

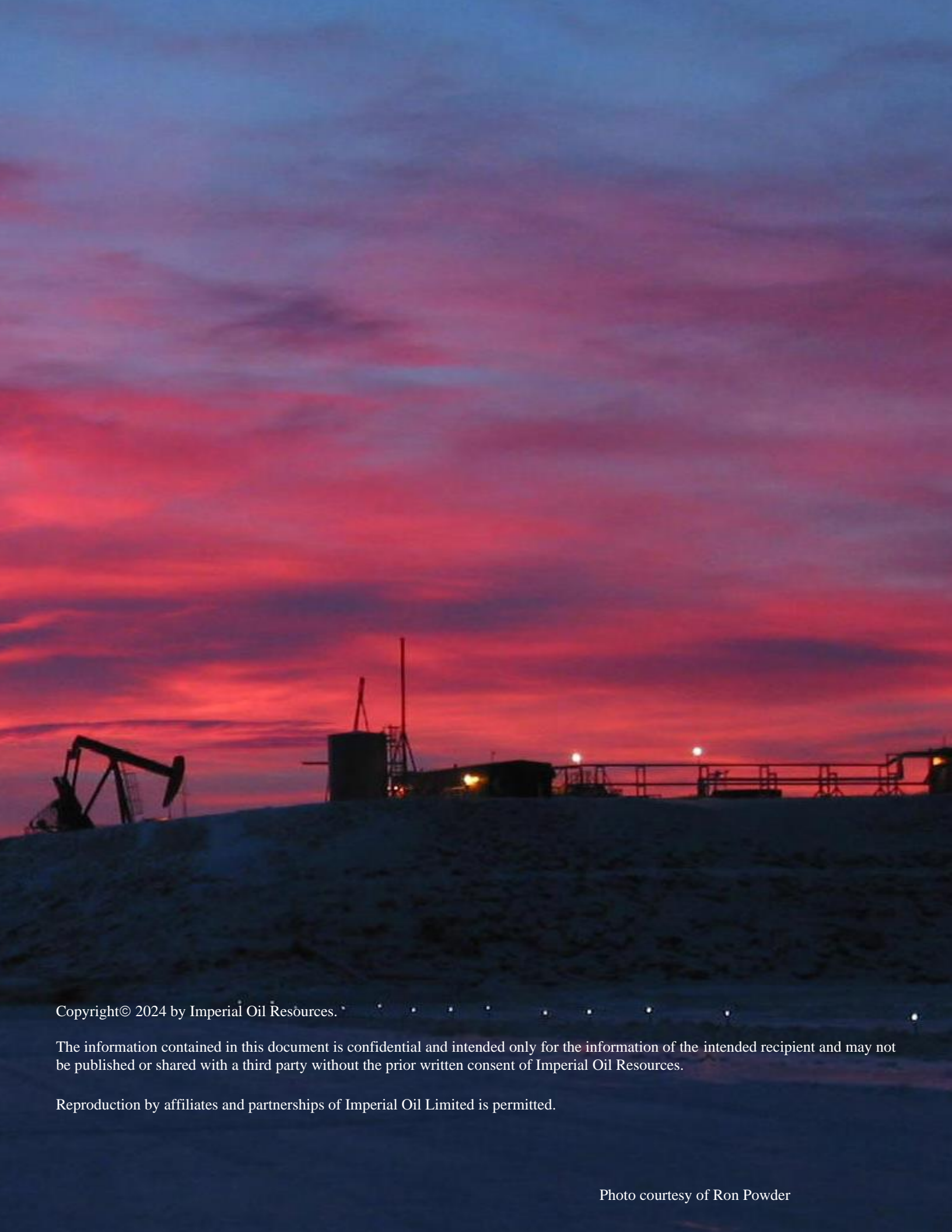


Norman Wells Operations Annual Flowline Integrity and Break-Up Report

January 2024

Imperial Oil Resources N.W.T. Limited
Bag 5000, 1001 Canol Drive
Norman Wells, Northwest Territories
X0E 0V0, Canada

Switch Board: (867) 587-3100



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ACRONYMS

BIT	Bear Island Terminal
cm	Centimeters
CER	Canada Energy Regulator
CIRNAC	Crown Indigenous Relations and Northern Affairs Canada
CPF	Central Processing Facility
DoC	Depth of cover
GIT	Goose Island Terminal
GPS	Global Positioning System
ILI	In-Line Inspection
IMU	Inertial mapping unit
IOR	Imperial Oil Resources
LT	Land Terminal
m³	meters cubed
m	Meters
masl	meters above sea level
MFL	Magnetic flux leakage
N/A	Not applicable
NDE	Non-destructive evaluation
NWO	Norman Wells Operations
PM	Preventative Maintenance
RTK	Real Time Kinematic
SLWB	Sahtu Land and Water Board
SSSV	Subsurface Safety Valves
TRS Advisian	Tłegóhł Reclamation Services Advisian

1 INTRODUCTION

Imperial Oil Resources N.W.T. Limited (Imperial) is required by the Sahtu Land and Water Board (SLWB) Water Licence S13L1-007 (Schedule 5, Item 1) and Canada Energy Regulator (CER) Operations Authorization OA1210-001 to annually submit a Flowline Integrity and Break-Up Report no later than October 31st of the year being reported.

Imperial advised the CER and the SLWB that submission of the 2023 report would be delayed for a number of reasons. The 2023 bathymetric survey was postponed from July 2023 to September 2023 due to wildfire impacts and poor air quality conditions on-site. This delayed Imperial's receipt of the bathymetric survey results and accompanying report from Arcadis.

Details on the Licence requirements for this report and the corresponding sections within the report can be found in the following concordance table.

Licence Requirement		Section of Report
a)	The results and inspections of the physical condition of each Artificial and Natural Island, including channel erosion, island scour holes and erosion, flowline landfalls, the condition of rip rap and the following information:	Sections 4 & 5
	i. Locations, depth, and volume of channel scour in the vicinity of any Flowline(s)	Section 4
	ii. Locations and magnitude of Artificial Island slope erosion	Section 5
	iii. Locations and severity of Artificial Island rip rap disturbance	Section 5
	iv. Structural integrity of the Artificial Islands, and other related structures	Section 5
	v. Structural integrity of the Natural Islands where it is applicable to project activities	Section 5
b)	The dates and results of Flowline(s) and fuel storage tank integrity tests	Section 6
c)	Details on necessary repair and maintenance work along with a schedule for completing such work prior to the following spring Mackenzie River Break-Up period.	Section 4 & 5

2 2023 BREAK-UP SUMMARY

As required by Water Licence S13L1-007, Imperial shall undertake any necessary annual maintenance required to preserve the structural integrity of the islands (Part F, Item 2). Imperial inspects the riverbeds, channels, and banks of the Mackenzie River in the vicinity of the flowline(s). To determine structural integrity of the islands, Imperial conducts an annual artificial island inspection. The results of these surveys are included in this report.

The average water level during the Mackenzie River break-up at Norman Wells is approximately 9 m (44.5 masl) and typically occurs between May 10th and May 15th. In 2023, break-up occurred on May 12th.

2.1 Annual Inspections

This year's bathymetric survey was completed in September 2023. The survey was originally scheduled for July 2023. However, due to wildfire impacts and poor air quality conditions on-site, the survey was postponed to September. The results of this survey are summarized in Section 4 of this report and Appendix A.

The annual artificial island inspection was performed in August 2023 and is summarized in Section 5.

3 BREAK-UP PREPARATION

Prior to each year's Mackenzie River break-up, a number of essential tasks must be completed. The key items are listed below.

- Spot heavy equipment on Bear and Goose Island
- Service equipment (e.g. compressors, operator trucks, etc.)
- Plug wells (e.g. wireline activity)
- Verify bunker lids and water intake hatch are secured and protected from ice flow
- Install and function test sub surface safety valves (SSSVs)
- Ensure adequate supply of chemical, fuel and potable water on island locations
- Remove equipment from low lying areas
- Inspect Bear Island purge equipment and review purge plan
- Finalize helicopter plans in preparation for ice road closure
- Execute weekly ice profiles
- Close ice road to equipment
- Remove ice road signage
- Monitor river levels and upstream break up conditions

4 2023 BATHYMETRIC SURVEY

The annual bathymetric survey was performed in September 2023 by Arcadis. The purpose of the survey is to:

- Determine the amount of instream cover over Imperial’s eight cross river flowline bundles located in the bed of the Mackenzie River.
- Monitor the riverbed immediately adjacent to eight cross river flowline bundles enabling interception of scour hole movement towards flowline bundles.
- Monitor the riverbed at the base of the six artificial islands and Bear and Goose causeways for possible erosion or scouring.
- Monitor the build-up or movement of the sandbars over the flowline bundles.
- Identify any changes in the shape and elevation of the riverbed in the areas adjacent to the islands, causeways, and docks.

In addition to the standard bathymetric survey scope of work in 2023, Arcadis resurveyed the flowline bundle elevations, enabling the display of flowline and riverbed elevations in the current geodic datum.

Information on the methodology and equipment used for the Norman Wells bathymetric survey scope can be found in Section 2 of the 2023 Norman Wells Bathymetric Survey Report (Appendix A), prepared by Arcadis.

4.1 Bathymetric Survey Results

The scope of work for the annual bathymetric survey is to measure the elevation of the river bottom for the entire length of each cross-river flowline corridor and compare to the measured elevations of the flowlines to determine the depth of cover along the entire channel.

The 2023 cross-river flowline bundle survey results can be found in Section 4.4 of Appendix A. The bathymetric survey drawings for each flowline corridor are found in Appendix B of the bathymetric report (Appendix A). The list of flowline corridors and the corresponding bathymetric survey drawing is provided in Table A below.

Table A: List of Flowlines and Associated Bathymetric Survey Drawings

Drawing Number	Drawing Title
Figure B1	Key Plan
Figure B2	Mainland to Island 1 Pipeline Bundle – Plan and Profile
Figure B3	Mainland to Island 2 Pipeline Bundle – Plan and Profile
Figure B4	Mainland to Island 3 Pipeline Bundle – Plan and Profile
Figure B5	Goose Island to Island 3 Pipeline Bundle – Plan and Profile
Figure B6	Goose Island to Island 4 Pipeline Bundle – Plan and Profile
Figure B7	Bear Island to Island 5 Pipeline Bundle – Plan and Profile
Figure B8	Bear Island to Island 6 Pipeline Bundle – Plan and Profile
Figure B9	Goose Island to Bear Island Pipeline Bundle – Plan and Profile

The corridors are managed on a case-by-case basis based on historical fluctuation and future projections of potential scour. Cover material is intended to:

- 1) Provide protection against physical impact, and
- 2) Provide protection against failure modes due to pipeline free span (e.g. vortex induced vibration, bending).

The primary intent of the bathymetric survey is to verify that flowline bundles are not exposed (i.e. depth of cover remains > 0m), such that the risks outlined above are reduced to the extent possible. Areas which show relatively low cover (< 1.0m) or significant increases or decreases in cover between surveys are flagged for review on an annual basis as locations to be monitored.

A summary of the depth of cover measured in 2023 is shown below in Table B for each cross-river bundle.

In cases where exposure or near-exposure of the bundle is confirmed, appropriate remedial action is triggered. Remedial action typically consists of deposition of armoring rock on the pipeline corridor. This armoring rock is sized to be stable during anticipated river flow rates and is not expected to be subject to scour. If armoring material is confirmed to be in place, the flowline corridor underneath it is considered to be protected from the risks described above. Following the placement of armoring, the corridor will continue to be surveyed annually to monitor for any further changes to the riverbed.

4.2 Summary of Depth of Cover Readings

Section 4.4 of the bathymetric report (Appendix A) sets out the depth of cover survey findings for all flowline corridors surveyed as listed in Table A above. Table B below summarizes the depth of cover measurements for the flowline corridors identified for closer monitoring due to possessing less than one meter of cover.

In 2023, Imperial retained a new contractor (Arcadis) for its bathymetric survey work. This enabled additional data to be captured during the survey including the depth of cover on land as well as the pipeline elevation underneath the riverbed. This allowed the flowline profiles, which infer depth of cover, to be updated from the historical construction profile elevations. As a part of the survey work, Arcadis also ensured that the entire extent of the channel was surveyed, to record the riverbed and pipeline elevations. This approach provided complete coverage of each crossing. Table B lists any locations where depth of cover along the entire corridor, including the inland and channel portions, were found to be less than one meter. The location of a section with low cover is included in the table in the furthest right column to denote whether the reading was found inland or within the river channel.

The pipeline elevation data was an important additional data set collected during the 2023 survey. It allowed the pipe elevation and riverbed to be compared in the modern NAD83 geodic datum and when this was done, it was observed that the pipeline elevation was higher than shown on previous bathymetric surveys. This updated survey data has resulted in a decrease in the depth of cover measure during the 2023 survey when compared to recent years. The updated pipeline elevation data was the main source of decreases in depth of cover observed across the asset rather than changes in the river morphology due to scouring and sediment loss. Flowline elevations will be resurveyed in 2024 to reconfirm pipeline flowline depth.

Table B: 2023 Bathymetric Survey Depth of Cover Summary

Figure	Pipeline Alignment	Minimum DoC (m)	Minimum DoC Station (m)	DoC < 1m Station Start (m)	DoC < 1m Station End (m)	Location
B2	Mainland to Island 1	0.00	0+000	0+000	0+002.5	Island 1
		0.11	0+237	0+215	0+290	Channel
		0.45	0+358	0+335	0+375	Channel
		0.71	0+605	0+590	0+630	Channel
B3	Mainland to Island 2	0.00	0+000	0+000	0+002.5	Island 2
		0.77	0+134.5	0+125	0+140	Channel
		0.21	0+307	0+210	0+370	Channel
		0.09	0+617	0+450	0+700	Channel
		0.67	0+800.3	0+760	0+810	Channel
B4	Mainland to Island 3	1.00	0+925	0+910	0+930	Channel
		0.00	0+000	0+000	0+002.5	Island 3
		0.84	0+166	0+155	0+170	Channel
		0.60	0+824	0+810	0+835	Channel
B5	Goose Island to Island 3	0.78	0+947	0+940	0+955	Channel
		0.00	0+000	0+000	0+002.5	Goose Island
		0.26	0+075	0+040	0+270	Goose Island
B6	Goose Island to Island 4	0.65	0+659	0+640	0+665	Channel
		0.00	0+000	0+000	0+620	Goose Island
B7	Bear Island to Island 5	0.77	1+330	1+325	1+345	Channel
		0.60	0+384	0+340	0+400	Channel
B8	Bear Island to Island 6	0.88	0+805	0+795	0+810	Channel
		0.43	0+007.5	0+007.5	0+045	Bear Island
B9	Bear Island to Goose Island	1.30	0+486			Channel
		0.67	0+250	0+170	0+260	Bear Island
		-0.80	1+105	1+060	1+140	Channel
		0.89	1+858	1+820	1+920	Goose Island
		0.80	2+102	2+080	2+180	Goose Island

To compliment the bathymetric survey, Arcadis also developed a hydrodynamic model for the Mackenzie River to estimate river flows and predict potential future scour along each flowline corridor to help inform flowline integrity risk. The hydrodynamic model summary report can be found in Appendix B, titled “Depth of Cover Assessment”. Based on the results of the bathymetric survey and the hydrodynamic model, Imperial is able to provide the following summary for each crossing below:

4.2.1 Island 1 to Mainland

The bathymetric survey found that the flowlines between Island 1 and the Mainland were buried below the channel bottom. The corridor was found to possess a minimum depth of cover of 0.11m at Station 0+237m and 0.45m at Station 0+358. While no major changes to the riverbed morphology were observed, this depth of cover is less than reported in previous years due to the pipeline elevation profile being updated in 2023 and being found to be higher than shown on previous bathymetric surveys. Comparison of the riverbed bathymetric data in the location of low depth of cover shows the riverbed has not changed appreciably in the locations of the low cover since 2005.

Due to the low amount of cover present at Station 0+237 and 0+358, Imperial is currently planning to armor the flowline corridor in this location to increase the pipeline cover. Going forward Imperial will continue to monitor the depth of cover through the annual bathymetric survey. Once the armoring has been installed, Imperial will update the hydrodynamic model utilizing the results of future bathymetric surveys to reflect the new riverbed morphology to assess the future scour potential of the corridor. This revised scour profile will then be utilized to inform Imperial’s management of the crossing going forward.

4.2.2 Island 2 to Mainland

The bathymetric survey found that the flowlines between Island 2 and the Mainland were buried below the channel bottom. The corridor crossing was found to possess a minimum of 0.09m of cover at Station 0+617m. Additionally depth of cover was less than 1m between Stations 0+210m and 0+370m with a minimum depth of cover of 0.2m in this location.

While no major changes to the riverbed morphology were observed, the depth of cover found was less than reported in previous years due to the pipeline elevation profile being updated in 2023 and being found to be higher than shown on previous bathymetric surveys. Evaluation of the historical riverbed surveys has shown the region between 0+210m and 0+370m has changed negligibly between 2005 and 2023, while the riverbed at 0+617m has remained consistent since 2014 when a small fluctuation

occurred but apart from that fluctuation it has also stayed relatively consistent since 2005 as well.

Due to the low amount of cover present at Station 0+617m and between 0+210m and 0+370m, Imperial is currently pursuing armoring of the flowline corridor in this location to increase the pipeline cover. Going forward Imperial will continue to monitor the depth of cover through the annual bathymetric survey. Once the armoring has been installed, Imperial will update the hydrodynamic model utilizing the results of future bathymetric surveys to reflect the new riverbed morphology to assess the future scour potential of the corridor. This revised scour profile will then be utilized to inform Imperial's management of the crossing going forward.

4.2.3 Mainland to Island 3

The 2023 bathymetric survey found the flowlines between the Mainland and Island 3 were buried below the channel bottom. The minimum depth of cover identified by the survey along the Mainland to Island 3 corridor was 0.6m at Station 0+824m. Similar to other crossings, the reported depth of cover is less than reported in previous surveys due largely to the updated pipeline elevation data captured in 2023.

The hydrodynamic model predicted scour estimates for the Mainland to Island 3 crossing and indicated that due to high variability in the historic sediment data a wide range of scour outcomes may occur. While in the Type 1 (most erodible) sediment scenario, the pipeline may be exposed in a 2-year flood event, in the Type 2 (least erodible) sediment scenario, the pipeline would remain buried even during a 100-year flood.

Evaluation of the riverbed morphology from previous bathymetric surveys dating back to 2005, has shown the riverbed morphology between Island 3 and the Mainland to be relatively consistent, indicating that the sediment near the crossing may be closer to the Type 2 scenario modeled. Based on the results of the bathymetric survey and hydrodynamic model, Imperial plans to perform a risk assessment on this crossing, accounting for the uncertainty in sediment size to identify if additional mitigative measures may be required. In 2024, sediment sampling will be incorporated into the bathymetric survey scope to refine the crossings scour potential.

4.2.4 Goose Island to Island 3

The 2023 bathymetric survey found the flowlines between Goose and Island 3 were buried below the channel bottom. The minimum depth of cover noted between Goose to Island 3 was 0.6m at Station 0+662m. Similar to other crossings, the reported depth

of cover is less than reported in previous surveys due largely to the updated pipeline elevation data capture in 2023.

In 2015, Imperial placed armoring from Station 0+530m to 0+690m. Given the area of low cover at Station 0+662m is underneath a location previously armored by Imperial, the potential for future scouring is considered low and the location will be monitored during future inspections for any changes.

In addition to the area of low cover, a scour hole was observed to be forming near Station 1+125 m to 1+145. Depth of cover at this location was found to be 1.2m, however, based on the hydrodynamic model results it was predicted that in the event of a 10-year flood the corridor may become exposed at this location. Based on this data Imperial will be conducting a risk assessment to determine a mitigation and monitoring plan for the corridor.

4.2.5 Goose Island to Island 4

The 2023 bathymetric survey found the flowlines between the Goose and Island 4 were buried below the channel bottom. The minimum depth of cover noted between Goose to Island 4 was 0.77m at Station 1+330m. Similar to other crossings, the reported depth of cover is less than reported in previous surveys which was mainly due to the updated pipeline elevation data. The development of a scour hole was noted in the location of low cover near Station 1+340. The area is a location previously armored by Imperial and so minimal change in depth of cover is expected in the future and this location will be inspected annually to monitor for any changes.

The hydrodynamic model output for the Goose to Island 4 crossing projected a range of possible scour outcomes given the variation in historical sediment data collected. While in the more Type 1 sediment case, the flowlines may become exposed near the edge of the armoring at Station 1+400 in a 50-year flood, the remainder of the crossing will remain covered in flooding scenarios up to a 100-year event. In the Type 2 sediment case, the flowlines would remain covered in a 100-year event.

Evaluation of the historic riverbed profiles for this corridor shows that the crossing has remained relatively consistent since 2005 indicating that the sediment near the corridor may be more reflected by the Type 2 case. Based on the results of the bathymetric survey and hydrodynamic model, Imperial plans to perform a risk assessment on this crossing, accounting for the uncertainty in sediment size to identify if any additional mitigative measures may be required. In 2024, sediment samples will be incorporated in the bathymetric survey scope to refine the crossings scour potential.

4.2.6 Bear to Island 5

The 2023 bathymetric survey found the flowlines between Bear and Island 5 were buried below the channel bottom. The minimum depth of cover noted between Bear and Island 5 was 0.6m at Station 0+385m. Similar to other crossings, the reported depth of cover is less than reported in previous surveys mainly due to the updated pipeline elevation data.

The historical sediment data taken near the Bear to Island 5 corridor demonstrated consistent sediment sizes resulting in minimal uncertainty in the sediment size utilized in the model resulting in identical Type 1 and Type 2 scour projections. These projections are supported by the historical river bottom profiles captured in previous surveys which display minimal fluctuations dating back to 2005. As a result, the corridor is not considered to be at risk of exposure as it will remain covered in up to a 200-year flood event, but will continue to be monitored annually for any changes.

4.2.7 Bear to Island 6

The 2023 bathymetric survey found the flowlines between Bear and Island 6 were buried below the channel bottom. The minimum depth of cover noted between Bear and Island 6 was 1.6m between Stations 0+945 m and 0+960 m.

Historical sediment data indicated the sediment in this crossing was larger than the majority of the other crossings in the asset, but some variation in sediment size along the corridor was still observed. Sensitivity analysis of the sediment size indicated that in a Type 1 case, the pipeline may become exposed for a short length near Island 6 during a 50-year flood event, however, in the Type 2 sediment case the flowline remained submerged in all but a 10,000-year flood event. Based on the Type 2 sediment data point being sampled near the area of concern and the minimal variation observed in the river bottom in past surveys, the potential for the flowline to become exposed is low and the sediment data is likely closer to the Type 2 value.

Based on the results of the bathymetric survey and hydrodynamic model, Imperial plans to perform a risk assessment on this crossing, accounting for the uncertainty in sediment size to identify if any additional mitigative measures may be required. In 2024, sediment samples will be incorporated in the bathymetric survey scope to refine the crossings scour potential.

4.2.8 Bear to Goose Island

Similar to the results of the 2022 survey, suspended flowlines were observed between Bear to Goose Island. The flowlines within this corridor remain shut-in and purged,

since August 2022 as part of Imperial's response to the Line 490 failure (INC2022-122, NT-NU 2022382). At this time, Imperial has no plans to resume operation of this corridor and is currently working a plan to add additional cover to the suspended flowlines.

4.3 Planned Depth of Cover Repairs

Due to the low depth of cover identified within the Island 1 and 2 corridors, Imperial is currently assessing plans to add additional cover to each of these corridors where there is less than 0.6m of cover. Prior to completing the work, Imperial will submit all required regulatory notifications and applications to receive required approvals prior to execution.

Additional repairs in the future may be driven by the outcomes of Imperial's risk assessment process utilizing the outputs of the hydrodynamic model to develop monitoring and mitigation plans for each crossing.

5 ARTIFICIAL ISLAND PROTECTION ASSESSMENT AND MAINTENANCE

5.1 2023 Completed Repairs

Artificial island armoring repair work was successfully completed between March to April 2023 per recommendations provided by Wim M. Veldman Consulting and TRS Advisian, the contractors who completed 2022 artificial island inspection. Details of the repairs completed are described in the sections below.

5.1.1 Island 1

The inspection showed Island 1 to be in good condition; therefore, no repairs were required during the winter 2023 season.

5.1.2 Island 2

The inspection showed Island 2 to be in good condition; therefore, no repairs were required during the winter 2023 season.

5.1.3 Island 3

The armoring repair scope of work was completed in March 2023, which included the placement of riprap toe protection armour rock and the re-positioning of slipped concrete blocks along the NE corner of the island. Approximately 1300 m³ of Class E riprap was placed at the Island toe. The work was completed in advance of the 2023 Mackenzie River break-up to prevent additional slippage and erosion from advancing.

5.1.4 Island 4

The armoring repair scope of work was completed in April 2023, which included the placement of riprap toe protection armour rock and the re-positioning of slipped concrete blocks along the NE corner of the island. Approximately 100 m³ of Class E riprap was placed at the Island toe. The work was completed in advance of the 2023 Mackenzie River break-up to prevent additional slippage and erosion from advancing.

5.1.5 Island 5

The inspection showed Island 5 to be in good condition; therefore, no repairs were required during the winter 2023 season.

5.1.6 Island 6

The inspection showed Island 6 to be in good condition; therefore, no repairs were required during the winter 2023 season.

5.2 2024 Proposed Repairs

The 2023 Artificial Island inspection was completed in August by Wim M. Veldman Consulting and TRS Advisian. The 2023 recommendations put forth by the inspectors are summarized below. Based on the findings from the 2023 survey, there are no planned repairs scoped for 2024. The upcoming artificial island inspection is scheduled to be completed later this year in August 2024.

5.2.1 Island 1

The inspection showed Island 1 to be in good condition; therefore, no immediate repairs are required during the 2023/2024 winter period.

5.2.2 Island 2

The inspection showed Island 2 to be in good condition; therefore, no immediate repairs are required during the 2023/2024 winter period.

5.2.3 Island 3

The inspection showed Island 3 to be in good condition; therefore, no immediate repairs are required during the 2023/2024 winter period.

5.2.4 Island 4

The inspection showed Island 4 to be in good condition; therefore, no immediate repairs are required during the 2023/2024 winter period.

5.2.5 Island 5

The inspection showed Island 5 to be in good condition; therefore, no immediate repairs are required during the 2023/2024 winter period.

5.2.6 Island 6

The inspection showed Island 6 to be in good condition; therefore, no immediate repairs are required during the 2023/2024 winter period.

6 FLOWLINE AND FUEL STORAGE TANK INTEGRITY

The operational integrity of all critical equipment is stewarded through Imperial’s preventative maintenance program, which is derived from the OIMS Facility Integrity Management System (FIMS). FIMS is the system that identifies critical equipment and sets forth the required preventative maintenance programs and frequencies.

6.1 Fuel Storage Tank Integrity Inspections

Table C lists the fuel storage tanks on site, the type and frequency of inspection performed on each tank, along with the results.

Table C: 2023 Fuel Storage Tank Integrity Inspections Results

Tank Name	Type of Inspection	Results
Goose Island Diesel	5 Year External Visual	<ul style="list-style-type: none"> – Last inspection completed in 2020; no issues – Next inspection due in 2025
	10 Year External Visual and UT Survey	<ul style="list-style-type: none"> – New vessel installed in 2015. Baseline UT survey completed in 2015; no issues – Next inspection due in 2025
	1 Month External Visual	<ul style="list-style-type: none"> – Completed monthly; no issues
Goose Island Gas	5 Year External Visual	<ul style="list-style-type: none"> – Last completed in 2020; no issues – Next inspection due in 2025
	10 Year External Visual and UT Survey	<ul style="list-style-type: none"> – New vessel installed in 2015. Baseline UT survey completed in 2015; no issues – Next inspection due in 2025
	1 Month External Visual	<ul style="list-style-type: none"> – Completed monthly; no issues
Bear Island Gas	5 Year External Visual and UT Survey	<ul style="list-style-type: none"> – 2021 inspection completed; no issues – Next inspection due in 2026
	1 Month External Visual	<ul style="list-style-type: none"> – Completed monthly; no issues
Bear Island Diesel	5 Year External Visual and UT Survey	<ul style="list-style-type: none"> – New vessel installed in 2020 – Next inspection due in 2025
	1 Month External Visual	<ul style="list-style-type: none"> – Completed monthly; no issues
Mainland Diesel	5 Year External Visual	<ul style="list-style-type: none"> – New vessel installed in 2015 – Last inspection completed in 2020; no issues – Next inspection due in 2025
	10 Year External Visual and UT Survey	<ul style="list-style-type: none"> – New vessel installed in 2015. Baseline UT survey completed in 2015; no issues – Next inspection due in 2025
	1 Month External Visual	<ul style="list-style-type: none"> – Completed monthly; no issues
CPF T-103 Diesel	5 Year External Settlement	<ul style="list-style-type: none"> – External settlement inspection completed in 2022; no issues – Next inspection due in 2027
	5 Year External Visual	<ul style="list-style-type: none"> – Last completed in 2021; no issues – Next inspection due in 2026
	10 Year Internal	<ul style="list-style-type: none"> – Last completed in 2015; no issues

		<ul style="list-style-type: none"> - Next inspection due in 2025
T-104 Emergency Generator Diesel	5 Year External Visual	<ul style="list-style-type: none"> - Last completed in 2019; no issues - Next inspection due in 2024
	10 Year External UT	<ul style="list-style-type: none"> - Last completed 2017; no issues - Next inspection due in 2027
Mainland Heating Oil	1 Month External Visual	<ul style="list-style-type: none"> - Completed monthly; no issues.
CPF Heating Oil Double Wall Tank	1 Month External Visual	<ul style="list-style-type: none"> - New tank installed in 2018 - Completed monthly; no issues.
Warehouse Heating Oil Double Wall Tank	1 Month External Visual	<ul style="list-style-type: none"> - New tank installed in 2018 - Completed monthly; no issues.
Mud Plant Heating Oil Double Wall Tank	1 Month External Visual	<ul style="list-style-type: none"> - New tank installed in 2018 - Completed monthly; no issues.

6.2 Flowline Integrity

The Norman Wells flowline system includes the network of flowlines used to connect the mainland and cross-river operations to the Central Processing Facility (CPF). The cross-river flowlines are inspected using a combination of in-line inspection and non-destructive examination (NDE). Conservative assumptions coupled with an evaluation of inspection results are used to determine the inspections frequencies. Table D lists the planned flowline integrity (cross-river and land based) inspections that were completed in 2023, along with the inspection type for each of the flowlines, and the inspection results.

Table D: 2023 Flowline Integrity Inspections Results

Flowline	Route	Cross-river (Y/N)	Date	Scope	Type of repairs completed	Anomaly Description		Comments
60	Island 1 to LPT 1	Y	July 12, 2023	Inline Inspection (ILI) MFL, IMU, Caliper	No repairs completed in 2023	Depth and Length of anomaly	D: 40% w.t. L: 38 mm	The pipeline was inspected using Baker Hughes MFL (MFL+Caliper+IMU) Combo tool in July 2023. The deepest feature found was 40% w.t. external metal loss. The failure pressure was calculated as required by CSA-Z662 10.10.2.5.1 and 10.10.2.6 for this feature and found to be far above the line's Maximum Allowable Operating Pressure of 5100 kPa. Therefore, based on engineering judgement, the pipeline is fit for continued operation while a formal engineering assessment can be completed. The final Engineering Assessment for Line 60, which provides a more comprehensive understanding of the line's fitness for service over time, is in its final review before being issued.
						Position of anomaly (o'clock)	6:15	
						Distance from nearest girthweld (m)	0.129 m downstream to girthweld (GW) 200	
123	Island 4 to BIT 4	Y	August 18, 2023	Inline Inspection (ILI) MFL, IMU, Caliper	No repairs completed in 2023	Depth and Length of anomaly	D: 41% w.t. L: 23 mm	The pipeline was inspected using Baker Hughes MFL (MFL+Caliper+IMU) Combo tool in July 2023. The deepest feature found was 41% w.t. external metal loss. The failure pressure was calculated as required by CSA-Z662 10.10.2.5.1 and 10.10.2.6 for this feature and found to be far above the line's Maximum Allowable Operating Pressure of 5100 kPa. Therefore, based on engineering judgement, the pipeline is fit for continued operation while a formal engineering assessment can be completed. The final Engineering Assessment for Line 123, which provides a more comprehensive understanding of the line's fitness for service over time, is in its preparation.
						Position of anomaly (o'clock)	5:45	
						Distance from nearest girthweld (m)	Distance to Downstream girthweld (GW) 520: 13.444 m	
128	Island 5 to BIT 5	Y	August 16, 2023	Inline Inspection (ILI) MFL, IMU, Caliper	No repairs completed in 2023	Depth and Length of anomaly	D: 39% w.t. L: 31 mm	The pipeline was inspected by Baker Hughes using MFL (MFL+Caliper+IMU) Combo tool in July 2023. The deepest feature found was 39% w.t. external metal loss. The failure pressure was calculated as required by CSA-Z662 10.10.2.5.1 and 10.10.2.6 for this feature and found to be far above the line's Maximum Allowable Operating Pressure of 5100 kPa. Therefore, based on engineering judgement, the pipeline is fit for continued operation while a formal engineering assessment can be completed. The final Engineering Assessment for Line 128, which provides a more comprehensive understanding of the line's fitness for service over time, is in its preparation.
						Position of anomaly (o'clock)	12:30	
						Distance from nearest girthweld (m)	0.254 m downstream to girthweld (GW) 450	

87	Island 3 to Line 65/77	N	August 9, 2023 (First Investigative Dig),	NDE (Ultrasonic Testing (UT), Magnetic Particle Testing, Long Range UT Ground riser visual inspection.	Replacement of section of Line 87 with Line 87B	Depth of anomaly	Wall loss finding: 68% w.t.	Excavation and subsequent direct examination was used to identify and characterize corrosion features on Line 87. Site selection for this detailed examination was determined based on accessibility and to expand the understanding of Line 87's integrity. The dig was extended, and then another site was inspected. A ground riser visual inspection also performed.
88	Island 3 to Line 71/82	N	August 9, 2023	NDE (Ultrasonic Testing (UT), Magnetic Particle Testing, Long Range UT	No repairs	No significant internal or external corrosion found	Wall loss finding: 8.8% w.t.	Excavation and subsequent direct examination of approximately 2.5 m of exposed flowline was used to identify and characterize any corrosion features on Line 88. Site selection for this detailed examination was determined based on the limited excavation areas available on Island 3.
242	Line 235/239 to Island 3	N	August 9, 2023	NDE (Ultrasonic Testing (UT), Magnetic Particle Testing, Long Range UT	No repairs	No significant internal or external corrosion found	Wall loss finding: 5.3% w.t.	Excavation and subsequent direct examination of 1.45m of exposed flowline was used to identify and characterize any corrosion features on Line 242. Site selection for this detailed examination was determined based on the limited excavation areas available on Island 3.
527	Line 451 to Island 3	N	August 9, 2023	NDE (Ultrasonic Testing (UT), Magnetic Particle Testing, Long Range UT	No repairs	Minor external corrosion, general internal corrosion. Pipe has internal liner installed.	Wall loss finding: 30% w.t	Excavation and subsequent direct examination of 3.7m of exposed flowline was used to identify and characterize any corrosion features on Line 527. It is important to note that this line had a liner installed and corrosion is not expected to progress. Site selection for this detailed examination was determined based on the limited excavation areas available on Island 3.
263	GIT 4 to BIT 4	Y (Riser section on land)	October 19, 2023	Ground Riser Inspection: Visual, Holiday testing	No repairs	No significant findings.	N/A	(BIT 4 Riser) Excavation to expose riser, external coating determined to be in good condition, Holiday testing performed with no damage found.
270	BIT 4 to Island 5	Y (Riser section on land)	September 25, 2023 October 19, 2023	Ground Riser Inspection: Visual, Holiday testing	Removed coating defect, inspected bare pipe, minimal surface corrosion, repaired coating defect,	Small defect found on Yellow Jacket section of riser	N/A	(BIT 4 and ISL5 Risers) Excavation to expose riser, external coating determined to be in good condition, two small defects found on Island 5 side, bare pipe inspected and cleaned, coating repaired, Holiday testing performed.

					installed new outer wrap.			
273	BIT 4 to Island 6	Y (Riser section on land)	September 25, 2023 October 19, 2023	Ground Riser Inspection: Visual, Holiday testing	No repairs required	No significant findings.	N/A	(BIT4 and ISL6 Risers) Excavation to expose riser, external coating determined to be in good condition, Holiday testing performed with no damage found.
504/ 511	BIT 4 to Island 5	Y (Riser section on land)	September 25, 2023 October 19, 2023	Ground Riser Inspection: Visual	No repairs required	No significant findings.	N/A	(BIT 4 and ISL5 Risers) Excavation to expose riser, external coating determined to be in good condition.
509/ 510	BIT 4 to Island 6	Y (Riser section on land)	September 25, 2023 October 19, 2023	Ground Riser Inspection: Visual	No repairs required	No significant findings.	N/A	(BIT4 and ISL6 Risers) Excavation to expose riser, external coating determined to be in good condition.

7 LIST OF APPENDICES

Appendix A: 2023 Norman Wells Bathymetric Survey Report (Arcadis)

Appendix B: 2023 Norman Wells Hydrodynamic Model Report – Depth of Cover Assessment (Arcadis)

SUBJECT
IOL Norman Wells 2023 Mackenzie River
Pipeline Depth of Cover and Bathymetric Survey

TO
Kyle Newman, Imperial Oil

DATE
November 20, 2023
Revised November 28, 2023

OUR REF
30180401

COPIES TO
Natalie Arnold, Imperial Oil
Godson Gummadi, Arcadis

NAME
Aaron Dayton, Arcadis
Chris Akelaitis, Arcadis
Timothy Webb-Horvath, Arcadis

1.0 Introduction

Arcadis staff completed a program to survey the Mackenzie River channel bottom, upland areas, and pipeline depth of cover, within and adjacent to the Right-of-Ways (RoW) of the Imperial Oil Limited (IOL) pipeline bundles where they cross the Mackenzie River near the town of Norman Wells, Northwest Territories (NWT). The scope of work was completed between September 5 and September 12, 2023 to collect updated channel bottom bathymetry and to identify whether any of the pipelines were exposed or suspended along the channel bottom of the river. The reach of the Mackenzie River visited, including the surveyed pipeline RoW alignments (shown in pink), is shown on **Figure 1**.

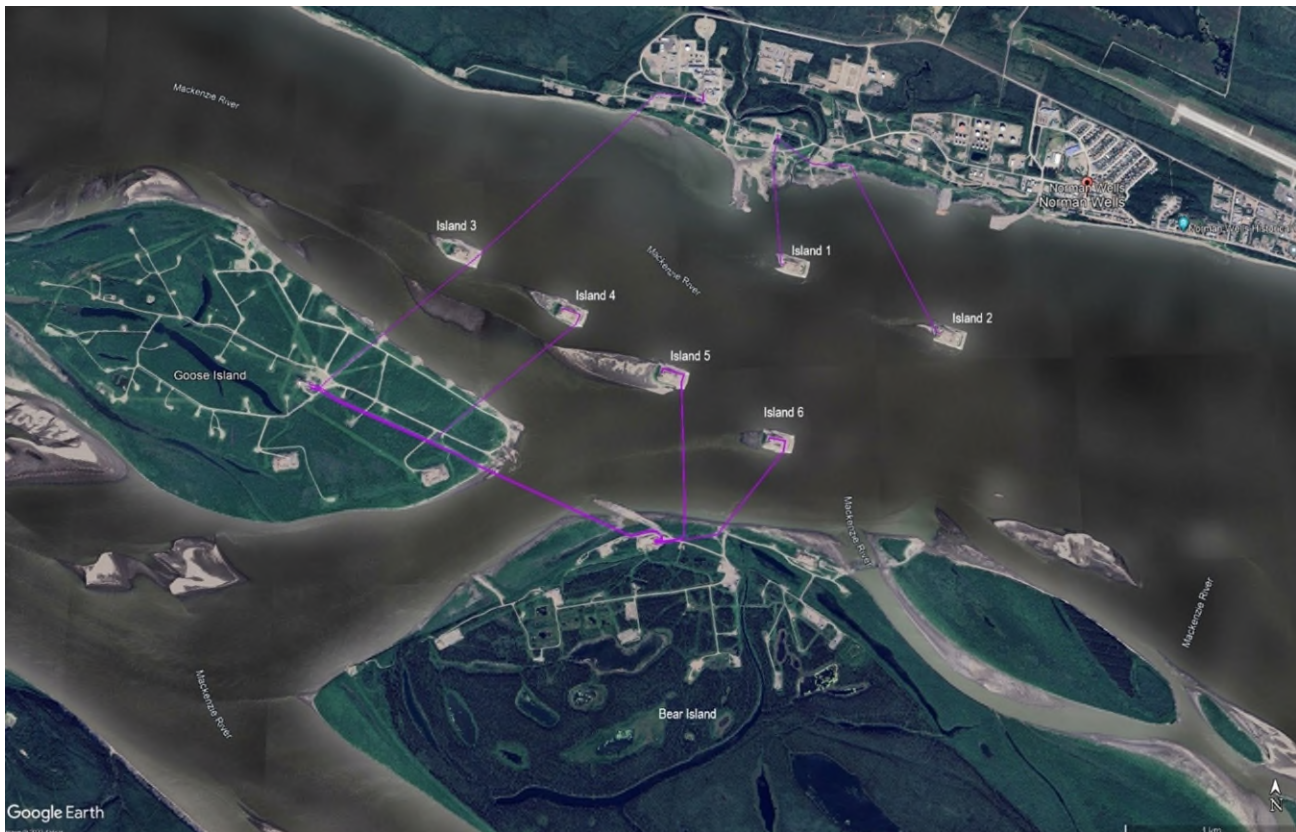


Figure 1: Mackenzie River and IOL pipeline RoW alignments

2.0 Methodology and Equipment

The survey work completed in 2023 included:

- Discrete ground survey was completed at points within the pipeline RoW approximately every 50 linear meters in upland areas using a global navigation satellite system (GNSS) global positioning system (GPS) base station with rover units.
- Discrete survey of pipeline depth of cover measurements were recorded at points in both upland areas and across the wetted width of the channel. Pipeline depth of cover data were collected approximately every 50 to 100 linear meters using the GNSS GPS based rover units and electromagnetic line locating equipment.
- Detailed bathymetric survey of the channel bottom was completed using a multi-beam sonar survey system.

