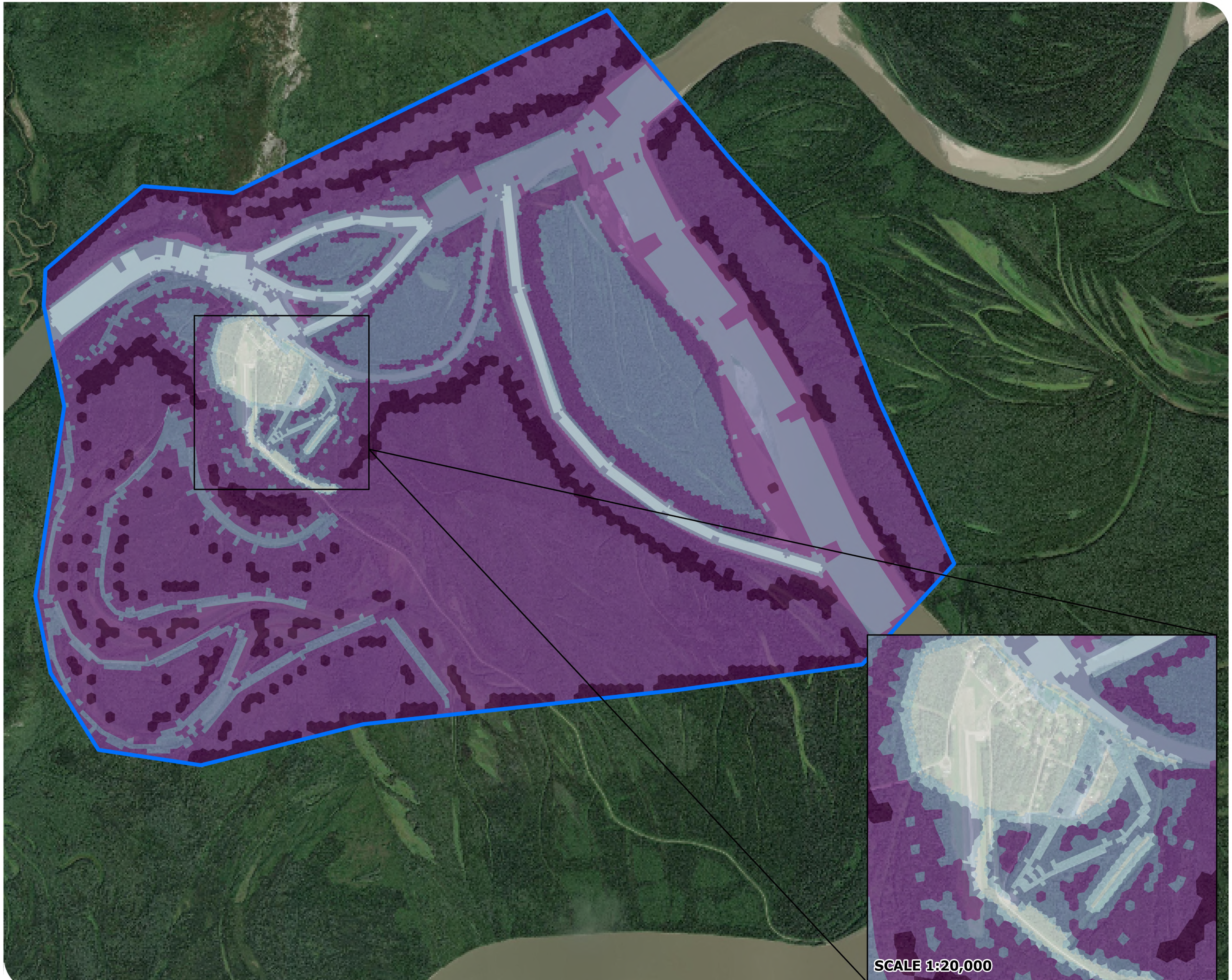
6.1.2 Geometric Data: 2D Flow Areas

2D Flow Areas are regions of the model in which the flow will be computed with the HEC-RAS two-dimensional flow computation algorithms. 2D Flow Areas are defined by laying out a polygon that represents the outer boundary of the 2D Flow Area. Then the 2D computational mesh must be defined.

For this study, a 2D computational mesh was generated using the terrain data described above. In mesh generation, the cell size is a critical parameter representing a trade-off: smaller cells provide higher resolution and accuracy but significantly increase computational time. As such, mesh refinement was implemented to better capture dynamics in critical areas. The “Refinement Region” option was used to refine the mesh around the community of Nahanni Butte and also the surrounding area of the South Nahanni River as it is braided and there are islands in front of the community. Additionally, breaklines were incorporated into the mesh for the specific areas to refine the mesh including along the main channel of the South Nahanni and Liard Rivers, the edges of significant islands, edge of areas with significant elevation change such as elevated roadways, cliffs or hills. The detail of cell size and mesh refinement are as follows:

- The base 2D cells of 100 m x 100 m hexagonal cells were generated for the general floodplain areas which is majority of the simulated area.
- 50 m x 50 m hexagonal cells were used to represent the area surrounding the South Nahanni River.
- 10 m x 10 m hexagonal cells were used to represent the community of Nahanni Butte.
- The low flow channels of the South Nahanni River were further defined with break lines to create 25 m x 25 m rectangular cells that follow the natural flow of the river.
- The low flow channels of the Liard River were further defined with break lines to create 50 m x 50 m rectangular cells that follow the natural flow of the river.

The extent of the 2D flow area along with the generated mesh is provided in **Figure 6-1**.



NAHANNI BUTTE FLOOD ASSESSMENT

FLOOD HAZARD MAPPING

HYDRAULIC MODEL COVERAGE AND RESOLUTION

FIGURE 6-1

- 10 x 10 Cell
- 25 x 25 Cell
- 50 x 50 Cell
- 100 x 100 Cell
- Cell greater than 100 x 100
- Hydraulic Model Extent

SCALE 1:40,000

0 375 750 1,500 Meters

N S W E

MAP DRAWING INFORMATION:
DATA PROVIDED BY GNWT, Dillon Consulting Limited, ESRI Base Imagery

MAP CREATED BY: DS
MAP CHECKED BY: ML
MAP PROJECTION: NAD 1983 CSRS UTM Zone 10N

DILLON CONSULTING

PROJECT: 23-7137
STATUS: FINAL
DATE: 2025-08-20

FILE LOCATION: K:\2023\237137\Product\Client\NahanniButte_2025\NahanniButte_2025.aprx; LAYOUT: Figure_6-1_HydraulicModel_CoverageResolution

6.1.3 Unsteady Flow Data: Boundary Conditions and Initial Conditions

Boundary conditions define how water enters and exits the 2D modeled area. For this study the boundary conditions were uses as follows:

- **Upstream Boundary Conditions**
  As unsteady flow condition was considered for 2D modelling, daily flow hydrographs for the South Nahanni and Liard Rivers were separately incorporated into the model as upstream boundary conditions. Using the flow hydrograph allows a more realistic simulation of flow dynamics and better reflects the combined hydraulic influence of both river systems on the downstream floodplain. The flow hydrographs were generated from the simulated flows for the South Nahanni and Liard Rivers using Raven hydrologic modelling. Refer to **Section 5.6** for details of hydrograph creation.
- **Downstream Boundary Conditions**
  For the model downstream boundary conditions, the Normal Depth was assumed. This requires use of the friction slope as an input parameter (the slope of energy grade line at the downstream end). The model uses this parameter in Manning's equation to calculate the water surface elevation at downstream end.

In addition to boundary conditions, initial conditions (flow and stage) must be established within the 2D flow area. The following initial conditions for the 2D flow area were set for the model:

- The initial elevation for 2D flow area was set at a constant water surface elevation of 170 m.
- The initial flow distribution for each river was set to use the boundary conditions

6.1.4 Surface Roughness (Manning's n)

Manning's roughness (n) values were assigned based on ortho-imagery and standard values based on land use including the main river channel and floodplain. A consistent Manning's roughness value was considered for all areas of the floodplain, but the buildings footprint was excluded by incorporating them into the land cover layer and assigning an overly high value of roughness to them (n = 0.5).

Overbank and river Manning's roughness, downstream boundary conditions (friction slope), and inflow hydrographs (which are flow hydrographs at the upstream boundary) were considered as calibration parameters for this project. The following sections describe the sensitivity analysis, calibration, and validation of the hydraulic model.

6.2 Hydraulic Model Sensitivity Analysis

A one-at-a-time local univariate sensitivity analysis on the HEC-RAS model was undertaken to observe the effects of changing model parameters on water level, and by proxy, flow depths and inundation areas. The parameters that were considered in the sensitivity analysis are Manning's roughness for the river(n), the friction slope at the downstream boundary condition (S), and the magnitude of the inflow hydrograph (Peak).

The sensitivity analysis and calibration are important steps in understanding the hydraulic model. The baseline conditions presented in this section represent a parameter set that results in a water surface elevation close to 2012 flood, therefore a local sensitivity analysis was completed, targeting high flow conditions for the model. For comparison purposes, the simulated water surface elevation was compared for the two HWMs corresponding to the 2012 flood. Surveyed Points 1 and 2 correspond to the simulated water elevations (in metres, CGVD2013) and are further explained in the calibration discussion in **Section 6.3**.

The sensitivity analysis was executed by varying the input parameter values for n and S by ±10, ±20, and ±50% as compared to baseline, and documenting the resulting elevation at the two points. In contrast, the Peak was adjusted by increments of +3%, +6%, and +9%. **Table 6-1** presents the results of the sensitivity analysis, which are also provided in **Figure 6-2**.

Table 6-1: Summary of Sensitivity Analysis on HEC RAS Model

Parameter	Sensitivity Analysis Scenario	Water Surface Elevation (m)		Water Surface Elevation Change Compared to Baseline (m)	
		Surveyed Point 1	Surveyed Point 2	Surveyed Point 1	Surveyed Point 2
	Baseline	182.67	182.73	-	-
S_b	+10%	182.54	182.59	-0.13	-0.14
	+20%	182.44	182.47	-0.23	-0.26
	+50%	182.18	182.18	-0.49	-0.55
	-10%	182.81	182.88	0.14	0.15
	-20%	182.97	183.05	0.3	0.32
	-50%	183.66	183.71	0.99	0.98
n_b	+10%	183.07	183.16	0.4	0.43
	+20%	183.41	183.49	0.74	0.76
	+50%	184.13	184.2	1.46	1.47
	-10%	182.17	No Water[1]	-0.5	-
	-20%	No Water[1]	No Water[1]	-	-
	-50%	No Water[1]	No Water[1]	-	-
$Peak_b$	+3%	182.70	182.77	0.03	0.04
	+6%	182.83	182.92	0.16	0.19
	+9%	182.97	183.05	0.3	0.32
	-3%	182.41	182.43	-0.26	-0.3
	-6%	182.25	182.25	-0.42	-0.48
	-9%	182.09	182.08	-0.58	-0.65

Note:
[1]There is no flood inundation on the target point under this scenario

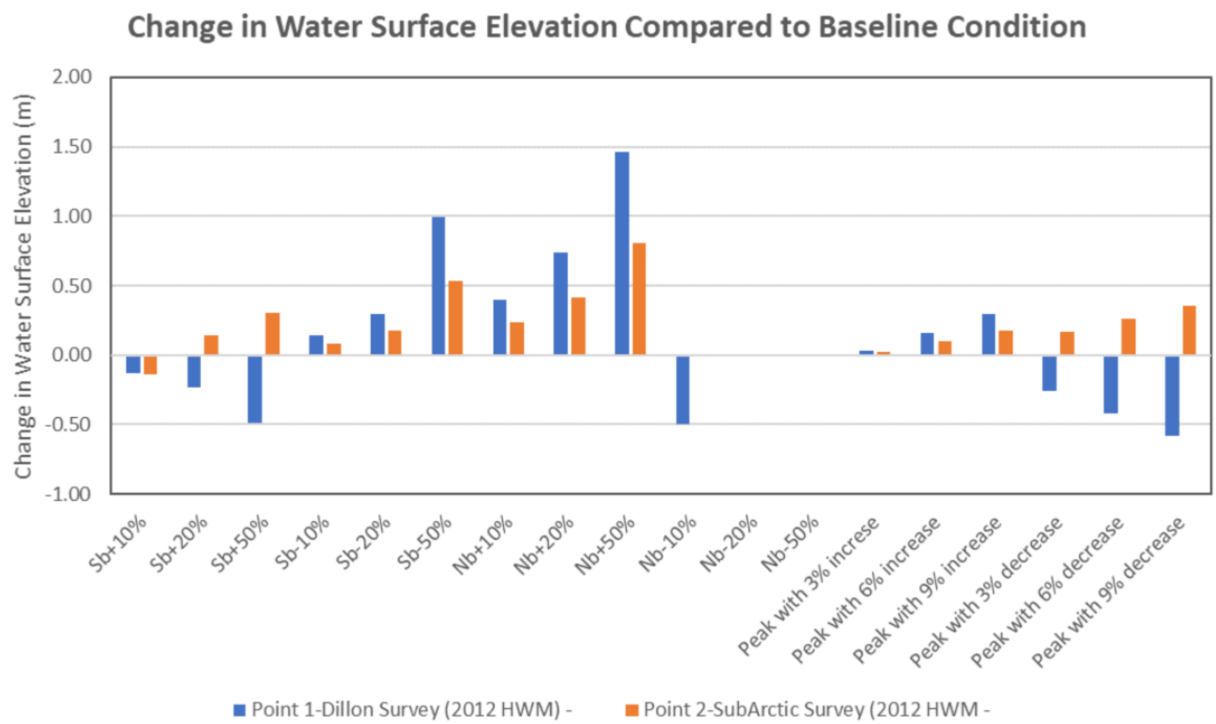


Figure 6-2: Summary of Sensitivity Analysis of HEC RAS Model

The sensitivity analysis results indicate that the model performance is more sensitive to Manning's roughness values than boundary conditions or inflow hydrograph. The maximum change in water surface elevation observed in the sensitivity analysis was approximately 1.5 m as a result of increasing the roughness by 50%. The model appears to be less sensitive to friction slope, with a maximum change in water surface elevation of approximately 1 m for a 50% decrease in friction slope, whereas a 50% decrease in Manning's roughness results in no ponding at the two chosen representative points.

Based on the provided sensitivity analysis, for the scenarios with a 20% and 50% decrease in Manning's roughness (n_b), there is no inundation at the target points. This is due to the significant reduction in channel friction. A lower Manning's roughness value simulates a smoother, less resistant channel, enabling water to flow more easily and quickly. This increased flow efficiency prevents the water level from rising to a depth that would cause inundation at the surveyed target points. This aligns with the overall findings of the sensitivity analysis that the model is more sensitive to Manning's n than other parameters.

The sensitivity of the model to peak flow is less informative to the model construction, but provides insight to variable flow conditions and the expected response of the system. When the peak flow increases by 3, 6, and 9%, we can expect the water surface elevation to increase up to approximately 0.3 m in response. Conversely, a decrease by the same amount results in a decrease in water surface elevation of up to 0.6 m

6.3 Calibration of Hydraulic Model

The hydraulic model calibration was completed based on the historical flood that occurred in 2012 and HWM surveyed points based on observations by community members. The newly established hydrometric gauge immediately upstream of the community has not yet captured high water events that would be useful for calibration of a flood model; therefore, the surveyed points were used. There were more measured HWMs from the 2012 survey within the study area; however, as they are in a flat area, only two of them were selected for the calibration. The model results indicate that the water surface elevation does not change significantly over the study area, so using these two points in calibration are suitably representative.

The 2012 event hydrographs for the South Nahanni and Liard Rivers extracted from the calibrated Raven hydrologic model were used as inflow boundary conditions of the hydraulic model, and the resultant hydraulic grade line (HGL) elevations were compared to the available observed water elevations from 2012 flood evidence. The HWM survey completed by others in 2012 following the flood identified a maximum flood elevation in the centre of the community as 182.59 m in CGVD28 (Sub-Arctic Surveys Ltd., 2012), which is equivalent to 182.72 m in CGVD2013. The HWM surveyed by Dillon in summer 2024 on the shoreline in front of the store has an elevation of 182.66 m in CGVD 2013. This elevation was based on a photo provided of the flood, which is provided in **Appendix A** as **Figure A.1**. These two locations were used as calibration points. The 2022 event was used to validate the calibrated model as described in the next section.

While water levels have been published from late 2024 for the hydrometric station “South Nahanni River near Liard River Confluence” (10EC004), it was not used to calibrate the HEC-RAS model. The model's calibration was primarily based on surveyed high water marks from past flood events. The 2024 data from 10EC004, representing low-flow conditions, was not suitable for a flood assessment model. Additionally, a flow hydrograph for the 2024 period was not available to enable a comparison, as the hydrologic assessment described in **Section 5.0** extends only to 2022.

The Manning’s n value for the river and floodplain, in addition to the friction slope at the downstream boundary condition, were used as the calibration parameters. The parameters were changed until the HGL matched with the observed water surface elevation at the two surveyed points. The Manning’s n for the built environment of the community were not changed during the calibration. The general roughness within the community was set at 0.05, except for building footprints which were set at 0.5 to represent an obstruction to flow. The calibrated model parameters are provided in **Table 6-2**. A summary of calibration results is provided in **Table 6-3** based on both surveyed HWMs.

Table 6-2: Calibrated Model Parameters

Parameter	Value	Unit
Manning's Roughness-River	0.07	-
Manning's Roughness-Floodplain	0.14	-
Boundary Condition-Friction Slope	0.00145	m/m

Table 6-3: Summary of Hydraulic Model Calibration Results

Location	Observed Water Elevation (m CGVD2013)	Simulated Water Elevation (m CGVD2013)	Difference (m)
2012 Flood HWM (Chair Seat, Dillon) [1]	182.66	182.67	+0.01
2012 Flood HWM (Sub-Arctic Surveys, 2012)	182.72	182.73	+0.01

Note:
[1] refer to **Figure A.1** in **Appendix A**

The difference of +0.01 between the modeled and observed high water elevations is considered acceptable. A profile showing the South Nahanni River water level in the calibrated model along with the HWM is provided in **Figure 6-3** with reference points to the approximate confluence of the Liard and South Nahanni rivers and the approximate calibration point. The precise location of the calibration point is shown in **Figure 6-4**.

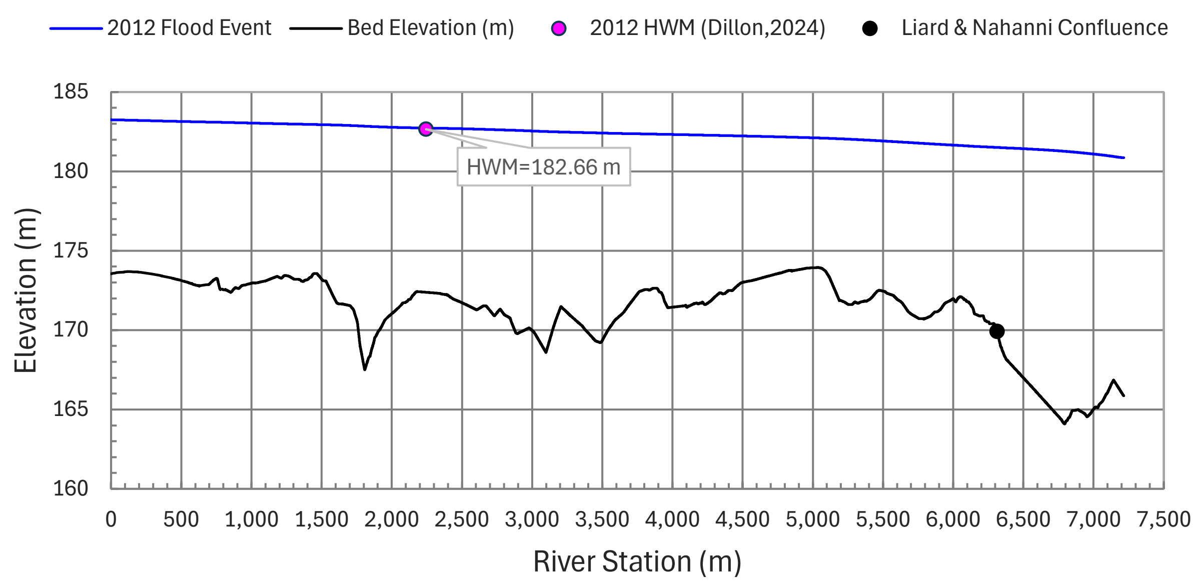


Figure 6-3: South Nahanni River Water Level Profile in Calibrated Model

6.4 Validation of Hydraulic Model

The hydraulic model validation was performed based on the 2022 flood. The hydrographs generated from the hydrologic model as discussed in **Section 5.4** were applied as inflow boundary conditions to the calibrated hydraulic model. **Table 6-4** shows the observed and simulated water levels for the validation event (2022). The location of validation point is presented in **Figure 6-4** and **Table 6-4**.

Table 6-4: Summary of Model Validation Results

Location	Observed Water Elevation (m CGVD2013)	Simulated Water Elevation (m CGVD2013)	Difference (m)
2022 Flood High Water Mark [1]	181.43	181.24	- 0.19

Note:
[1] refer to **Figure A.2** in **Appendix A**

The observed water elevation is 0.19 m greater than the modeled elevation and the difference is greater than what is typically acceptable for flood mapping studies. However, the observed water elevation was surveyed based on a photograph of the boat ramp in 2022. It is possible that the point surveyed could be slightly too far up the ramp and is overestimating the water level. This contrasts with the HWM used in the calibration, which was collected from a fixed point on infrastructure that has been in place since at least 2012. Despite this uncertainty, the overall agreement between the modeled and observed water elevations is reasonable, and the results are suitable for proceeding with the analysis.

6.5 Comparison of Water Surface Elevation Under Different Scenarios

For the purpose of comparison, the water surface elevation in front of the Band Office (coordinate of 61° 02’ 08.6” N, 123° 22’ 59.1” W) under different flooding scenarios is provided in **Table 6-5**.

Table 6-5: Comparison of Water Surface Elevation at Band Office Under Different Scenarios

Scenario	2012 Historical Flood of Record	1% AEP Open Water Flood	0.5% AEP Open Water Flood	Climate Change Scenario 1: 0.5% AEP, Climate Change to 2050, SSP2-4.5	Climate Change Scenario 2: 0.5% AEP, Climate Change to 2050, SSP5-8.5
Water Surface Elevation (m)	182.68	182.60	182.81	182.74	182.78

The results indicate that the water surface elevation associated with the 2012 flood of record was slightly greater than that of the 1% AEP flood, and less than the 0.5% AEP flood. The 0.5% AEP flood for the climate change scenarios resulted in a slightly lower water surface elevation than the existing conditions 0.5% AEP Flood: 0.07 m lower for climate change scenario 1 using SSP2-4.5 and 0.03 m lower for climate change scenario 2 using SSP5-8.5. While these results indicate that the community may experience lower flood depths as climate change progresses, the difference is minor, and as presented in **Section 7.0**, the magnitude of flooding is still significant.

Nahɂa Dehé Dene Band

NAHANNI BUTTE FLOOD ASSESSMENT
FLOOD HAZARD MAPPING

SURVEYED HIGH WATER MARKS
FIGURE 6-4

- Sub-Arctic Surveys (2012)

Dillon Survey (2024)
- Survey - Model Calibration
- Survey - Model Validation
- Staff Guage

SCALE 1:3,000

0 25 50 100 Meters

N E S W

MAP DRAWING INFORMATION:
DATA PROVIDED BY GNWT, Dillon Consulting Limited, ESRI Base Imagery

MAP CREATED BY: DS
MAP CHECKED BY: ML
MAP PROJECTION: NAD 1983 CSRS UTM Zone 10N

DILLON CONSULTING

PROJECT: 23-7137
STATUS: FINAL
DATE: 2025-08-20

FILE LOCATION: K:\2023\237137\Product\Client\NahanniButte_2025\NahanniButte_2025.aprx; LAYOUT: Figure_6-4_HighWaterMarks

7.0 Flood Hazard Mapping

This study was completed by Dillon's engineers' expertise with open water flood line mapping projects developed through work on prior projects in various provinces in Canada, and in collaboration with project partners at the GNWT, NRCan, and ECCC.

The hydrologic and hydraulic analysis discussed in the previous sections were used to develop flood maps for Nahanni Butte. The draft flood maps provided along with this draft report include one inundation map and four flood hazard maps as follows:

- Flood Inundation Map for
  - 2012 Flood
- Flood Hazard Maps for
  - Historical Flood Scenarios:
    - 1% AEP; and
    - 0.5% AEP.
  - Climate Change Flood Scenarios:
    - Scenario 1: 0.5% AEP climate change to 2050, SSP2-4.5; and
    - Scenario 2: 0.5% AEP climate change to 2050, SSP5-8.5.

Two additional climate change scenarios were provided to the GNWT as spatial data, but were not included as flood maps. These are as follows:

- 0.5% AEP for climate change, 2076-2100, SSP2-4.5; and
- 0.5% AEP for climate change, 2076-2100, SSP5-8.5.

The flood inundation map was prepared for the most severe flood in recent memory, which occurred in June 2012 as discussed in previous sections.

Each flood hazard map shows the floodway and flood fringe for the scenario in question. As discussed in **Section 7.1**, the floodway is defined as areas where water depths exceed 1 m or where local velocities are greater than 1 m/s. The "flood fringe" includes any flooded areas outside the floodway.

In Nahanni Butte, where the South Nahanni and Liard Rivers meet, velocities exceed 1 m/s only in certain sections of the main river channels. As a result, depth is the dominant criterion for defining the floodway in this community.

The four flood hazard maps highlight the undulating topography of Nahanni Butte. Due to this uneven terrain, a consistent water level results in varying flood depths across the community. Few areas are expected to remain outside the flood fringe, and those that tend to be isolated by surrounding floodwaters from the confluence of the Liard and South Nahanni Rivers. The community is well aware of its flooding tendencies and remains optimistic about future mitigation and preparedness efforts.

Note that approximately 15 km of the Liard River—including 2 km downstream of its confluence with the South Nahanni River and 5 km of a parallel channel— and about 10 km of the South Nahanni River upstream from the confluence were included in the bathymetric survey as described in **Section 4.2**. The total area covered by the 2D hydraulic model extent, and therefore is 54.35 km^2.

7.1 Floodway and Flood Fringe Terminology and Criteria

This section outlines the terminology and criteria used in the NWT for determining the floodway and flood fringe in flood hazard mapping, specifically for open water flooding. The floodway is defined based on the following criteria:

- **Active Channel:** The floodway must always encompass the main channel of the river.
- **Depth and Velocity:** Areas where water depths exceed 1 metre or where local velocities are greater than 1 m/s are also considered part of the floodway. An exception is made for ice jam floods, where depth is the sole determining criterion.

For clarity, the "flood fringe" is defined as any flooded area not included within the floodway. These criteria are further detailed in a high-level zone classification table (**Table 7-1**).

Table 7-1: NWT Flood Zone Classification

Water Velocity	Ice Jam Flood Zones		Open Water Flood Zones	
	Less than 1 m depth	Greater than 1 m depth	Less than 1 m depth	Greater than 1 m depth
Less than 1 m/s velocity	Flood fringe	Floodway	Flood fringe	Floodway
Greater than 1 m/s velocity	Flood fringe	Floodway	Floodway	Floodway

The floodway and flood fringe were defined for Nahanni Butte according to the definitions provided by GNWT for open water flooding.

The floodway is designed to extend across the entire channel, including areas that do not strictly meet the 1-metre depth or 1-m/s velocity criteria, such as small islands. Exceptions may be made for larger islands with extensive dry areas or areas protected by engineered flood control structures, subject to approval from the project manager and community consultation

7.2 Flood Depth and Flow Velocity Computations

Since the flood mapping for this project utilized a 2D computational modeling approach in HEC-RAS, flow depths and velocities were computed differently than in a 1D model. In a 2D model, depths and velocities are calculated for each cell within the computational mesh, providing a continuous spatial output rather than just at cross-section locations. This process generates a velocity raster, allowing for a more detailed and accurate representation of flow patterns and velocities across the entire floodplain. The area with depth exceeding 1 m and with flow velocities of 1 m/s or more is then identified from this detailed spatial output. No hydraulic smoothing was completed on the model outputs.

7.3 Assumptions and Limitations

As with any project, assumptions were made to achieve robust results with reasonable computational expenditure. Some assumptions made along the way include:

- The underlying terrain data, combined from the provided LiDAR and Dillon's bathymetric and drone survey, are assumed to be accurate and complete;
- Rather than considering joint probabilities, maximum daily flows were assumed to be concurrent on the South Nahanni and Liard Rivers;
- Based on data and literature reviews, as well as input from community meetings, open water flooding has historically been the dominant flood mechanism in Nahanni Butte, and it is assumed that this will continue to be the case in the future.
- The RFFA relies on hydrometric stations in the Liard River basin that are more than 50 km away from the community; these are considered to be representative for this purpose;
- A major limitation is the availability and accuracy of data for calibration, as the hydrometric gauge at the community was not active during the calibration period;
- The small differences between modeled and observed water levels during calibration (+0.01 m) and validation (-0.19 m), despite higher uncertainty for the validation point, are considered acceptable for the study's purpose;
- The shape of the hydrographs from the 2012 flood was scaled to the chosen flood scenarios;
- The maximum daily flow rates for the South Nahanni and Liard Rivers represent the magnitude of flow at the confluence of the two rivers, but is applied in the hydraulic model as a boundary condition approximately 7 km upstream;
- The daily time step of the hydrologic and hydraulic models does not capture extreme instantaneous flood intensity;
- Although an erosion rate of 1 m per year was calculated in Phase 1 of this assessment, erosion is not accounted for in the hydraulic model; the flood maps assume current (2024) shoreline geometry. As morphology changes, the floodway would expand, which could result in a lower expected water level. Therefore, the current topography was used as a conservative choice;
- Manning's roughness was assumed to remain consistent across model runs; and
- The climate change scenarios were selected through extensive discussions with the project team at GNWT, ECCC, and NRCan, informed by the sensitivity analysis. The near-future period (2022-2050) was chosen assuming it is the most practical for short-term planning.

8.0 Conclusion

This study successfully produced quality flood inundation and flood hazard maps for the community of Nahanni Butte. Informed in part by local knowledge and community engagement, the detailed hydrologic and hydraulic analysis leveraged publicly available datasets and site-specific observations to create quality flood inundation and hazard maps. The analysis considers significant historical events for model calibration and validation and has been prepared in consultation with the Government of the Northwest Territories (GNWT), Environment and Climate Change Canada (ECCC), and Natural Resources Canada (NRCan).

Numerical simulation of flood scenarios using Raven and HEC-RAS were completed for calibration and validation events. The results of the analysis of the 2012 flood of record were used to produce a flood inundation map. The results of the hydrologic and hydraulic assessments were applied to 1% and 0.5% AEP flood scenarios for historical conditions to produce flood hazard maps. For the future (climate change) scenario, the hydrologic sensitivity analysis was conducted on a variety of climate change parameters to select two scenarios for use in the hydraulic model to predict flood hazard under climate change. The resultant flood hazard maps present the community of Nahanni Butte with a glimpse to the future under two climate change scenarios: SSP2-4.5 and SSP5-8.5. Together, these flood inundation and hazard maps offer the community of Nahanni Butte a vital tool for planning a safer future.

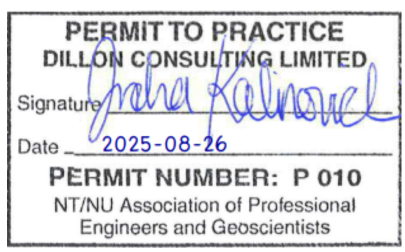
9.0 Closure

This report was prepared exclusively for the purposes, project and Site location(s) outlined herein. The document is based on information provided to, or obtained by Dillon Consulting Limited (Dillon) as indicated in the memo, and applies solely to Site conditions existing at the time of the site investigation(s).

This report was prepared by Dillon for the Nahanni Butte Dene Band in collaboration with GNWT Environment and Climate Change Waters Division, Environment and Climate change Canada, and Natural Resources Canada under the Flood Hazard Information and Mapping Program (FHIMP). The material contained herein reflects Dillon's best judgment in light of the information available to it at the time of preparation.

Sincerely,

DILLON CONSULTING LIMITED



Meggie Letman, P.Eng.
Project Manager, Associate

Appendix A

Historical Flood Images

Figure A.1 – Observed Water Elevation of 2012 Flood High-Water Mark

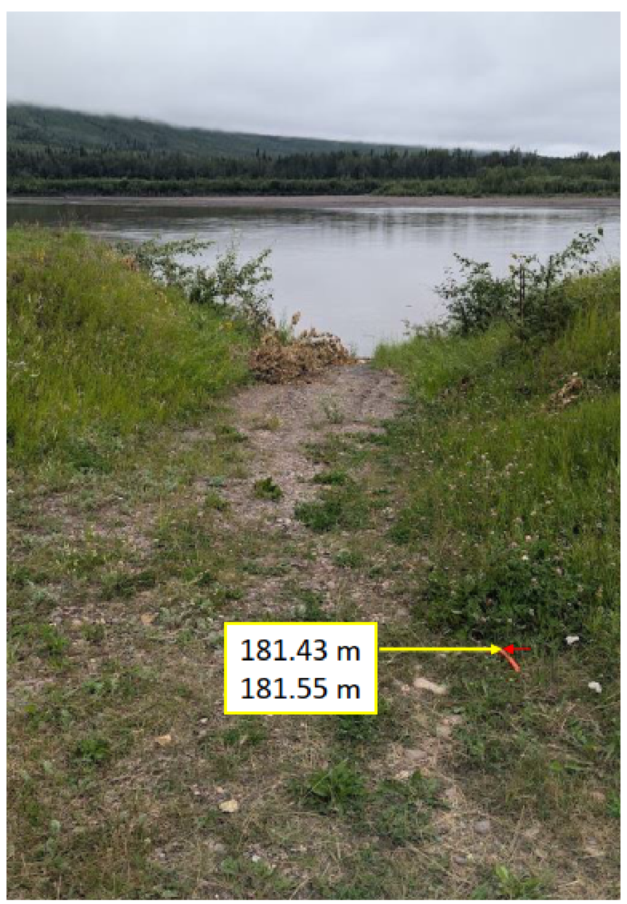
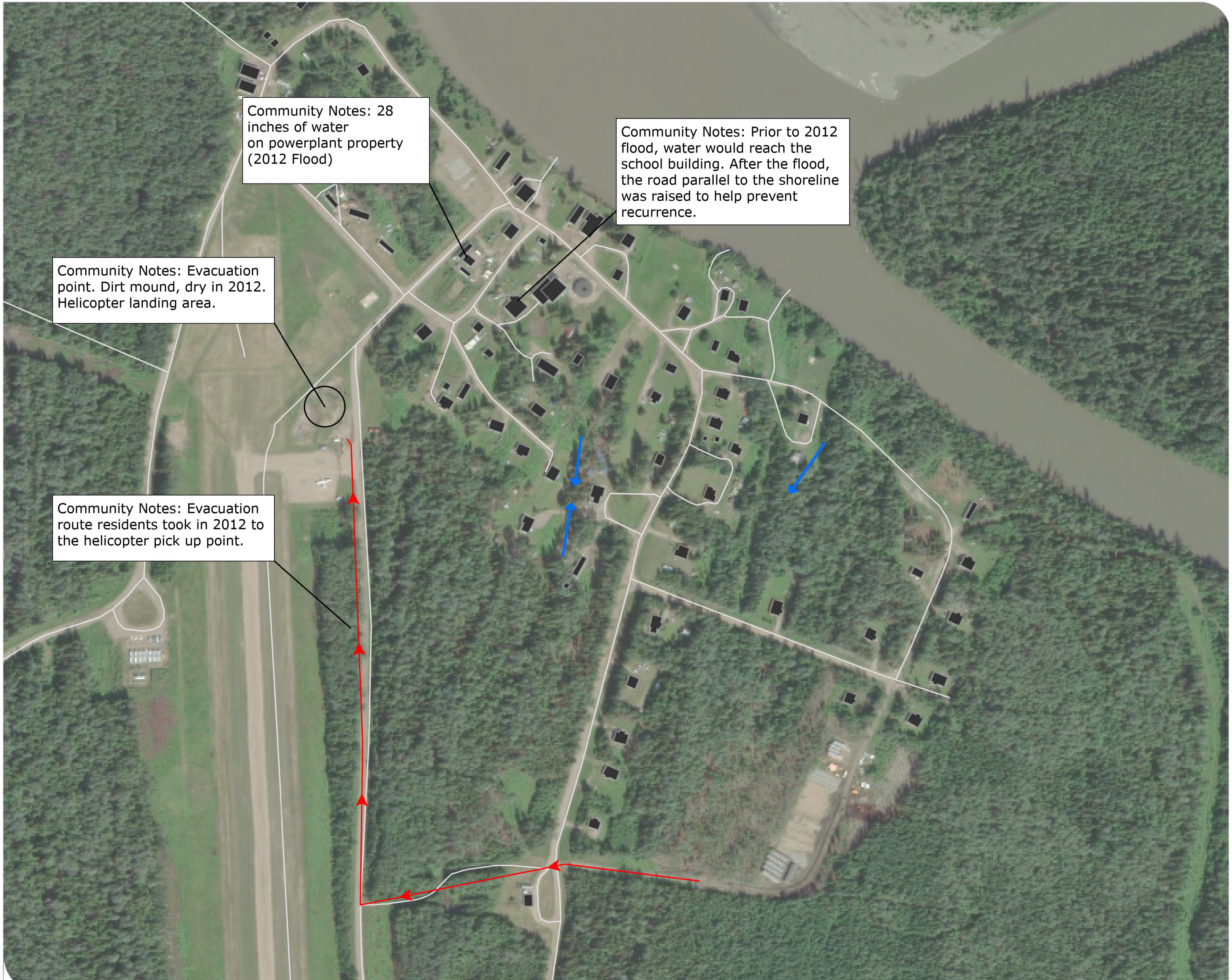


Figure A.2 – Observed Water Elevation of 2022 Flood High-Water Mark



Nahʔa Dehé Dene Band

NAHANNI BUTTE FLOOD ASSESSMENT

FLOOD HAZARD MAP

COMMUNITY ENGAGEMENT

FIGURE A-3

- Evacuation Route
- Flood Direction
- Building Footprints
- Road

Dillon Consulting carried out a community engagement session on December 20, 2024 with the residents of Nahanni Butte. All of the engagement notes came from insights from the attendees using their experience of the 2012 flood the community experienced.

