SOLSTICE
Environmental Management

MURIEL LAKE BASIN HYDROLOGICAL NETWORK PROJECT

Prepared for:

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1. INTRODUCTION

1.1. STUDY AIM AND OBJECTIVE

The Muriel Lake Basin Management Society (MLBMS), a watershed management association interested in the sustainable use of Muriel Lake, has expressed concerns of severe environmental degradation resulting from water level loss. As such, this hydrology study initiated by MLBMS aims to investigate the effects of human disturbance further, to identify and ideally prioritize those disturbances relative to their impact on contributing areas of the watershed, and ultimately on lake water levels.

Identifying and prioritizing the main flow barriers to Muriel Lake will inform potential management actions, such as improving culvert connections at road crossings or restoring disturbed areas.

To realize this project aim, the main objective of this study is as follows:

- Using available LiDAR (Light Detection and Ranging) and remotely sensed imagery, assess the impact of physical impediments to surface water flow to the lake, based on hydrological analysis of terrain models generated from available data.

1.2. MURIEL LAKE WATERSHED – CONTEXT

Muriel Lake, situated in the Muriel Creek sub-watershed (HUC8) within the Beaver River Watershed in east-central Alberta, has a surface area of approximately 6,900 ha (Figure 1). The lake is the largest water body in the Muriel Creek sub-watershed within which drainage patterns and hydrological connections between catchment-contributing regions are not directly discernible using the traditional aerial photography method. Over the past few decades, previous studies centred on understanding the hydrological patterns or dynamics around Muriel Lake have shown to be inconclusive. In a technical report, Donahue (2006) indicated that Reita Lake contributes surface water flow to Muriel Lake against the results of Millennium EMS Solutions Ltd. (2012), which concluded the opposite. The results of that study showed a notable decline in water levels to the extent of approximately 5 m caused by land-use pattern changes and climate change. Based on these results, suggestions were made to conduct a more in-depth surface-flow pattern analysis using ground and satellite-derived data. As part of the recommendations for further work, Millennium EMS Solutions Ltd. (2012) suggested that a LiDAR-based GIS assessment of Muriel Lake be conducted. Hence, the key objective of this study is to outline a cost-effective and informative LiDAR-based terrain assessment of Muriel Lake that would assist and inform MLBMS's efforts to improve drainage to the lake.

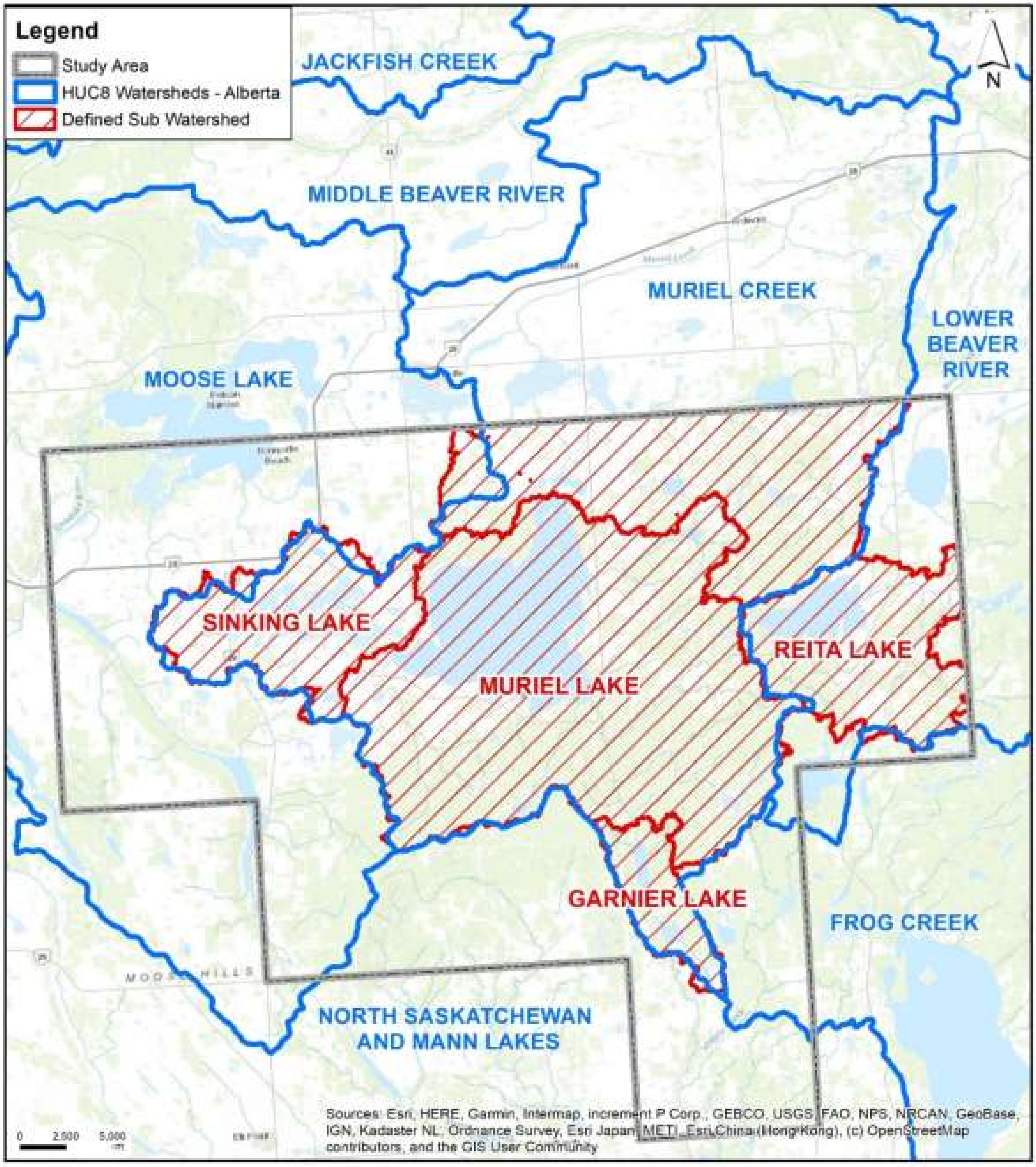

FIGURE 1. Map showing defined sub-watershed map covering the study area

2. DATA, METHODOLOGY, AND RESULTS

The focus of this study is to inform watershed management efforts directly related to improving surface water flow to Muriel Lake. To better understand surface water flow to Muriel Lake, and identify management action, two components were investigated:

- Muriel Lake drainage system analysis, and
- Inhibited flow analysis.

2.1. MURIEL LAKE DRAINAGE SYSTEM ANALYSIS

This component of the project entailed developing a model of the surface water flow contributing to Muriel Lake. To perform this analysis, a high-resolution 15-m bare earth LiDAR dataset was purchased for the project area and used to develop a hydrological model. The LiDAR-based approach of remote sensing analysis allowed for a detailed examination of the earth's surface. The dates of acquisition of the purchased LiDAR tiles were 2007, 2009, and 2010.

2.1.1.LiDAR Data Processing for Hydrology Modelling

Using Alberta Township System provincial boundary grids, a total of 14 tiles covering the project area, and including Muriel Lake (Figure 1 and Figure A.1), were purchased. The 15-m bare earth LiDAR digital elevation model (DEM) was mosaiced using standard GIS tools and used in subsequent spatial analysis.

To ensure the LiDAR DEM was suitable for hydrological modelling, it passed through a process of "*Hydro enforcement*." This process provided obstructions to flow in the DEM (such as roads, bridges, or culverts) were eliminated, thereby allowing the free flow of water channels in simulations developed using the same data. Typically, such obstructions in the DEM create a ponded area above road networks.

The three operations required to produce the hydro-enforced DEM included: (1) identification of impeded flows, (2) visualization of flow paths, and (3) manual cutting of the DEM. This three-step approach was an iterative process that usually requires multiple attempts to generate the best DEM suitable for watershed and other hydrological analysis. These steps were followed to process the supplied LiDAR DEM data.

When using an unfilled DEM, depressions present in the landscape can prevent continuous flow throughout the watershed. Using standard GIS tools for depression mapping, false impoundments observed in the DEM were identified. With the depression layer and flow-paths layers used as a background, the roads, culverts, and bridge GIS layers were used to identify potential obstructions to water flow and were manually cut from the DEM raster.

For this project, MLBMS provided the culvert and bridge location data used for correcting the LiDAR DEM. The Solstice geomatics team completed the LiDAR data processing described above with ArcGIS (www.esri.com) hydrological tools. The subsequent hydrological surface-flow analysis was based on the culvert-updated DEM.

2.1.2.Stream Analysis

The hydro-conditioned DEM was input in the GIS to generate flow direction and accumulation raster layers. Using the corrected DEM raster, the water flow direction for each cell was calculated. As part of the DEM processing, minor sinks and depressions were corrected. After the correction, the flow direction was calculated for each pixel with an eight-direction flow model (determining flow direction from each pixel to each of its adjacent 8 pixels) to identify the direction of flow from one raster cell to its steepest downward neighbour.

With the above results, a flow-accumulation map was created showing the accumulated flow into each raster cell and using the accumulated weights of all the cells that flow into each downslope cell. Areas of high flow accumulation indicate concentrated flow and are useful to identify stream channels, while low flow accumulation values depict ridges. With the flow-accumulation layer, a stream network was created based on the predicted flow lines of the streams. As part of the project, flow direction and flow accumulation surfaces were derived from the LiDAR DEM and the digital files provided as part of the deliverables.

2.1.3.Wetland Depression Analysis

Micro-depressions or presence/absence of wetlands and small lakes have the potential to hold water across the landscape, which subsequently prevents proper water drainage. In this stage of the project, the Solstice wetland depression tool was used to map, in detail, micro-depressions across the project area using the bare-earth LiDAR data.

The outputs of the micro-depression wetland mapping analysis included a predicted steam network, sub-watersheds, and depressions areas. By combining the habitat and micro-terrain mapping outputs with multispectral remote sensing results, a predicted wetland map of the project area was generated. Figure 2 and Figure A.2 (Appendix A) present the LiDAR-derived predicted stream network and the sub-basin boundaries of the watershed created in the study.

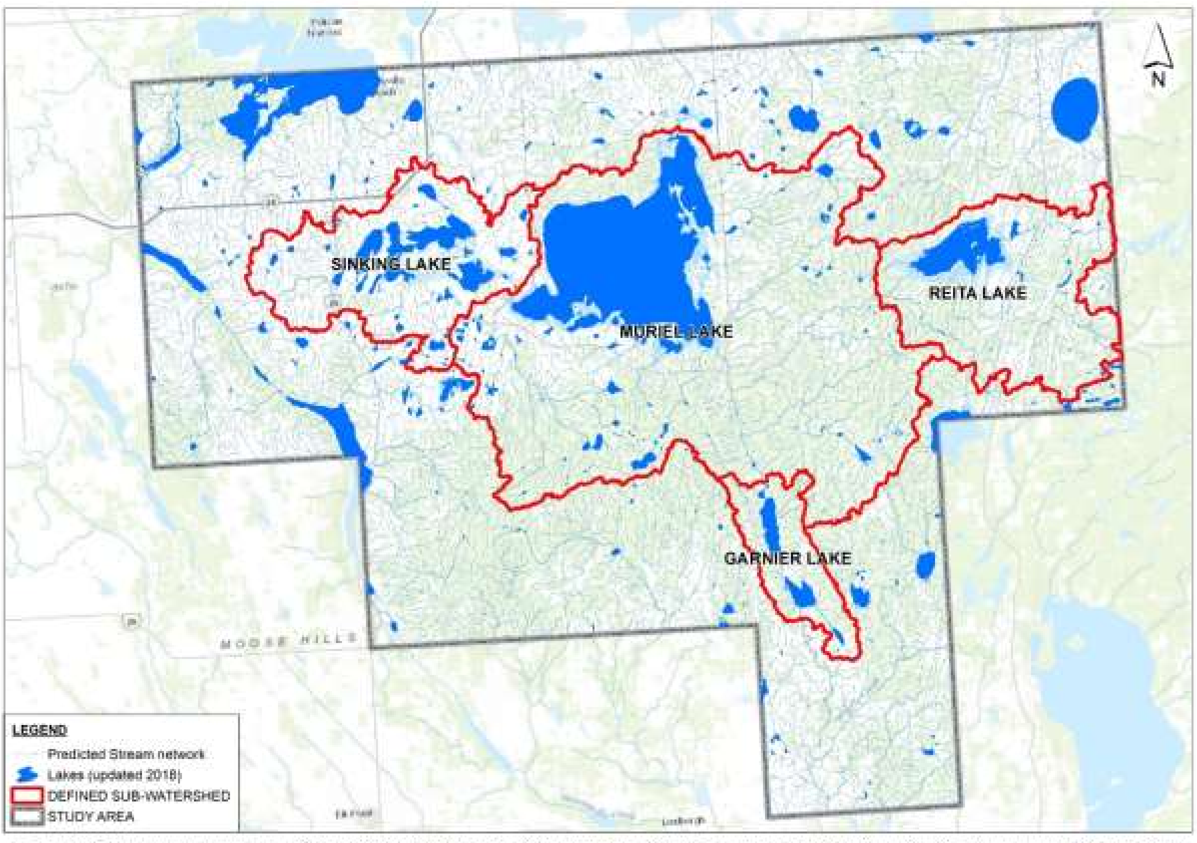

FIGURE 2. Map showing predicted stream and updated lakes in the study area.

2.2. WETLAND AND UPLAND CLASSIFICATION

This section of the report presents the methodology used for wetland and other upland landcover classification across the project area. In addition to the landcover classification, an optical index was used to accurately delineate the boundaries of the existing lakes and open water bodies. For the landcover classification component, a medium resolution Sentinel-2A (S2A) multispectral image, acquired in the summer of 2018, was used. S2 is a wide-swath, medium-resolution, multispectral imaging mission supporting Copernicus Land Monitoring studies, including the monitoring of vegetation, soil, and water cover, as well as observation of inland waterways and coastal areas.

The Google Earth Engine (GEE) cloud-computing platform (Gorelick et al., 2017) was used as a repository of processed satellite imagery for the project. The S2A image downloaded from GEE was Top of Atmosphere (ToA) multispectral data. The spectral bands used for image classification included the visible and near-infrared (VNIR) (i.e., bands 2, 3, 4, and 8), red edge (RE) (band 5), and shortwave infrared (SWIR) (bands 11 and 12).

With the S2 bands, the Modified Normalized Difference Water Index (MNDWI) (Xu, 2006) was calculated. The MNDWI optical index enhances open water features while suppressing and removing noise from built-up land, soil, and vegetation (see equation 1).

$$\text{MNDWI} = \frac{\rho_{Green} - \rho_{SWIR}}{\rho_{Green} + \rho_{SWIR}} \qquad \text{(equation 1)}$$

Using the selected spectral information and LiDAR-derived topographic variables, such as Saga Wetness Index (SWI), as inputs for a supervised Random Forest classifier algorithm, a current and accurate landcover map of the project area was generated in the study.

2.2.1. Training Data and Classification Scheme

The Alberta Biodiversity Monitoring (ABMI) 3x7 km Land Cover Photo plot data (Abmi Geospatial Center, 2016) was used as training data for image classification for this project. The ABMI land cover plot data is a detailed and comprehensive inventory characterizing moisture, management status, vegetation features, wetlands, land use, infrastructure, and land cover within the 1,656 ABMI 3x7-km sites that cover approximately 5% of Alberta.

Figure 3 presents an example of the ABMI 3x7 training data used for image classification in the study. For the classification process, 60% of the data was used to train the classifier, while 40% was used for accuracy assessment.

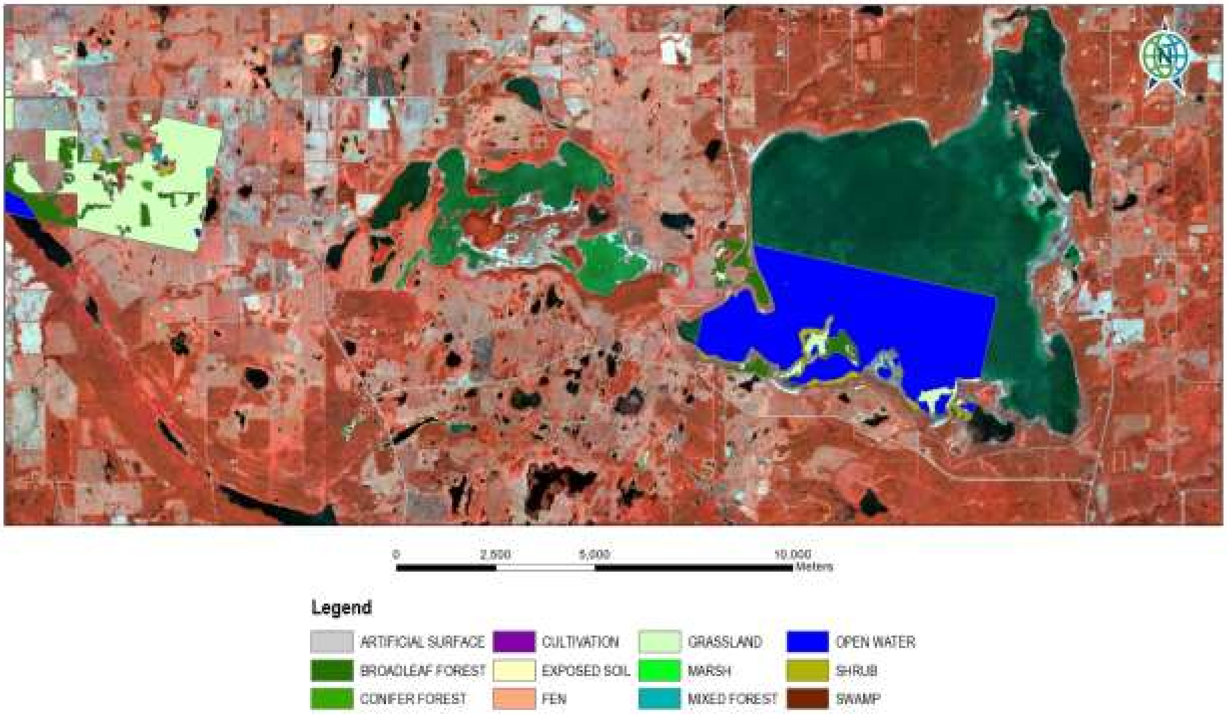

FIGURE 3. Example of wetland and upland classes extracted from the ABMI plot data used in classification

2.2.2.Random Forest Image Classifier

The pixel-based supervised Random Forest (RF) machine learning algorithm was selected for this study, as it is generally less affected by noise and overfitting of remotely sensed data, as noted by Teluguntla et al. (2018). The RF algorithm is a decision tree ensemble proposed by Breiman (2001) that is capable of handling high data dimensionality effectively. The RF classifier is known to be capable of producing significantly higher classification accuracy in comparison to traditional classifiers, such as the maximum likelihood classifier, while using a limited number of training samples (Ok et al., 2012; Tatsumi et al., 2015). The parameters required to define the RF include the number of decision trees to create (k) and the number of randomly selected variables (m) considered for splitting each node in a tree.