2.1 Survey Datums

2.1.1 Horizontal Datum

The North American Datum of 1983 (NAD83) Canadian Spatial Reference System (CSRS) was used as the horizontal datum for the ground, pipeline, and bathymetric surveys completed in 2023. The site is located in the Universal Transverse Mercator Grid Zone 9N.

2.1.2 Vertical Datum

The Canadian Geodetic Vertical Datum of 2013 (CGVD2013) and the Canadian Gravimetric Geoid model of 2013 – Version A (CGG2013a) was applied during the 2023 survey activities.

2.3 Base Station Set-Up and Equipment

A base station was installed on the Norman Wells mainland side of the channel to relay real time kinematic (RTK) corrected GPS coordinate observations to the R12i receivers used as rovers during the collection of ground survey points, pipeline depth of cover survey points, and for use in correcting the bathymetric survey data.

The base station comprised a Trimble R12i GNSS receiver mounted on a tri-pod installed directly over-top of a nail that was driven 150 millimeters (mm) into the ground with the top of the nail flush with the surrounding ground surface. The height of the base station above the nail was measured daily and input directly into the Trimble TSC-7 data loggers prior to the start of the daily survey data collection activities. The base station was operated daily during all periods when ground, pipeline, and bathymetric survey activities were occurring.

At the end of each day, the base station files were downloaded and submitted to the CSRS Precise Point Positioning (PPP) group to obtain the corrected location of the installed base station control point. The weighted mean of the base station control point from all of the data logged by the base station each day was determined to be located at:

- Northing = 7241613.18 meters (m);
- Easting = 599648.32 m; and
- Elevation (Geodetic) = 51.36 m.

During the subsequent survey days, the base station was installed directly over-top of the control point and the control points coordinates and elevation were entered into the TSC 7 data loggers along with the height of the base station above the control point (nail head). This allowed for RTK-corrected GPS coordinates to be relayed to the rover units. Prior to the daily set-up of the base station, the control point was inspected for signs of instability or movement that were not identified over the duration of the field program.

The locations of the installed base station and control point are shown on **Figures 2** through **4**.

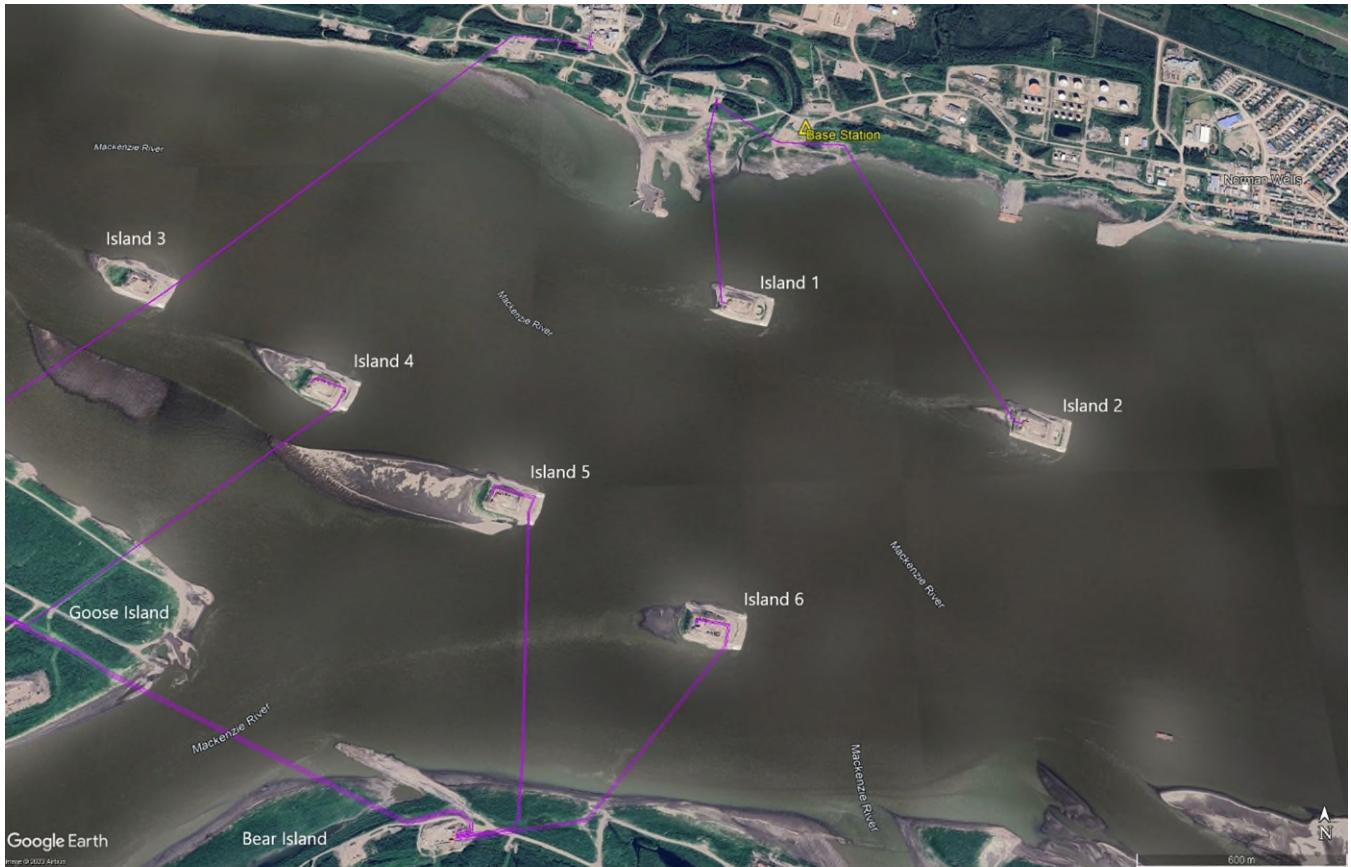


Figure 2: Base station location installed during 2023 survey activities



Figure 3: Base station with antennae installed during 2023 survey activities



Figure 4: Installed base station control point (nail head)

2.4 Ground Survey Equipment and Methodology

Trimble R12i GNSS rover units with TSC-7 data collectors were used to collect the coordinates and elevations of all surveyed ground points as well as the locations and elevations of the electromagnetic line locating equipment where pipeline depth of cover (DoC) data points were surveyed.

The rover units were connected to the installed base station to allow for RTK-corrected GPS coordinate observations to be recorded by the rover units during the collection of ground and pipeline depth of cover survey points.

As part of the 2023 survey activities, a control point was set at the top of a bolt at the bunker located near the IOL dock. The control point is located at:

- Northing = 7241255.19 m;
- Easting = 599110.884 m; and
- Elevation (Geodetic) = 43.437 m.



Figure 5: Survey control point (yellow) bolt near IOL dock

The control point was surveyed daily using the Trimble rover units as a quality control point to check the accuracy of the survey results. Based on the daily control point survey, the accuracy of the control point between survey days ranged between:

- Northing control point accuracy range +/- 16.56 mm;
- Easting control point accuracy range +/- 42.10 mm; and
- Vertical control point accuracy range +/- 8.64 mm.

2.5 Bathymetric Survey Equipment and Methodology

A Seafloor Systems Echoboat 160 was used to complete the bathymetric survey. The Echoboat 160 was equipped with a SeaRay INS sonar system. The position of the Echoboat 160 was obtained using two onboard Trimble GNSS receivers and was corrected using Post-Processed Kinematic (PPK). The heave, pitch, and roll of the Echoboat was corrected for via the redundant onboard Internal Motion Units (IMU). An AML sound velocity profiler was used to record the speed of sound throughout the water column to apply a sound velocity correction. A patch test was obtained to calibrate to the specific configuration between the GNSS receivers, the IMU, and the SeaRay INS. Based on the system used to collect the bathymetric data, the following accuracy can be expected:

- Position:
 - Horizontal: +/- (8mm +1ppm X Distance from PPK Station)
 - Vertical: +/- (15mm +1ppm X Distance from PPK Station)
 - (Assumes 1m GNSS Separation).
- Heading Accuracy:
 - 0.08° (PPK) with 2m Antenna Separation.
- Pitch/Roll Accuracy:
 - 0.03° Independent of Antenna Separation.
- Heave Accuracy: 5 centimeters (cm) or 5% (Real Time).

The Echoboat 160 was operated by towing behind a support boat across the channel to measure and record the channel bathymetry. The Echoboat 160 and support boat and operation are shown on **Figures 6** through **8**.



Figure 6: Echoboat 160 set-up



Figure 7: IOL supplied and operated survey support boat



Figure 8: IOL support boat towing the Echoboat 160 between Goose Island and Bear Island

2.6 Pipeline Electromagnetic Line Locating Equipment and Methodology

Radiodetection RD8200 electromagnetic (EM) line locators were used to locate the pipelines and to measure the depth of cover on top of each pipeline bundle. Radiodetection TX-10 transmitters were direct connected to the pipeline bundles by direct connection to piping to induce a current on the line that could then be detected by the line locating equipment. The line locators were operated in both cathodic protection signal (CPS) mode and by tracing the direct connection signal input onto the line. Given the small separation between the pipelines within each bundle and that the pipelines within each bundle appear to be cathodically bonded, it was not possible to identify and measure the DoC of each individual pipeline within each bundle. As a result, the pipeline depth of cover measurements are considered to be representative of the shallowest pipeline within each bundle. Pipeline DoC measurements were collected approximately every 50 linear meters along each pipeline bundle.

On ground, pipeline locations and DoC measurements were collected by locating the minimum depth of cover point reported by the line locator. When identified, the tip of the line locator was placed directly on the ground surface to measure the minimum DoC. The minimum DoC was then entered into the Trimble data collector and the GPS location surveyed with the rover.

In water, the DoC measurements were recorded using a non-metallic zodiac boat operated by IOL staff. The zodiac travelled upstream until the minimum pipeline DoC was identified and then held steady over that point while the DoC measurement was entered into the data collector and then the location surveyed. The bottom of the survey pole and tip of the line locator were coincidentally located at the floor of the zodiac. No metallic boats were used during the collection of the DoC points in the channel to avoid interference of the EM line locator with the metallic boat.

At the time of the pipeline DoC survey, an open excavation was observed near the northeast corner of Island 3 where the Mainland to Island 3 pipeline bundles were exposed. To confirm the accuracy of the line locating equipment, the elevation of the top of the highest pipeline observed in the excavation was surveyed. Pipeline DoC measurements were then collected using the line locator in CPS mode and in direct connection mode immediately adjacent to the east excavation wall. **Table 1** summarizes the results of the line locating accuracy check.

Table 1: 2023 Mainland to Island 3 Line Locating Accuracy Quality Control Check

Pipeline	Surveyed Top of Pipe Elevation (m)	Surveyed Ground Elevation at Line Locating Measurement Location (m)	CPS Derived Top of Pipe Elevation (m)	Direct Connection Derived Top of Pipe Elevation (m)
Exposed pipeline at northeast corner of Island 3	51.408	53.1	50.711	51.166

Radio detection technical manuals specify the DoC accuracy of the RD8200 line locating equipment as approximately +/- 5% of the measurement depth. Based on the above measurements, the depth of the pipeline would be approximately 1.7 m below the ground level at the location of the DoC measurements.

Based on the above measurements, the direct connection provided a more accurate results (+/- 15% of the depth) compared to the CPS measurements (+/- 40 % of depth) and direct connection was thus used to measure pipeline DoC where available and possible. It is noted that other infrastructure including metallic pump jacks, well covers, buildings and powerlines and cables are present in close proximity to the open pipe excavation on Island 3 where the DoC accuracy assessment was completed. This infrastructure will interfere with the EM based line locating equipment and thus the +/- 40% accuracy of the line locator in CPS mode and +/- 15% by direct connection at this location, are considered to be the upper limits of the accuracy of the DoC measurements reported by the line locating equipment. In areas situated away from the pipeline and oil production facilities such as within the Mackenzie River channel where there is minimal infrastructure other than the pipelines to interfere with the EM line locating equipment, the accuracy of the line locating equipment is considered to typically range between 5% of the depth when measurements are completed on land and 15% of the depth when measurements are taken from a boat on moving water.

3.0 Site Conditions

Weather conditions in Norman Wells, NWT at the time of the survey activities between September 5 and September 12, 2023 were sunny to partly cloudy with no precipitation and temperatures ranging from lows of -1 degree Celsius to highs of 23.9 degrees Celsius. Winds were typically light with maximum gusts of up to 37 kilometers per hour on September 9, 2023.

Water levels and flow conditions were low and generally calm during the data collection activities. Discharge measured at the Environment and Climate Change Canada (ECCC) gauge 10KA001 Mackenzie River at Norman Wells, located on Island 2, ranged from 7,950 cubic meters per second (m³/s) to 7,400 m³/s (**Figure 9**). Surface water velocities varied across the channel with the velocities near shore and in protected areas very being very low (i.e., less than 0.5 meter per second [m/s]) and in the main channel upwards of 1 m/s.

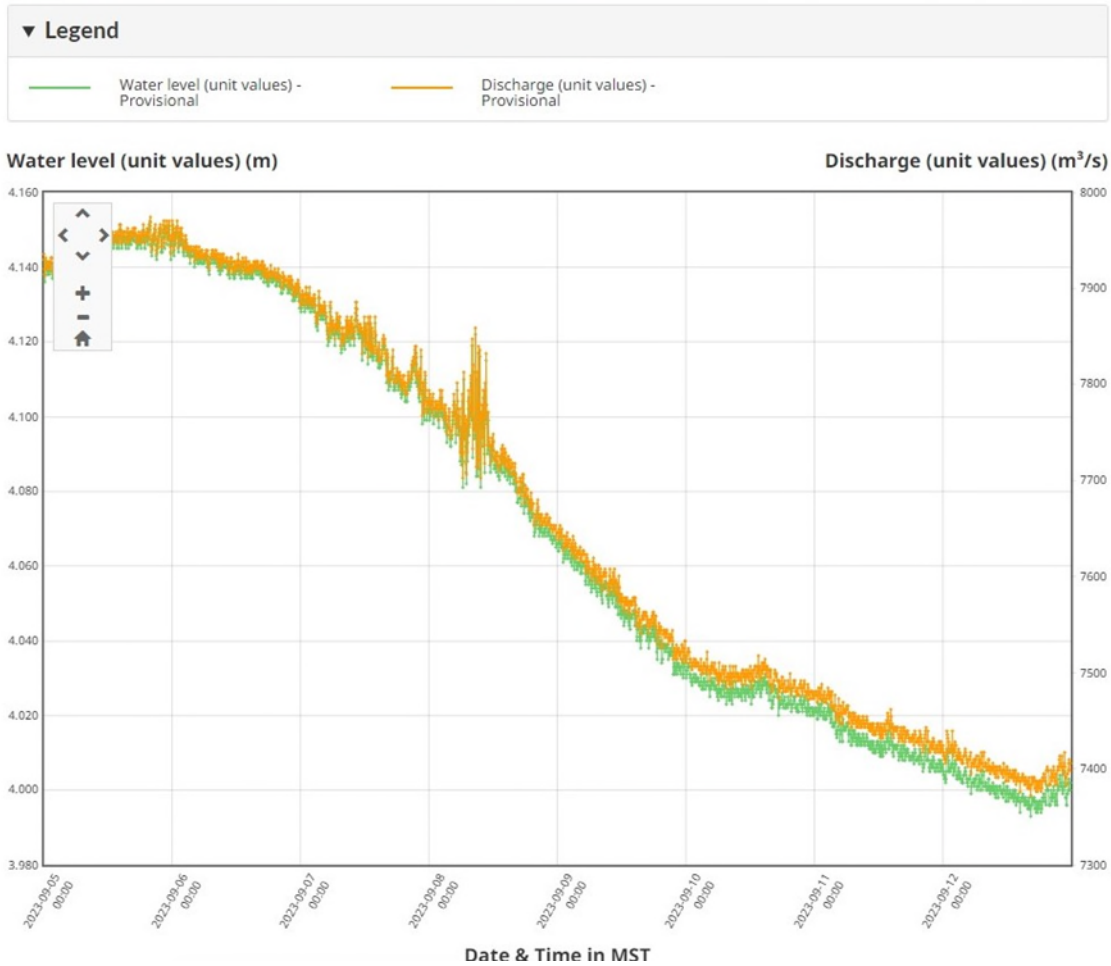


Figure 9: Mackenzie River Water Level and Discharge Measurements from ECCG Gauge 10KA001 between September 5 and 12, 2023

Weather and riverine flow conditions during the survey period were considered to be ideal conditions for the collection of pipeline DoC and bathymetric data. Site photographs showing the site conditions during the 2023 survey activities are provided in **Appendix A**.

4.0 Data Reduction and Analysis

4.1 Bathymetry

The bathymetry data were processed using PPK. The PPK correction was determined in Qinertia to account for the positional difference between the position stored in the Applanix data collected by the GNSS receivers on the Echoboat 160 to the position of the GNSS base station as stored in the RINEX files that were logged during the respective collection of bathymetry data each day. The PPK correction, patch test, and sound velocity correction were applied in Hypack. The corrected bathymetry data were then cleaned using Combined Uncertainty and Bathymetry Estimator (CUBE) filter to remove noise. Additional hand cleaning of the data was performed to remove noise over the pipelines that was missed by the CUBE filtering. The cleaned data were then exported into

XYZ files with a 10 cm resolution corresponding to each continuous section of surveyed pipeline. These XYZ files were then imported to CAD alongside the topography data.

4.2 Ground Survey

Ground survey points were corrected in real time using the base station coordinates derived by CSRS-PPP and input into the data collectors. The topography data were separated by continuous land data and brought into CAD such that surfaces could be generated corresponding to each island and the mainland.

4.3 Pipeline Depth of Cover Survey

Pipeline DoC measurements from the RD8200 line locators are measured to the centre of the pipelines. The DoC data were subsequently corrected to be to the top of the pipelines by subtracting the radius of the largest pipeline in each pipeline bundle from the recorded DoC measurement. The pipeline points were separated from the topography data, adjusted such that the elevation would correspond to the top of pipe elevation and brought into CAD for each respective pipeline. The top of pipeline points and trendlines were then reviewed to remove redundant and anomalous DoC measurements and to select the top of pipeline points used to generate the polyline and profile for each pipeline bundle.

4.4 Final Survey Drawings

The following bathymetric and topographic survey drawings were produced for this report and are provided in **Appendix B**.

Table 2: 2023 Mackenzie River Pipeline Crossings Survey Plans and Profiles Figure List

Drawing Number	Drawing Title
Figure B1	Key Plan
Figure B2	Mainland to Island 1 Pipeline Bundle – Plan and Profile
Figure B3	Mainland to Island 2 Pipeline Bundle – Plan and Profile
Figure B4	Mainland to Island 3 Pipeline Bundle – Plan and Profile
Figure B5	Goose Island to Island 3 Pipeline Bundle – Plan and Profile
Figure B6	Goose Island to Island 4 Pipeline Bundle – Plan and Profile
Figure B7	Bear Island to Island 5 Pipeline Bundle – Plan and Profile
Figure B8	Bear Island to Island 6 Pipeline Bundle – Plan and Profile
Figure B9	Goose Island to Bear Island Pipeline Bundle – Plan and Profile

The multibeam bathymetry imagery of the channel bottom shown on **Figures B2** through **B9** are color coded using a color temperature scale to represent depth, where dark blues indicate deeper water and dark red indicates shallow water. For clarity, yellow indicates deeper water than orange on the elevation scale.

Findings for each survey area are discussed in Sections 4.4.1 to 4.4.8 below and should be reviewed in tandem with the corresponding Figure for the Plan and Profile for each area as outlined in **Table 2**. The minimum DoC

and location, reported for each pipeline alignment are provided in **Table C1** in **Appendix C**. This Table also identifies the locations along each pipeline alignment where the DoC is less than 1 m.

4.4.1 Mainland to Island 1

The 2023 bathymetric and pipeline depth of cover surveys show that the IOL pipelines between the Mainland and Island 1 are buried below the channel bottom (**Appendix B - Figure B2**). The top of the pipelines within the channel based on the collected DoC measurements ranged from approximately 2 m off the shoreline of Island 1 between Stations 0+110 m and 0+195 m to approximately 0.1 m in the vicinity of a scour hole that has developed between Stations 0+235 m and 0+260 m. Between Stations 0+260 m and 0+375 m, the top of the pipelines were buried between 0.4 m to 1.2 m below the bottom of the channel.

Arcadis recommends that the DoC and channel bottom on top of the Mainland to Island 1 pipeline bundle continue to be monitored for sediment change and bed loss, which could result in the exposure and suspension of the pipelines within this bundle. The primary zone of concern is between Stations 0+235 m and 0+260 m where the pipeline DoC was 0.1 m and between Stations 0+260 m and 0+375 m where the pipeline DoC was generally less than 1 m.

4.4.2 Mainland to Island 2

The 2023 bathymetric and pipeline DoC surveys show that the IOL pipelines between the Mainland and Island 2 are buried below the channel bottom but with minimal DoC (**Appendix B – Figure B3**). The pipeline DoC measured within the channel ranged from 2.4 m near Station 0+972 m to 0.1 m near Station 0+619 m. The minimum DoC on top of the pipeline bundle was inferred to be 0.1 m at Station 0+616 m and less than 0.1 m between Stations 0+300 m and 0+340 m based on the pipeline DoC measurements recorded to either side of these stations and compared to the channel bottom elevation derived from the multi-beam bathymetric survey.

During the survey of this pipeline bundle, the EM line locating equipment reported a pipeline DoC at Station 0+339 m that would place the top of the pipeline bundle at elevation 36.83 m, at or immediately below the channel bottom at this location. Based on a comparison of the channel bottom surface and the inferred top of pipeline elevation derived by drawing a straight line between the measured pipeline points at Station 0+339 m and 0+251 m, the top of the pipeline would be exposed above the channel bottom between Station 0+305 m to 0+310 m and between Stations 0+325 m and 0+335 m. A review of the processed multi-beam data sets did not identify the presence of any exposed or suspended pipelines above the channel bottom along this RoW. The top of the pipeline elevation at Station 0+339 m was thus lowered to elevation 36.25 m to show the pipeline as buried but with minimal DoC between Stations 0+251 m and 0+339 m.

Arcadis recommends that the DoC and channel bottom on top of the Mainland to Island 2 pipeline bundle continue to be monitored for sediment change and bed loss, which could result in the exposure and suspension of the pipelines within this bundle. The primary zone of concern is between Stations 0+220 m and 0+340 m where the pipeline DoC was generally less than 0.5 m and between Stations 0+460 m and +0820 m where the pipeline DoC was generally less than 1 m. In addition, the pipeline trendline between Stations 0+200 m and 0+420 m is anomalous compared to the other data points collected. Future pipeline DoC surveys should be completed to obtain additional DoC data to confirm whether the pipeline trendline as shown on **Appendix B - Figure B3** is accurate or if the pipeline is situated deeper below the channel.

4.4.3 Mainland to Island 3

The 2023 bathymetric and pipeline DoC surveys show that the IOL pipelines between the Mainland and Island 3 are buried below the channel bottom with the pipeline typically located at depths greater than 1 m below the channel bottom (**Appendix B – Figure B4**) with some isolated sections where the pipeline DoC is less than 1 m. The minimum pipeline DoC on top of the pipeline was measured to be 0.6 m at Station 0+824 m.

During the pipeline DoC survey along this RoW, the EM line locating equipment reported pipeline DoC measurements that would place the pipelines above or immediately below the channel bottom at Stations 0+446 m, 0+532 m, 0+675 m, and 0+726 m. A review of the processed multi-beam data sets did not identify the presence of any exposed or suspended pipelines above the channel bottom along this RoW. These points are presented and highlighted on **Appendix B – Figure B4** and are considered anomalous as there is a consistent trendline for the top of the pipeline at greater depths based on other pipeline DoC data collected along this RoW in 2023.

Given the uncertainty in the EM pipeline DoC measurements along this RoW, Arcadis recommends that the DoC and channel bottom on top of the Mainland to Island 3 pipeline bundle continue to be monitored for sediment change and bed loss and to obtain additional pipeline DoC data points to increase the confidence in the top of pipeline elevation data set along this RoW.

4.4.4 Goose Island to Island 3

The 2023 bathymetric survey was completed during low water level conditions. Due to the shallow conditions at the time of the survey between Goose Island and Island 3, multi-beam bathymetry was completed between Stations 0+620 m and 0+660 m and between Stations 0+980 m and 1+180 m with the remainder of the RoW surveyed from the ground surface using the Trimble R12i rover units.

The 2023 bathymetric and pipeline DoC surveys show that the IOL pipelines between the Goose Island and Island 3 are buried below the channel bottom (**Appendix B – Figure B5**). Rip-rap armour stone has been placed on top of the pipeline bundle between the top of the left bank on Goose Island at Stations 0+530 m to 0+690 m. The placement of the rip rap armour stone has elevated the channel bottom along the RoW in this section as compared to the channel bottom up and downstream of the RoW creating a causeway. A large sandbar was exposed at the time of the 2023 survey between Stations 0+740 m and 0+970 m.

The minimum pipeline DoC within the active channel was measured to be 0.6 m near Station 0+662 m and greater than 1 m to either side of this station. A scour hole is observed near the toe of Island 3 between Stations 1+125 m and 1+145 m. The DoC on top of the pipeline below this scour hole is inferred to be approximately 1.2 m based on pipeline DoC data points measured to either side of the scour hole in 2023.

Arcadis recommends that the DoC and channel bottom on top of the Goose Island to Island 3 pipeline bundle continue to be monitored for sediment change and bed loss, which could result in the exposure and suspension of the pipelines within this bundle. The primary zone of concern is near Station 0+660 m where the minimum DoC was measured and between Stations 1+125 m and 1+145 m where a scour hole is developing.

4.4.5 Goose Island to Island 4

The 2023 bathymetric survey was completed during low water level conditions. Due to the shallow conditions at the time of the survey between Goose Island and Island 4, multi-beam bathymetry was completed between

Stations 1+330 m and 1+410 m and between Stations 1+765 m and 1+880 m with the remainder of the RoW surveyed from the ground surface using the Trimble R12i rover units.

The 2023 bathymetric and pipeline DoC surveys show that the IOL pipelines between the Goose Island and Island 4 are buried below the channel bottom (**Appendix B – Figure B6**). Rip-rap armour stone has been placed on top of the pipeline bundle from the top of the left bank on Goose Island between Station 1+185 m and 1+400 m, elevating the channel bottom along the RoW in this section as compared to the channel bottom up and downstream of the RoW. A scour hole is observed to be forming near Station 1+340 m. A large sandbar was exposed at the time of the 2023 survey between Stations 1+420 m and 1+755 m.

The minimum pipeline DoC within the active channel was measured to be 0.6 m near Stations 1+334 m and 1+340 m in the vicinity of the observed scour hole, with the pipeline DoC typically greater than 1 m to either side of this area.

Arcadis recommends that the DoC and channel bottom on top of the Goose Island to Island 4 pipeline bundle continue to be monitored for sediment change and bed loss, which could result in the exposure and suspension of the pipelines within this bundle. The primary zone of concern is between Stations 1+335 m and 1+340 m where the minimum DoC was measured, and a scour hole is forming.

4.4.6 Bear Island to Island 5

The 2023 bathymetric survey was completed during low water level conditions. Due to the shallow conditions (<0.5 m) at the time of the survey, the multi-beam data collected between Stations 0+580 m and 0+700 m exhibited noise and the channel bottom elevations inferred on the plan and profile presented on **Appendix B – Figure B7** within this area are considered to be a best estimate.

The 2023 bathymetric and pipeline DoC surveys show that the IOL pipelines between Bear Island and Island 5 are buried below the channel bottom (**Appendix B – Figure B7**). The minimum inferred DoC on top of the pipeline bundle is 0.6 m at Station 0+385 m and 0.8 m near Station 0+805 m with the DoC to either side of these stations greater than 1 m. Scour holes are observed between Bear Island and the Sandbar between Stations 0+490 m and 0+510 m and between the Sandbar and Island 5 between Stations 0+780 m and 0+820 m.

Arcadis recommends that the DoC and channel bottom on top of the Bear Island to Island 5 pipeline bundle continue to be monitored for sediment change and bed loss, which could result in the exposure and suspension of the pipelines within this bundle. The primary zones of concern are near Stations 0+385 m and 0+805 m where the minimum DoC was measured and within the area of the scour hole between Stations 0+490 m and 0+510 m.

4.4.7 Bear Island to Island 6

The 2023 bathymetric and pipeline DoC surveys show that the IOL pipelines between Bear Island and Island 6 are buried below the channel bottom (**Appendix B – Figure B8**). The minimum inferred DoC on top of the pipeline bundle is 1.6 m between Stations 0+945 m and 0+960 m where a scour hole has formed. The pipeline DoC beyond this section is typically greater than 2 m. Pipeline DoC measurements recorded from land on Bear Island between Stations 0+509 m and 0+622 m are located at greater depths than the top of pipe trendline generated from the DoC measurements recorded within the channel between Stations 0+658 m and 0+980 m.

Arcadis recommends that the DoC and channel bottom on top of the Bear Island to Island 6 pipeline bundle continue to be monitored for sediment change and bed loss and to obtain additional pipeline DoC data to increase

the confidence in the pipeline DoC between Stations 0+509 m and 0+622 m. The primary zones of concern for continued bed loss and potential exposure/suspension of the pipelines are near the scour hole between Stations 0+945 m and 0+955 m.

4.4.8 Goose Island to Bear Island

The 2023 bathymetric and pipeline DoC surveys for the pipeline bundle between Bear and Goose Islands is provided in Plan and Profile on **Appendix B - Figure B9**. The 2023 bathymetric and pipeline DoC surveys completed along the Goose to Bear Island pipeline RoW identified the presence of rip-rap armour stone placed in the channel on top of the pipeline bundle between Stations 0+915 m and 1+050 m. It is understood that the rip-rap armour stone was previously placed in this area by IOL as a mitigation to protect the pipelines within the RoW from becoming exposed and subjected to riverine forces. The placement of this rip-rap armour stone has effectively narrowed the channel width resulting in increased flow velocities and the development of a scour hole near the Goose Island shoreline between Stations 1+050 m and 1+130 m. As initially identified in the 2022 bathymetric survey, the 2023 survey continued to show the presence of an exposed pipeline near the shoreline of Goose Island between Stations 1+078 m and 1+128 m. The pipeline DoC was typically greater than 1 m below the channel bottom beyond these Stations.

Arcadis recommends that the DoC and channel bottom on top of the Goose Island to Bear Island pipeline bundle continue to be monitored for sediment change and bed loss and to monitor for increased lengths of pipeline becoming exposed/suspended. The primary zone of concern for monitoring is the scour hole and section of exposed/suspended pipeline between Stations 1+078m and 1+128 m.

5.0 Conclusions and Recommendations

The 2023 bathymetric and pipeline DoC survey completed over the IOL pipeline crossings of the Mackenzie River near Norman Wells, NWT, identified a 50 m length of exposed/suspended pipeline along the Goose to Bear Island RoW near the Goose Island shoreline. All other pipelines were located below the channel bottom in 2023; however, minimal depth of cover was report on top of the pipelines of:

- <0.1 m were reported along the Mainland to Island 1 and Mainland to Island 2 pipeline RoWs;
- 0.6 m along the Goose to Island 3, Goose to Island 4 and Bear to Island 5 pipeline ROWs;
- <1 m along the Mainland to Island 3 pipeline RoW; and
- 1.6 m along the Bear Island to Island 6 pipeline RoW.

Some anomalous pipeline DoC values were measured along the Mainland to Island 3 pipeline RoW, which would indicate that the pipelines are located above or immediately below the channel bottom at Stations 0+446 m, 0+532 m, 0+675 m, and 0+726 m (**Appendix B - Figure B5**). A review of the processed multi-beam data sets did not identify the presence of any exposed or suspended pipelines above the channel bottom along this RoW and these points are considered anomalous as there is a consistent trendline for the top of the pipeline at greater depths based on other pipeline DoC data collected along this RoW in 2023. The minimum DoC and location, reported for each pipeline alignment are provided in **Table C1** in **Appendix C**. This Table also identifies the locations along each pipeline alignment where the DoC is less than 1 m.

The reach of the Mackenzie River in the vicinity of the IOL pipelines is a dynamic system with a high suspended sediment and bed load. Sandbars have developed along the downstream sides of artificial islands that have been

constructed within the Mackenzie River channel and between the artificial islands and Goose Island and Bear Island. Sand dune bed forms were also observed along the exposed sections of sandbars and on the channel bottom in the multi-beam sonar imagery collected during the 2023 surveys.

Previous bathymetric surveys of the IOL pipeline RoWs along this reach of the Mackenzie River have been completed by others. As discussed with IOL staff prior to the start of the 2023 survey program, the previous surveys were conducted using various horizontal and vertical datums requiring the data to be shifted to allow for a comparison between the surveys. The decision was made to conduct the 2023 survey work using the most current horizontal and vertical datums available from the CSRS and to use the 2023 bathymetric survey as a baseline for all future surveys moving forward.

Future surveys should be completed using the NAD83 CSRS horizontal datum and CGVD2013 vertical datum with the CGG2013a geoid model applied to allow for a direct comparison with the 2023 bathymetric survey data and identify areas of change including channel bed loss and gain.

Given the dynamic conditions of the river system and the potential for bed scour and movement and the shallow DoC on top of the IOL pipelines, Arcadis recommends that the DoC and channel bottom on top of the IOL pipeline RoWs continue to be monitored annually to identify areas of bed loss, which could result in the exposure and suspension of the IOL pipeline crossings of the Mackenzie River. In addition, subsequent years of pipeline DoC data sets would provide additional confidence in the 2023 survey inferred top of pipeline elevations in areas where some anomalous readings were recorded (Mainland to Island 3 RoW). Arcadis also recommends collecting updated bathymetry throughout the river channel in 2024 or shortly thereafter to update the 2D HEC-RAS model of this reach of the river, which is currently based on bathymetry collected between 2012 and 2022. Beyond the limits of the RoWs, the updated bathymetry could be collected along survey transects using a single beam sonar unit.

Appendix A

Norman Wells 2023 Bathymetric Survey Photo Log

Photograph Log

IOL Mackenzie River 2023 Bathymetric and Pipeline Depth of Cover Survey

30170428



Photograph: 1

Description: Standing on right bank of the Mackenzie River on the Mainland looking southwest towards Island 3

Date: 9/6/2023



Photograph: 2

Description: Standing on right bank of the Mackenzie River on the Mainland looking southwest towards Island 3

Date: 9/6/2023

Photograph Log

IOL Mackenzie River 2023 Bathymetric and Pipeline Depth of Cover Survey

30170428



Photograph: 3

Description: Standing at top of right bank of the Mackenzie River near base station set-up looking southwest towards Island 2

Date: 9/8/2023



Photograph: 4

Description: Standing at top of right bank of the Mackenzie River near base station set-up looking southwest towards Island 2

Date: 9/8/2023

Photograph Log

IOL Mackenzie River 2023 Bathymetric and Pipeline Depth of Cover Survey

30170428



Photograph: 5

Description: Standing in the middle of the channel overtop of the Goose Island to Island 4 pipeline bundle looking downstream (southwest) towards the Goose Island left bank

Date: 9/8/2023



Photograph: 6

Description: Standing at top of left bank on Goose Island looking northeast along rip rap armour stone placed overtop of Goose Island to Island 4 pipeline bundle with Island 4 in background

Date: 9/10/2023

Photograph Log

IOL Mackenzie River 2023 Bathymetric and Pipeline Depth of Cover Survey

30170428



Photograph: 7

Description: Standing at top of left bank on Goose Island at the Goose Island to Island 4 pipeline bundle looking upstream (southeast) with, from left to right, Island 5, Island 6 and Bear Island in background

Date: 9/10/2023



Photograph: 8

Description: Standing at top of left bank on Goose Island at the Goose Island to Island 4 pipeline bundle looking upstream (southeast)

Date: 9/11/2023

Photograph Log

IOL Mackenzie River 2023 Bathymetric and Pipeline Depth of Cover Survey

30170428



Photograph: 9

Description: Standing at top of left bank on Goose Island at the Goose Island to Island 4 pipeline bundle looking downstream (northwest)

Date: 9/11/2023



Photograph: 10

Description: Standing at top of left bank on Goose Island looking northeast along rip rap armour stone placed overtop of Goose Island to Island 3 pipeline bundle with Island 3 in background

Date: 9/10/2023

Photograph Log

IOL Mackenzie River 2023 Bathymetric and Pipeline Depth of Cover Survey

30170428



Photograph: 11

Description: Standing at top of left bank on Goose Island at Goose Island to Island 3 pipeline bundle looking upstream (southeast)

Date: 9/10/2023



Photograph: 12

Description: Standing at top of left bank on Goose Island at the Goose Island to Island 3 pipeline bundle looking downstream (northwest)

Date: 9/10/2023

Photograph Log

IOL Mackenzie River 2023 Bathymetric and Pipeline Depth of Cover Survey

30170428



Photograph: 13

Description: Standing middle of channel looking at Rip Rap armour pipe protection placed otop of the Goose Island to Island 3 pipeline bundle

Date: 9/10/2023



Photograph: 14

Description: Standing middle of channel on the Goose Island to Island 3 pipeline bundle looking downstream (northwest)

Date: 9/10/2023

Photograph Log

IOL Mackenzie River 2023 Bathymetric and Pipeline Depth of Cover Survey

30170428



Photograph: 15

Description: Standing at the top of the left bank of Goose Island at the Goose Island to Island 3 pipeline bundle looking upstream (southeast) with, from left to right, Islands 4, 5 and 6 in background

Date: 9/10/2023



Photograph: 16

Description: Standing on Goose Island flood plain at Goose Island to Island 3 pipeline bundle. Looking northeast along pipeline RoW toward the channel with Island 3 in background

Date: 9/11/2023

Photograph Log

IOL Mackenzie River 2023 Bathymetric and Pipeline Depth of Cover Survey

30170428



Photograph: 17

Description: Middle of channel between Island 4 and Mainland looking at Mainland

Date: 9/6/2023



Photograph: 18

Description: Middle of channel between Island 4 and Mainland looking downstream

Date: 9/6/2023

Photograph Log

IOL Mackenzie River 2023 Bathymetric and Pipeline Depth of Cover Survey

30170428



Photograph: 19

Description: Middle of channel between Island 4 and Mainland looking upstream

Date: 9/6/2023



Photograph: 20

Description: Standing on Bear Island floodplain looking towards Mackenzie River channel and Island 5

Date: 9/7/2023

Photograph Log

IOL Mackenzie River 2023 Bathymetric and Pipeline Depth of Cover Survey

30170428



Photograph: 21

Description: Standing at top of left bank on Bear Island looking toward Island 6

Date: 9/7/2023



Photograph: 22

Description: Standing on Riprap armour pipe protection between Bear Island and Island 6 looking toward Bear Island

Date: 9/7/2023

Photograph Log

IOL Mackenzie River 2023 Bathymetric and Pipeline Depth of Cover Survey

30170428



Photograph: 23

Description: Standing on Riprap armour pipe protection between Bear Island and Island 6 looking toward Island 6

Date: 9/7/2023



Photograph: 24

Description: Standing on top of left bank on Bear Island looking at Goose Island

Date: 9/7/2023

Photograph Log

IOL Mackenzie River 2023 Bathymetric and Pipeline Depth of Cover Survey

30170428



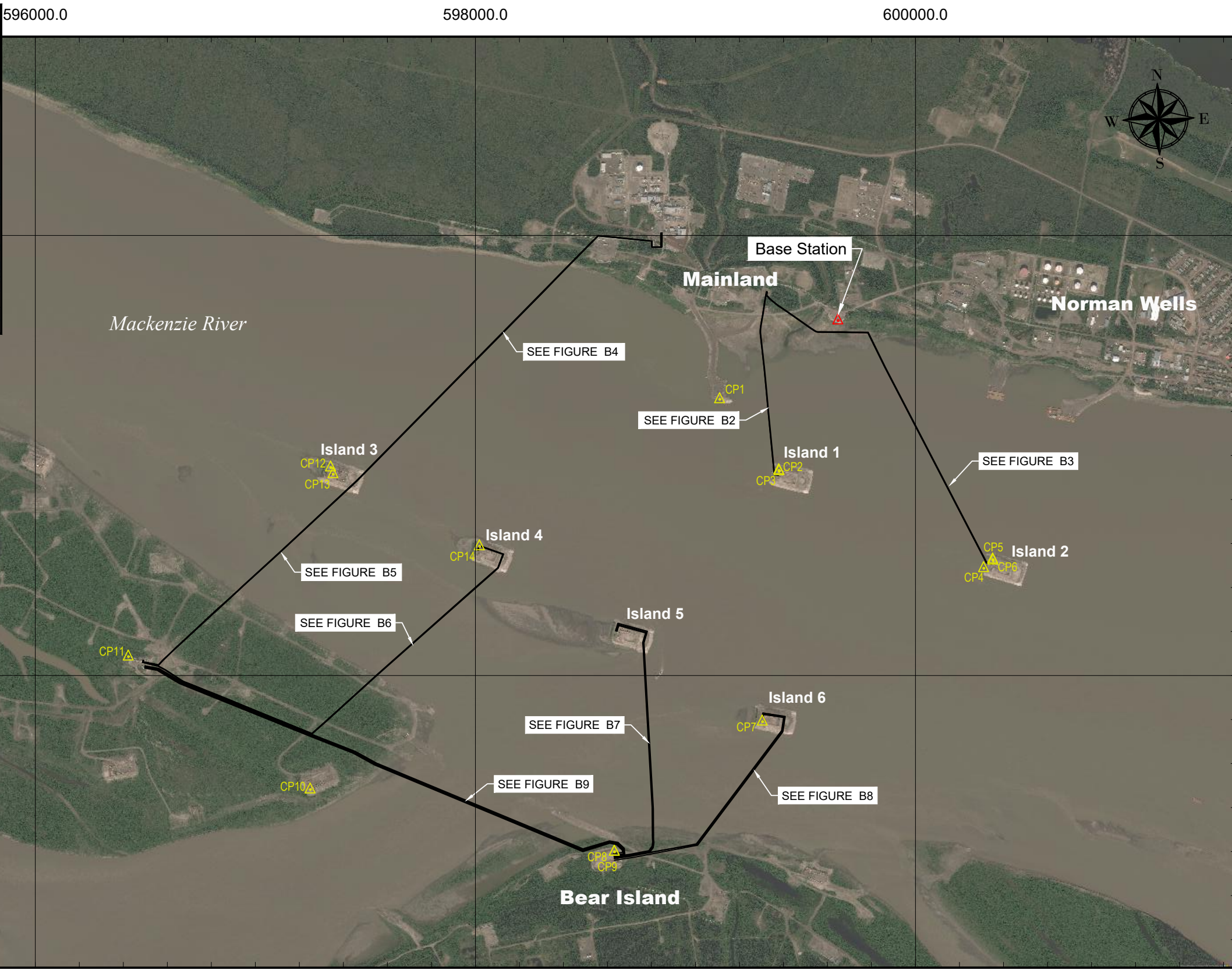
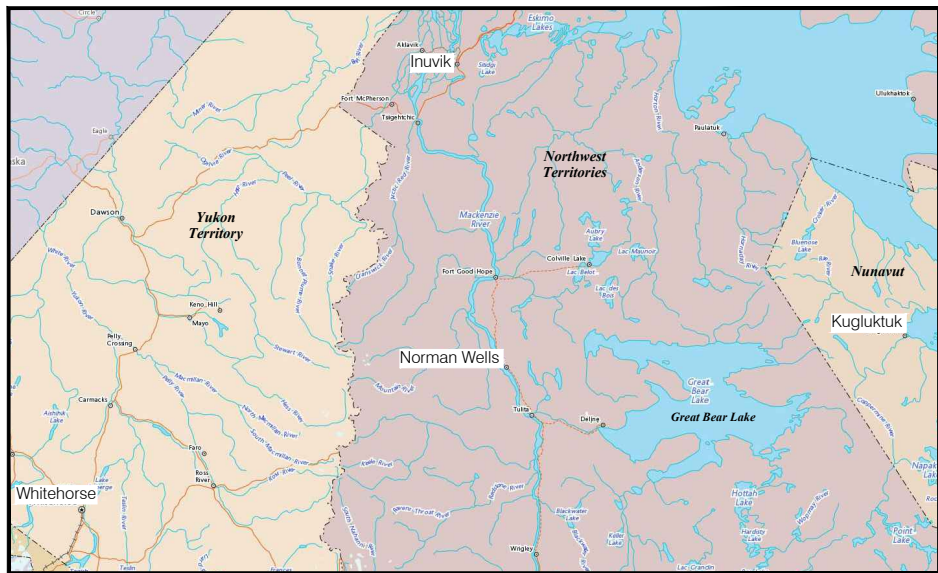
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Description: Standing on top of bank between Goose Island and Island 4 looking toward floodplain on Goose Island