SCALE 1:4,000

0 37.5 75 150 Meters

N E S W

MAP DRAWING INFORMATION:
DATA PROVIDED BY GNWT, Dillon Consulting Limited, ESRI Base Imagery

MAP CREATED BY: VF
MAP CHECKED BY: ML
MAP PROJECTION: NAD 1983 CSRS UTM Zone 10N

DILLON CONSULTING

PROJECT: 23-7137
STATUS: FINAL
DATE: 2025-08-20

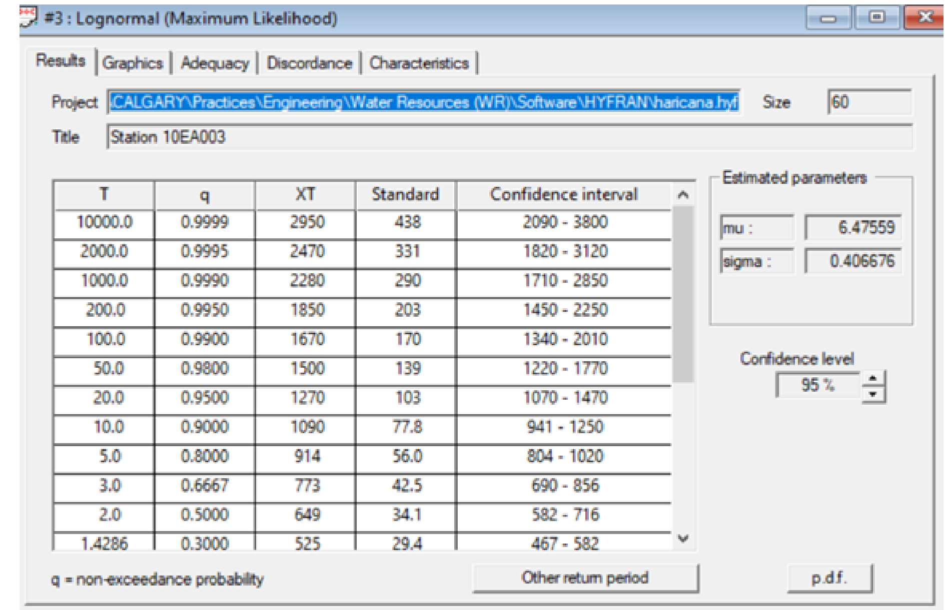
Appendix B

Flood Frequency Analysis

RFFA RESULTS: ANNUAL INSTANTANEOUS PEAK FLOWS AT STATION 10EA003

Year	Annual Peak Flow (m^3/s)
1961	742
1963	1070
1964	742
1965	479
1966	379
1968	920
1969	496
1971	538
1900	1390
1973	1040
1974	714
1975	940
1976	487
1977	538
1978	1350
1979	806
1980	570
1981	543
1984	532
1985	449
1986	752
1989	669
1990	1030
1991	566
1992	1130
1993	426
1994	713
1995	282
1996	454
1998	390
1999	1460
2000	415
2001	990
2002	750
2003	450
2004	712
2005	596
2006	1020
2008	780
2009	538
2010	919
2011	1143
2012	1420
2013	1146
2014	642
2015	353

FFA: Annual Instantaneous Flows				
Fit:	Lognormal			
RI	Probability	Flow (m^3/s)	STD	CI
10000	0.9999	2950	438	2090 - 3800
2000	0.9995	2470	331	1820 - 3120
1000	0.999	2280	290	1710 - 2850
200	0.995	1850	203	1450 - 2250
100	0.99	1670	170	1340 - 2010
50	0.98	1500	139	1220 - 1770
20	0.95	1270	103	1070 - 1470
10	0.9	1090	77.8	941 - 1250
5	0.8	914	56	804 - 1020
3	0.6667	773	42.5	690 - 856
2	0.5	649	34.1	582 - 716
1.4286	0.3	525	29.4	467 - 582
1.25	0.2	461	28.2	406 - 516
1.1111	0.1	385	27.4	332 - 439
1.0526	0.05	332	26.9	280 - 385
1.0204	0.02	282	26.2	230 - 333
1.0101	0.01	252	25.6	202 - 302
1.005	0.005	228	25	179 - 277
1.001	0.001	185	23.5	139 - 231
1.0005	0.0005	170	22.8	126 - 215
1.0001	0.0001	143	21.3	101 - 185


#3 : Lognormal (Maximum Likelihood)

Results | Graphics | Adequacy | Discordance | Characteristics

Project: .CALGARY\Practices\Engineering\Water Resources (WR)\Software\HYFRAN\haricana.hyf — Size: 60

Title: Station 10EA003

T	q	XT	Standard	Confidence interval
10000.0	0.9999	2950	438	2090 - 3800
2000.0	0.9995	2470	331	1820 - 3120
1000.0	0.9990	2280	290	1710 - 2850
200.0	0.9950	1850	203	1450 - 2250
100.0	0.9900	1670	170	1340 - 2010
50.0	0.9800	1500	139	1220 - 1770
20.0	0.9500	1270	103	1070 - 1470
10.0	0.9000	1090	77.8	941 - 1250
5.0	0.8000	914	56.0	804 - 1020
3.0	0.6667	773	42.5	690 - 856
2.0	0.5000	649	34.1	582 - 716
1.4286	0.3000	525	29.4	467 - 582

Estimated parameters

mu : 6.47559

sigma : 0.406676

Confidence level: 95 %

q = non-exceedance probability

Other return period

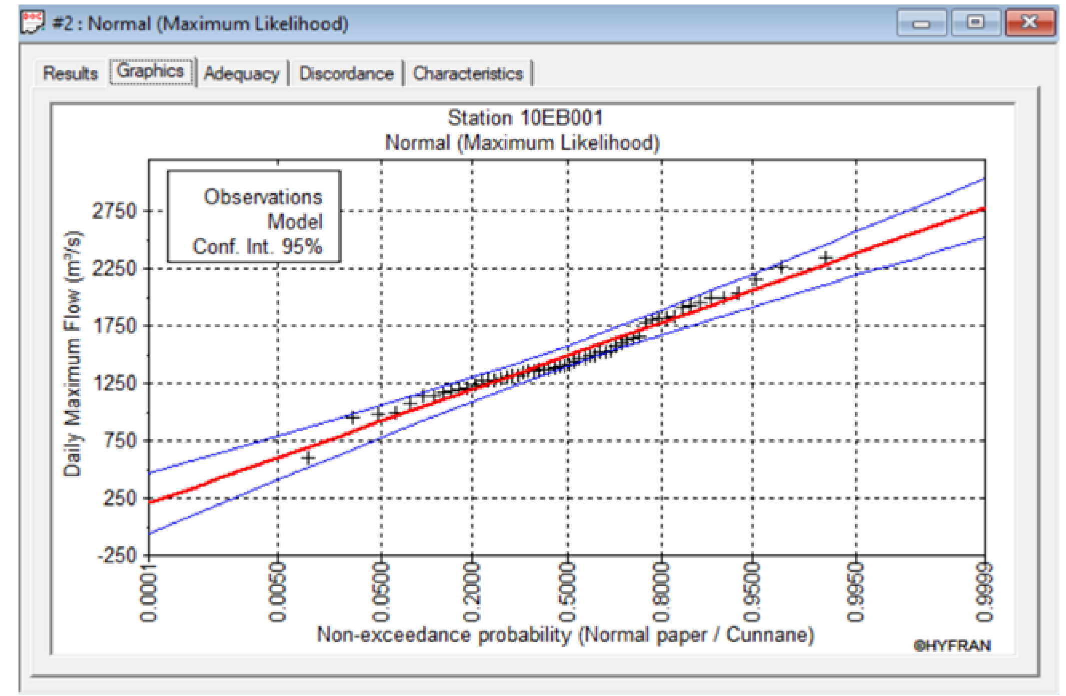
p.d.f.

RFFA RESULTS: ANNUAL INSTANTANEOUS PEAK FLOWS AT STATION 10EB001

Year	Annual Peak Flow (m^3/s)
1963	1320
1964	2030
1965	949
1966	1470
1967	1370
1970	1630
1971	1290
1900	2350
1974	999
1975	1930
1976	1380
1977	1140
1978	1780
1979	1370
1981	1360
1982	1820
1900	1950
1984	1280
1985	1820
1900	1640
1987	1400
1989	2260
1990	2000
1991	1200
1992	1910
1993	1840
1994	1350
1995	980
1996	1170
1997	1280
1998	1530
1999	1520
2000	1300
2001	1520
2002	1180
2003	1320
2004	1610
2007	1570
2008	1390
2009	1440
2010	1210
2011	1664
2012	1993
2013	1501
2014	1078
2015	1359
2016	1273
2017	1420
2019	1150

FFA: Annual Instantaneous Flows

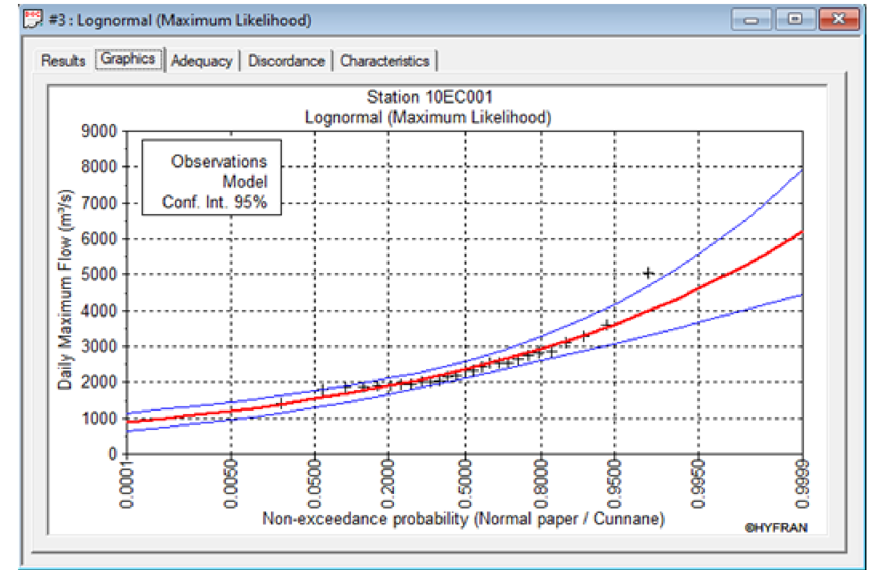
Fit:	Normal			
RI	**Probability**	**Flow (m3/s)**	**STD**	**CI**
10000	0.9999	2780	131	2520 - 3040
2000	0.9995	2630	118	2400 - 2860
1000	0.999	2560	112	2340 - 2780
200	0.995	2380	96.8	2190 - 2570
100	0.99	2300	89.6	2120 - 2470
50	0.98	2200	82.1	2040 - 2360
20	0.95	2060	71.3	1920 - 2200
10	0.9	1930	62.7	1810 - 2060
5	0.8	1780	54	1680 - 1890
3	0.6667	1640	48.4	1540 - 1730
2	0.5	1490	46.3	1400 - 1580
1.4286	0.3	1310	49.4	1210 - 1410
1.25	0.2	1200	54	1090 - 1310
1.1111	0.1	1050	62.7	924 - 1170
1.0526	0.05	921	71.3	781 - 1060
1.0204	0.02	780	82.1	619 - 940
1.0101	0.01	685	89.6	509 - 861
1.005	0.005	599	96.8	409 - 789
1.001	0.001	421	112	201 - 640
1.0005	0.0005	352	118	120 - 583
1.0001	0.0001	203	131	-53.9 - 460



RFFA RESULTS: ANNUAL INSTANTANEOUS PEAK FLOWS AT STATION 10EC001

Year	Annual Peak Flow (m^3/s)
1969	1870
1970	2630
1971	1860
1972	5130
1974	2830
1975	3280
1976	2180
1977	1900
1978	3110
1979	1950
1980	2010
1982	1950
1983	2330
1984	2060
1985	2160
1986	2550
1988	2340
1989	2760
1990	2860
1991	1790
1992	3600
1993	2420
1994	2550
1995	1420

FFA: Annual Instantaneous Flows				
Fit:	Lognormal			
RI	Probability	Flow (m3/s)	STD	CI
10000	0.9999	6,210	890	4460 - 7950
2000	0.9995	5,550	716	4150 - 6960
1000	0.999	5,270	645	4010 - 6530
200	0.995	4,610	487	3650 - 5560
100	0.99	4,320	423	3490 - 5150
50	0.98	4,020	360	3320 - 4730
20	0.95	3,620	281	3070 - 4170
10	0.9	3,290	224	2850 - 3730
5	0.8	2,930	172	2600 - 3270
3	0.6667	2,640	138	2370 - 2910
2	0.5	2360	118	2130 - 2590
1.4286	0.3	2060	110	1840 - 2270
1.25	0.2	1890	111	1680 - 2110
1.1111	0.1	1690	115	1460 - 1910
1.0526	0.05	1540	119	1300 - 1770
1.0204	0.02	1380	124	1140 - 1620
1.0101	0.01	1290	126	1040 - 1530
1.005	0.005	1210	127	955 - 1450
1.001	0.001	1050	129	801 - 1310
1.0005	0.0005	1000	129	748 - 1250
1.0001	0.0001	895	128	643 - 1150

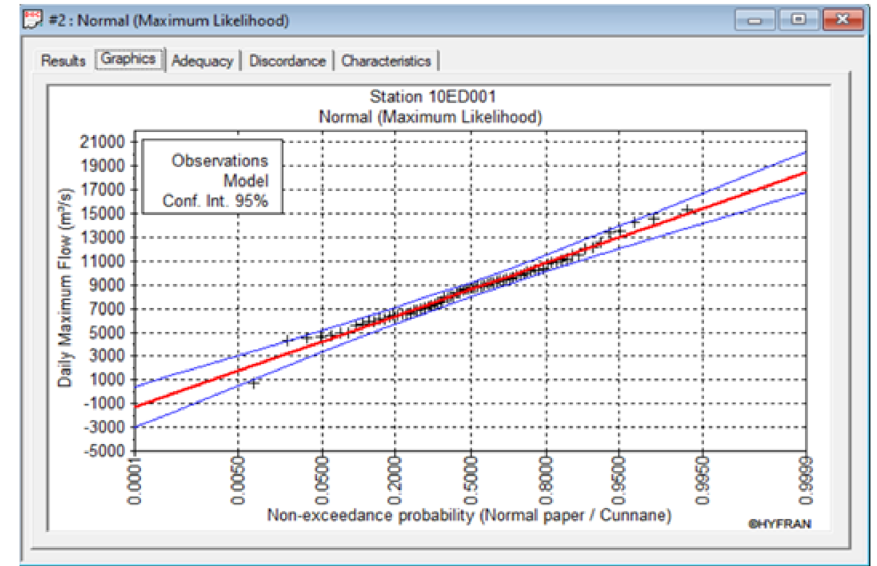


RFFA RESULTS: ANNUAL INSTANTANEOUS PEAK FLOWS AT STATION 10ED001

Year	Annual Peak Flow (m^3/s)
1966	6480
1967	7390
1968	9230
1970	7960
1971	10400
1972	10100
1973	11500
1974	12600
1976	12000
1977	14600
1978	4980
1979	11500
1981	9530
1982	11100
1983	6980
1984	9010
1985	7640
1986	9860
1987	9420
1988	14300
1989	7180
1990	13400
1991	7890
1992	10200
1993	6140
1994	8040
1995	4520
1996	8830
1997	8660
1999	10100
2000	5890
2001	10900
2002	8680
2004	6430
2005	10300
2006	9910
2007	10800
2008	10900
2009	9540
2010	4940
2011	9122
2012	15315
2013	11219
2014	8540
2015	5914
2016	7059
2017	6620
2018	8840
2019	4700

FFA: Annual Instantaneous Flows

Fit:	Normal			
RI	**Probability**	**Flow (m3/s)**	**STD**	**CI**
10000	0.9999	18,500.00	874	1.68E+004 -2.02E+004
2000	0.9995	17,400.00	787	1.58E+004 -1.89E+004
1000	0.999	16,800.00	747	1.54E+004 -1.83E+004
200	0.995	15,500.00	645	1.42E+004 -1.67E+004
100	0.99	14,800.00	598	1.36E+004 -1.60E+004
50	0.98	14,100.00	547	1.30E+004 -1.51E+004
20	0.95	13,000.00	476	1.21E+004 -1.39E+004
10	0.9	12,000.00	418	1.12E+004 -1.28E+004
5	0.8	10,900.00	360	1.01E+004 -1.16E+004
3	0.6667	9,760.00	323	9130 -1.04E+004
2	0.5	8,620.00	309	8010 - 9220
1.4286	0.3	7,220.00	330	6580 - 7870
1.25	0.2	6,380.00	360	5670 - 7090
1.1111	0.1	5,210.00	418	4390 - 6030
1.0526	0.05	4,240.00	476	3310 - 5180
1.0204	0.02	3,160.00	547	2090 - 4230
1.0101	0.01	2,430.00	598	1260 - 3610
1.005	0.005	1,770.00	645	506 - 3040
1.001	0.001	404.00	747	-1060 - 1870
1.0005	0.0005	(128.00)	787	-1670 - 1410
1.0001	0.0001	(1,270.00)	874	-2980 - 448

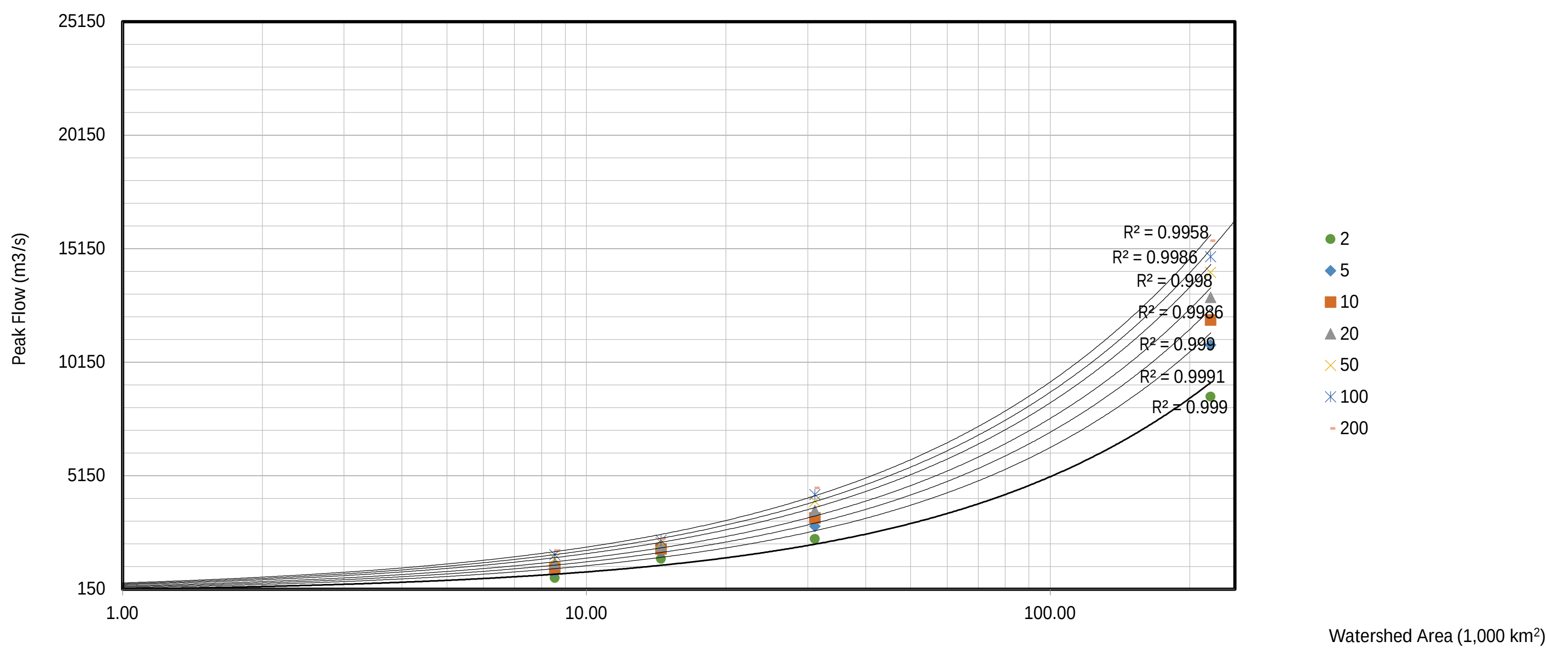


Estimated Regional Instantaneous Peak Flow for Each Station Using Frequency Analysis

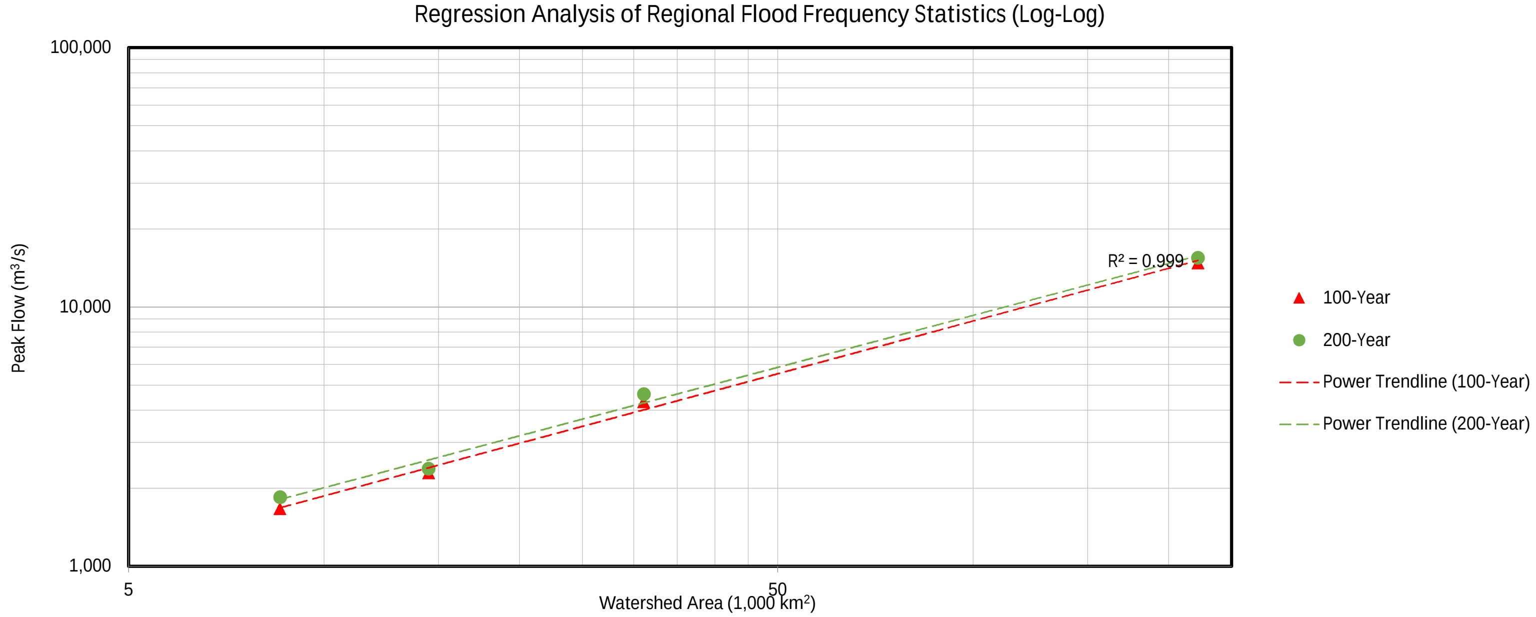
		Flood Flows (m^3/s)			
	Station Name	FLAT RIVER NEAR THE MOUTH	SOUTH NAHANNI RIVER ABOVE VIRGINIA FALLS	SOUTH NAHANNI RIVER ABOVE CLAUSEN CREEK	LIARD RIVER AT FORT LIARD
	Station ID	10EA003	10EB001	10EC001	10ED001
	Comment	Medium - Natural	Medium - Natural	Medium - Natural	Large - Cities/Towns
Return Period (Year)	2	649	1490	2360	8620
	5	914	1780	2930	10900
	10	1090	1930	3290	12000
	20	1270	2060	3620	13000
	50	1500	2200	4020	14100
	100	1670	2300	4320	14800
	200	1850	2380	4610	15500
	Drainage Area (1000 km^2)	8.56	14.50	31.10	222.00
	100-yr Unit Runoff ($m^3/s/km^2$)	195.09	158.62	138.91	66.67

Frequency Analysis completed using HYFRAN software, best fit distribution selected based on minimum AIC: see following station specific pages

Regional Instantaneous Peak Flow vs. Drainage Area Relationship



Regression Analysis of Regional Flood Frequency Statistics (Log-Log)



Estimated Peak Flows for Nahanni River Watershed at Nahanni-Liard Confluence Using Transposition Method

Drainage Area (1000 km^2)	Peak Flow (m^3/s) 36
2-Year	2391.2
5-Year	3040.4
10-Year	3410.1
20-Year	3754.3
50-Year	4156.9
100-Year	4440.8
200-Year	4716.4

Nahanni River Drainage Area at Nahanni-Liard Confluence	Unit
36	[1000 km^2]

Estimated Peak Flows for Liard River Watershed at Nahanni-Liard Confluence Using Transposition Method

Drainage Area (1000 km^2)	Peak Flow (m^3/s) 229
2-Year	9470.3
5-Year	11700.6
10-Year	12772.4
20-Year	13721.5
50-Year	14758.0
100-Year	15430.2
200-Year	16084.0

Liard River Drainage Area at Nahanni-Liard Confluence	Unit
229	[1000 km^2]

Transposition of Flood Discharges

Sometimes it is necessary to transpose a discharge from a gauging station to another point on the same stream or to an adjacent basin where the discharge is unknown. If the basins have similar characteristic, instantaneous peak discharges can be transposed directly using the expression

$$Q_2 = Q_1 \left(\frac{A_2}{A_1} \right)^{0.75} \qquad (8.31)$$

Where:

Q_1 = known peak discharge
Q_2 = unknown peak discharge
A_1 = known basin area
A_2 = unknown basin area

This expression is based on the modified index flood method. If the basins have significantly different hydrologic characteristics, it would be preferable to use the modified index flood method directly, possibly using the transposed figure as a check.

Where two or more gauging stations are available in a reasonably homogeneous watershed, the discharge corresponding to a given frequency at each station can be plotted on logarithmic paper and the required discharge interpolated or extrapolated, within reasonable limits.

RFFA RESULTS: MAXIMUM DAILY FLOWS AT STATION 10EA003

Year	Flow
1960	535
1961	685
1962	555
1963	949
1964	702
1965	445
1966	360
1967	236
1968	835
1969	456
1970	221
1971	501
1972	1250
1973	934
1974	583
1975	810
1976	453
1977	467
1978	1100
1979	709
1980	527
1981	486
1982	555
1983	300
1984	472
1985	420
1986	699
1987	450
1988	640
1989	630
1990	810
1991	491
1992	894
1993	384
1994	652
1995	265
1996	422
1997	720
1998	371
1999	1190
2000	405
2001	825
2002	647
2003	429
2004	672
2005	577
2006	984
2007	563
2008	709
2009	477
2010	850
2011	1020
2012	1210
2013	978
2014	580
2015	324
2016	266
2017	506
2018	614
2019	338
2020	480

Rivière Harricana à Amos

Results of the fitting

Lognormal (Maximum Likelihood)

Number of observations 61

Parameters

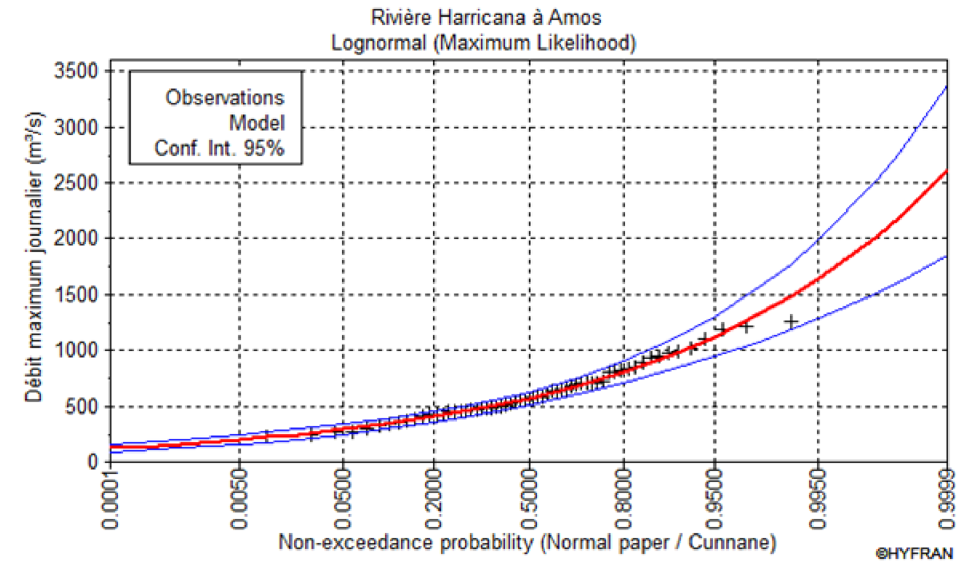
mu	6.343991
sigma	0.409609

Quantiles

q = F(X) : non-exceedance probability

T = 1/(1-q)

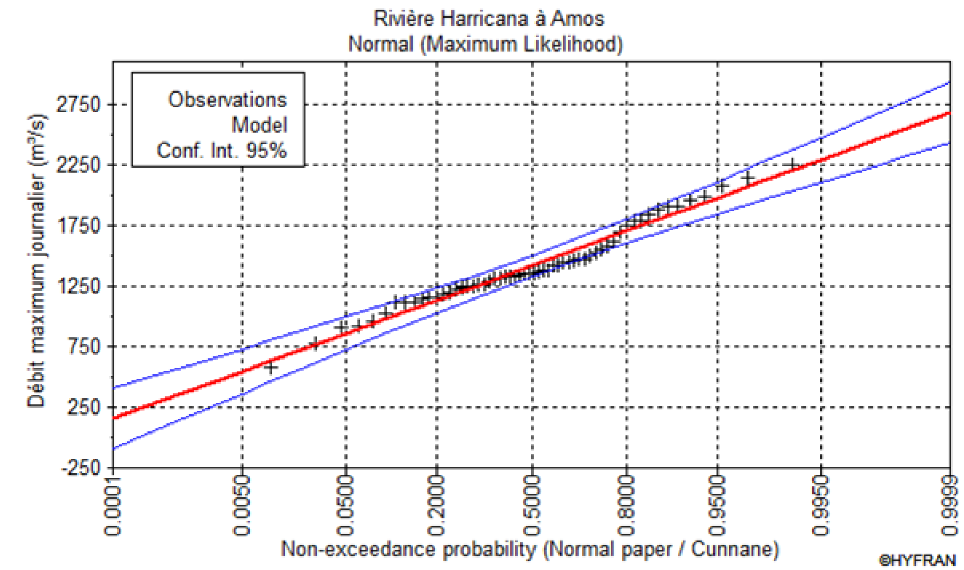
T	q	XT	Standard devi	Confidence interval (95%)	
10000	0.9999	2610	388	1850	3370
2000	0.9995	2190	293	1620	2760
1000	0.999	2020	256	1520	2520
200	0.995	1630	179	1280	1990
100	0.99	1480	150	1180	1770
50	0.98	1320	123	1080	1560
20	0.95	1120	90.3	939	1290
10	0.9	962	68.3	828	1100
5	0.8	803	49.1	707	900
3	0.6667	679	37.2	606	752
2	0.5	569	29.8	511	628
1.4286	0.3	459	25.7	409	510
1.25	0.2	403	24.7	355	451
1.1111	0.1	337	23.9	290	384
1.0526	0.05	290	23.4	244	336
1.0204	0.02	245	22.8	201	290
1.0101	0.01	219	22.3	176	263
1.005	0.005	198	21.7	155	241
1.001	0.001	160	20.4	121	200
1.0005	0.0005	148	19.8	109	187
1.0001	0.0001	124	18.4	87.9	160



RFFA RESULTS: MAXIMUM DAILY FLOWS AT STATION 10EB001

Year	Flow
1962	583
1963	1290
1964	1960
1965	900
1966	1380
1967	1310
1968	1320
1969	1120
1970	1460
1971	1250
1972	2250
1973	1420
1974	964
1975	1840
1976	1320
1977	1120
1978	1700
1979	1310
1980	1200
1981	1340
1982	1790
1983	1900
1984	1240
1985	1750
1986	1470
1987	1370
1988	1350
1989	2140
1990	1910
1991	1180
1992	1880
1993	1790
1994	1330
1995	921
1996	1150
1997	1220
1998	1520
1999	1450
2000	1260
2001	1500
2002	1150
2003	1250
2004	1580
2005	1450
2006	2080
2007	1550
2008	1350
2009	1420
2010	1140
2011	1620
2012	1980
2013	1470
2014	1030
2015	1350
2016	1260
2017	1380
2018	778
2019	1120

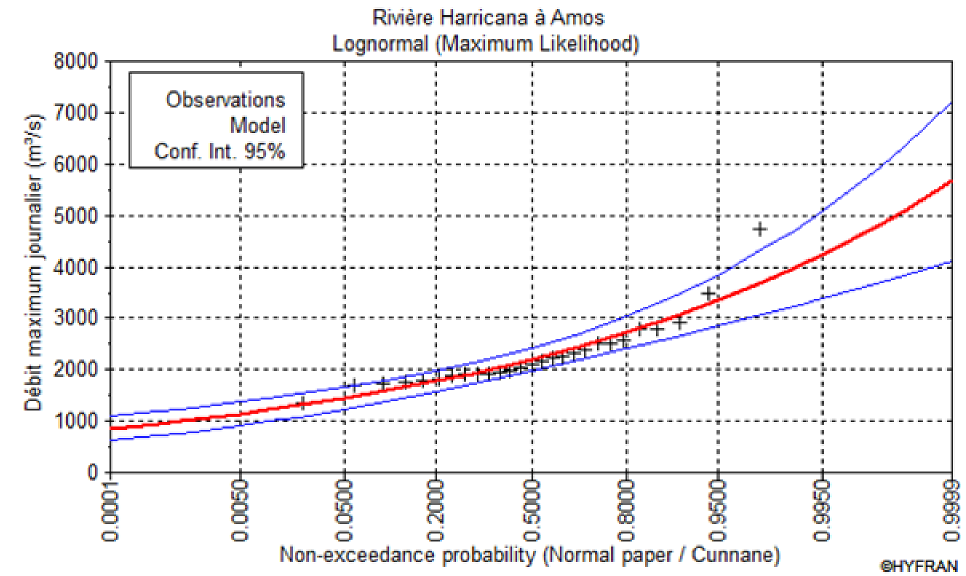
Results of the fitting					
Normal (Maximum Likelihood)					
Number of observations 58					
Parameters					
mu	1415.7931				
sigma	338.825202				
Quantiles					
q = F(X) : non-exceedance probability					
T = 1/(1-q)					
T	q	XT	Standard devi	Confidence interval (95%)	
10000	0.9999	2680	126	2430	2920
2000	0.9995	2530	114	2310	2750
1000	0.999	2460	108	2250	2670
200	0.995	2290	93.1	2110	2470
100	0.99	2200	86.2	2040	2370
50	0.98	2110	78.9	1960	2270
20	0.95	1970	68.6	1840	2110
10	0.9	1850	60.3	1730	1970
5	0.8	1700	51.9	1600	1800
3	0.6667	1560	46.5	1470	1650
2	0.5	1420	44.5	1330	1500
1.4286	0.3	1240	47.5	1150	1330
1.25	0.2	1130	51.9	1030	1230
1.1111	0.1	982	60.3	863	1100
1.0526	0.05	858	68.6	724	993
1.0204	0.02	720	78.9	565	875
1.0101	0.01	627	86.2	458	796
1.005	0.005	543	93.1	360	725
1.001	0.001	369	108	158	580
1.0005	0.0005	301	114	78.3	523
1.0001	0.0001	156	126	-91.6	403



RFFA RESULTS: MAXIMUM DAILY FLOWS AT STATION 10EC001

Year	Flow
1969	1830
1970	1690
1971	1740
1972	4750
1973	2380
1974	2570
1975	2800
1976	2040
1977	1870
1978	2920
1979	1920
1980	1930
1981	1900
1982	1910
1983	2260
1984	1970
1985	2090
1986	2230
1987	1780
1988	2170
1989	2510
1990	2780
1991	1760
1992	3470
1993	2320
1994	2500
1995	1340

Results of the fitting					
Lognormal (Maximum Likelihood)					
Number of observations 27					
Parameters					
mu	7.695815				
sigma	0.254512				
Quantiles					
q = F(X) : non-exceedance probability					
T = 1/(1-q)					
T	q	XT	Standard devi	Confidence interval (95%)	
10000	0.9999	5670	794	4110	7220
2000	0.9995	5080	641	3830	6340
1000	0.999	4830	577	3700	5960
200	0.995	4240	438	3380	5090
100	0.99	3980	380	3230	4720
50	0.98	3710	325	3070	4350
20	0.95	3340	254	2840	3840
10	0.9	3050	203	2650	3450
5	0.8	2720	156	2420	3030
3	0.6667	2450	126	2210	2700
2	0.5	2200	108	1990	2410
1.4286	0.3	1920	101	1730	2120
1.25	0.2	1780	102	1580	1970
1.1111	0.1	1590	106	1380	1790
1.0526	0.05	1450	110	1230	1660
1.0204	0.02	1300	114	1080	1530
1.0101	0.01	1220	116	988	1440
1.005	0.005	1140	118	910	1370
1.001	0.001	1000	120	767	1240
1.0005	0.0005	952	120	717	1190
1.0001	0.0001	853	120	619	1090



RFFA RESULTS: MAXIMUM DAILY FLOWS AT STATION 10ED001

Year	Flow
1944	6230
1945	6770
1946	5570
1947	7920
1948	9710
1949	8610
1950	5610
1951	8230
1952	7230
1953	6050
1954	7370
1955	9310
1956	9500
1957	9120
1958	4310
1959	6800
1960	8670
1961	12000
1962	4530
1966	6400
1967	7330
1968	9090
1969	6230
1970	7840
1971	10400
1972	10000
1973	11300
1974	12500
1975	12600
1976	11800
1977	14200
1978	4960
1979	11500
1980	6510
1981	9460
1982	11000
1983	6870
1984	8890
1985	7610
1986	9680
1987	9320
1988	14300
1989	6930
1990	13400
1991	7680
1992	10200
1993	6090
1994	7990
1995	4430
1996	8760
1997	8620
1998	6510
1999	9980
2000	5840
2001	10700
2002	8420
2003	6870
2004	6300
2005	10100
2006	9740
2007	10700
2008	10900
2009	9500
2010	4870
2011	9080
2012	15300
2013	11100
2014	8410
2015	5880
2016	6480
2017	6510
2018	8590
2019	4640
2020	13400
2021	9220

Results of the fitting

Normal (Maximum Likelihood)

Number of observations 75

Parameters

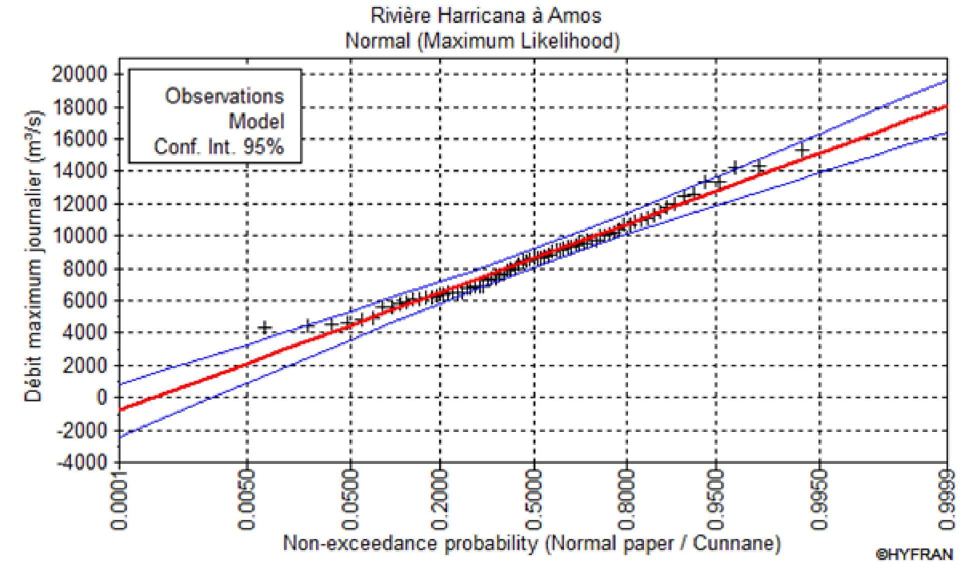
mu	8619.6
sigma	2530.27797

Quantiles

q = F(X) : non-exceedance probability

T = 1/(1-q)