The Image Analyst extension of ArcGIS Pro (www.esri.com) was used for RF classification. For wetland and upland landcover classification, the *Alberta Wetland Classification System* was used as a guide to categorize the data into five wetland classes: Bog, Fen, Swamp, Marsh, and Open (and shallow) Water. Table 1 presents a summary of the mapped spatial extent and percentage cover generated in the study. Figures 4 and 5 show the mapped landcover classes and the wetland classes for the project area. The wetland map was created by reclassifying the landcover classification to the prominent wetland classes and non-wetlands (Figure 5). In Appendix A, Figure A.3 provides a detailed landcover classification map showing the wetland and upland classes generated in the study.

Using high-resolution aerial imagery, the generated landcover maps were compared to determine the level of accuracy obtained. The results showed a close correlation between the mapped upland and wetland classes with the referenced high-resolution satellite data (see Appendix B).

TABLE 1. Summary of spatial extent and percentage cover for wetland and upland classes mapped across the study area

Landcover Class	Area (ha)	Percentage Cover Landcover Class
Developed area	8,270	6
Broadleaf forest	54,752	41
Coniferous forest	6,001	5
Cultivation	6,171	5
Exposed soil	1,563	1
Fen	2,765	2
Grassland	21,222	16
Marsh	4,024	3
Mixed forest	8,810	7
Open water	12,581	9
Shrub	3,659	3
Swamp	3,130	2
Total	**132,947**	**100**

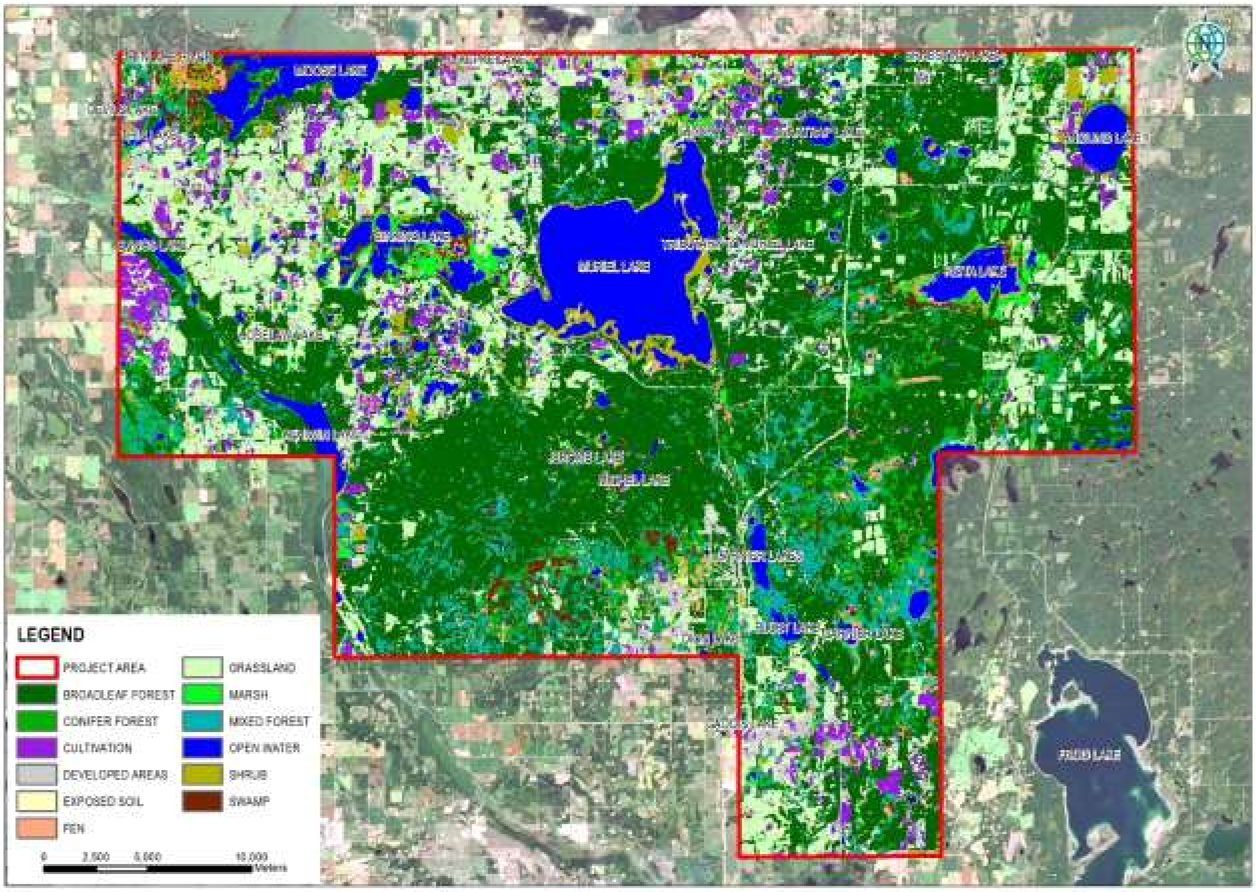

FIGURE 4. Random forest wetland and upland classification of the project area

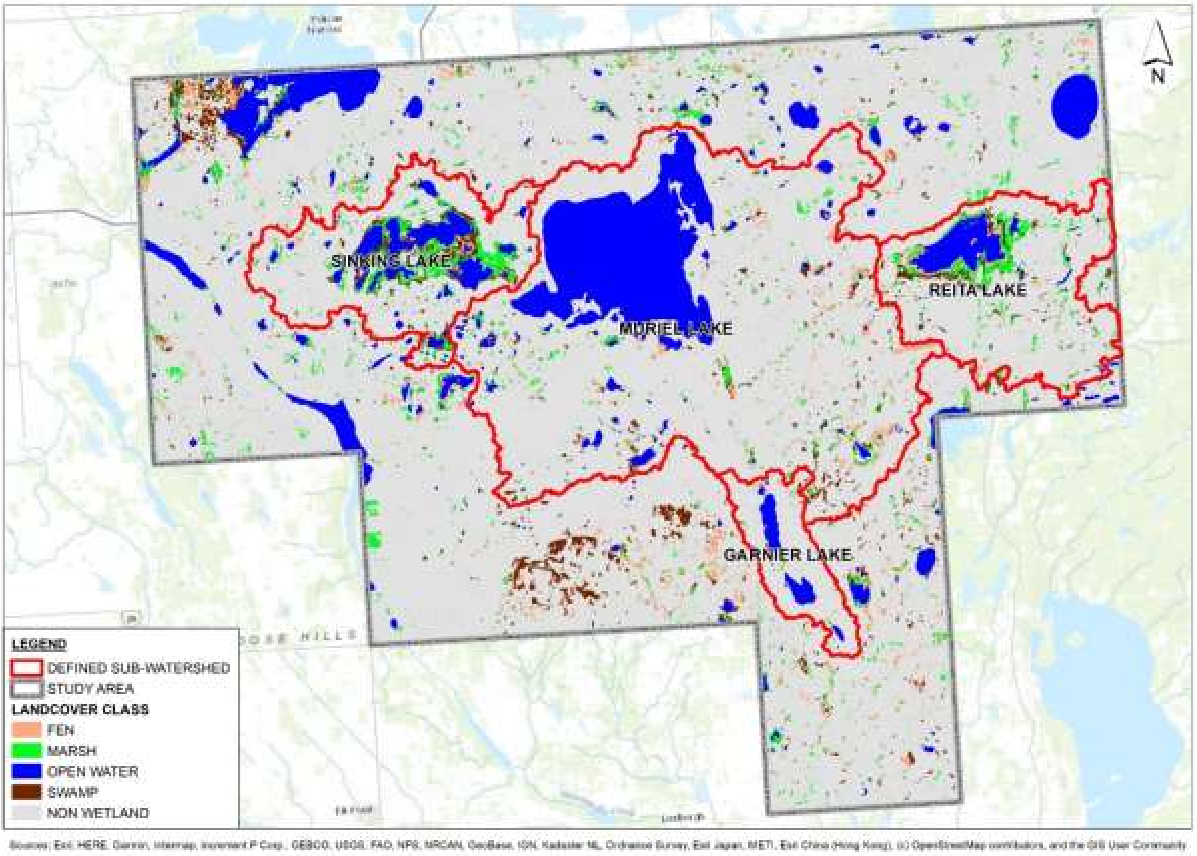

FIGURE 5. Wetland and non-wetland classification of the project area

2.3. ROUGHNESS SCORE INDEX CALCULATION

The surface roughness of the sub-watershed was calculated to ascertain which sub-watersheds contributed to the water-flow of Muriel Lake. The term *roughness* indicates the degree of irregularity of the surface. It is derived from the largest inter-cell difference of a central pixel and its surrounding cell.

The determination of the roughness plays a role in the analysis of terrain elevation data and is useful for calculating river morphology. For this project, the roughness was computed using the GDAL tool in the open-source QGIS software. This command outputs a single-band raster with values derived from the processed LiDAR DEM.

With the refined sub-watershed boundary, a zonal statistics analysis was performed to generate roughness scores per sub-watershed. The results indicated that the Muriel Lake, Garnier Lake, and Sinking Lake sub-watersheds had high roughness values, while the Reita Lake sub-watershed had the lowest roughness (see Table 2).

TABLE 2. Summary of roughness measures for sub-watershed evaluated in the study

Sub-watershed	Area (ha)	Min.	Max.	Range	Mean	Standard Deviation	Sum
Reita Lake	8,894.1	0	14.8	14.8	1.3	1.3	495,305
Sinking Lake	8,522.7	0	24.8	24.8	1.7	1.7	642,449.8
Muriel Lake	32,893.6	0	23.5	23.5	2.1	2.3	3,262,072.5
Garnier Lake	2,861.7	0	23.5	23.5	2.1	2.3	3,262,072.5

2.4. INHIBITED FLOW ANALYSIS

The inhibited flow analysis aims to identify locations of impoundments and therefore increased standing surface water. The approach involved performing a longitudinal profile analysis of stream and creek channels using standard GIS tools. The stream profile analysis was performed using the high-resolution LiDAR data and Alberta Fisheries and Wildlife Management Information System (FWMIS) hydrology arcs to identify the spatial representation of streams and rivers (Government of Alberta, 2018).

2.4.1.Stream Longitudinal Profile Analysis

The longitudinal profile analysis indicated locations along the tributary, where water elevation increased due to any form of impoundment. The approach for this component of the study entailed utilizing elevation information from the high-resolution LiDAR data and 3D Analyst GIS tools for the analysis.

The selected FWMIS hydrology arcs per sub-watershed (i.e. Garnier, Muriel and Sinking lakes sub-watershed) were analyzed in this study. Appendix C of this report presents the results of the stream longitudinal profile analysis. These results show the location of potential impoundments or barriers to water flow along the identified streams or creeks.

Based on the results obtained, impounded locations requiring immediate attention were identified due to small beaver dams or blocked culverts. For example, obstructions to water flow on the stream segment ML6 were identified at chainages 480 m, 620 m, and 2,480 m, respectively. The obstacle at chainage 2,480 m was an access road leading to an abandoned oil well site, remediation of which has been assigned to the Orphan Well Association (OWA). Beaver's activity in this area is extensive, and MLBMS report that blockage of culverts had previously required mechanical clearing of the culverts by the operating oil company and, more recently, OWA. In July 2020, MLBMS provided drone imagery, which showed that the road had washed out, and the culverts were destroyed. Figure 6 shows field verification photos of the obstructions to the river segment ML6 evaluated in the stream analysis. A segment of the culvert is visible far downstream, and there is evidence of beaver activity to dam the breach. This location is identified for immediate management action.

FIGURE 6. Field verification photograph showing confirmed beaver activity resulting in obstruction to water flow along stream segment ML6 analyzed in the study

Solstice has provided the MLBMS with a list of potential impoundment locations identified from the analysis that needs to be field-verified and checked through onsite investigations. With the use of drone images and videos, and "*actual-walk throughs,"* these identified locations can be inspected, and necessary management actions identified. Appendix D provides a summary of potential impoundment areas generated in the study. The impoundment location is provided as a GIS shapefile and an Excel spreadsheet in the project deliverables.

2.4.2. Topographic variability of selected locations

To understand the topographic variability of these locations of interest, transect lines crossing the respective points perpendicular to the closest road intersection and in the opposite direction were generated. With the "*location of interest*" position being the center point of the transect line, the Chainage 0m point is the start of the line, and the perpendicular intersection to the closest road link serves as the end chainage point. Hence, the length of each transect line is dependent on the distance between the locations of concern and the closest road intersection. Using elevation information provided by the LiDAR DEM raster, profiles of the transect lines were generated and deductions of the topography made. Locations 2, 3, 4, 5, 18 and 25 were successfully generated (Table 3).

TABLE 3. Selected location of concern analyzed using transect profile analysis

Location	Latitude (degrees)	Longitude (degrees)	Eastings (meters)	Northings (meters)	Elevation (meters)	Description
Location #2	54.117	-110.741	516,897.12	5,996,570.71	560.96	Location #2 - Slough/Improper culvert at Muriel lake Drive near 2nd Street
Location #3	54.156	-110.608	525,583.69	6,000,919.38	571.02	Location #3: Beaumieux South
Location #4	54.153	-110.610	525,470.43	6,000,615.00	562.96	Location #4
Location #5	54.062	-110.612	525,395.36	5,990,489.47	609.05	Location #5
Location #18	54.052	-110.605	525,892.46	5,989,379.58	604.57	County of St Paul
Location #25	54.097	-110.755	516,012.65	5,994,286.10	578.07	Location 25: Culvert Blocked at Range Road 60

3. FURTHER INVESTIGATIONS AND CONCLUSION

3.1. SCOPE FOR FURTHER ANALYSIS

In addition to mapping potential impoundment locations in the Muriel Lake basin, having an understanding of climatic variability (such as evapotranspiration, precipitation, temperature, and land-use change dynamics) is a significant step in better understanding the dynamics of surface water change in Muriel Lake. Some preliminary analysis related to evapotranspiration, utilizing earth observation data, was performed as part of this study. A summary of the observations made and plans for subsequent analysis are presented in this section of the report.

3.1.1. Evapotranspiration Analysis

The term Evapotranspiration (ET) refers to the process of water loss from the land surface to the atmosphere through evaporation and transpiration (Zotarelli et al., 2010). For this study, the MODIS (Moderate Resolution Imaging Spectroradiometer) derived MOD16A2 (Version 6) Evapotranspiration/Latent Heat Flux (MOD16) product, an 8-day composite product produced at 500-m pixel resolution (Running et al., 2017), was obtained from the GEE cloud-based platform (Figure 7). The MOD16 data product is based on the Penman-Monteith equation.

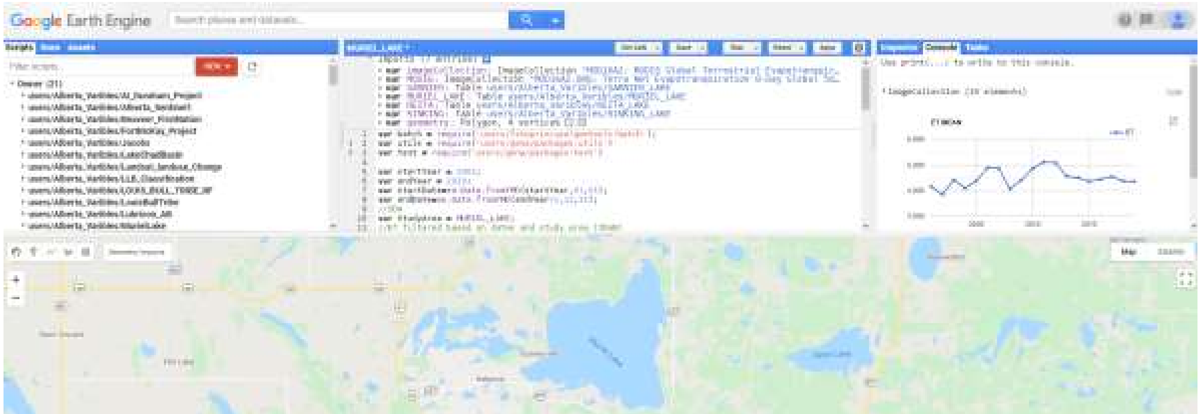

FIGURE 7. Google Earth Engine platform showing the MOD16 global terrestrial evapotranspiration image collection

Using the MOD16 data, a temporal chart detailing yearly changes of ET for all four sub-watersheds was generated. For the ET analysis, available data from 2001 to 2019 (19 years) was collected. The yearly mean ET plot shows a general rise in water loss for all four sub-watersheds (i.e., Muriel Lake, Garnier Lake, Sinking Lake, and Reita Lake) over 19 years (2001 – 2019). This trend could be attributed to a host of factors such as rising temperature, changes in humidity levels, wind speed, water availability, soil type, and landcover change dynamics.

To better describe the observed trend, a land-cover change detection analysis is recommended. The understanding of landcover change over time, combined with the study of selected climatic variables, will provide some context to the changes in ET over the 19 years analyzed. Figure 8 presents a chart of the mean annual ET for all four sub-basins over 19 years (2001 – 2019).

FIGURE 8. Chart showing the mean annual evapotranspiration of the four sub-watersheds investigated in the study from 2001 – 2019

3.1.2. Multi-temporal Surface Water Analysis

A suggested approach to understanding the water balance of Muriel Lake and other major lakes in the study area is observing the changes in surface water over time. Multi-temporal remote sensing can be used to detect historical changes in open water extent from the 1980s to date. Using the rich repository of earth observation data, such as Landsat imagery, it is possible to estimate the spatial size of open-water surfaces and its changes over time.