Date: 9/7/2023

Appendix B

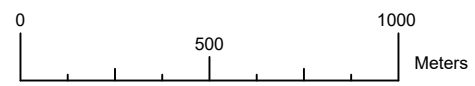
Norman Wells 2023 Mackenzie River Bathymetric and Pipeline Depth of Cover Survey Plans and Profiles



LEGEND

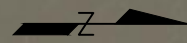
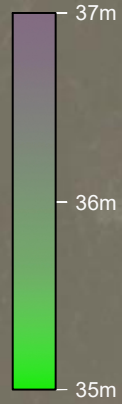
- Survey Control Point
- Base Station
- IOL Pipelines

Control Point Number	Northing (m)	Easting (m)	Elevation (m)
Base Station	7241613.18	599648.32	51.36
CP1	7241255.19	599110.88	43.44
CP2	7240932.34	599379.67	53.91
CP3	7240927.99	599380.80	52.93
CP4	7240487.52	600310.45	41.94
CP5	7240527.30	600351.59	53.80
CP6	7240522.03	600352.90	53.03
CP7	7239790.34	599304.70	53.60
CP8	7239199.00	598632.34	53.61
CP9	7239199.00	598632.34	53.61
CP10	7239481.95	597250.10	53.43
CP11	7240085.86	596423.61	52.32
CP12	7240945.34	597343.02	53.47
CP13	7240914.70	597353.85	53.09
CP14	7240586.92	598019.20	52.71



Title: Key Plan	
Project: IOL Norman Wells 2023 Pipeline Depth of Cover and Bathymetric Survey	
Client: Imperial Oil Limited	
	Date: November 2023
	FIGURE B1

LEGEND



PLAN VIEW

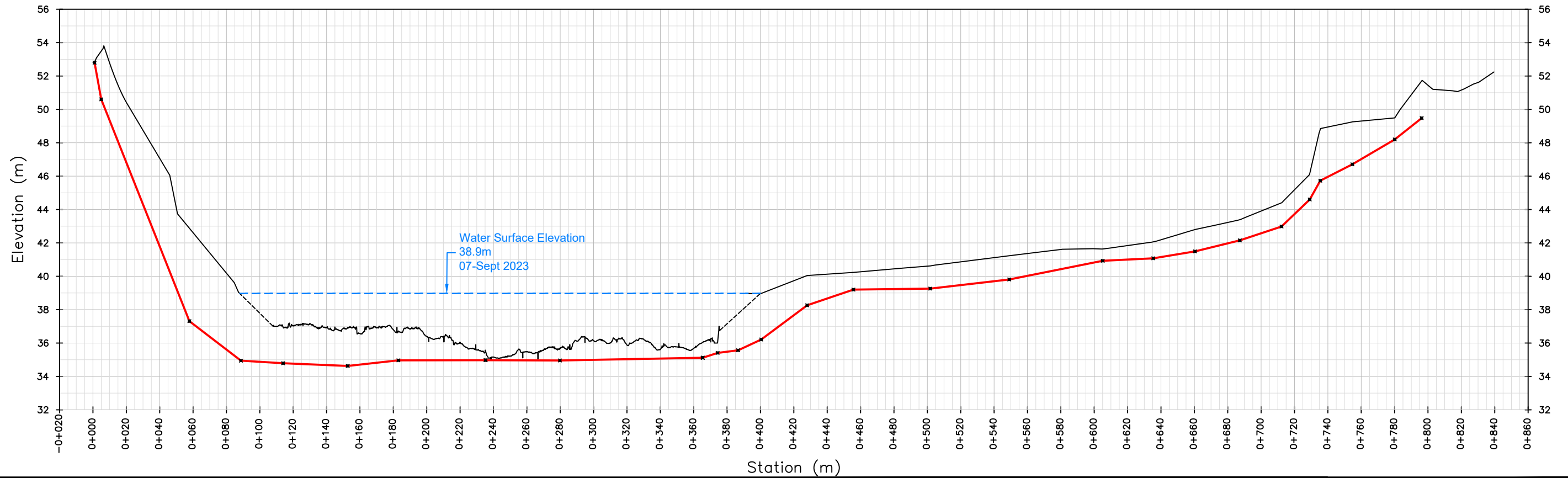
Mackenzie River

Mainland

Island 1

Flow Direction

PROFILE VIEW



LEGEND

- Water Level
- Topo/Bathymetry Ground Surface
- - - Inferred Topo/Bathymetry Ground Surface
- Top of Pipe
- ✱ EM Measured Top of Pipeline Point
- CP2 Control Point

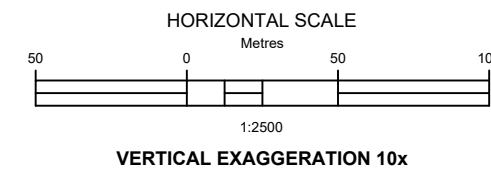
GEODETIC SETTINGS

Horizontal Datum: UTM with NAD83 (CSRS), Zone 9 North
Vertical Datum: Canadian Geodetic Vertical Datum of 2023 (CGVD2023)
Units: Survey Meter
GEOID: Canadian Gravimetric Geoid Model of 2013 - Version A (CGG2013a)

NOTES

Survey Method:
 A multi-beam sonar system was used to identify bathymetric elevations in the area surrounding this pipeline RoW. A GNSS base station with GNSS survey grade rover units were used to record ground surface elevations in upland areas adjacent to the pipeline RoW. All Pipeline DoC measurements were taken using EM-based Line Locating Equipment.

- DoC** - Depth of Cover
- EM** - Electromagnetic
- GNSS** - Global Navigation Satellite System
- RoW** - Right of Way



Title: Mainland to Island 1 Pipeline Bundle - Plan and Profile

Project: IOL Norman Wells
 2023 Pipeline Depth of Cover and Bathymetric Survey

Client: Imperial Oil Limited

Date: November 2023

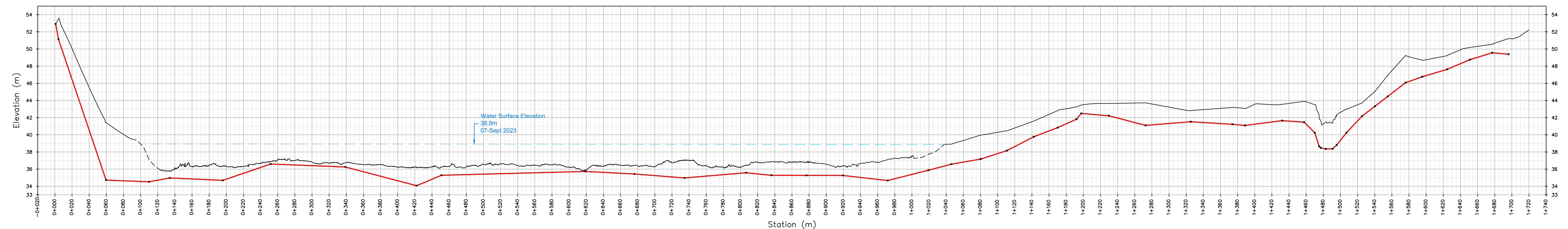


FIGURE B2

PLAN VIEW



PROFILE VIEW



LEGEND

- Water Level
- Topo/Bathymetry Ground Surface
- - - Inferred Topo/Bathymetry Ground Surface
- Top of Pipe
- EM Measured Top of Pipeline Point
- ▲ Control Point

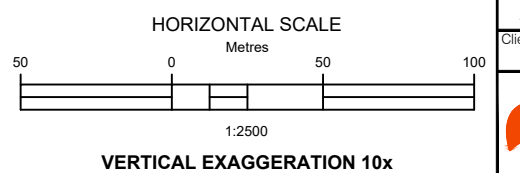
GEODETIC SETTINGS

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Vertical Datum: Canadian Geodetic Vertical Datum of 2023 (CGVD2023)
Units: Survey Meter
GEOID: Canadian Gravimetric Geoid Model of 2013 - Version A (CGG2013a)

NOTES

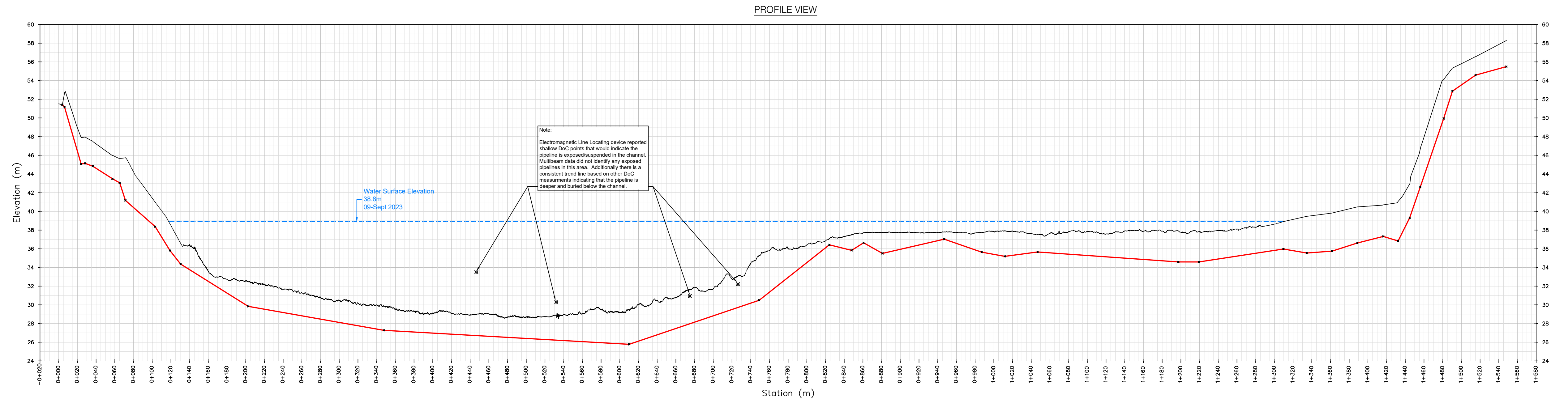
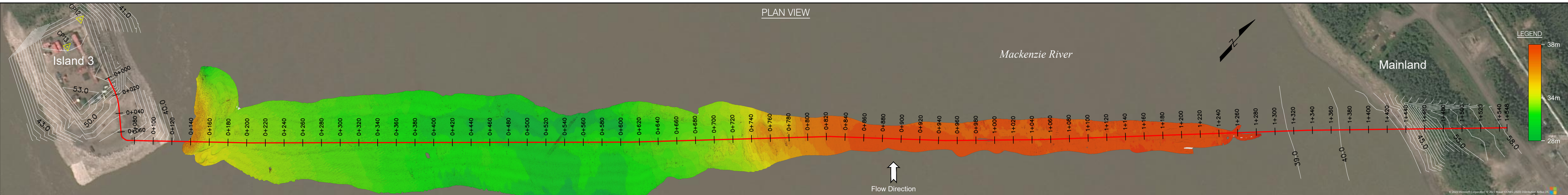
Survey Method:
 A multi-beam sonar system was used to identify bathymetric elevations in the area surrounding this pipeline RoW. A GNSS base station with GNSS survey grade rover units were used to record ground surface elevations in upland areas adjacent to the pipeline RoW. All Pipeline DoC measurements were taken using EM-based Line Locating Equipment.

- DoC** - Depth of Cover
- EM** - Electromagnetic
- GNSS** - Global Navigation Satellite System
- RoW** - Right of Way

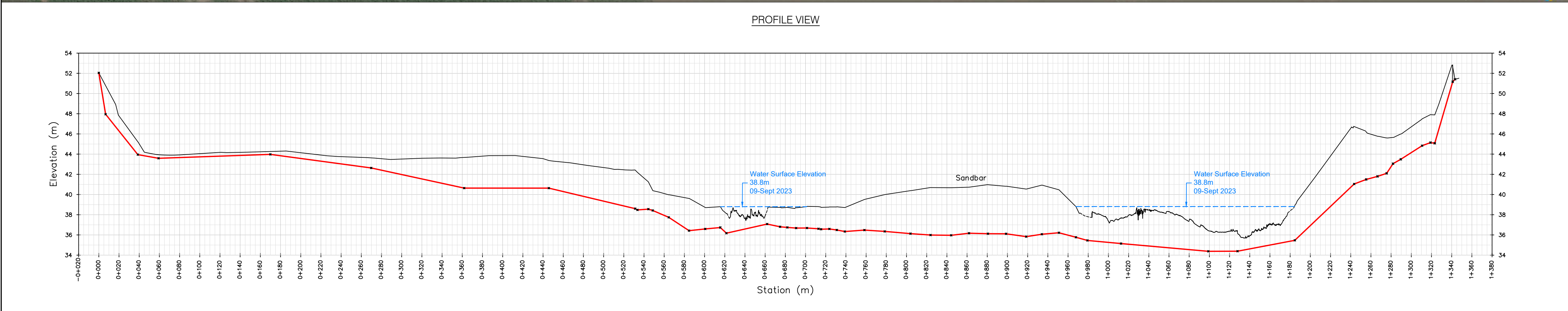
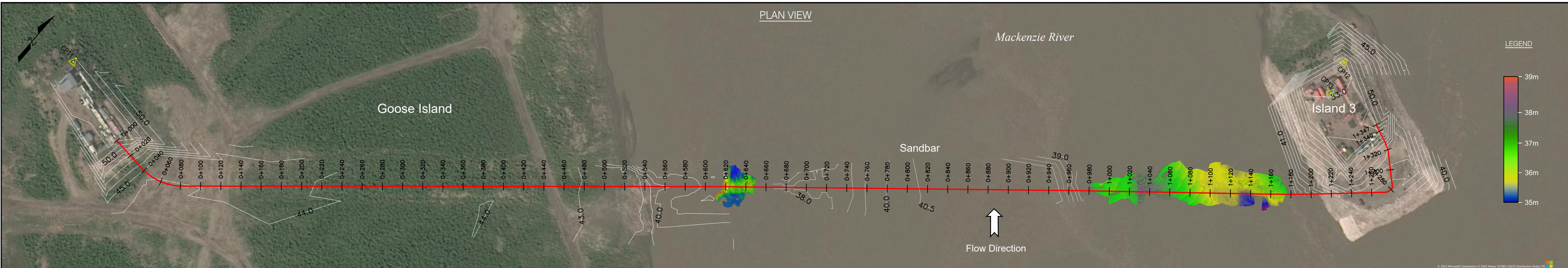


Title: Mainland to Island 2 Pipeline Bundle - Plan and Profile	
Project: IOL Norman Wells 2023 Pipeline Depth of Cover and Bathymetric Survey	
Client: Imperial Oil Limited	
Date: November 2023	FIGURE B3





<p>LEGEND</p> <ul style="list-style-type: none"> --- Water Level --- Topo/Bathymetry Ground Surface - - - - Inferred Topo/Bathymetry Ground Surface --- Top of Pipe ✕ EM Measured Top of Pipeline Point CP12 Control Point 	<p>GEODETIC SETTINGS</p> <p>Horizontal Datum: UTM with NAD83 (CSRS), Zone 9 North</p> <p>Vertical Datum: Canadian Geodetic Vertical Datum of 2023 (CGVD2023)</p> <p>Units: Survey Meter</p> <p>GEOID: Canadian Gravimetric Geoid Model of 2013 - Version A (CGG2013a)</p>	<p>NOTES</p> <p>Survey Method: A multi-beam sonar system was used to identify bathymetric elevations in the area surrounding this pipeline RoW. A GNSS base station with GNSS survey grade rover units were used to record ground surface elevations in upland areas adjacent to the pipeline RoW. All Pipeline DoC measurements were taken using EM-based Line Locating Equipment.</p> <p>DoC - Depth of Cover EM - Electromagnetic GNSS - Global Navigation Satellite System RoW - Right of Way</p>	<p style="text-align: center;">HORIZONTAL SCALE</p> <p style="text-align: center;">Metres</p> <p style="text-align: center;">VERTICAL EXAGGERATION 10x</p>	<p>Title: Mainland to Island 3 Pipeline Bundle - Plan and Profile</p> <p>Project: IOL Norman Wells</p> <p>2023 Pipeline Depth of Cover and Bathymetric Survey</p> <p>Client: Imperial Oil Limited</p> <p>Date: November 2023</p> <p style="text-align: center;">ARCADIS</p> <p style="text-align: center;">FIGURE B4</p>
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LEGEND

- Water Level
- Topo/Bathymetry Ground Surface
- - - - Inferred Topo/Bathymetry Ground Surface
- Top of Pipe
- ✕ EM Measured Top of Pipeline Point
- CP2 Control Point

GEODETTIC SETTINGS

Horizontal Datum: UTM with NAD83 (CSRS), Zone 9 North

Vertical Datum: Canadian Geodetic Vertical Datum of 2023 (CGVD2023)

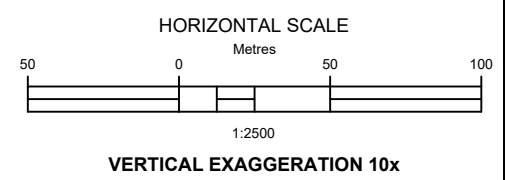
Units: Survey Meter

GEOID: Canadian Gravimetric Geoid Model of 2013 - Version A (CGG2013a)

NOTES

Survey Method:
A multi-beam sonar system was used to identify bathymetric elevations in the area surrounding this pipeline RoW. A GNSS base station with GNSS survey grade rover units were used to record ground surface elevations in upland areas adjacent to the pipeline RoW. All Pipeline DoC measurements were taken using EM-based Line Locating Equipment.

- DoC** - Depth of Cover
- EM** - Electromagnetic
- GNSS** - Global Navigation Satellite System
- RoW** - Right of Way



Title: Goose Island to Island 3 Pipeline Bundle - Plan and Profile

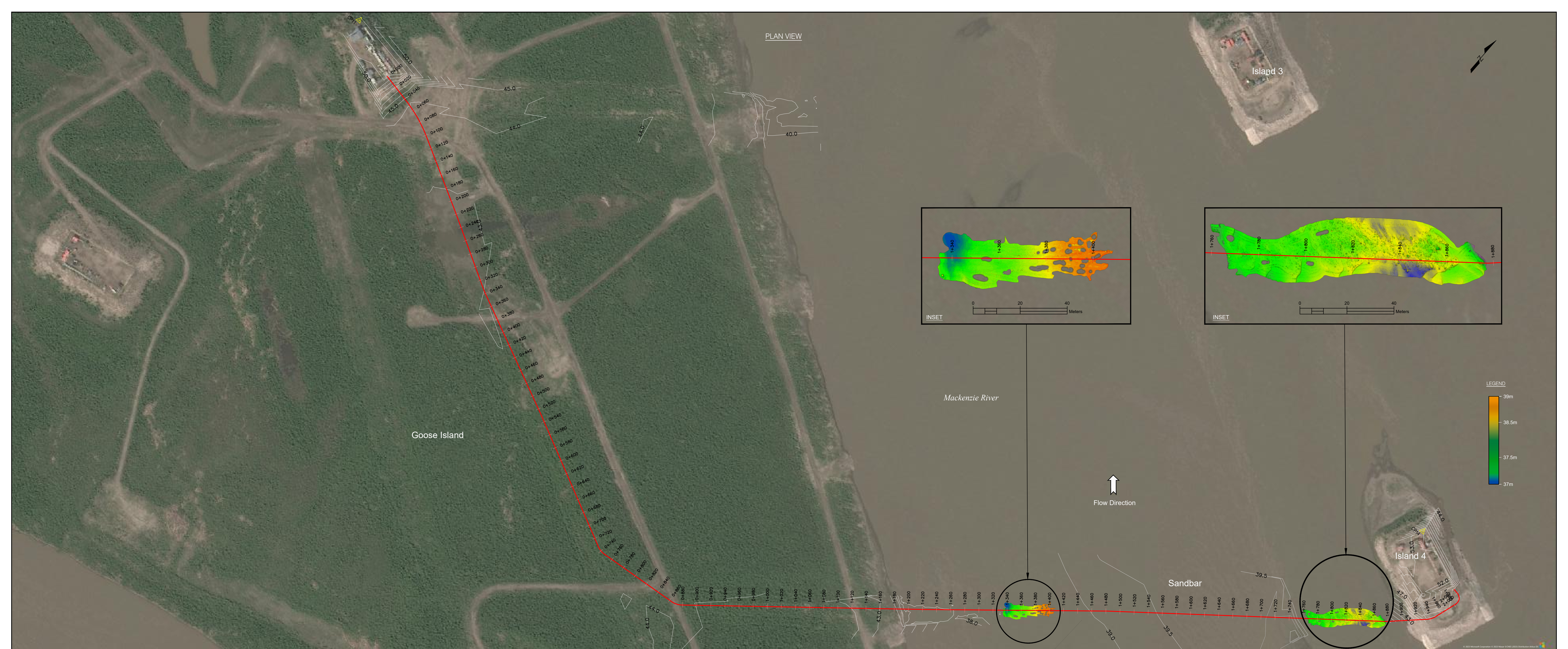
Project: IOL Norman Wells
2023 Pipeline Depth of Cover and Bathymetric Survey

Client: Imperial Oil Limited

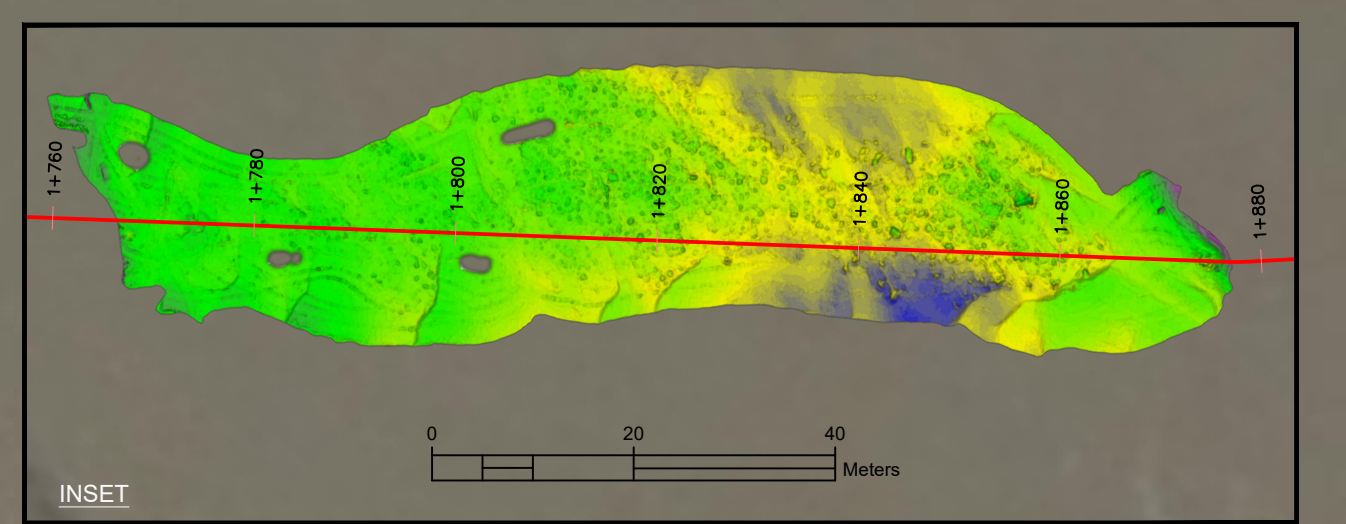
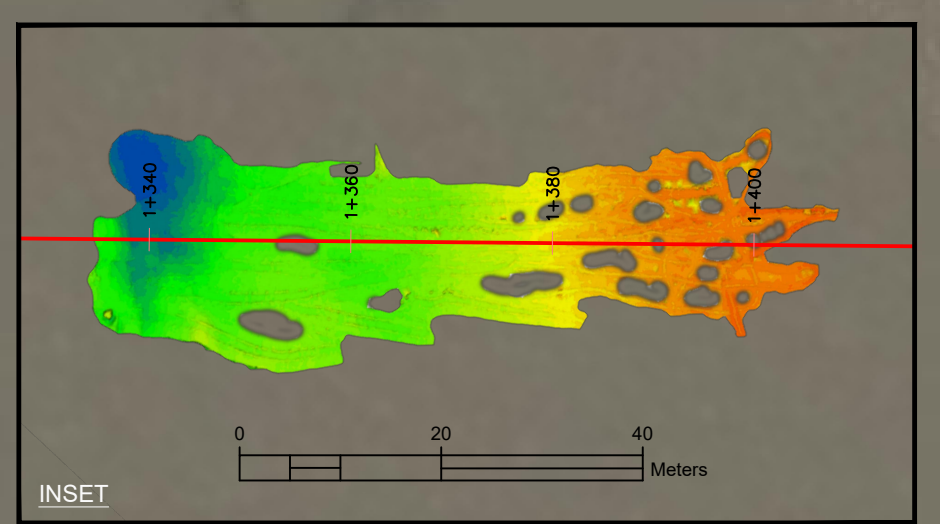
Date: November 2023

ARCADIS

FIGURE B5

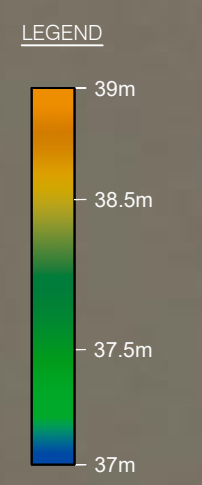


PLAN VIEW

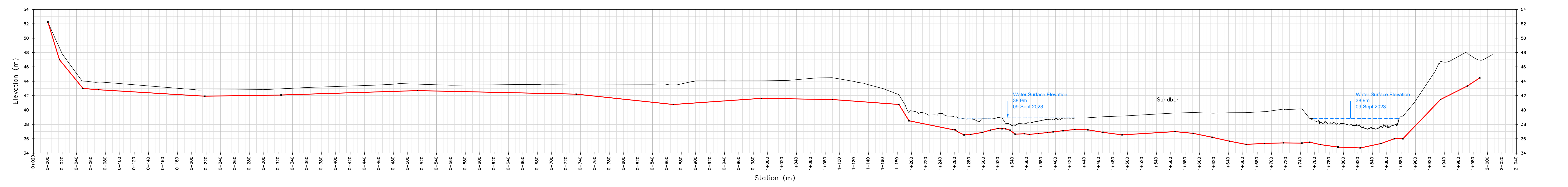


Mackenzie River

Flow Direction



PROFILE VIEW



LEGEND

- Water Level
- Topo/Bathymetry Ground Surface
- Inferred Topo/Bathymetry Ground Surface
- Top of Pipe
- EM Measured Top of Pipeline Point
- Control Point

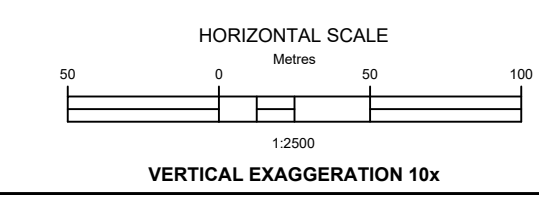
GEODETTIC SETTINGS

Horizontal Datum: UTM with NAD83 (CSRS), Zone 9 North
Vertical Datum: Canadian Geodetic Vertical Datum of 2023 (CGVD2023)
Units: Survey Meter
GEOID: Canadian Gravimetric Geoid Model of 2013 - Version A (CGG2013a)

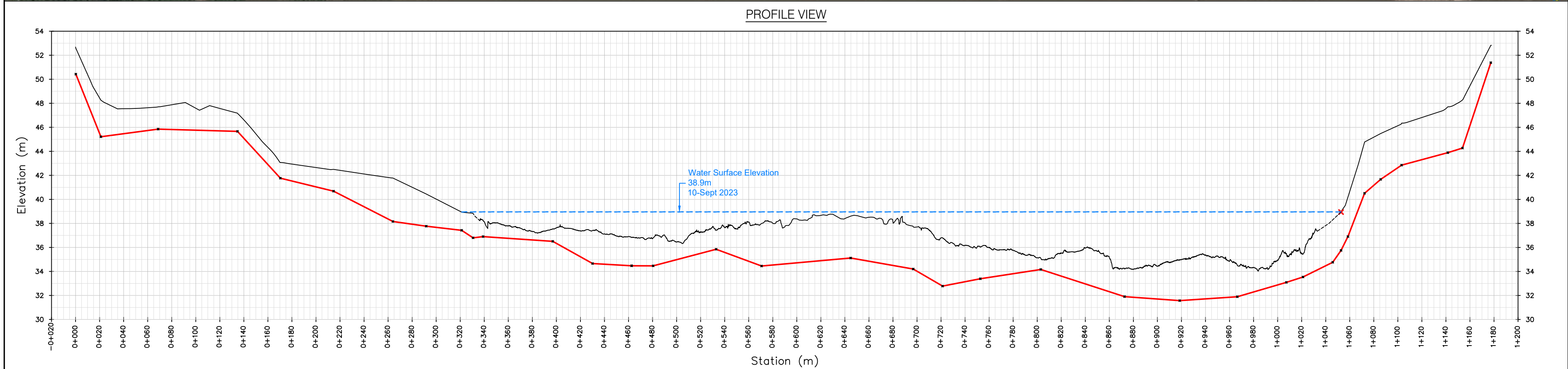
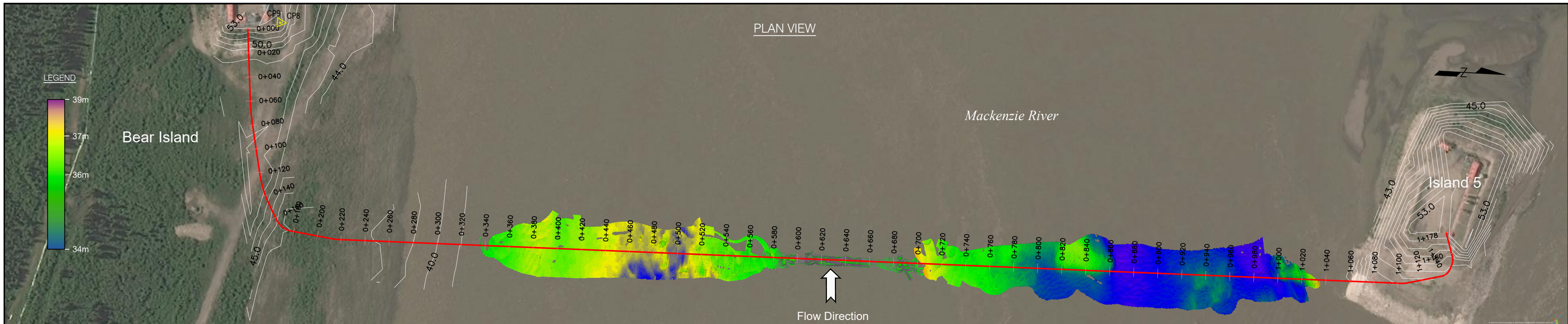
NOTES

Survey Method: A multi-beam sonar system was used to identify bathymetric elevations in the area surrounding this pipeline ROW. A GNSS base station with GNSS survey grade rover units were used to record ground surface elevations in upland areas adjacent to the pipeline ROW. All Pipeline DoC measurements were taken using EM-based Line Locating Equipment.

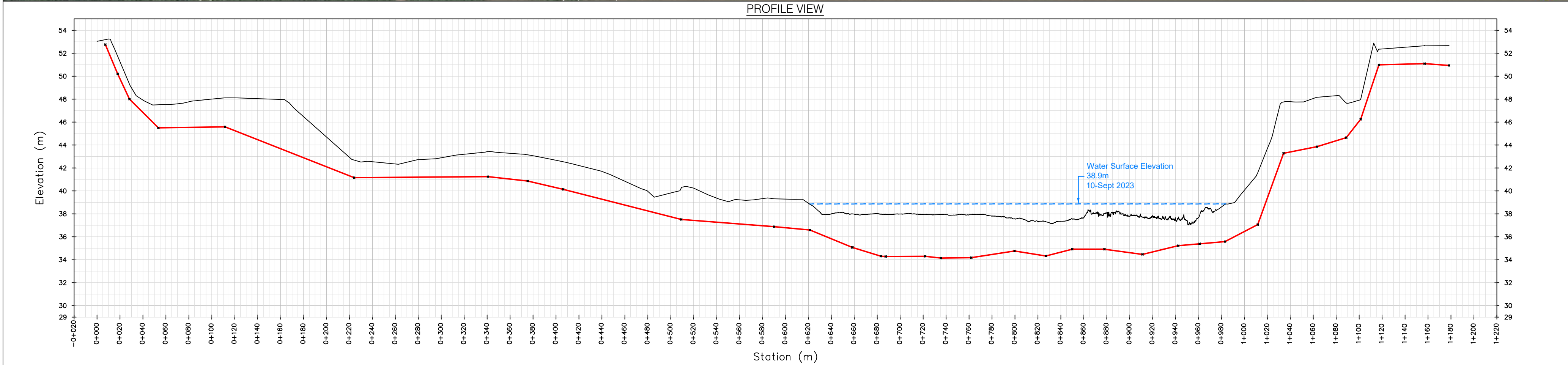
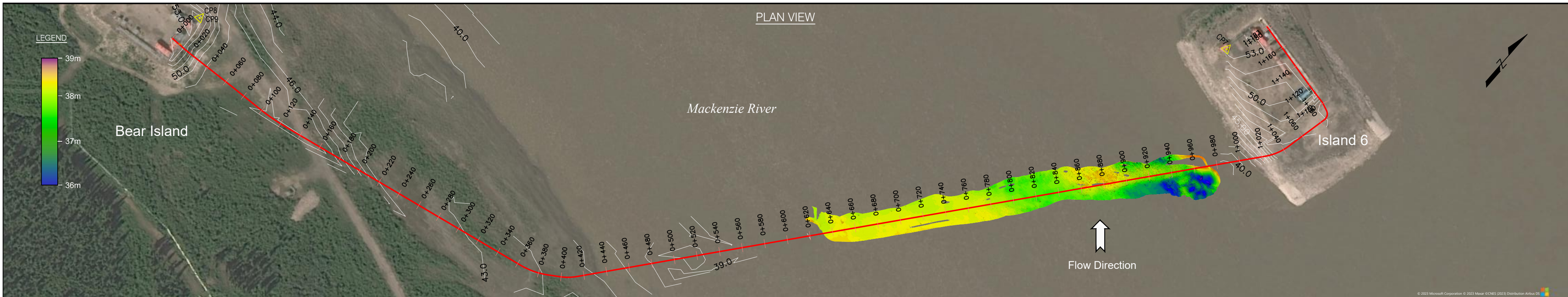
DoC - Depth of Cover
EM - Electromagnetic
GNSS - Global Navigation Satellite System
RoW - Right of Way



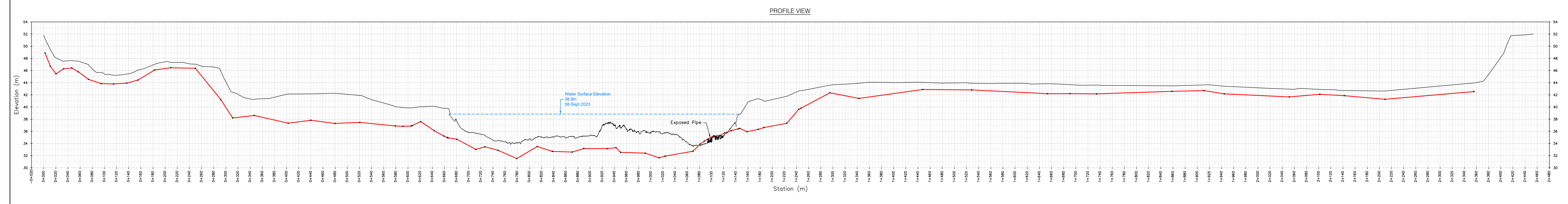
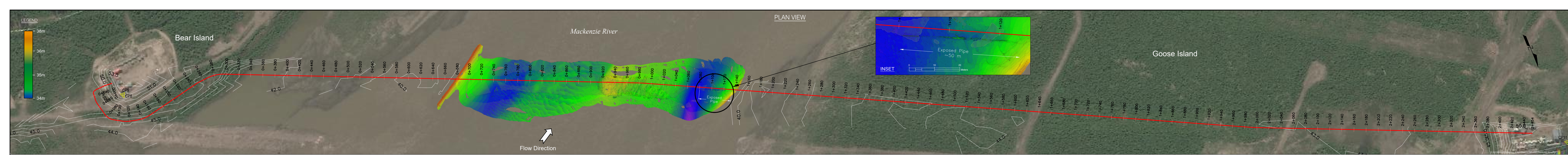
Project: **Goose Island to Island 4 Pipeline Bundle - Plan and Profile**
 Client: **IOI Norman Wells**
 Project: **2023 Pipeline Depth of Cover and Bathymetric Survey**
 Client: **Imperial Oil Limited**
 Date: **November 2023**
ARCADIS
FIGURE B6



<p>LEGEND</p> <ul style="list-style-type: none"> --- Water Level — Topo/Bathymetry Ground Surface - - - Inferred Topo/Bathymetry Ground Surface — Top of Pipe ✕ EM Measured Top of Pipeline Point △ CP7 Control Point 	<p>GEODETTIC SETTINGS</p> <p>Horizontal Datum: UTM with NAD83 (CSRS), Zone 9 North</p> <p>Vertical Datum: Canadian Geodetic Vertical Datum of 2023 (CGVD2023)</p> <p>Units: Survey Meter</p> <p>GEOID: Canadian Gravimetric Geoid Model of 2013 - Version A (CGG2013a)</p>	<p>NOTES</p> <p>Survey Method: A multi-beam sonar system was used to identify bathymetric elevations in the area surrounding this pipeline RoW. A GNSS base station with GNSS survey grade rover units were used to record ground surface elevations in upland areas adjacent to the pipeline RoW. All Pipeline DoC measurements were taken using EM-based Line Locating Equipment.</p>	<p>DoC - Depth of Cover</p> <p>EM - Electromagnetic</p> <p>GNSS - Global Navigation Satellite System</p> <p>RoW - Right of Way</p>	<p>HORIZONTAL SCALE</p> <p style="text-align: center;">Metres</p> <p style="text-align: center;">1:2500</p> <p>VERTICAL EXAGGERATION 10x</p>	<p>Title: Bear Island to Island 5 Pipeline Bundle - Plan and Profile</p> <p>Project: IOL Norman Wells 2023 Pipeline Depth of Cover and Bathymetric Survey</p> <p>Client: Imperial Oil Limited</p> <p>Date: November 2023</p> <p style="text-align: right;">FIGURE B7</p>
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<p>LEGEND</p> <ul style="list-style-type: none"> --- Water Level — Topo/Bathymetry Ground Surface - - - Inferred Topo/Bathymetry Ground Surface — Top of Pipe ✱ EM Measured Top of Pipeline Point △ Control Point 	<p>GEODETIC SETTINGS</p> <p>Horizontal Datum: UTM with NAD83 (CSRS), Zone 9 North</p> <p>Vertical Datum: Canadian Geodetic Vertical Datum of 2023 (CGVD2023)</p> <p>Units: Survey Meter</p> <p>GEOID: Canadian Gravimetric Geoid Model of 2013 - Version A (CGG2013a)</p>	<p>NOTES</p> <p>Survey Method: A multi-beam sonar system was used to identify bathymetric elevations in the area surrounding this pipeline RoW. A GNSS base station with GNSS survey grade rover units were used to record ground surface elevations in upland areas adjacent to the pipeline RoW. All Pipeline DoC measurements were taken using EM-based Line Locating Equipment.</p>	<p>DoC - Depth of Cover</p> <p>EM - Electromagnetic</p> <p>GNSS - Global Navigation Satellite System</p> <p>RoW - Right of Way</p>	<div style="text-align: center;"> <p>HORIZONTAL SCALE</p> <p>VERTICAL EXAGGERATION 10x</p> </div>	<p>Title: Bear Island to Island 6 Pipeline Bundle - Plan and Profile</p> <p>Project: IOL Norman Wells 2023 Pipeline Depth of Cover and Bathymetric Survey</p> <p>Client: Imperial Oil Limited</p> <p>Date: November 2023</p> <p style="text-align: right;">FIGURE B8</p>
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<p>LEGEND</p> <ul style="list-style-type: none"> --- Water Level --- Topo/Bathymetry Ground Surface --- Inferred Topo/Bathymetry Ground Surface --- Top of Pipe ■ EM Measured Top of Pipeline Point CP8 Control Point 	<p>GEODETTIC SETTINGS</p> <p>Horizontal Datum: UTM with NAD83 (CSRS), Zone 9 North</p> <p>Vertical Datum: Canadian Geodetic Vertical Datum of 2023 (CGVD2023)</p> <p>Units: Survey Meter</p> <p>GEOID: Canadian Gravimetric Geoid Model of 2013 - Version A (CGG2013a)</p>	<p>NOTES</p> <p>Survey Method: A multi-beam sonar system was used to identify bathymetric elevations in the area surrounding this pipeline RoW. A GNSS base station with GNSS survey grade rover units were used to record ground surface elevations in upland areas adjacent to the pipeline RoW. All Pipeline DoC measurements were taken using EM-based Line Locating Equipment.</p>	<p>DoC - Depth of Cover</p> <p>EM - Electromagnetic</p> <p>GNSS - Global Navigation Satellite System</p> <p>RoW - Right of Way</p>	<p>HORIZONTAL SCALE</p> <p>0 50 100 Metres</p> <p>VERTICAL EXAGGERATION 10x</p>	<p>FIGURE B9</p> <p>ARCADIS</p> <p>November 2023</p>	<p>Title: Goose Island to Bear Island Pipeline Bundle - Plan and Profile</p> <p>Project: IOL Norman Wells</p> <p>2023 Pipeline Depth of Cover and Bathymetry Survey</p> <p>Client: Imperial Oil Limited</p>
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Appendix C

Norman Wells 2023 Mackenzie River Bathymetric and Pipeline Depth of Cover Survey - Summary of Minimum Pipeline Depth of Cover Measurements

Table C1
Summary of Norman Wells 2023 Pipeline Depth of Cover Measurements

Figure	Pipeline Alignment	Minimum DoC (m)	Minimum DoC Station (m)	DoC < 1m Station Start (m)	DoC <1 m Station End (m)	Location
B2	Mainland to Island 1	0.00	0+000	0+000	0+002.5	Island 1
		0.11	0+237	0+215	0+290	Channel
		0.45	0+358	0+335	0+375	Channel
		0.71	0+605	0+590	0+630	Channel
B3	Mainland to Island 2	0.00	0+000	0+000	0+002.5	Island 2
		0.77	0+134.5	0+125	0+140	Channel
		0.21	0+307	0+210	0+370	Channel
		0.09	0+617	0+450	0+700	Channel
		0.67	0+800.3	0+760	0+810	Channel
		1.00	0+925	0+910	0+930	Channel
B4	Mainland to Island 3	0.00	0+000	0+000	0+002.5	Island 3
		0.84	0+166	0+155	0+170	Channel
		0.60	0+824	0+810	0+835	Channel
		0.78	0+947	0+940	0+955	Channel
B5	Goose Island to Island 3	0.00	0+000	0+000	0+002.5	Goose Island
		0.26	0+075	0+040	0+270	Goose Island
		0.65	0+659	0+640	0+665	Channel
B6	Goose Island to Island 4	0.00	0+000	0+000	0+620	Goose Island
		0.77	1+330	1+325	1+345	Channel
B7	Bear Island to Island 5	0.60	0+384	0+340	0+400	Channel
		0.88	0+805	0+795	0+810	Channel
B8	Bear Island to Island 6	0.43	0+007.5	0+007.5	0+045	Bear Island
		1.30	0+486			Channel
B9	Bear Island to Goose Island	0.67	0+250	0+170	0+260	Bear Island
		-0.80	1+105	1+060	1+140	Channel
		0.89	1+858	1+820	1+920	Goose Island
		0.80	2+102	2+080	2+180	Goose Island

Imperial Oil Limited

Depth of Cover Assessment

Norman Wells, Northwest Territories

Mackenzie River

January 30, 2024

Prepared By:
Arcadis, Inc.