T	q	XT	Standard devi	Confidence interval (95%)	
10000	0.9999	1.80E+04	827	1.64E+04	1.97E+04
2000	0.9995	1.69E+04	744	1.55E+04	1.84E+04
1000	0.999	1.64E+04	706	1.51E+04	1.78E+04
200	0.995	1.51E+04	610	1.39E+04	1.63E+04
100	0.99	1.45E+04	565	1.34E+04	1.56E+04
50	0.98	1.38E+04	518	1.28E+04	1.48E+04
20	0.95	1.28E+04	450	1.19E+04	1.37E+04
10	0.9	1.19E+04	396	1.11E+04	1.26E+04
5	0.8	1.07E+04	341	1.01E+04	1.14E+04
3	0.6667	9710	306	9110	1.03E+04
2	0.5	8620	292	8050	9190
1.4286	0.3	7290	312	6680	7910
1.25	0.2	6490	341	5820	7160
1.1111	0.1	5380	396	4600	6150
1.0526	0.05	4460	450	3570	5340
1.0204	0.02	3420	518	2410	4440
1.0101	0.01	2730	565	1620	3840
1.005	0.005	2100	610	905	3300
1.001	0.001	800	706	-584	2180
1.0005	0.0005	293	744	-1170	1750
1.0001	0.0001	-791	827	-2410	830



RFFA RESULTS: MAXIMUM DAILY FLOWS AT STATIONS 10EA003, 10EB001, 10EC001, AND 10ED001

Estimated Regional Maximum Daily Flow for Each Station Using Frequency Analysis

		Flood Flows (m^3/s)			
	Station Name	FLAT RIVER NEAR THE MOUTH	SOUTH NAHANNI RIVER ABOVE VIRGINIA FALLS	SOUTH NAHANNI RIVER ABOVE CLAUSEN CREEK	LIARD RIVER AT FORT LIARD
	Station ID	10EA003	10EB001	10EC001	10ED001
	Comment	Medium - Natural	Medium - Natural	Medium - Natural	Large - Cities/Towns
Return Period (Year)	2	569	1420	2200	8620
	5	803	1700	2720	10700
	10	962	1850	3050	11900
	20	1120	1970	3340	12800
	50	1320	2110	3710	13800
	100	1480	2200	3980	14500
	200	1630	2290	4240	15100
	Drainage Area (1000 km^2)	8.56	14.50	31.10	222.00
	100-yr Unit Runoff ($m^3/s/km^2$)	172.90	151.72	127.97	65.32

Frequency Analysis completed using HYFRAN software, best fit distribution selected based on minimum AIC: see following station specific pages

Estimated Maximum Flows for Nahanni River Watershed at Nahanni-Liard Confluence Using Transposition Method

Drainage Area (1000 km^2)	Maximum Flow (m^3/s) 36
2-Year	2260.1
5-Year	2857.1
10-Year	3219.2
20-Year	3529.7
50-Year	3902.1
100-Year	4171.8
200-Year	4421.6

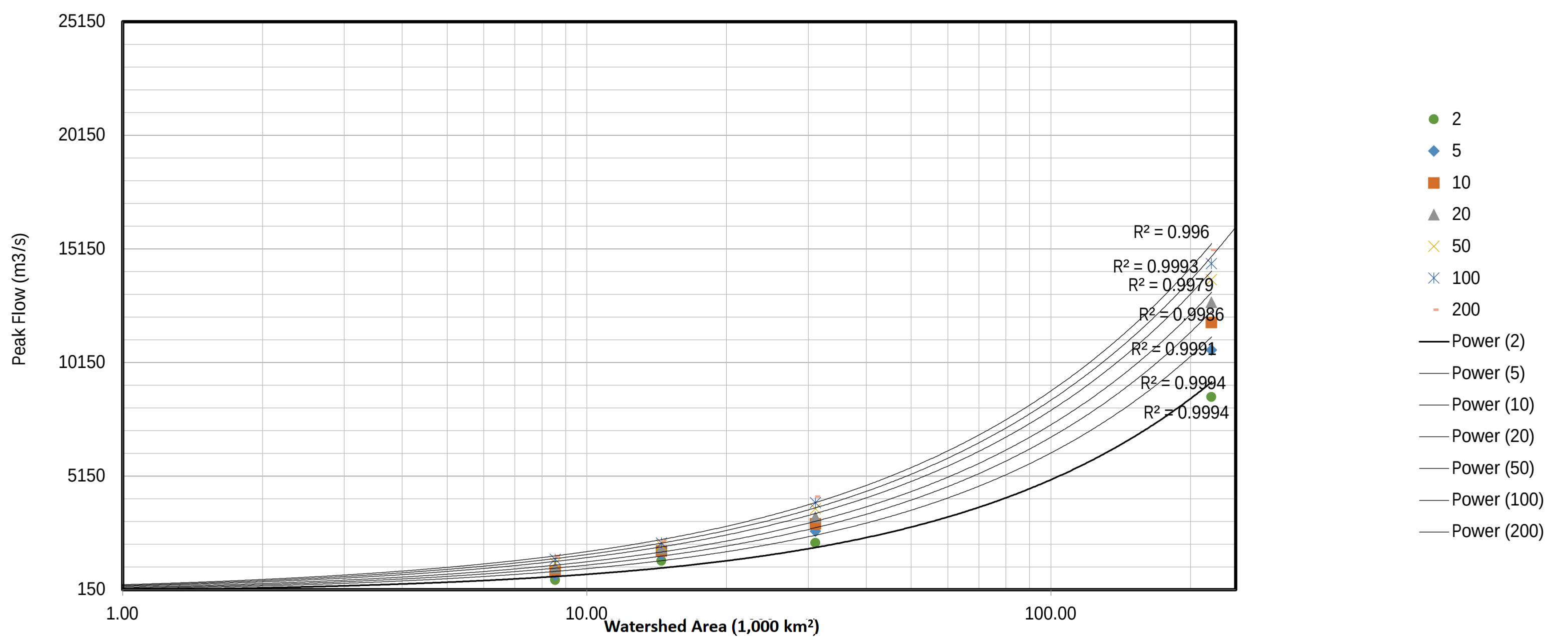
Nahanni River Drainage Area at Nahanni-Liard Confluence	Unit
36.1	[1000 km^2]

Estimated Maximum Flows for Liard River Watershed at Nahanni-Liard Confluence Using Transposition Method

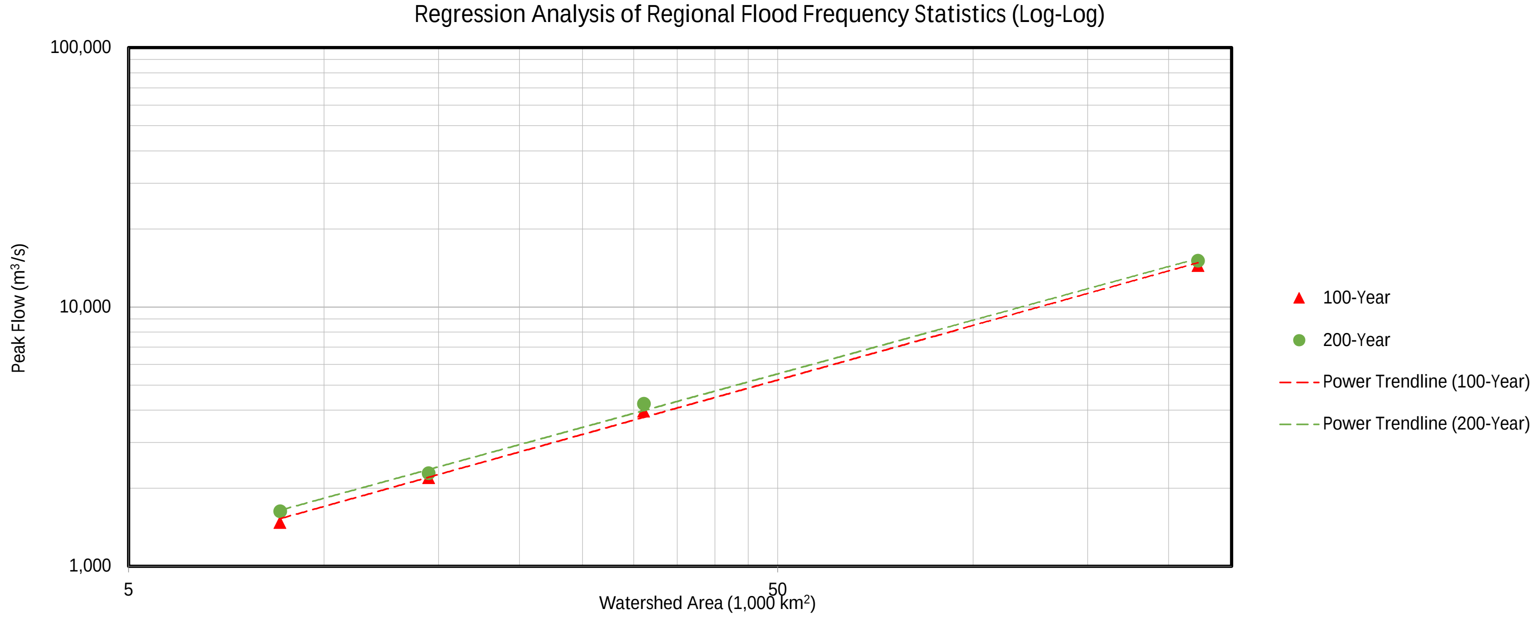
Drainage Area (1000 km^2)	Maximum Flow (m^3/s) 229
2-Year	9511.9
5-Year	11540.0
10-Year	12699.3
20-Year	13539.9
50-Year	14490.0
100-Year	15139.0
200-Year	15708.6

Liard River Drainage Area at Nahanni-Liard Confluence	Unit
228.8	[1000 km^2]

Regional Maximum Daily Flow vs. Drainage Area Relationship



Regression Analysis of Regional Flood Frequency Statistics (Log-Log)



Transposition of Flood Discharges

Sometimes it is necessary to transpose a discharge from a gauging station to another point on the same stream or to an adjacent basin where the discharge is unknown. If the basins have similar characteristic, instantaneous peak discharges can be transposed directly using the expression

$$Q_2 = Q_1 \left(\frac{A_2}{A_1} \right)^{0.75} \quad (8.31)$$

Where:

- Q_1 = known peak discharge
- Q_2 = unknown peak discharge
- A_1 = known basin area
- A_2 = unknown basin area

This expression is based on the modified index flood method. If the basins have significantly different hydrologic characteristics, it would be preferable to use the modified index flood method directly, possibly using the transposed figure as a check.

Where two or more gauging stations are available in a reasonably homogeneous watershed, the discharge corresponding to a given frequency at each station can be plotted on logarithmic paper and the required discharge interpolated or extrapolated, within reasonable limits.

FFA RESULTS: HISTORICAL SIMULATED DAILY FLOW FOR SOUTH NAHANNI RIVER

Flow	Year
2633.35	1985
2681.72	1986
3374.48	1987
2194.58	1988
2700.36	1989
1894.59	1990
3053.74	1991
2034.73	1992
2701.81	1993
1907.73	1994
2260.26	1995
2547.64	1996
1747.75	1997
2980.58	1998
1798.69	1999
2320.06	2000
2661.51	2001
2412.67	2002
2398.71	2003
2711.15	2004
2942.65	2005
2772.59	2006
2649.93	2007
2706.54	2008
1745.92	2009
2875.97	2010
3865.9	2011
3020.01	2012
2488.76	2013
2640.9	2014
1954.75	2015
2563.14	2016
2652.2	2017
2160.07	2018
2876.13	2019
2587.09	2020
2745.02	2021

Best Based on AIC & BIC

Normal

Rivière Harricana à Amos

Results of the fitting

Normal (Maximum Likelihood)

Number of observations 37

Parameters

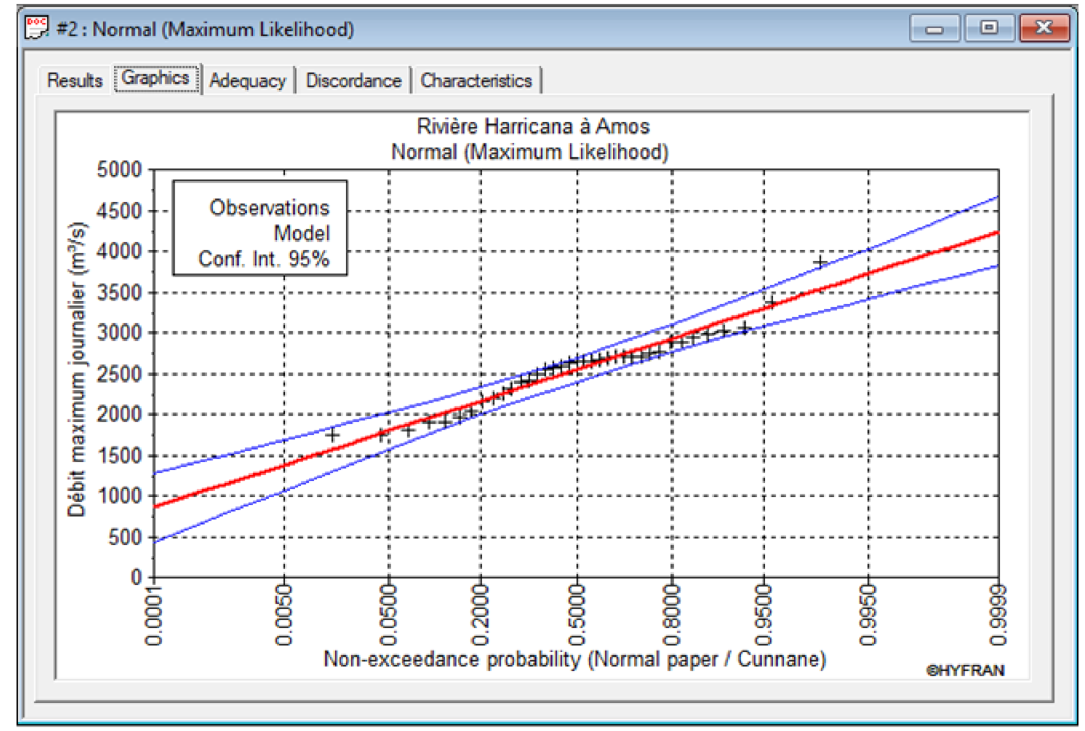
mu	2547.667
sigma	455.3968

Quantiles

q = F(X) : non-exceedance probability

T = 1/(1-q)

T	q	XT	Standard devi	Confidence interval (95%)	
10000	0.9999	4240	213	3820	4660
2000	0.9995	4050	192	3670	4420
1000	0.999	3960	182	3600	4310
200	0.995	3720	157	3410	4030
100	0.99	3610	146	3320	3890
50	0.98	3480	133	3220	3740
20	0.95	3300	116	3070	3520
10	0.9	3130	102	2930	3330
5	0.8	2930	87.4	2760	3100
3	0.6667	2740	78.3	2590	2900
2	0.5	2550	74.9	2400	2690
1.4286	0.3	2310	80	2150	2470
1.25	0.2	2160	87.4	1990	2340
1.1111	0.1	1960	102	1760	2160
1.0526	0.05	1800	116	1570	2030
1.0204	0.02	1610	133	1350	1870
1.0101	0.01	1490	146	1200	1770
1.005	0.005	1370	157	1070	1680
1.001	0.001	1140	182	784	1500
1.0005	0.0005	1050	192	673	1430
1.0001	0.0001	854	213	436	1270



FFA RESULTS: HISTORICAL SIMULATED DAILY FLOW FOR LIARD RIVER

Flow	Year
2633.35	1985
2681.72	1986
3374.48	1987
2194.58	1988
2700.36	1989
1894.59	1990
3053.74	1991
2034.73	1992
2701.81	1993
1907.73	1994
2260.26	1995
2547.64	1996
1747.75	1997
2980.58	1998
1798.69	1999
2320.06	2000
2661.51	2001
2412.67	2002
2398.71	2003
2711.15	2004
2942.65	2005
2772.59	2006
2649.93	2007
2706.54	2008
1745.92	2009
2875.97	2010
3865.9	2011
3020.01	2012
2488.76	2013
2640.9	2014
1954.75	2015
2563.14	2016
2652.2	2017
2160.07	2018
2876.13	2019
2587.09	2020
2745.02	2021

Best based on AIC and BIC

Log-Normal

Rivière Harricana à Amos

Results of the fitting

Lognormal (Maximum Likelihood)

Number of observations 37

Parameters

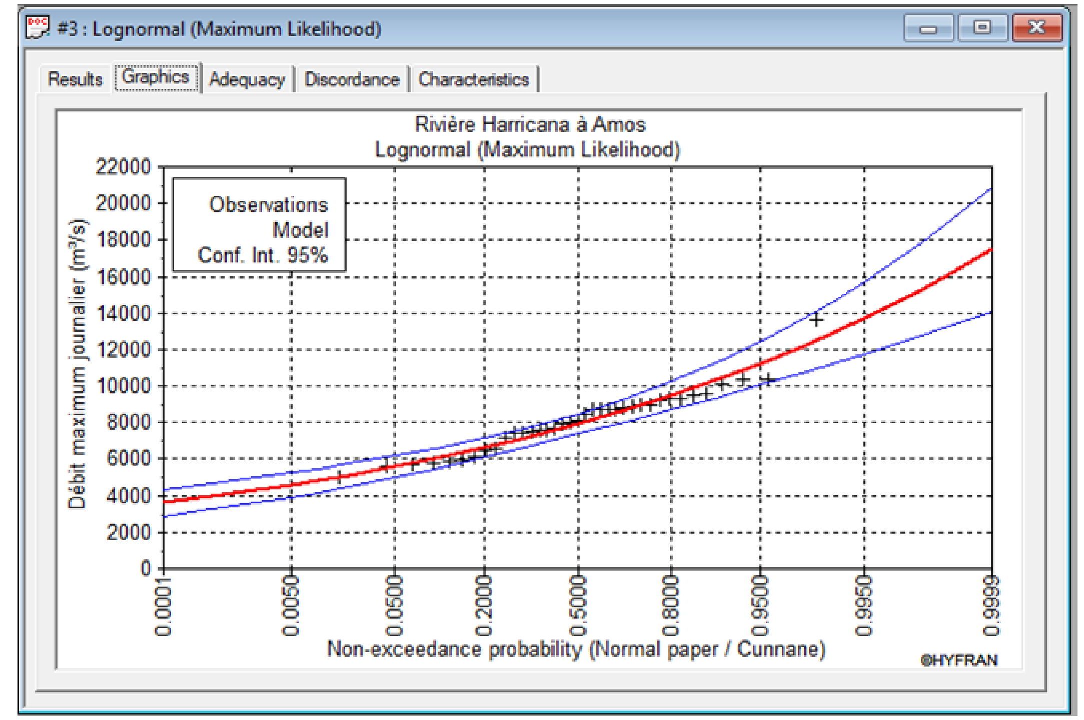
mu	8.977778
sigma	0.212931

Quantiles

q = F(X) : non-exceedance probability

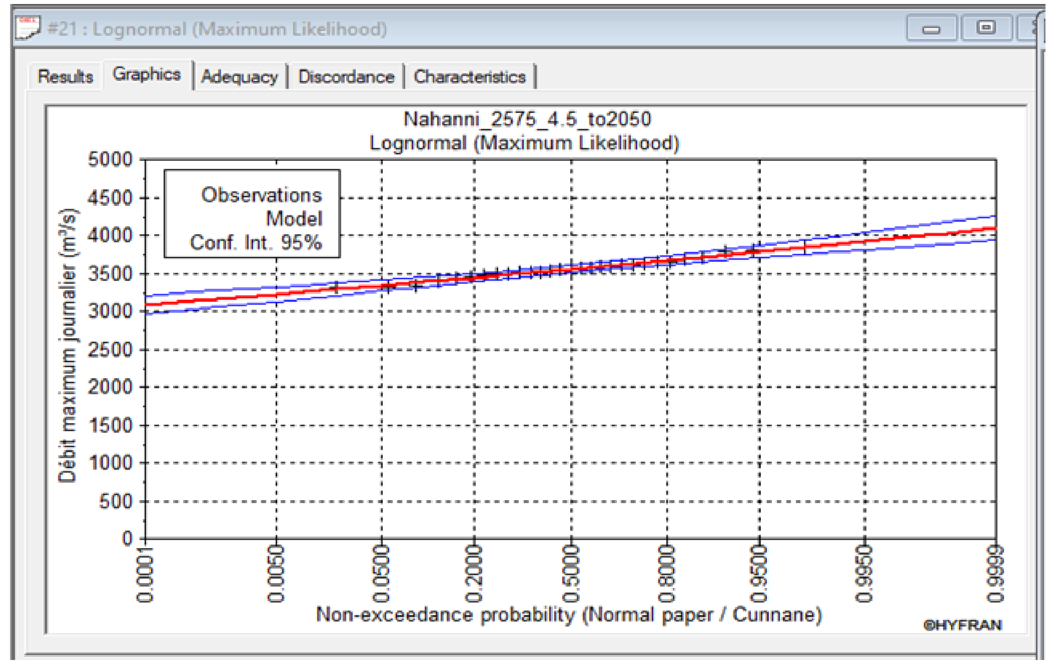
T = 1/(1-q)

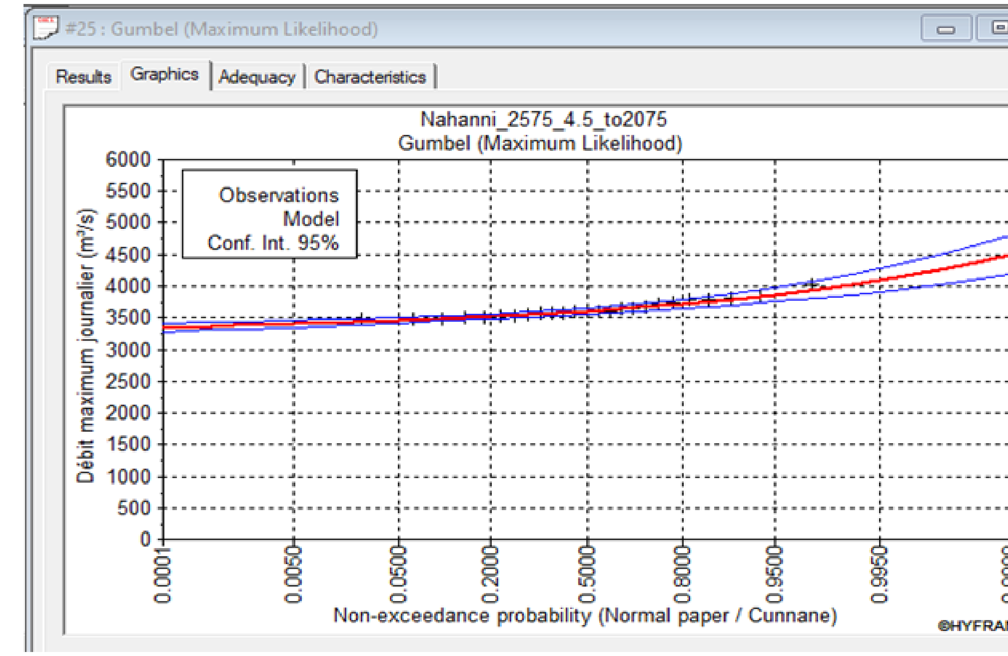
T	q	XT	Standard d	Confidence interval (95%)	
10000	0.9999	17495.4	1743.89	14076.7	20914.1
2000	0.9995	15970.2	1432.4	13162.2	18778.3
1000	0.999	15303.6	1302.16	12750.9	17856.4
200	0.995	13716.3	1008.38	11739.4	15693.1
100	0.99	13006.7	885.474	11270.9	14742.6
50	0.98	12273.3	764.753	10774	13772.5
20	0.95	11249.7	608.924	10055.9	12443.4
10	0.9	10411.8	494.962	9441.51	11382.1
5	0.8	9480.1	387.557	8720.34	10239.9
3	0.6667	8685.42	318.174	8061.67	9309.16
2	0.5	7925.01	277.42	7381.15	8468.86
1.4286	0.3	7088.31	265.059	6568.69	7607.93
1.25	0.2	6625	270.837	6094.06	7155.95
1.1111	0.1	6032.15	286.759	5469.99	6594.31
1.0526	0.05	5582.89	302.192	4990.48	6175.31
1.0204	0.02	5117.28	318.86	4492.19	5742.37
1.0101	0.01	4828.71	328.729	4184.27	5473.15
1.005	0.005	4578.92	336.63	3918.99	5238.85
1.001	0.001	4103.97	349.2	3419.4	4788.54
1.0005	0.0005	3932.67	352.729	3241.18	4624.16
1.0001	0.0001	3589.84	357.825	2888.36	4291.32

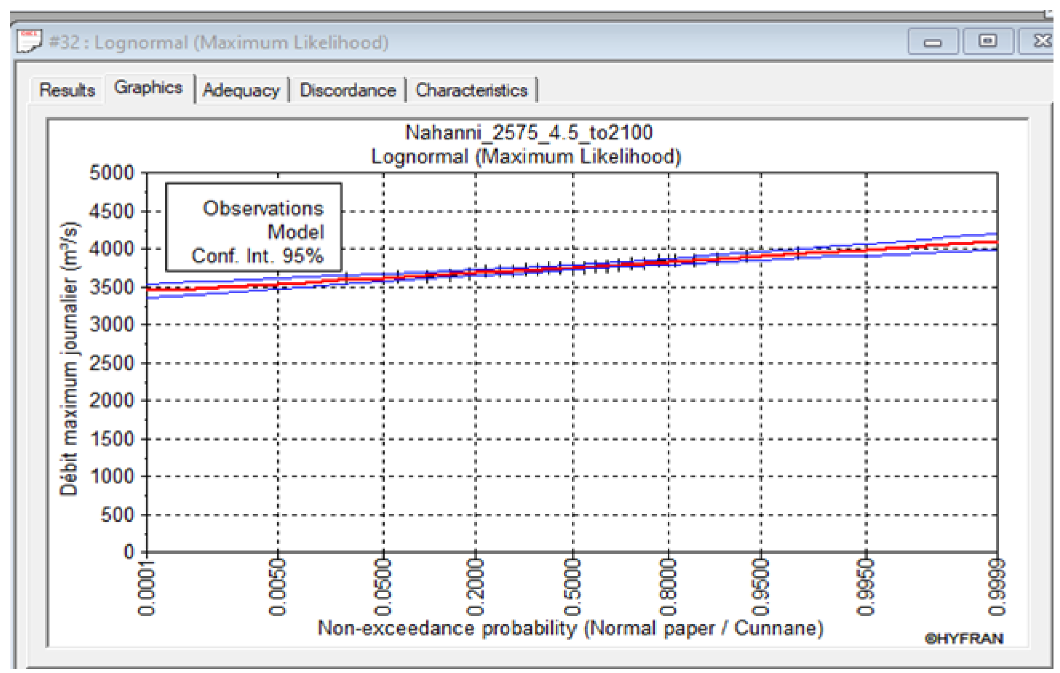


FFA RESULTS: FUTURE SIMULATED FLOW (CLIMATE CHANGE) FOR SOUTH NAHANNI RIVER - 25TH AND 75TH PERCENTILE SSP2-4.5

Year	Flow							
2022	3315.35	RFFA - Entire Period		T	Q	XT	Standard	CI
2023	3531.25	Chosen Distribution:	Normal	10000	0.9999	4190	46.9	4100 - 4280
2024	3580.72	200-year	4020.00	2000	0.9995	4130	42.2	4050 - 4210
2025	3501.73	100-year	3990.00	1000	0.999	4100	40	4020 - 4180
2026	3385.71	Stationarity?	No	200	0.995	4020	34.6	3950 - 4090
2027	3498.16			100	0.99	3990	32	3920 - 4050
2028	3578.19			50	0.98	3950	29.3	3890 - 4000
2029	3331.8			20	0.95	3890	25.5	3840 - 3940
2030	3638.94			10	0.9	3830	22.4	3790 - 3880
2031	3844.72			5	0.8	3770	19.3	3730 - 3810
2032	3604.34			3	0.6667	3710	17.3	3670 - 3740
2033	3443.22			2	0.5	3640	16.6	3610 - 3680
2034	3647.55			1.4286	0.3	3570	17.7	3530 - 3600
2035	3540.96			1.25	0.2	3520	19.3	3480 - 3560
2036	3690.86			1.1111	0.1	3450	22.4	3410 - 3500
2037	3787.79			1.0526	0.05	3400	25.5	3350 - 3450
2038	3315.3			1.0204	0.02	3340	29.3	3280 - 3400
2039	3487.39			1.0101	0.01	3300	32	3240 - 3360
2040	3515.48			1.005	0.005	3260	34.6	3200 - 3330
2041	3472.51			1.001	0.001	3190	40	3110 - 3270
2042	3712.86			1.0005	0.0005	3160	42.2	3080 - 3240
2043	3621.83			1.0001	0.0001	3100	46.9	3000 - 3190
2044	3603.34							
2045	3806.99	RFFA - to 2050		T	Q	XT	Standard	CI
2046	3592.03	Chosen Distribution:	Lognormal	10000	0.9999	4090	82.8	3930 - 4260
2047	3428.44	200-year	3920	2000	0.9995	4030	73.3	3880 - 4170
2048	3513.43	100-year	3880	1000	0.999	4000	69	3860 - 4130
2049	3540.31	Stationarity?	Yes	200	0.995	3920	58.5	3800 - 4030
2050	3574.82			100	0.99	3880	53.6	3780 - 3990
2051	3595.16			50	0.98	3840	48.6	3750 - 3940
2052	3664.83			20	0.95	3780	41.5	3700 - 3860
2053	3528.32			10	0.9	3730	35.9	3660 - 3800
2054	3577.9			5	0.8	3670	30.4	3610 - 3730
2055	4023.65			3	0.6667	3610	26.8	3560 - 3660
2056	3751.99			2	0.5	3550	25.2	3500 - 3600
2057	3592.79			1.4286	0.3	3480	26.4	3430 - 3530
2058	3570.47			1.25	0.2	3440	28.5	3380 - 3500
2059	3492.65			1.1111	0.1	3380	32.6	3320 - 3450
2060	3476.52			1.0526	0.05	3340	36.6	3270 - 3410
2061	3549.74			1.0204	0.02	3290	41.5	3200 - 3370
2062	3529.01			1.0101	0.01	3250	44.9	3160 - 3340
2063	3604.72			1.005	0.005	3220	48	3130 - 3310
2064	3639.08			1.001	0.001	3160	54.5	3050 - 3260
2065	3639.79			1.0005	0.0005	3130	57	3020 - 3250
2066	3494.6			1.0001	0.0001	3080	62.4	2960 - 3210
2067	3476.53							
2068	3497.58							
2069	3710.23	RFFA - to 2075		T	Q	XT	Standard	CI
2070	3810.18	Chosen Distribution:	Gumbel	10000	0.9999	4490	155	4180 - 4790
2071	3799.46	200-year	4100	2000	0.9995	4330	129	4070 - 4580
2072	3795.23	100-year	4030	1000	0.999	4260	118	4030 - 4490
2073	3599.68	Stationarity?	Yes	200	0.995	4100	93	3920 - 4280
2074	3831.14			100	0.99	4030	82.2	3870 - 4190
2075	3577.07			50	0.98	3960	71.4	3820 - 4100
2076	3710.42			20	0.95	3870	57.2	3750 - 3980
2077	3902.78			10	0.9	3800	46.6	3700 - 3890
2078	3606.03			5	0.8	3720	36.1	3650 - 3790
2079	3870.11			3	0.6667	3660	28.6	3610 - 3720
2080	3779.03			2	0.5	3610	23.2	3560 - 3650
2081	3747.99			1.4286	0.3	3550	20.1	3510 - 3590
2082	3794.89			1.25	0.2	3520	19.9	3490 - 3560
2083	3723.04			1.1111	0.1	3490	21.1	3450 - 3530
2084	3811.48			1.0526	0.05	3460	22.9	3420 - 3510
2085	3768.47			1.0204	0.02	3440	25.3	3390 - 3490
2086	3744.23			1.0101	0.01	3420	27	3370 - 3470
2087	3746.12			1.005	0.005	3410	28.6	3350 - 3460
2088	3734.35			1.001	0.001	3380	31.8	3320 - 3440
2089	3626.57			1.0005	0.0005	3370	33	3310 - 3440
2090	3947.01			1.0001	0.0001	3350	35.5	3280 - 3420
2091	3627.95							
2092	3641.83			T	Q	XT	Standard	CI
2093	3737.51	RFFA - to 2100		10000	0.9999	4090	54.7	3990 - 4200
2094	3773.88	Chosen Distribution:	Lognormal	2000	0.9995	4050	48.7	3960 - 4150
2095	3696.63	200-year	3960	1000	0.999	4040	46	3940 - 4130
2096	3669.12	100-year	3940	200	0.995	3990	39.2	3910 - 4060
2097	3706.18	Stationarity?	No	100	0.99	3960	36.1	3890 - 4030
2098	3845.77			50	0.98	3940	32.8	3870 - 4000
2099	3839.11			20	0.95	3900	28.2	3850 - 3960
2100	3837.6			10	0.9	3870	24.6	3820 - 3920
				5	0.8	3830	20.9	3790 - 3870
				3	0.6667	3790	18.5	3760 - 3830
				2	0.5	3750	17.5	3720 - 3790
				1.4286	0.3	3710	18.5	3670 - 3750
				1.25	0.2	3680	20.1	3640 - 3720
				1.1111	0.1	3640	23.1	3600 - 3690
				1.0526	0.05	3610	26.2	3560 - 3660
				1.0204	0.02	3580	29.8	3520 - 3640
				1.0101	0.01	3560	32.4	3490 - 3620
				1.005	0.005	3540	34.8	3470 - 3600
				1.001	0.001	3490	39.8	3420 - 3570
				1.0005	0.0005	3480	41.8	3400 - 3560
				1.0001	0.0001	3440	46	3350 - 3530