3.1.3. Further Analysis of Locations of concern

Further study to evaluate locations of concern identified by the Client is recommended. This component shall build on the results of this study and previous projects like the 2012 Millennium EMS Solutions Ltd. Review of Muriel Lake Hydrology. The scope of this proposed study shall focus on the following:

- Identify the predicted wetland and upland classifications of the Locations of concern provided by MLBMS. This can build on the results obtained in this study. The Solstice generated wetland and upland classification results of the study area, which forms part of the project deliverable can be utilized for this component.
- Generate an elevation profile for the locations provided and identify drainage areas (if present) around such sites. For elevation profile analysis, a minimum elevation profile chart and/or transect profiles to the nearest lakes or streams (if any) is suggested.

3.1.4. Reita Lake – Muriel Lake hydrology study

The overall objective of this recommended study is to better understand the hydrological connectivity between Reita Lake and Muriel Lake. This scope shall build on the extensive stream profile analysis conducted in this study. The focus of this study is generating stream profiles of creeks or rivers running west to Muriel Lake from Reita Lake (i.e. ML 3, ML 2-7, and ML 2, respectively).

3.2. SUMMARY

For this study, a LiDAR-based hydrological model was used to generate a comprehensive stream network and perform stream longitudinal profile analysis for the Muriel Lake basin. The longitudinal profile analysis provided potential impoundment locations along streams and creeks in the Muriel Lake and Garnier Lake sub-watershed. The list of possible impoundment locations identified from the longitudinal stream profile analysis can serve as a valuable resource for management action.

In addition to the results obtained, the recommended additional studies will provide further information needed to manage better and understand environmental concerns related to Muriel Lake and the surrounding lakes in the watershed unit.

Solstice is pleased to provide MLBMS with a proposal that would outline the costs of performing the recommended studies.

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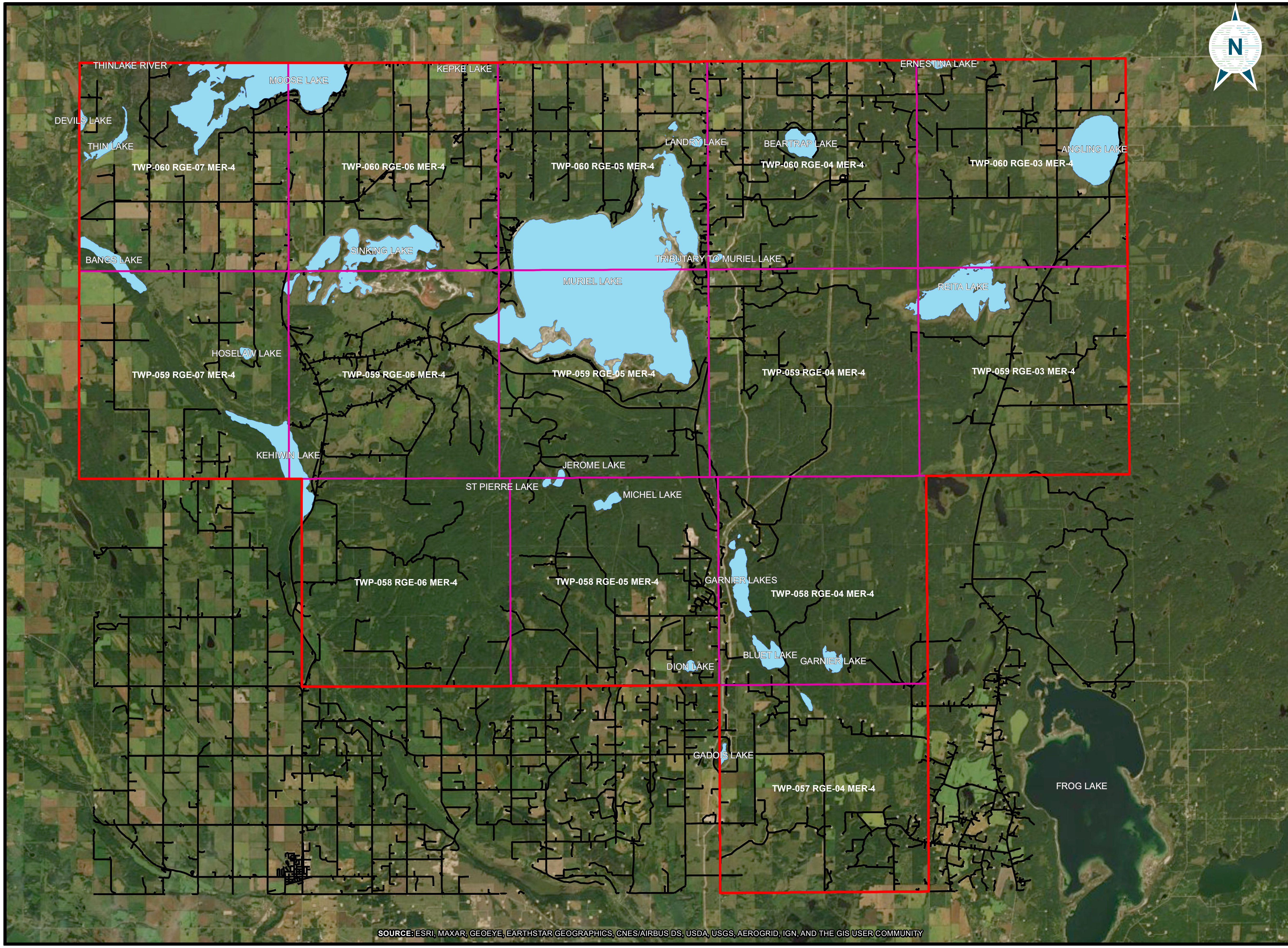
APPENDIX A. MAP OUTPUTS GENERATED FOR THE STUDY



LEGEND

- Road network
- Lake
- City
- Study area
- Alberta provincial township grid

0 1.5 3 km

Muriel Lake Basin Management Society

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MURIEL LAKE BASIN SOCIETY
HYDROLOGICAL NETWORK PROJECT
MURIEL LAKE WATERSHED BASEMAP

DATE:	PROJECTION:	DATUM:
AUGUST 13, 2020	UTM ZONE 12N	NAD83
PROJECT CODE: 19-12621-35	**FIGURE A.1**	
SCALE: 1:170,000		

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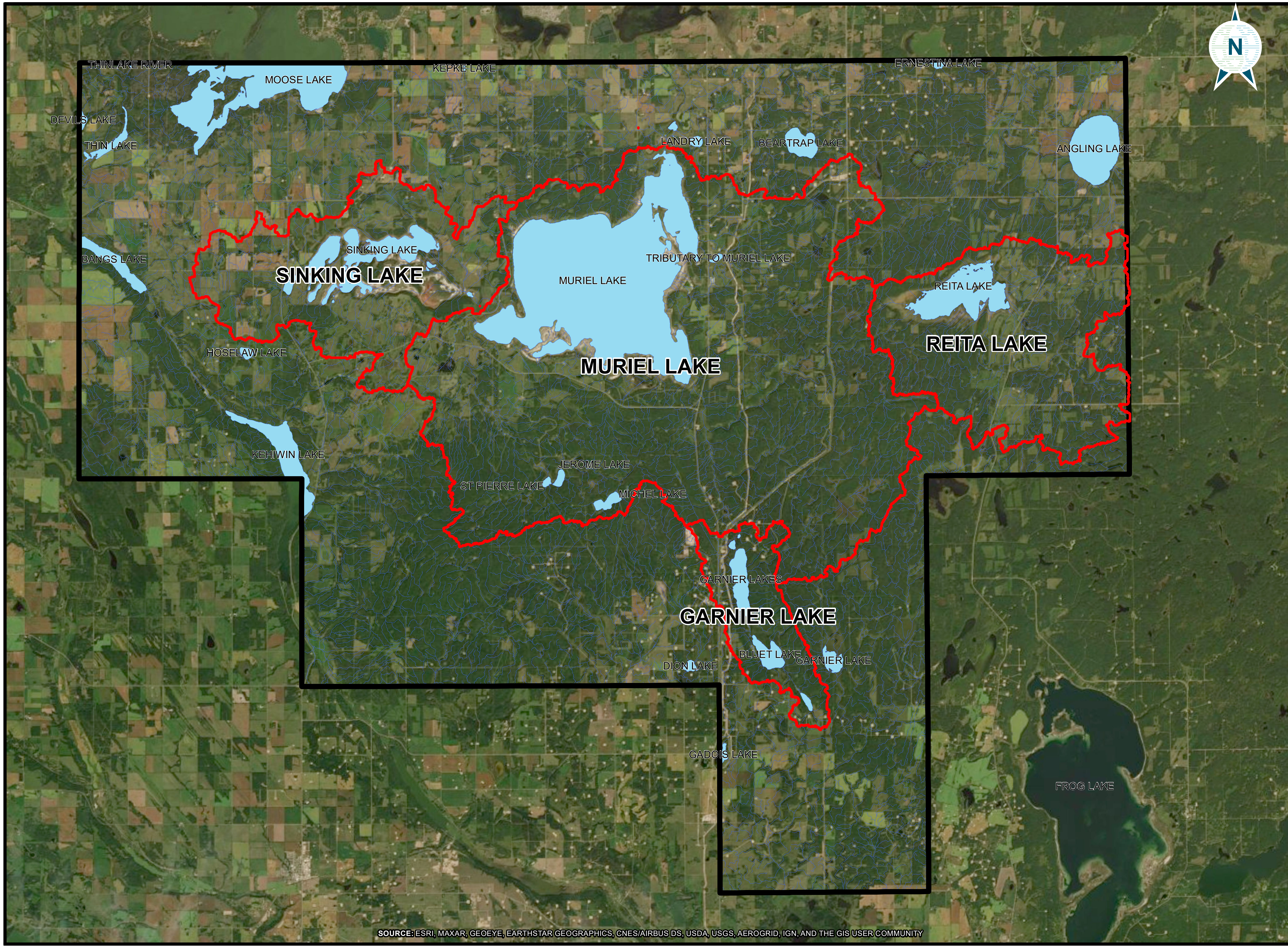

LEGEND

- Predicted Stream network
- Lake
- City
- Defined sub-watershed
- Study area

0 1.5 3 km

Muriel Lake Basin Management Society

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MURIEL LAKE BASIN SOCIETY
HYDROLOGICAL NETWORK PROJECT
SUB-WATERSHED BOUNDARIES & STREAMS

DATE:	PROJECTION:	DATUM:
AUGUST 13, 2020	UTM ZONE 12N	NAD83
PROJECT CODE: 19-12621-35	**FIGURE A.2**	
SCALE: 1:170,000		

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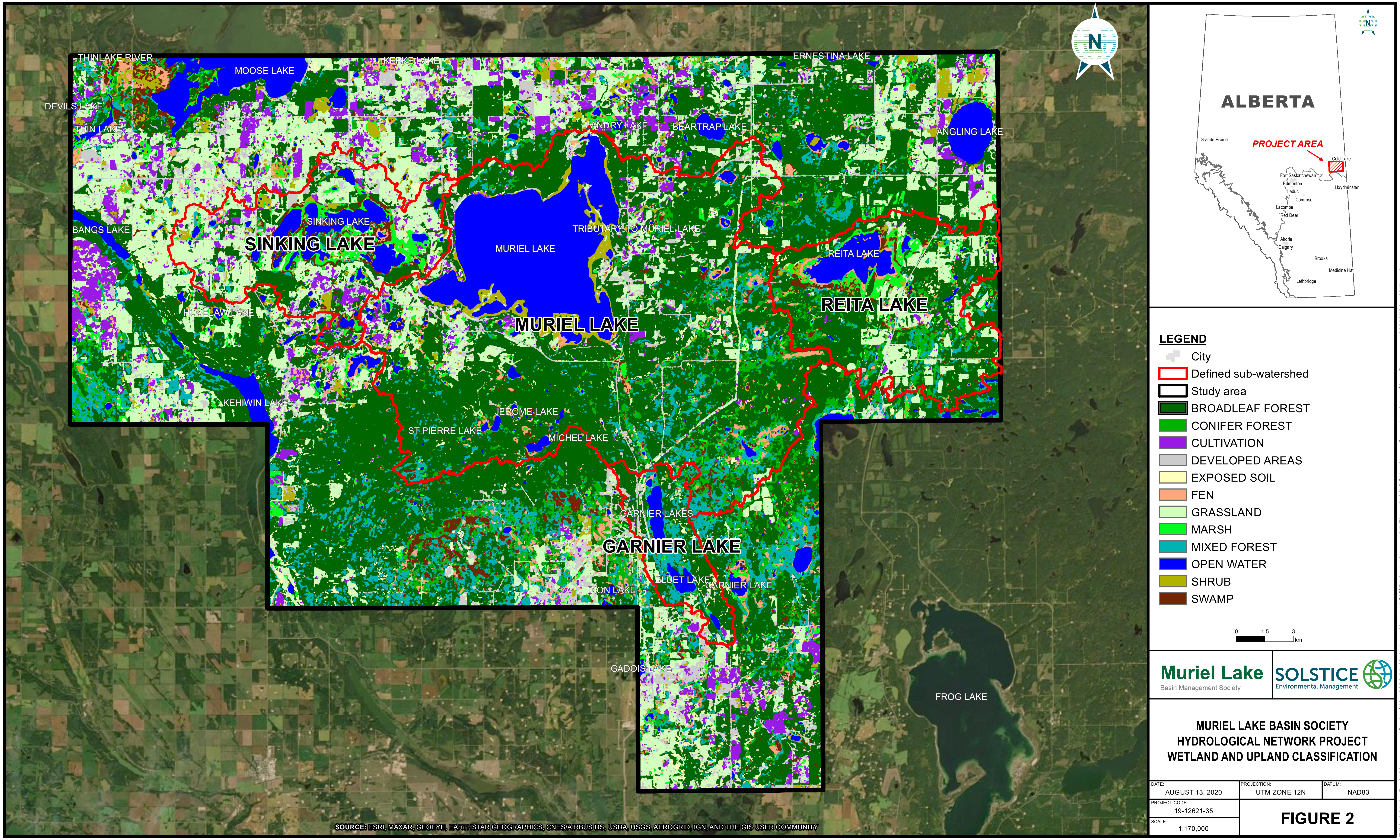

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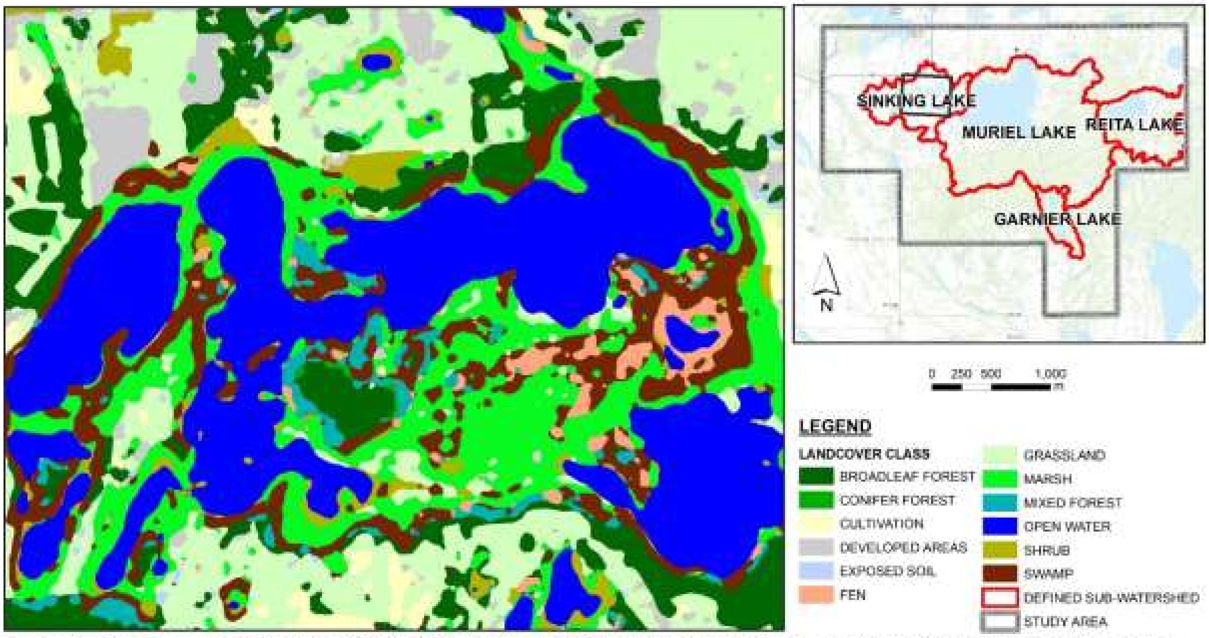
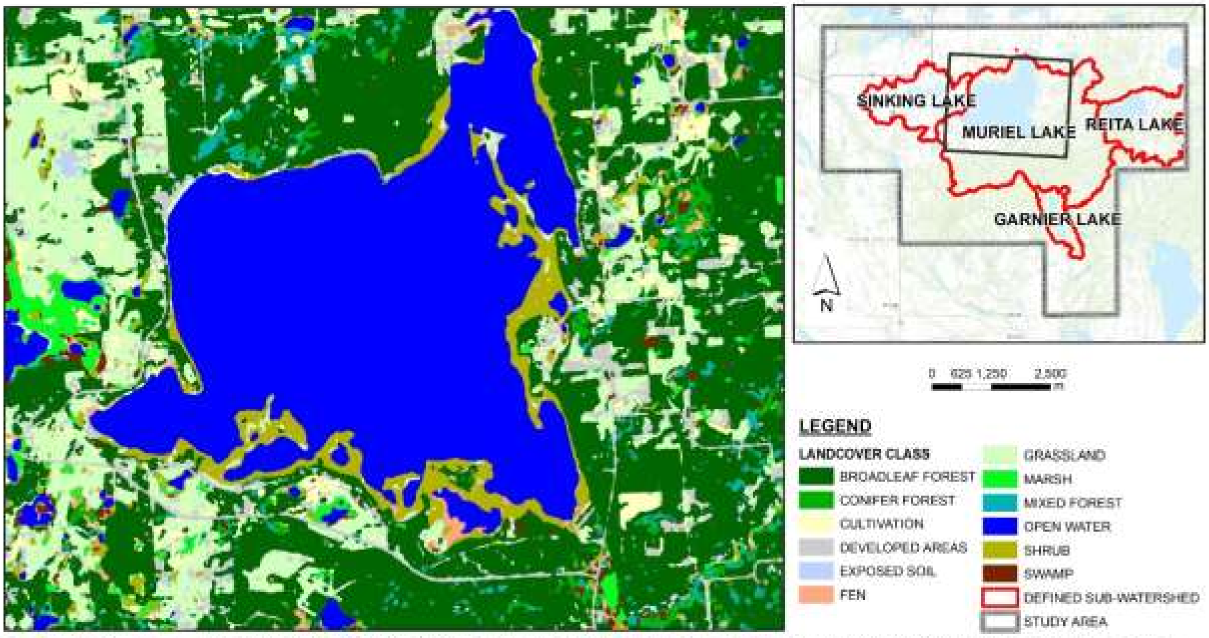
APPENDIX B. COMPARISON OF LANDCOVER CLASSIFICATION AND HIGH-RESOLUTION SATELLITE IMAGERY OF STUDY AREA