Prepared For:
Imperial Oil Limited

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Appendices

- Appendix A** Sediment Data and Scenarios by Pipeline
- Appendix B** Combined Scour Result Plots by Pipeline
- Appendix C** Calculation Results by Pipeline (*provided via spreadsheets*)
- Appendix D** Critical Velocities by Pipeline

1 Introduction

The Imperial Oil Limited facility near the town of Norman Wells, Northwest Territories (NWT) along the Mackenzie River includes eight pipeline bundles that cross various portions of the River and parts of six artificial islands and two natural islands. A diagram of these pipelines in this reach of the River is shown in **Figure 1** below.



Figure 1. Norman Wells Aerial View with Pipeline Bundles Identified

Arcadis staff conducted hydrodynamic analysis to calculate water depths and water velocities across the entire extent of this reach of the River for various flow events. The modeled hydrodynamic conditions were used to estimate scour depths and potential for exposure along the pipeline corridors for these flow events. Potential hydrodynamic loads and stresses were calculated for potentially exposed and suspended pipeline segments and are documented in a companion report.

2 Hydrodynamic Modeling

2.1 Modeling Domain and Mesh

Measured data is not available for depth and flow velocity, so hydrodynamic modeling is necessary to supply these data calculating scour potential and depth of cover. Due to the complex flow patterns in this reach of the river - i.e. flow splits due to the natural and artificial islands – it was determined that a 2D, rather than a 1D, model of this river reach was necessary to accurately capture the flow dynamics. The United States Army Corps of Engineers (USACE) Hydrologic Engineering Center – River Analysis System (HEC-RAS) Version 6.4.1 was utilized for this project. This free and publicly available software is used and trusted widely by government, industry, and academia and represents the state of practice for computing riverine flows.

A 2D hydrodynamic model is comprised of cells that make up a mesh, or grid of calculation points at which the flow field is computed. For the model developed for the Norman Wells reach of the Mackenzie River (the model), the cell size was chosen to be 50 meters everywhere except near Goose and Bear Islands, the six artificial islands, and on the Mainland where IOL's operational assets are located. At those locations the cell size was set to 25 meters to provide greater refinement of the terrain and more accuracy of the computed flow field. Additionally, breaklines were used along the shorelines of the river and all islands to align the computational cells along these important landscape features. The modeling domain for this project captures all eight pipeline corridors as well as the river reach stretching approximately 5 km upstream and downstream of the IOL facility near Norman Wells. The domain is seen in **Figure 2** below.



Figure 2. Extent of the two-dimensional Modeling Domain used for Norman Wells

2.2 Modeling Inputs

2.2.1 Digital Elevation Model (DEM)

To provide topographic and bathymetric elevations to the model, a digital elevation model (DEM) is needed for the entire extent of the model domain. The only available source of elevation data that covers the full model extent is the composite topo-bathy data collected and compiled by WorleyParsons in 2012 [1]. This data was provided to Arcadis in the form of xyz points at a 50m spacing. These data points were interpolated using GIS to create the necessary DEM at a 1m spacing.

Additionally, GeoVerra [2] collected bathymetric data for the channel between Goose and Bear Islands in September of 2022. This data was especially important to capture in the hydrodynamic modeling as the pipelines between Goose and Bear Islands have previously experienced reduced cover and exposure near Goose Island. IOL has since placed rock armoring in the area to mitigate the problem and prevent further erosion in the area. However, erosion has continued near the mitigation, resulting in as much as 3m of scour. Bathymetric data that captures both the mitigation and the scour hole is essential for this project. Furthermore, in September of 2023,

Arcadis completed a highly detailed bathymetric survey of all eight pipeline corridors. More information on the 2023 survey and field activities can be found in a separate memo [3].

Both the data collected by GeoVerra in 2022 and by Arcadis in 2023 was incorporated into the 2012 DEM used in the hydraulic model. Because of discrepancies in the horizontal datum used in the 2022 survey, the 2022 DEM was shifted horizontally to align with the 2023 DEM of a known datum. **Figures 3 and 4** show the 2022 and 2023 DEM before and after this shift. Because the river is highly mobile, significant erosion and deposition occurred in the short time span between the 2022 and 2023 survey dates. Because of this, the 2022 data was smoothed and the large scour hole near Goose Island was filled in to better align with the 2023 data and to prevent sudden shifts in the DEM that would result in irregularities in the modeling results. These manual edits result in a best estimate of overall river bed elevations in this region. The final DEM used to represent the channel between Goose and Bear Islands is shown in **Figure 5**.

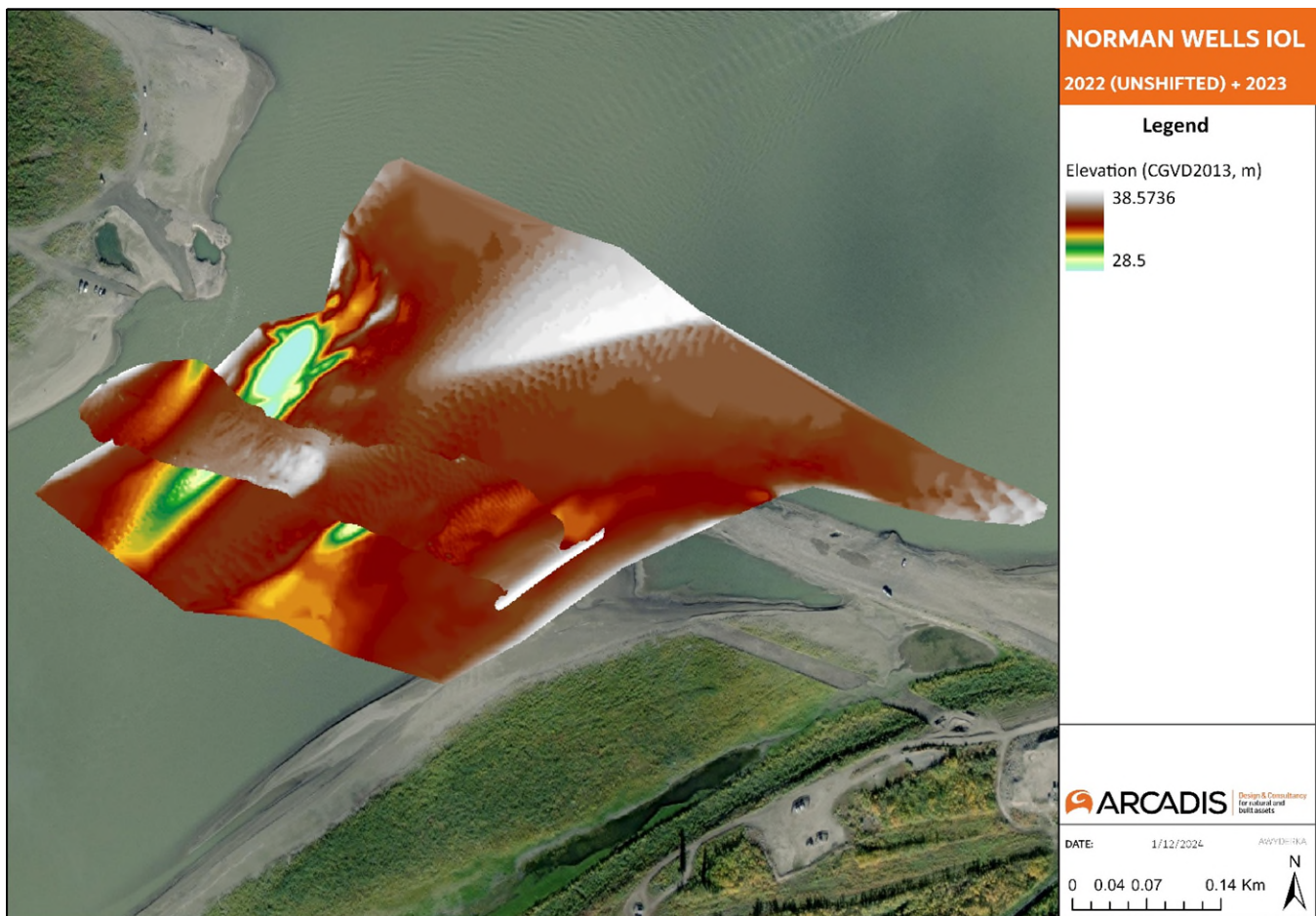


Figure 3. DEM using 2023 Survey Data overlaid on 2022 Survey Data (unshifted)

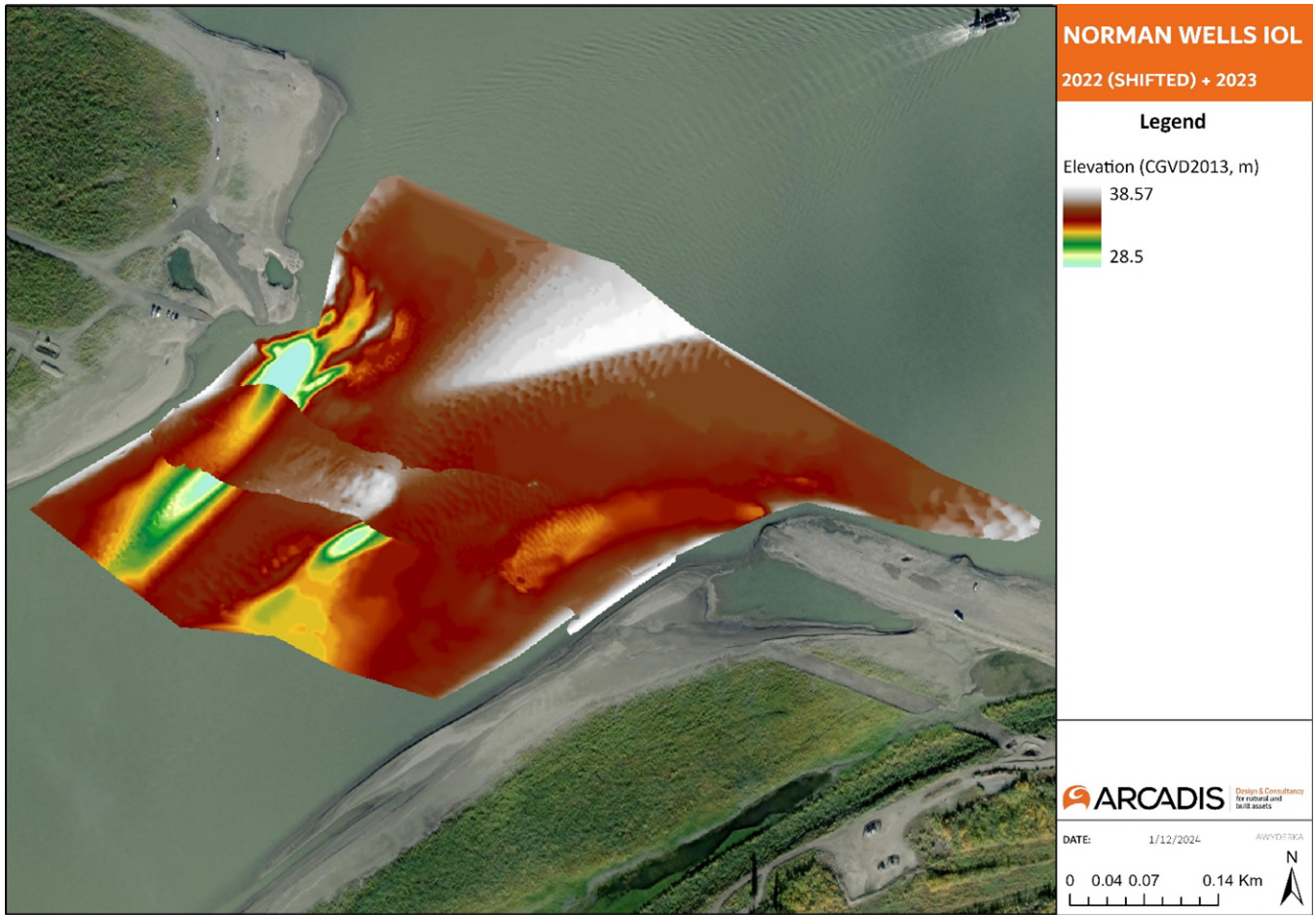


Figure 4. DEM Made using 2023 Survey Data overlaid on shifted 2022 Survey Data

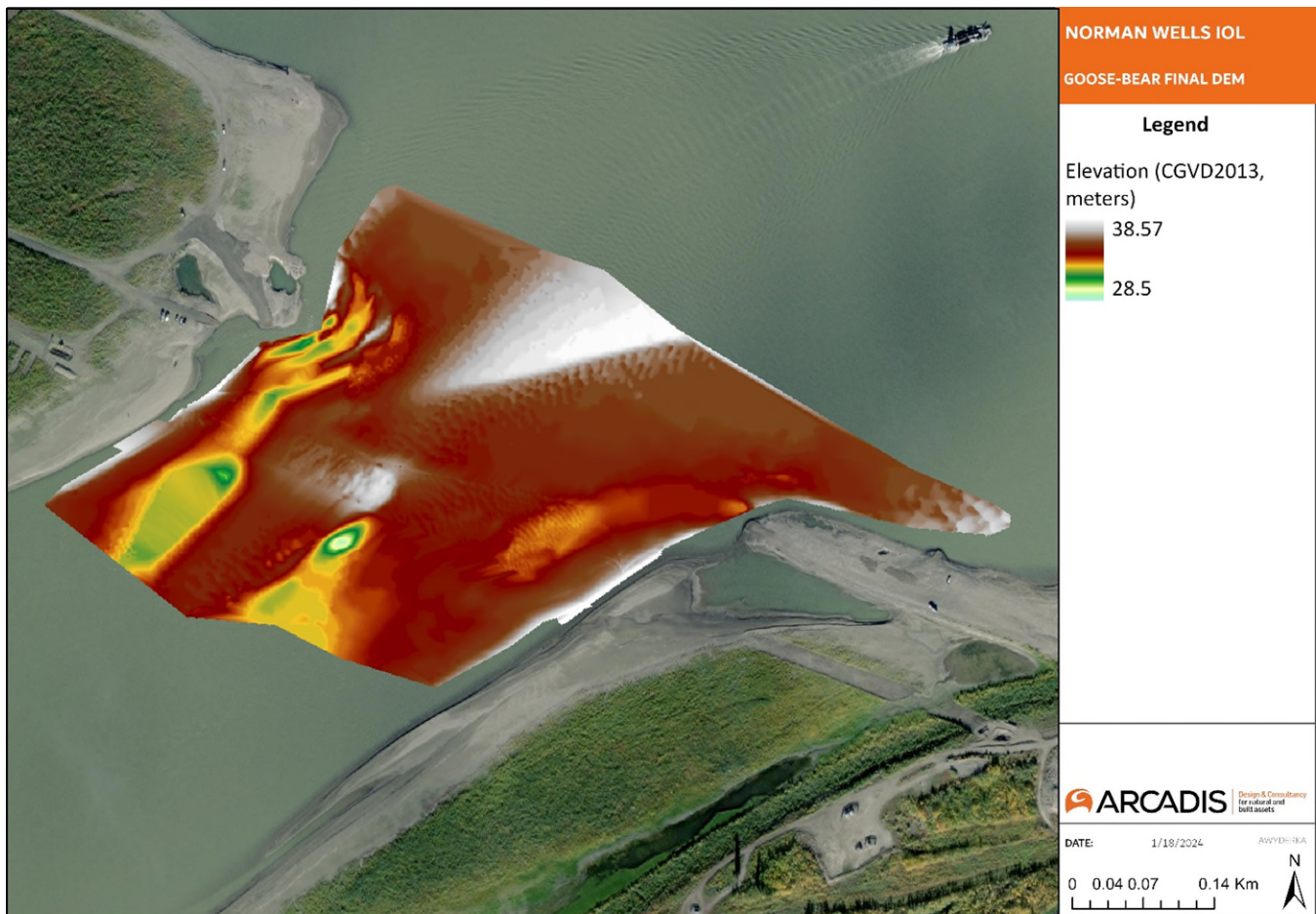


Figure 5. 2023 Survey Data combined with Smoothed and Shifted 2022 Survey Data to approximate current bed elevations

The survey conducted by Arcadis in 2023 also included topographic and bathymetric data collected at the remaining seven pipeline bundles. However, it was determined that this data not be included in the hydrodynamic model as it was not extensive enough to improve the accuracy of the 2D DEM or the modeling results. If the sparse 2023 data had been included, the resulting DEM would have contained artificial irregularities resulting in modeling anomalies due to artificial ‘dips’ and ‘hills’ in the DEM. Note that the detailed 2023 elevation survey along the pipeline corridors was used in post-processing the modeling results to identify any areas where scour may potentially expose the pipelines.

The final DEM is shown in **Figure 6** and incorporates the following data sources in the following priority:

- 1) 2023 Arcadis Survey between Bear and Goose Islands
- 2) 2022 GeoVerra Survey between Bear and Goose Islands
- 3) 2012 WorleyParsons Survey in all remaining areas of the river reach

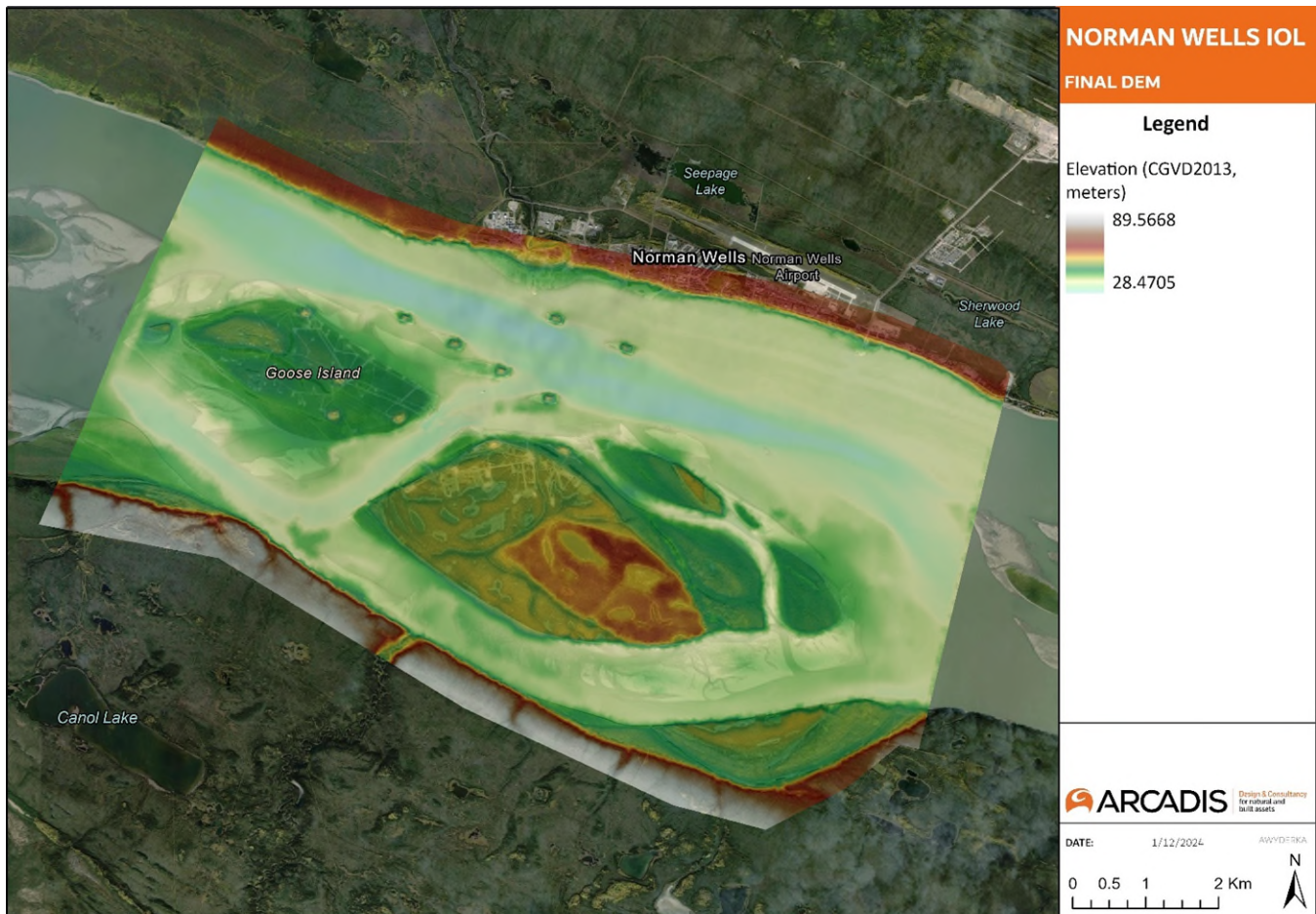


Figure 6. Final DEM Used in 2D Model

While some portions the 2023 Arcadis survey data were not incorporated into the hydraulic model, it is highly accurate and critical for providing accurate and up-to-date depth of cover estimates. Therefore, it was incorporated into the depth of cover calculations, which are described in **Section 3**.

2.2.2 Land Cover

In addition to a DEM, a land cover dataset is also needed in the hydraulic model. Land Cover data for this model was gathered by the Canada Centre for Remote Sensing (CCRS) at a 30m spatial resolution. **Figure 7** below shows the land cover in this river reach. Land Cover data is essential for the assignment of Manning's N values in the model. Manning's N values quantify the roughness of a specific land cover type and are a critical component in the water surface elevation and water velocity computations of the model. The assigned Manning's n values by land cover type are in **Table 1**. The Manning's N value used for water of .035 was determined by calibration of the model to the nearby gage's rating curve (gage 10KA001, operated by the Water Survey of Canada).

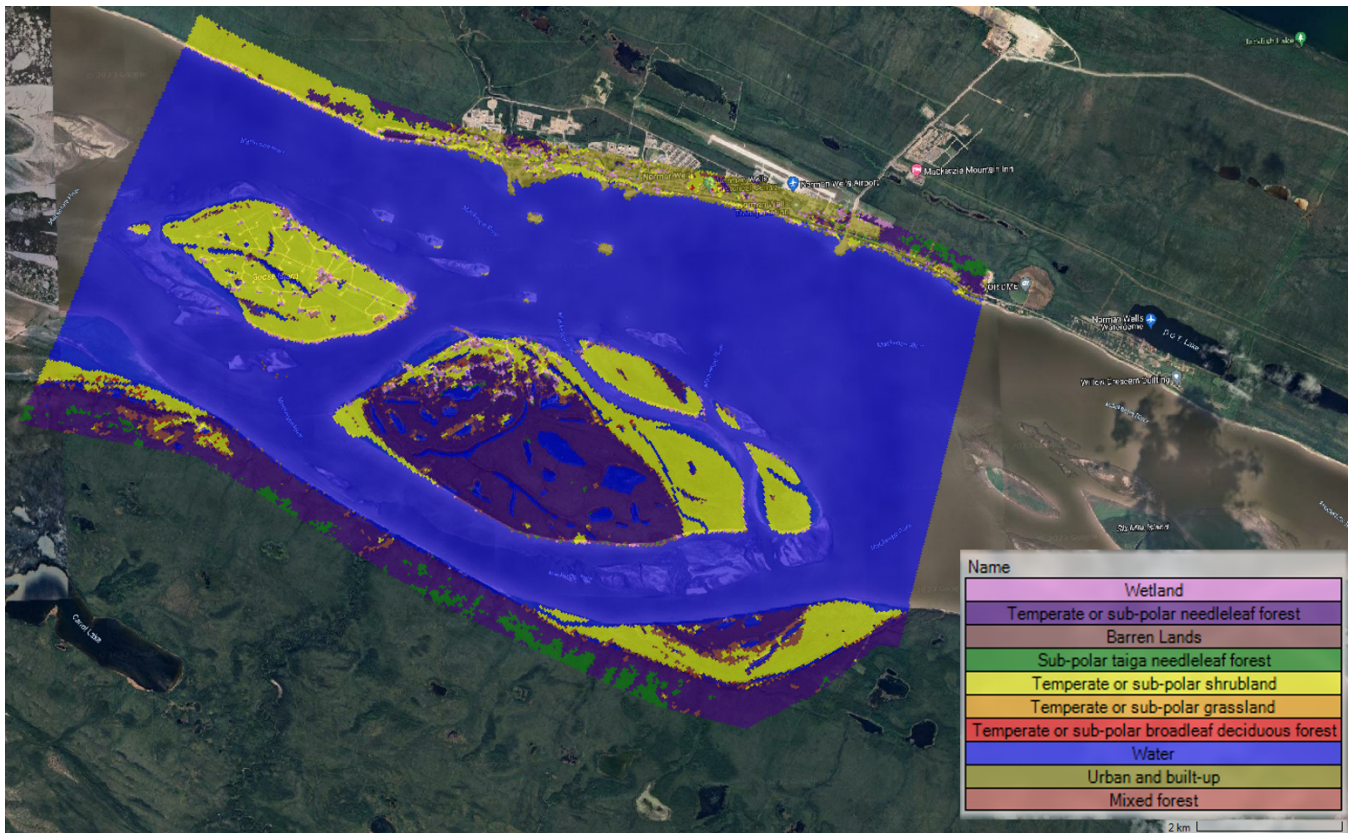


Figure 7. Land Cover Classifications in the Project Reach

Table 1. Manning's N Value by Land Cover Type

Land Cover Type	Manning's N Value
Wetland	.08
Temperate or sub-polar needleleaf forest	.12
Barren Lands	.03
Sub-polar taiga needleleaf forest	.12
Temperate or sub-polar shrubland	.08
Temperate or sub-polar grassland	.04
Temperate or sub-polar broadleaf deciduous forest	.1
Water	.035
Urban and built-up	.08
Mixed forest	.12

2.3 Boundary Conditions

In addition to a DEM and land cover data, boundary conditions are needed to specify how and where flow enters and leaves the model domain. The upstream boundary conditions is a flow hydrograph, which specifies the flow in cubic meters per second (cms) over time. The downstream boundary condition is a series of normal depth estimates with the friction slope set to a representative value of the riverbed gradient at that location. Additional information about boundary condition types and specifications for the HEC-RAS model can be found in the HEC-RAS 2D Modeling Manual [4].

The flow hydrograph applied at the upstream boundary of the model domain is adjusted to simulate different flow events. For this study, flow events for nine return periods were run through the model. The flow events and their corresponding flow are listed in **Table 2** below. The flow hydrographs for these events were set to a constant flow for the duration of the run (48 hours), and results were taken from the last time step of each event to allow time for the model to reach a steady state in the River. Analysis of the results from the runs shows that the River reaches steady state after only a few hours, giving validity to the use of a constant flow hydrograph.

Table 2. Return Period Flow Events and Corresponding Peak Flow

Return Period	Flow (cms)
2	24,300
5	27,700
10	29,800
20	31,800
50	34,300
100	36,100
200	37,900
1000	45,009
10000	55,860

Flow values for the 2-year through 200-year return period events are taken from a 2018 WorleyParsons report [1]. In addition to these flow events, IOL requested that the 1,000-year and 10,000-year flow events be modeled. To estimate flow for these two events, a log-linear interpolation of the remaining return period events was undertaken. It should be noted that there is great uncertainty regarding the flow for these extreme flow events. The gage record at this River, though lengthy, (~80 years) is not long enough to determine these extreme events with a high-level of confidence.

2.4 Hydrodynamic Modeling Results

These nine flow events were run through the model at a six-second computational time step for 48 hours. The Froude number for each of these events was checked throughout the model domain and all flow events had Froude numbers less than 1 throughout the domain. Resultant water depths and velocities¹ were extracted from

¹ Water velocities from the HEC-RAS model are depth-averaged velocities. However, they are not channel-averaged or cross-section-averaged, meaning that variation in velocity from bank to bank is captured.

these models for the scour and depth of cover calculations. **Figures 8-13** below show the water depth and velocity for the 2-year, 100-year, and 10,000-year events.