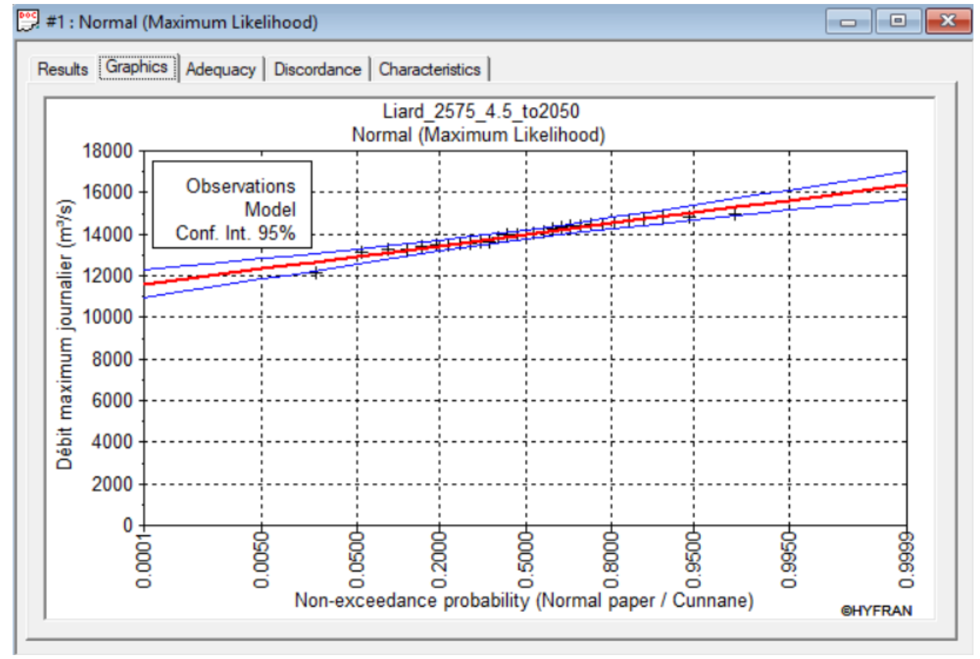


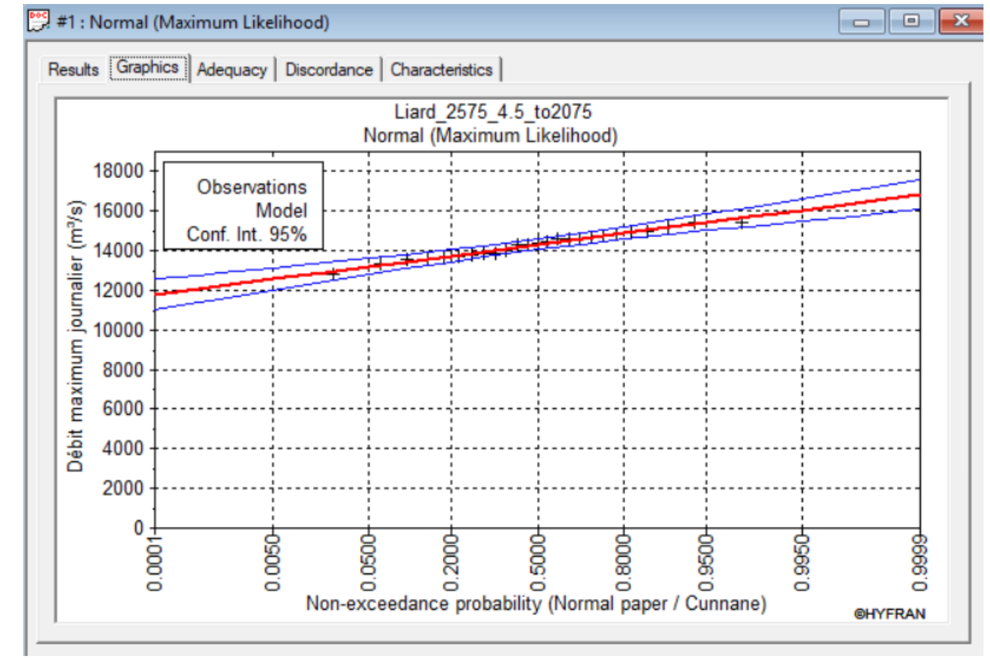


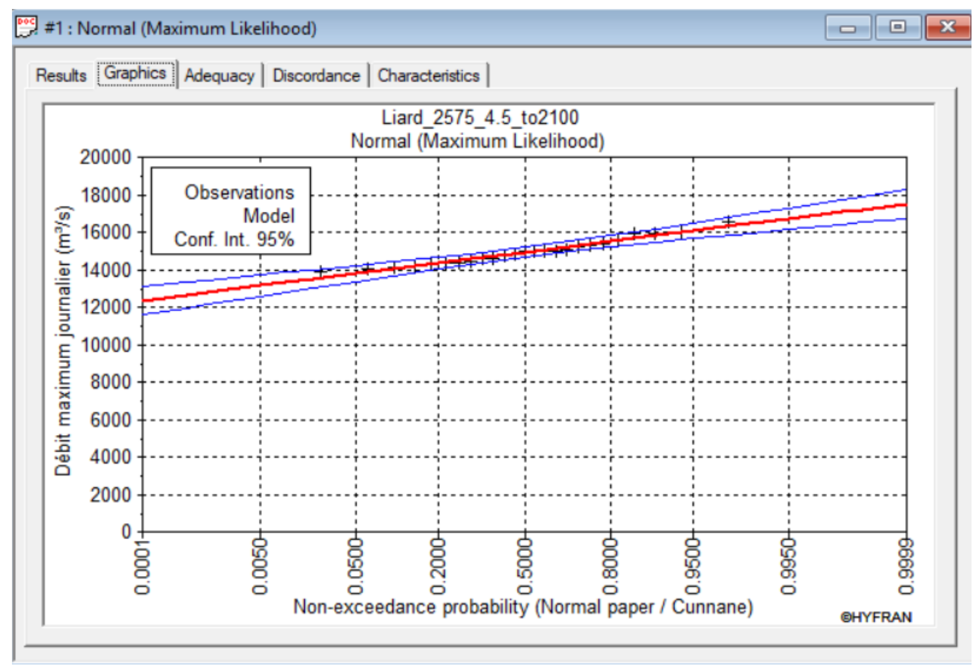


FFA RESULTS: FUTURE SIMULATED FLOW (CLIMATE CHANGE) FOR LIARD RIVER - 25TH AND 75TH PERCENTILE SSP2-4.5

Year	Flow	Year							
2022	12150.1	2022	RFFA - Entire Period		T	Q	XT	Standard	CI
2023	13457.5	2023	Chosen Distribution:	Normal	10000	0.9999	1.73E+04	245.3	1.677E+004 -1.773E+004
2024	13397.6	2024	200-year	16370	2000	0.9995	1.69E+04	220.7	1.649E+004 -1.735E+004
2025	13267.6	2025	100-year	16180	1000	0.999	1.68E+04	209.4	1.636E+004 -1.718E+004
2026	14230.8	2026	Stationarity?	No	200	0.995	1.64E+04	181	1.602E+004 -1.673E+004
2027	14046.7	2027			100	0.99	1.62E+04	167.7	1.585E+004 -1.651E+004
2028	13964.3	2028			50	0.98	1.60E+04	153.5	1.567E+004 -1.627E+004
2029	13136.7	2029			20	0.95	1.57E+04	133.5	1.539E+004 -1.592E+004
2030	14562.2	2030			10	0.9	1.54E+04	117.3	1.514E+004 -1.560E+004
2031	14362.3	2031			5	0.8	1.50E+04	101	1.484E+004 -1.523E+004
2032	14488.8	2032			3	0.6667	1.47E+04	90.66	1.454E+004 -1.490E+004
2033	13969	2033			2	0.5	1.44E+04	86.69	1.422E+004 -1.456E+004
2034	13801.5	2034			1.4286	0.3	1.40E+04	92.52	1.380E+004 -1.416E+004
2035	14996.5	2035			1.25	0.2	1.37E+04	101	1.354E+004 -1.394E+004
2036	14747.9	2036			1.1111	0.1	1.34E+04	117.3	1.317E+004 -1.363E+004
2037	14825.1	2037			1.0526	0.05	1.31E+04	133.5	1.286E+004 -1.338E+004
2038	13298.3	2038			1.0204	0.02	1.28E+04	153.5	1.250E+004 -1.310E+004
2039	14152.7	2039			1.0101	0.01	1.26E+04	167.7	1.226E+004 -1.292E+004
2040	13653	2040			1.005	0.005	1.24E+04	181	1.205E+004 -1.276E+004
2041	13613.7	2041			1.001	0.001	1.20E+04	209.4	1.159E+004 -1.242E+004
2042	13945.2	2042			1.0005	0.0005	1.19E+04	220.7	1.142E+004 -1.228E+004
2043	14710.8	2043			1.0001	0.0001	1.15E+04	245.3	1.104E+004 -1.200E+004
2044	14820.7	2044							
2045	14475.1	2045	RFFA - to 2050		T	Q	XT	Standard	CI
2046	14410.3	2046	Chosen Distribution:	Normal	10000	0.9999	1.73E+04	419.9	1.652E+004 -1.816E+004
2047	14376.2	2047	200-year	16430	2000	0.9995	1.70E+04	377.8	1.626E+004 -1.774E+004
2048	13565.4	2048	100-year	16240	1000	0.999	1.68E+04	358.4	1.614E+004 -1.754E+004
2049	13533.9	2049	Stationarity?	No	200	0.995	1.64E+04	309.6	1.583E+004 -1.704E+004
2050	13495.3	2050			100	0.99	1.62E+04	286.6	1.567E+004 -1.680E+004
2051	14610.8	2051			50	0.98	1.60E+04	262.3	1.551E+004 -1.654E+004
2052	14772.5	2052			20	0.95	1.57E+04	227.8	1.525E+004 -1.614E+004
2053	13864.5	2053			10	0.9	1.54E+04	199.9	1.502E+004 -1.580E+004
2054	14338.8	2054			5	0.8	1.51E+04	171.8	1.472E+004 -1.540E+004
2055	14986.3	2055			3	0.6667	1.47E+04	153.9	1.443E+004 -1.504E+004
2056	14633.5	2056			2	0.5	1.44E+04	147	1.411E+004 -1.468E+004
2057	14670.9	2057			1.4286	0.3	1.40E+04	157.1	1.367E+004 -1.429E+004
2058	14444.6	2058			1.25	0.2	1.37E+04	171.8	1.339E+004 -1.407E+004
2059	13971.9	2059			1.1111	0.1	1.34E+04	199.9	1.299E+004 -1.377E+004
2060	12839.8	2060			1.0526	0.05	1.31E+04	227.8	1.265E+004 -1.354E+004
2061	13372.4	2061			1.0204	0.02	1.28E+04	262.3	1.225E+004 -1.328E+004
2062	14297.5	2062			1.0101	0.01	1.26E+04	286.6	1.199E+004 -1.312E+004
2063	15424.1	2063			1.005	0.005	1.24E+04	309.6	1.175E+004 -1.296E+004
2064	15451.8	2064			1.001	0.001	1.20E+04	358.4	1.125E+004 -1.265E+004
2065	13560.2	2065			1.0005	0.0005	1.18E+04	377.8	1.105E+004 -1.253E+004
2066	13846.4	2066			1.0001	0.0001	1.15E+04	419.9	1.063E+004 -1.227E+004
2067	13773.9	2067							
2068	13587.4	2068							
2069	15006.5	2069	RFFA - to 2075		T	Q	XT	Standard	CI
2070	14858.6	2070	Chosen Distribution:	Normal	10000	0.9999	1.73E+04	463.4	1.641E+004 -1.823E+004
2071	14369.1	2071	200-year	16390	2000	0.9995	1.70E+04	416.9	1.615E+004 -1.779E+004
2072	13637.4	2072	100-year	16190	1000	0.999	1.68E+04	395.5	1.603E+004 -1.758E+004
2073	13702.3	2073	Stationarity?	No @ 5 but yes at 1	200	0.995	1.64E+04	341.6	1.572E+004 -1.706E+004
2074	15204.7	2074			100	0.99	1.62E+04	316.2	1.557E+004 -1.681E+004
2075	14585.1	2075			50	0.98	1.60E+04	289.3	1.540E+004 -1.654E+004
2076	15952.2	2076			20	0.95	1.56E+04	251.1	1.515E+004 -1.613E+004
2077	14401.2	2077			10	0.9	1.54E+04	220.4	1.491E+004 -1.578E+004
2078	14817.5	2078			5	0.8	1.50E+04	189.3	1.462E+004 -1.536E+004
2079	16039	2079			3	0.6667	1.47E+04	169.4	1.432E+004 -1.499E+004
2080	14985.2	2080			2	0.5	1.43E+04	161.8	1.399E+004 -1.463E+004
2081	14549.3	2081			1.4286	0.3	1.39E+04	173	1.355E+004 -1.422E+004
2082	14954.2	2082			1.25	0.2	1.36E+04	189.3	1.326E+004 -1.400E+004
2083	14225	2083			1.1111	0.1	1.33E+04	220.4	1.284E+004 -1.370E+004
2084	14951.3	2084			1.0526	0.05	1.30E+04	251.1	1.249E+004 -1.347E+004
2085	15955.4	2085			1.0204	0.02	1.27E+04	289.3	1.208E+004 -1.321E+004
2086	13893.7	2086			1.0101	0.01	1.24E+04	316.2	1.181E+004 -1.305E+004
2087	15598.6	2087			1.005	0.005	1.22E+04	341.6	1.155E+004 -1.289E+004
2088	14760.2	2088			1.001	0.001	1.18E+04	395.5	1.103E+004 -1.258E+004
2089	14102.2	2089			1.0005	0.0005	1.17E+04	416.9	1.083E+004 -1.246E+004
2090	16538.2	2090			1.0001	0.0001	1.13E+04	463.4	1.039E+004 -1.221E+004
2091	14570.2	2091							
2092	14352.8	2092							
2093	14977.8	2093	RFFA - to 2100		T	Q	XT	Standard	CI
2094	15176.6	2094	Chosen Distribution:	Normal	10000	0.9999	1.98E+04	886.1	1.810E+004 -2.157E+004
2095	14324.9	2095	200-year	17610	2000	0.9995	1.89E+04	740.1	1.747E+004 -2.037E+004
2096	15315.1	2096	100-year	17220	1000	0.999	1.85E+04	677.4	1.720E+004 -1.986E+004
2097	15377.7	2097	Stationarity?	Yes	200	0.995	1.76E+04	532.5	1.657E+004 -1.866E+004
2098	14041.9	2098			100	0.99	1.72E+04	470.4	1.629E+004 -1.814E+004
2099	14292.3	2099			50	0.98	1.68E+04	408.6	1.602E+004 -1.762E+004
2100	15065.1	2100			20	0.95	1.63E+04	327.5	1.565E+004 -1.693E+004
					10	0.9	1.59E+04	266.7	1.536E+004 -1.640E+004
					5	0.8	1.55E+04	206.6	1.505E+004 -1.586E+004
					3	0.6667	1.51E+04	163.7	1.479E+004 -1.544E+004
					2	0.5	1.48E+04	132.8	1.455E+004 -1.507E+004
					1.4286	0.3	1.45E+04	115.1	1.427E+004 -1.472E+004
					1.25	0.2	1.43E+04	114	1.411E+004 -1.455E+004
					1.1111	0.1	1.41E+04	121	1.389E+004 -1.436E+004
					1.0526	0.05	1.40E+04	131.2	1.372E+004 -1.423E+004
					1.0204	0.02	1.38E+04	144.9	1.354E+004 -1.411E+004
					1.0101	0.01	1.37E+04	154.6	1.343E+004 -1.404E+004
					1.005	0.005	1.37E+04	163.6	1.333E+004 -1.397E+004
					1.001	0.001	1.35E+04	181.9	1.315E+004 -1.386E+004
					1.0005	0.0005	1.35E+04	188.8	1.308E+004 -1.382E+004
					1.0001	0.0001	1.33E+04	203.1	1.294E+004 -1.374E+004

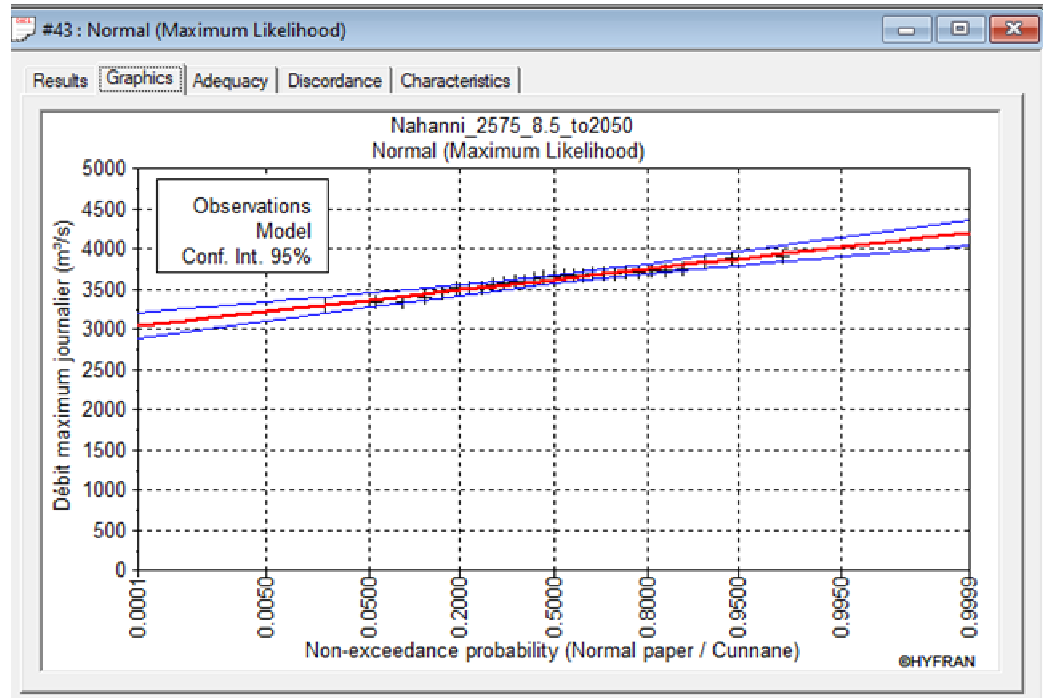


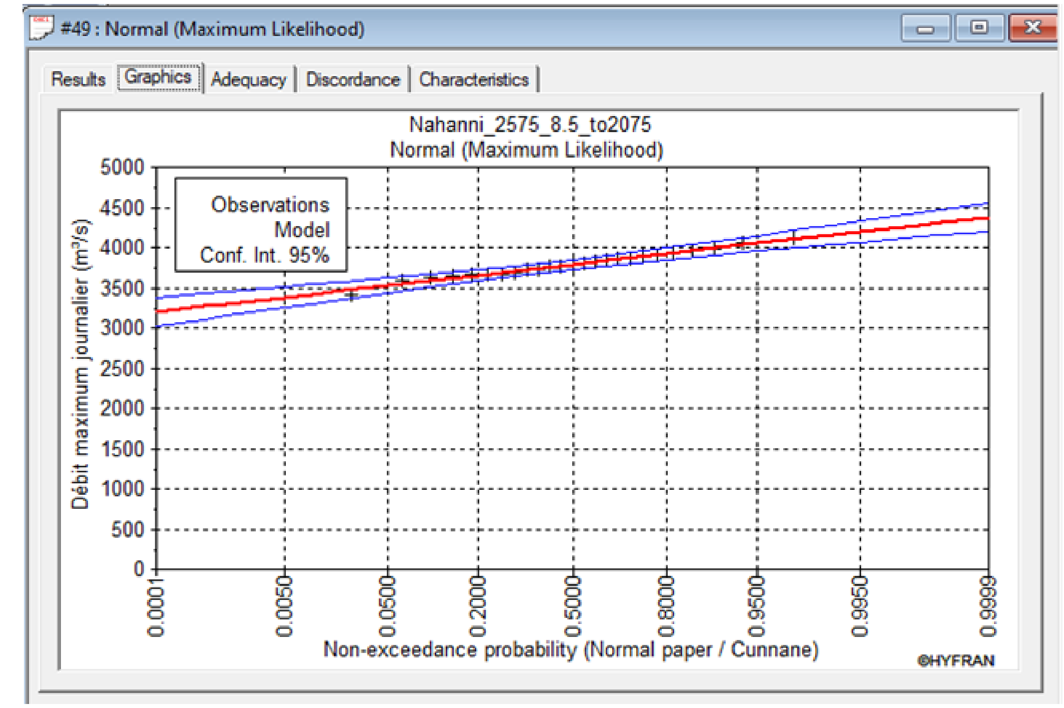


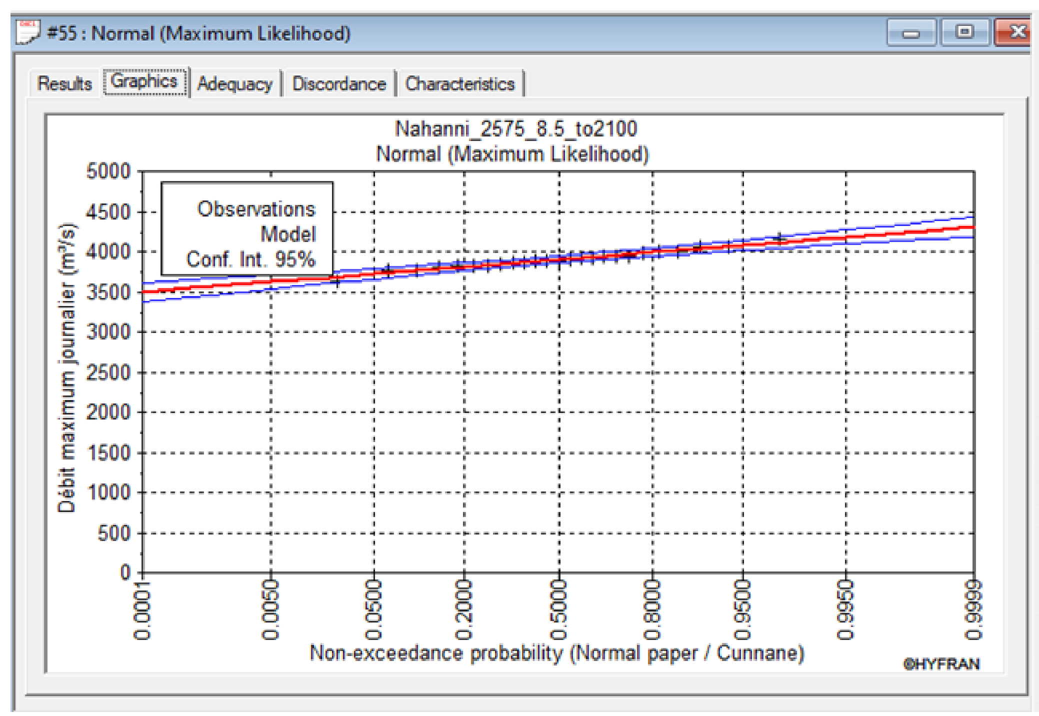


FFA RESULTS: FUTURE SIMULATED FLOW (CLIMATE CHANGE) FOR SOUTH NAHANNI RIVER - 25TH AND 75TH PERCENTILE SSP5-8.5

Year	Flow			T	Q	XT	Standard	CI
3339.14	2022	RFFA - Entire Period		T	Q	XT	Standard	CI
3695.44	2023	Chosen Distribution:	Normal	10000	0.9999	4450	58.9	4330 - 4560
3711.4	2024	200-year	4240.00	2000	0.9995	4370	53	4270 - 4470
3594.9	2025	100-year	4190.00	1000	0.999	4330	50.3	4230 - 4430
3501.11	2026	Stationarity?	No	200	0.995	4240	43.5	4150 - 4320
3655.4	2027			100	0.99	4190	40.3	4110 - 4270
3289.69	2028			50	0.98	4140	36.9	4070 - 4210
3658.27	2029			20	0.95	4070	32.1	4000 - 4130
3573.04	2030			10	0.9	4000	28.2	3940 - 4050
3508.25	2031			5	0.8	3920	24.3	3870 - 3960
3679.04	2032			3	0.6667	3840	21.8	3800 - 3880
3336.77	2033			2	0.5	3760	20.8	3720 - 3800
3649.49	2034			1.4286	0.3	3660	22.2	3620 - 3710
3449.42	2035			1.25	0.2	3600	24.3	3560 - 3650
3691.75	2036			1.1111	0.1	3520	28.2	3470 - 3580
3852.13	2037			1.0526	0.05	3460	32.1	3390 - 3520
3669.8	2038			1.0204	0.02	3380	36.9	3310 - 3450
3585.73	2039			1.0101	0.01	3330	40.3	3250 - 3410
3386.45	2040			1.005	0.005	3280	43.5	3200 - 3370
3620.42	2041			1.001	0.001	3190	50.3	3090 - 3290
3734.76	2042			1.0005	0.0005	3150	53	3050 - 3260
3896.61	2043			1.0001	0.0001	3070	58.9	2960 - 3190
3658.53	2044							
3751.2	2045	RFFA - to 2050		T	Q	XT	Standard	CI
3551.89	2046	Chosen Distribution:	Normal	10000	0.9999	4190	82.5	4030 - 4360
3726.48	2047	200-year	4020	2000	0.9995	4130	74.2	3980 - 4270
3713.74	2048	100-year	3980	1000	0.999	4100	70.4	3960 - 4230
3512.68	2049	Stationarity?	Yes	200	0.995	4020	60.8	3900 - 4140
3880	2050			100	0.99	3980	56.3	3870 - 4090
3777.92	2051			50	0.98	3940	51.5	3830 - 4040
3722.81	2052			20	0.95	3870	44.7	3780 - 3960
3662.43	2053			10	0.9	3820	39.3	3740 - 3890
3762.47	2054			5	0.8	3750	33.8	3680 - 3810
3650.52	2055			3	0.6667	3680	30.2	3620 - 3740
3687.84	2056			2	0.5	3620	28.9	3560 - 3670
3825.7	2057			1.4286	0.3	3530	30.9	3470 - 3600
3865.7	2058			1.25	0.2	3490	33.8	3420 - 3550
3664.46	2059			1.1111	0.1	3420	39.3	3340 - 3490
3957.66	2060			1.0526	0.05	3360	44.7	3270 - 3450
3803.66	2061			1.0204	0.02	3300	51.5	3200 - 3400
3893.49	2062			1.0101	0.01	3250	56.3	3140 - 3360
3766.36	2063			1.005	0.005	3220	60.8	3100 - 3330
3718.21	2064			1.001	0.001	3140	70.4	3000 - 3270
3629.9	2065			1.0005	0.0005	3100	74.2	2960 - 3250
3664.91	2066			1.0001	0.0001	3040	82.5	2880 - 3200
3586.58	2067							
4125.08	2068							
3931.32	2069	RFFA - to 2075		T	Q	XT	Standard	CI
3407.47	2070	Chosen Distribution:	Normal	10000	0.9999	4380	90.9	4200 - 4560
3841.02	2071	200-year	4200	2000	0.9995	4310	81.8	4150 - 4470
3859.68	2072	100-year	4160	1000	0.999	4280	77.5	4130 - 4430
3903.5	2073	Stationarity?	Yes	200	0.995	4200	67	4070 - 4330
3975.73	2074			100	0.99	4160	62	4040 - 4280
4052.3	2075			50	0.98	4120	56.7	4000 - 4230
4001.89	2076			20	0.95	4050	49.3	3950 - 4150
3914.57	2077			10	0.9	3990	43.2	3910 - 4080
4058.43	2078			5	0.8	3920	37.1	3850 - 4000
4059.29	2079			3	0.6667	3860	33.2	3790 - 3920
3636.09	2080			2	0.5	3790	31.7	3730 - 3850
3882.88	2081			1.4286	0.3	3710	33.9	3640 - 3770
3890.12	2082			1.25	0.2	3660	37.1	3580 - 3730
3761.16	2083			1.1111	0.1	3590	43.2	3500 - 3670
3851.14	2084			1.0526	0.05	3530	49.3	3430 - 3630
3829.5	2085			1.0204	0.02	3460	56.7	3350 - 3570
3887.92	2086			1.0101	0.01	3420	62	3300 - 3540
3942.13	2087			1.005	0.005	3380	67	3250 - 3510
3808.63	2088			1.001	0.001	3300	77.5	3150 - 3450
3999.94	2089			1.0005	0.0005	3270	81.8	3110 - 3430
3945.56	2090			1.0001	0.0001	3200	90.9	3020 - 3380
3828.41	2091							
3978.86	2092							
3814.52	2093	RFFA - to 2100		T	Q	XT	Standard	CI
4150.95	2094	Chosen Distribution:	Normal	10000	0.9999	4310	62.5	4180 - 4430
3919.47	2095	200-year	4180	2000	0.9995	4260	56.2	4150 - 4370
3862.12	2096	100-year	4150	1000	0.999	4240	53.3	4130 - 4340
3941.2	2097	Stationarity?	Yes	200	0.995	4180	46.1	4090 - 4270
3857.62	2098			100	0.99	4150	42.6	4070 - 4240
3900.47	2099			50	0.98	4120	39	4050 - 4200
3763.89	2100			20	0.95	4080	33.9	4010 - 4150
				10	0.9	4040	29.7	3980 - 4100
				5	0.8	3990	25.5	3940 - 4040
				3	0.6667	3950	22.8	3900 - 3990
				2	0.5	3900	21.8	3860 - 3940
				1.4286	0.3	3840	23.3	3800 - 3890
				1.25	0.2	3810	25.5	3760 - 3860
				1.1111	0.1	3760	29.7	3700 - 3820
				1.0526	0.05	3720	33.9	3650 - 3790
				1.0204	0.02	3680	39	3600 - 3750
				1.0101	0.01	3650	42.6	3560 - 3730
				1.005	0.005	3620	46.1	3530 - 3710
				1.001	0.001	3560	53.3	3460 - 3670
				1.0005	0.0005	3540	56.2	3430 - 3650
				1.0001	0.0001	3490	62.5	3370 - 3620

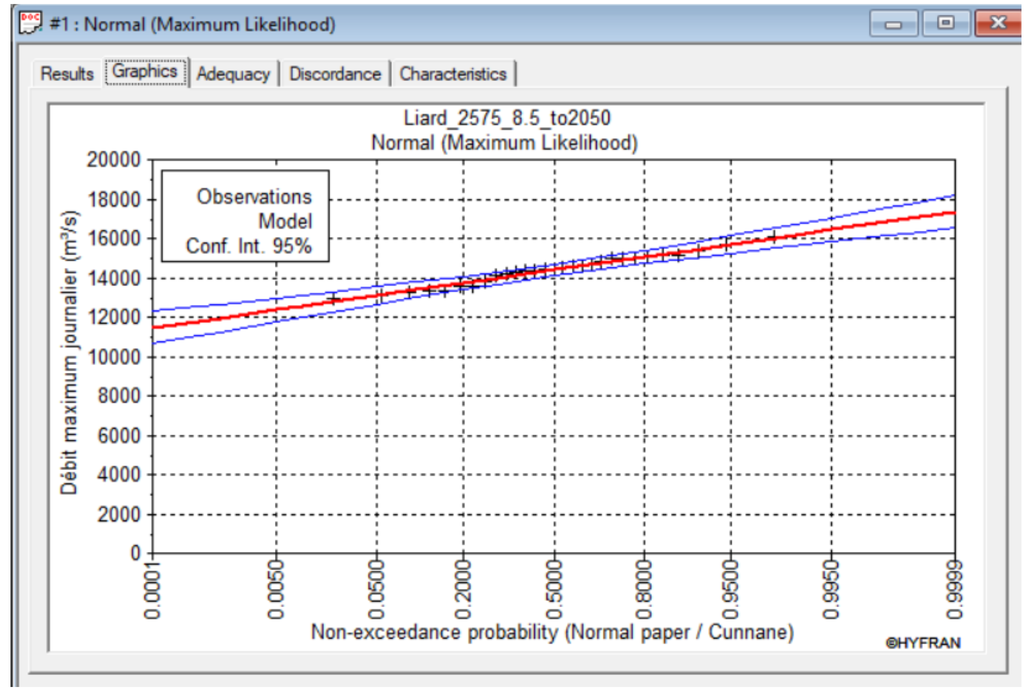


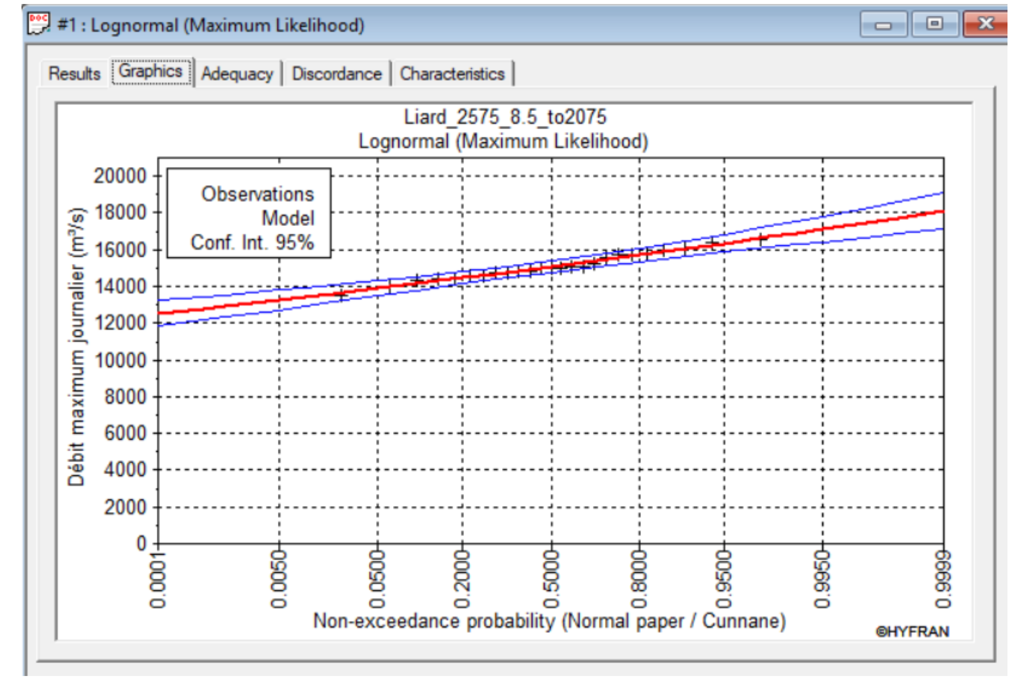


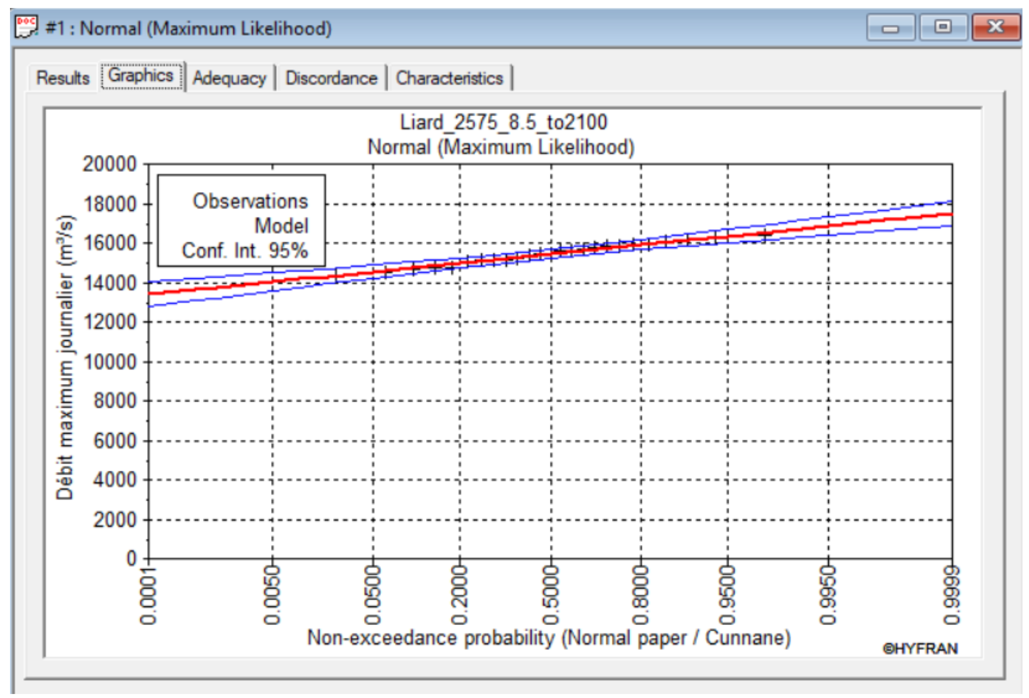


FFA RESULTS: FUTURE SIMULATED FLOW (CLIMATE CHANGE) FOR LIARD RIVER - 25TH AND 75TH PERCENTILE SSP5-8.5

Flow	Year			T	Q	XT	Standard	CI
13238.2	2022	RFFA - Entire Period		T	Q	XT	Standard	CI
13546.2	2023	Chosen Distribution:	Normal	10000	0.9999	1.80E+04	264.2	1.751E+004 -1.855E+004
14379.6	2024	200-year	17080.00	2000	0.9995	1.77E+04	237.8	1.721E+004 -1.814E+004
14448.7	2025	100-year	16880.00	1000	0.999	1.75E+04	225.6	1.707E+004 -1.795E+004
12917.2	2026	Stationarity?	No	200	0.995	1.71E+04	195	1.670E+004 -1.747E+004
14620.6	2027			100	0.99	1.69E+04	180.6	1.652E+004 -1.723E+004
13300.7	2028			50	0.98	1.67E+04	165.4	1.633E+004 -1.698E+004
14480.3	2029			20	0.95	1.63E+04	143.8	1.603E+004 -1.659E+004
14239.6	2030			10	0.9	1.60E+04	126.4	1.576E+004 -1.626E+004
14149.6	2031			5	0.8	1.56E+04	108.8	1.543E+004 -1.586E+004
14554	2032			3	0.6667	1.53E+04	97.66	1.511E+004 -1.549E+004
13305.2	2033			2	0.5	1.50E+04	93.38	1.476E+004 -1.513E+004
14672.8	2034			1.4286	0.3	1.45E+04	99.67	1.432E+004 -1.471E+004
14220	2035			1.25	0.2	1.43E+04	108.8	1.403E+004 -1.446E+004
13569.3	2036			1.1111	0.1	1.39E+04	126.4	1.363E+004 -1.413E+004
15664.6	2037			1.0526	0.05	1.36E+04	143.8	1.330E+004 -1.386E+004
15103.4	2038			1.0204	0.02	1.32E+04	165.4	1.292E+004 -1.357E+004
14977.2	2039			1.0101	0.01	1.30E+04	180.6	1.266E+004 -1.337E+004
13113.6	2040			1.005	0.005	1.28E+04	195	1.243E+004 -1.319E+004
13808.3	2041			1.001	0.001	1.24E+04	225.6	1.194E+004 -1.282E+004
14984.4	2042			1.0005	0.0005	1.22E+04	237.8	1.175E+004 -1.268E+004
16069.6	2043			1.0001	0.0001	1.19E+04	264.2	1.134E+004 -1.238E+004
14851.8	2044							
15105.5	2045	RFFA - to 2050						
14392.2	2046	Chosen Distribution:	Normal	10000	0.9999	1.73E+04	420	1.65E+004 -1.82E+004
15350.1	2047	200-year	16400	2000	0.9995	1.70E+04	378	1.63E+004 -1.77E+004
14973.7	2048	100-year	16200	1000	0.999	1.68E+04	358	1.61E+004 -1.75E+004
15028.5	2049	Stationarity?	No	200	0.995	1.64E+04	310	1.58E+004 -1.70E+004
14391.3	2050			100	0.99	1.62E+04	287	1.57E+004 -1.68E+004
15082.2	2051			50	0.98	1.60E+04	262	1.55E+004 -1.65E+004
15019.1	2052			20	0.95	1.57E+04	228	1.53E+004 -1.61E+004
14951.7	2053			10	0.9	1.54E+04	200	1.50E+004 -1.58E+004
14812.2	2054			5	0.8	1.51E+04	172	1.47E+004 -1.54E+004
14600.9	2055			3	0.6667	1.47E+04	154	1.44E+004 -1.50E+004
14751.3	2056			2	0.5	1.44E+04	147	1.41E+004 -1.47E+004
15799.2	2057			1.4286	0.3	1.40E+04	157	1.37E+004 -1.43E+004
16043	2058			1.25	0.2	1.37E+04	172	1.34E+004 -1.41E+004
13972.2	2059			1.1111	0.1	1.34E+04	200	1.30E+004 -1.38E+004
16013.9	2060			1.0526	0.05	1.31E+04	228	1.26E+004 -1.35E+004
14988.7	2061			1.0204	0.02	1.28E+04	262	1.23E+004 -1.33E+004
14445.1	2062			1.0101	0.01	1.26E+04	287	1.20E+004 -1.31E+004
15721.1	2063			1.005	0.005	1.24E+04	310	1.17E+004 -1.30E+004
14700.6	2064			1.001	0.001	1.19E+04	358	1.12E+004 -1.27E+004
14561.6	2065			1.0005	0.0005	1.18E+04	378	1.10E+004 -1.25E+004
14336.7	2066			1.0001	0.0001	1.15E+04	420	1.06E+004 -1.23E+004
14444.8	2067							
16416.4	2068							
14863.9	2069	RFFA - to 2075						
13486.1	2070	Chosen Distribution:	Lognormal	10000	0.9999	1.81E+04	513	1.71E+004 -1.91E+004
15584.6	2071	200-year	17100	2000	0.9995	1.77E+04	452	1.68E+004 -1.86E+004
15721.3	2072	100-year	16900	1000	0.999	1.76E+04	425	1.67E+004 -1.84E+004
15069.1	2073	Stationarity?	Yes	200	0.995	1.71E+04	358	1.64E+004 -1.78E+004
15230.7	2074			100	0.99	1.69E+04	327	1.63E+004 -1.75E+004
16550	2075			50	0.98	1.67E+04	295	1.61E+004 -1.73E+004
15715.1	2076			20	0.95	1.63E+04	251	1.59E+004 -1.68E+004
15345.9	2077			10	0.9	1.61E+04	216	1.56E+004 -1.65E+004
15770.4	2078			5	0.8	1.57E+04	182	1.54E+004 -1.61E+004
15145	2079			3	0.6667	1.54E+04	159	1.51E+004 -1.57E+004
14741.7	2080			2	0.5	1.51E+04	149	1.48E+004 -1.54E+004
15922.6	2081			1.4286	0.3	1.47E+04	155	1.44E+004 -1.50E+004
16256.6	2082			1.25	0.2	1.45E+04	167	1.41E+004 -1.48E+004
15575.1	2083			1.1111	0.1	1.41E+04	191	1.38E+004 -1.45E+004
16042.4	2084			1.0526	0.05	1.39E+04	213	1.35E+004 -1.43E+004
15424.5	2085			1.0204	0.02	1.36E+04	241	1.31E+004 -1.41E+004
14688.5	2086			1.0101	0.01	1.34E+04	260	1.29E+004 -1.39E+004
15245	2087			1.005	0.005	1.33E+04	277	1.27E+004 -1.38E+004
15089	2088			1.001	0.001	1.29E+04	313	1.23E+004 -1.35E+004
14380.9	2089			1.0005	0.0005	1.28E+04	326	1.22E+004 -1.34E+004
15437.6	2090			1.0001	0.0001	1.25E+04	355	1.18E+004 -1.32E+004
14540.3	2091							
16176	2092							
15142.1	2093	RFFA - to 2100						
16354.9	2094	Chosen Distribution:	Normal	10000	0.9999	1.75E+04	316	1.69E+004 -1.81E+004
15627.8	2095	200-year	16900	2000	0.9995	1.73E+04	284	1.67E+004 -1.78E+004
15173	2096	100-year	16700	1000	0.999	1.71E+04	270	1.66E+004 -1.77E+004
15813.2	2097	Stationarity?	Yes	200	0.995	1.69E+04	233	1.64E+004 -1.73E+004
15808.7	2098			100	0.99	1.67E+04	216	1.63E+004 -1.72E+004
15950	2099			50	0.98	1.66E+04	197	1.62E+004 -1.70E+004
14738.6	2100			20	0.95	1.64E+04	171	1.60E+004 -1.67E+004
				10	0.9	1.62E+04	150	1.59E+004 -1.64E+004
				5	0.8	1.59E+04	129	1.57E+004 -1.62E+004
				3	0.6667	1.57E+04	116	1.55E+004 -1.59E+004
				2	0.5	1.54E+04	110	1.52E+004 -1.57E+004
				1.4286	0.3	1.52E+04	118	1.49E+004 -1.54E+004
				1.25	0.2	1.50E+04	129	1.47E+004 -1.52E+004
				1.1111	0.1	1.47E+04	150	1.44E+004 -1.50E+004
				1.0526	0.05	1.45E+04	171	1.42E+004 -1.49E+004
				1.0204	0.02	1.43E+04	197	1.39E+004 -1.47E+004
				1.0101	0.01	1.42E+04	216	1.37E+004 -1.46E+004
				1.005	0.005	1.40E+04	233	1.36E+004 -1.45E+004
				1.001	0.001	1.37E+04	270	1.32E+004 -1.43E+004
				1.0005	0.0005	1.36E+04	284	1.31E+004 -1.42E+004
				1.0001	0.0001	1.34E+04	316	1.28E+004 -1.40E+004