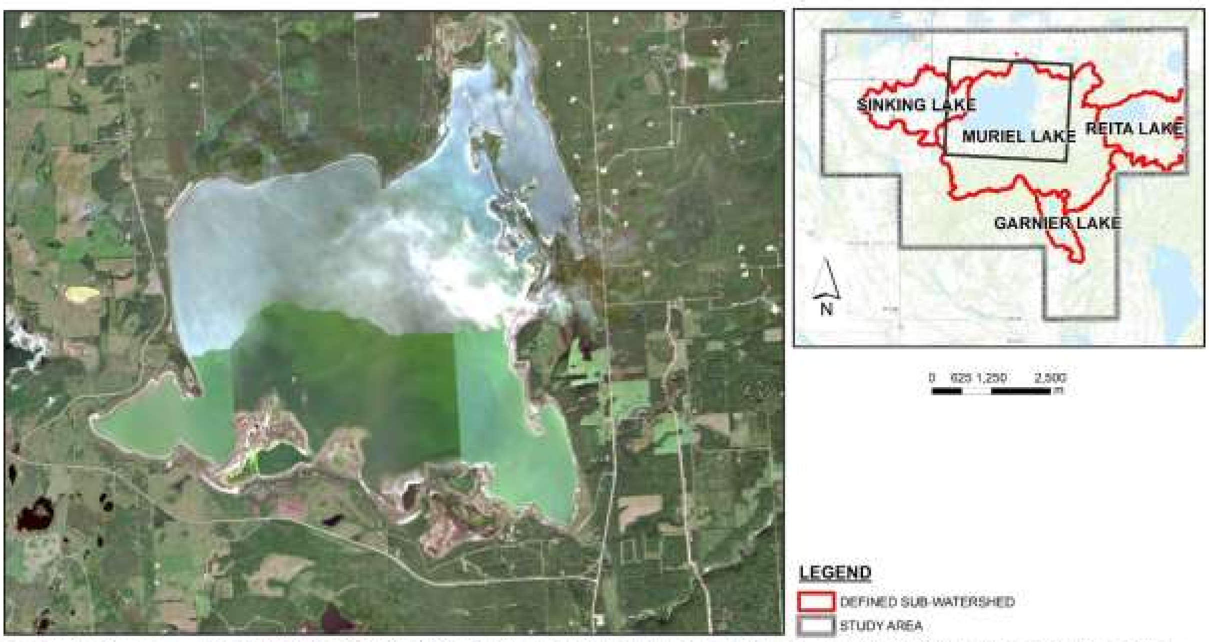


Source: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

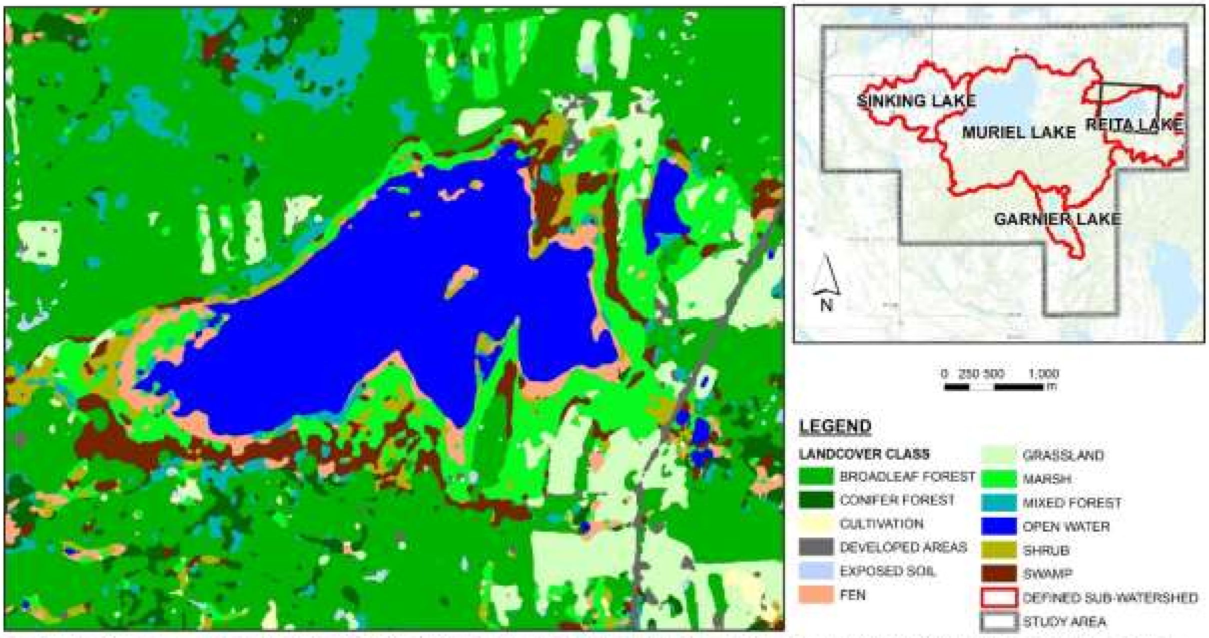
Source: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community



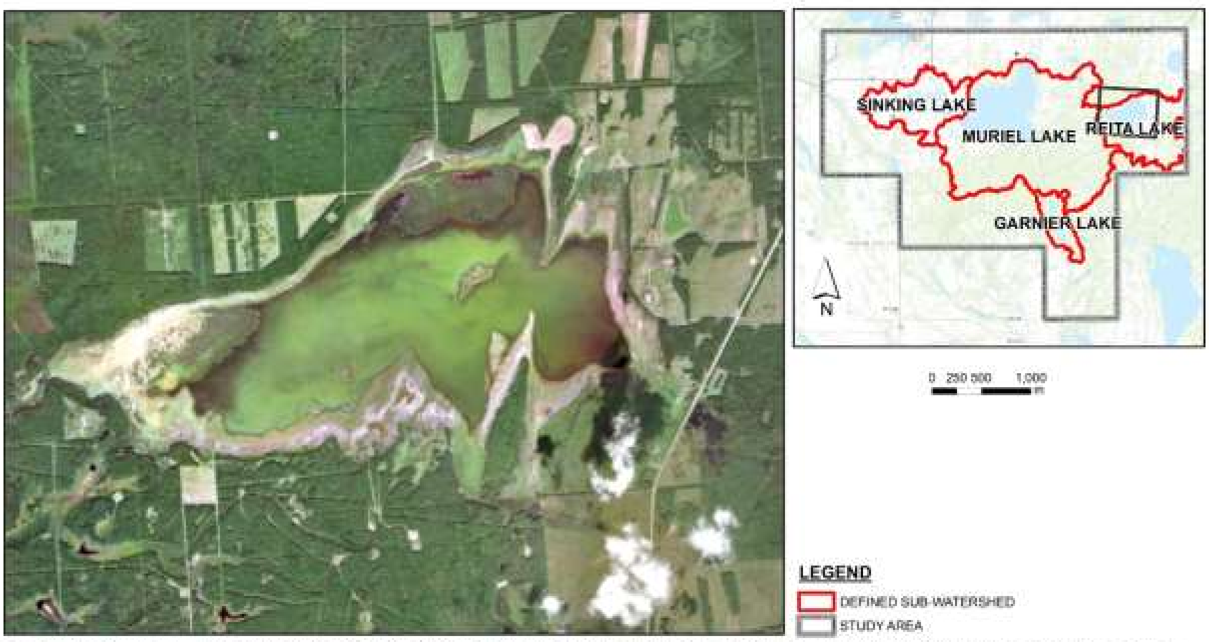
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community



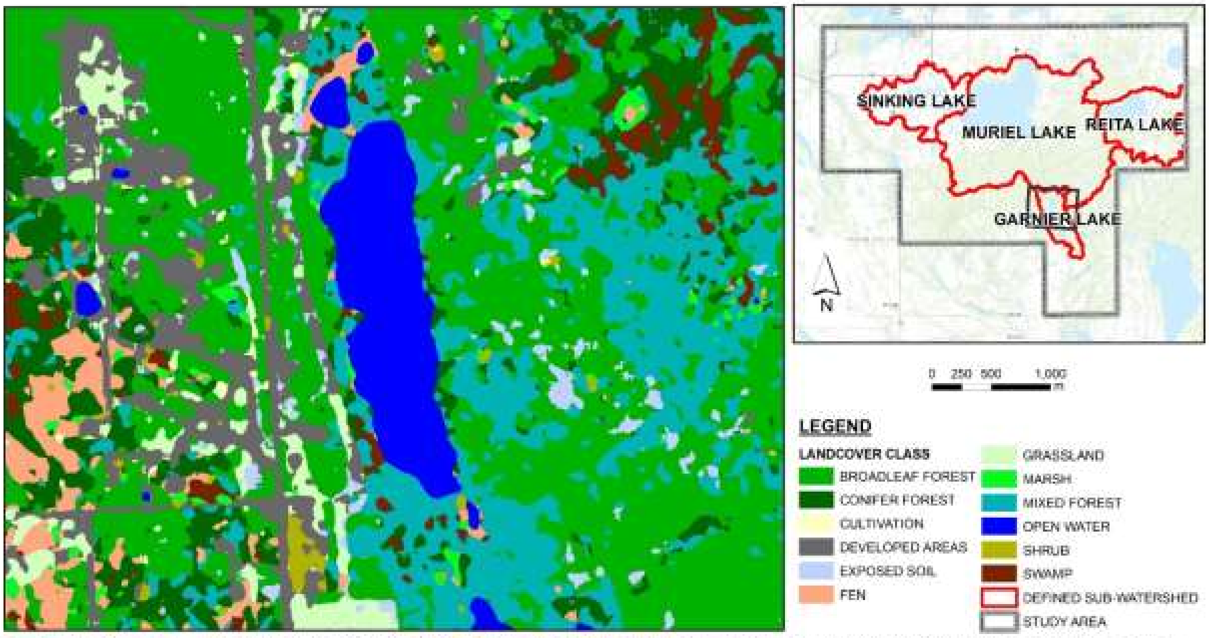
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community



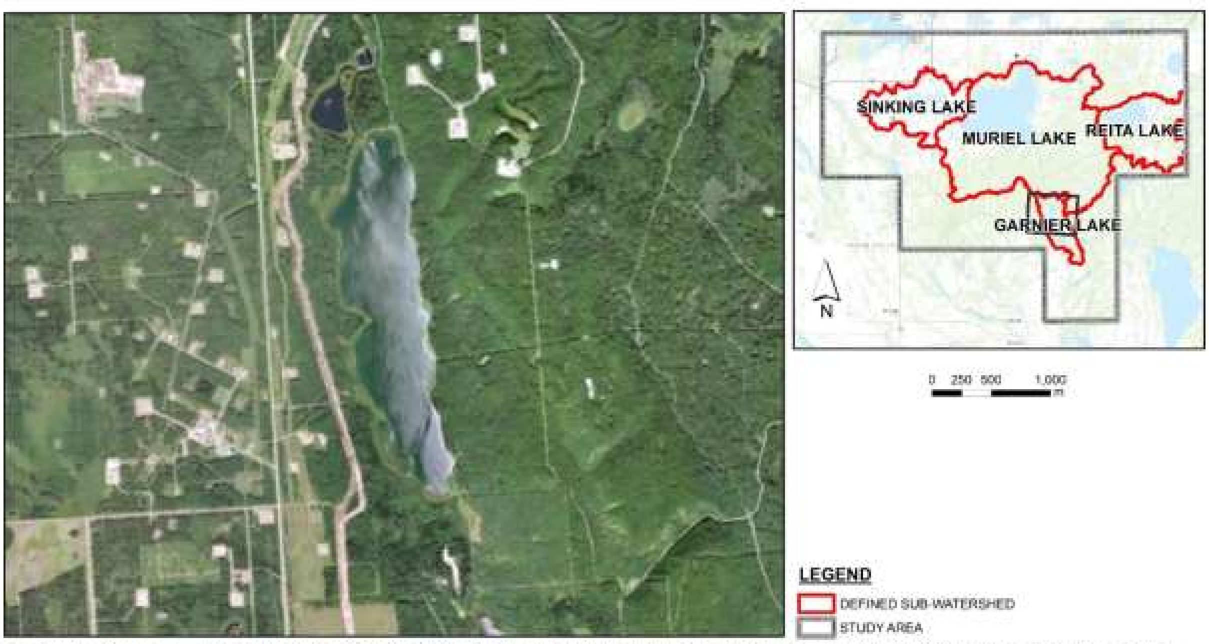
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community



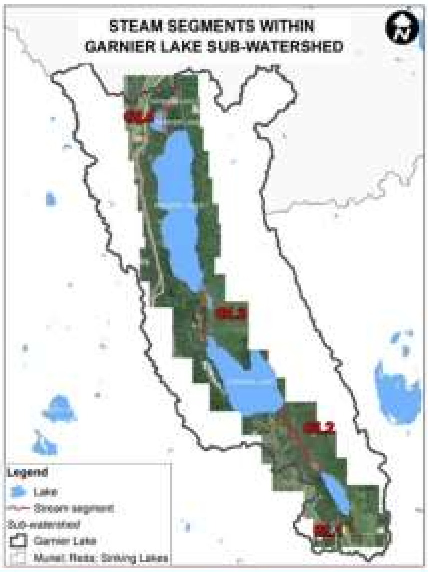
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community



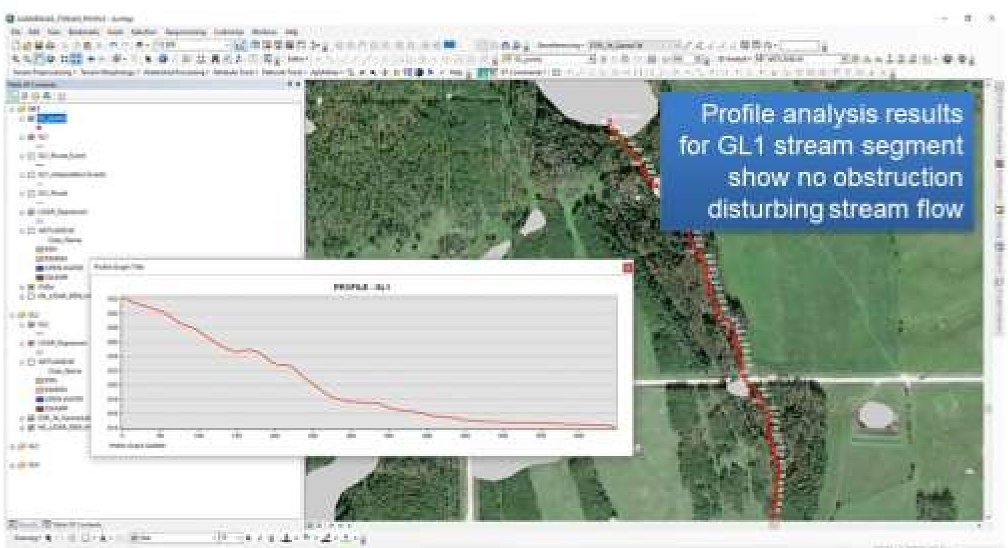
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