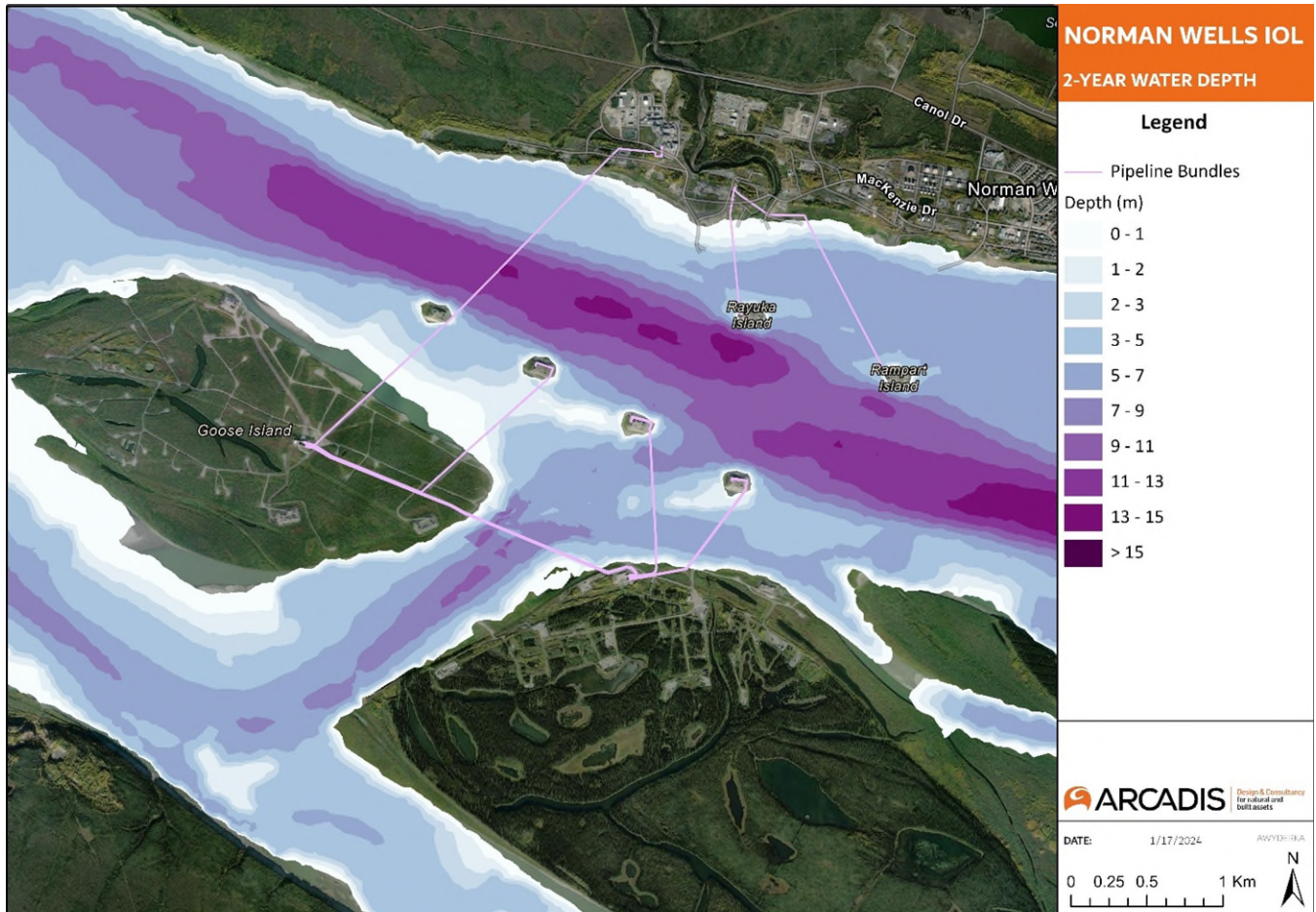


Figure 8. Modeled Water Depth During the 2-Year Flow Event

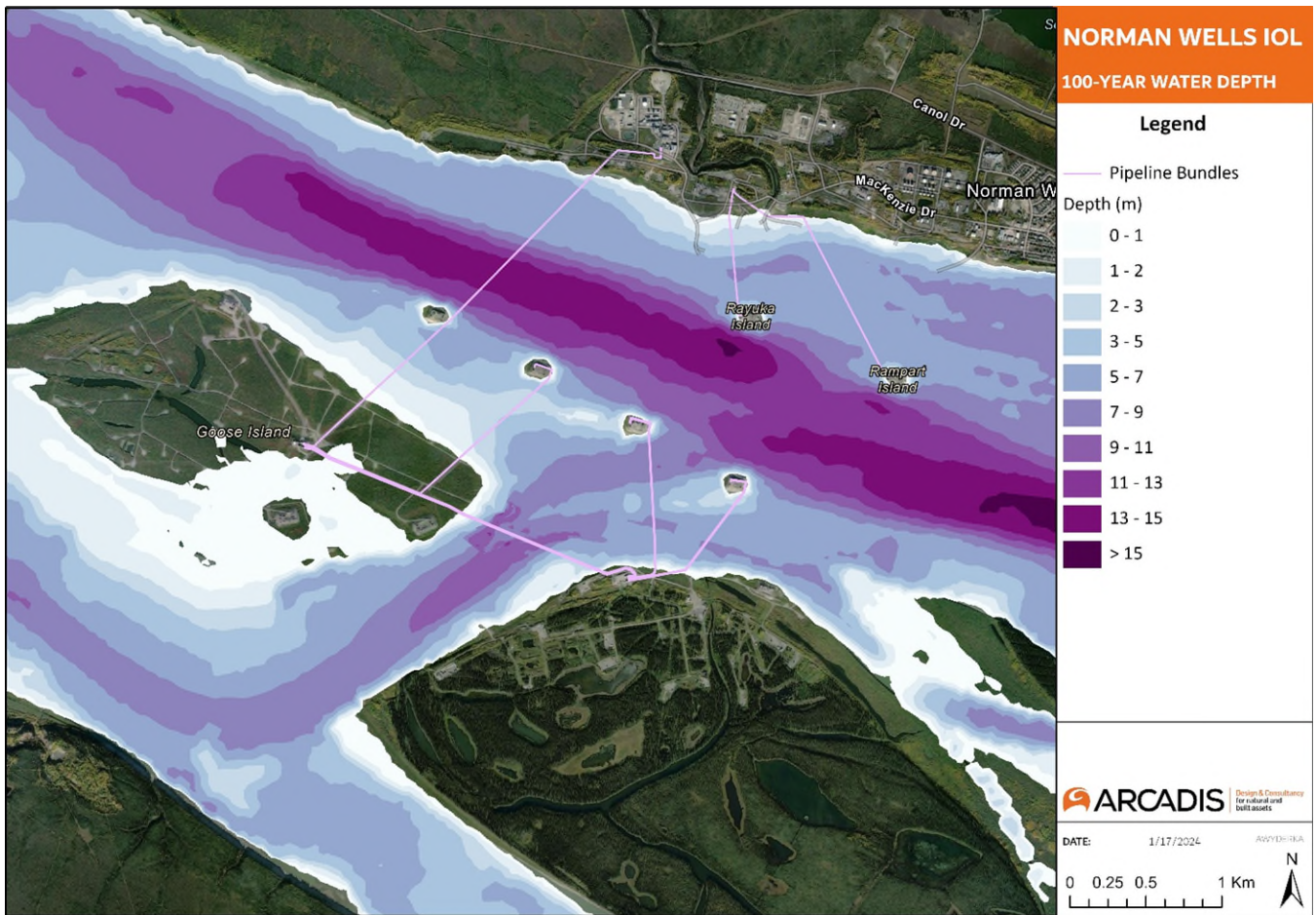


Figure 9. Modeled Water Depth During the 100-Year Flow Event

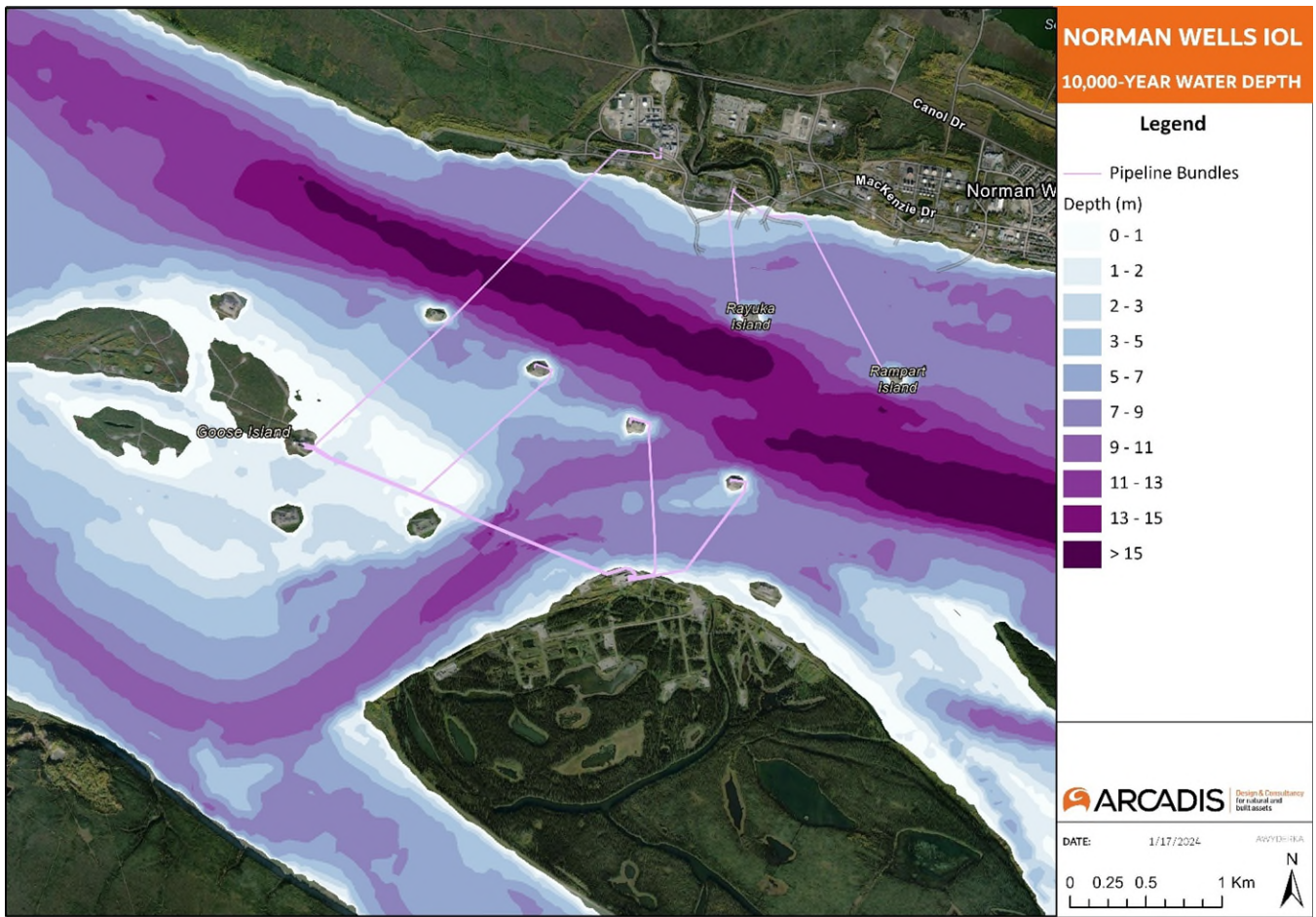


Figure 10. Modeled Water Depth During the 10,000-Year Flow Event

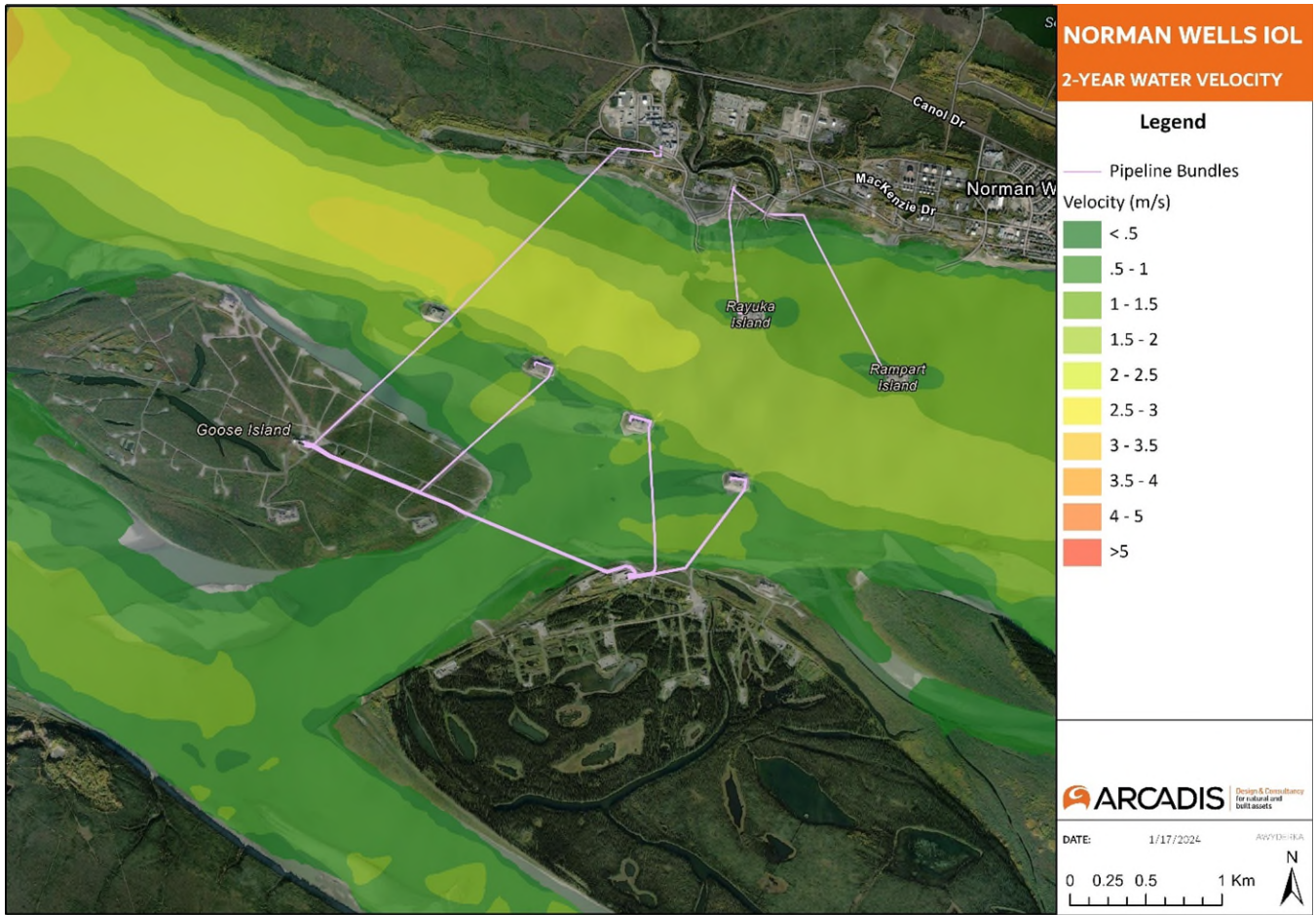


Figure 11. Modeled Water Velocity During the 2-Year Flow Event

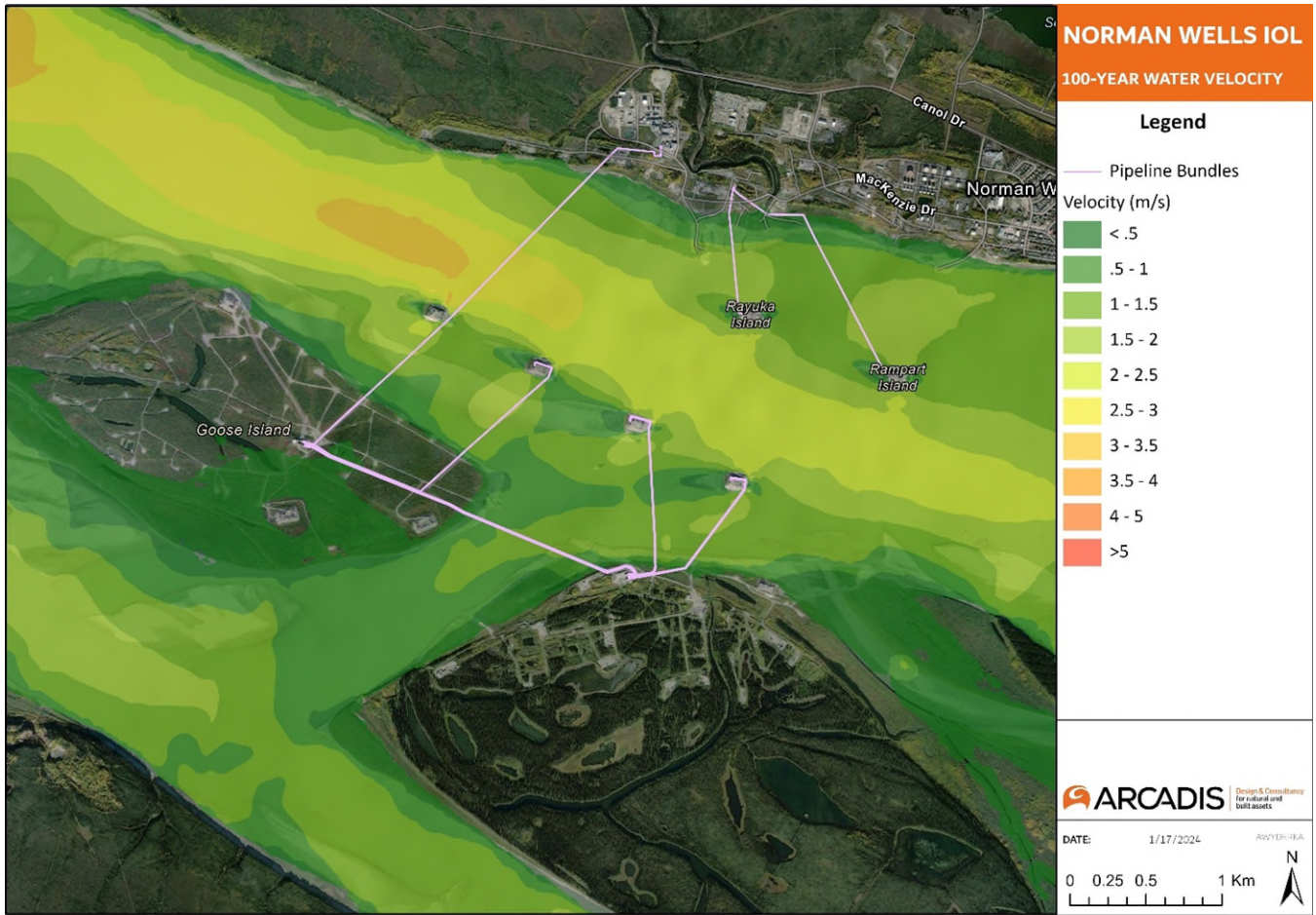


Figure 12. Modeled Water Velocity During the 100-Year Flow Event

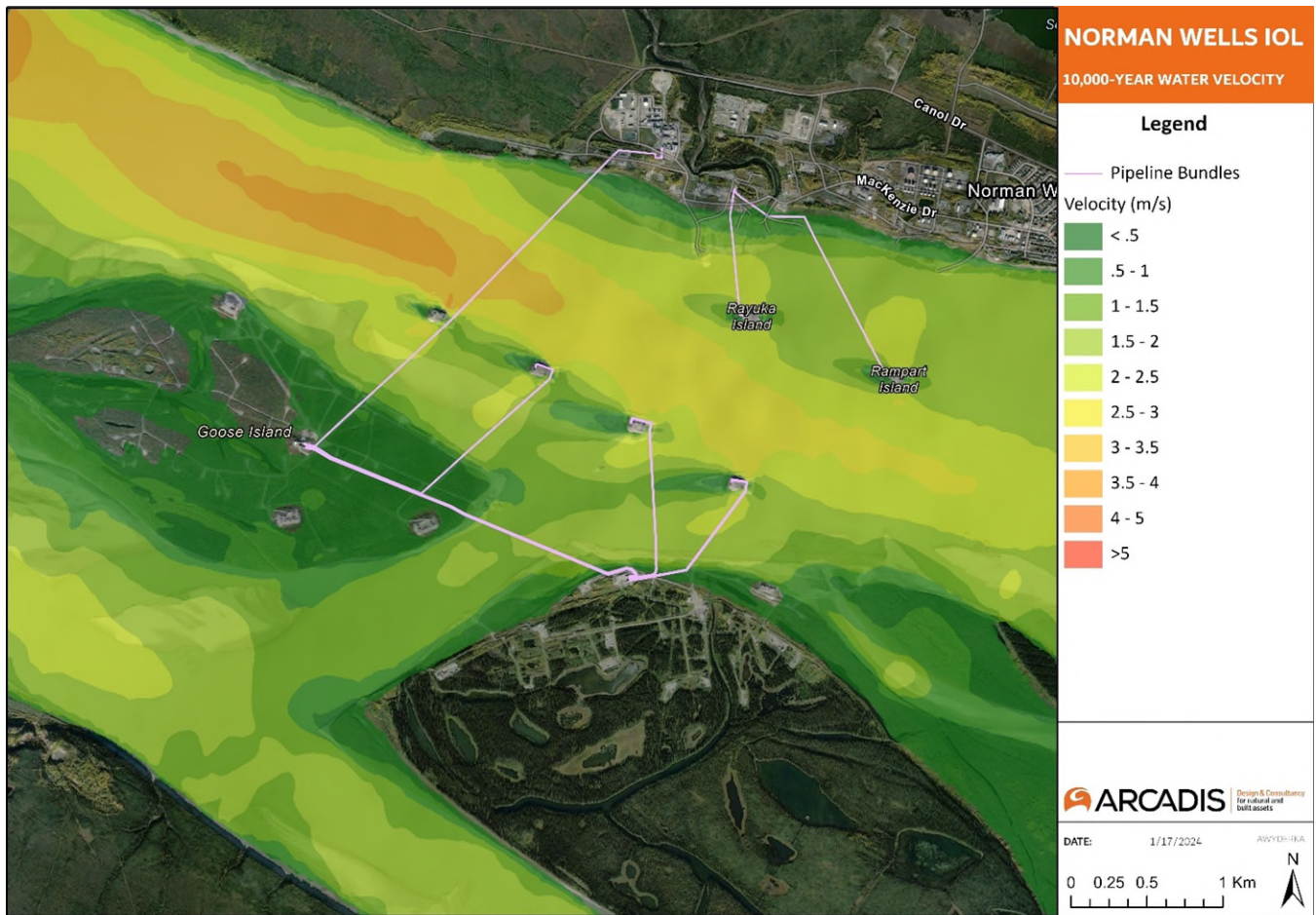


Figure 13. Modeled Water Velocity During the 10,000-Year Flow Event

Additionally, the water depth and velocity have been plotted by return period for a few locations in the project area. These locations are shown in **Figure 14** below, and their corresponding graphs are in **Figures 15-18**. These locations have been selected as they are in deep areas of their respective channels.

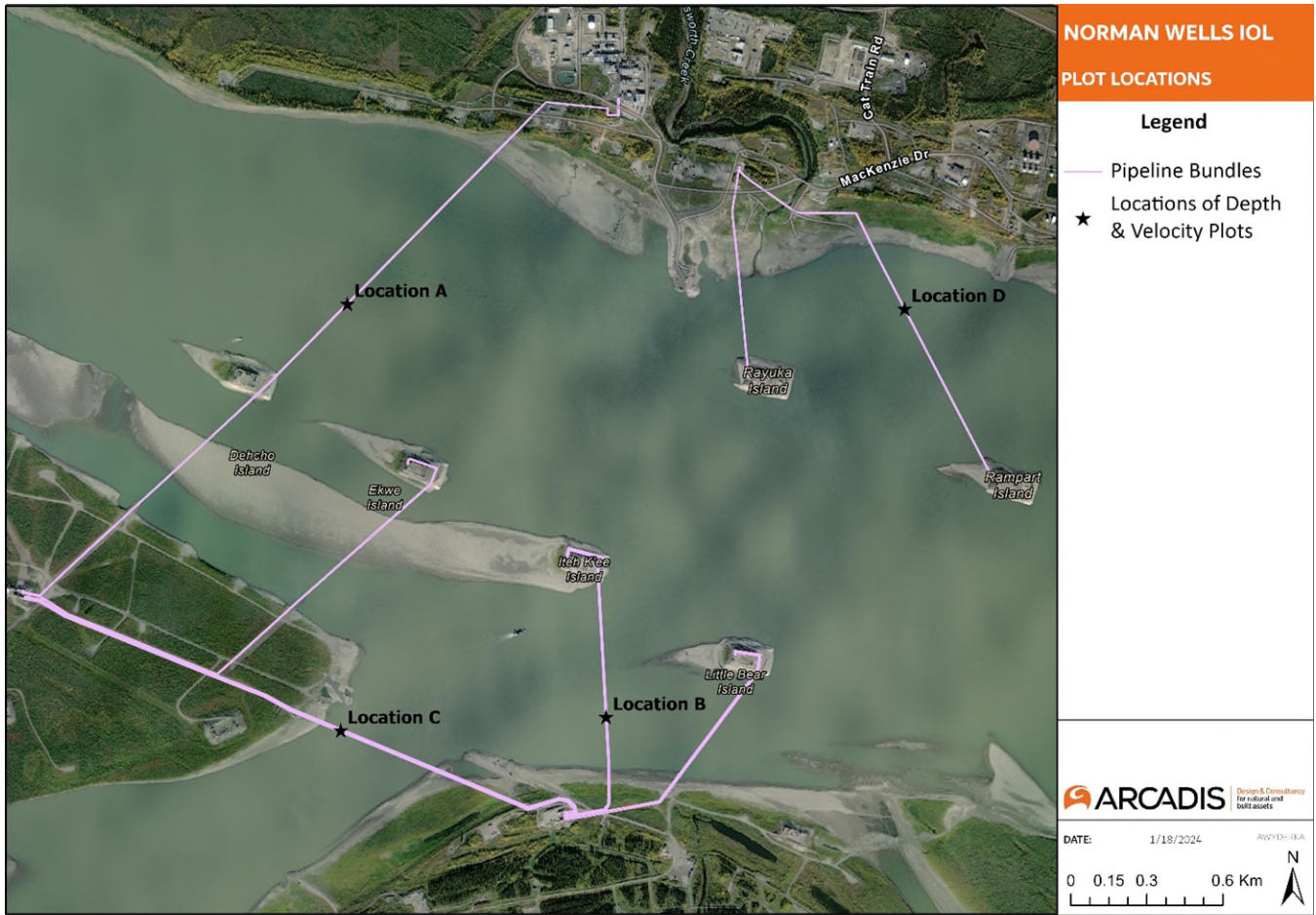


Figure 14. Locations of Points Selected for Depth and Velocity by Return Period Plots

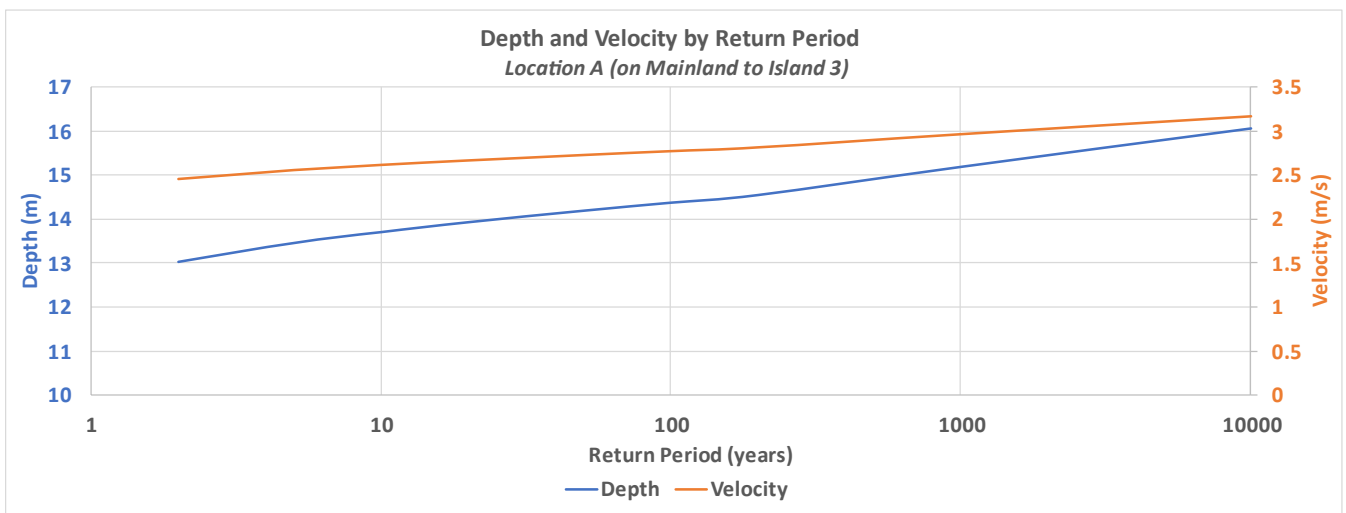


Figure 15. Depth and Velocity by Return Period at Location A on Mainland to Island 3

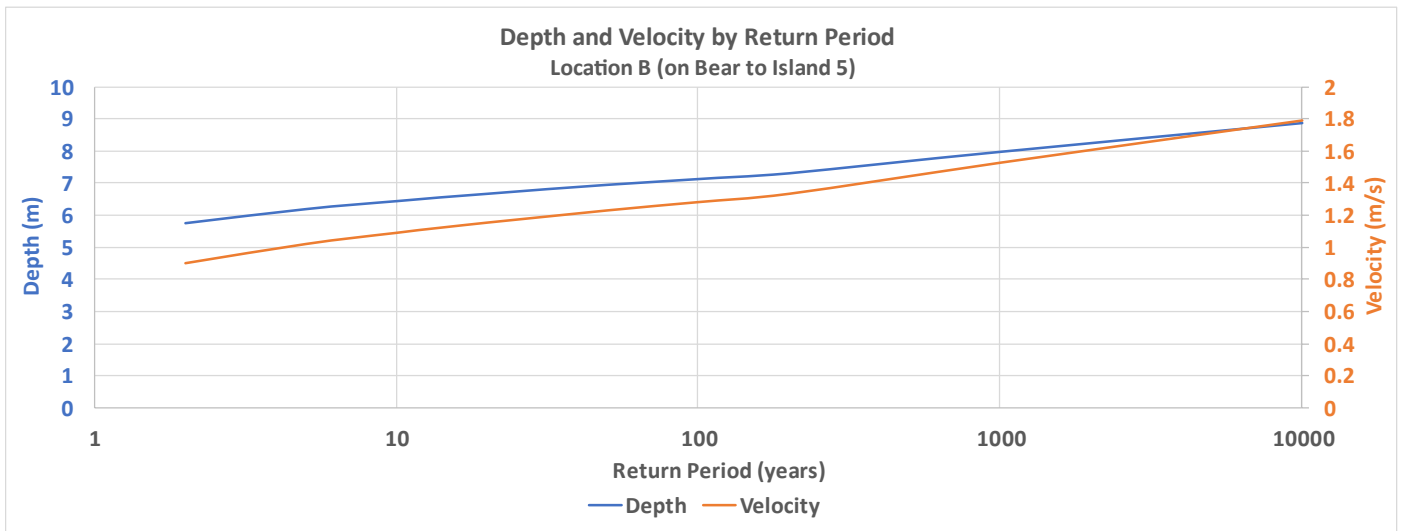


Figure 16. Depth and Velocity by Return Period at Location B on Bear to Island 5

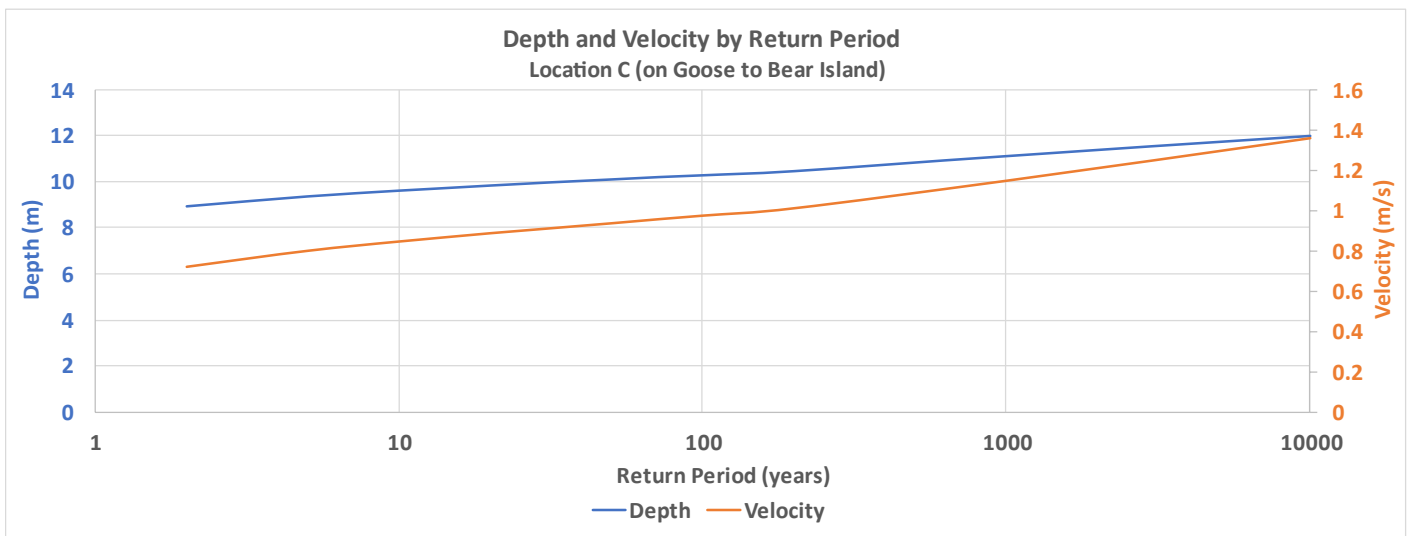


Figure 17. Depth and Velocity by Return Period at Location C on Goose to Bear Island

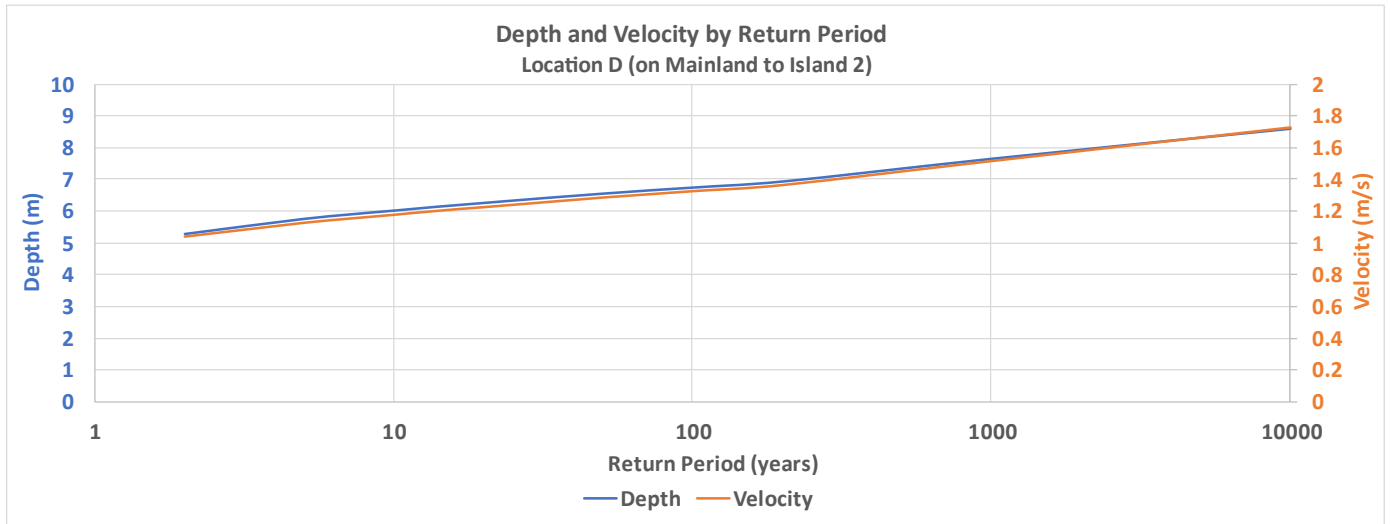


Figure 18. Depth and Velocity by Return Period at Location D on Mainland to Island 2

As can be seen in the figures, the maximum water depth in the main channel does not vary significantly between events – ranging from about 13m in the 2-year flow event to about 16m in the 10,000-year event. As the flow increases, the inundation extent also increases. It is worth noting that in the worst-case scenario modeled (the 10,000-year event) the model simulation does not predict that the IOL Operational Assets on the Mainland will be inundated. As with water depth, water velocities peak in the main channel with the 10,000-year event seeing a maximum velocity of 3.7 m/s in the main channel. The lowest velocities are observed in the two-year event with a maximum velocity in the main channel of about 2.75 m/s. The highest velocities are seen just downstream of the Mainland to Island 3 pipeline crossing. Velocities in inundated areas on land are very low (< .5 m/s).

3 Scour Depth and Depth of Cover Calculations

The purpose of the hydrodynamic model was to provide water depth and velocity inputs to scour calculations in order to estimate depth of cover during various flow events along the eight pipeline bundles. General and dune scour were calculated at each point and added together to create a combined scour estimate. Depth of cover was calculated by subtracting the scour depth from the riverbed elevation and comparing to known top-of-pipe elevations. The following sections will explain how these depth of cover estimates were derived.

3.1 Scour Depth Calculations

After exporting the water depth and velocity data for all nine return period events throughout the model domain, the calculation extents and points were determined. Scour depths were calculated along the pipeline bundles to the extents of the 100-year flow event and water depth and velocity were extracted every 10m along each of the pipelines – about 830 calculation points in total across the eight pipelines. **Figure 19** shows the ‘calculation points’ at which scour depths were calculated for the Goose to Island 3 crossing. Note that the stationing is in meters, and that for all pipelines, stationing is from left to right looking downstream. It should also be noted that Mainland to Island 3 and Goose to Island 3 were computed separately and results for these two pipelines are listed separately.



Figure 19. Calculation Points Along Goose to Island 3 Pipeline Bundle

3.1.1 General Scour

The Competent Method as described by the U.S. Bureau of Reclamation [5] was used to calculate general scour. This method first calculates a competent, or critical, velocity that is needed to mobilize sediment based off of the sediment type and the water depth. If the water velocity at any point exceeds the critical velocity, a second equation is then used to calculate the general scour based off the water depth, water velocity, and critical velocity at that location. To determine critical velocity, it must first be determined whether the sediment is cohesive or cohesionless. Silts and clays tend to be cohesive, while larger particles – sands and gravels – tend to be cohesionless. If the soil is cohesive, the values in **Table 3** are used to determine the critical velocity. The critical velocity for these cohesive materials is also dependent upon the erodibility of the sediment. Soils with higher plasticity are less erodible.

Table 3. Competent Velocities for the Erosion of Cohesive Materials

Depth of Flow (m)	Competent Mean Velocity (m/s)		
	Easily Erodeable Materials	Average	Resistant Materials
1.5	.6	1	1.8
3	.65	1.2	2.0
6	.7	1.3	2.3
15	.8	1.5	2.6

The critical velocity for cohesionless sediments is determined from a set of curves illustrated in Figure 20.

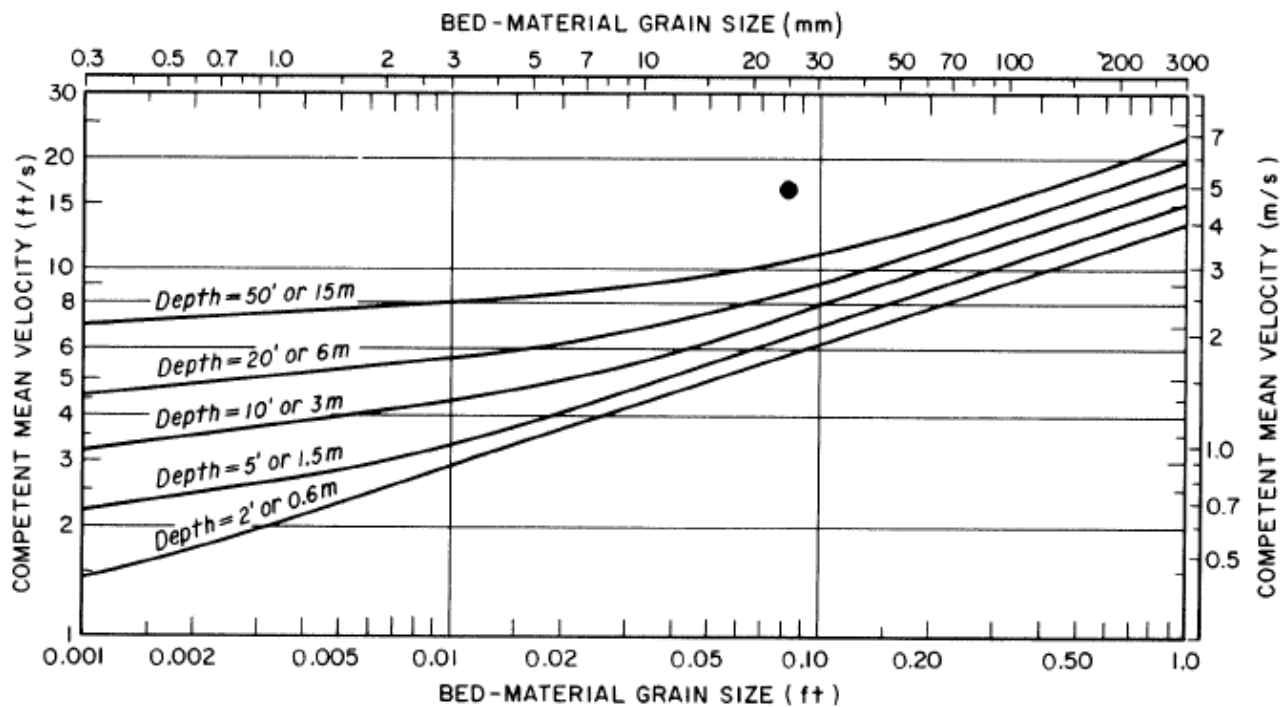


Figure 12. - Suggested competent mean velocities for significant bed movement of cohesionless materials, in terms of grain size and depth of flow (after Neill, 1973).

Figure 20. Competent Velocities for the Erosion of Cohesionless Materials[5]

Instead of estimating critical velocity from the set of curves, a set of equations created by Chang and Davis [6] from these curves was used. Which equation to use is dependent upon D_{50} , a measure of sediment size.

$$\text{For } D_{50} > .03\text{m: } V_C = 6.35y^{1/6}D_{50}^{1/3}$$

$$\text{For } .0003\text{m} \leq D_{50} \leq .03\text{m: } V_C = .3048^{-.65-x}11.5y^x D_{50}^{.35}$$

$$\text{For } D_{50} < .0003\text{m: } V_C = .55217\sqrt{y}$$

where;

$$x = .788 \frac{.123}{D_{50}^2}$$

$$V_C = \text{Critical Velocity } \left(\frac{m}{s}\right)$$

$$D_{50} = \text{Sediment Size (m)}$$

$$y = \text{water depth (m)}$$

Once critical velocity was determined at each calculation point and for each flow event, general scour depth was calculated using the following equation:

$$d_s = y \left(\frac{V_m}{V_C} - 1 \right)$$

where;

$$d_s = \text{Scour Depth Below Streambed (m)}$$

$$y = \text{Water Depth (m)}$$

$$V_m = \text{Mean Velocity } \left(\frac{m}{s}\right)$$

$$V_C = \text{Critical Velocity } \left(\frac{m}{s}\right)$$

In addition to the competent method, USDA Technical Supplement 14B [7] provides a method for estimating the maximum potential general scour [8]. Calculated general scour was limited to the maximum given by the following equation:

$$d_s(\text{max}) = 3.8D_{50}^{-.11}$$

where;

$$d_s(\text{max}) = \text{maximum scour depth}$$

$$D_{50} = \text{Sediment Size (mm)}$$

3.1.2 Dune Scour

Dune scour is a form of bedform scour where dunes in the riverbed may be displaced by a flow event thereby producing scour in the area the dune has moved from. Dune scour can be estimated using the following equation, based off equations provided in USDA Technical Supplement 14B [7]:

$$d_d = 1.25D_{50}^3 y^{-7}$$

where;

$$d_d = \text{dune height (m)}$$

$$D_{50} = \text{Sediment Size (m)}$$

$$y = \text{Water Depth (m)}$$

Estimates of dune scour across all pipelines are nonzero and increase as the flow event (and therefore water depth) increase. Note that dune scour is not dependent upon water velocity.

3.1.3 Combined Scour

Combined scour is calculated by adding up the dune and general scour estimates at each location. This provides for the most conservative estimate of scour as it assumes that both types of scour will occur at the same time. Note that at locations where no general scour is predicted, combined scour will be equal to dune scour.

3.1.4 Soil Data

The equations to calculate scour depth require knowledge of the sediment material on the riverbed. For this study, only the topmost or superficial layer of sediment was used for analysis. Information on the sediment size, D_{50} , as well as erodibility in the case of cohesive sediments, was needed for the calculations. Sediment data came from two sources: the first is a Geotechnical Report from Komex Consultants (1980) [9] and the second is the 2018 Report from WorleyParsons [1]. The Report from Komex provided soil borings at 116 locations and provided grain distribution analysis (from which D_{50} can be gathered) for about 40 of those locations. The WorleyParsons Report provided grain size distribution analyses at 18 locations, however, four of those samples were deemed to be outliers, leaving 14 locations where the D_{50} is provided. **Figure 21** below illustrates the locations of all soil samples. For more detailed information on the sediment data available see **Appendix A**, which provides figures of the D_{50} data at each pipeline.

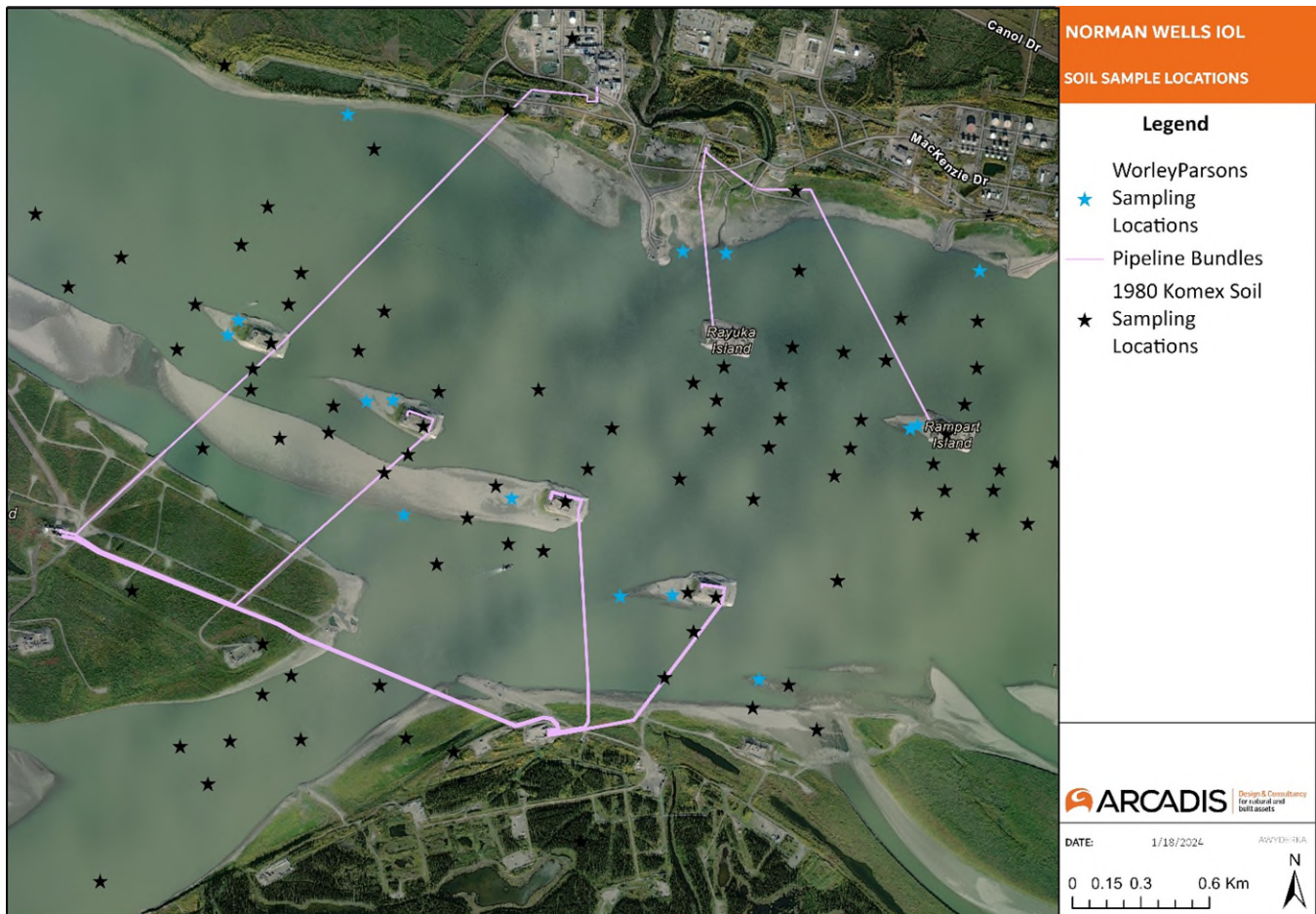


Figure 21. Soil Sample Locations

Additionally, some of the borings documented in the 1980 Report go to refusal and thereby supply information of depth to bedrock. It is mainly around Mainland to Island 2 that depth to bedrock is known. From the soil borings, it appears that the bedrock is about 2m below the surface in the area directly around the pipeline of Mainland to Island 2. When the pipeline in this area was placed, the bedrock was blasted through and sand was placed on top of the pipeline to cover it up.

3.1.5 Sensitivity Analysis

Because much of the sediment data used in the analysis is older and because sediment data was sparse along many pipelines, there is uncertainty regarding the sediment characteristics along the extent of each pipeline corridor. Therefore, a sensitivity analysis was undertaken to understand the minimum and maximum scour depths possible at each pipeline based on the variation in sediment data along each pipeline corridor. To do this, scour depths at each calculation point were computed using the range of measured sediment characteristics documented for each pipeline location. These sediment values used in the final analysis can be seen in **Table 4** below. **Appendix A** provides further information on the selection of Sediment Types for each pipeline.

Plots of each pipeline showing the potential combined scour during the 100-year event for both sediment scenarios, as well as the distribution of potential scour for all nine flow events are provided in **Appendix B**. An

example of the plots for Mainland to Island 2 is provided in **Figures 22-24**. Because the change in sediment type can have opposite effects on general and dune scour (i.e. an increase in sediment size can lead to a decrease in general scour potential but lead to an increase in dune scour potential), it is possible that for some pipelines, the scour lines of the different sediment types may cross. It should also be noted that several of the pipelines have riprap for some portion of the pipeline. Where riprap is known to exist, all scour has been set to zero and this is reflected in all provided tables and figures.