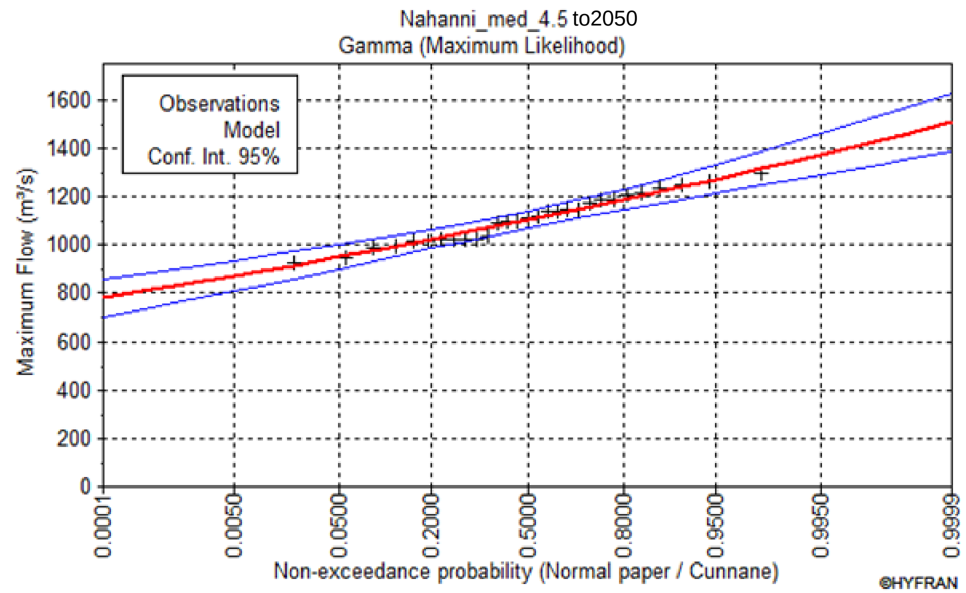


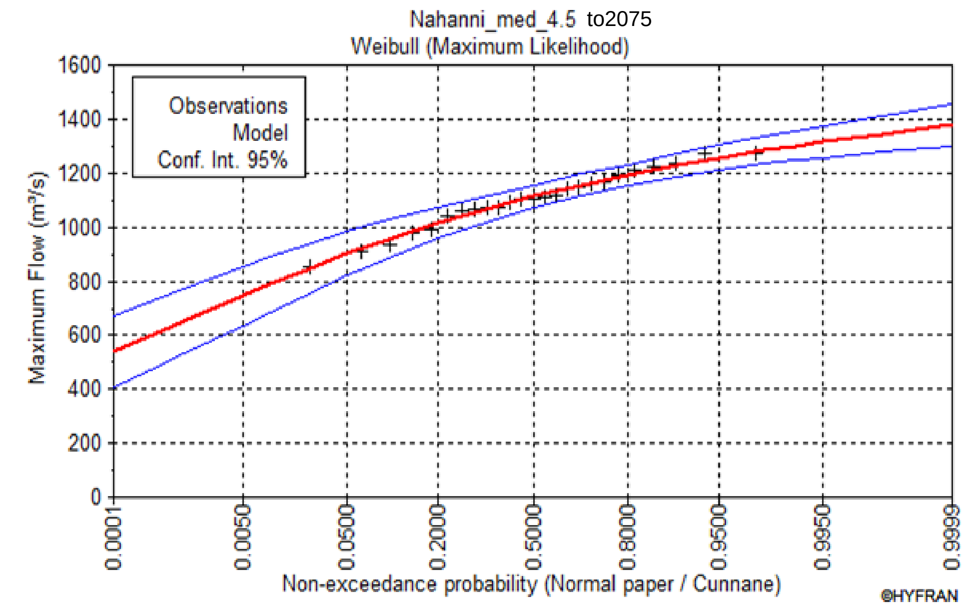


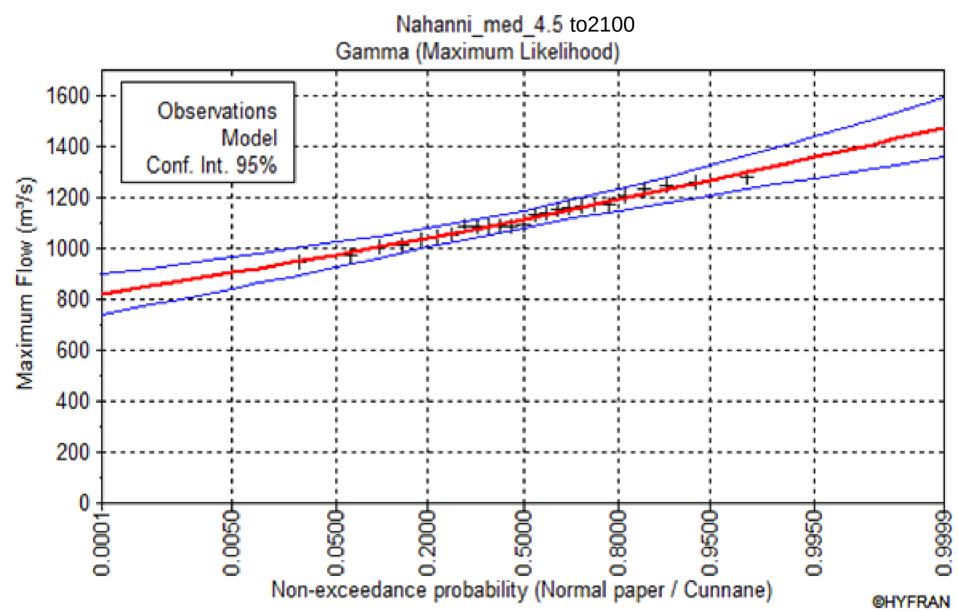


FFA RESULTS: FUTURE SIMULATED FLOW (CLIMATE CHANGE) FOR SOUTH NAHANNI RIVER - MEDIAN (50TH PERCENTILE) SSP2-4.5

Flow	Year							
926.771	2022	RFFA - Entire Period		T	Q	XT	Standard	CI
1088.55	2023	Chosen Distribution:	Weibull	10000	0.9999	1.37E+03	20.7	1330 - 1410
995.204	2024	200-year	1310.00	2000	0.9995	1.35E+03	19	1310 - 1390
1233.58	2025	100-year	1300.00	1000	0.999	1.34E+03	18.2	1300 - 1380
1149.35	2026	Stationarity?	Yes	200	0.995	1.31E+03	16.1	1280 - 1340
1120.89	2027			100	0.99	1.30E+03	15	1270 - 1330
1141.94	2028			50	0.98	1.28E+03	14	1260 - 1310
987.284	2029			20	0.95	1.26E+03	12.4	1230 - 1280
1184.6	2030			10	0.9	1.23E+03	11.3	1210 - 1250
1110.57	2031			5	0.8	1.20E+03	10.5	1180 - 1220
1137.4	2032			3	0.6667	1.16E+03	10.5	1140 - 1180
1021.54	2033			2	0.5	1.12E+03	11.5	1100 - 1140
1096.21	2034			1.4286	0.3	1.06E+03	14.1	1040 - 1090
1295.47	2035			1.25	0.2	1.03E+03	16.2	994 - 1060
1189.77	2036			1.1111	0.1	9.67E+02	19.6	929 - 1010
1249.43	2037			1.0526	0.05	9.15E+02	22.7	870 - 959
1036.02	2038			1.0204	0.02	8.51E+02	26.2	799 - 902
1097.1	2039			1.0101	0.01	8.06E+02	28.6	750 - 861
1019.26	2040			1.005	0.005	7.63E+02	30.6	703 - 823
1023.31	2041			1.001	0.001	6.73E+02	34.2	606 - 740
1024.87	2042			1.0005	0.0005	6.37E+02	35.4	568 - 707
1207.03	2043			1.0001	0.0001	5.62E+02	37.4	489 - 636
1260.05	2044							
1173.47	2045							
1145.09	2046	RFFA - to 2050						
948.932	2047	Chosen Distribution:	Gamma	10000	0.9999	1.51E+03	62.5	1380 - 1630
1017.41	2048	200-year	1370	2000	0.9995	1.46E+03	55	1350 - 1560
1012.91	2049	100-year	1350	1000	0.999	1.43E+03	51.6	1330 - 1530
1213.23	2050	Stationarity?	Yes	200	0.995	1.37E+03	43.4	1290 - 1460
1115.4	2051			100	0.99	1.35E+03	39.7	1270 - 1420
1272.23	2052			50	0.98	1.32E+03	35.8	1250 - 1390
935.261	2053			20	0.95	1.27E+03	30.5	1210 - 1330
1144.64	2054			10	0.9	1.23E+03	26.3	1180 - 1290
1189.86	2055			5	0.8	1.19E+03	22.1	1140 - 1230
1223.64	2056			3	0.6667	1.15E+03	19.4	1110 - 1190
1275.82	2057			2	0.5	1.10E+03	18.1	1070 - 1140
1071.41	2058			1.4286	0.3	1.05E+03	18.7	1020 - 1090
988.59	2059			1.25	0.2	1.02E+03	20	985 - 1060
853.952	2060			1.1111	0.1	9.84E+02	22.6	940 - 1030
1091.92	2061			1.0526	0.05	9.52E+02	25.2	902 - 1000
1044.39	2062			1.0204	0.02	9.16E+02	28.2	861 - 971
1210.63	2063			1.0101	0.01	8.93E+02	30.2	834 - 952
1110.96	2064			1.005	0.005	8.72E+02	32	809 - 935
977.529	2065			1.001	0.001	8.30E+02	35.7	760 - 900
1104.28	2066			1.0005	0.0005	8.14E+02	37	742 - 887
1160.63	2067			1.0001	0.0001	7.81E+02	39.8	703 - 859
1070.34	2068							
1234.51	2069							
1060.94	2070	RFFA - to 2075						
1164.78	2071	Chosen Distribution:	Weibull	10000	0.9999	1.38E+03	38.8	1300 - 1450
1067.6	2072	200-year	1320	2000	0.9995	1.36E+03	35.6	1290 - 1430
909.001	2073	100-year	1300	1000	0.999	1.35E+03	34	1280 - 1410
1107.08	2074	Stationarity?	Yes	200	0.995	1.32E+03	30	1260 - 1380
1151	2075			100	0.99	1.30E+03	28.1	1250 - 1360
1279.38	2076			50	0.98	1.28E+03	26.1	1230 - 1340
1011.25	2077			20	0.95	1.26E+03	23.2	1210 - 1300
1089.41	2078			10	0.9	1.23E+03	21.1	1190 - 1270
1142.1	2079			5	0.8	1.19E+03	19.6	1160 - 1230
1176.16	2080			3	0.6667	1.16E+03	19.6	1120 - 1200
1087.61	2081			2	0.5	1.11E+03	21.4	1070 - 1160
1046.06	2082			1.4286	0.3	1.06E+03	26.1	1000 - 1110
1096.34	2083			1.25	0.2	1.02E+03	30	957 - 1070
1052.59	2084			1.1111	0.1	9.55E+02	36.2	884 - 1030
1033.69	2085			1.0526	0.05	9.01E+02	41.7	819 - 982
971.619	2086			1.0204	0.02	8.34E+02	48.1	740 - 929
1150.43	2087			1.0101	0.01	7.88E+02	52.2	686 - 890
1208.9	2088			1.005	0.005	7.44E+02	55.7	635 - 854
1084.73	2089			1.001	0.001	6.52E+02	62	531 - 774
1235.17	2090			1.0005	0.0005	6.16E+02	64	491 - 742
1085.33	2091			1.0001	0.0001	5.40E+02	67	409 - 672
1158.23	2092							
1260.42	2093							
1247.36	2094	RFFA - to 2100						
1006.73	2095	Chosen Distribution:	Gamma	10000	0.9999	1.48E+03	59.6	1360 - 1590
1133.39	2096	200-year	1360	2000	0.9995	1.43E+03	52.6	1330 - 1530
1173.03	2097	100-year	1330	1000	0.999	1.41E+03	49.4	1310 - 1510
948.75	2098	Stationarity?	Yes	200	0.995	1.36E+03	41.7	1280 - 1440
1169.28	2099			100	0.99	1.33E+03	38.1	1260 - 1410
1088.82	2100			50	0.98	1.31E+03	34.5	1240 - 1370
				20	0.95	1.27E+03	29.4	1210 - 1320
				10	0.9	1.23E+03	25.4	1180 - 1280
				5	0.8	1.19E+03	21.4	1150 - 1230
				3	0.6667	1.15E+03	18.9	1120 - 1190
				2	0.5	1.12E+03	17.6	1080 - 1150
				1.4286	0.3	1.07E+03	18.2	1030 - 1110
				1.25	0.2	1.04E+03	19.6	1000 - 1080
				1.1111	0.1	1.01E+03	22.2	963 - 1050
				1.0526	0.05	9.77E+02	24.7	928 - 1030
				1.0204	0.02	9.44E+02	27.8	890 - 998
				1.0101	0.01	9.23E+02	29.9	864 - 981
				1.005	0.005	9.03E+02	31.7	841 - 966
				1.001	0.001	8.65E+02	35.5	795 - 934
				1.0005	0.0005	8.50E+02	36.9	778 - 922
				1.0001	0.0001	8.19E+02	39.9	741 - 897

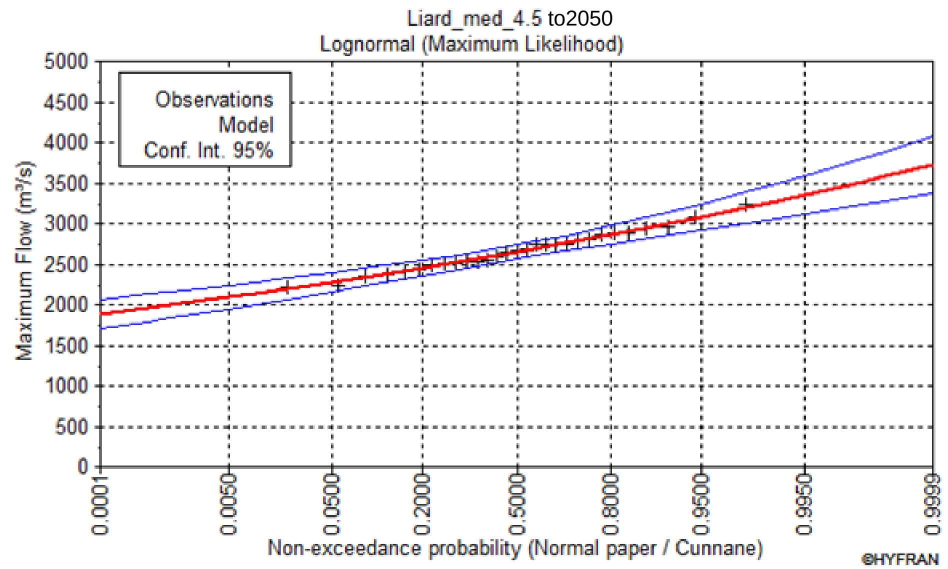


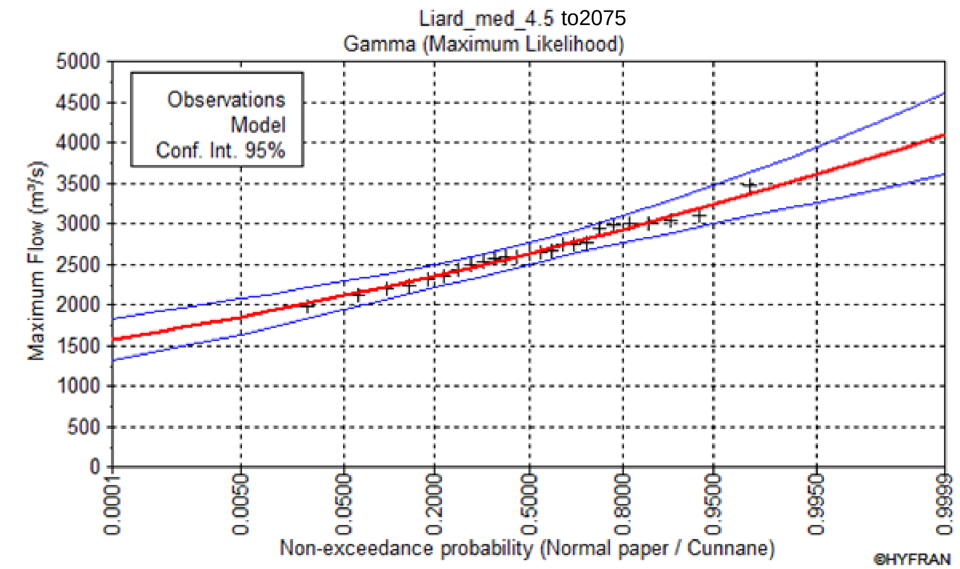


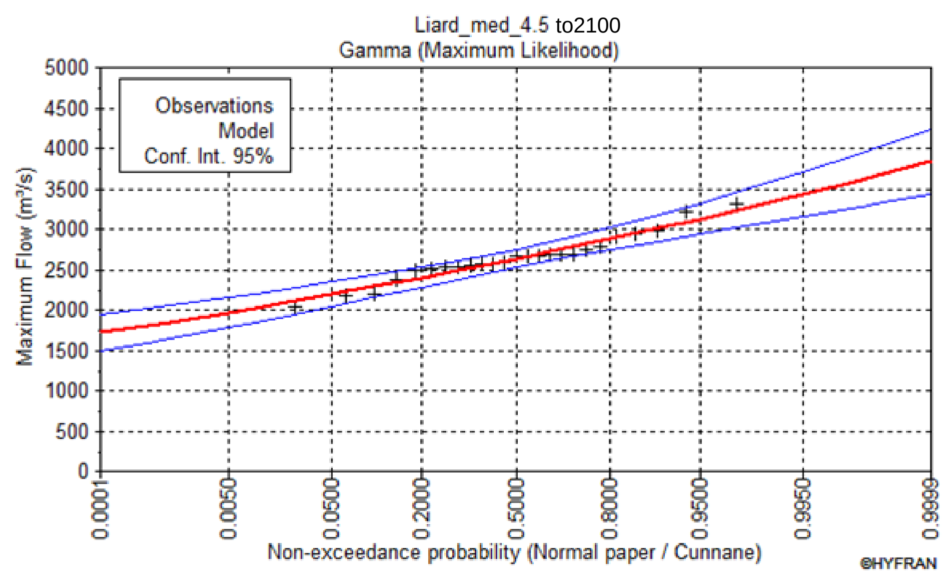


FFA RESULTS: FUTURE SIMULATED FLOW (CLIMATE CHANGE) FOR LIARD RIVER - MEDIAN (50TH PERCENTILE) SSP2-4.5

Flow	Year							
2374.61	2022	RFFA - Entire Period		T	Q	XT	Standard	CI
2643.77	2023	Chosen Distribution:	Gamma	10000	0.9999	3.86E+03	117	3630 - 4090
2495.9	2024	200-year	3450.00	2000	0.9995	3.70E+03	103	3500 - 3900
2867.04	2025	100-year	3370.00	1000	0.999	3.63E+03	96.1	3440 - 3820
2963.21	2026	Stationarity?	Yes	200	0.995	3.45E+03	80.4	3290 - 3610
2664.53	2027			100	0.99	3.37E+03	73.3	3220 - 3510
2743.93	2028			50	0.98	3.28E+03	65.9	3150 - 3410
2242.11	2029			20	0.95	3.14E+03	55.8	3030 - 3250
2681.68	2030			10	0.9	3.03E+03	47.9	2930 - 3120
2804.65	2031			5	0.8	2.89E+03	40	2810 - 2970
2774.93	2032			3	0.6667	2.77E+03	35	2700 - 2840
2434.02	2033			2	0.5	2.64E+03	32.4	2580 - 2700
2523.02	2034			1.4286	0.3	2.49E+03	33.2	2430 - 2560
3236.7	2035			1.25	0.2	2.40E+03	35.4	2340 - 2470
2933.34	2036			1.1111	0.1	2.29E+03	39.8	2210 - 2370
2738.26	2037			1.0526	0.05	2.19E+03	44	2110 - 2280
2414.27	2038			1.0204	0.02	2.09E+03	48.9	2000 - 2190
2540.37	2039			1.0101	0.01	2.02E+03	52.2	1920 - 2130
2595.51	2040			1.005	0.005	1.97E+03	55.1	1860 - 2070
2213.34	2041			1.001	0.001	1.85E+03	60.8	1730 - 1970
2536.47	2042			1.0005	0.0005	1.80E+03	62.8	1680 - 1930
2890.86	2043			1.0001	0.0001	1.71E+03	67	1580 - 1840
3072.41	2044							
2883.98	2045							
2753.91	2046	RFFA - to 2050						
2360.78	2047	Chosen Distribution:	Lognormal	10000	0.9999	3.72E+03	180	3370 - 4080
2501.9	2048	200-year	3350	2000	0.9995	3.58E+03	156	3270 - 3890
2515.47	2049	100-year	3280	1000	0.999	3.51E+03	145	3230 - 3800
2742.04	2050	Stationarity?	Yes	200	0.995	3.35E+03	120	3120 - 3590
2628.85	2051			100	0.99	3.28E+03	108	3060 - 3490
3099.75	2052			50	0.98	3.20E+03	96.8	3010 - 3390
2200.58	2053			20	0.95	3.08E+03	81	2920 - 3240
2640.92	2054			10	0.9	2.98E+03	68.8	2840 - 3110
2990.31	2055			5	0.8	2.86E+03	56.8	2750 - 2970
3466.88	2056			3	0.6667	2.76E+03	49	2660 - 2850
3034.99	2057			2	0.5	2.65E+03	45	2560 - 2740
2498.16	2058			1.4286	0.3	2.53E+03	45.8	2440 - 2620
2354.98	2059			1.25	0.2	2.45E+03	48.7	2360 - 2550
1985.64	2060			1.1111	0.1	2.36E+03	54.4	2250 - 2460
2322.4	2061			1.0526	0.05	2.28E+03	60	2160 - 2400
2429.46	2062			1.0204	0.02	2.20E+03	66.5	2070 - 2330
3002.56	2063			1.0101	0.01	2.14E+03	70.9	2000 - 2280
2990.01	2064			1.005	0.005	2.09E+03	74.8	1950 - 2240
2230.1	2065			1.001	0.001	2.00E+03	82.7	1840 - 2160
2579.61	2066			1.0005	0.0005	1.96E+03	85.6	1790 - 2130
2560.1	2067			1.0001	0.0001	1.89E+03	91.4	1710 - 2070
2746.12	2068							
2765.55	2069							
2539.03	2070	RFFA - to 2075						
2661.79	2071	Chosen Distribution:	Gamma	10000	0.9999	4.10E+03	255	3600 - 4600
2592.01	2072	200-year	3600	2000	0.9995	3.91E+03	223	3470 - 4350
2124.57	2073	100-year	3500	1000	0.999	3.82E+03	208	3410 - 4230
2754.16	2074	Stationarity?	Yes	200	0.995	3.60E+03	173	3260 - 3940
2942.86	2075			100	0.99	3.50E+03	158	3190 - 3810
2938.63	2076			50	0.98	3.39E+03	141	3110 - 3670
2512.97	2077			20	0.95	3.23E+03	119	3000 - 3460
2594.62	2078			10	0.9	3.09E+03	102	2890 - 3290
3305.57	2079			5	0.8	2.93E+03	84.6	2760 - 3090
2679.55	2080			3	0.6667	2.78E+03	73.6	2640 - 2930
2563.12	2081			2	0.5	2.63E+03	67.7	2500 - 2760
2482.9	2082			1.4286	0.3	2.46E+03	69	2320 - 2590
2545.01	2083			1.25	0.2	2.36E+03	73.2	2210 - 2500
2570.62	2084			1.1111	0.1	2.22E+03	81.7	2060 - 2380
2533.54	2085			1.0526	0.05	2.11E+03	89.9	1940 - 2290
2048.09	2086			1.0204	0.02	1.99E+03	99.3	1800 - 2190
2660.52	2087			1.0101	0.01	1.92E+03	105	1710 - 2130
2778.34	2088			1.005	0.005	1.85E+03	111	1630 - 2070
2523.68	2089			1.001	0.001	1.72E+03	121	1480 - 1960
3221.76	2090			1.0005	0.0005	1.67E+03	125	1430 - 1920
2379.01	2091			1.0001	0.0001	1.57E+03	132	1310 - 1830
2738.22	2092							
2672.2	2093							
2907.3	2094	RFFA - to 2100						
2199.64	2095	Chosen Distribution:	Gamma	10000	0.9999	3.83E+03	205	3430 - 4240
2663.44	2096	200-year	3430	2000	0.9995	3.68E+03	179	3330 - 4030
2694.32	2097	100-year	3350	1000	0.999	3.61E+03	168	3280 - 3940
2168.29	2098	Stationarity?	Yes	200	0.995	3.43E+03	141	3160 - 3710
2988.19	2099			100	0.99	3.35E+03	128	3100 - 3600
2695.91	2100			50	0.98	3.26E+03	115	3030 - 3490
				20	0.95	3.13E+03	97.6	2940 - 3320
				10	0.9	3.01E+03	83.8	2850 - 3180
				5	0.8	2.88E+03	70.1	2740 - 3020
				3	0.6667	2.76E+03	61.3	2640 - 2880
				2	0.5	2.63E+03	56.7	2520 - 2740
				1.4286	0.3	2.49E+03	58.3	2370 - 2600
				1.25	0.2	2.40E+03	62.1	2280 - 2520
				1.1111	0.1	2.29E+03	69.8	2150 - 2420
				1.0526	0.05	2.19E+03	77.2	2040 - 2340
				1.0204	0.02	2.09E+03	85.9	1920 - 2260
				1.0101	0.01	2.03E+03	91.7	1850 - 2210
				1.005	0.005	1.97E+03	96.8	1780 - 2160
				1.001	0.001	1.85E+03	107	1640 - 2060
				1.0005	0.0005	1.81E+03	110	1590 - 2020
				1.0001	0.0001	1.72E+03	118	1480 - 1950

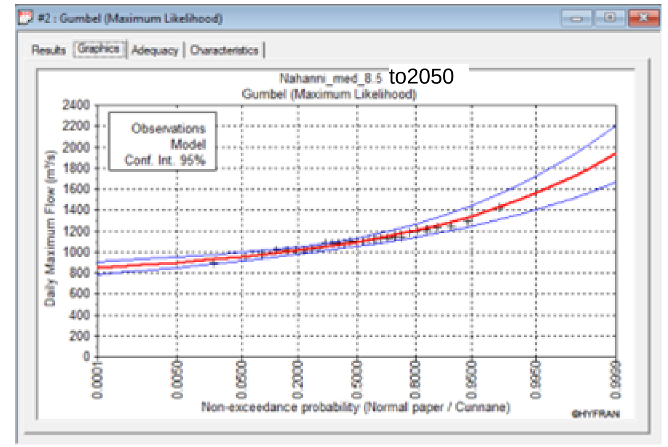


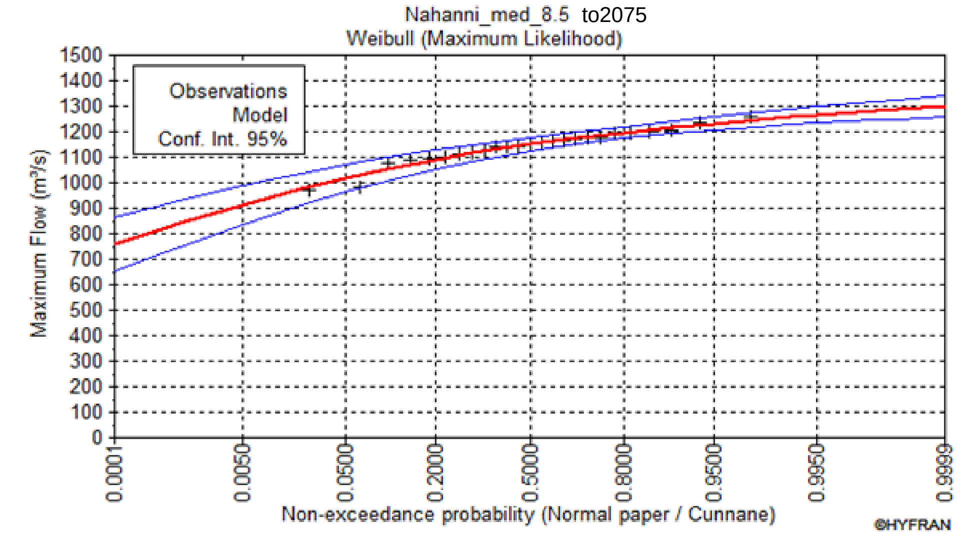


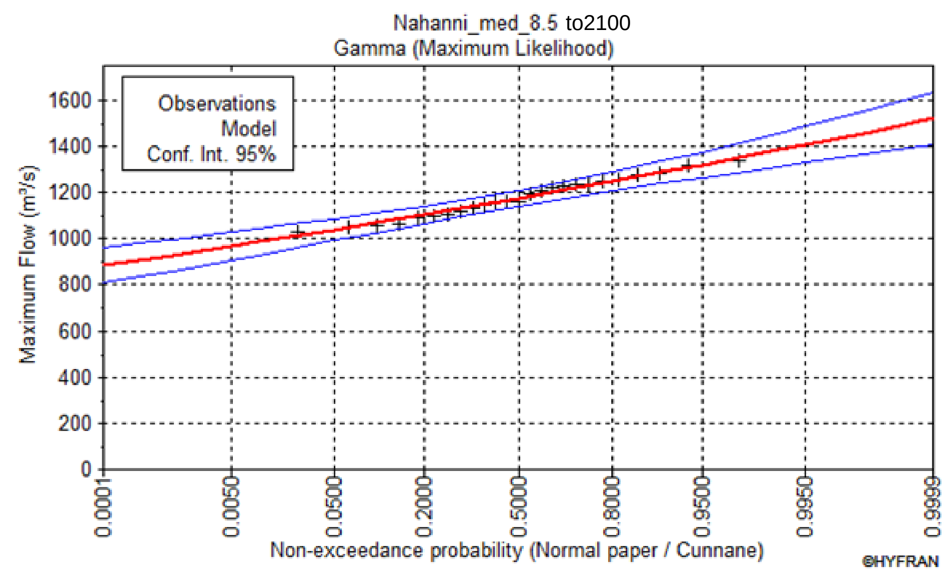


FFA RESULTS: FUTURE SIMULATED FLOW (CLIMATE CHANGE) FOR SOUTH NAHANNI RIVER - MEDIAN (50TH PERCENTILE) SSP5-8.5

Flow	Year							
898.047	2022	RFFA - Entire Period		T	Q	XT	Standard	CI
1014.95	2023	Chosen Distribution:	Gamma	10000	0.9999	1.52E+03	35.5	1450 - 1590
1211.07	2024	200-year	1390.00	2000	0.9995	1.47E+03	31.3	1410 - 1530
1081.29	2025	100-year	1370.00	1000	0.999	1.45E+03	29.4	1390 - 1510
1013.25	2026	Stationarity?	No	200	0.995	1.39E+03	24.8	1340 - 1440
1233.85	2027			100	0.99	1.37E+03	22.7	1320 - 1410
1023.36	2028			50	0.98	1.34E+03	20.5	1300 - 1380
1287.35	2029			20	0.95	1.30E+03	17.4	1260 - 1330
1123.48	2030			10	0.9	1.26E+03	15.1	1230 - 1290
1020.69	2031			5	0.8	1.22E+03	12.7	1190 - 1240
1098.73	2032			3	0.6667	1.18E+03	11.2	1160 - 1200
960.492	2033			2	0.5	1.14E+03	10.4	1120 - 1160
1103.91	2034			1.4286	0.3	1.09E+03	10.8	1070 - 1110
1136	2035			1.25	0.2	1.06E+03	11.6	1040 - 1080
1084.44	2036			1.1111	0.1	1.02E+03	13.1	998 - 1050
1083.45	2037			1.0526	0.05	9.92E+02	14.6	964 - 1020
1080.28	2038			1.0204	0.02	9.58E+02	16.4	926 - 990
1129.86	2039			1.0101	0.01	9.36E+02	17.6	901 - 970
972.59	2040			1.005	0.005	9.16E+02	18.7	879 - 952
1035.27	2041			1.001	0.001	8.75E+02	20.9	834 - 916
1417.93	2042			1.0005	0.0005	8.60E+02	21.7	817 - 902
1187.33	2043			1.0001	0.0001	8.27E+02	23.4	782 - 873
1102.3	2044							
1107.33	2045							
1246.37	2046	RFFA - to 2050						
1208.7	2047	Chosen Distribution:	Gumbel	10000	0.9999	1.94E+03	137	1670 - 2200
1130.92	2048	200-year	1560	2000	0.9995	1.78E+03	115	1560 - 2010
1020.62	2049	100-year	1500	1000	0.999	1.72E+03	105	1510 - 1920
1139.5	2050	Stationarity?	Yes	200	0.995	1.56E+03	82.6	1400 - 1720
1261.75	2051			100	0.99	1.50E+03	73	1350 - 1640
1124.58	2052			50	0.98	1.43E+03	63.4	1310 - 1550
1193.29	2053			20	0.95	1.34E+03	50.8	1240 - 1440
1140.94	2054			10	0.9	1.27E+03	41.4	1190 - 1350
1094.97	2055			5	0.8	1.20E+03	32.1	1140 - 1260
1075.75	2056			3	0.6667	1.14E+03	25.5	1090 - 1190
1157.42	2057			2	0.5	1.09E+03	20.7	1050 - 1130
1177.07	2058			1.4286	0.3	1.04E+03	17.9	1000 - 1080
972.698	2059			1.25	0.2	1.01E+03	17.7	978 - 1050
1162.27	2060			1.1111	0.1	9.78E+02	18.8	941 - 1020
1206.65	2061			1.0526	0.05	9.53E+02	20.4	913 - 993
1141.14	2062			1.0204	0.02	9.28E+02	22.5	884 - 972
1120.11	2063			1.0101	0.01	9.12E+02	24	865 - 959
1176.49	2064			1.005	0.005	8.99E+02	25.3	849 - 949
1086.63	2065			1.001	0.001	8.74E+02	28.2	818 - 929
1100.03	2066			1.0005	0.0005	8.64E+02	29.2	807 - 922
1112.27	2067			1.0001	0.0001	8.46E+02	31.4	784 - 908
1234.65	2068							
1169.17	2069							
979.724	2070	RFFA - to 2075						
1197.84	2071	Chosen Distribution:	Weibull	10000	0.9999	1.30E+03	21.1	1260 - 1340
1140.19	2072	200-year	1270	2000	0.9995	1.29E+03	19.4	1250 - 1330
1155.45	2073	100-year	1260	1000	0.999	1.28E+03	18.6	1250 - 1320
1162.12	2074	Stationarity?	Yes	200	0.995	1.27E+03	16.6	1230 - 1300
1193.75	2075			100	0.99	1.26E+03	15.6	1230 - 1290
1280.84	2076			50	0.98	1.25E+03	14.6	1220 - 1280
1234.58	2077			20	0.95	1.23E+03	13.1	1210 - 1260
1278.72	2078			10	0.9	1.22E+03	12	1190 - 1240
1161.52	2079			5	0.8	1.20E+03	11.3	1170 - 1220
1157.23	2080			3	0.6667	1.18E+03	11.4	1150 - 1200
1223.79	2081			2	0.5	1.15E+03	12.7	1130 - 1180
1095.62	2082			1.4286	0.3	1.11E+03	15.9	1080 - 1150
1192.47	2083			1.25	0.2	1.09E+03	18.5	1050 - 1130
1315.88	2084			1.1111	0.1	1.05E+03	22.9	1010 - 1100
1247.75	2085			1.0526	0.05	1.02E+03	27.1	964 - 1070
1054.64	2086			1.0204	0.02	9.74E+02	32.2	911 - 1040
1257.58	2087			1.0101	0.01	9.42E+02	35.9	872 - 1010
1028.52	2088			1.005	0.005	9.12E+02	39.2	835 - 989
1147.74	2089			1.001	0.001	8.45E+02	46.2	755 - 936
1104.24	2090			1.0005	0.0005	8.18E+02	48.8	723 - 914
1092.88	2091			1.0001	0.0001	7.59E+02	54.1	652 - 865
1225.43	2092							
1061.44	2093							
1339	2094	RFFA - to 2100						
1206.07	2095	Chosen Distribution:	Gamma	10000	0.9999	1.52E+03	57.1	1410 - 1630
1118.68	2096	200-year	1410	2000	0.9995	1.48E+03	50.4	1380 - 1580
1232.6	2097	100-year	1380	1000	0.999	1.46E+03	47.4	1370 - 1550
1132.58	2098	Stationarity?	Yes	200	0.995	1.41E+03	40	1330 - 1490
1161.42	2099			100	0.99	1.38E+03	36.7	1310 - 1460
1051.8	2100			50	0.98	1.36E+03	33.2	1290 - 1420
				20	0.95	1.32E+03	28.3	1260 - 1380
				10	0.9	1.29E+03	24.5	1240 - 1330
				5	0.8	1.25E+03	20.7	1210 - 1290
				3	0.6667	1.21E+03	18.3	1180 - 1250
				2	0.5	1.17E+03	17.1	1140 - 1210
				1.4286	0.3	1.13E+03	17.8	1100 - 1160
				1.25	0.2	1.10E+03	19.1	1070 - 1140
				1.1111	0.1	1.07E+03	21.7	1030 - 1110
				1.0526	0.05	1.04E+03	24.2	992 - 1090
				1.0204	0.02	1.01E+03	27.2	954 - 1060
				1.0101	0.01	9.86E+02	29.3	929 - 1040
				1.005	0.005	9.67E+02	31.2	906 - 1030
				1.001	0.001	9.29E+02	35	861 - 998
				1.0005	0.0005	9.15E+02	36.4	843 - 986
				1.0001	0.0001	8.84E+02	39.4	807 - 962