APPENDIX C. STREAM LONGITUDINAL PROFILE RESULTS

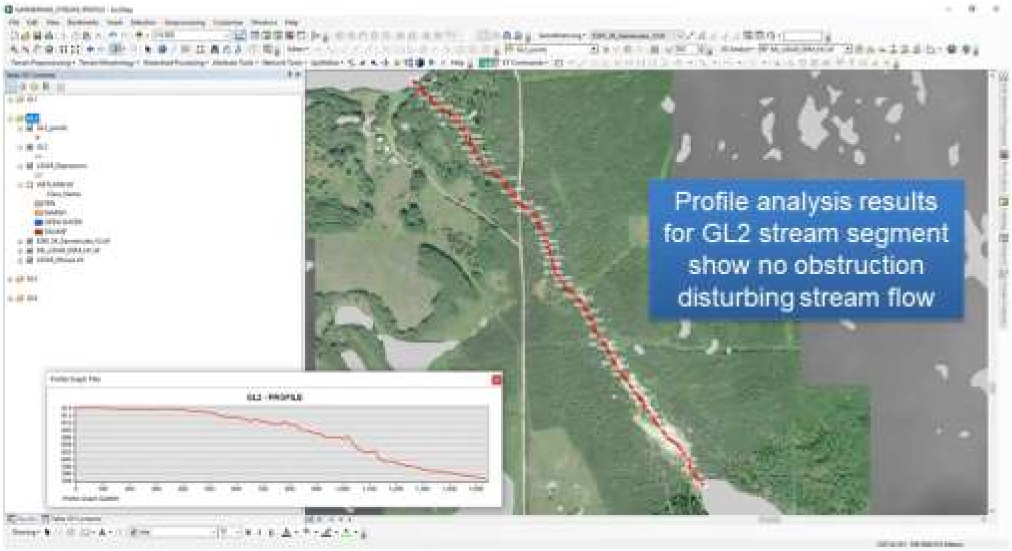
Garnier Lake Sub-watershed



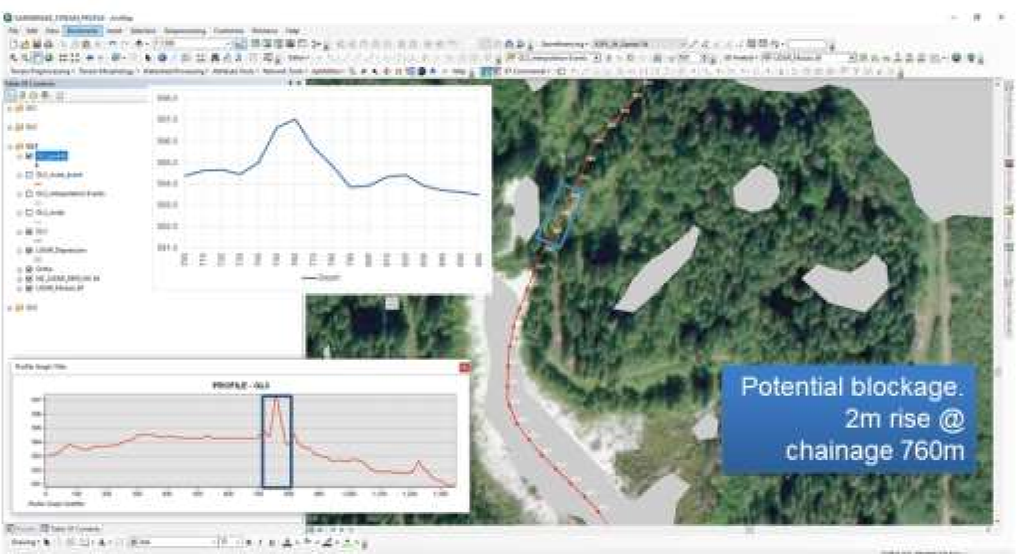
GL1 stream profile



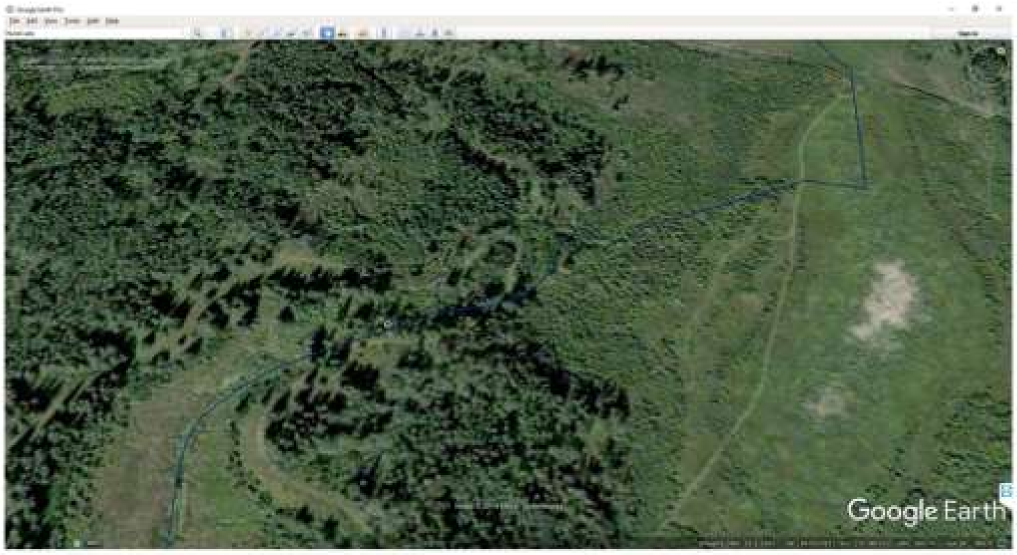
GL2 stream profile



GL3 stream profile

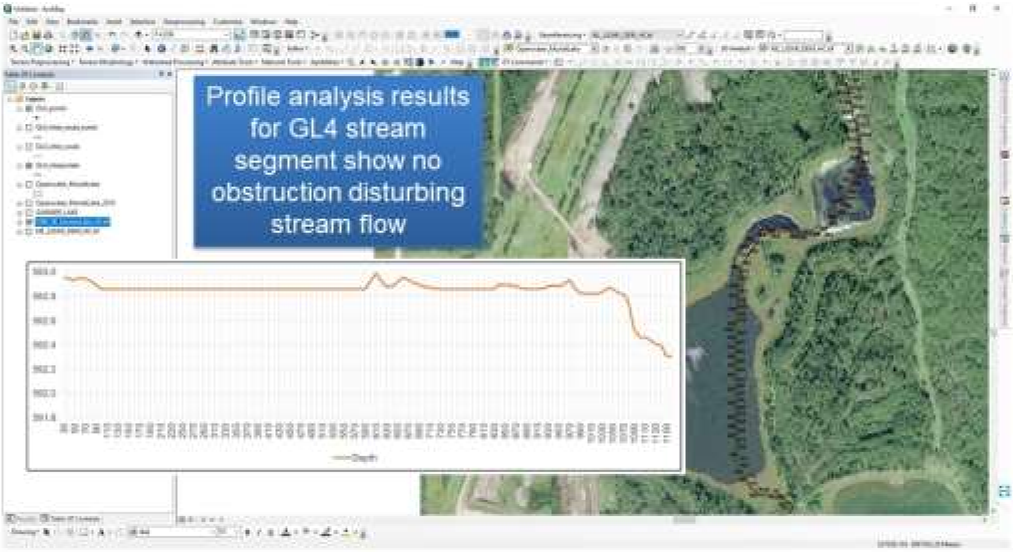


GL3 stream - 2003

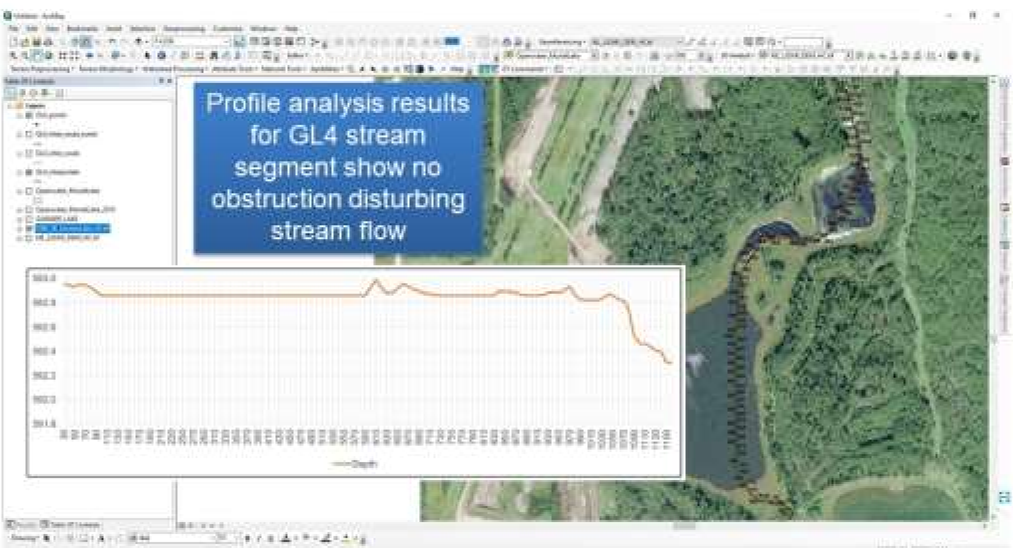


GL3 stream - 2019

GL4 stream profile

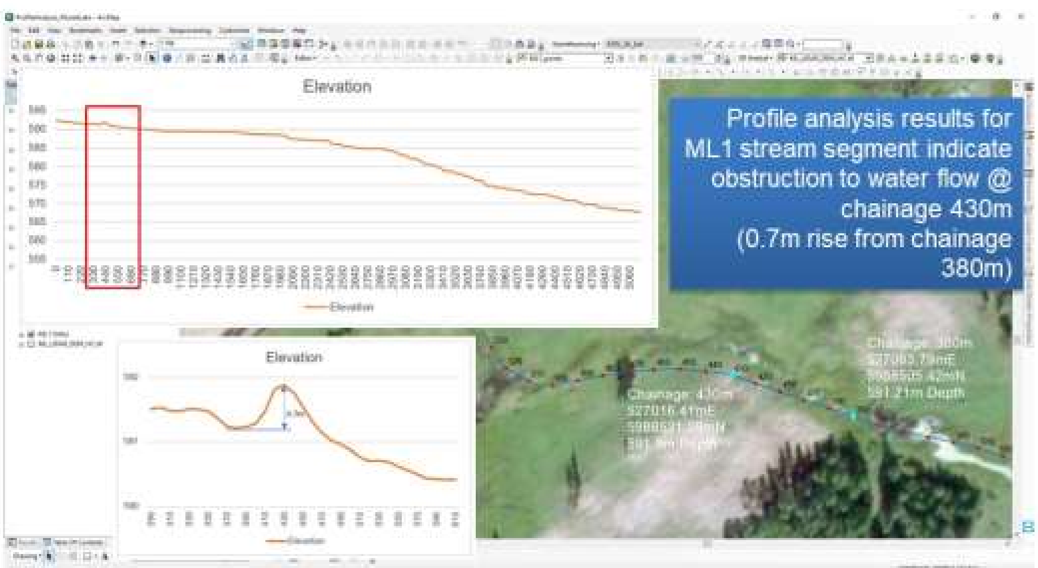


GL4 stream profile

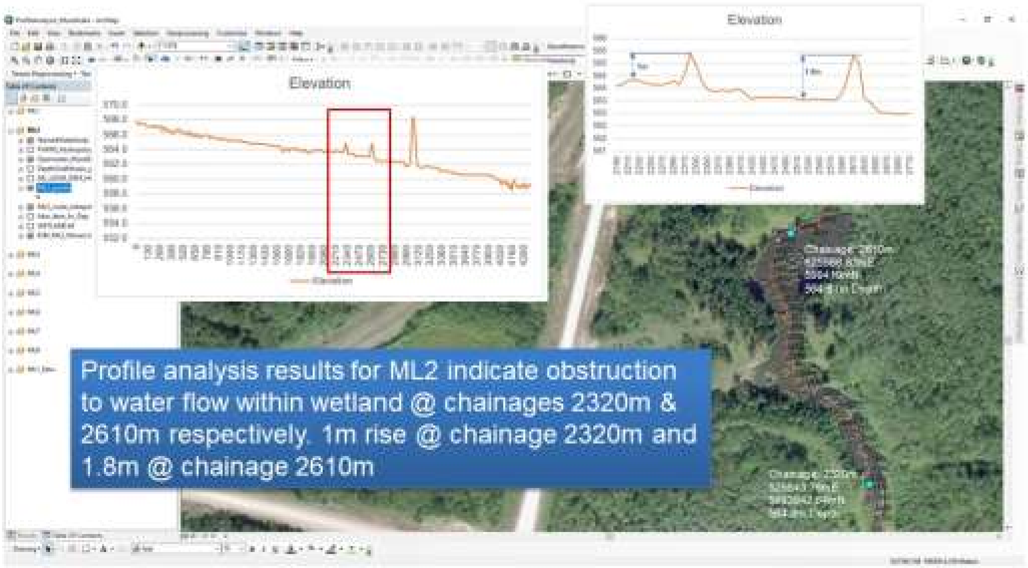


Muriel Lake Sub-watershed

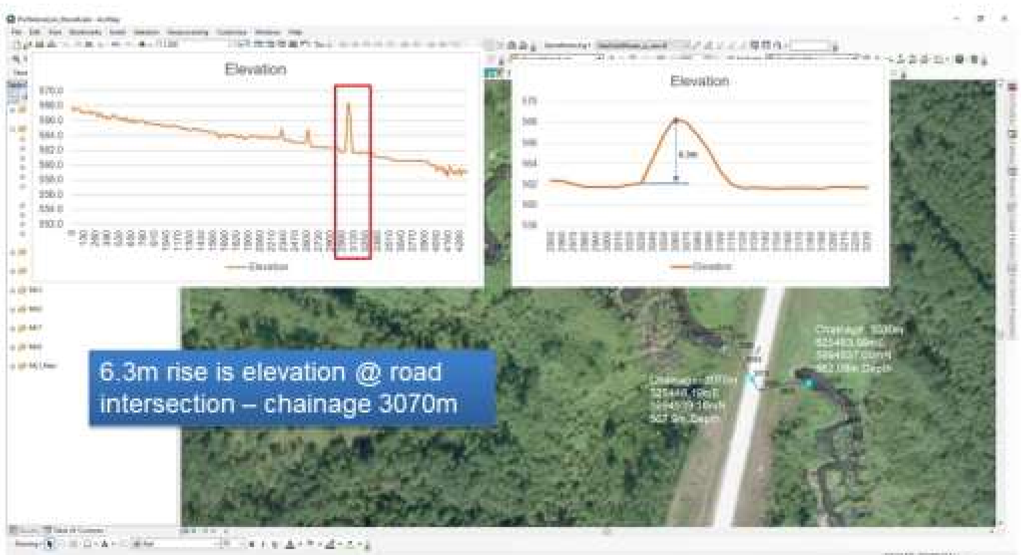
ML1 stream profile



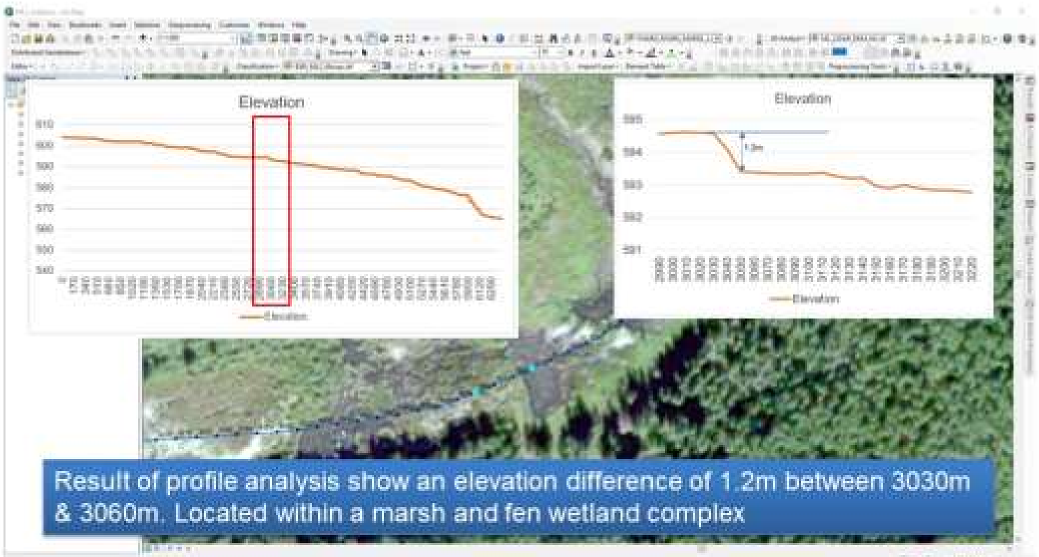
ML2 stream profile



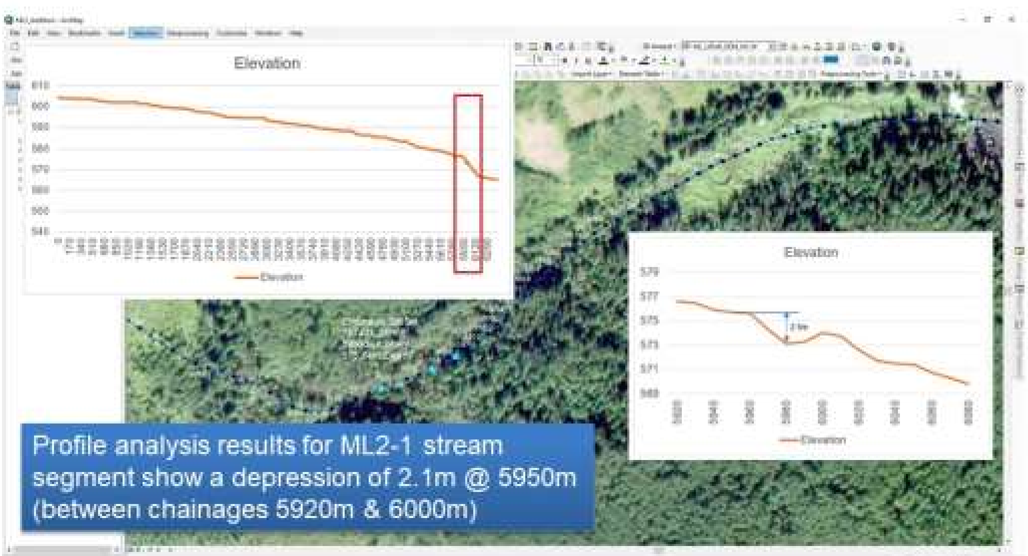
ML2 stream profile