Table 4. Sediment Scenarios Used in Scour Analysis

Pipeline	Scenario	Sediment Properties			Implication	
		D_{50} (mm)	Cohesive	Erodibility	General Scour Potential	Dune Scour Potential
Mainland To Island 1	Sediment Type 1	.013	Yes	Medium	Higher	Similar
	Sediment Type 2	.013	Yes	Low	Lower	Similar
Mainland To Island 2	Sediment Type 1	.2	No	N/A	Higher	Lower
	Sediment Type 2	1	No	N/A	Lower	Higher
Mainland To Island 3	Sediment Type 1	.075	No	N/A	Higher	Similar
	Sediment Type 2	.075	Yes	Low	Lower	Similar
Goose To Island 3	Sediment Type 1	.25	No	N/A	Similar	Higher
	Sediment Type 2	.075	No	N/A	Similar	Lower
Goose To Island 4	Sediment Type 1	.09	No	N/A	Higher	Higher
	Sediment Type 2	.075	Yes	Low	Lower	Lower
Bear To Island 5	Sediment Type 1	.25	No	N/A	Similar	Higher
	Sediment Type 2	.19	No	N/A	Similar	Lower
Bear To Island 6	Sediment Type 1	.25	No	N/A	Higher	Lower
	Sediment Type 2	4.76	No	N/A	Lower	Higher
Goose To Bear	Sediment Type 1	.25	No	N/A	Higher	Higher
	Sediment Type 2	.07	Yes	Low	Lower	Lower

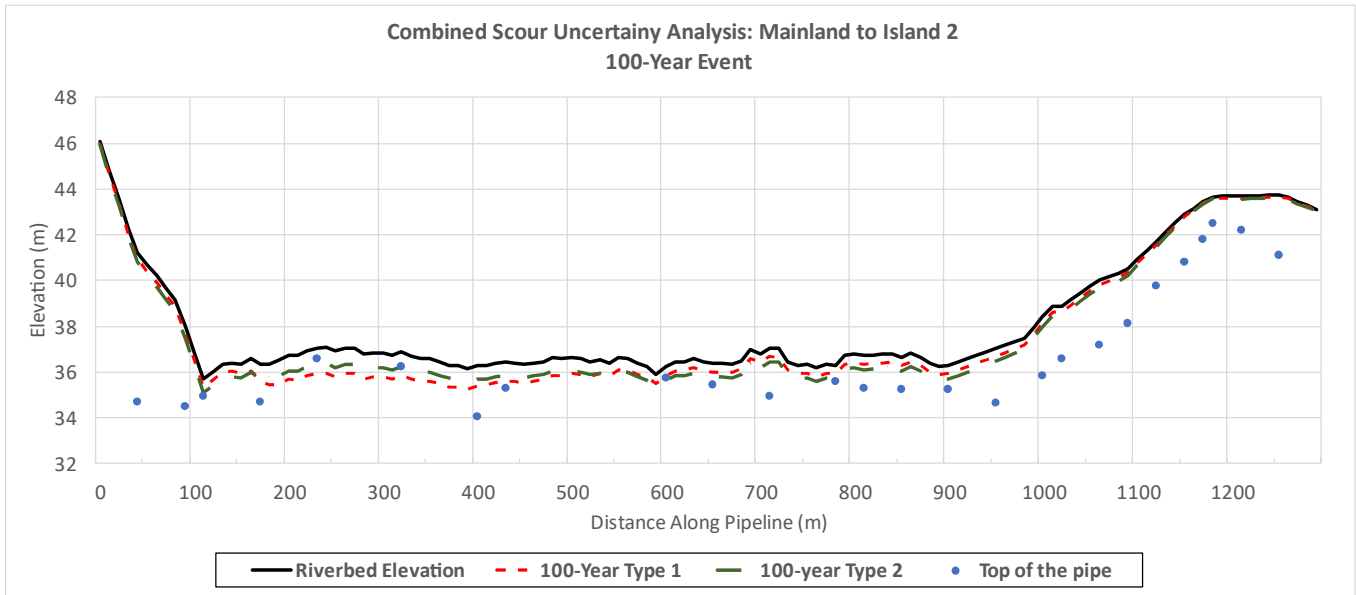


Figure 22. Combined Scour During the 100-Year Flow Event on Mainland to Island 2 for Both Sediment Scenarios

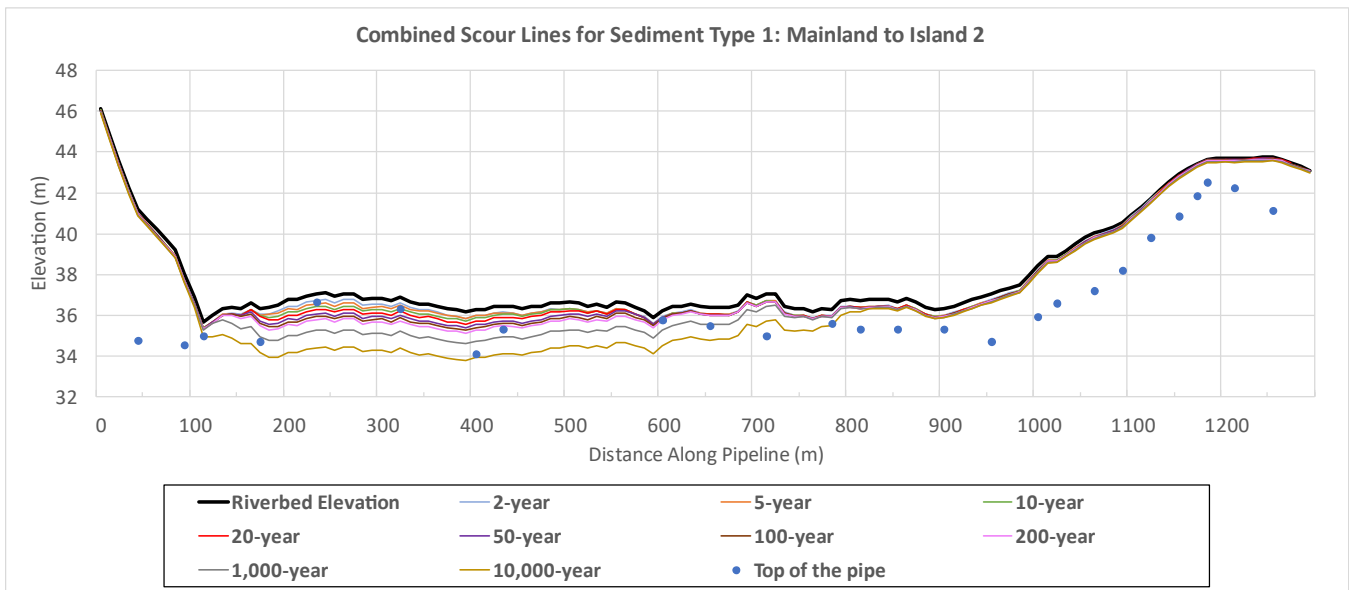


Figure 23. Combined Scour Along Mainland to Island 2 with Sediment Type 1

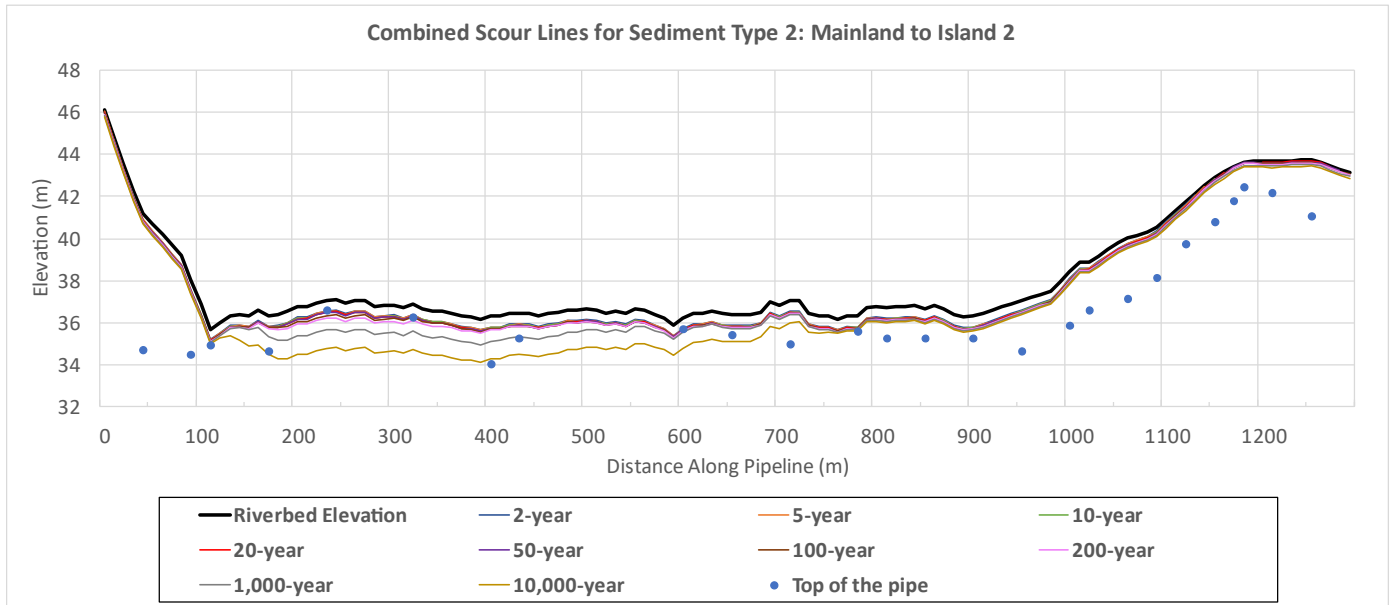


Figure 24. Combined Scour Along Mainland to Island 2 with Sediment Type 2

3.2 Depth of Cover Calculations

To estimate depth of cover remaining after the computed scour potential, co-located information is needed about the riverbed elevation and the top-of-pipe elevation. Data for both the riverbed and top-of-pipe elevations was taken from the Arcadis 2023 survey data. Because the top-of-pipe data is not available at every calculation point, estimated post-scour depth of cover is only calculated at locations where the top-of-pipe is known.

3.3 Limitations

Due to the limited extents of recent survey data, the DEM used for the model is from survey data taken in 2012 at a 50m resolution. Because the riverbed experiences significant changes from year to year, there may be shifts in the riverbed that are not currently being captured in the hydrodynamic model. This limitation is mitigated by using the most recent 2023 topobathy survey data for depth of cover calculations.

A second limitation relates to the sediment data available, which is mostly from 1980 and does not provide comprehensive sediment data along the pipelines. Additionally, most of the sediment data for the project area is from 1980 and before the artificial islands were constructed. Because of this, the sediment data that was taken then may not match what is currently at and around the pipelines. This limitation is accounted for with the uncertainty analysis which aids in understanding which pipelines' depth of cover estimates are most impacted by the uncertainty in the sediment.

Lastly, the water velocity data that is output from the hydrodynamic model is depth-averaged velocity data. Because of this, it is the depth-averaged velocity that is used in scour calculations rather than the water velocity at the bottom of the riverbed.

4 Results and Conclusions

4.1 Scour Depth Results

The scour depths at each calculation point for all nine return period events and for both sediment scenarios are provided in spreadsheet format as part of **Appendix C**. Additionally, **Tables 5-12** below summarize the general, dune, and combined scour possible during the 100-year flow event at each pipeline. The tables summarize the data every 50 meters, however, **Appendix C** provides the data at each calculation point (every 10 meters) and for all nine flow events modeled.

Table 5. Scour Depths Along Mainland to Island 1 During the 100-Year Flow Event

Station Information			Sediment Type 1			Sediment Type 2		
Station (m)	Depth (m)	Velocity (m/s)	General Scour (m)	Dune Scour (m)	Combined Scour (m)	General Scour (m)	Dune Scour (m)	Combined Scour (m)
0	0.6	0.1	0	0	0	0	0	0
50	3.7	1.1	0	0.1	0.1	0	0.1	0.1
100	5.8	1.6	1.6	0.1	1.8	0	0.1	0.1
150	6.4	1.8	2.6	0.2	2.8	0	0.2	0.2
200	7	1.8	2.9	0.2	3	0	0.2	0.2
250	7.2	1.8	2.9	0.2	3	0	0.2	0.2
300	7	1.8	2.8	0.2	3	0	0.2	0.2
350	5.9	1.8	2.3	0.1	2.4	0	0.1	0.1
400	4.5	1.4	0.5	0.1	0.6	0	0.1	0.1
450	3.2	1	0	0.1	0.1	0	0.1	0.1
500	2.3	0.7	0	0.1	0.1	0	0.1	0.1
550	2.1	0.6	0	0.1	0.1	0	0.1	0.1
600	1.6	0.5	0	0.1	0.1	0	0.1	0.1
650	0.4	0.2	0	0	0	0	0	0

Table 6. Scour Depths Along Mainland to Island 2 During the 100-Year Flow Event

Station Information			Sediment Type 1			Sediment Type 2		
Station (m)	Depth (m)	Velocity (m/s)	General Scour (m)	Dune Scour (m)	Combined Scour (m)	General Scour (m)	Dune Scour (m)	Combined Scour (m)
0	1.1	0.2	0	0.1	0.1	0	0.2	0.2
50	4.3	0.6	0	0.3	0.3	0	0.4	0.4
100	6	1.2	0	0.3	0.3	0	0.5	0.5

150	6.7	1.4	0	0.4	0.4	0	0.6	0.6
200	6.7	1.6	0.7	0.4	1.1	0.1	0.6	0.7
250	6.6	1.6	0.7	0.4	1.1	0.1	0.6	0.7
300	6.5	1.6	0.7	0.4	1	0.1	0.6	0.6
350	6.6	1.5	0.6	0.4	1	0	0.6	0.6
400	6.7	1.5	0.5	0.4	0.9	0	0.6	0.6
450	6.6	1.5	0.5	0.4	0.8	0	0.6	0.6
500	6.6	1.5	0.4	0.4	0.7	0	0.6	0.6
550	6.7	1.5	0.2	0.4	0.6	0	0.6	0.6
600	6.8	1.4	0	0.4	0.4	0	0.6	0.6
650	6.8	1.4	0	0.4	0.4	0	0.6	0.6
700	6.7	1.4	0	0.4	0.4	0	0.6	0.6
750	6.8	1.3	0	0.4	0.4	0	0.6	0.6
800	6.8	1.3	0	0.4	0.4	0	0.6	0.6
850	6.9	1.2	0	0.4	0.4	0	0.6	0.6
900	6.8	1.1	0	0.4	0.4	0	0.6	0.6
950	6.2	1	0	0.3	0.3	0	0.6	0.6
1000	4.5	0.9	0	0.3	0.3	0	0.4	0.4
1050	3.4	0.6	0	0.2	0.2	0	0.4	0.4
1100	2.4	0.4	0	0.2	0.2	0	0.3	0.3
1150	0.9	0.2	0	0.1	0.1	0	0.1	0.1
1200	0.6	0.1	0	0.1	0.1	0	0.1	0.1
1250	0.6	0.1	0	0.1	0.1	0	0.1	0.1

Table 7. Scour Depths Along Mainland to Island 3 During the 100-Year Flow Event

Station Information			Sediment Type 1			Sediment Type 2		
Station (m)	Depth (m)	Velocity (m/s)	General Scour (m)	Dune Scour (m)	Combined Scour (m)	General Scour (m)	Dune Scour (m)	Combined Scour (m)
0	2.6	1.3	1.2	0.1	1.4	0	0.1	0.1
50	5.4	2.2	3.9	0.2	4.2	0	0.2	0.2
100	10.1	2.5	4.3	0.4	4.6	0.2	0.4	0.6
150	11.8	2.5	4	0.4	4.4	0.2	0.4	0.6
200	12.3	2.6	4.4	0.4	4.8	0.6	0.4	1
250	12.8	2.7	4.8	0.4	5.2	1	0.4	1.4
300	13.4	2.8	5	0.4	5.5	1.2	0.4	1.7

350	13.8	2.8	5	0.5	5.5	1.3	0.5	1.7
400	14.2	2.8	4.8	0.5	5.3	1.2	0.5	1.6
450	14.4	2.8	4.6	0.5	5.1	1.1	0.5	1.5
500	14	2.7	4.5	0.5	4.9	0.9	0.5	1.3
550	12.9	2.7	4.4	0.4	4.8	0.7	0.4	1.1
600	11.5	2.6	4.2	0.4	4.6	0.4	0.4	0.8
650	9.7	2.4	4	0.4	4.4	0	0.4	0.4
700	7.9	2.3	3.7	0.3	4	0	0.3	0.3
750	6.6	2.1	3.2	0.3	3.4	0	0.3	0.3
800	6	1.9	2.5	0.3	2.8	0	0.3	0.3
850	6	1.8	1.9	0.3	2.2	0	0.3	0.3
900	6	1.7	1.4	0.3	1.7	0	0.3	0.3
950	6	1.6	1	0.3	1.2	0	0.3	0.3
1000	6	1.5	0.6	0.3	0.8	0	0.3	0.3
1050	5.9	1.4	0.3	0.3	0.6	0	0.3	0.3
1100	5.9	1.3	0	0.2	0.3	0	0.2	0.2
1150	5.7	1.3	0	0.2	0.2	0	0.2	0.2
1200	5	1.1	0	0.2	0.2	0	0.2	0.2
1250	3.6	0.9	0	0.2	0.2	0	0.2	0.2
1300	2.4	0.3	0	0.1	0.1	0	0.1	0.1

Table 8. Scour Depths Along Goose to Island 3 During the 100-Year Flow Event

Station Information			Sediment Type 1			Sediment Type 2		
Station (m)	Depth (m)	Velocity (m/s)	General Scour (m)	Dune Scour (m)	Combined Scour (m)	General Scour (m)	Dune Scour (m)	Combined Scour (m)
0	0.2	0.1	0	0	0	0	0	0
50	0.7	0.4	0	0	0	0	0	0
100	0.9	0.6	0	0	0	0	0	0
150	1.3	0.8	0	0	0	0	0	0
200	1.6	0.9	0.6	0.1	0.7	0.6	0.1	0.7
250	1.9	1.1	0.8	0.2	0.9	0.8	0.1	0.9
300	2.3	1.2	1	0.2	1.2	1	0.1	1.1
350	2.8	1.3	1.3	0.2	1.5	1.3	0.1	1.4
400	3.4	1.5	1.6	0.2	1.8	1.6	0.2	1.7
450	3.9	1.6	1.8	0.3	2.1	1.8	0.2	2

500	4.3	1.7	2.2	0.3	2.5	2.2	0.2	2.4
550	5	1.8	2.4	0.3	2.8	2.4	0.2	2.7
600	5.4	1.9	2.4	0.3	2.7	2.4	0.2	2.6
650	5.6	1.7	1.6	0.3	1.9	1.6	0.2	1.8
700	4.4	1.3	0.6	0.3	0.9	0.6	0.2	0.8
750	1.7	0.8	0.3	0.1	0.5	0.3	0.1	0.4

Table 9. Scour Depths Along Goose to Island 4 During the 100-Year Flow Event

Station Information			Sediment Type 1			Sediment Type 2		
Station (m)	Depth (m)	Velocity (m/s)	General Scour (m)	Dune Scour (m)	Combined Scour (m)	General Scour (m)	Dune Scour (m)	Combined Scour (m)
0	0.2	0.3	0	0	0	0	0	0
50	1.3	0.9	0	0	0	0	0	0
100	1.9	1.2	0	0	0	0	0	0
150	2.1	1.3	0	0	0	0	0	0
200	2.2	1.4	0	0	0	0	0	0
250	2.4	1.5	0	0	0	0	0	0
300	2.9	1.5	1.8	0.2	2	0	0.2	0.2
350	3.2	1.6	1.9	0.2	2	0	0.2	0.2
400	3.2	1.6	2	0.2	2.1	0	0.2	0.2
450	2.8	1.6	2.1	0.2	2.2	0	0.1	0.1
500	2.5	1.6	2.1	0.1	2.3	0	0.1	0.1
550	2.4	1.5	1.9	0.1	2.1	0	0.1	0.1
600	2.5	1.4	1.6	0.1	1.8	0	0.1	0.1
650	3	1.3	1.1	0.2	1.3	0	0.2	0.2
700	3.2	1.2	0.8	0.2	0.9	0	0.2	0.2
750	2.2	0.7	0	0.1	0.1	0	0.1	0.1
800	0.4	0.2	0	0	0	0	0	0

Table 10. Scour Depths Along Bear to Island 5 During the 100-year Flow Event

Station Information			Sediment Type 1			Sediment Type 2		
Station (m)	Depth (m)	Velocity (m/s)	General Scour (m)	Dune Scour (m)	Combined Scour (m)	General Scour (m)	Dune Scour (m)	Combined Scour (m)
0	0.4	0.2	0	0.1	0.1	0	0.1	0.1

50	2.9	0.9	0	0.2	0.2	0	0.2	0.2
100	5.8	1.4	0.2	0.4	0.5	0.2	0.3	0.5
150	6.7	1.5	0.2	0.4	0.6	0.2	0.4	0.5
200	6.8	1.5	0.1	0.4	0.5	0.1	0.4	0.5
250	7	1.4	0	0.4	0.4	0	0.4	0.4
300	7.1	1.4	0	0.4	0.4	0	0.4	0.4
350	6.9	1.2	0	0.4	0.4	0	0.4	0.4
400	6.1	1	0	0.4	0.4	0	0.3	0.3
450	5.7	0.8	0	0.4	0.4	0	0.3	0.3
500	5.9	0.7	0	0.4	0.4	0	0.3	0.3
550	6.7	0.7	0	0.4	0.4	0	0.4	0.4
600	7.8	0.9	0	0.4	0.4	0	0.4	0.4
650	8.5	1.2	0	0.5	0.5	0	0.4	0.4
700	8.8	1.4	0	0.5	0.5	0	0.4	0.4
750	8.7	1.5	0	0.5	0.5	0	0.4	0.4
800	8.3	1.6	0	0.5	0.5	0	0.4	0.4
850	5.2	1.4	0.7	0.3	1.1	0.7	0.3	1
900	0.5	0.6	0.2	0.1	0.3	0.2	0.1	0.3

Table 11. Scour Depths Along Bear to Island 6 During the 100-year Flow Event

Station Information			Sediment Type 1			Sediment Type 2		
Station (m)	Depth (m)	Velocity (m/s)	General Scour (m)	Dune Scour (m)	Combined Scour (m)	General Scour (m)	Dune Scour (m)	Combined Scour (m)
0	0.2	0.1	0	0	0	0	0.1	0.1
50	0.5	0.1	0	0.1	0.1	0	0.1	0.1
100	1	0.3	0	0.1	0.1	0	0.3	0.3
150	3.9	0.9	0	0.3	0.3	0	0.6	0.6
200	6	1.3	0	0.4	0.4	0	0.9	0.9
250	6.9	1.4	0	0	0	0	0	0
300	7	1.5	0	0	0	0	0	0
350	7	1.5	0	0	0	0	0	0
400	6.8	1.5	0.3	0.4	0.7	0	1	1
450	6.6	1.5	0.6	0.4	1	0	0.9	0.9
500	6.3	1.5	0.7	0.4	1.1	0	0.9	0.9
550	5.2	1.5	1.1	0.3	1.4	0	0.8	0.8

600	3.6	1.5	1.6	0.3	1.8	0	0.6	0.6
650	2.7	1.6	1.9	0.2	2.1	0.1	0.5	0.6
700	2.3	1.5	1.7	0.2	1.9	0	0.4	0.5

Table 12. Scour Depths Along Goose to Bear Island During the 100-year Flow Event

Station Information			Sediment Type 1			Sediment Type 2		
Station (m)	Depth (m)	Velocity (m/s)	General Scour (m)	Dune Scour (m)	Combined Scour (m)	General Scour (m)	Dune Scour (m)	Combined Scour (m)
0	0.7	0.1	0	0.1	0.1	0	0.1	0.1
50	3	0.4	0	0.2	0.2	0	0.2	0.2
100	2.9	0.6	0	0.2	0.2	0	0.2	0.2
150	2.7	0.8	0	0.2	0.2	0	0.1	0.1
200	3.1	0.9	0	0.2	0.2	0	0.2	0.2
250	3.6	1.1	0.1	0.3	0.4	0	0.2	0.2
300	4.5	1.1	0	0.3	0.3	0	0.2	0.2
350	5.9	1.1	0	0.4	0.4	0	0.2	0.2
400	8.5	1.1	0	0.5	0.5	0	0.3	0.3
450	10	1.1	0	0.5	0.5	0	0.4	0.4
500	9	1.1	0	0.5	0.5	0	0.3	0.3
550	9	1.1	0	0.5	0.5	0	0.3	0.3
600	7.8	1.1	0	0	0	0	0	0
650	8.1	1	0	0	0	0	0	0
700	8.2	1	0	0	0	0	0	0
750	10.5	1	0	0.5	0.5	0	0.4	0.4
800	8.6	1	0	0.5	0.5	0	0.3	0.3
850	4.2	0.8	0	0.3	0.3	0	0.2	0.2
900	2.3	0.4	0	0.2	0.2	0	0.1	0.1
950	0.8	0.2	0	0.1	0.1	0	0.1	0.1

4.2 Depth of Cover Results

Tables of the post-scour depth of cover along each pipeline for the nine flow events evaluated at both sediment scenarios are available in **Appendix C**. The results are also summarized in **Figures 25-27** below which show the depth of cover with green, yellow, or red coloring depending on the available depth of cover for current conditions

(Figure 25) and during the 100-Year flow event (Figures 26-27). Note that depth of cover can only be evaluated at locations where the top-of-pipe elevation is known.



Figure 25. Existing Depth of Cover (based on 2023 survey)



Figure 26. Minimum Depth of Cover During the 100-Year Event with the Sediment Type 2 Scenario



Figure 27. Minimum Depth of Cover During the 100-Year Event with the Sediment Type 1 Scenario

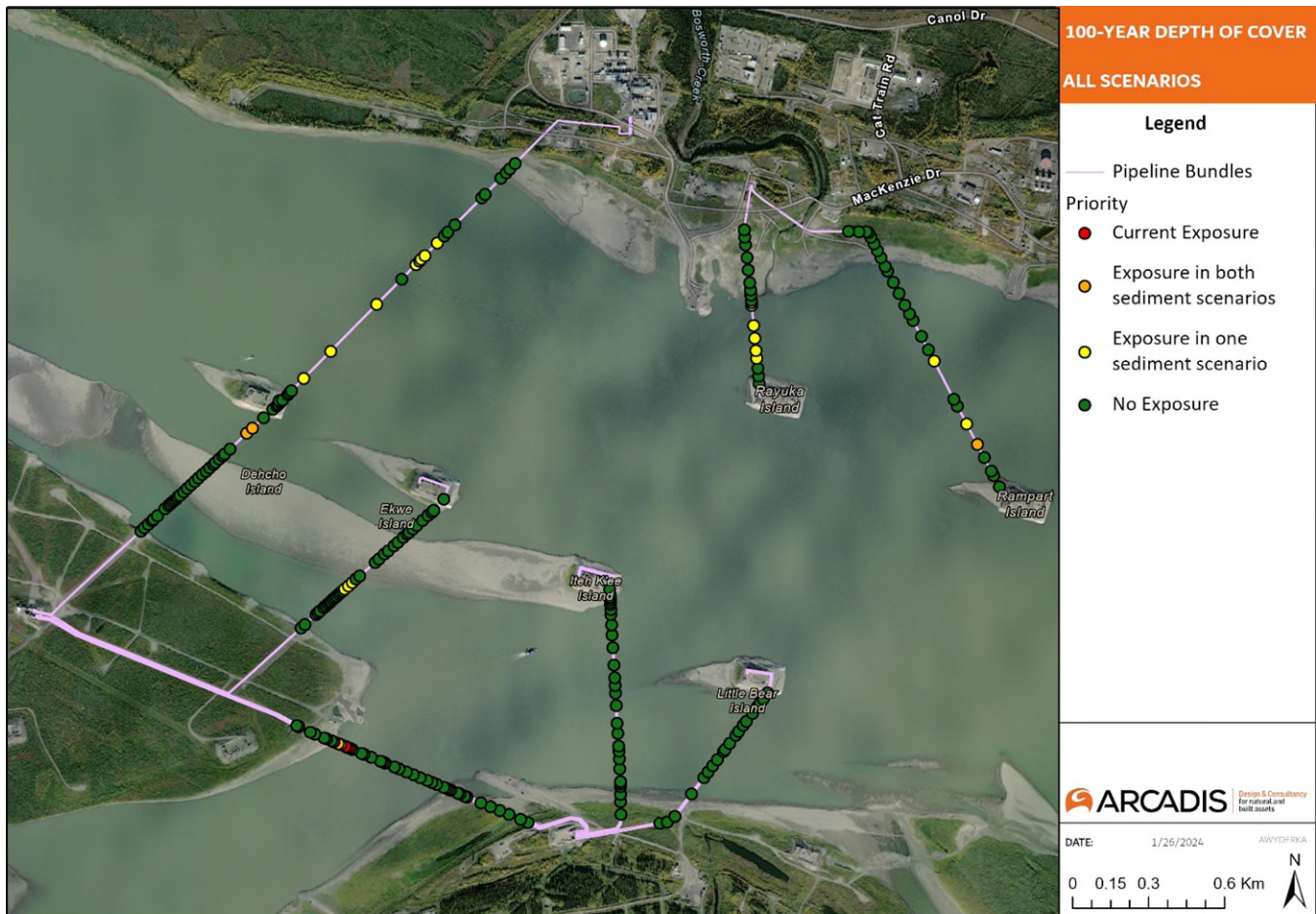


Figure 28. Pipeline Exposure During the 100-Year Event

As is illustrated in the figures, certain pipelines are more sensitive to a change in sediment than others. **Figure 28** makes this clear, with the yellow areas indicating that there is exposure during only one sediment scenario and orange areas indicating exposure for both sediment scenarios. The pipeline bundles from Mainland to Island 1 and Mainland to Island 3 as well as Goose to Island 4 are the most sensitive to a change in sediment type. At these pipelines, there is no exposure estimated during the 100-year flow event for the Sediment Type 2 scenario, whereas exposure is estimated at some locations for all three of these pipelines for the Sediment Type 1 scenario. For the pipelines from Bear to Island 5 and Bear to Island 6, no exposure is expected during the 100-year event for either sediment scenario. From Goose to Bear Island, there is currently exposure along the pipeline bundle (closer to Goose Island) which is slightly worsened during both sediment scenarios. Along Goose to Island 3 and Mainland to Island 2, the 100-year event is expected to cause exposure to the pipeline for both sediment scenarios.

4.3 Pipeline Prioritization

Considering the sensitivity analysis and the range of scour predicted with various flow events, the following prioritization of pipeline areas is proposed for consideration of possible mitigation activities. Higher prioritization is given to pipelines where the extent of exposure is greater and/or more likely to occur or where depth of cover is

already minimal. It should be noted that because of the high uncertainty regarding the sediment data, more sediment data is needed to be sure of the priorities.

High Priority:

There are regions of estimated scour potential along the pipeline corridors between Goose to Bear Island, Mainland to Island 1, Mainland to Island 2, and Mainland to Island 3 which are considered to be a high priority concern. In the case of Goose to Bear Island, the pipeline is currently exposed from about station 750 to 800². While this exposure is not estimated to significantly worsen with future flow events, it still poses a threat to the safety of the pipeline.

Mainland to Island 1 is deemed to be a high priority because under the Sediment Type 1 Scenario, even the 2-year flow event is predicted to expose or nearly expose the pipeline between station 200 to 350. While the Sediment Type 2 scenario is not predicted to cause significant scour, there is very high uncertainty regarding the sediment type in this area. Additionally, Mainland to Island 1 currently has minimal depth of cover at multiple locations. In the case of Mainland to Island 2, there is minimal depth of cover from approximately station 230 to station 320 and near station 600. These areas are projected to become exposed during the 5-year flow event for both sediment scenarios. Soil borings from the 1980 Komex report indicate that bedrock was located 2 meters below the riverbed at the time of survey, and it is known that this pipeline was laid on top of bedrock and sand was placed on top of the pipeline afterwards. This knowledge limits the uncertainty of the sediment type in the area, but the precise bedrock elevation is not known to be able to provide a precise vertical limit of scour potential. Mainland to Island 3 is also selected to be a 'high priority' pipeline because the 2-year flow event is estimated to cause significant exposure to the pipeline between station 50 to station 650 under the Sediment Type 1 Scenario. It is important to note, however, that under the Sediment Type 2 scenario, no exposure is expected to occur during the 100-year event. For this pipeline crossing especially, more sediment data is needed to be sure of its vulnerability. For Mainland to Islands 1, 2 and 3, the presence of a tributary entering the river on the right bank may supply fine silts into the river potentially leading to a high probability of fine, and therefore more mobile, sediments composing the superficial layer of the riverbed.

Medium Priority:

Several areas along the pipeline bundles from Goose to Island 4 and Goose to Island 3 are considered to be a medium priority. Goose to Island 3 is considered to be of medium priority because in both sediment scenarios, exposure is estimated to occur around station 580 to 620 for even the 10-year flow event. Despite this, much of the pipeline currently has adequate depth of cover, and it is expected that about 80 meters of pipeline would be exposed during the 100-year flow event, regardless of the sediment type in the area. On Goose to Island 4, exposure is only expected for events greater than the 50-year for a small section of the pipeline (around station 300) and only for Sediment Type 1. For both Goose to Island 3 and Goose to Island 4, the sand bars currently present off the coast of Goose Island were likely not there during the 1980 soil survey (which was before the presence of the artificial islands). It is possible that these sand bars have since affected sediment characteristics of the riverbed. Additionally, commentary in the 1980 Komex report indicates fine silts (a high mobility sediment type) off the coast of Goose Island. In light of these facts, and especially for Goose to Island 4 where the sediment type greatly affects scour estimates, greater conservatism should be employed when making mitigation plans based off of depth of cover estimates.

² Station numbers are based off figures provided in **Appendix B** of this report.

Low Priority:

Bear to Island 5 and Bear to Island 6 are both considered to be low priority. In the case of Bear to Island 5, no pipeline exposure is predicted to occur during the 100-year flow event, with either sediment type scenario. In the case of Bear to Island 6, with Sediment Type 1, only about 10 meters of pipeline is expected to be exposed during the 100-year flow event.

4.4 Critical Velocities

As described in **Section 3.1.1**, general scour only occurs if the water velocity exceeds a certain critical velocity. This critical velocity is dependent upon the water depth as well as soil characteristics, and therefore varies across each pipeline and for different flow events. Critical velocity increases with increased water depth, as the increased weight of the water column increases the stability of the underlying soil.

Figures illustrating how the critical velocity changes across the span of each pipeline for both the high and low mobility soil scenarios and for three return periods are provided in **Appendix D**.

5 References

- [1] 'River-related Facility Operation and Abandonment Plan supported by Hydrotechnical Analysis of Mackenzie River at Norman Wells', Calgary, Alberta, Sep. 2018.
- [2] 'Norman Wells Bathymetric Survey', Dec. 2022.
- [3] A. Dayton, C. Akelaitis, and T. Webb-Horvath, 'IOL Norman Wells 2023 Mackenzie River Pipeline Depth of Cover and Bathymetric Survey', Nov. 2023.
- [4] G. Brunner, 'HEC-RAS 2D User's Manual', 2023.
- [5] E. L. Pemberton and J. M. Lara, 'Computing Degradation and Local Scour', Denver, CO, Jan. 1984.
- [6] F. Chang and S. Davis, 'Maryland Procedure for Estimating Scour at Bridge Abutments, Part 2 - Clear Water Scour', in *International Water Resources Engineering Conference*, Memphis, TN: ASCE, 1998, pp. 169–173.
- [7] 'Technical Supplement 14B Scour Calculations', Aug. 2007.
- [8] J. C. Blodgett, 'Rock Riprap Design for Protection of Stream Channels Near Highway Structures', Sacramento, California, 1986.
- [9] 'Norman Wells Expansion Project 1980 Geotechnical Investigations', Calgary, Alberta Canada, Oct. 1980.

APPENDIX A
**Sediment Data and Scenarios by
Pipeline**

Norman Wells, NWT
Depth of Cover Assessment

Mainland to Island 1

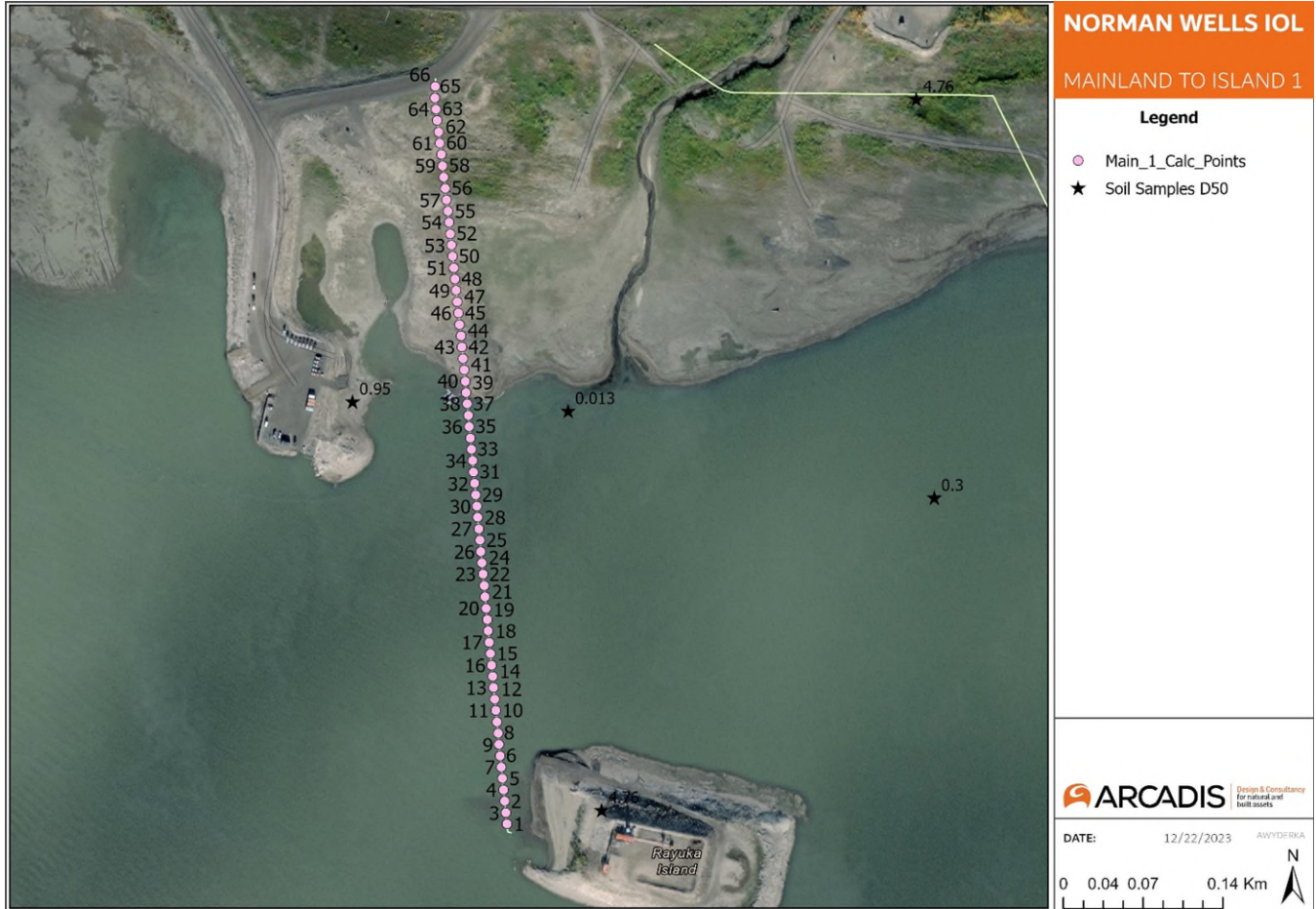


Figure 1. Sediment Data Near Mainland to Island 1

Scenario	Sediment Properties			Implication	
	D_{50} (mm)	Cohesive	Erodibility	General Scour Potential	Dune Scour Potential
Sediment Type 1	.013	Yes	Medium	Higher	Similar
Sediment Type 2	.013	Yes	Low	Lower	Similar

It should be noted that while there are some sediment samples near Mainland to Island 1 indicating the presence of sediments larger than .013mm, scour analysis conducted with the sediment types listed in the table above produced the maximum and minimum scour depths out of all the sediment type possibilities. Therefore, these

sediment types were chosen to represent the full range of scour potential at this pipeline. Additionally, the soil classification of the .013mm sample is unknown, therefore variations in erodibility¹ are possible.

Mainland to Island 2



Figure 2. Depth to Bedrock Near Mainland to Island 1

Scenario	Sediment Properties			Implication	
	D_{50} (mm)	Cohesive	Erodibility	General Scour Potential	Dune Scour Potential
Sediment Type 1	.2	No	N/A	Higher	Lower
Sediment Type 2	1	No	N/A	Lower	Higher

¹ In this case, erodibility refers to the classification of cohesive soils as having low (resistant materials), medium, or high (easily erodible) erodibility. This classification is needed for cohesive soils to calculate the critical velocity at which general scour can occur.

Note on Figure 2: instead of showing the D50's of the superficial sediment layer around Mainland to Island 2, the figure shows the approximate depth to bedrock (in meters) of the soil borings near this pipeline. This was the only pipeline with numerous borings showing that bedrock was an upper layer. Additionally, the soil borings reveal the presence of shallow bedrock, which aligns with a record of having to blast through bedrock during construction to place the pipelines here. When the pipelines were laid through the bedrock here, sand was placed on top of the pipeline. Because the size of the sand placed on top is unknown, a range of sand sizes is used.