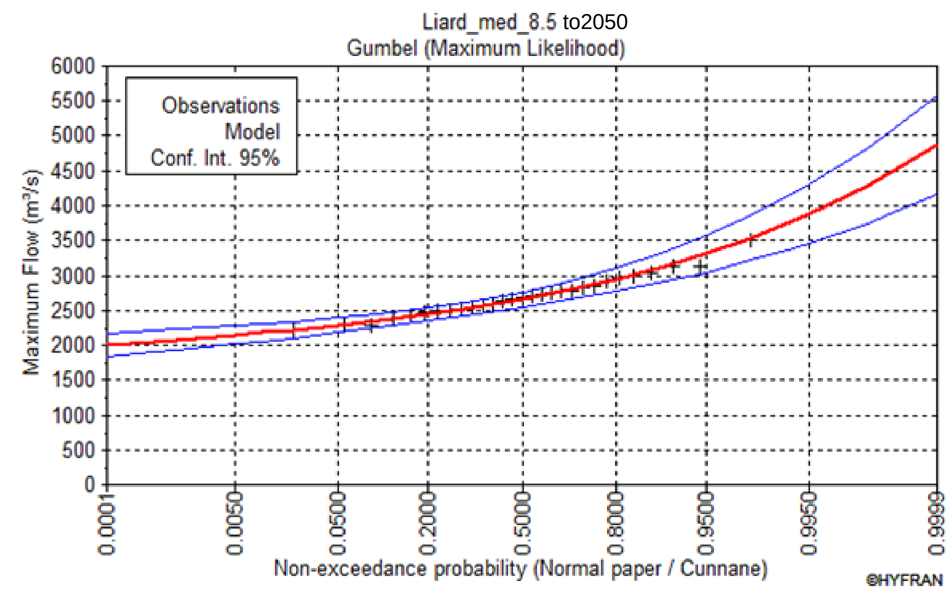


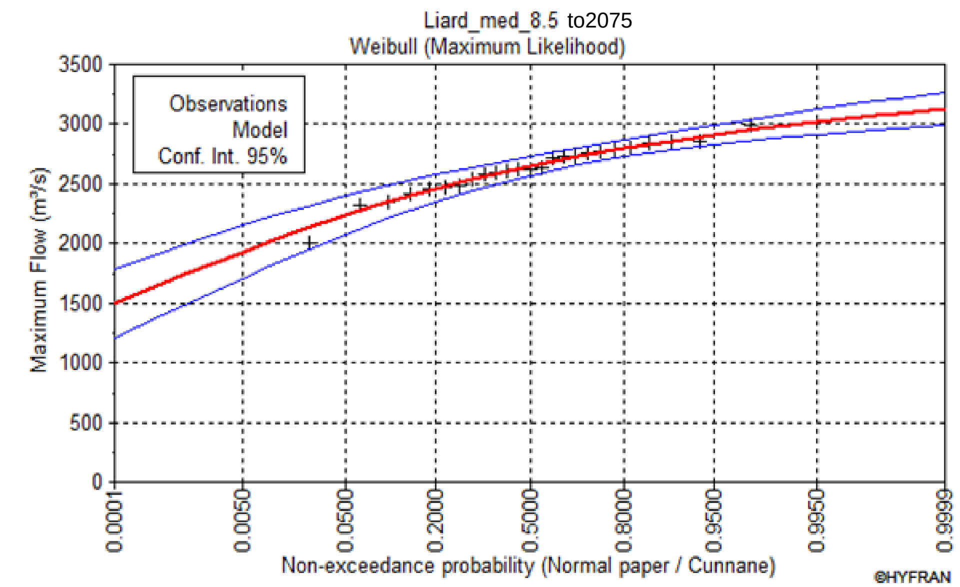


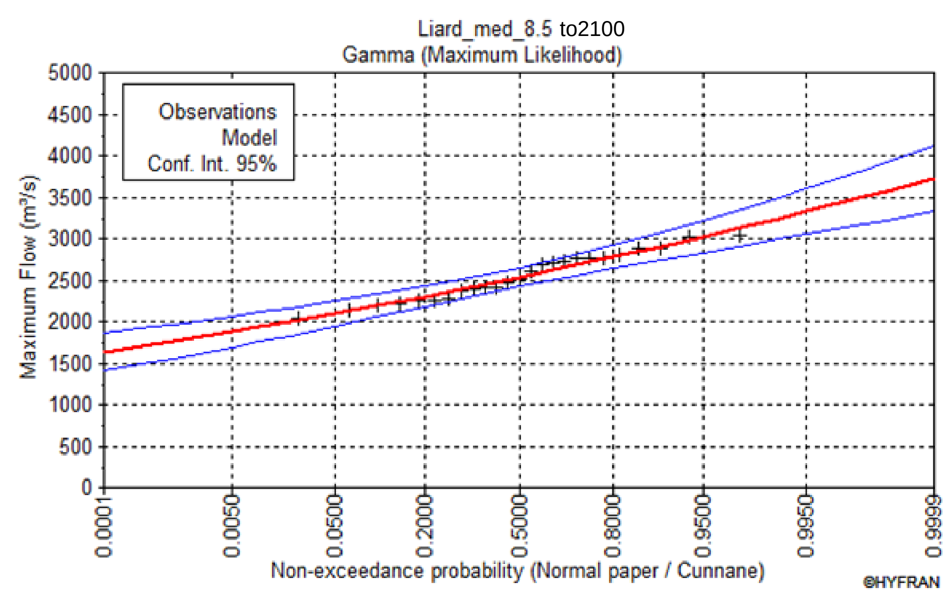


FFA RESULTS: FUTURE SIMULATED FLOW (CLIMATE CHANGE) FOR LIARD RIVER - MEDIAN (50TH PERCENTILE) SSP5-8.5

Flow	Year							
2416.85	2022	RFFA - Entire Period		T	Q	XT	Standard	CI
2371.72	2023	Chosen Distribution:	Lognormal	10000	0.9999	3.85E+03	128	3600 - 4100
3122.56	2024	200-year	3420.00	2000	0.9995	3.68E+03	110	3460 - 3890
2549.58	2025	100-year	3330.00	1000	0.999	3.60E+03	102	3400 - 3800
2504.72	2026	Stationarity?	Yes	200	0.995	3.42E+03	83.6	3250 - 3580
2840.09	2027			100	0.99	3.33E+03	75.4	3180 - 3480
2293.26	2028			50	0.98	3.23E+03	67.1	3100 - 3370
2921.93	2029			20	0.95	3.10E+03	55.9	2990 - 3210
2687.52	2030			10	0.9	2.98E+03	47.3	2890 - 3080
2556.38	2031			5	0.8	2.85E+03	38.9	2770 - 2930
2964.13	2032			3	0.6667	2.73E+03	33.5	2670 - 2800
2523.38	2033			2	0.5	2.61E+03	30.6	2550 - 2670
2479.09	2034			1.4286	0.3	2.47E+03	30.9	2410 - 2530
2599.24	2035			1.25	0.2	2.39E+03	32.7	2330 - 2460
2625.88	2036			1.1111	0.1	2.29E+03	36.2	2210 - 2360
2768.86	2037			1.0526	0.05	2.20E+03	39.7	2120 - 2280
3039.38	2038			1.0204	0.02	2.11E+03	43.8	2020 - 2190
2664.77	2039			1.0101	0.01	2.05E+03	46.5	1960 - 2140
2201.64	2040			1.005	0.005	2.00E+03	48.9	1900 - 2090
2288.23	2041			1.001	0.001	1.89E+03	53.6	1790 - 2000
3506.77	2042			1.0005	0.0005	1.85E+03	55.3	1750 - 1960
2728.56	2043			1.0001	0.0001	1.77E+03	58.8	1660 - 1890
2493.79	2044							
2984.61	2045							
3130.65	2046	RFFA - to 2050						
2767.34	2047	Chosen Distribution:	Gumbel	10000	0.9999	4.87E+03	361	4160 - 5580
2712.65	2048	200-year	3890	2000	0.9995	4.47E+03	301	3870 - 5060
2830.94	2049	100-year	3710	1000	0.999	4.29E+03	276	3750 - 4830
2743.37	2050	Stationarity?	Yes	200	0.995	3.89E+03	217	3460 - 4310
2991.54	2051			100	0.99	3.71E+03	192	3340 - 4090
2859.44	2052			50	0.98	3.54E+03	167	3210 - 3870
2835.92	2053			20	0.95	3.31E+03	134	3040 - 3570
2730.9	2054			10	0.9	3.13E+03	109	2910 - 3340
2577.32	2055			5	0.8	2.94E+03	84.4	2770 - 3100
2539.56	2056			3	0.6667	2.79E+03	66.9	2660 - 2920
2632.66	2057			2	0.5	2.65E+03	54.3	2550 - 2760
2471.82	2058			1.4286	0.3	2.52E+03	47.1	2420 - 2610
2346.46	2059			1.25	0.2	2.44E+03	46.6	2350 - 2530
2616.09	2060			1.1111	0.1	2.35E+03	49.4	2260 - 2450
2770.73	2061			1.0526	0.05	2.29E+03	53.5	2180 - 2390
2622.05	2062			1.0204	0.02	2.22E+03	59	2110 - 2340
2761.52	2063			1.0101	0.01	2.18E+03	63	2060 - 2300
2788.54	2064			1.005	0.005	2.14E+03	66.6	2010 - 2280
2421.51	2065			1.001	0.001	2.08E+03	74	1930 - 2220
2602.04	2066			1.0005	0.0005	2.05E+03	76.8	1900 - 2210
2312.87	2067			1.0001	0.0001	2.01E+03	82.6	1840 - 2170
2855.03	2068							
2798.58	2069							
2003.65	2070	RFFA - to 2075						
2487.36	2071	Chosen Distribution:	Weibull	10000	0.9999	3.13E+03	69.5	2990 - 3270
2590.57	2072	200-year	3020	2000	0.9995	3.09E+03	63.9	2970 - 3220
2714.24	2073	100-year	2990	1000	0.999	3.07E+03	61.2	2950 - 3190
2454.73	2074	Stationarity?	Yes	200	0.995	3.02E+03	54.3	2910 - 3130
2734.58	2075			100	0.99	2.99E+03	50.9	2890 - 3090
3027.82	2076			50	0.98	2.96E+03	47.4	2870 - 3050
2755.39	2077			20	0.95	2.91E+03	42.4	2830 - 2990
2802.13	2078			10	0.9	2.86E+03	38.8	2790 - 2940
2393.84	2079			5	0.8	2.80E+03	36.1	2730 - 2870
2380.04	2080			3	0.6667	2.73E+03	36.3	2660 - 2800
2769.55	2081			2	0.5	2.65E+03	40.1	2570 - 2730
2885.72	2082			1.4286	0.3	2.54E+03	49.5	2440 - 2630
2465.44	2083			1.25	0.2	2.46E+03	57.2	2350 - 2570
2876.5	2084			1.1111	0.1	2.35E+03	69.9	2210 - 2480
2406.77	2085			1.0526	0.05	2.24E+03	81.7	2080 - 2400
2204.52	2086			1.0204	0.02	2.11E+03	95.7	1920 - 2300
2754.99	2087			1.0101	0.01	2.02E+03	105	1810 - 2220
2250.53	2088			1.005	0.005	1.93E+03	114	1700 - 2150
2223.17	2089			1.001	0.001	1.74E+03	130	1480 - 1990
2688.46	2090			1.0005	0.0005	1.66E+03	136	1390 - 1930
2031.47	2091			1.0001	0.0001	1.50E+03	146	1210 - 1780
2516.4	2092							
2139.81	2093							
3031.2	2094	RFFA - to 2100						
2403.01	2095	Chosen Distribution:	Gamma	10000	0.9999	3.72E+03	204	3330 - 4120
2281.62	2096	200-year	3330	2000	0.9995	3.57E+03	178	3220 - 3920
2698.62	2097	100-year	3240	1000	0.999	3.50E+03	167	3170 - 3830
2719.69	2098	Stationarity?	Yes	200	0.995	3.33E+03	140	3050 - 3600
2617.39	2099			100	0.99	3.24E+03	127	2990 - 3490
2255.09	2100			50	0.98	3.15E+03	114	2930 - 3380
				20	0.95	3.02E+03	96.8	2830 - 3210
				10	0.9	2.91E+03	83.1	2750 - 3070
				5	0.8	2.78E+03	69.4	2640 - 2910
				3	0.6667	2.66E+03	60.7	2540 - 2780
				2	0.5	2.53E+03	56.1	2420 - 2640
				1.4286	0.3	2.39E+03	57.5	2280 - 2500
				1.25	0.2	2.30E+03	61.3	2180 - 2420
				1.1111	0.1	2.19E+03	68.8	2050 - 2320
				1.0526	0.05	2.10E+03	76.1	1950 - 2250
				1.0204	0.02	2.00E+03	84.6	1830 - 2160
				1.0101	0.01	1.93E+03	90.2	1760 - 2110
				1.005	0.005	1.88E+03	95.2	1690 - 2060
				1.001	0.001	1.76E+03	105	1560 - 1970
				1.0005	0.0005	1.72E+03	108	1510 - 1930
				1.0001	0.0001	1.63E+03	115	1400 - 1860





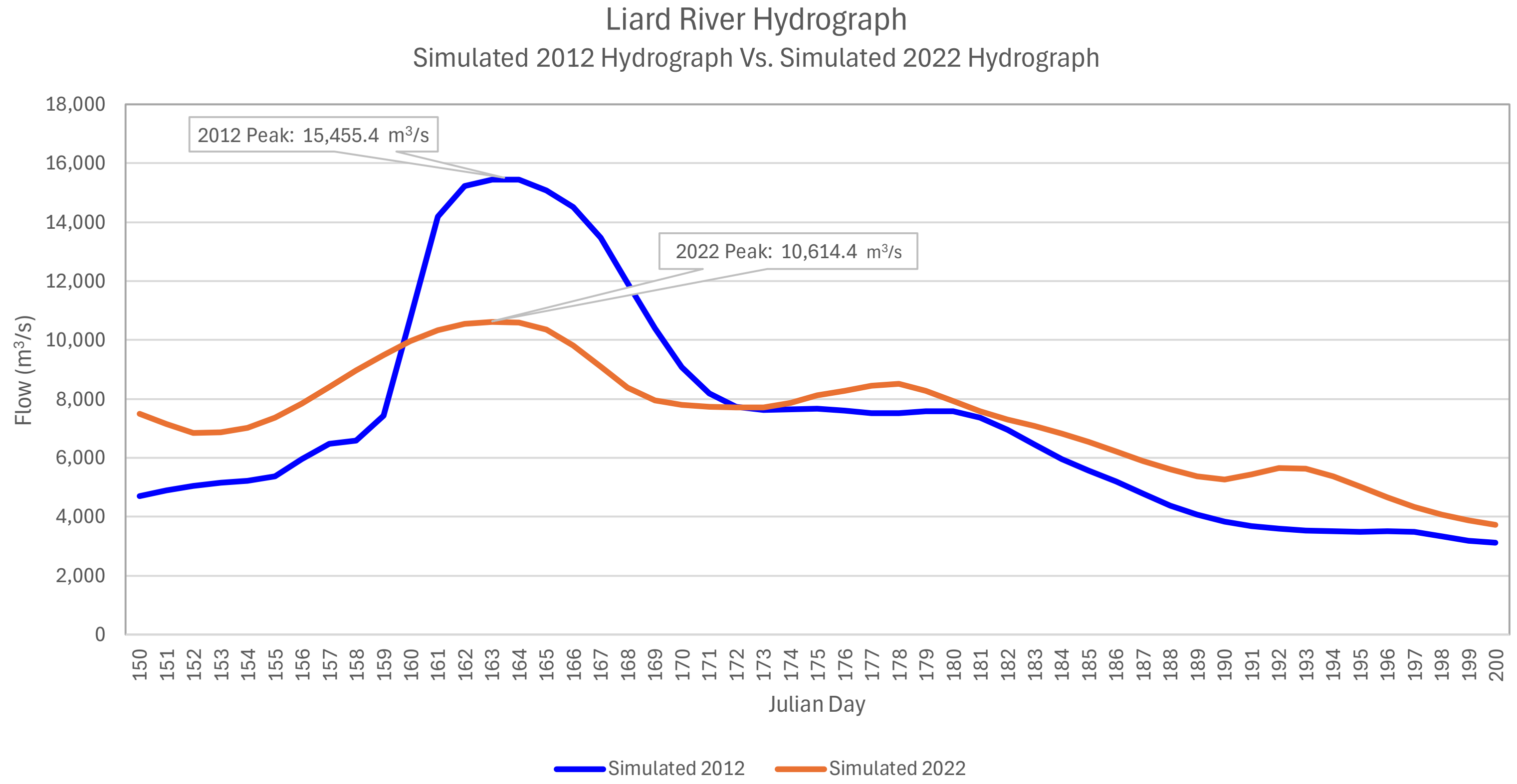


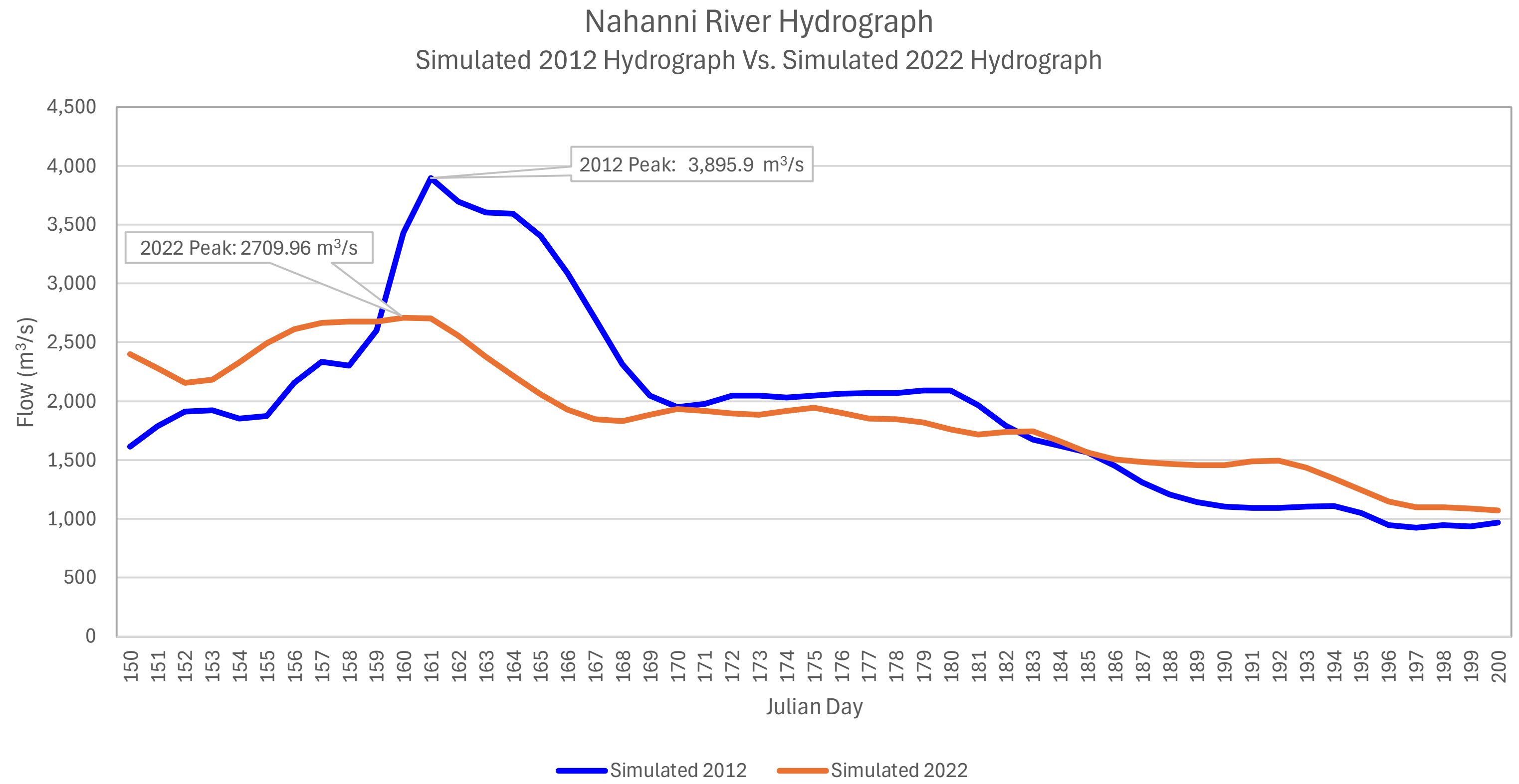
Appendix C

Inflow Hydrographs

Raven-simulated 2012 Daily Hydrograph and 2022 Daily Hydrograph

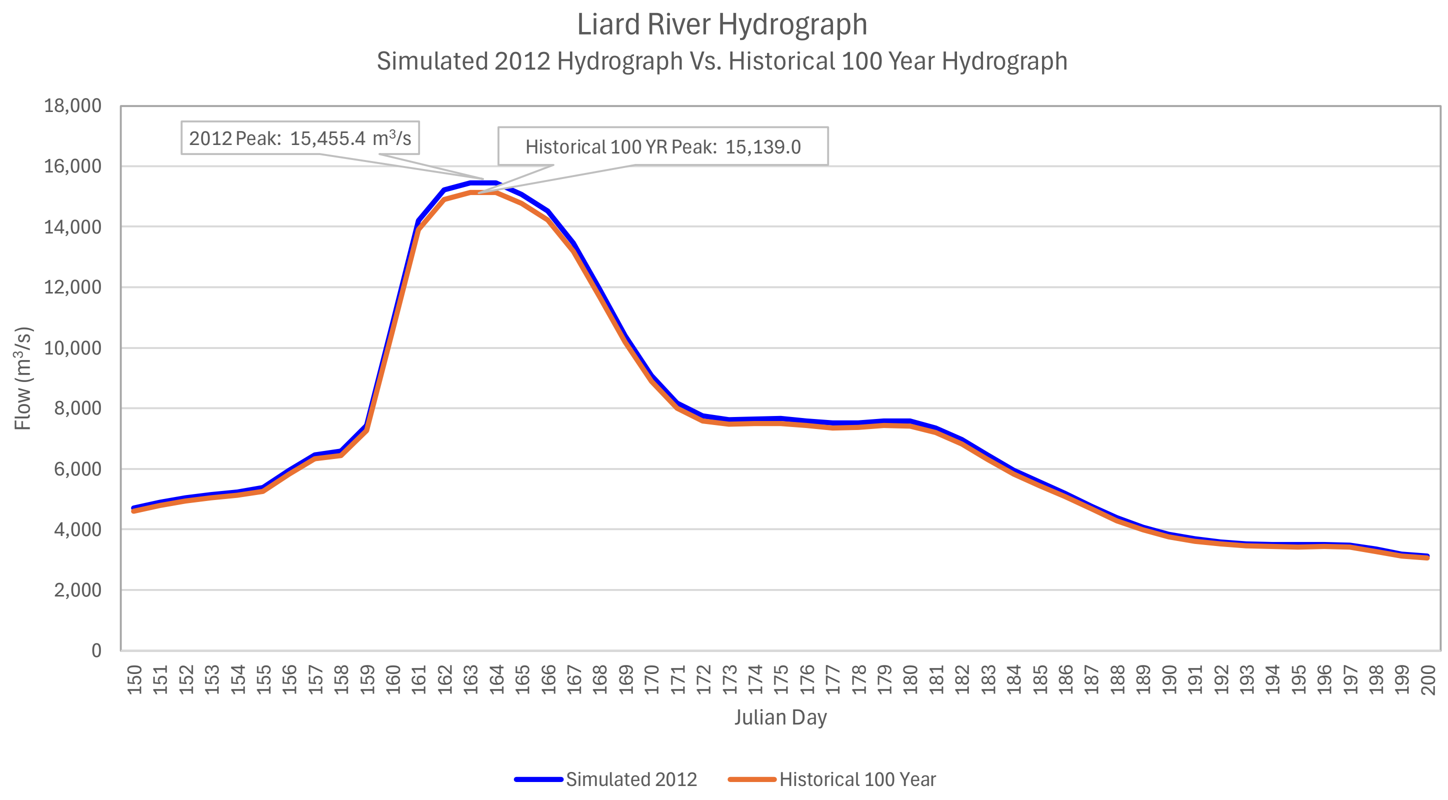
Julian Day	South Nahanni River		Liard River	
	Simulated 2012	Simulated 2022	Simulated 2012	Simulated 2022
150	1,612.3	2,399.2	4,699.6	7,487.1
151	1,788.2	2,278.7	4,897.9	7,148.1
152	1,910.2	2,154.8	5,051.7	6,848.4
153	1,923.6	2,181.5	5,159.2	6,856.5
154	1,851.4	2,327.4	5,229.8	7,025.5
155	1,875.1	2,492.5	5,374.0	7,354.4
156	2,154.5	2,613.1	5,946.2	7,832.6
157	2,332.1	2,665.1	6,470.1	8,393.5
158	2,302.6	2,674.7	6,581.6	8,959.4
159	2,602.1	2,675.5	7,425.7	9,486.2
160	3,428.6	2,710.0	10,747.3	9,967.9
161	3,895.9	2,701.5	14,190.4	10,339.6
162	3,696.5	2,554.2	15,216.9	10,540.2
163	3,601.2	2,375.0	15,455.4	10,614.4
164	3,590.0	2,216.0	15,444.9	10,589.6
165	3,399.9	2,056.2	15,068.7	10,355.2
166	3,087.5	1,925.4	14,514.1	9,821.9
167	2,702.3	1,848.2	13,467.9	9,099.1
168	2,309.9	1,829.0	11,934.4	8,389.8
169	2,048.6	1,881.8	10,395.6	7,952.4
170	1,948.0	1,930.6	9,081.8	7,800.3
171	1,975.3	1,916.4	8,179.9	7,729.5
172	2,046.3	1,894.5	7,741.5	7,702.6
173	2,045.9	1,886.2	7,623.6	7,705.6
174	2,031.8	1,914.5	7,654.6	7,863.6
175	2,044.7	1,942.1	7,664.6	8,113.8
176	2,065.7	1,898.3	7,592.7	8,277.9
177	2,070.5	1,851.6	7,511.7	8,455.9
178	2,066.3	1,848.3	7,517.7	8,502.0
179	2,089.9	1,818.1	7,589.3	8,270.7
180	2,088.5	1,757.5	7,573.3	7,924.7
181	1,965.2	1,718.0	7,354.7	7,581.5
182	1,793.5	1,739.7	6,959.4	7,299.4
183	1,673.6	1,745.1	6,455.3	7,073.0
184	1,616.1	1,659.2	5,957.8	6,829.9
185	1,564.8	1,562.8	5,569.2	6,548.4
186	1,452.3	1,506.1	5,202.7	6,223.9
187	1,309.4	1,482.4	4,776.7	5,899.9
188	1,204.4	1,467.0	4,381.5	5,614.2
189	1,143.3	1,454.5	4,072.4	5,380.2
190	1,102.9	1,457.2	3,845.1	5,267.0
191	1,091.8	1,489.0	3,689.4	5,428.2
192	1,094.5	1,493.6	3,587.1	5,662.6
193	1,104.3	1,435.0	3,531.1	5,629.4
194	1,109.5	1,344.1	3,506.8	5,372.4
195	1,048.3	1,242.0	3,498.8	5,022.2
196	944.5	1,149.1	3,506.9	4,654.6
197	926.0	1,100.0	3,482.5	4,333.4
198	946.8	1,095.6	3,343.8	4,076.5
199	937.5	1,087.2	3,176.4	3,868.5
200	970.6	1,072.6	3,124.3	3,727.9

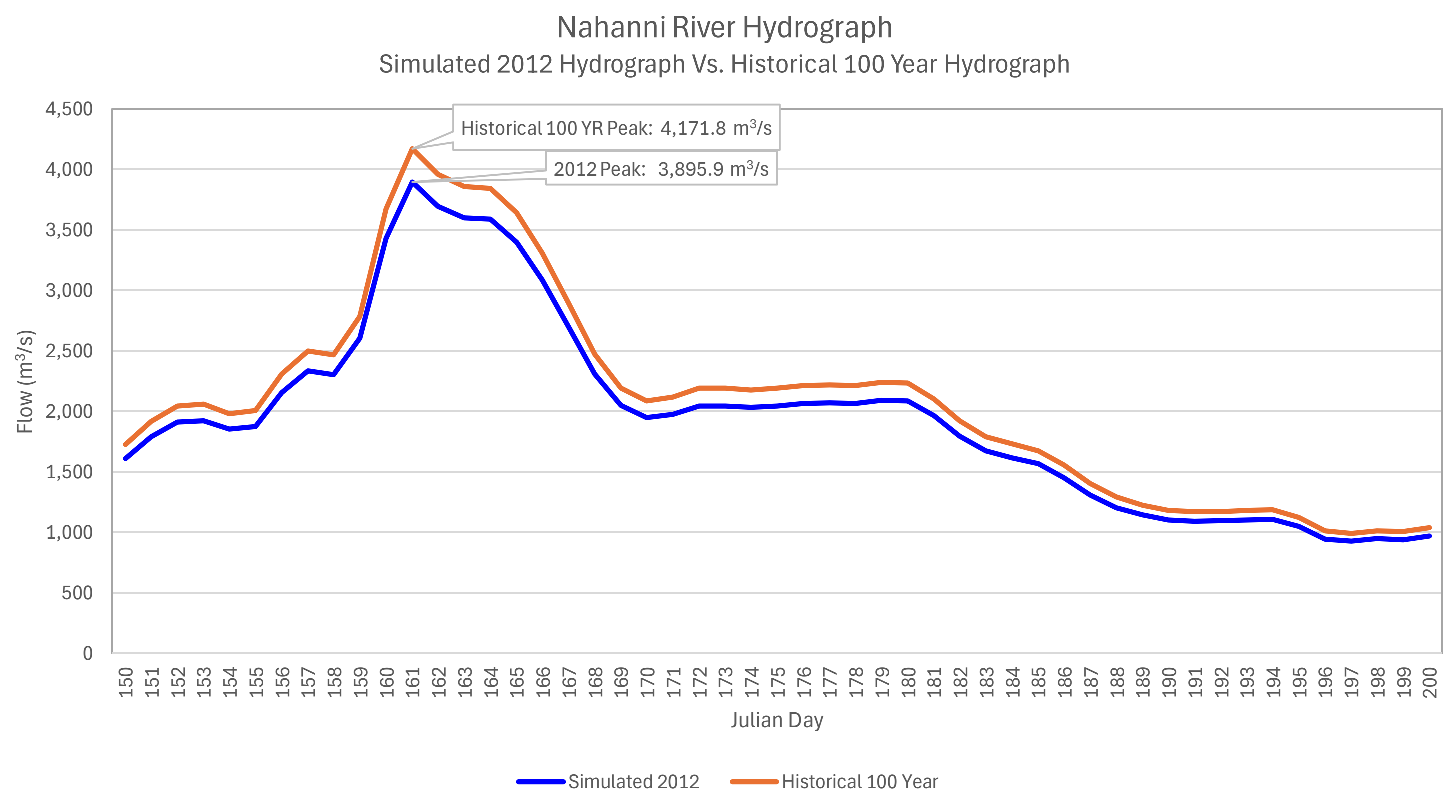




Raven-simulated 2012 Daily Hydrograph and 100 Year Hydrograph Under Historical Conditions

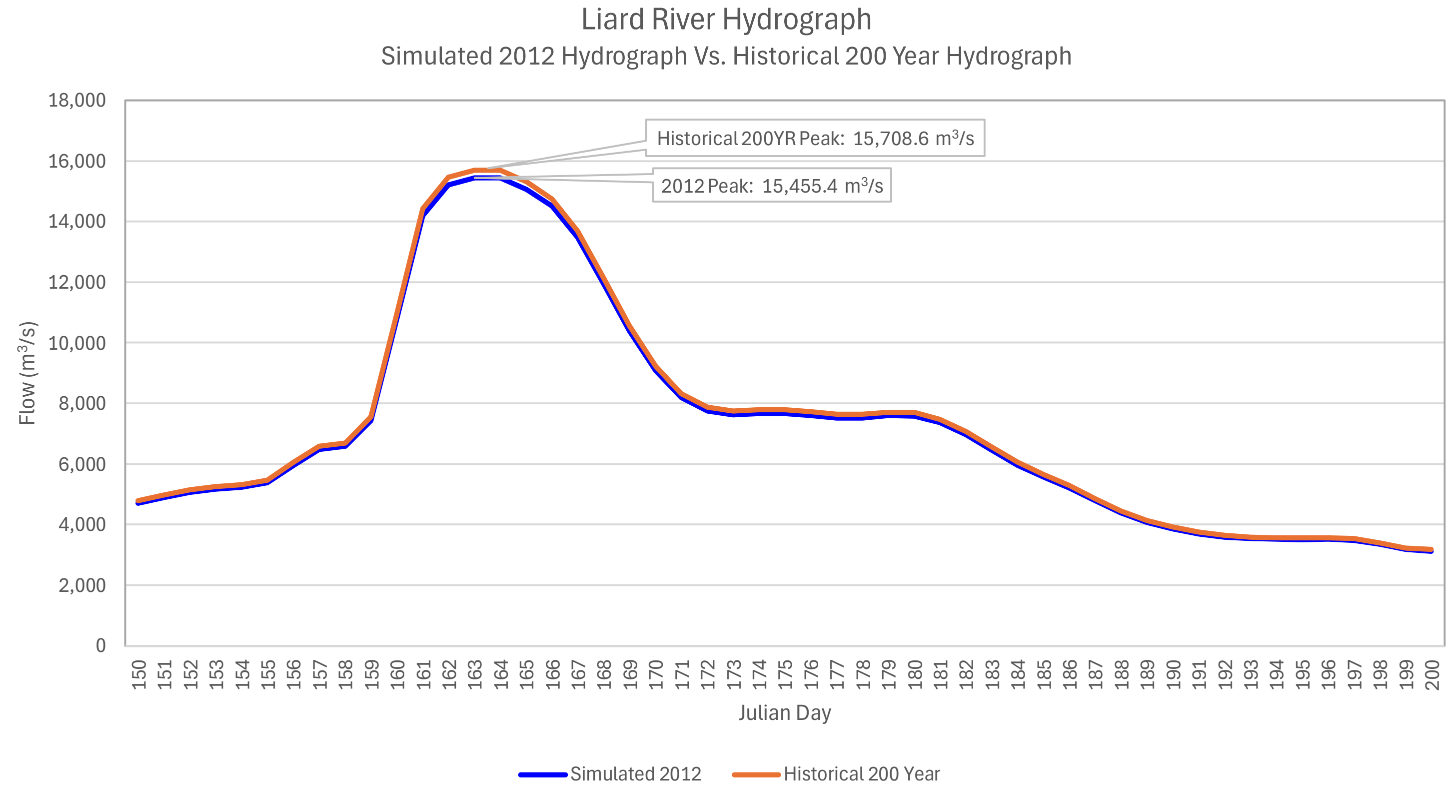
Julian Day	South Nahanni River		Liard River	
	Simulated 2012	Historical 100 Year	Simulated 2012	Historical 100 Year
150	1,612.3	1,726.5	4,699.6	4,603.4
151	1,788.2	1,914.8	4,897.9	4,797.6
152	1,910.2	2,045.5	5,051.7	4,948.3
153	1,923.6	2,059.8	5,159.2	5,053.5
154	1,851.4	1,982.5	5,229.8	5,122.7
155	1,875.1	2,007.9	5,374.0	5,264.0
156	2,154.5	2,307.1	5,946.2	5,824.5
157	2,332.1	2,497.2	6,470.1	6,337.6
158	2,302.6	2,465.6	6,581.6	6,446.9
159	2,602.1	2,786.4	7,425.7	7,273.7
160	3,428.6	3,671.5	10,747.3	10,527.3
161	3,895.9	4,171.8	14,190.4	13,899.9
162	3,696.5	3,958.3	15,216.9	14,905.4
163	3,601.2	3,856.2	15,455.4	15,139.0
164	3,590.0	3,844.2	15,444.9	15,128.7
165	3,399.9	3,640.7	15,068.7	14,760.2
166	3,087.5	3,306.2	14,514.1	14,217.0
167	2,702.3	2,893.7	13,467.9	13,192.2
168	2,309.9	2,473.4	11,934.4	11,690.1
169	2,048.6	2,193.6	10,395.6	10,182.8
170	1,948.0	2,085.9	9,081.8	8,895.8
171	1,975.3	2,115.2	8,179.9	8,012.4
172	2,046.3	2,191.2	7,741.5	7,583.0
173	2,045.9	2,190.8	7,623.6	7,467.5
174	2,031.8	2,175.7	7,654.6	7,497.9
175	2,044.7	2,189.5	7,664.6	7,507.7
176	2,065.7	2,212.0	7,592.7	7,437.2
177	2,070.5	2,217.2	7,511.7	7,357.9
178	2,066.3	2,212.6	7,517.7	7,363.8
179	2,089.9	2,238.0	7,589.3	7,433.9
180	2,088.5	2,236.4	7,573.3	7,418.3
181	1,965.2	2,104.4	7,354.7	7,204.1
182	1,793.5	1,920.5	6,959.4	6,816.9
183	1,673.6	1,792.1	6,455.3	6,323.1
184	1,616.1	1,730.6	5,957.8	5,835.8
185	1,564.8	1,675.6	5,569.2	5,455.2
186	1,452.3	1,555.1	5,202.7	5,096.2
187	1,309.4	1,402.1	4,776.7	4,678.9
188	1,204.4	1,289.6	4,381.5	4,291.8
189	1,143.3	1,224.2	4,072.4	3,989.0
190	1,102.9	1,181.0	3,845.1	3,766.4
191	1,091.8	1,169.1	3,689.4	3,613.9
192	1,094.5	1,172.0	3,587.1	3,513.7
193	1,104.3	1,182.6	3,531.1	3,458.8
194	1,109.5	1,188.1	3,506.8	3,435.0
195	1,048.3	1,122.5	3,498.8	3,427.2
196	944.5	1,011.4	3,506.9	3,435.1
197	926.0	991.5	3,482.5	3,411.2
198	946.8	1,013.8	3,343.8	3,275.4
199	937.5	1,003.9	3,176.4	3,111.3
200	970.6	1,039.3	3,124.3	3,060.4

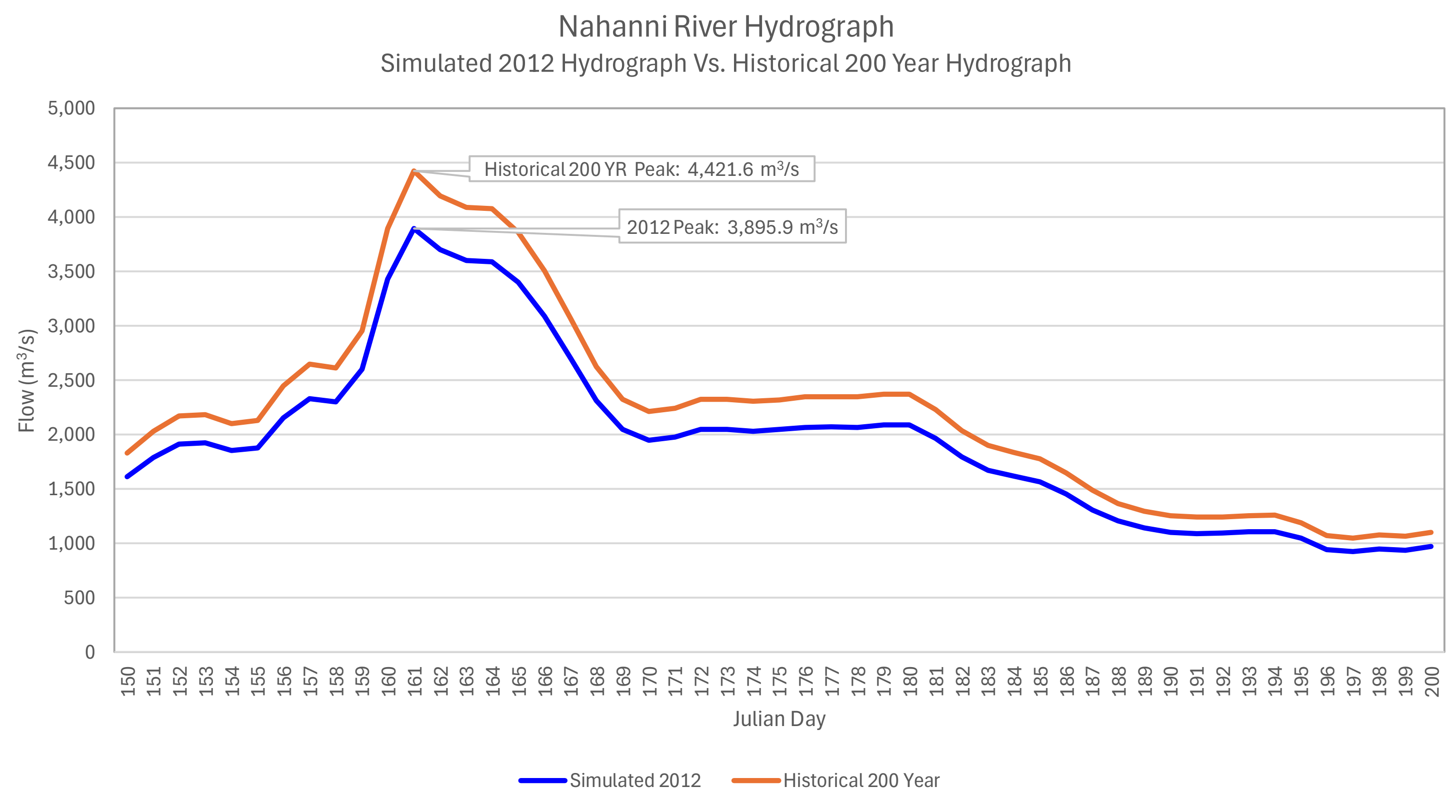




Raven-simulated 2012 Daily Hydrograph and 200 Year Hydrograph Under Historical Conditions