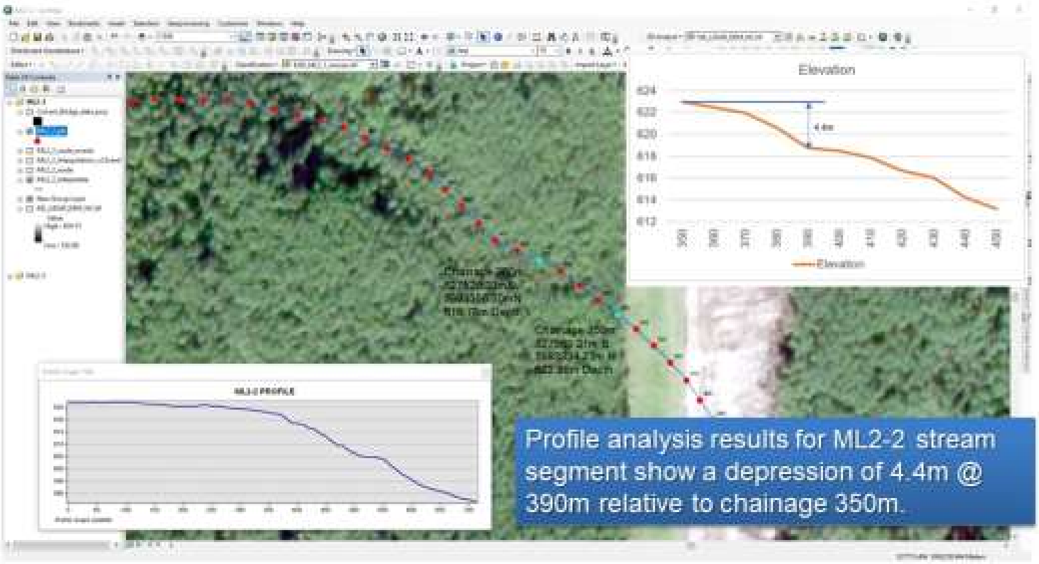
ML2-1 stream profile



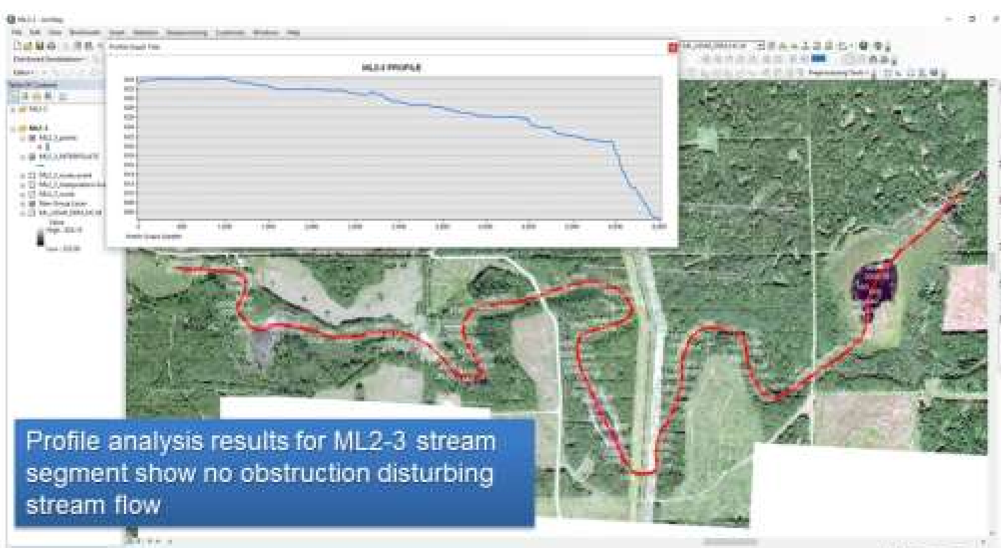
ML2-1 stream profile



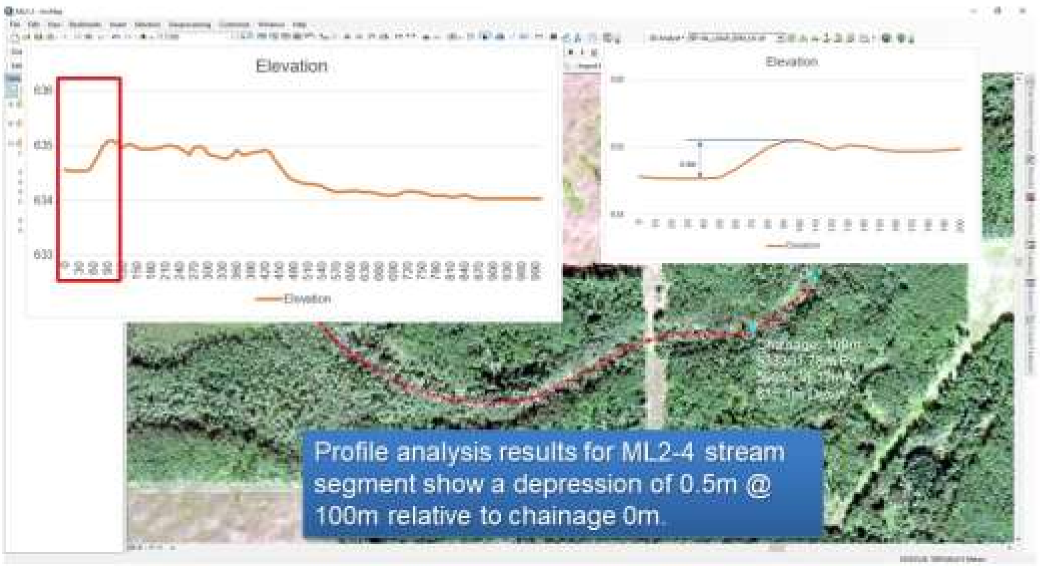
ML2-2 stream profile



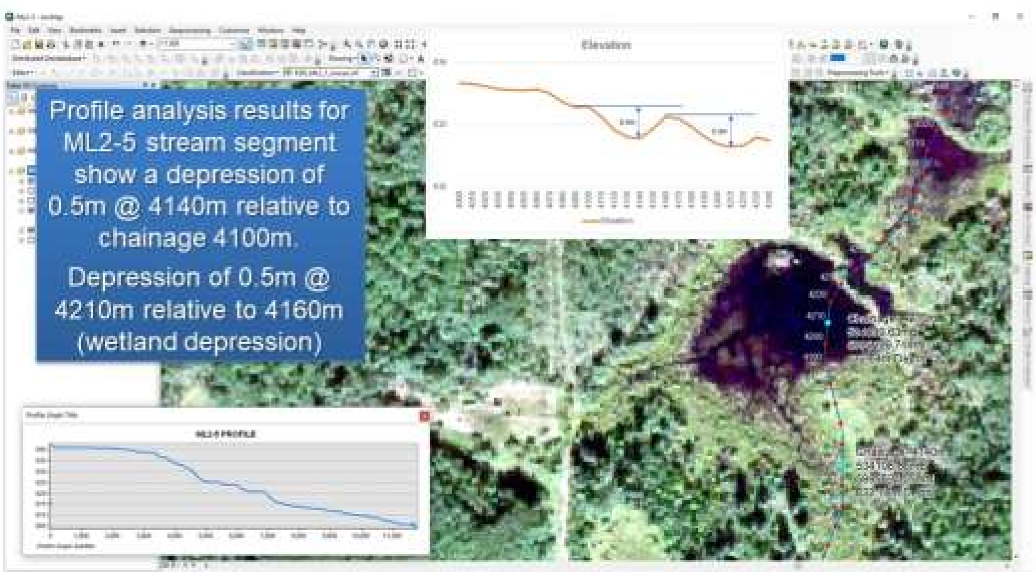
ML2-3 stream profile



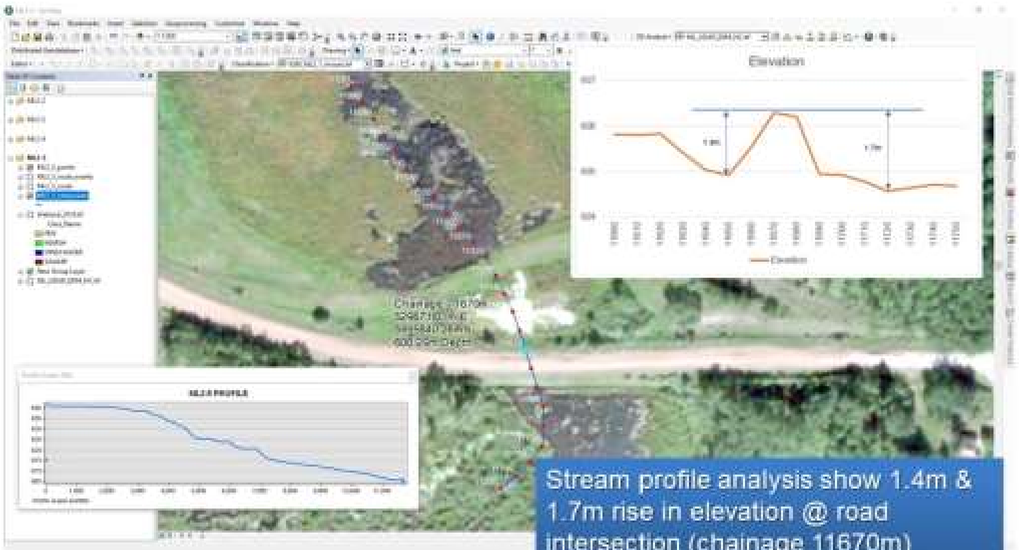
ML2-4 stream profile



ML2-5 stream profile

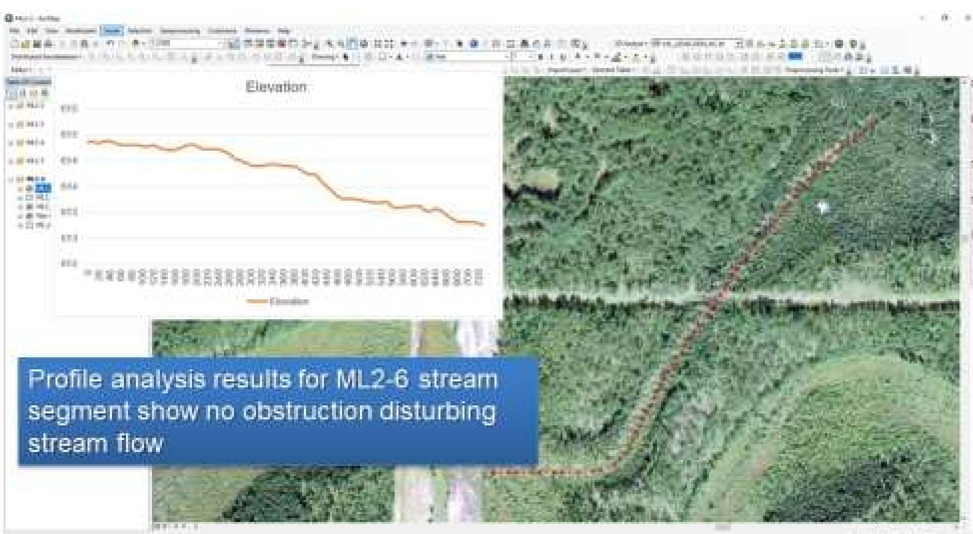


ML2-5 stream profile



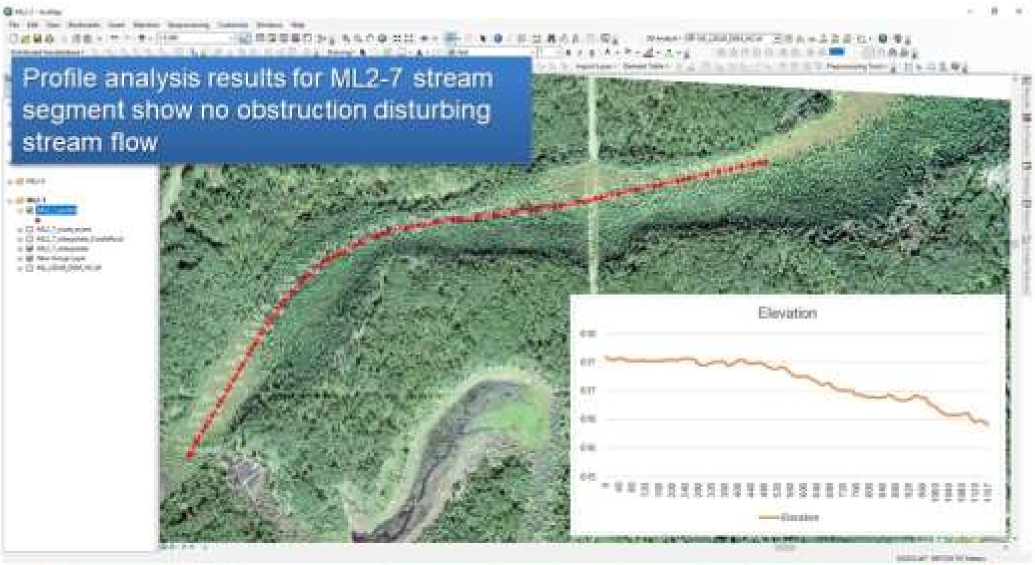
Stream profile analysis show 1.4m & 1.7m rise in elevation @ road intersection (chainage 11670m)

ML2-6 stream profile

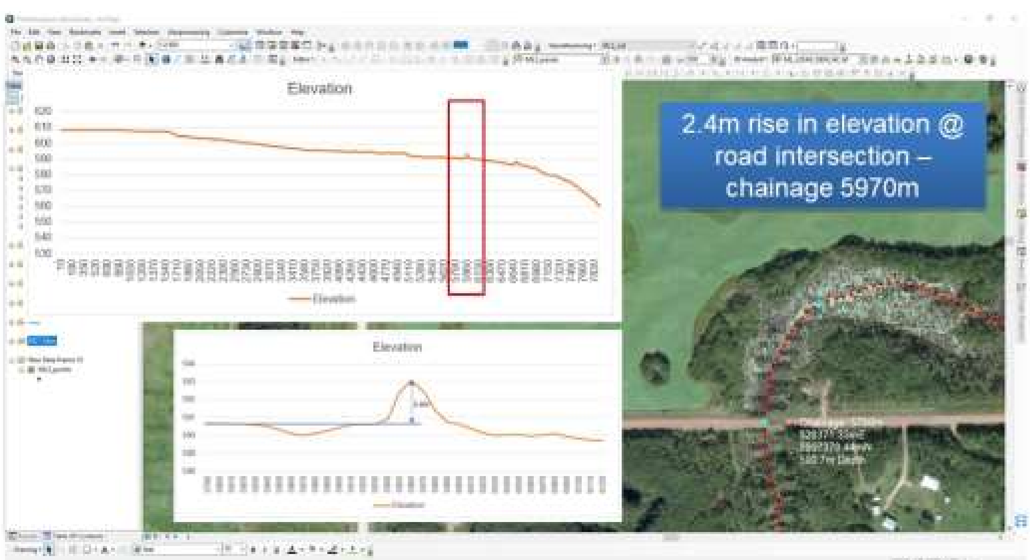


Profile analysis results for ML2-6 stream segment show no obstruction disturbing stream flow