Mainland to Island 3

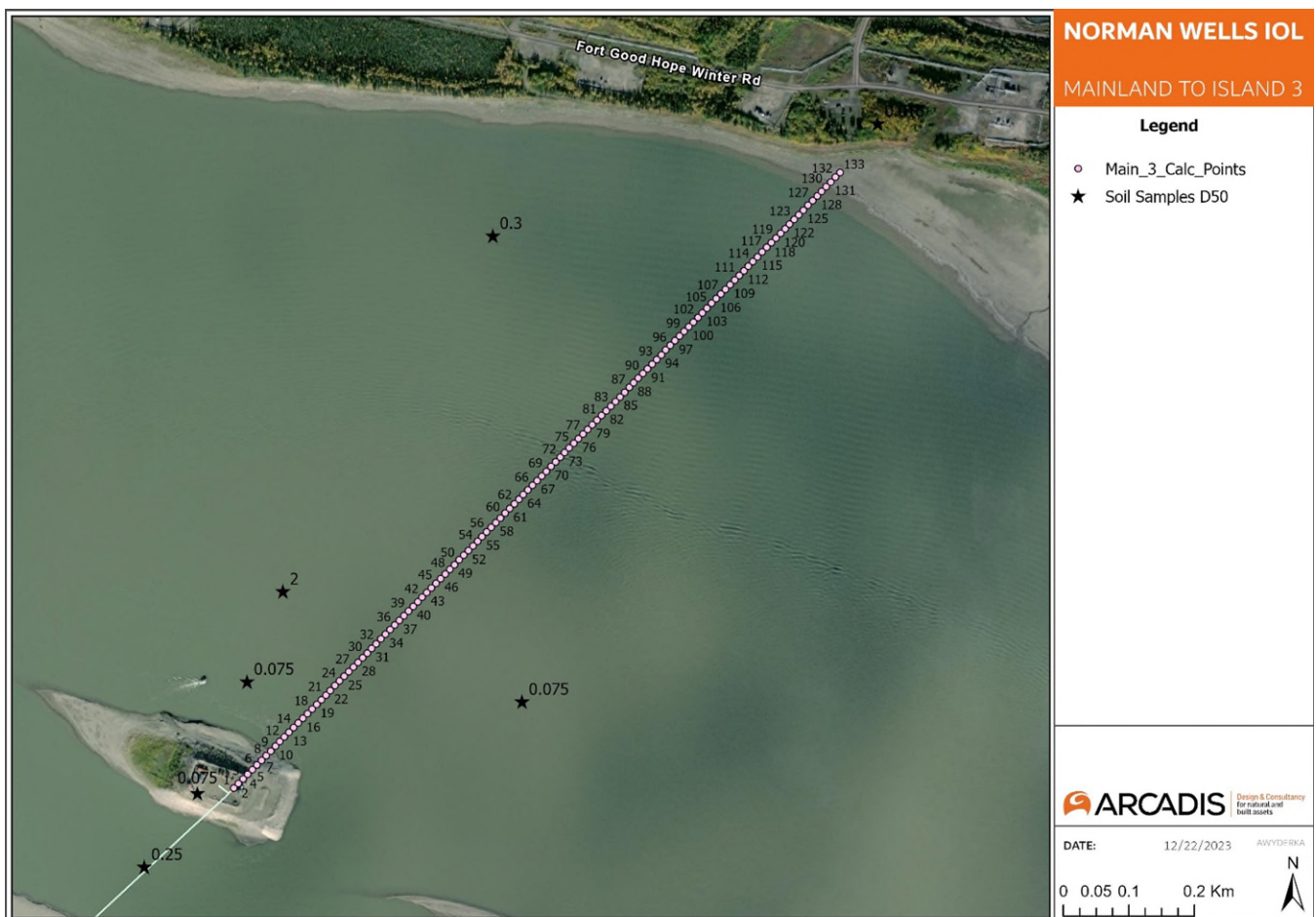


Figure 3. Sediment Data Near Mainland to Island 3

Scenario	Sediment Properties			Implication	
	D_{50} (mm)	Cohesive	Erodibility	General Scour Potential	Dune Scour Potential
Sediment Type 1	.075	No	N/A	Higher	Similar

Sediment Type 2	.075	Yes	Low	Lower	Similar
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As with Mainland to Island 1, even though there is evidence of larger sediment in the area near Mainland to Island 3, the sediment types selected for scour analysis represent the full range of scour potential for this pipeline out of all the sediment possibilities around this pipeline.

Goose to Island 3

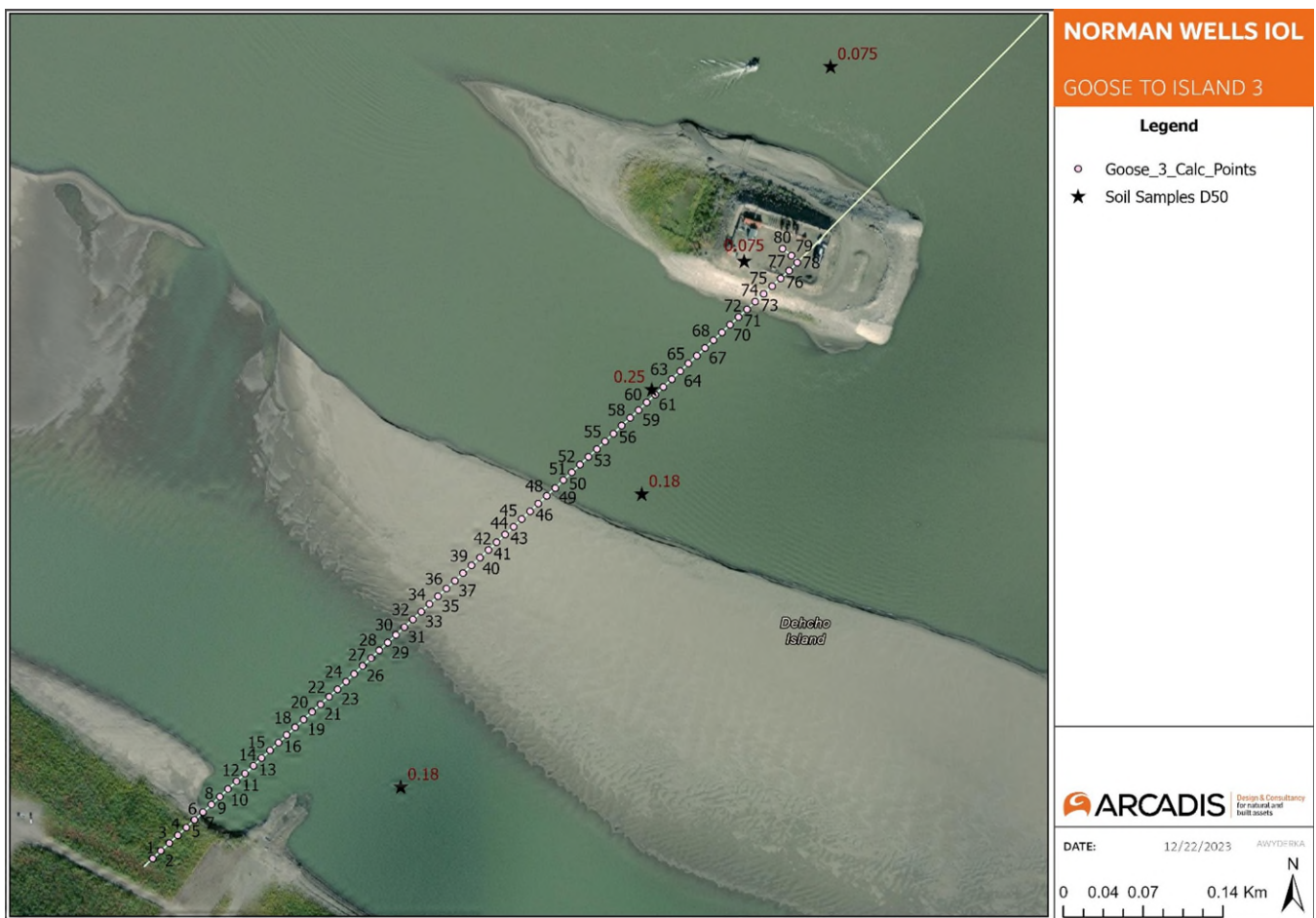


Figure 4. Sediment Data Near Goose to Island 3

Scenario	Sediment Properties			Implication	
	D_{50} (mm)	Cohesive	Erodibility	General Scour Potential	Dune Scour Potential
Sediment Type 1	.25	No	N/A	Similar	Higher

Sediment Type 2	.075	No	N/A	Similar	Lower
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Goose to Island 4

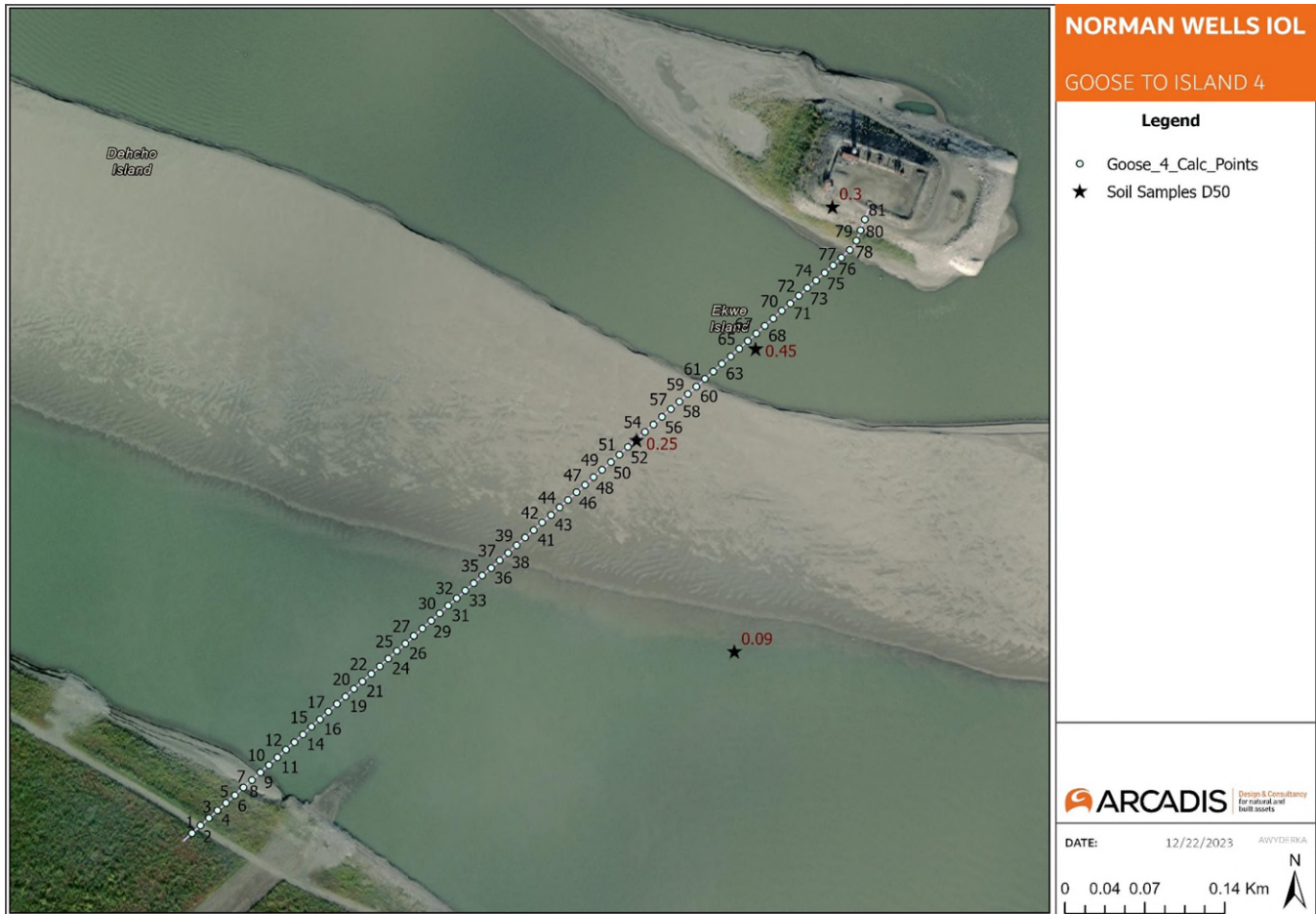


Figure 5. Sediment Data Near Goose to Island 4

Scenario	Sediment Properties			Implication	
	D_{50} (mm)	Cohesive	Erodibility	General Scour Potential	Dune Scour Potential
Sediment Type 1	.09	No	N/A	Higher	Higher
Sediment Type 2	.075	Yes	Low	Lower	Lower

For Sediment Type 2, the D50 is approximated as .075mm, based on the 1980 report from Komex indicating presence of fine silts off the coast of Goose Island.

Bear to Island 5

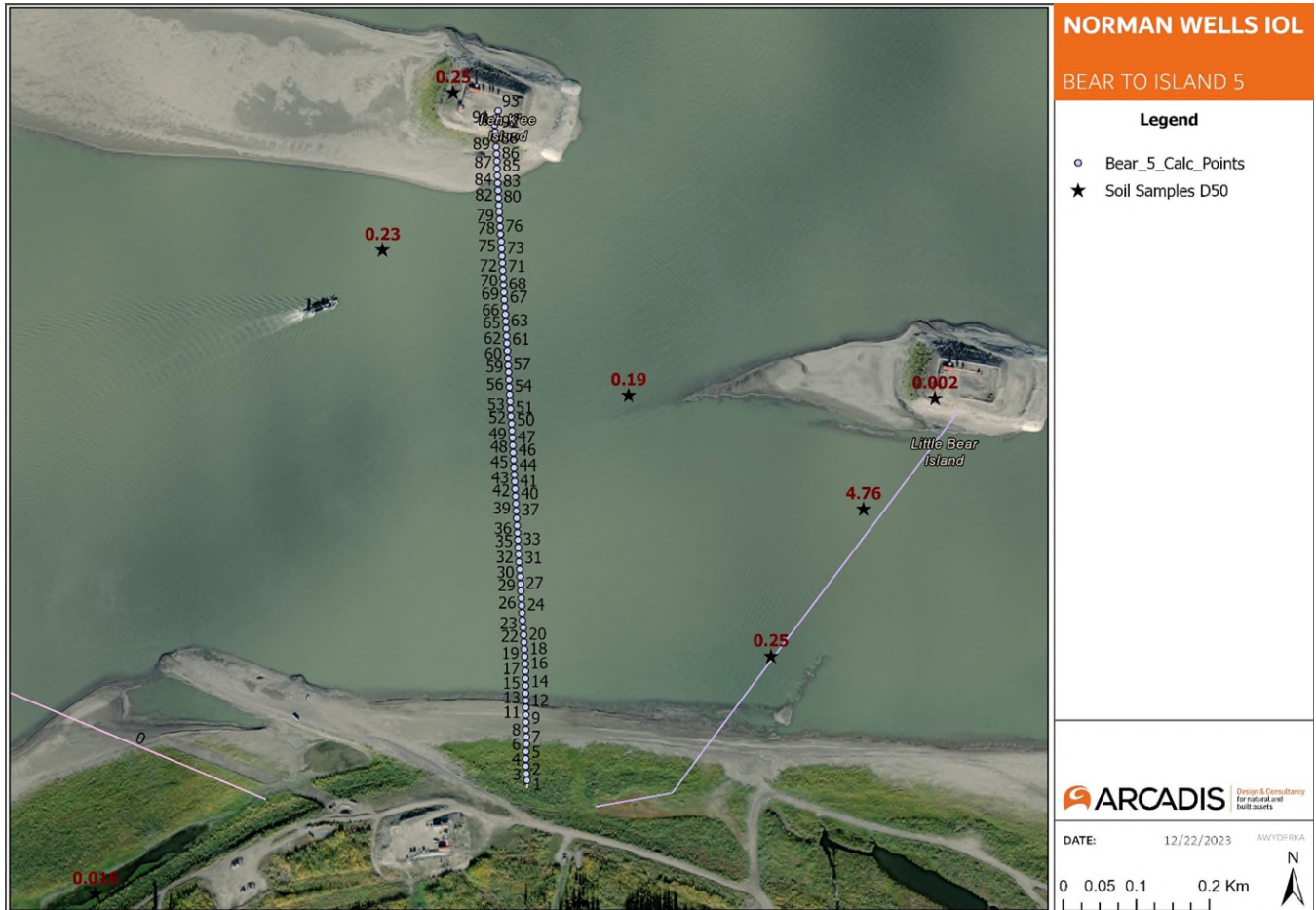


Figure 6. Sediment Data Near Bear to Island 5

Scenario	Sediment Properties			Implication	
	D_{50} (mm)	Cohesive	Erodibility	General Scour Potential	Dune Scour Potential
Sediment Type 1	.25	No	N/A	Similar	Higher
Sediment Type 2	.19	No	N/A	Similar	Lower

Bear to Island 6

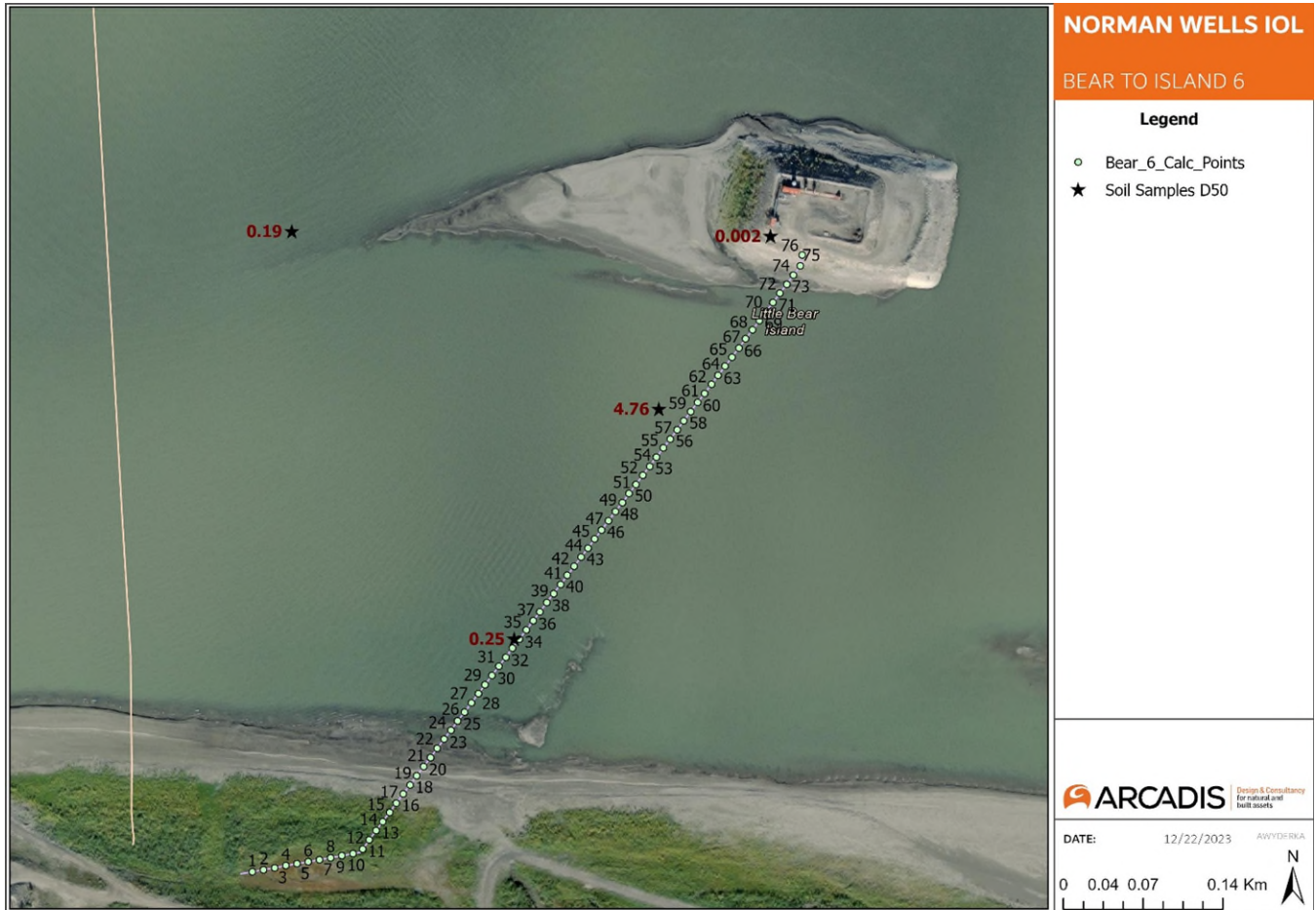


Figure 7. Sediment Data Near Bear to Island 6

Scenario	Sediment Properties			Implication	
	D_{50} (mm)	Cohesive	Erodibility	General Scour Potential	Dune Scour Potential
Sediment Type 1	.25	No	N/A	Higher	Lower
Sediment Type 2	4.76	No	N/A	Lower	Higher

Note: the sediment size of .002mm recorded on Island 6 was not considered in the analysis as it is likely that value is only present on the island and is not representative of values possible across the length of the pipeline.

Goose to Bear Island

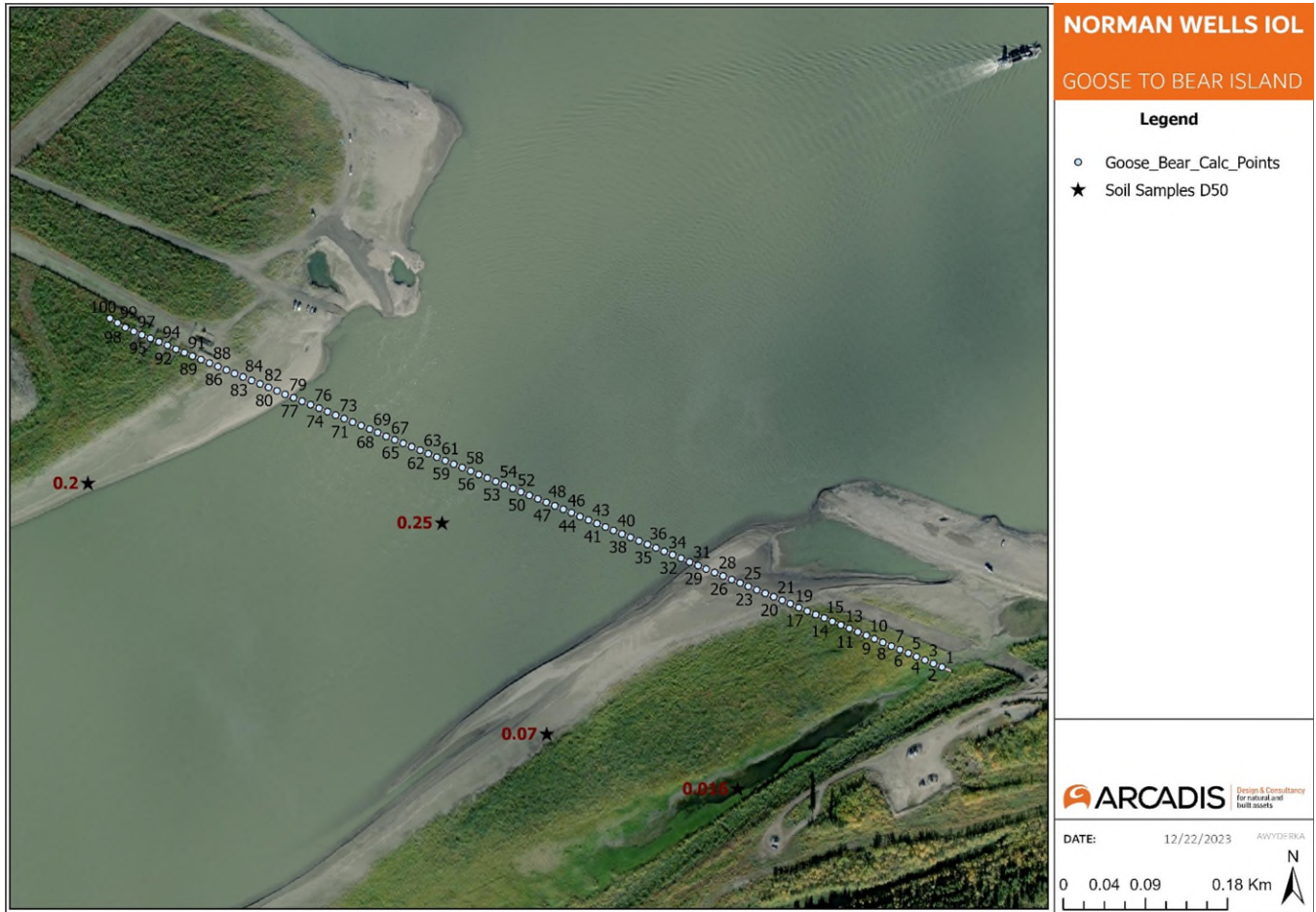


Figure 8. Sediment Data Near Goose to Bear Island

Scenario	Sediment Properties			Implication	
	D_{50} (mm)	Cohesive	Erodibility	General Scour Potential	Dune Scour Potential
Sediment Type 1	.25	No	N/A	Higher	Higher
Sediment Type 2	.07	Yes	Low	Lower	Lower

APPENDIX B
Combined Scour Result Plots
by Pipeline

Norman Wells, NWT
Depth of Cover Assessment

CALCULATION POINTS

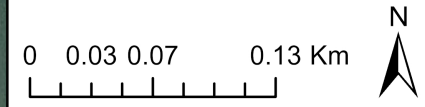
MAINLAND TO ISLAND 1

Legend

Calculation Points for Mainland to Island 1 (stationing shown in meters)

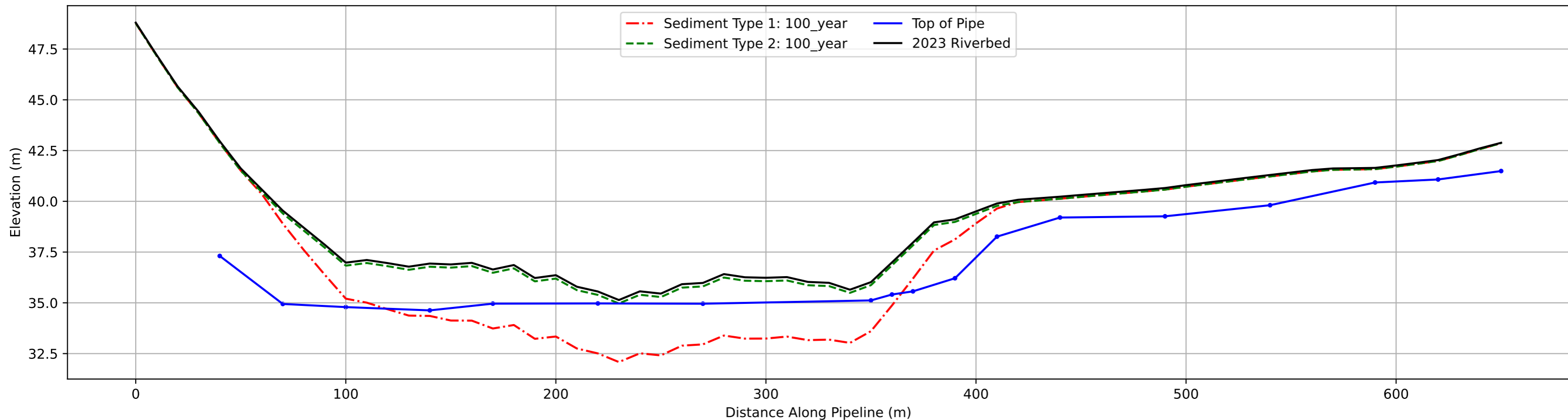


DATE: 1/18/2024 AWYDERKA



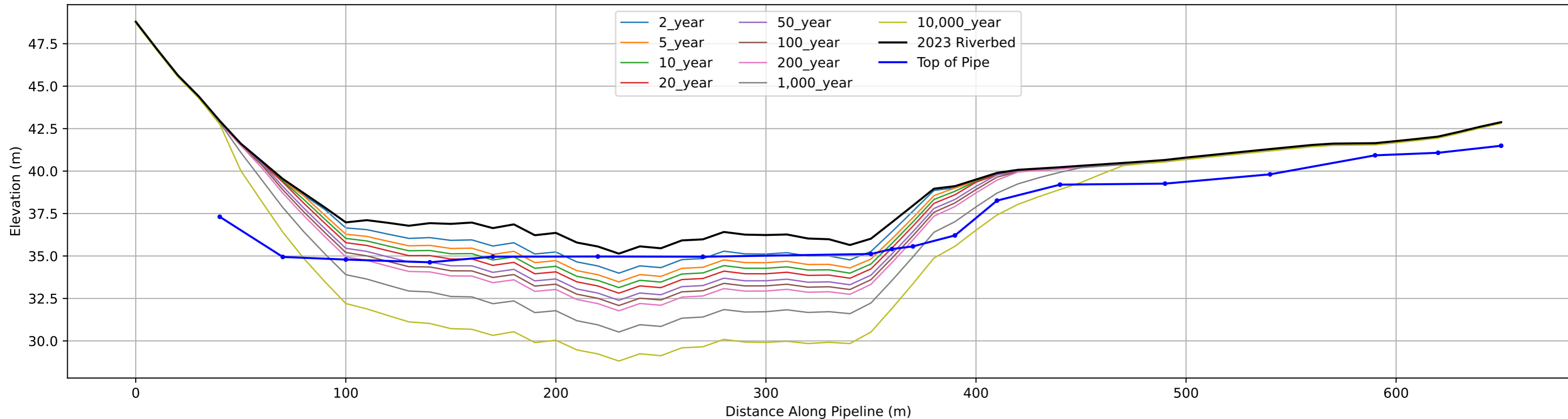
Combined Scour Uncertainty Analysis: Main_1_100_year

Note Vertical Exaggeration



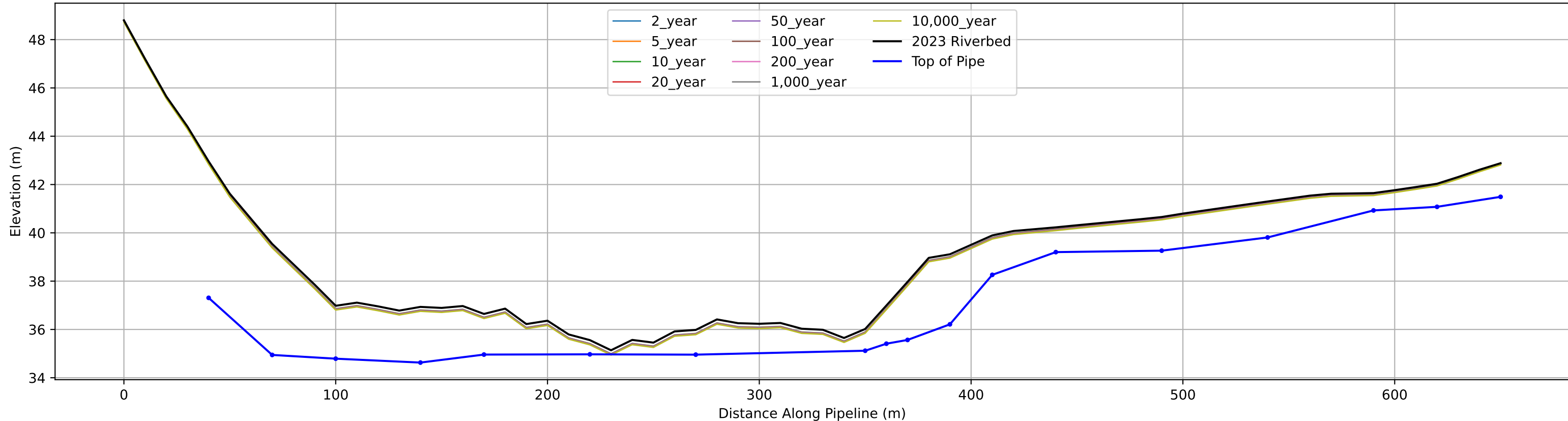
Combined Scour Lines for Sediment Type 1: Main_1

Note Vertical Exaggeration



Combined Scour Lines for Sediment Type 2: Main_1

Note Vertical Exaggeration





CALCULATION POINTS

MAINLAND TO ISLAND 2

Legend

- Calculation Points for Mainland to Island 2 (stationing shown in meters)

ARCADIS Design & Constallancy for natural and built assets

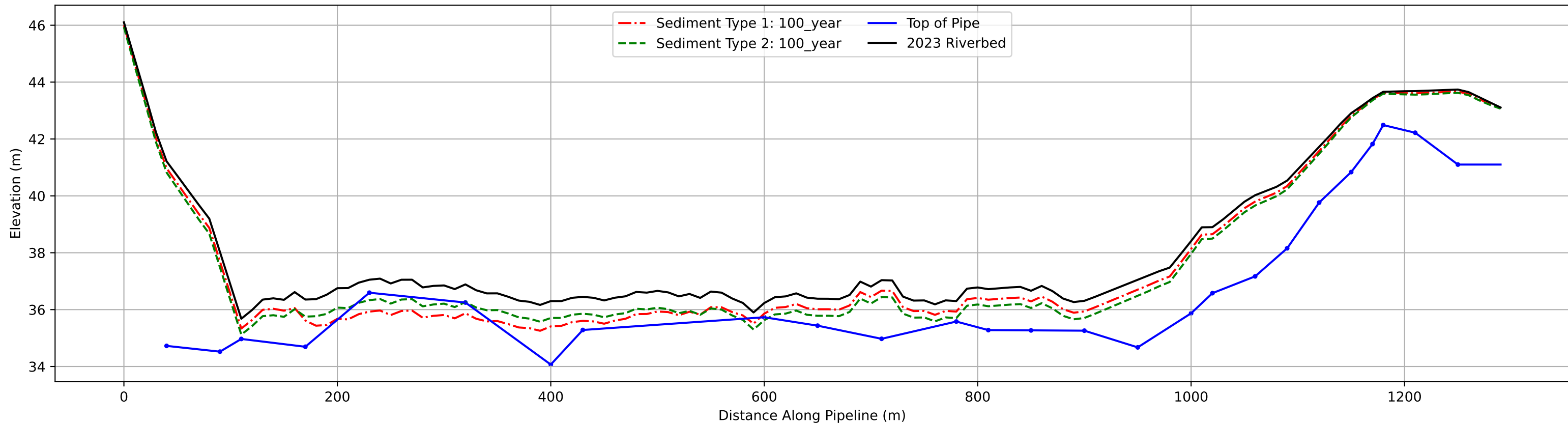
DATE: 1/18/2024 AWYDERKA

0 0.05 0.1 0.2 Km

N

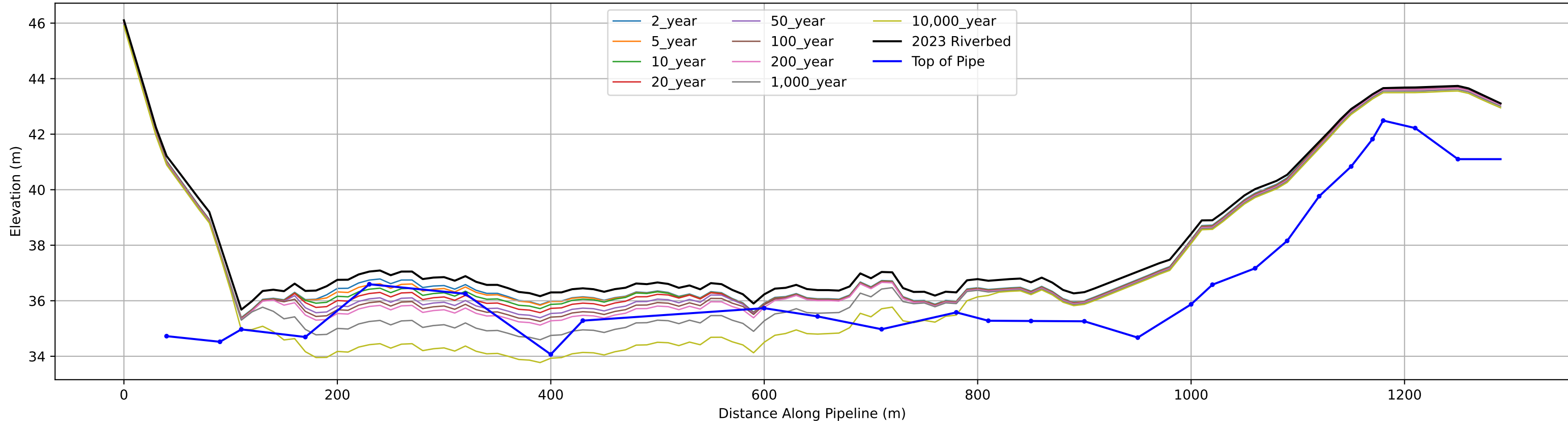
Combined Scour Uncertainty Analysis: Main_2_100_year

Note Vertical Exaggeration



Combined Scour Lines for Sediment Type 1: Main_2

Note Vertical Exaggeration

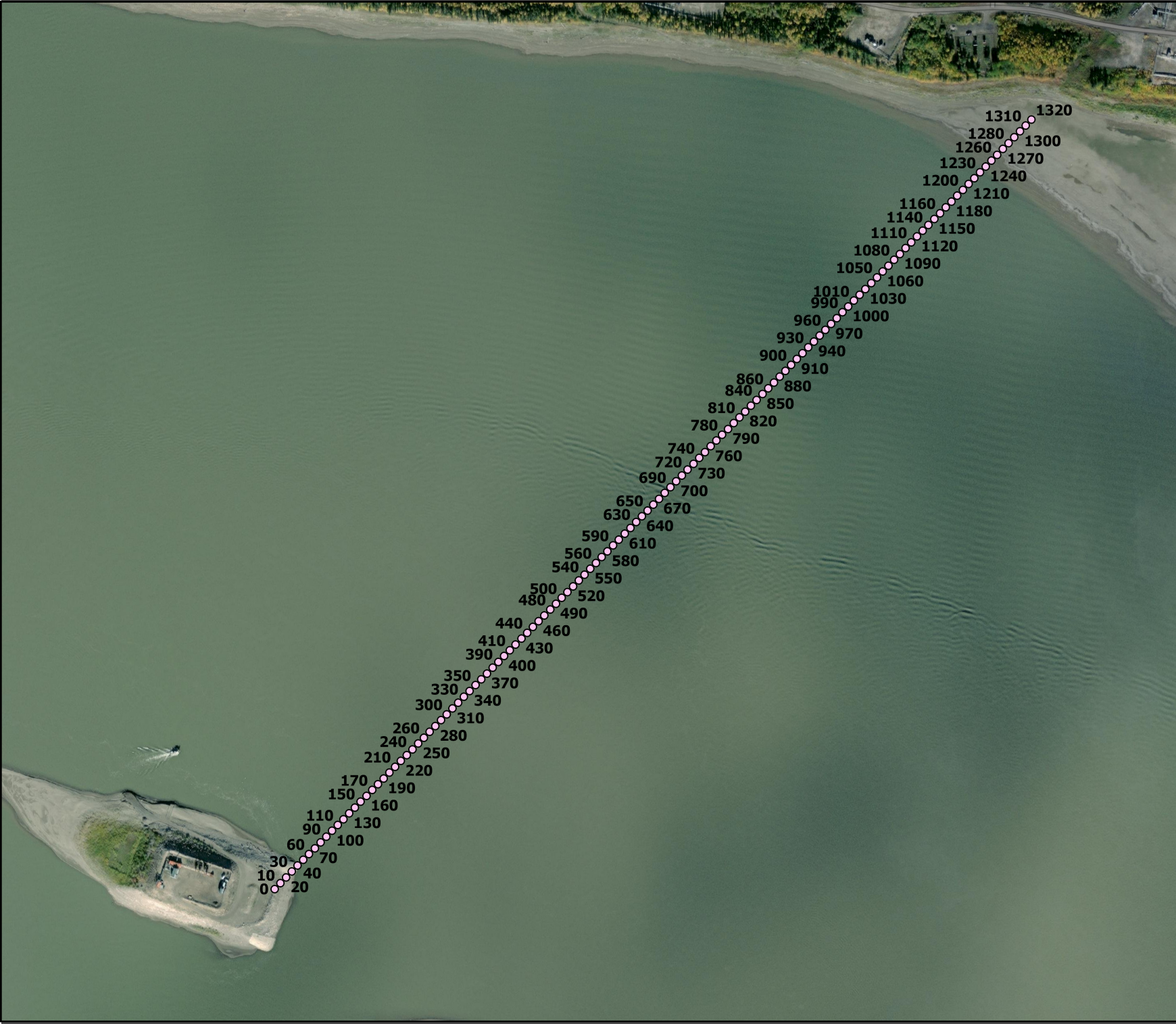


CALCULATION POINTS

MAINLAND TO ISLAND 3

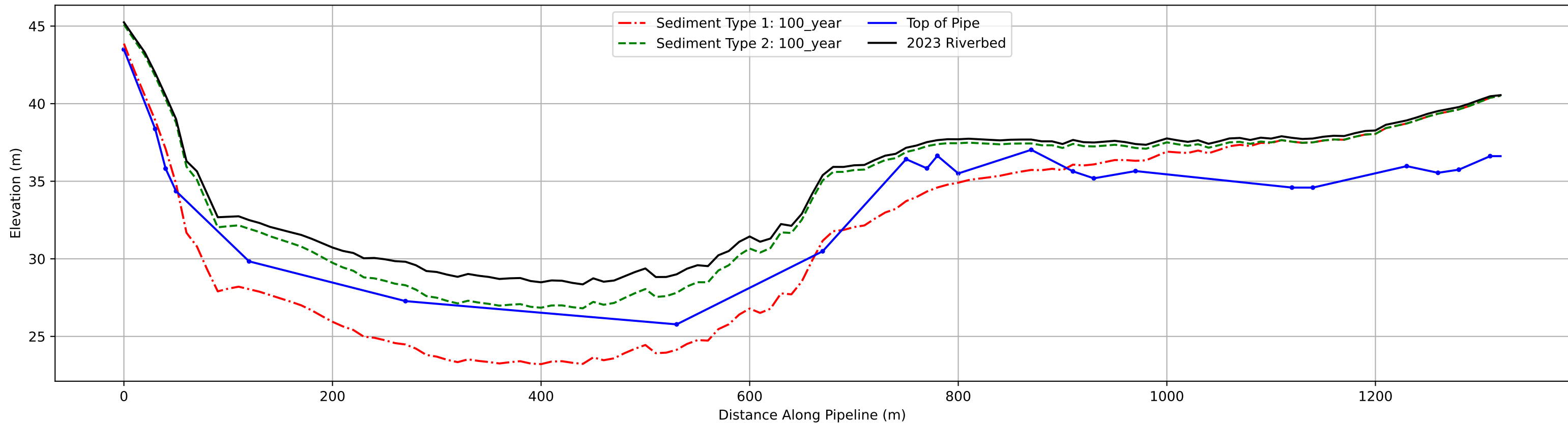
Legend

- Calculation Points for Mainland to Island 3 (stationign shown in meters)