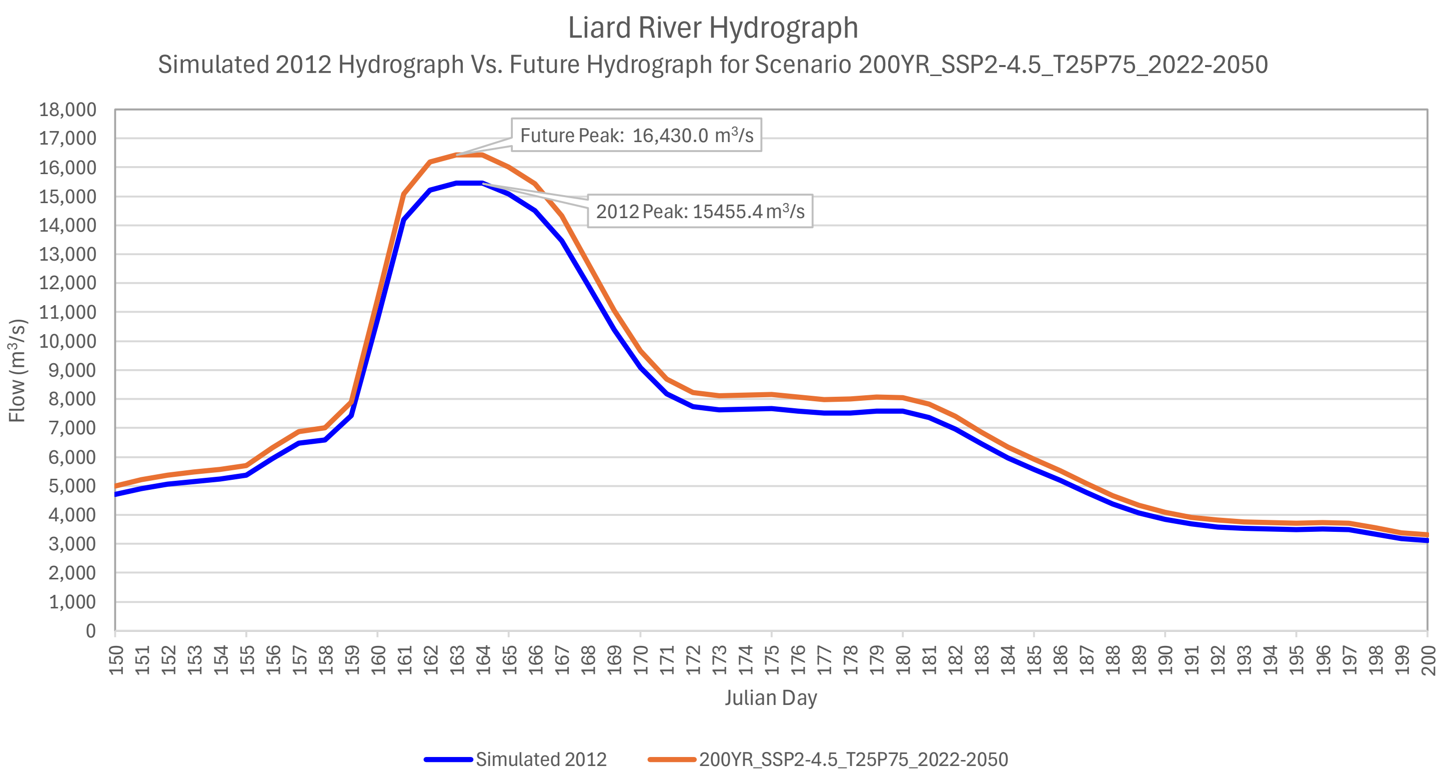
Julian Day	South Nahanni River		Liard River	
	Simulated 2012	Historical 200 Year	Simulated 2012	Historical 200 Year
150	1,612.3	1,829.8	4,699.6	4,776.6
151	1,788.2	2,029.5	4,897.9	4,978.1
152	1,910.2	2,168.0	5,051.7	5,134.5
153	1,923.6	2,183.2	5,159.2	5,243.7
154	1,851.4	2,101.2	5,229.8	5,315.4
155	1,875.1	2,128.1	5,374.0	5,462.0
156	2,154.5	2,445.2	5,946.2	6,043.6
157	2,332.1	2,646.7	6,470.1	6,576.1
158	2,302.6	2,613.3	6,581.6	6,689.4
159	2,602.1	2,953.3	7,425.7	7,547.4
160	3,428.6	3,891.3	10,747.3	10,923.4
161	3,895.9	4,421.6	14,190.4	14,422.9
162	3,696.5	4,195.3	15,216.9	15,466.2
163	3,601.2	4,087.1	15,455.4	15,708.6
164	3,590.0	4,074.4	15,444.9	15,697.9
165	3,399.9	3,858.7	15,068.7	15,315.6
166	3,087.5	3,504.2	14,514.1	14,751.9
167	2,702.3	3,067.0	13,467.9	13,688.5
168	2,309.9	2,621.6	11,934.4	12,129.9
169	2,048.6	2,325.0	10,395.6	10,565.9
170	1,948.0	2,210.8	9,081.8	9,230.5
171	1,975.3	2,241.8	8,179.9	8,313.9
172	2,046.3	2,322.4	7,741.5	7,868.3
173	2,045.9	2,321.9	7,623.6	7,748.5
174	2,031.8	2,306.0	7,654.6	7,780.0
175	2,044.7	2,320.6	7,664.6	7,790.2
176	2,065.7	2,344.5	7,592.7	7,717.1
177	2,070.5	2,349.9	7,511.7	7,634.8
178	2,066.3	2,345.1	7,517.7	7,640.8
179	2,089.9	2,372.0	7,589.3	7,713.6
180	2,088.5	2,370.3	7,573.3	7,697.4
181	1,965.2	2,230.4	7,354.7	7,475.1
182	1,793.5	2,035.5	6,959.4	7,073.4
183	1,673.6	1,899.4	6,455.3	6,561.1
184	1,616.1	1,834.2	5,957.8	6,055.4
185	1,564.8	1,775.9	5,569.2	5,660.4
186	1,452.3	1,648.3	5,202.7	5,287.9
187	1,309.4	1,486.1	4,776.7	4,855.0
188	1,204.4	1,366.9	4,381.5	4,453.2
189	1,143.3	1,297.5	4,072.4	4,139.1
190	1,102.9	1,251.7	3,845.1	3,908.1
191	1,091.8	1,239.1	3,689.4	3,749.9
192	1,094.5	1,242.2	3,587.1	3,645.9
193	1,104.3	1,253.4	3,531.1	3,589.0
194	1,109.5	1,259.2	3,506.8	3,564.2
195	1,048.3	1,189.8	3,498.8	3,556.1
196	944.5	1,072.0	3,506.9	3,564.4
197	926.0	1,050.9	3,482.5	3,539.5
198	946.8	1,074.5	3,343.8	3,398.6
199	937.5	1,064.0	3,176.4	3,228.4
200	970.6	1,101.6	3,124.3	3,175.5

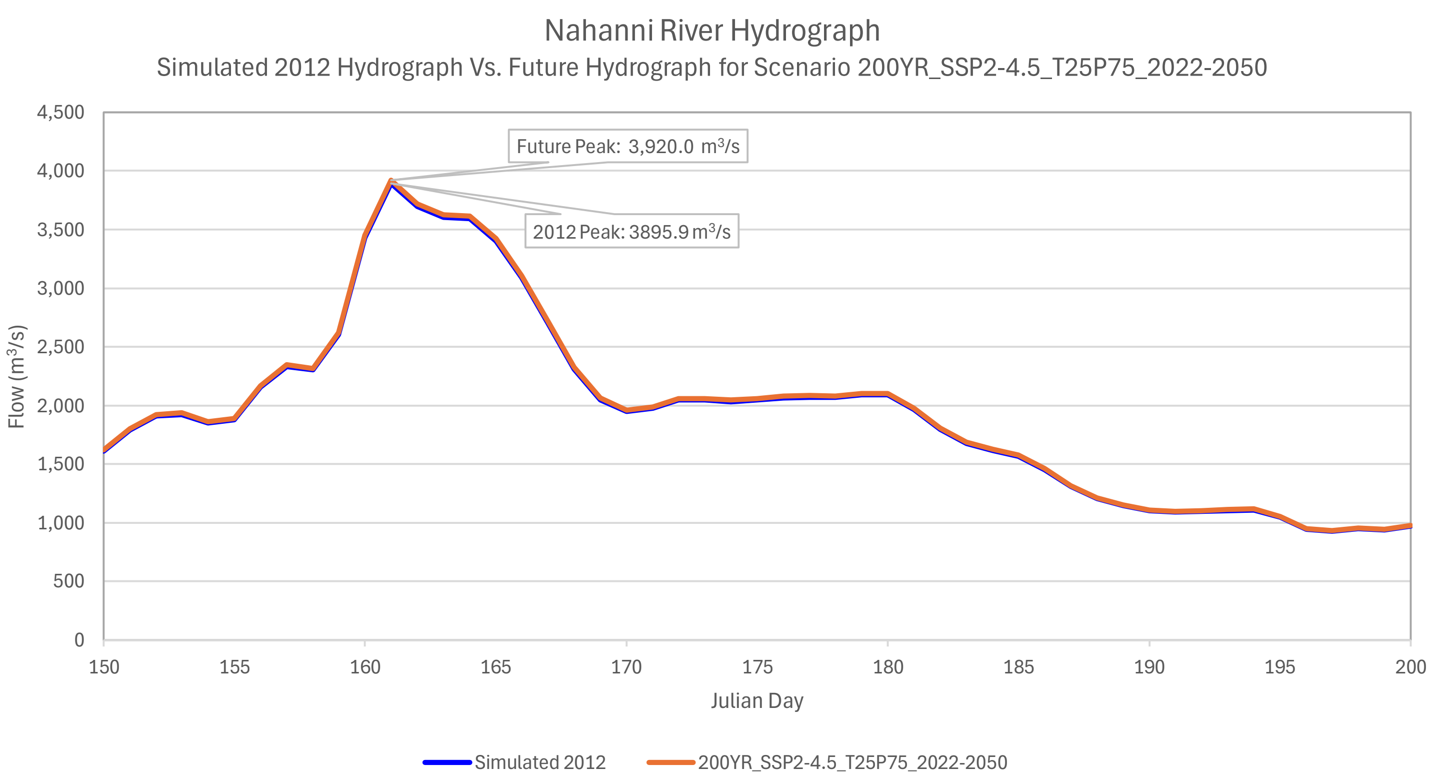




Raven-Simulated 2012 Daily Hydrograph and Future Hydrograph Under Scanario 200YR_SSP2-4.5_T25P75_2022-2050

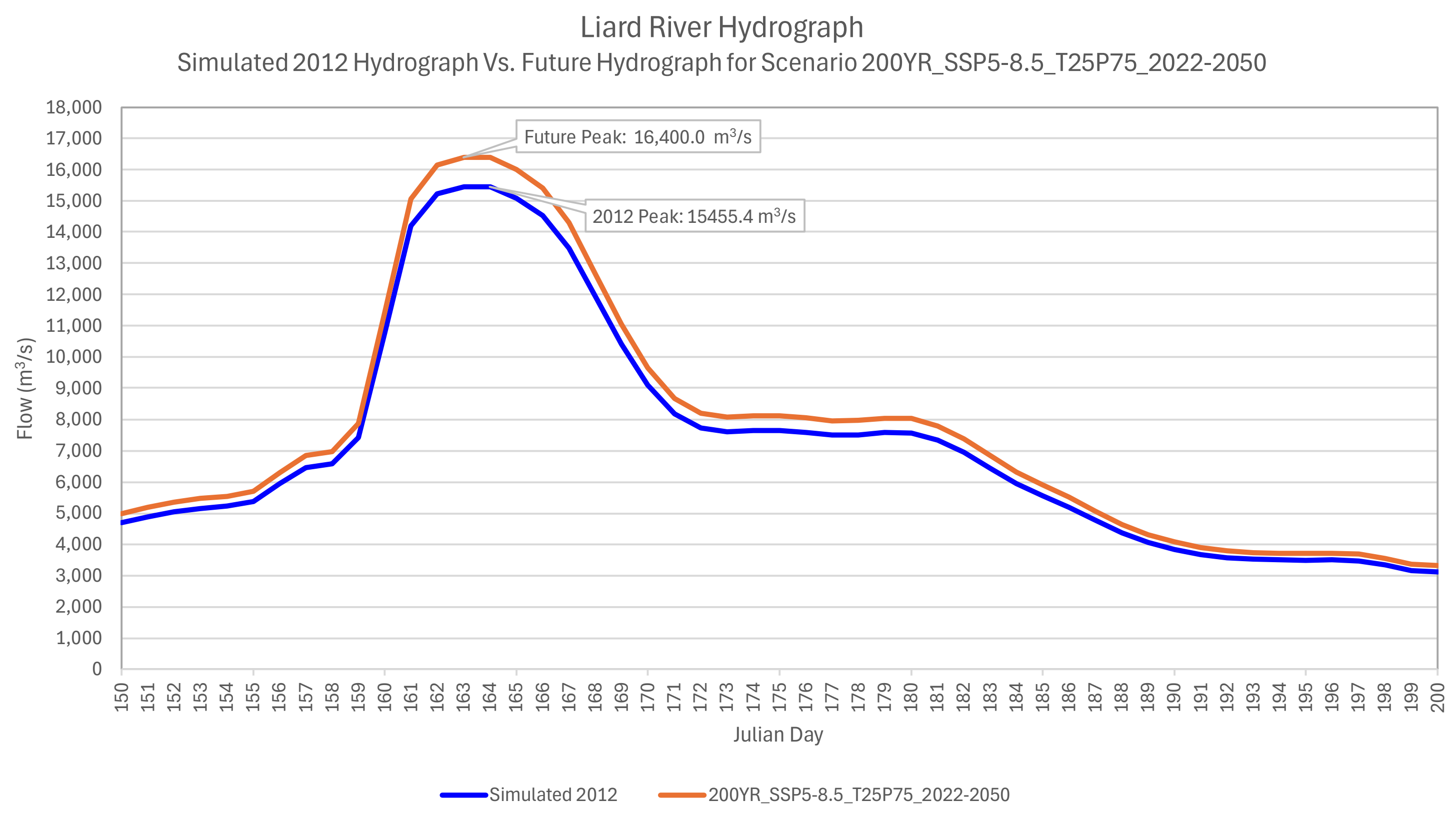
Julian Day	Nahanni River		Liard River	
	Simulated 2012	200YR_SSP2-4.5_T25P75_2022-2050	Simulated 2012	200YR_SSP2-4.5_T25P75_2022-2050
150	1,612.3	1,622.3	4,699.6	4,995.9
151	1,788.2	1,799.3	4,897.9	5,206.7
152	1,910.2	1,922.0	5,051.7	5,370.3
153	1,923.6	1,935.5	5,159.2	5,484.5
154	1,851.4	1,862.9	5,229.8	5,559.6
155	1,875.1	1,886.7	5,374.0	5,712.9
156	2,154.5	2,167.8	5,946.2	6,321.2
157	2,332.1	2,346.5	6,470.1	6,878.1
158	2,302.6	2,316.8	6,581.6	6,996.6
159	2,602.1	2,618.3	7,425.7	7,894.0
160	3,428.6	3,449.9	10,747.3	11,425.0
161	3,895.9	3,920.0	14,190.4	15,085.2
162	3,696.5	3,719.4	15,216.9	16,176.5
163	3,601.2	3,623.5	15,455.4	16,430.0
164	3,590.0	3,612.2	15,444.9	16,418.8
165	3,399.9	3,421.0	15,068.7	16,018.9
166	3,087.5	3,106.7	14,514.1	15,429.3
167	2,702.3	2,719.0	13,467.9	14,317.2
168	2,309.9	2,324.2	11,934.4	12,687.0
169	2,048.6	2,061.2	10,395.6	11,051.1
170	1,948.0	1,960.0	9,081.8	9,654.5
171	1,975.3	1,987.5	8,179.9	8,695.7
172	2,046.3	2,058.9	7,741.5	8,229.6
173	2,045.9	2,058.5	7,623.6	8,104.3
174	2,031.8	2,044.4	7,654.6	8,137.3
175	2,044.7	2,057.3	7,664.6	8,147.9
176	2,065.7	2,078.5	7,592.7	8,071.5
177	2,070.5	2,083.4	7,511.7	7,985.4
178	2,066.3	2,079.1	7,517.7	7,991.7
179	2,089.9	2,102.9	7,589.3	8,067.8
180	2,088.5	2,101.4	7,573.3	8,050.9
181	1,965.2	1,977.4	7,354.7	7,818.4
182	1,793.5	1,804.6	6,959.4	7,398.2
183	1,673.6	1,684.0	6,455.3	6,862.4
184	1,616.1	1,626.2	5,957.8	6,333.5
185	1,564.8	1,574.5	5,569.2	5,920.4
186	1,452.3	1,461.3	5,202.7	5,530.8
187	1,309.4	1,317.5	4,776.7	5,077.9
188	1,204.4	1,211.8	4,381.5	4,657.7
189	1,143.3	1,150.3	4,072.4	4,329.2
190	1,102.9	1,109.7	3,845.1	4,087.6
191	1,091.8	1,098.6	3,689.4	3,922.1
192	1,094.5	1,101.3	3,587.1	3,813.3
193	1,104.3	1,111.2	3,531.1	3,753.8
194	1,109.5	1,116.4	3,506.8	3,727.9
195	1,048.3	1,054.8	3,498.8	3,719.4
196	944.5	950.4	3,506.9	3,728.1
197	926.0	931.7	3,482.5	3,702.1
198	946.8	952.7	3,343.8	3,554.7
199	937.5	943.3	3,176.4	3,376.7
200	970.6	976.6	3,124.3	3,321.4

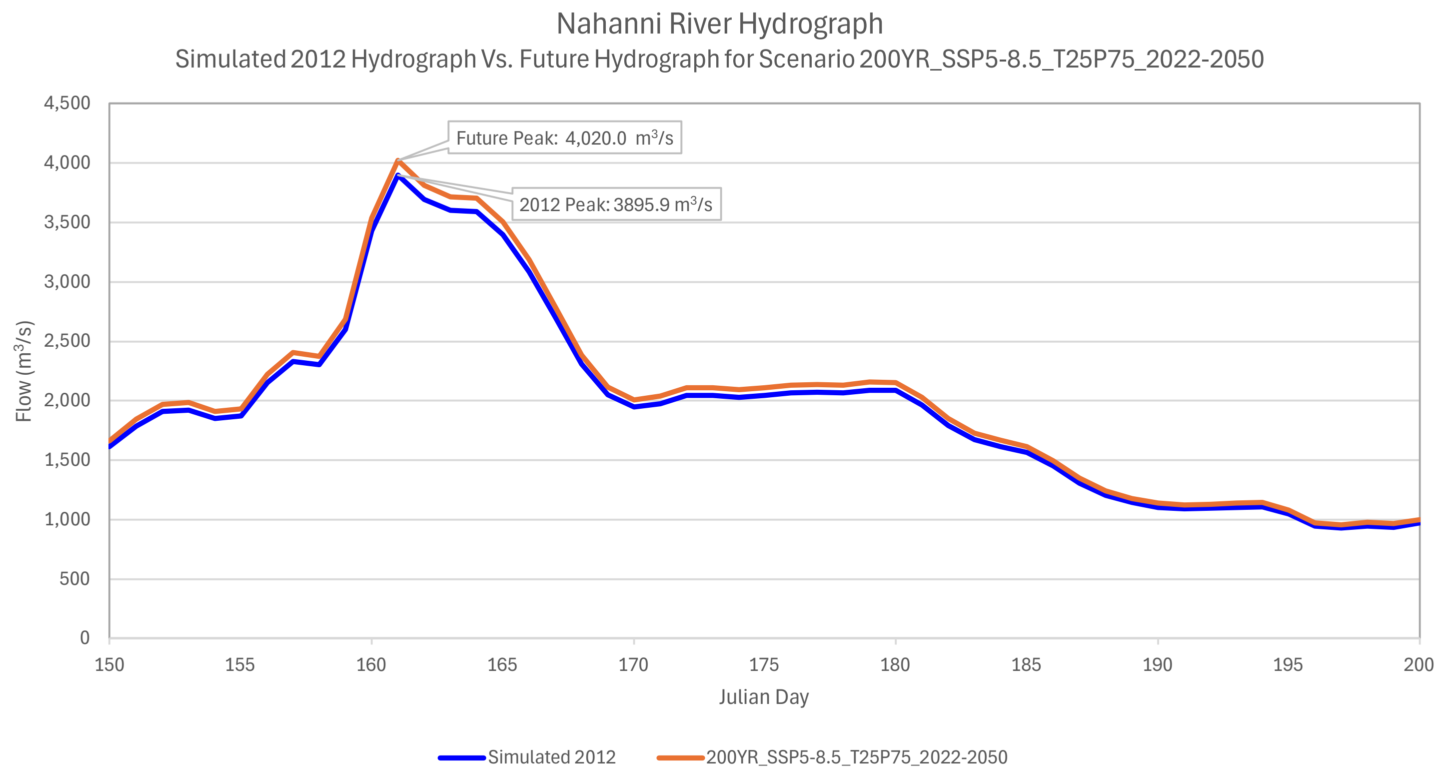




Raven-Simulated 2012 Daily Hydrograph and Future Hydrograph Under Scanario 200YR_SSP5-8.5_T25P75_2022-2050

Julian Day	Nahanni River		Liard River	
	Simulated 2012	200YR_SSP5-8.5_T25P75_2022-2050	Simulated 2012	200YR_SSP5-8.5_T25P75_2022-2050
150	1,612.3	1,663.6	4,699.6	4,986.8
151	1,788.2	1,845.1	4,897.9	5,197.2
152	1,910.2	1,971.1	5,051.7	5,360.5
153	1,923.6	1,984.9	5,159.2	5,474.5
154	1,851.4	1,910.4	5,229.8	5,549.4
155	1,875.1	1,934.8	5,374.0	5,702.5
156	2,154.5	2,223.1	5,946.2	6,309.6
157	2,332.1	2,406.4	6,470.1	6,865.5
158	2,302.6	2,375.9	6,581.6	6,983.8
159	2,602.1	2,685.1	7,425.7	7,879.6
160	3,428.6	3,537.9	10,747.3	11,404.2
161	3,895.9	4,020.0	14,190.4	15,057.7
162	3,696.5	3,814.3	15,216.9	16,146.9
163	3,601.2	3,715.9	15,455.4	16,400.0
164	3,590.0	3,704.3	15,444.9	16,388.9
165	3,399.9	3,508.3	15,068.7	15,989.7
166	3,087.5	3,185.9	14,514.1	15,401.2
167	2,702.3	2,788.4	13,467.9	14,291.0
168	2,309.9	2,383.5	11,934.4	12,663.8
169	2,048.6	2,113.8	10,395.6	11,031.0
170	1,948.0	2,010.0	9,081.8	9,636.8
171	1,975.3	2,038.2	8,179.9	8,679.8
172	2,046.3	2,111.5	7,741.5	8,214.6
173	2,045.9	2,111.1	7,623.6	8,089.5
174	2,031.8	2,096.6	7,654.6	8,122.4
175	2,044.7	2,109.8	7,664.6	8,133.1
176	2,065.7	2,131.5	7,592.7	8,056.7
177	2,070.5	2,136.5	7,511.7	7,970.8
178	2,066.3	2,132.1	7,517.7	7,977.1
179	2,089.9	2,156.5	7,589.3	8,053.1
180	2,088.5	2,155.0	7,573.3	8,036.2
181	1,965.2	2,027.8	7,354.7	7,804.2
182	1,793.5	1,850.7	6,959.4	7,384.7
183	1,673.6	1,726.9	6,455.3	6,849.8
184	1,616.1	1,667.6	5,957.8	6,321.9
185	1,564.8	1,614.6	5,569.2	5,909.6
186	1,452.3	1,498.6	5,202.7	5,520.7
187	1,309.4	1,351.1	4,776.7	5,068.6
188	1,204.4	1,242.7	4,381.5	4,649.2
189	1,143.3	1,179.7	4,072.4	4,321.3
190	1,102.9	1,138.0	3,845.1	4,080.1
191	1,091.8	1,126.6	3,689.4	3,914.9
192	1,094.5	1,129.4	3,587.1	3,806.4
193	1,104.3	1,139.5	3,531.1	3,746.9
194	1,109.5	1,144.9	3,506.8	3,721.1
195	1,048.3	1,081.7	3,498.8	3,712.7
196	944.5	974.6	3,506.9	3,721.3
197	926.0	955.5	3,482.5	3,695.3
198	946.8	977.0	3,343.8	3,548.2
199	937.5	967.4	3,176.4	3,370.5
200	970.6	1,001.5	3,124.3	3,315.3

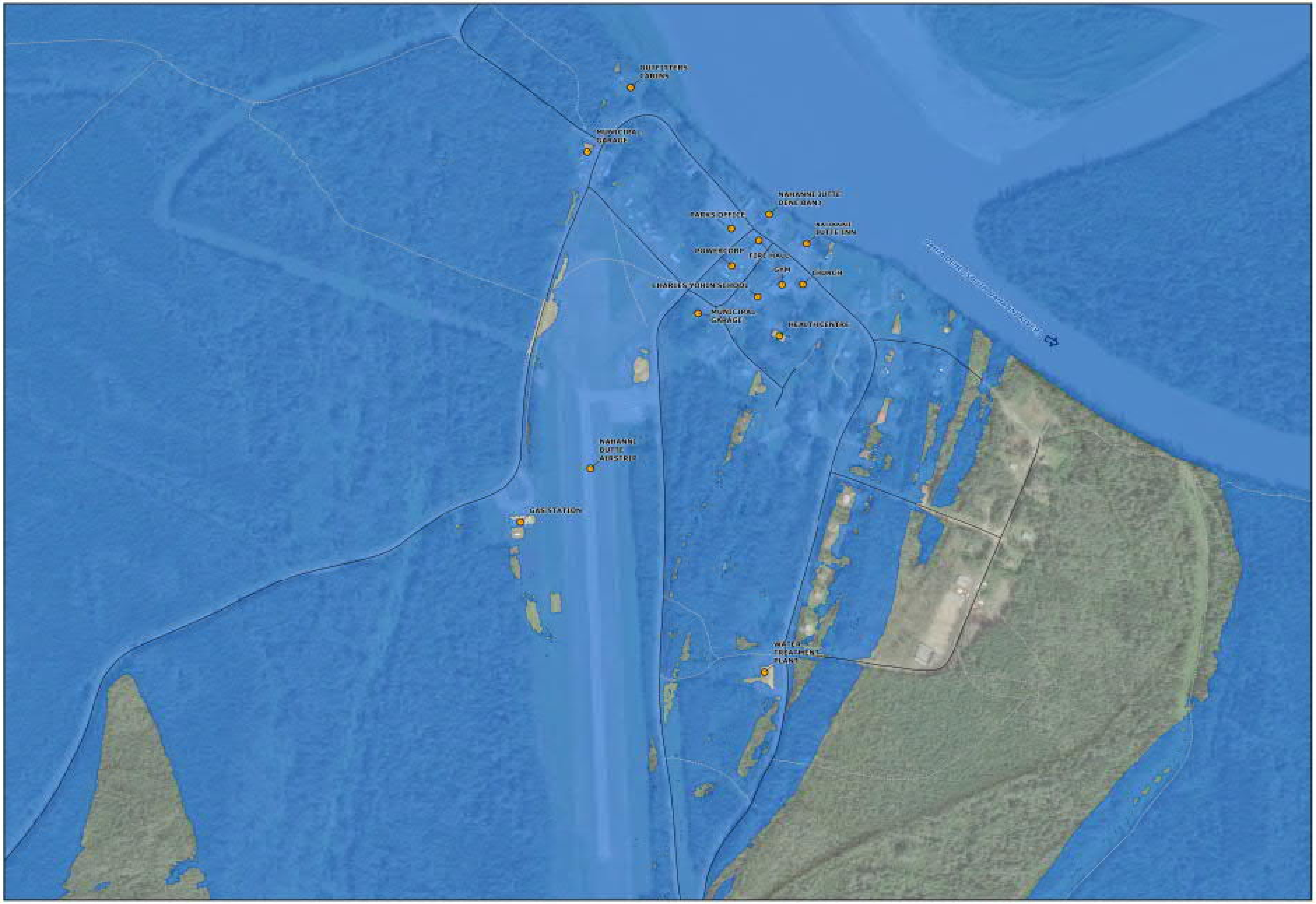




Appendix D

Flood Inundation and Hazard Maps

The full-size, stamped flood inundation and hazard maps have been provided separately. The following pages include lower-resolution versions that have not been stamped and are provided for information only.



Government of Northwest Territories
Gouvernement des Territoires du Nord-Ouest

Nahɂą Dehé Dene Band

Place of Interest
Flow Direction
Local Road
Trail
Inundation Extent

Canada

Funding for this project was provided by the Government of Northwest Territories and Natural Resources Canada, under the Flood Hazard Identification and Mapping Program (FHIMP)

FINAL

PERMIT TO PRACTICE

DILLON CONSULTING

Metres

GEOSPATIAL DATA SOURCES

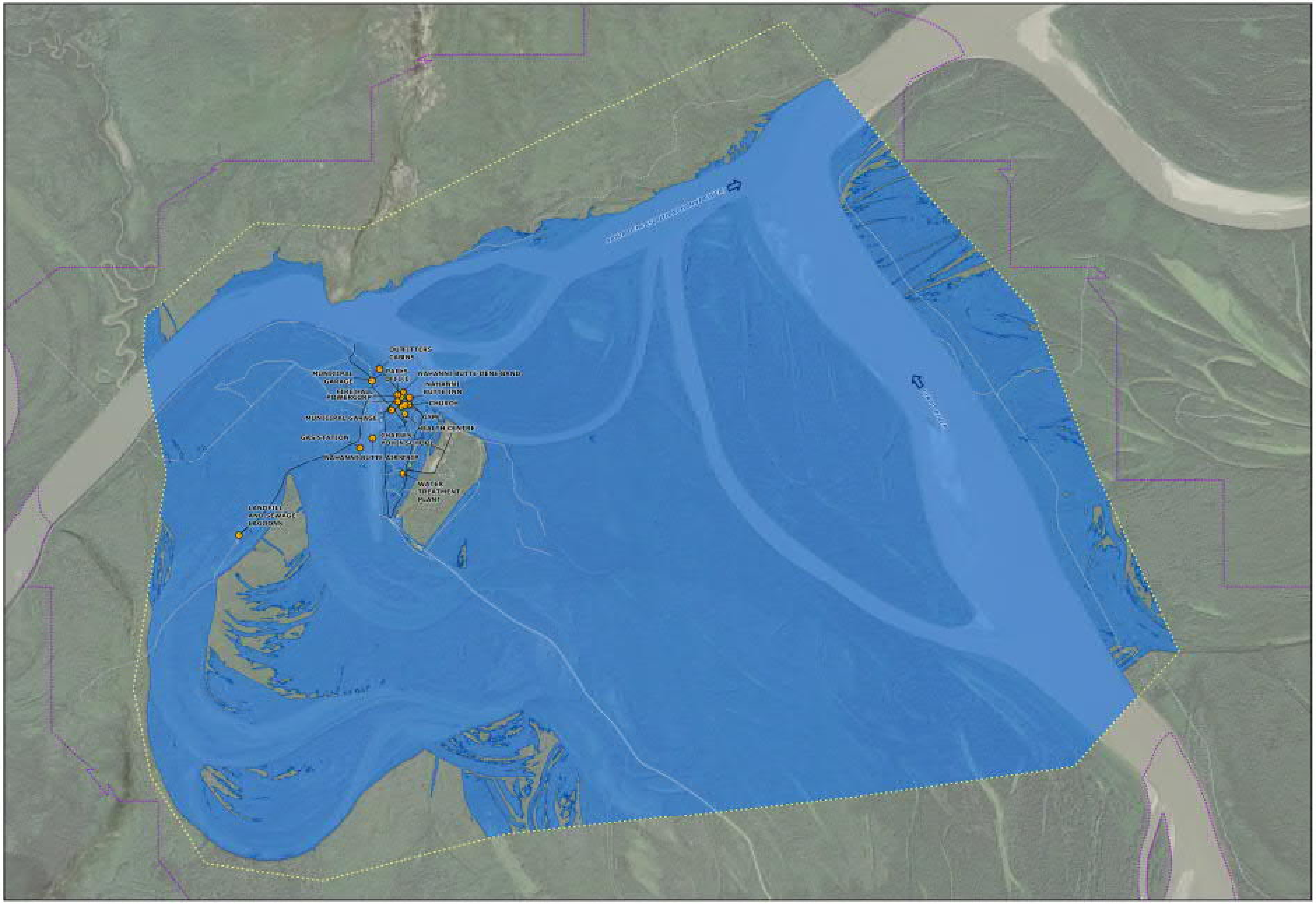
Created by:

Reviewed by:

2012
FLOOD INUNDATION MAP
NAHANNI BUTTE

Page Number: 1 of 2

THIS MAP IS INTENDED FOR EMERGENCY PLANNING PURPOSES



Place of Interest
Flow Direction
Local Road
Trail
Winter Road
Inundation Extent
Extent of 2025 Flood Assessment
Digital Elevation Model Limit (Dillon Consulting Limited, 2024; GNWT, 2020)

Canada

Funding for this project was provided by the Government of Northwest Territories and Natural Resources Canada, under the Flood Hazard Identification and Mapping Program (FHIMP)

FINAL

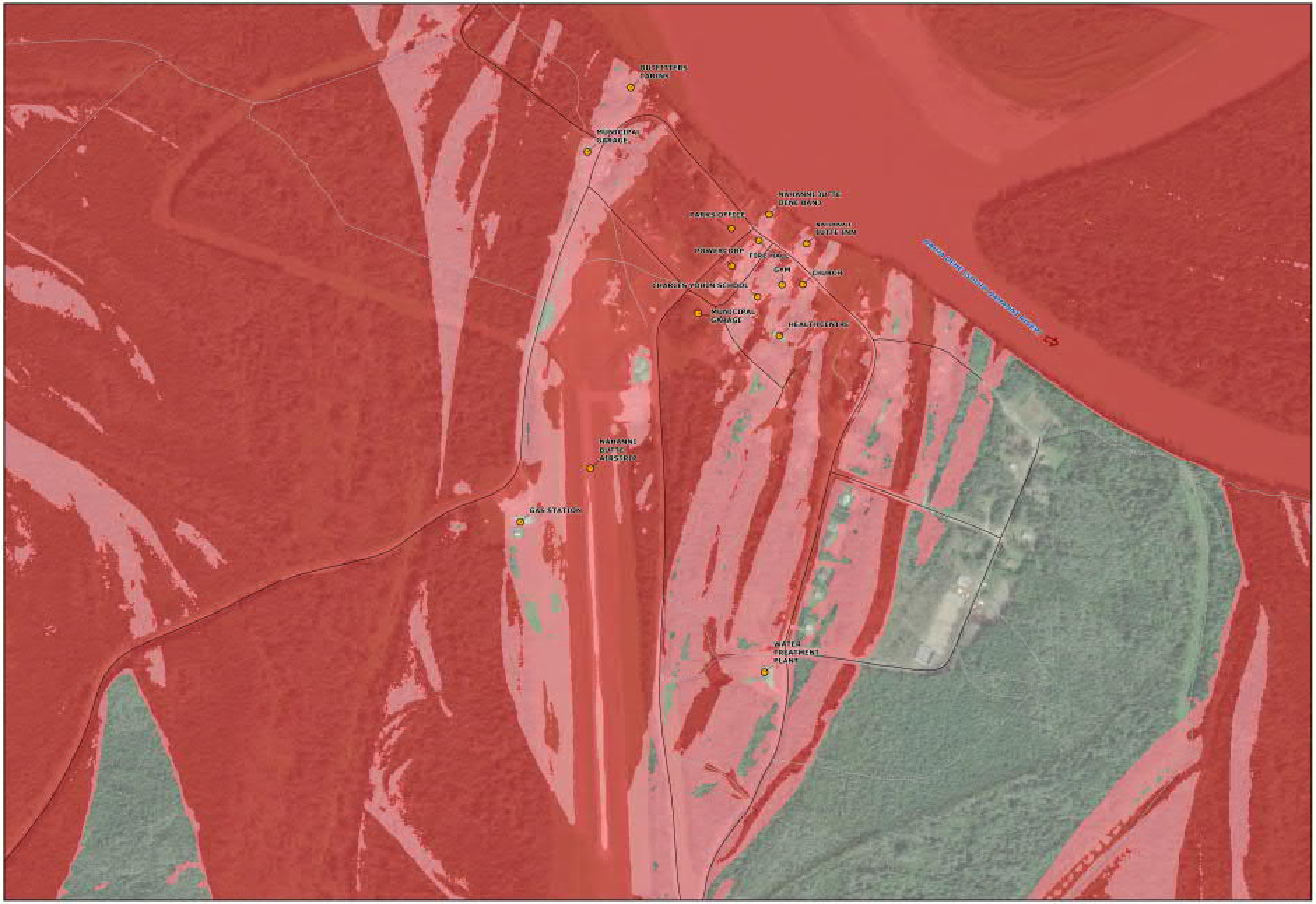
PERMIT TO PRACTICE

DILLON CONSULTING

GEOSPATIAL DATA SOURCES:

2012 FLOOD INUNDATION MAP NAHANNI BUTTE (TTHENÁÁDÓ)

THIS MAP IS INTENDED FOR EMERGENCY PLANNING PURPOSES



Government of Northwest Territories / Gouvernement des Territoires du Nord-Ouest

Nahɂą Dehé Dene Band

Place of Interest
Flow Direction
Local Road
Trail
Floodway
Flood Fringe

Canada

Funding for this project was provided by the Government of Northwest Territories and Natural Resources Canada, under the Flood Hazard Identification and Mapping Program (FHIMP)