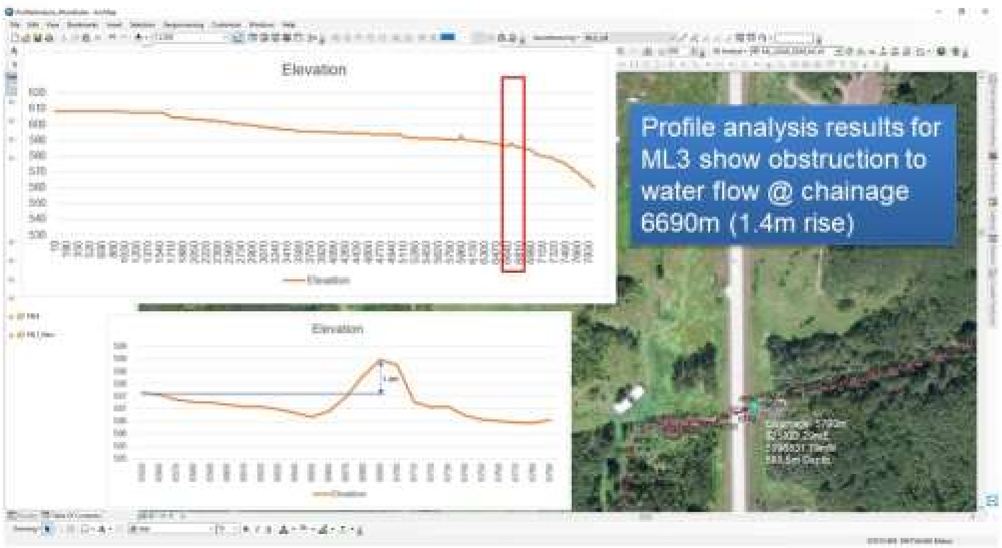
ML2-7 stream profile



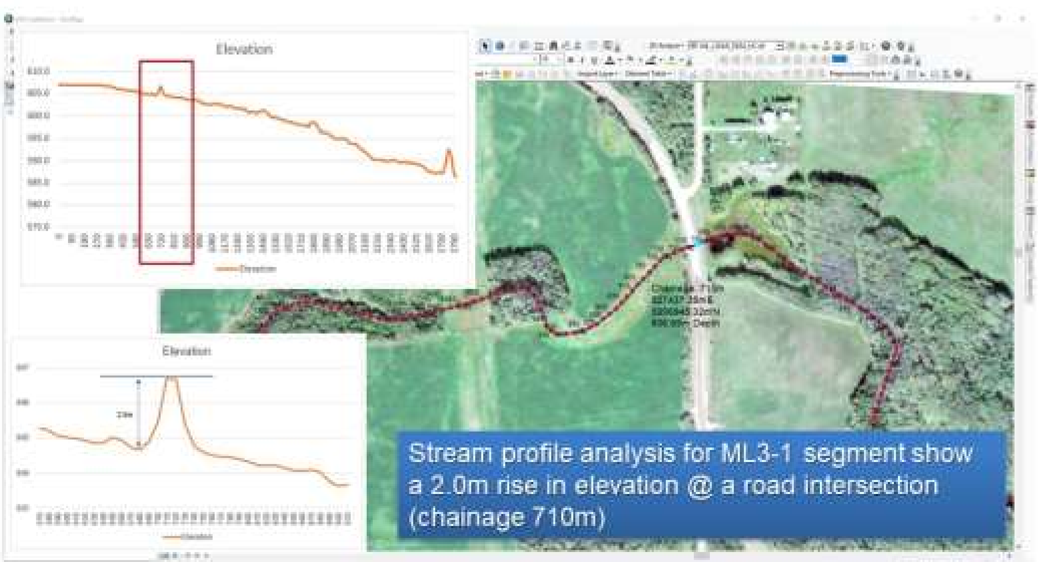
ML3 stream profile



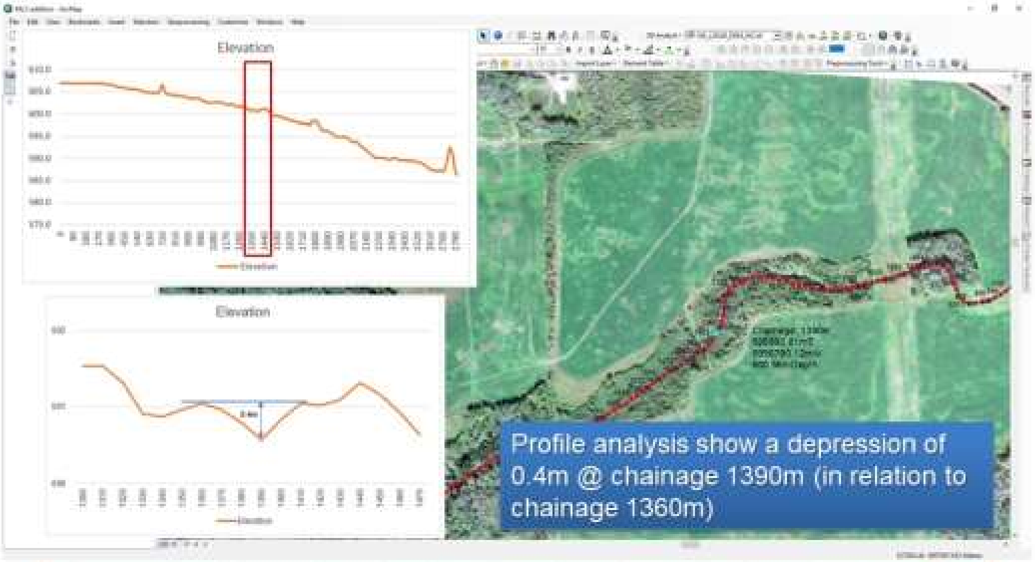
ML3 stream profile



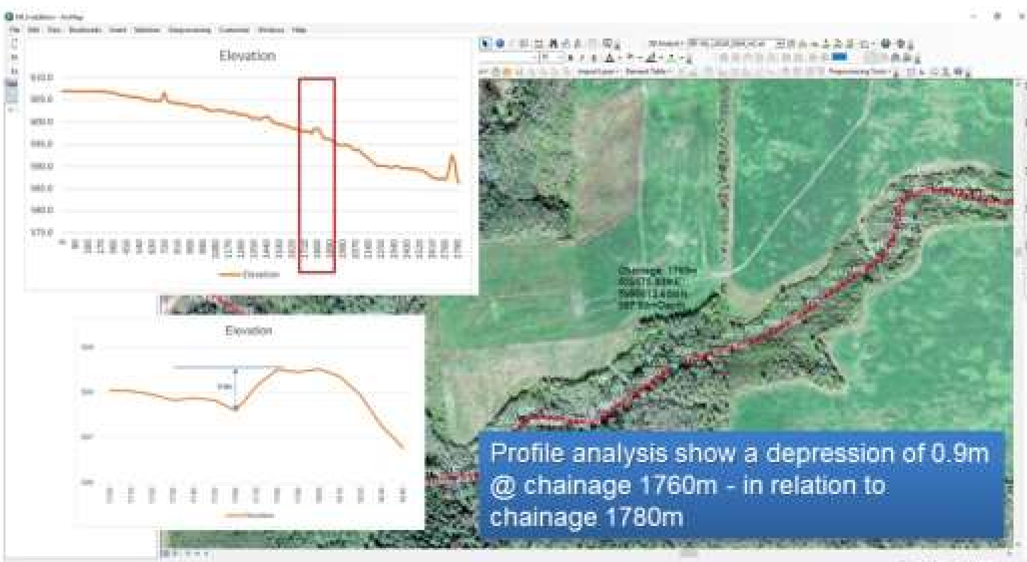
ML3-1 stream profile



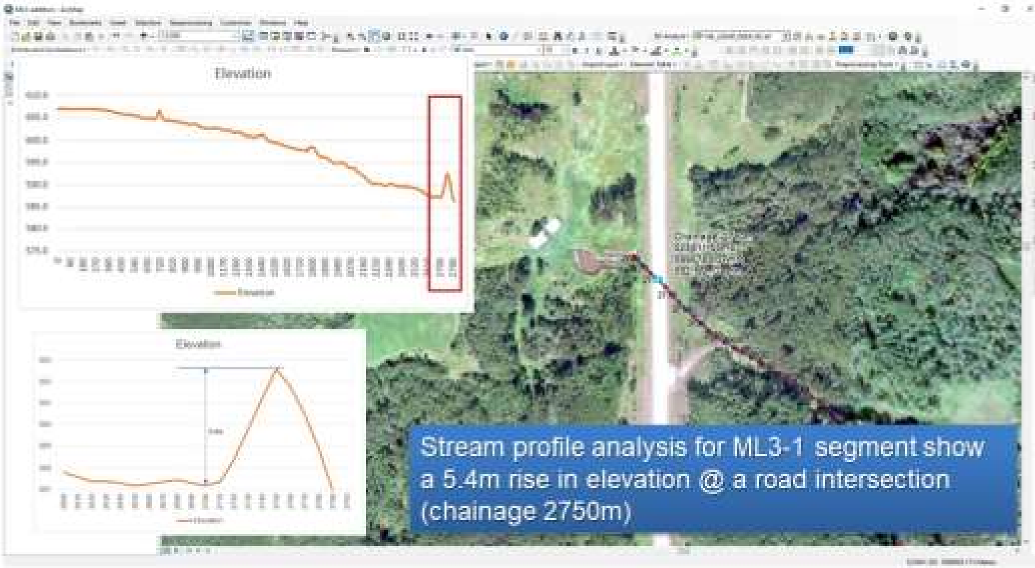
ML3-1 stream profile



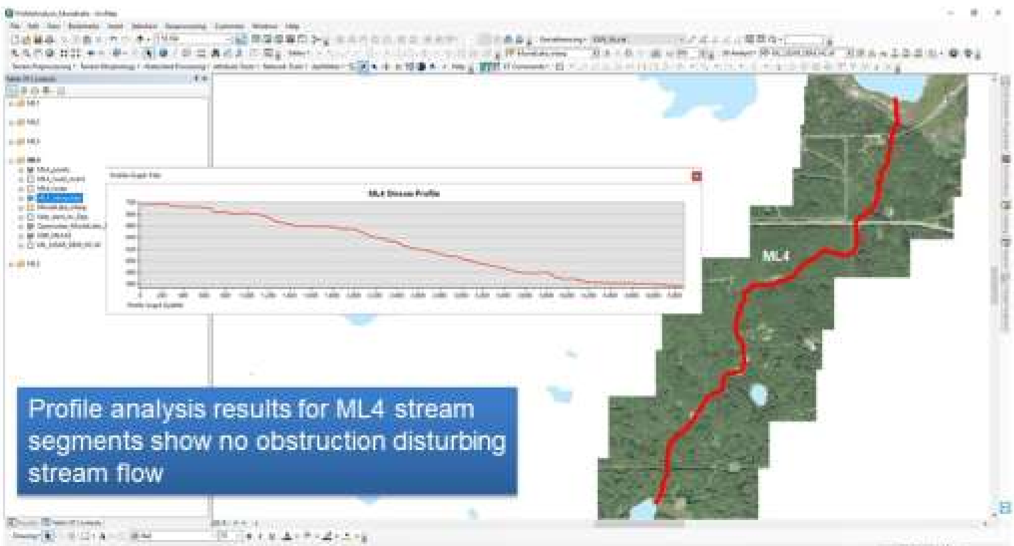
ML3-1 stream profile



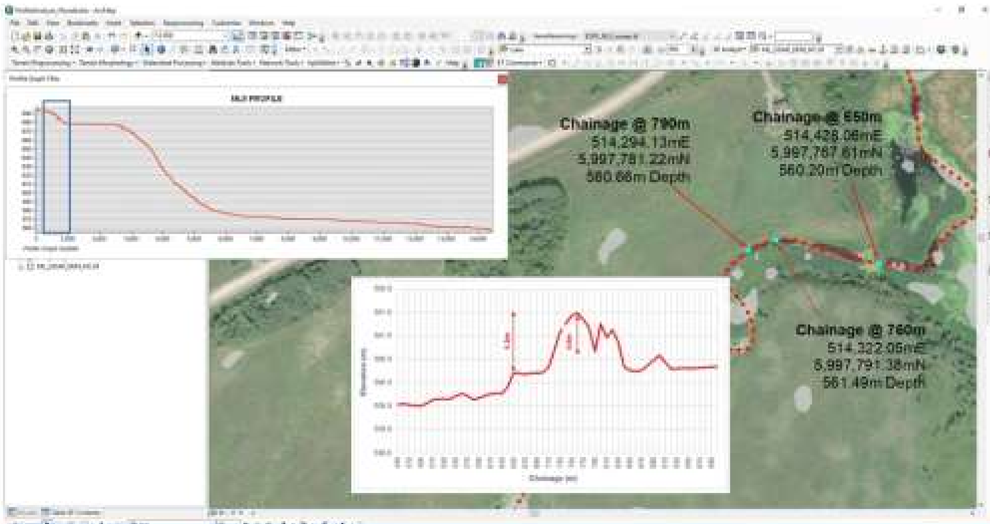
ML3-1 stream profile



ML4 stream profile



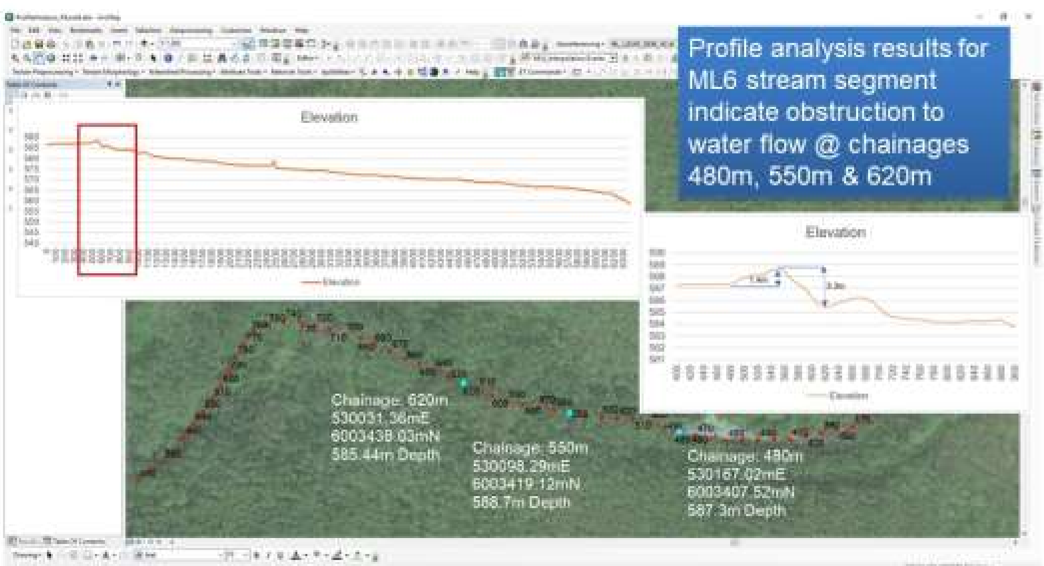
ML5 stream profile



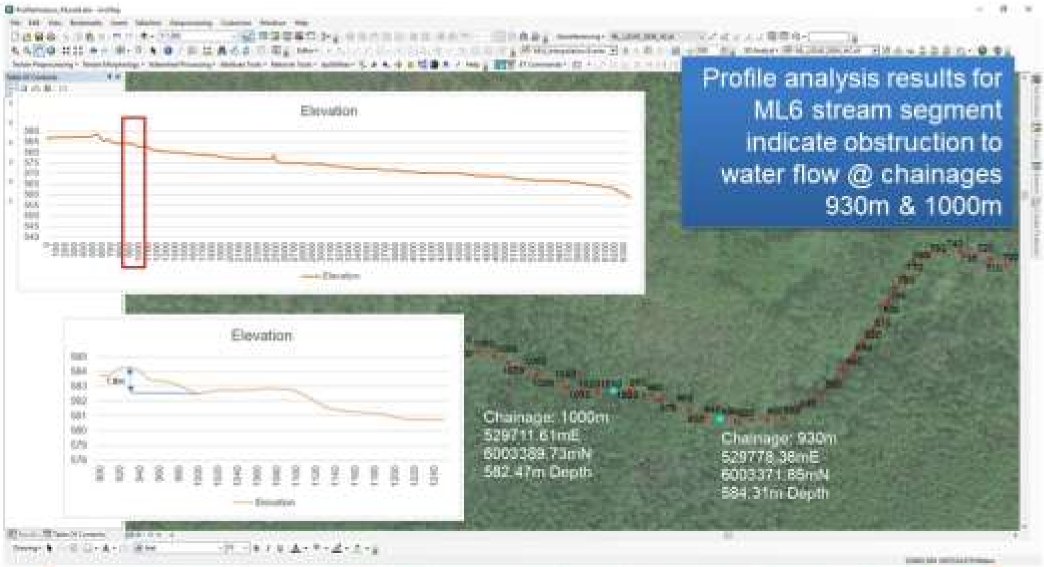
ML5: An impediment in stream flow direction was observed for stream line ML5. The results of stream profile analysis show a rise in elevation of 1.3m between chainages 650m and 760m. In addition, a height difference of 0.8m was observed between chainages 760m and 790m respectively.

ML6 stream profile

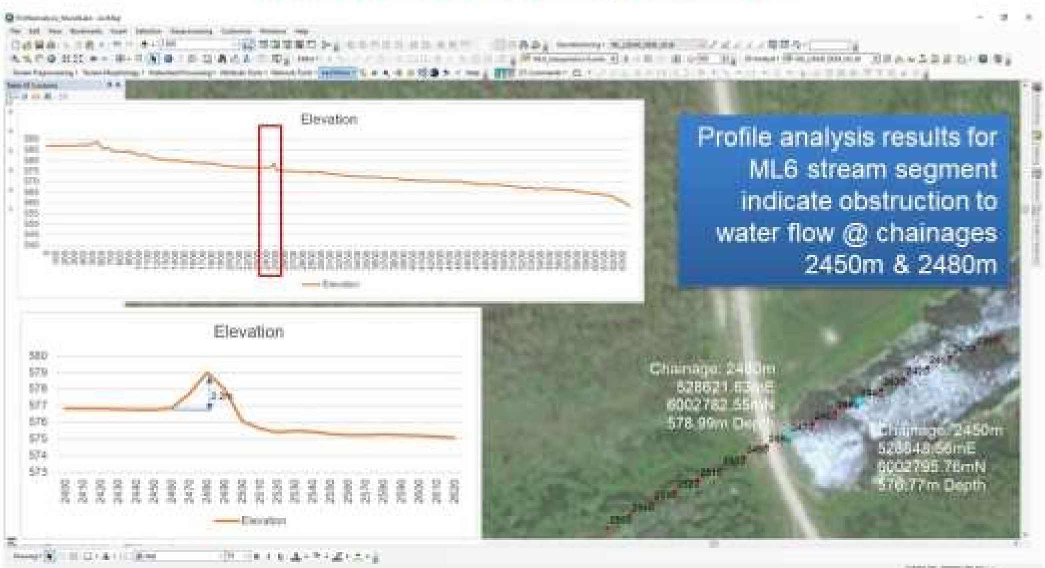
Profile analysis results for ML6 stream segment indicate obstruction to water flow @ chainages 480m, 550m & 620m