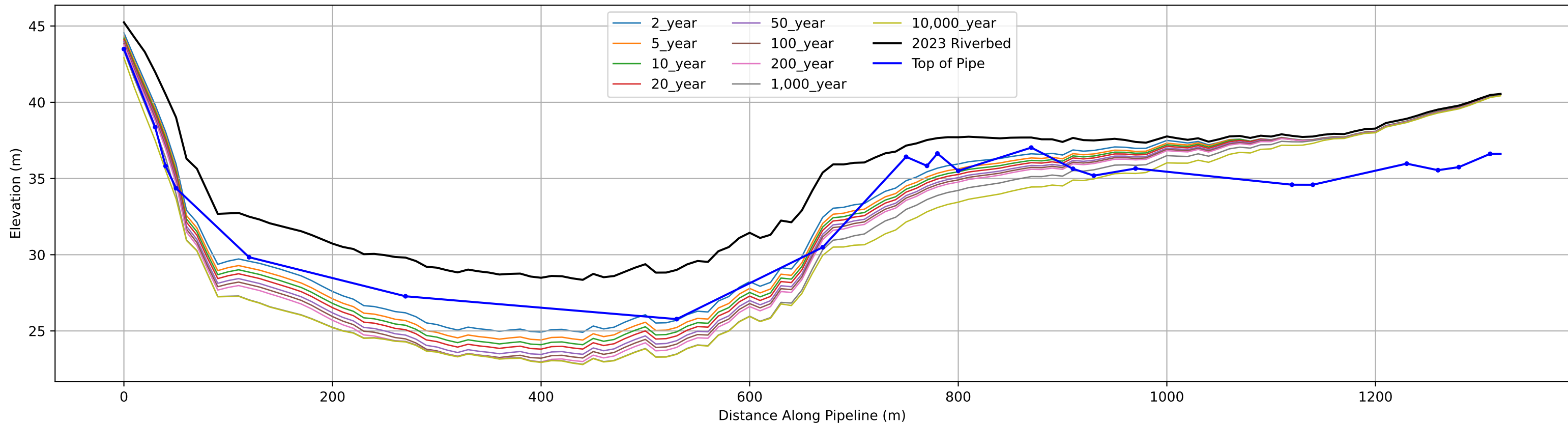
Combined Scour Uncertainty Analysis: Main_3_100_year

Note Vertical Exaggeration



Combined Scour Lines for Sediment Type 1: Main_3

Note Vertical Exaggeration



Legend

○ Calculation Points for Goose to Island 3 (stationing shown in meters)

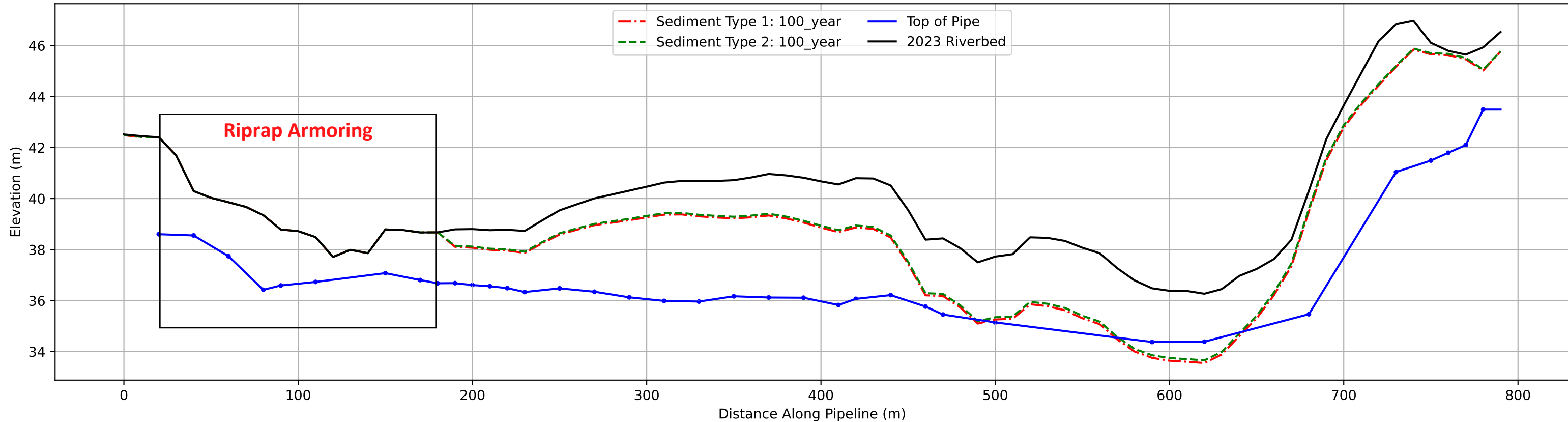


Dehcho Island



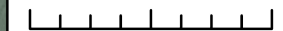
Combined Scour Uncertainty Analysis: Goose_3_100_year

Note Vertical Exaggeration



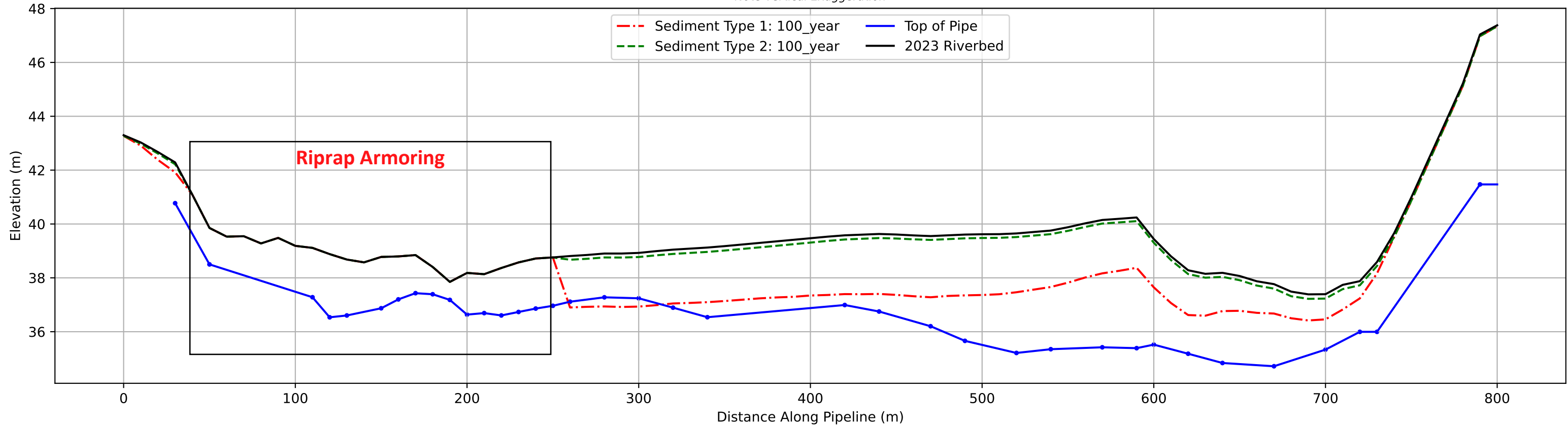
Legend

Calculation Points for Goose to Island 4 (stationing shown in meters)



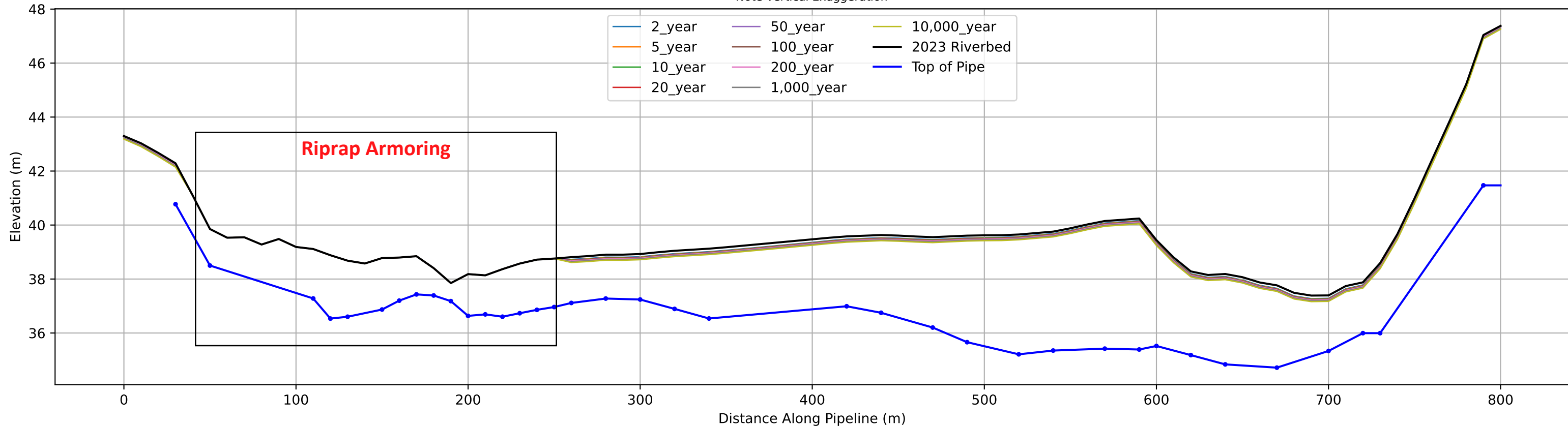
Combined Scour Uncertainty Analysis: Goose_4_100_year

Note Vertical Exaggeration



Combined Scour Lines for Sediment Type 2: Goose_4

Note Vertical Exaggeration



CALCULATION POINTS

BEAR TO ISLAND 5

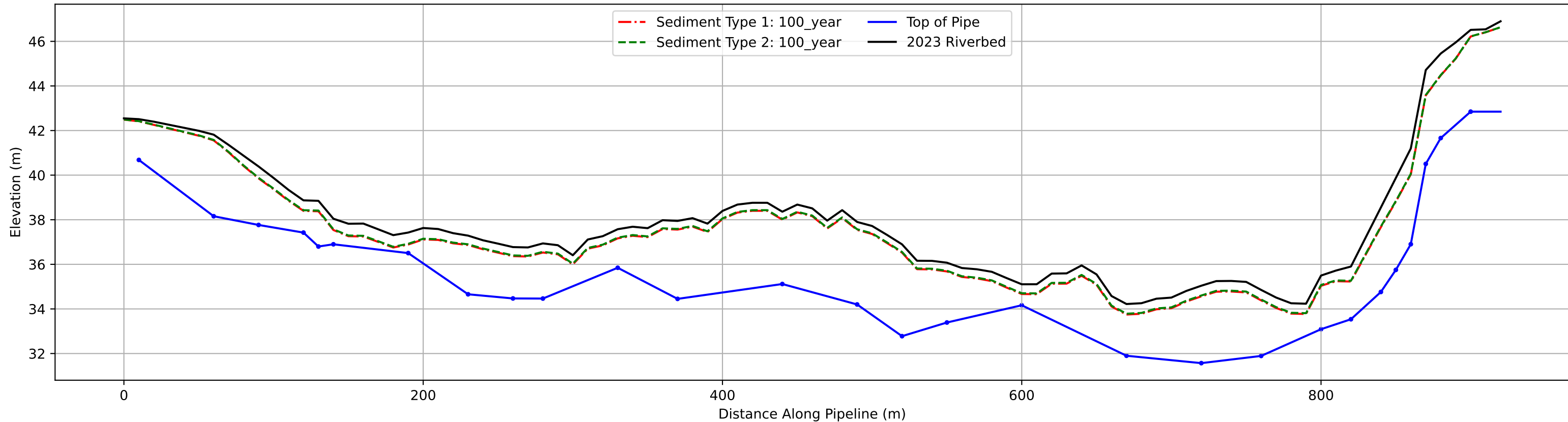
Legend

○ Calculation Points for Bear to Island 5 (stationing shown in meters)



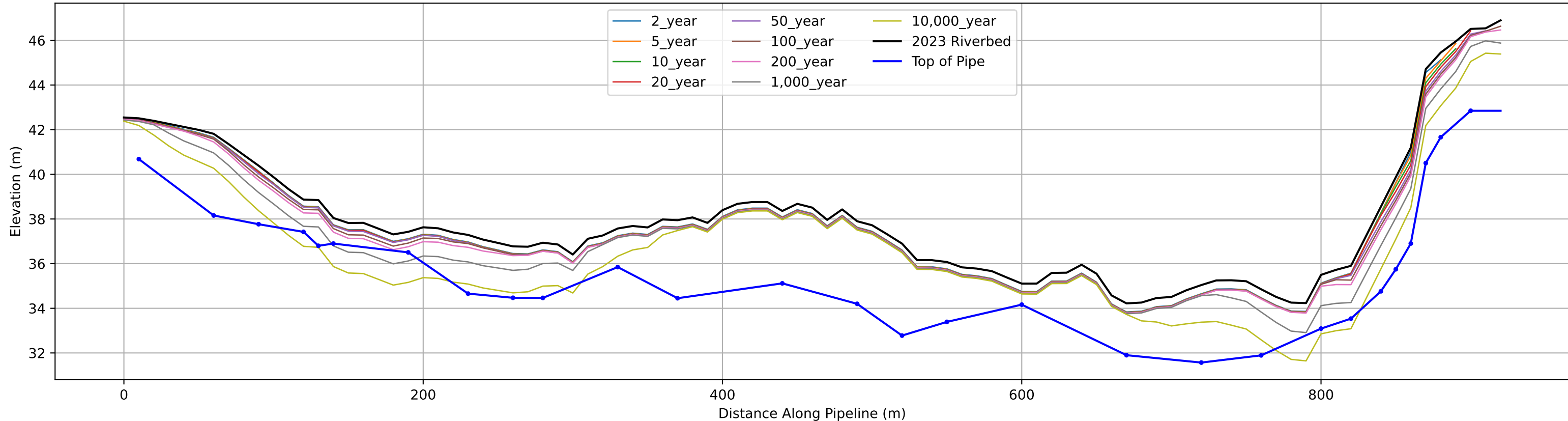
Combined Scour Uncertainty Analysis: Bear_5_100_year

Note Vertical Exaggeration



Combined Scour Lines for Sediment Type 2: Bear_5

Note Vertical Exaggeration



CALCULATION POINTS

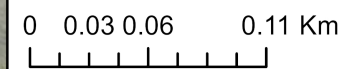
BEAR TO ISLAND 6

Legend

Calculation Points for Bear to Island 6 (stationing shown in meters)

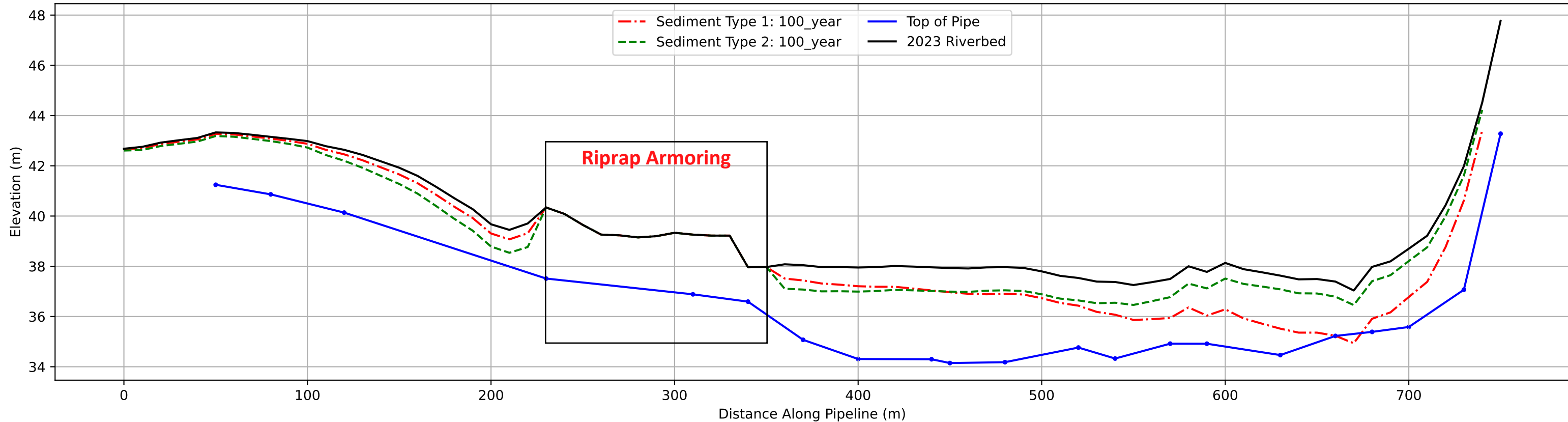


DATE: 1/18/2024 AWYDERKA



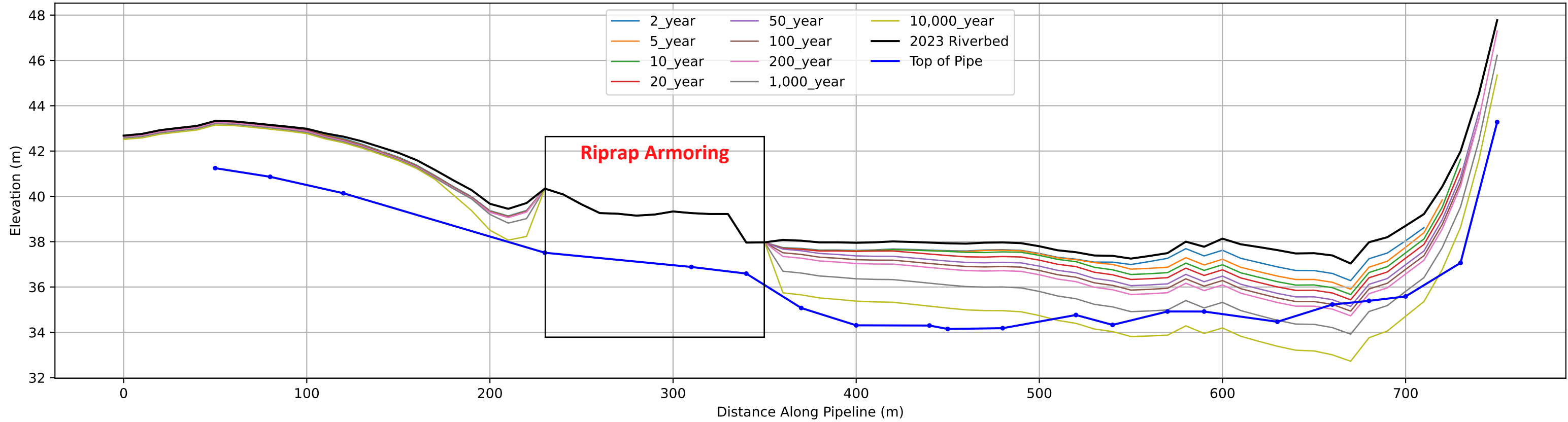
Combined Scour Uncertainty Analysis: Bear_6_100_year

Note Vertical Exaggeration



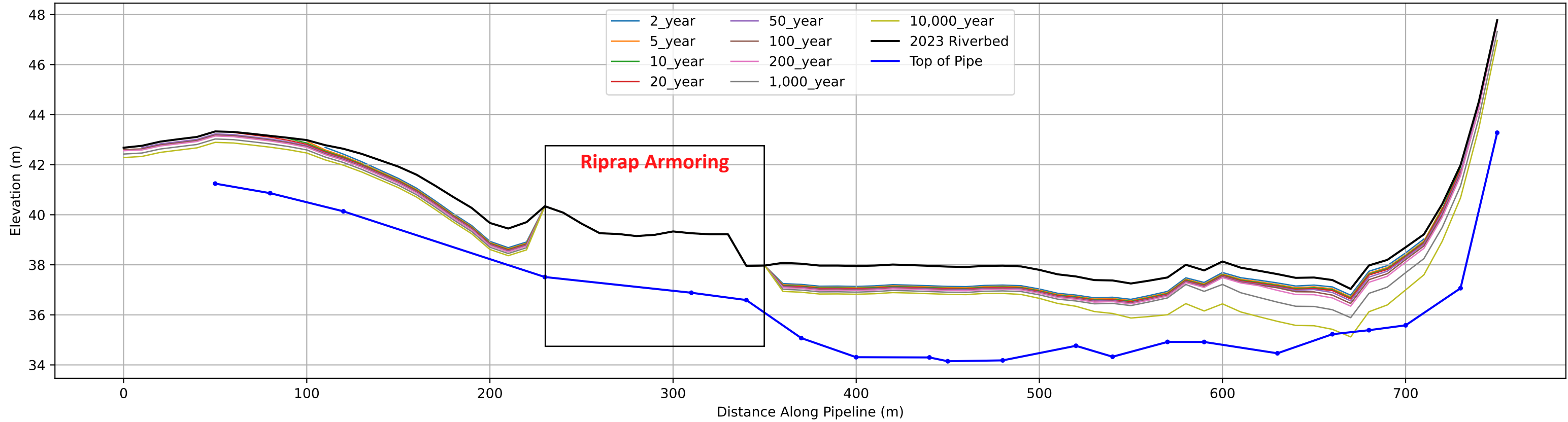
Combined Scour Lines for Sediment Type 1: Bear_6

Note Vertical Exaggeration



Combined Scour Lines for Sediment Type 2: Bear_6

Note Vertical Exaggeration



CALCULATION POINTS

GOOSE TO BEAR ISLAND

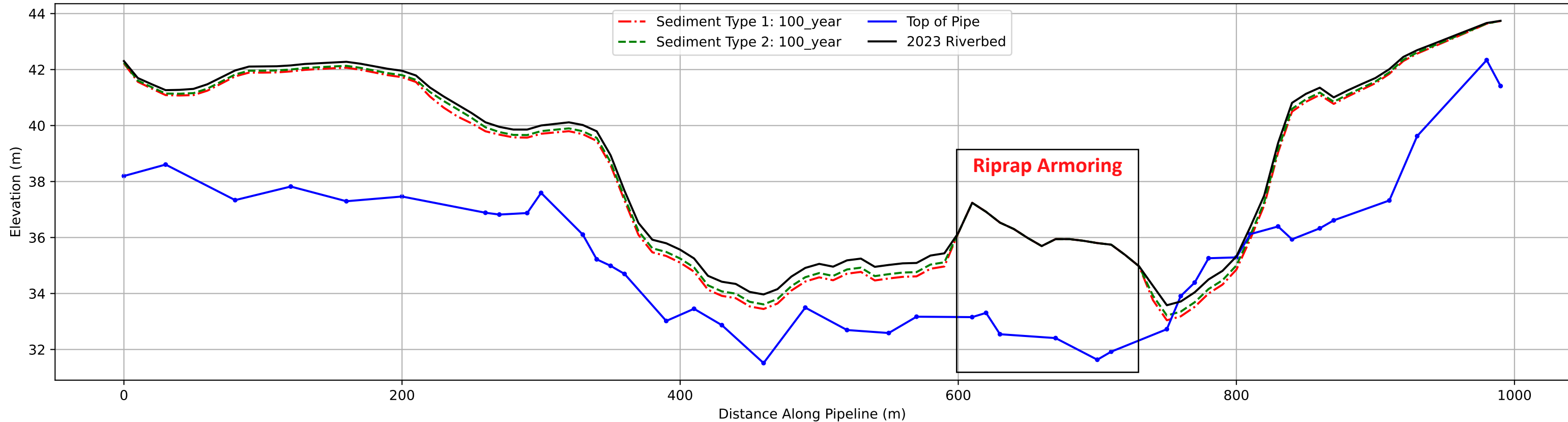
Legend

- Calculation Points for Goose to Bear Island



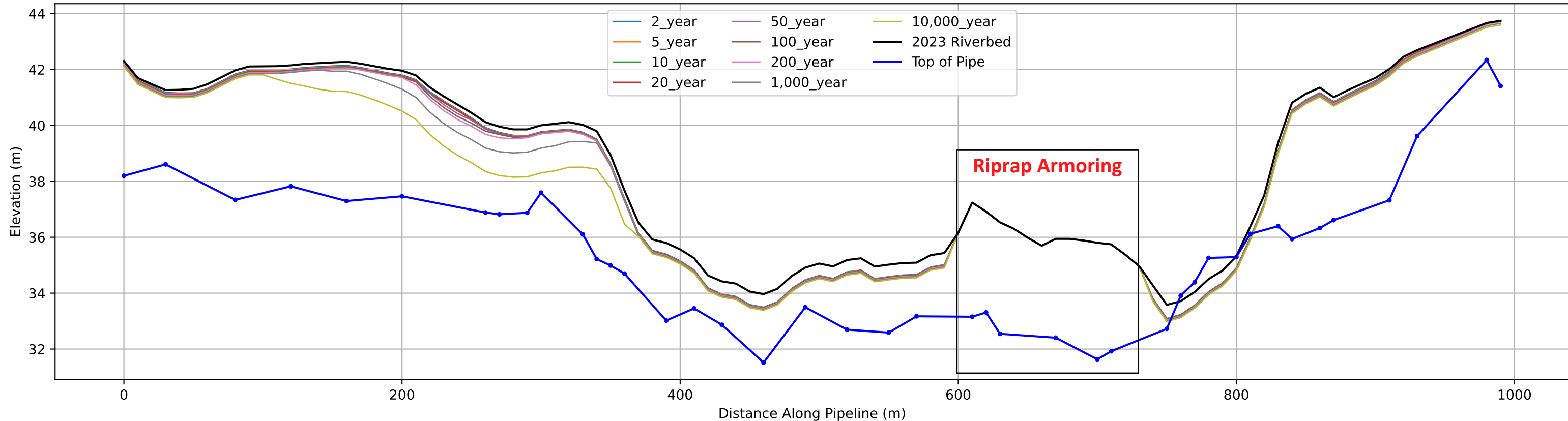
Combined Scour Uncertainty Analysis: Goose_Bear_100_year

Note Vertical Exaggeration



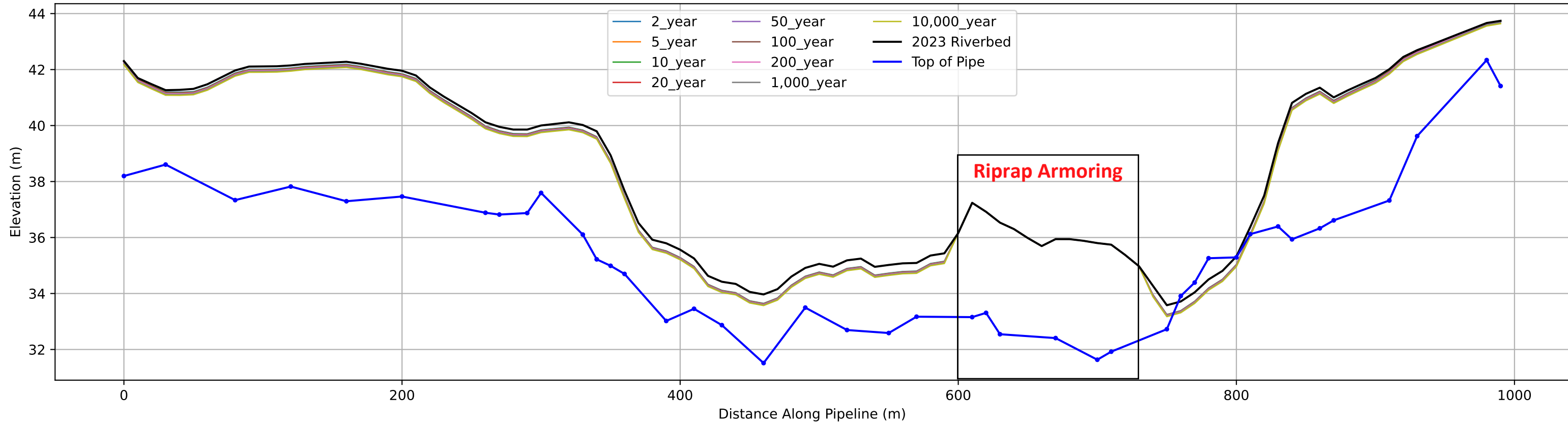
Combined Scour Lines for Sediment Type 1: Goose_Bear

Note Vertical Exaggeration



Combined Scour Lines for Sediment Type 2: Goose_Bear

Note Vertical Exaggeration



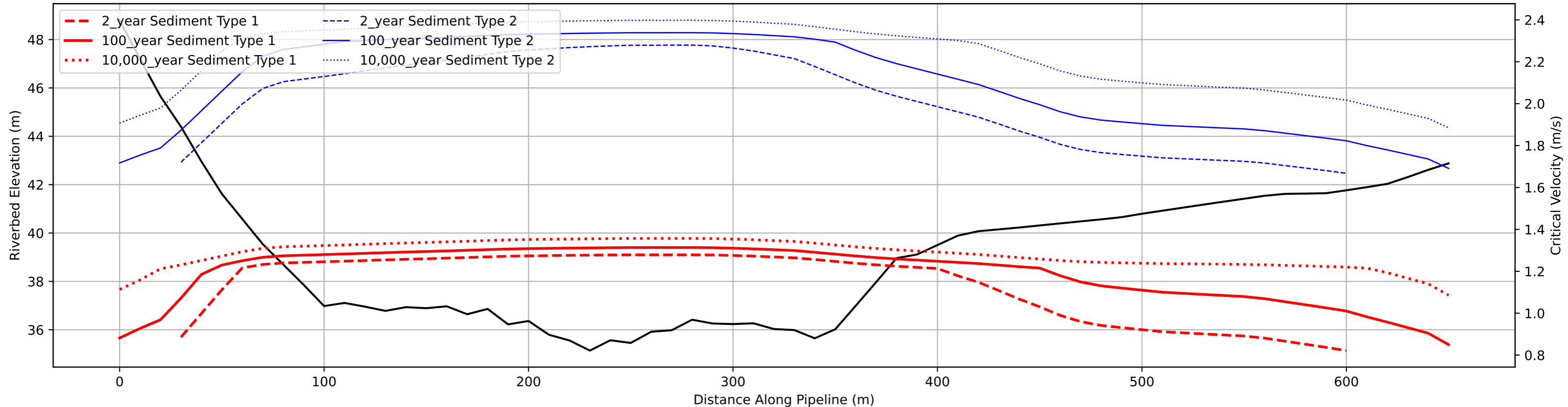
APPENDIX C
Calculation Results by Pipeline
Provided via spreadsheets

Norman Wells, NWT
Depth of Cover Assessment

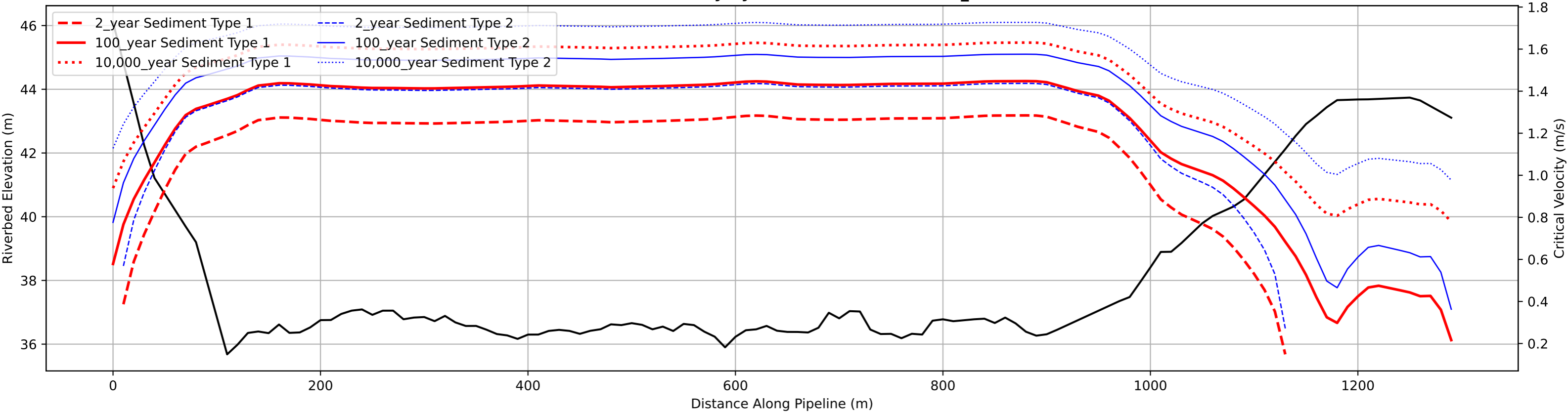
APPENDIX D
Critical Velocities by Pipeline

Norman Wells, NWT
Depth of Cover Assessment

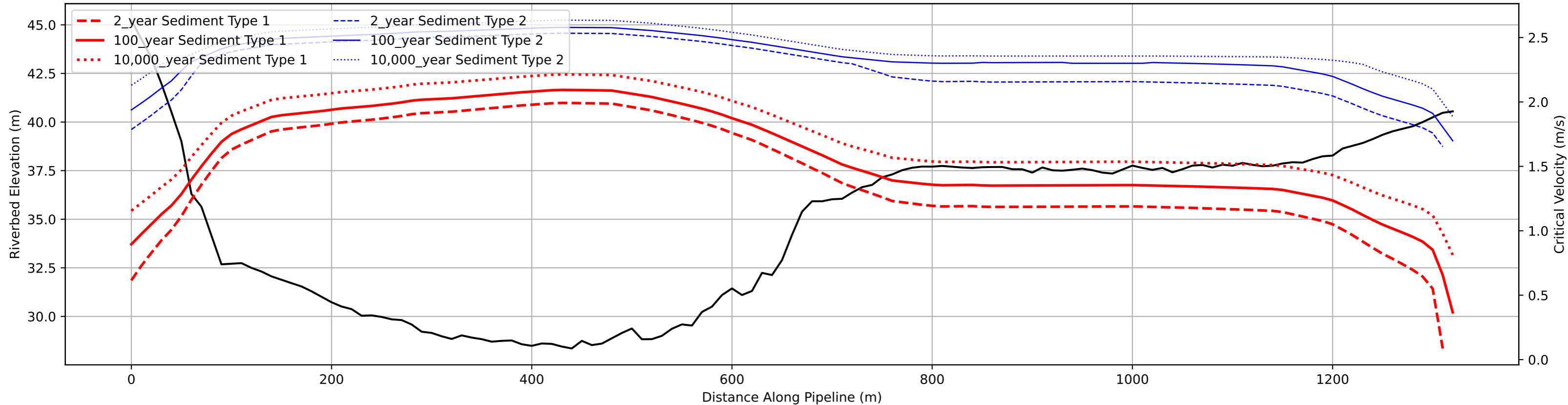
Critical Velocity by Return Period for Main_1



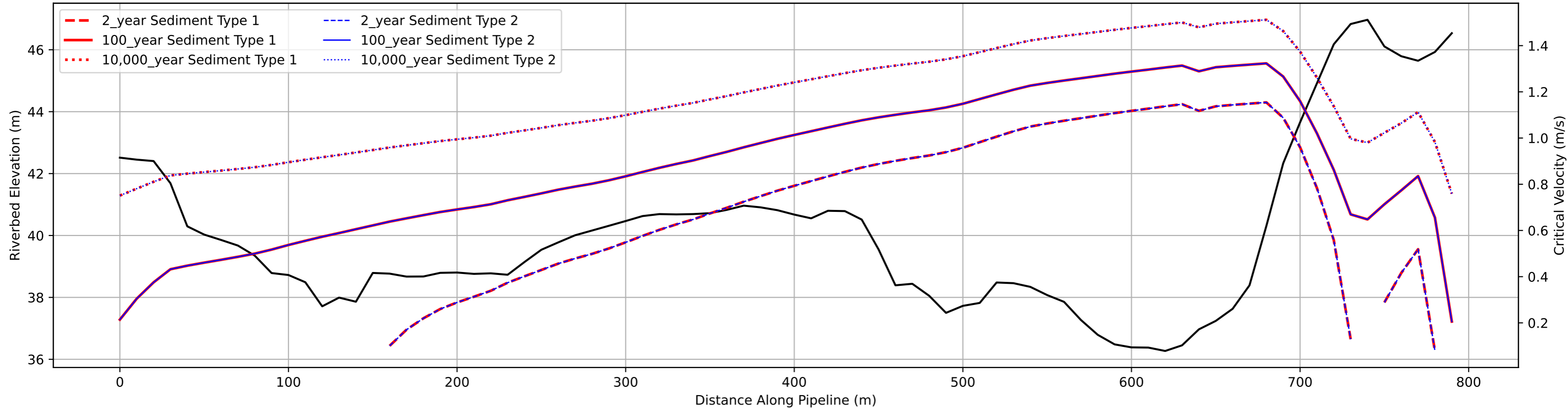
Critical Velocity by Return Period for Main_2



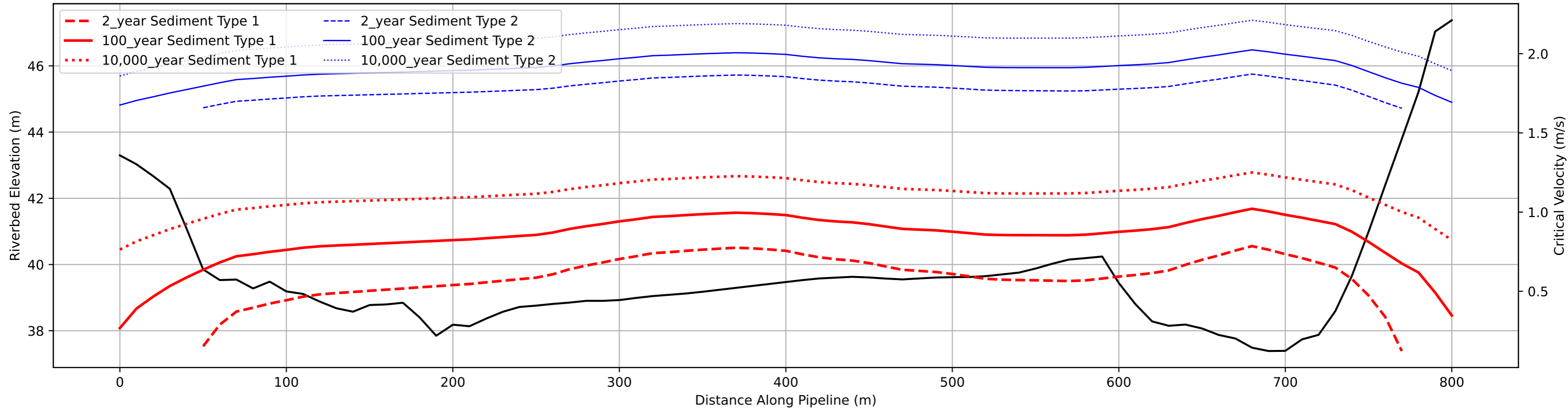
Critical Velocity by Return Period for Main_3



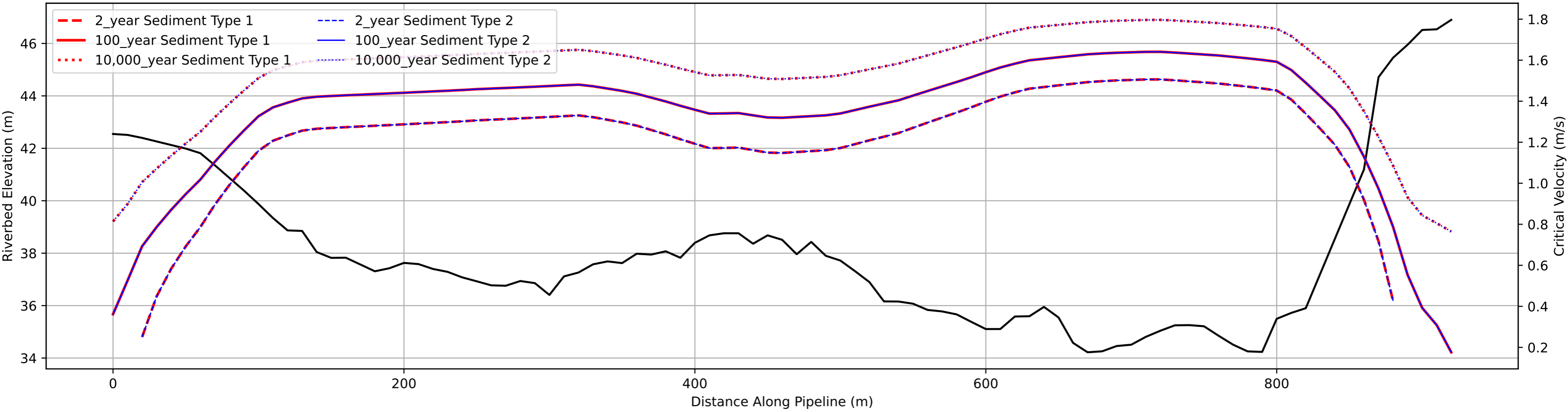
Critical Velocity by Return Period for Goose_3



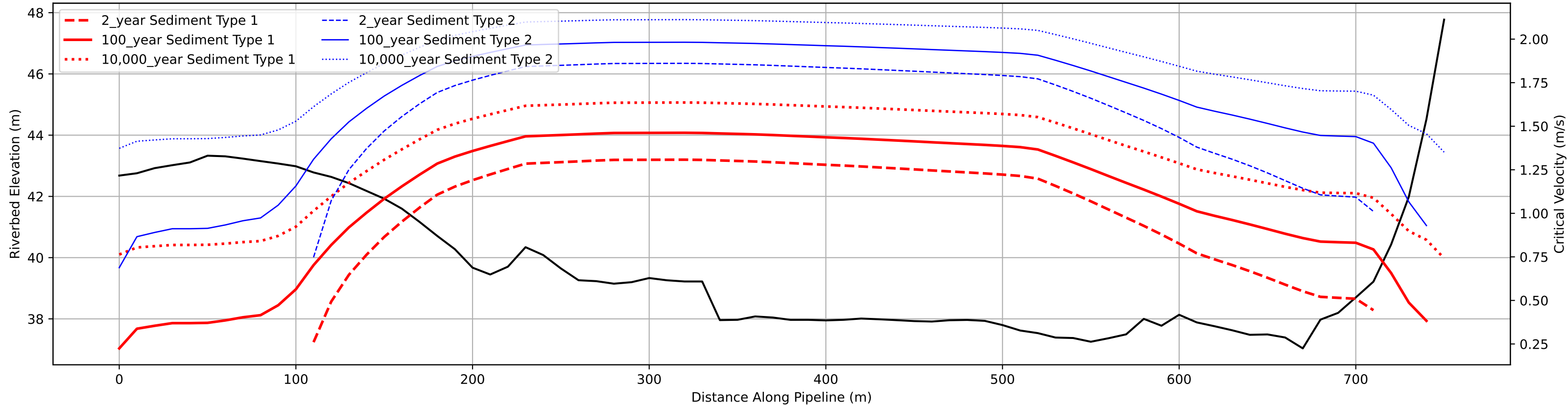
Critical Velocity by Return Period for Goose_4



Critical Velocity by Return Period for Bear_5



Critical Velocity by Return Period for Bear_6



Critical Velocity by Return Period for Goose_Bear