FINAL

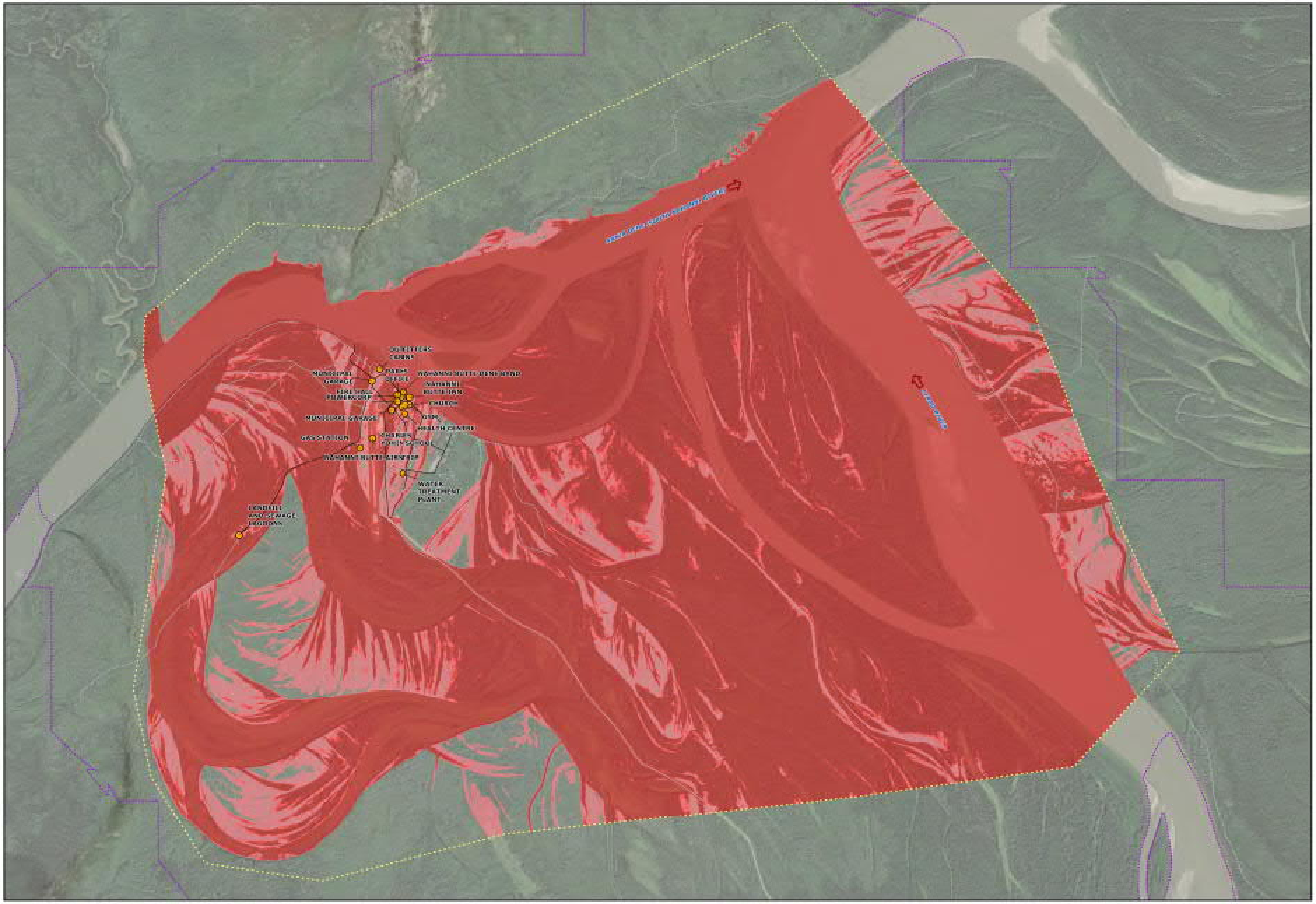
PERMIT TO PRACTICE

DILLON CONSULTING

GEOSPATIAL DATA SOURCES:

NAHANNI BUTTE (TTHENÁÁGÓ)
100 YEAR OPEN WATER FLOOD HAZARD MAP (1% ANNUAL EXCEEDANCE PROBABILITY - AEP)

THIS MAP IS INTENDED FOR COMMUNITY AND LAND USE PLANNING PURPOSES



Place of Interest
Local Road
Trail
Winter Road

Floodway
Flood Fringe
Extent of 2025 Flood Assessment
Digital Elevation Model Limit (Dillon Consulting Limited., 2024; GNWT, 2020)

Canada

Funding for this project was provided by the Government of Northwest Territories and Natural Resources Canada, under the Flood Hazard Identification and Mapping Program (FHIMP)

FINAL

PERMIT TO PRACTICE

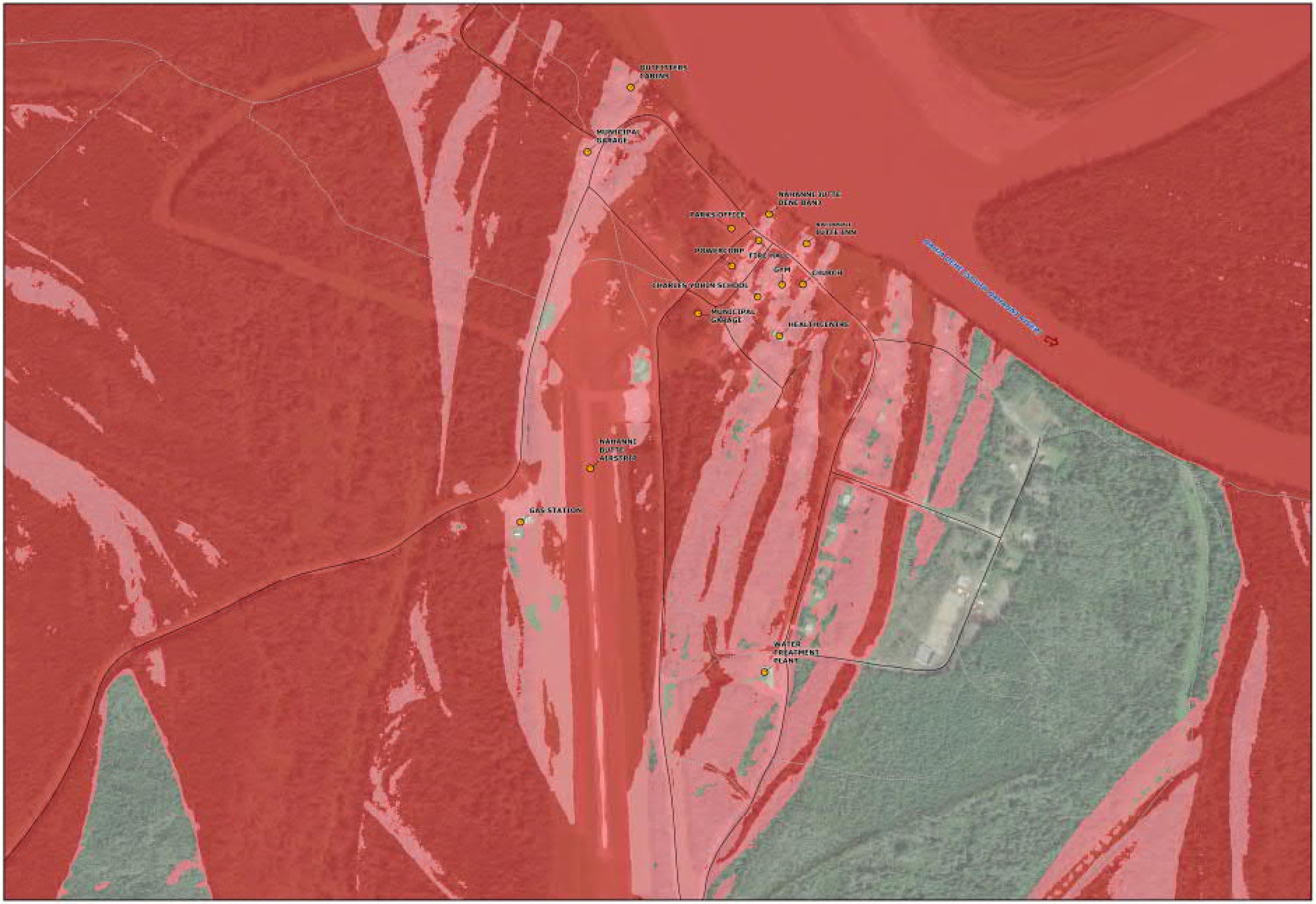
DILLON CONSULTING

Metres

GEOSPATIAL DATA SOURCES:

NAHANNI BUTTE (TTHENÁÁGÓ)
100 YEAR OPEN WATER FLOOD HAZARD MAP (1% ANNUAL EXCEEDANCE PROBABILITY - AEP)

Page Number: 2 of 2



Place of Interest
Flow Direction
Local Road
Trail
Floodway
Flood Fringe

Canada

Funding for this project was provided by the Government of Northwest Territories and Natural Resources Canada, under the Flood Hazard Identification and Mapping Program (FHIMP)

FINAL

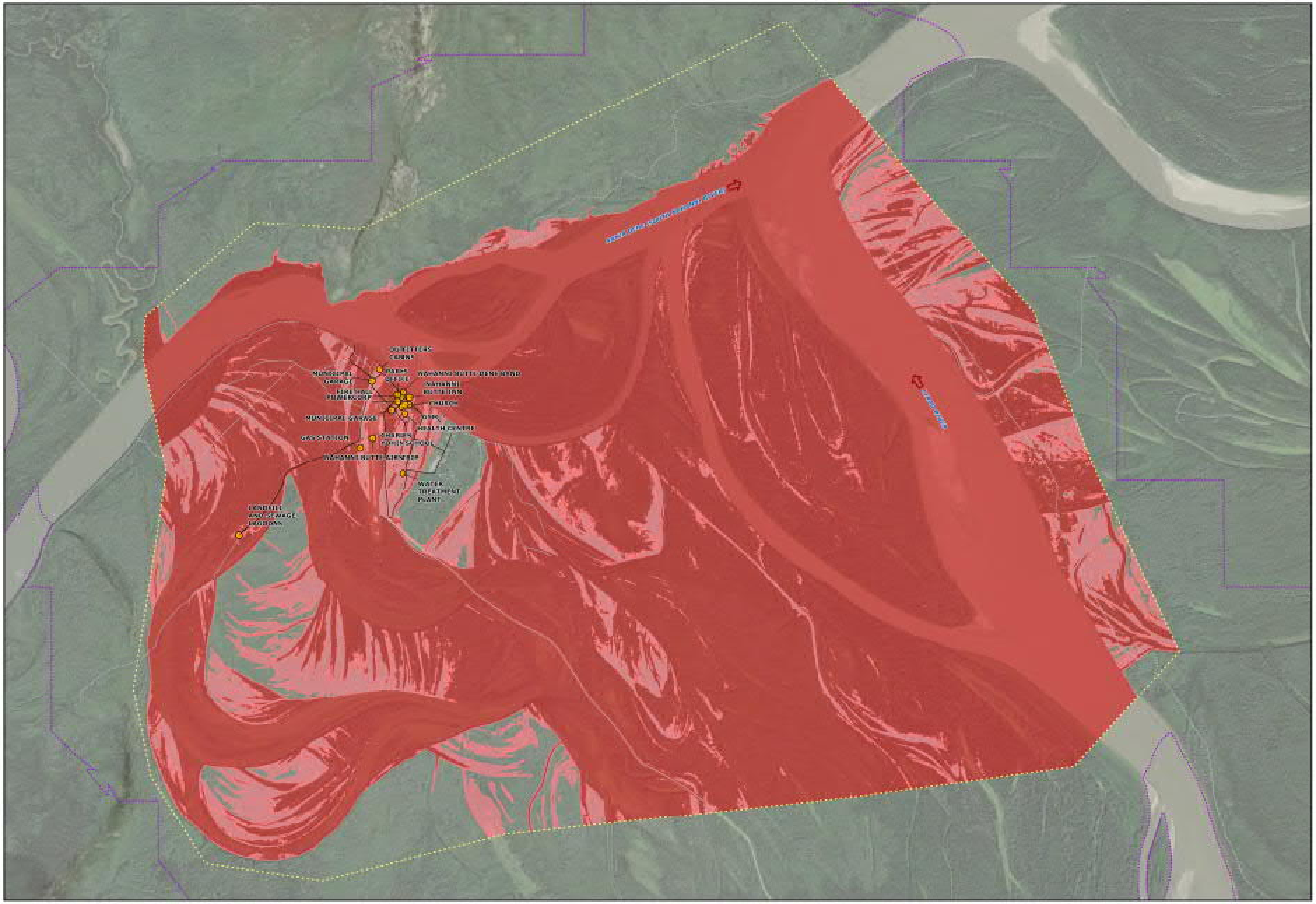
PERMIT TO PRACTICE

DILLON CONSULTING

NAHANNI BUTTE (TTHENÁÁGÓ) 200 YEAR OPEN WATER FLOOD HAZARD MAP (0.5% ANNUAL EXCEEDANCE PROBABILITY - AEP)

Page Number: 1 of 2

THIS MAP IS INTENDED FOR COMMUNITY AND LAND USE PLANNING PURPOSES



Canada

Funding for this project was provided by the Government of Northwest Territories and Natural Resources Canada, under the Flood Hazard Identification and Mapping Program (FHIMP)

FINAL

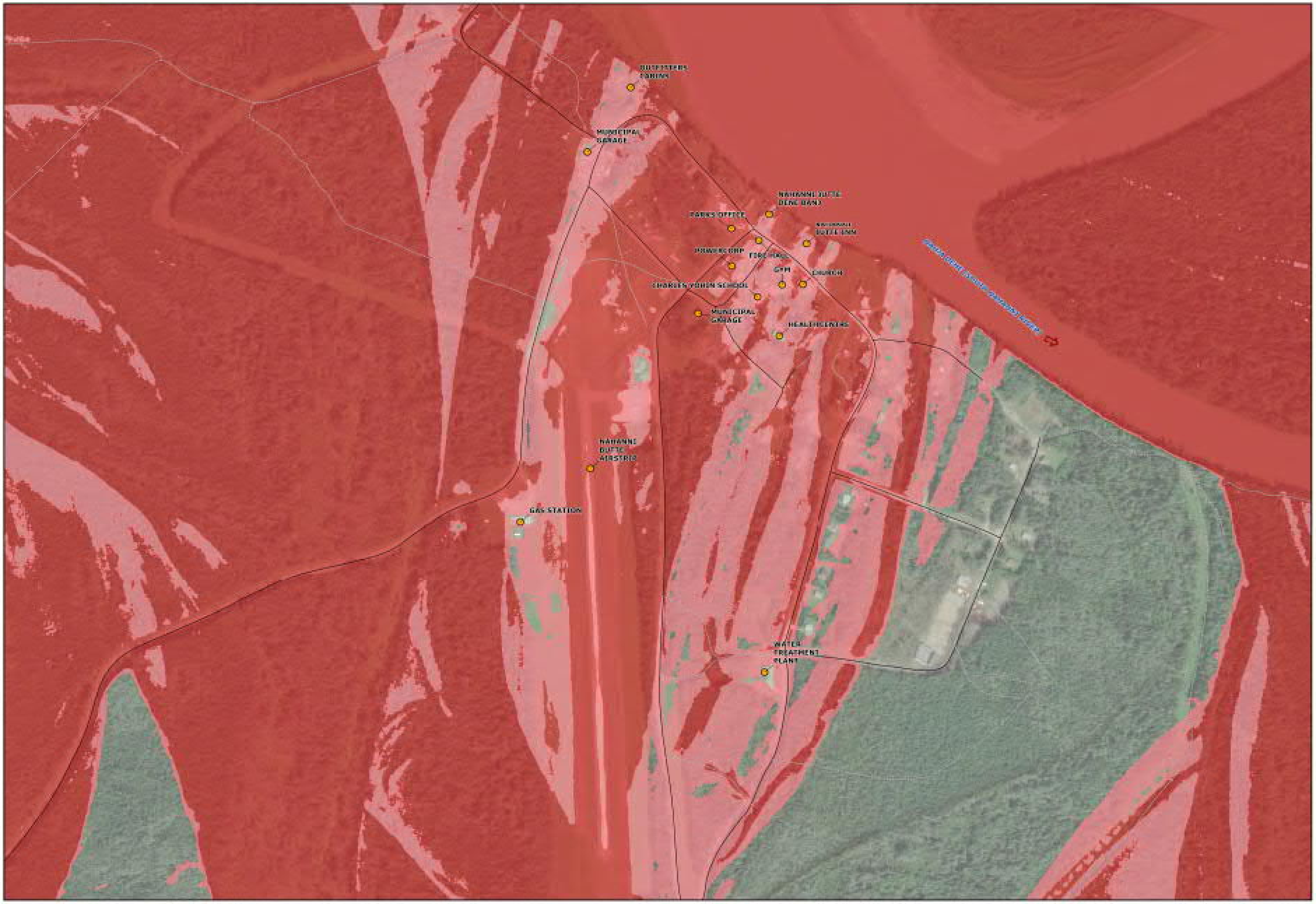
PERMIT TO PRACTICE

DILLON CONSULTING

NAHANNI BUTTE (TTHENÁÁGÓ) 200 YEAR OPEN WATER FLOOD HAZARD MAP (0.5% ANNUAL EXCEEDANCE PROBABILITY - AEP)

Page Number: 2 of 2

THIS MAP IS INTENDED FOR COMMUNITY AND LAND USE PLANNING PURPOSES



Place of Interest
Flow Direction
Local Road
Trail
Floodway
Flood Fringe

Canada

Funding for this project was provided by the Government of Northwest Territories and Natural Resources Canada, under the Flood Hazard Identification and Mapping Program (FHIMP)

FINAL

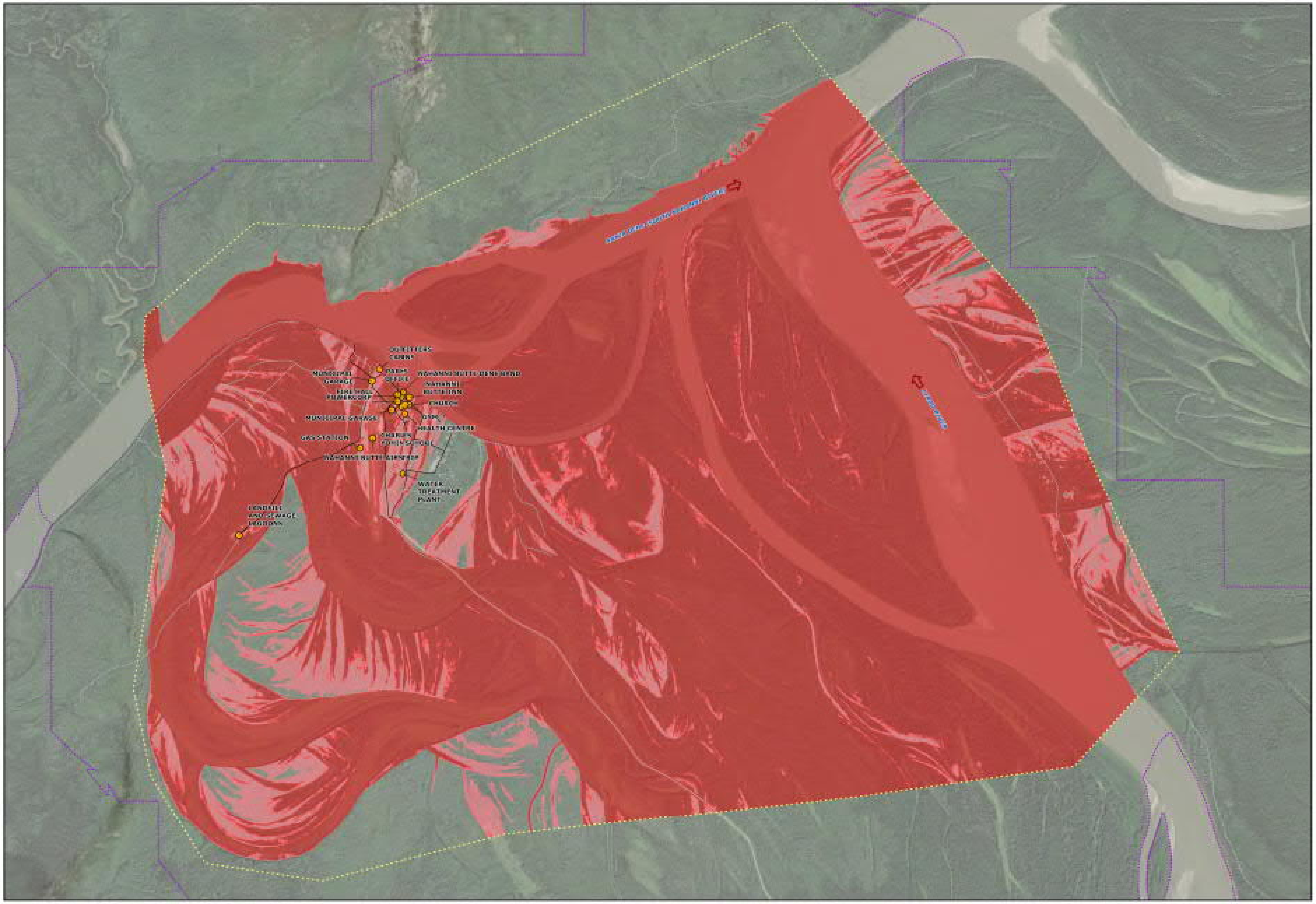
PERMIT TO PRACTICE

DILLON CONSULTING

NAHANNI BUTTE (TTHENÁÁGÓ)
200 YEAR OPEN WATER
FLOOD HAZARD MAP
(0.5% ANNUAL EXCEEDANCE PROBABILITY - AEP)
SCENARIO 1: CLIMATE CHANGE TO 2050, SSP2-4.5

Page Number: 1 of 2

THIS MAP IS INTENDED FOR COMMUNITY AND LAND USE PLANNING PURPOSES



Place of Interest
Flow Direction
Local Road
Trail
Winter Road
Floodway
Flood Fringe
Extent of 2025 Flood Assessment
Digital Elevation Model Limit (Dillon Consulting Limited., 2024; GNWT, 2020)

Canada

Funding for this project was provided by the Government of Northwest Territories and Natural Resources Canada, under the Flood Hazard Identification and Mapping Program (FHIMP)

FINAL

PERMIT TO PRACTICE

DILLON CONSULTING

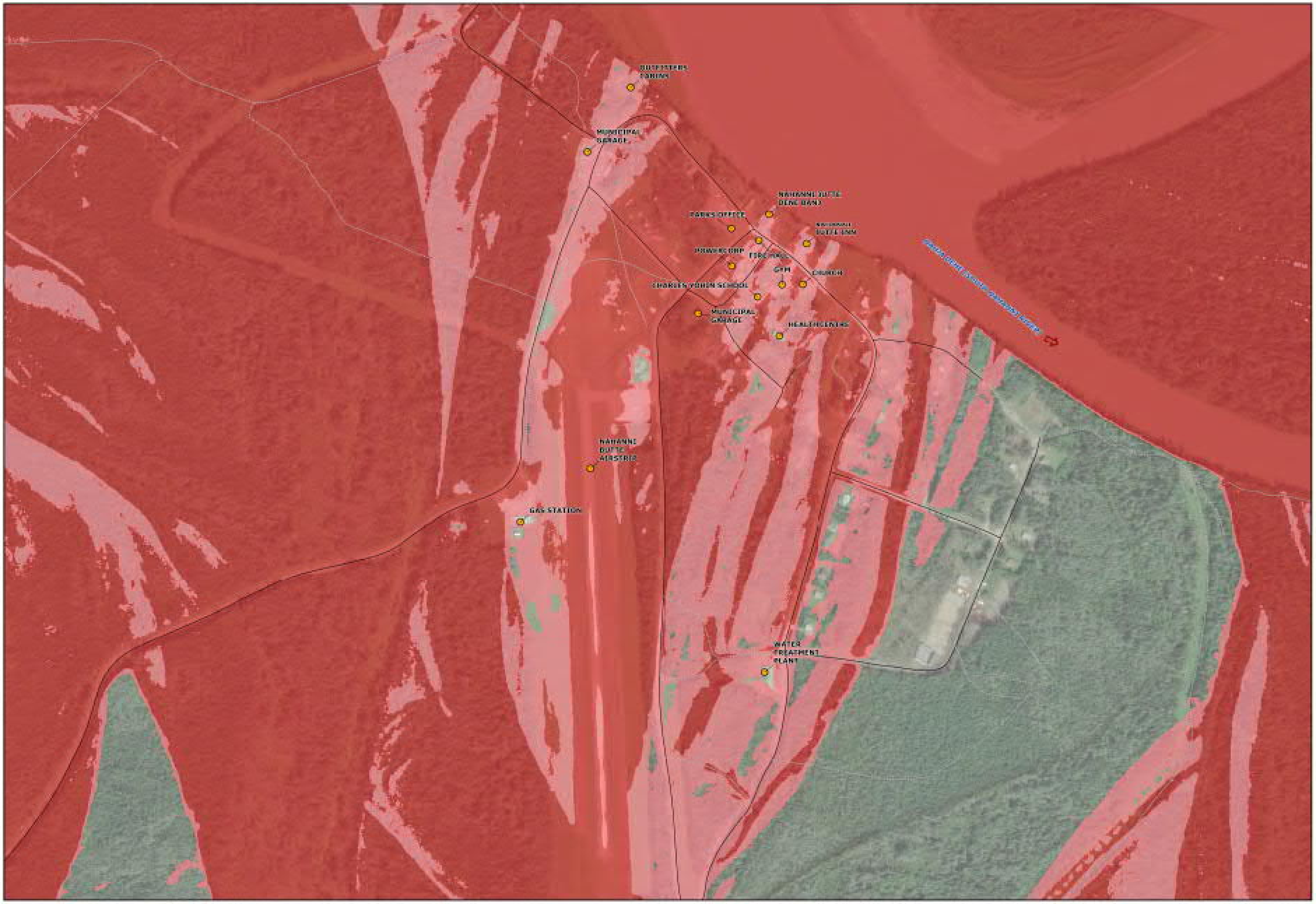
GEOSPATIAL DATA SOURCES:

NAHANNI BUTTE (TTHENÁĄGÓ) 200 YEAR OPEN WATER FLOOD HAZARD MAP (0.5% ANNUAL EXCEEDANCE PROBABILITY - AEP)

SCENARIO 1: CLIMATE CHANGE TO 2050, SSP2-4.5

Page Number: 2 of 2

THIS MAP IS INTENDED FOR COMMUNITY AND LAND USE PLANNING PURPOSES



Place of Interest
Flow Direction
Local Road
Trail
Floodway
Flood Fringe

Canada

Funding for this project was provided by the Government of Northwest Territories and Natural Resources Canada, under the Flood Hazard Identification and Mapping Program (FHIMP)

FINAL

PERMIT TO PRACTICE

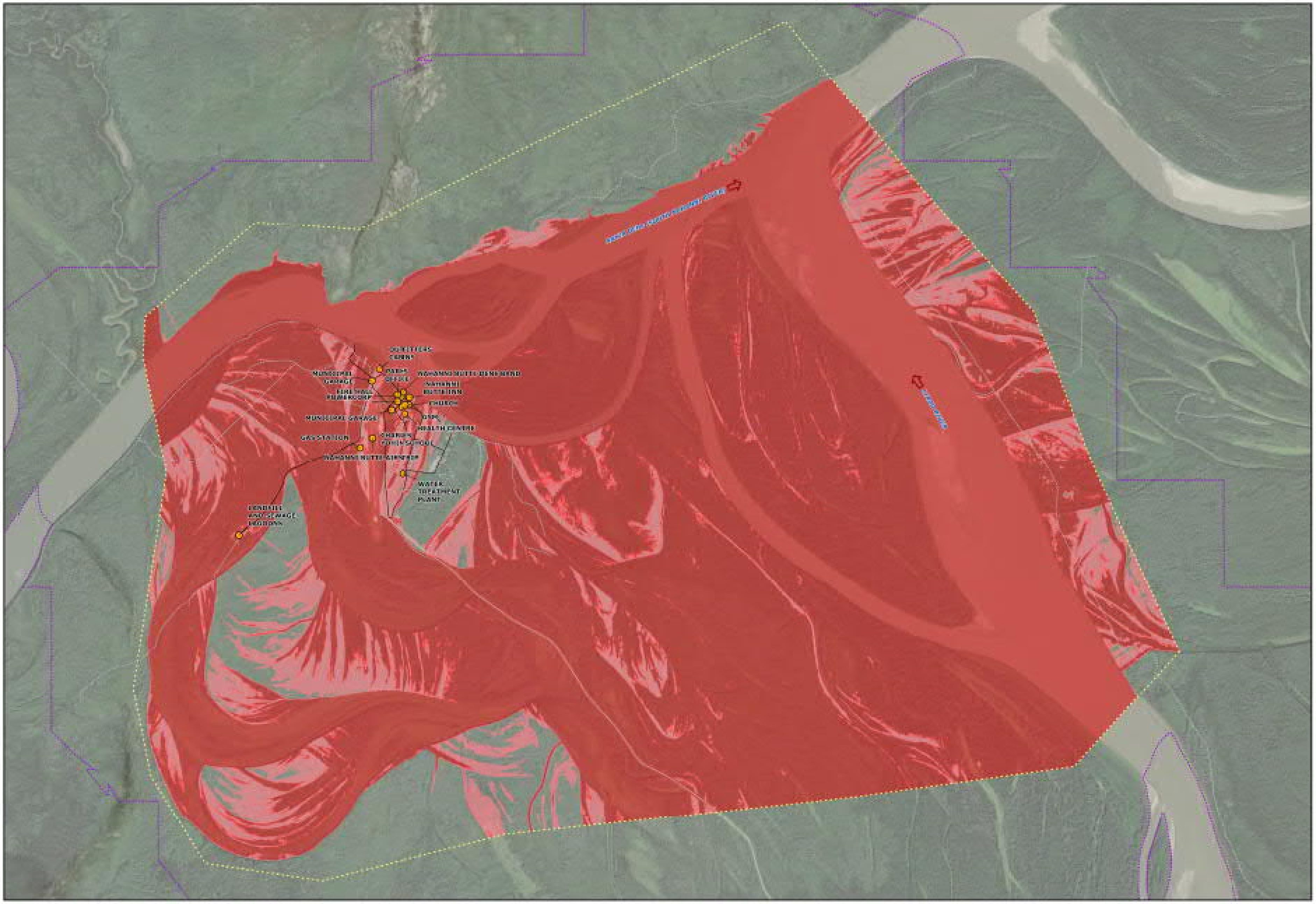
DILLON CONSULTING

NAHANNI BUTTE (TTHENÁÁGÓ)
200 YEAR OPEN WATER FLOOD HAZARD MAP (0.5% ANNUAL EXCEEDANCE PROBABILITY - AEP)

SCENARIO 2: CLIMATE CHANGE TO 2050, SSP5-8.5

Page Number: 1 of 2

THIS MAP IS INTENDED FOR COMMUNITY AND LAND USE PLANNING PURPOSES



Place of Interest
Flow Direction
Local Road
Trail
Winter Road
Floodway
Flood Fringe
Extent of 2025 Flood Assessment
Digital Elevation Model Limit (Dillon Consulting Limited., 2024; GNWT, 2020)

Canada

Funding for this project was provided by the Government of Northwest Territories and Natural Resources Canada, under the Flood Hazard Identification and Mapping Program (FHIMP)

FINAL

PERMIT TO PRACTICE

DILLON CONSULTING

Metres

GEOSPATIAL DATA SOURCES:

NAHANNI BUTTE (TTHENÁÁGÓ)
[illegible]
FLOOD HAZARD MAP (0.5% ANNUAL EXCEEDANCE PROBABILITY - AEP)
SCENARIO 2: CLIMATE CHANGE TO 2050, SSP5-8.5

Page Number: 2 of 2

THIS MAP IS INTENDED FOR COMMUNITY AND LAND USE PLANNING PURPOSES

References

Albers, S. J. (2017). tidyhydat: Extract and Tidy Canadian Hydrometric Data. The Journal of Open Source Software, 2(20), 511. https://doi.org/10.21105/joss.00511.

Ausenco Sandwell. (2011). British Columbia Ministry of Environment Guidelines for Management of Coastal Flood Hazard Land Use.

Brown, G., & Craig, J. R. (2020). *Multi-gauge calibration of a hydrological model of the Liard River basin*. Canadian Water Resources Journal.

CBC News. (2009, May 7). Nahanni Butte residents prepared to leave as Liard River rises. CBC. https://www.cbc.ca/news/canada/north/nahanni-butte-residents-prepared-to-leave-as-liard-river-rises-1.831558.

CBC News. (2012, June 11). Flooding creates weekend mayhem in Yukon and N.W.T. | CBC News. https://www.cbc.ca/news/canada/north/flooding-creates-weekend-mayhem-in-yukon-and-n-w-t-1.1146695.

CBC News. (2012, June 13). *Nahanni Butte, N.W.T, almost entirely flooded*. | CBC News. https://www.cbc.ca/news/canada/north/nahanni-butte-n-w-t-almost-entirely-flooded-1.1147929.

Chlumsky, R., Craig, J. R., Lin, S. G. M., Grass, S., Scantlebury, L., Brown, G., and Arabzadeh, R.: (2022). *RavenR v2.1.4: an open-source R package to support flexible hydrologic modelling*, Geosci. Model Dev., 15, 7017–7030, https://doi.org/10.5194/gmd-15-7017-2022, 2022.

City of Moncton. (2013). Climate Change Adaptation and Flood Management Strategy.

ClimateData.ca. (n.d.). Understanding shared socio-economic pathways (SSPs). ClimateData.ca. Retrieved August 5, 2025, from https://climatedata.ca/resource/understanding-shared-socio-economic-pathways-ssps/.

EBNFLO Environmental AquaResource Inc. (2010). Guide for assessment of hydrologic effects of climate change in Ontario. Ontario Ministry of Natural Resources and Ministry of the Environment, in partnership with Credit Valley Conservation.

Environment and Climate Change Canada [ECCC]. (2024). National hydrometric network basin polygons. Water Survey of Canada. https://wateroffice.ec.gc.ca/mainmenu/station_and_network_data_index_e.html

ECCC. (2025). Canadian Climate Normals 1991-2020. https://climate.weather.gc.ca/climate_normals/results_1991_2020_e.html?searchType=stnProv&lstProvince=NB&txtCentralLatMin=0&txtCentralLatSec=0&txtCentralLongMin=0&txtCentralLongSec=0&stnID=13000000&dispBack=0.

Eyring, V., Bony, S., Meehl, G. A., Senior, C., Stevens, B., Stouffer, R. J., & Taylor, K. E. (2016). Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. Geoscientific Model Development, 9(5), 1937–1958. https://doi.org/10.5194/gmd-9-1937-2016

Government of the Northwest Territories. (n.d.). Resources. NWT Centre for Geomatics. https://www.geomatics.gov.nt.ca/en/resources/field_resource_source/gnwt-138?search_api_views_fulltext=in%2Bland%2Bwater&utm_source=chatgpt.com

Government of Northwest Territories, NWT Centre for Geomatics. (2024). ATLAS (Administration of the Territorial Lands Act System). Government of Northwest Territories, Yellowknife, NT. https://www.maps.geomatics.gov.nt.ca/HTML5Viewer_Prod/index.html?viewer=ATLAS

Hamilton, A. S., Hutchinson, D. G., & Moore, R. D. (2000). Estimating winter streamflow using conceptual streamflow model. Journal of Cold Regions Engineering, 14(4). https://doi.org/10.1061/(asce)0887-381x(2000)14:4(158)

H. Lee & J. Romero, Eds. (n.d.). *Climate change 2023: Synthesis report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. AR6 Synthesis Report. https://doi.org/10.59327/IPCC/AR6-9789291691647.

INRS (2008) Hyfran-Plus Software. Quebec.

Jeong, D.I. & Cannon, A. (2023). *An Approach for Selecting Observationally-Constrained Global Climate Model Ensembles for Regional Climate Impacts and Adaptation Studies in Canada*. Atmosphere-Ocean. 61. 1-17. 10.1080/07055900.2023.2239194.

Krause, P., Boyle, D. P., & Bäse, F. (2005). *Comparison of different efficiency criteria for hydrological model assessment*. Advances in Geosciences, 5, 89–97. https://doi.org/10.5194/adgeo-5-89-2005

Kriwoken, L. 1983. *Historical flood review: Fort Simpson, Fort Norman, Fort Good Hope, Fort McPherson, Aklavik, Fort Liard, Nahanni Butte*. (Report prepared for Environment Canada, Inland Waters Directorate, Western and Northern Region, Rept. No. MR WNR 83/84-1. https://publications.pc.gc.ca/site/eng/9.898828/publication.html

Meinshausen, M., Nicholls, Z. R. J., Lewis, J., et al. (2020). *The shared socio-economic pathway (SSP) greenhouse gas concentrations and their extensions to 2500*. Geoscientific Model Development, 13, 3571–3605. https://doi.org/10.5194/gmd-13-3571-2020

Nash, J. E., & Sutcliffe, J. V. (1970). *River flow forecasting through conceptual models part I—A discussion of principles*. Journal of Hydrology, 10(3), 282–290.

Natural Resources Canada (NRCan). (2017*). CanVec 1:50000 layers: Road, watercourse*. Natural Resources Canada.

NRCan. (2023). *Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation*. Version 2.0 https://natural-resources.canada.ca/science-data/science-research/natural-hazards/flood-mapping/federal-hydrologic-hydraulic-procedures-flood-hazard-delineation

NRCan. (2024). Historical Flood Events (HFE). Open science and data platform - plateforme de science et de Données Ouvertes. (n.d.). https://osdp-psdo.canada.ca/dp/en/search/metadata/NRCAN-FGP-1-fe83a604-aa5a-4e46-903c-685f8b0cc33c

Northern News Network (NNN). (2006, June 26). *Nahanni Butte takes flood in stride*. NNN. https://nnsl-archive.blackpress.ca/nnsl/2006-06/jun26_06w.html#top

Northwest Hydraulic Consultants (NHC). (2017). *Flood mapping and climate change: City of Surrey case study final report*. Report prepared for Natural Resources Canada.

Ouranos Consortium. 2023. *Scientific guidelines to facilitate the use of climate projections*.

Pacific Climate Impacts Consortium, University of Victoria. (2021, December). *Statistically downscaled climate scenarios* (Method: BCCAQv2). https://data.pacificclimate.org/portal/downscaled_cmip6/map/

Pacific Climate Impacts Consortium, University of Victoria. (2023, July). *Statistically downscaled climate scenarios* (Method: MBCn). https://data.pacificclimate.org/portal/downscaled_cmip6/map/

PlanIt North. (2024). Nahanni Butte community land use plan: Background report.

Polar Geospatial Center (PGC); Porter, C., Howat, I., Noh, M. J., Husby, E., Khuvis, S., Danish, E., Tomko, K., Gardiner, J., Negrete, A., Yadav, B., Klassen, J., Kelleher, C., Cloutier, M., Bakker, J., Enos, J., Arnold, G., Bauer, G., & Morin, P. (2023). *ArcticDEM—Mosaics*, Version 4.1. Harvard Dataverse. https://doi.org/10.7910/DVN/3VDC4W

Public Safety Canada. (2013, September 12). *Canadian disaster database*. https://cdd.publicsafety.gc.ca/dtpg-eng.aspx?cultureCode=en-Ca&eventTypes=%27FL%27%2C%27TO%27%2C%27WF%2527SW%27%2C%27EQ%27&normalizedCostYear=1&dynamic=false&eventId=1054

Riahi, K., van Vuuren, D. P., Kriegler, E., Edmonds, J., O'Neill, B. C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J. C., KC, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., … Tavoni, M. (2017). *The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: An overview*. Global Environmental Change, 42, 153–168. https://doi.org/10.1016/j.gloenvcha.2016.05.009

Shen, H., Tolson, B. A., & Mai, J. (2022). *Time to update the split-sample approach in Hydrological Model calibration*. Water Resources Research, 58(3). https://doi.org/10.1029/2021wr031523

Sobie, S. R., Ouali, D., Curry, C. L., & Zwiers, F. W. (2024). *Multivariate Canadian downscaled climate scenarios for CMIP6 (CanDCS-M6)*. Geoscience Data Journal, 11, 806–824. https://doi.org/10.1002/gdj3.257

Sub-Arctic Surveys Ltd. (2012). *High water mark—Nahanni Butte, NWT*. Report prepared for Government of the Northwest Territories, Municipal and Community Affairs.

Understanding shared socio-economic pathways (ssps). ClimateData.ca. (2025, February 28). https://climatedata.ca/resource/understanding-shared-socio-economic-pathways-ssps/

U.S. Army Corps of Engineers, Hydrologic Engineering Center. (n.d.). HEC-RAS. https://www.hec.usace.army.mil/software/hec-ras/