ML6 stream profile

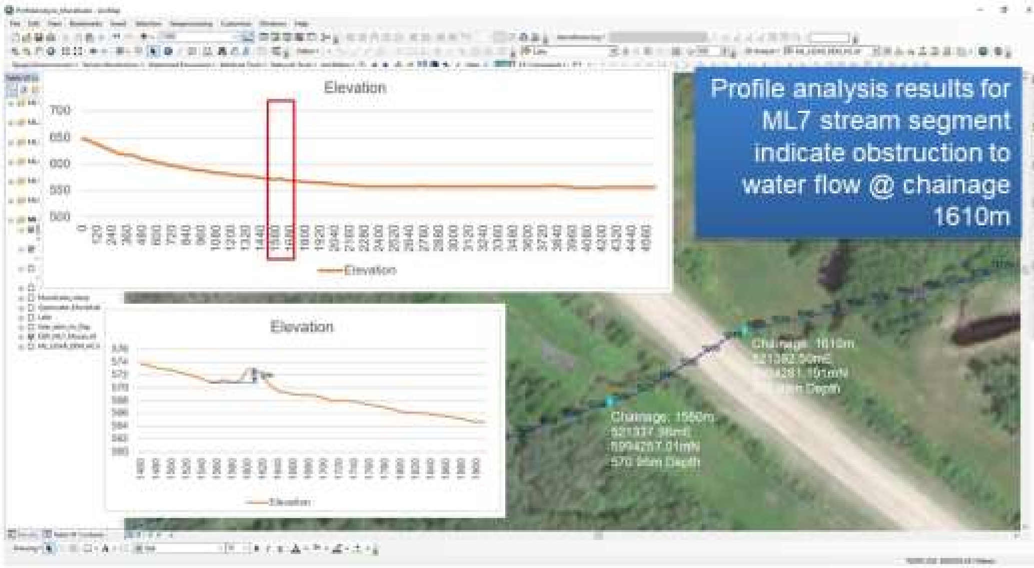


ML6 stream profile

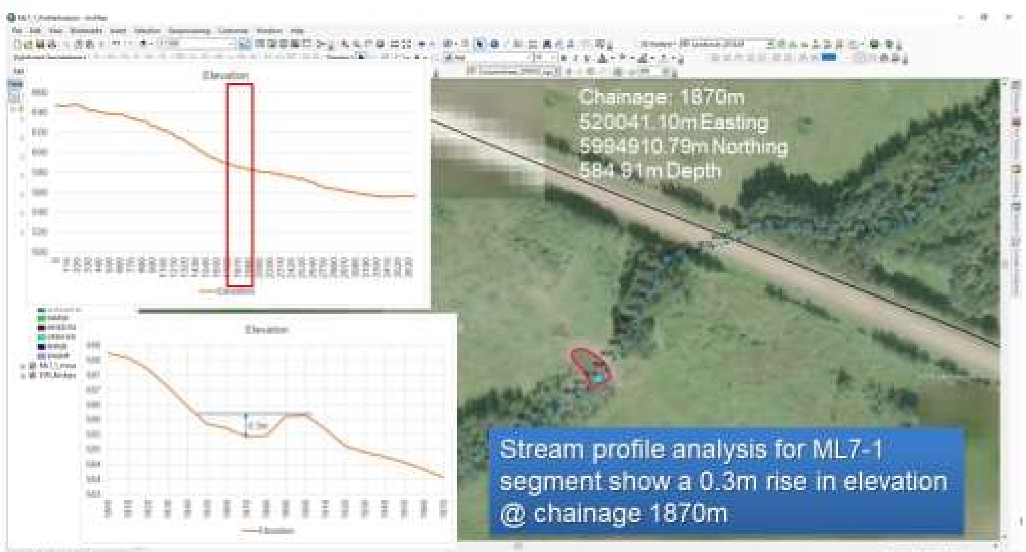


SOLSTICE
Environmental Management

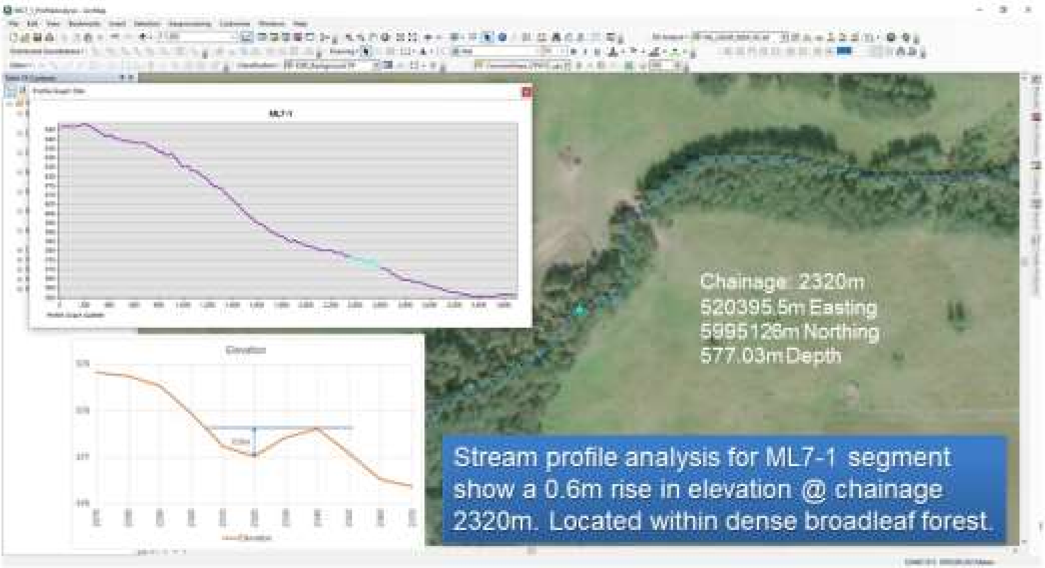
ML7 stream profile



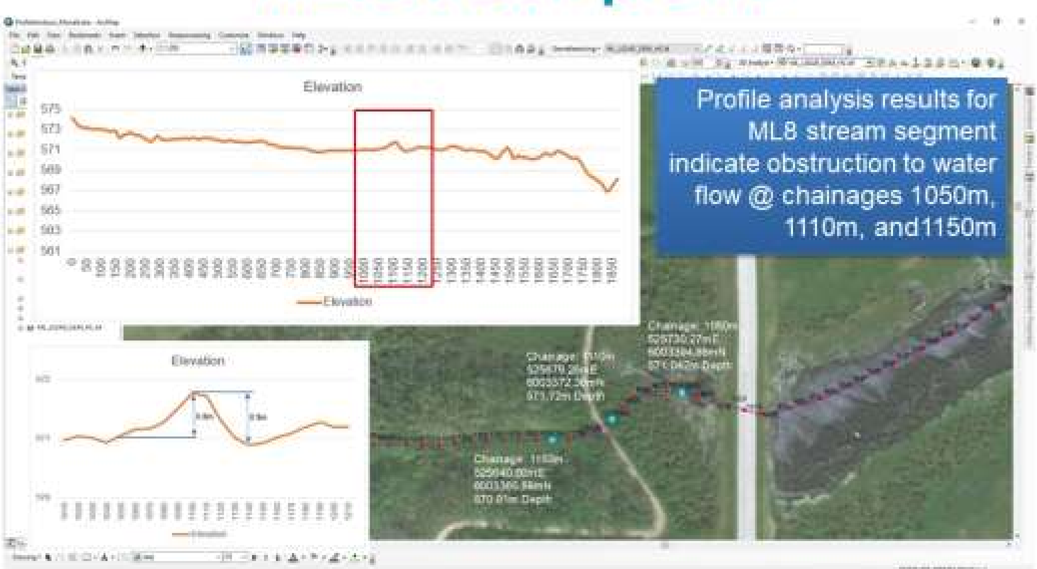
ML7-1 stream profile



ML7-1 stream profile

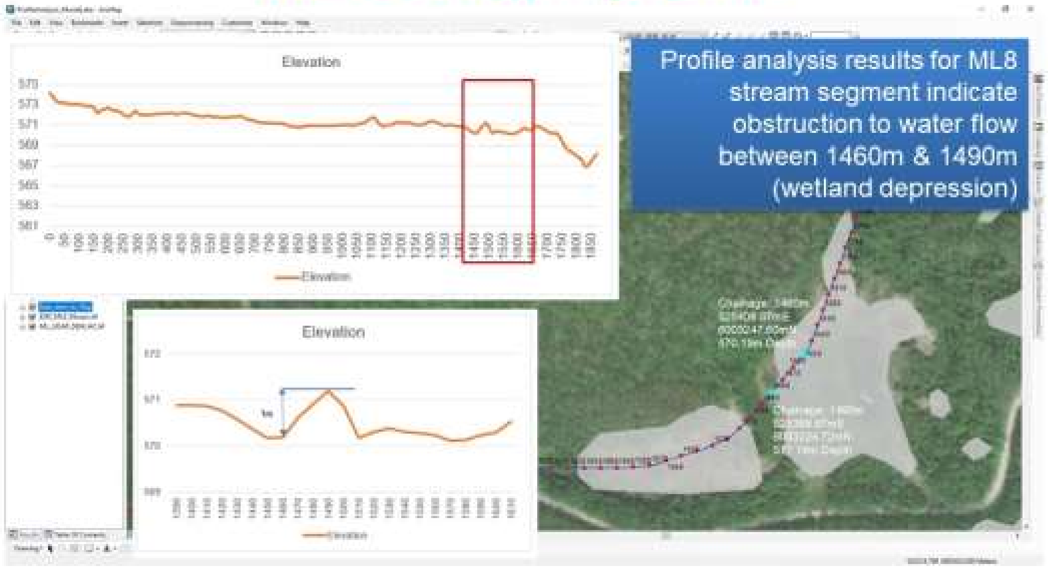


ML8 stream profile



SOLSTICE Environmental Management

ML8 stream profile

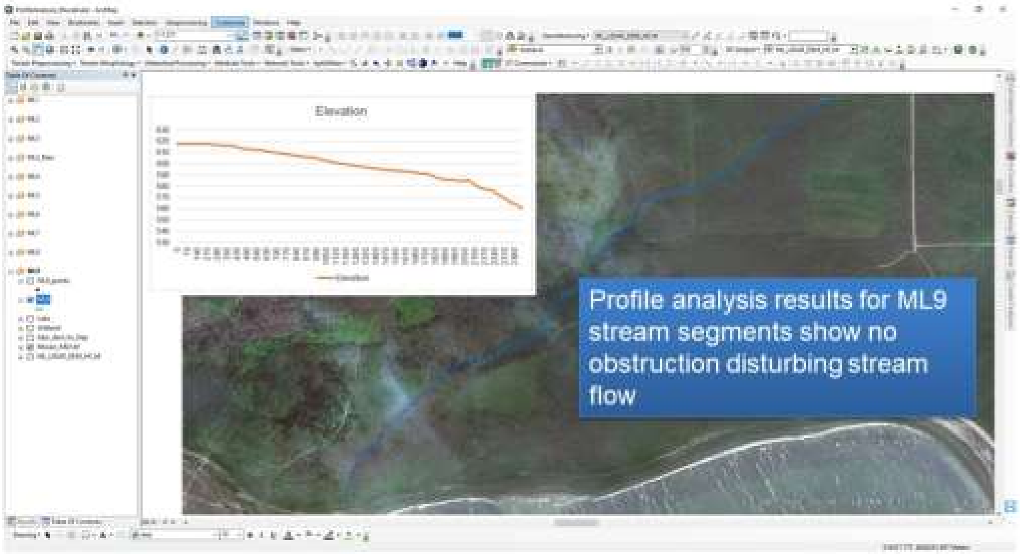


SOLSTICE

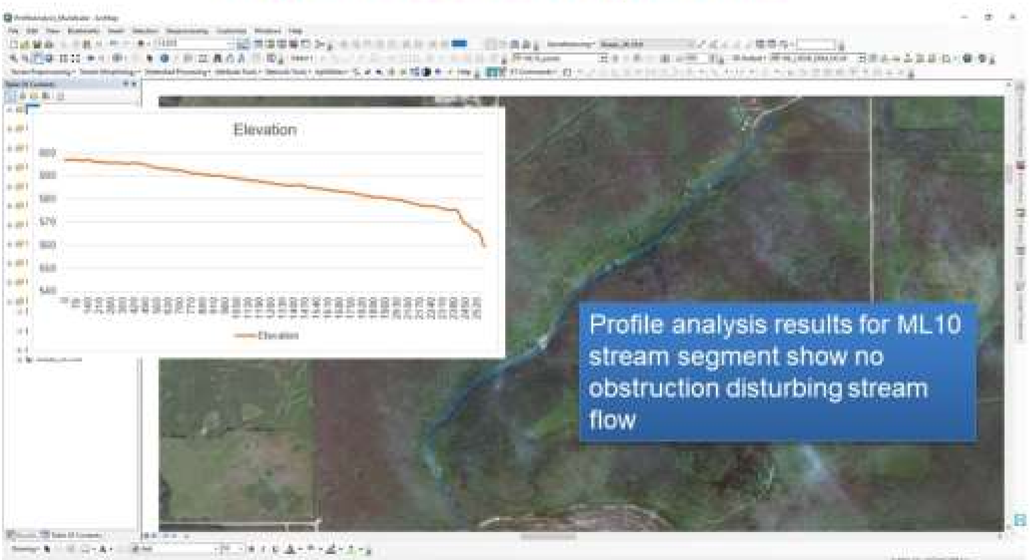
ML8 stream profile - wetland

SOLSTICE

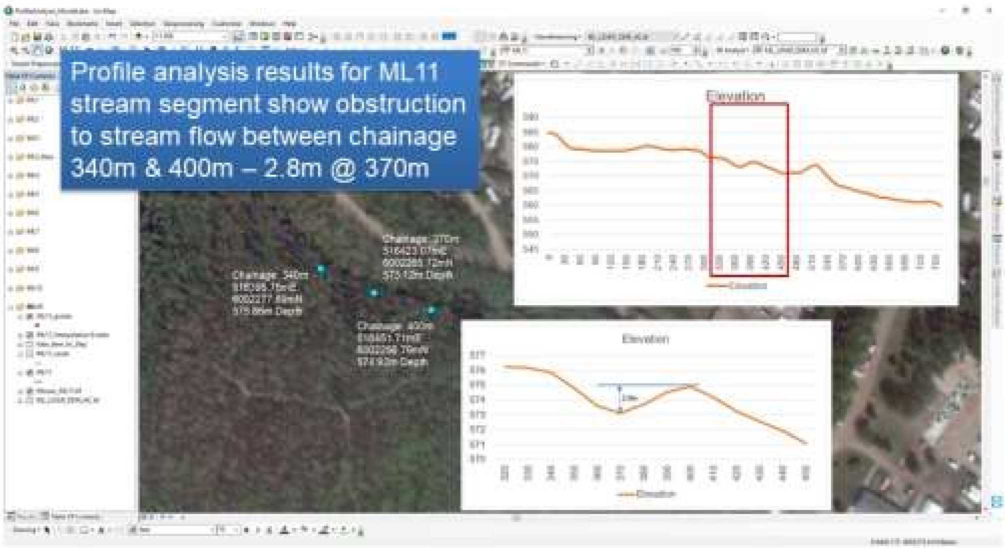
ML9 stream profile



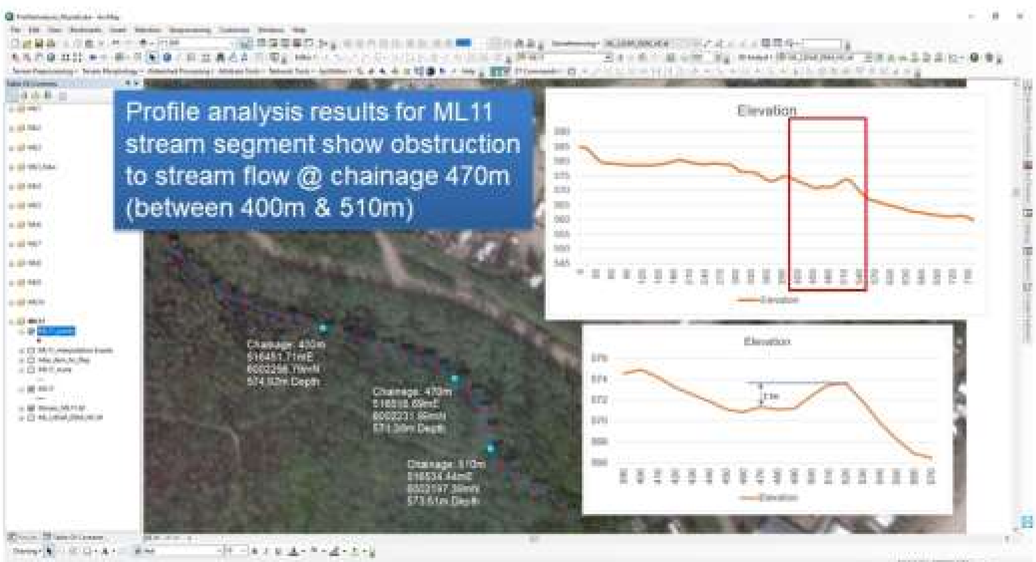
ML10 stream profile



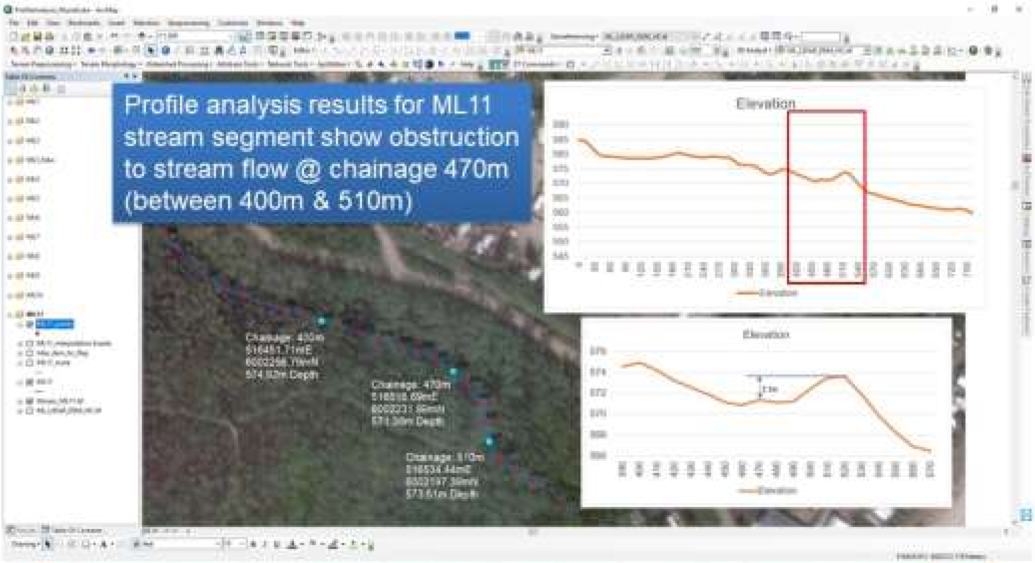
ML11 stream profile



ML11 stream profile



ML11 stream profile

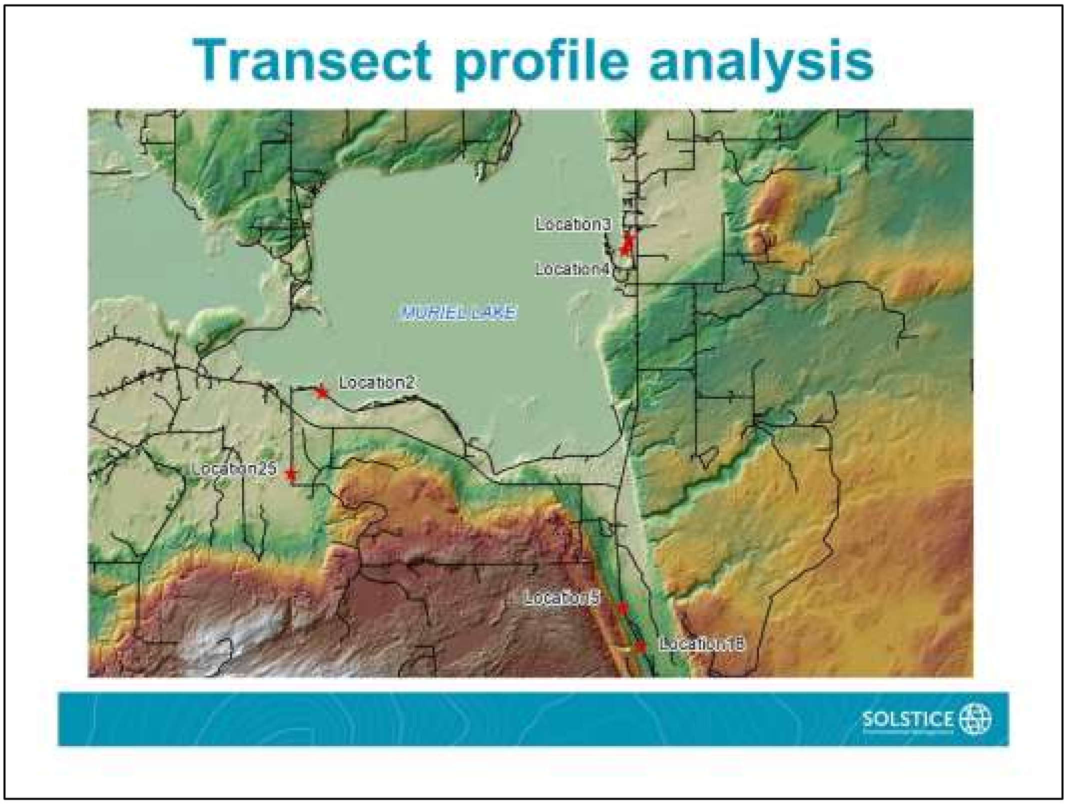


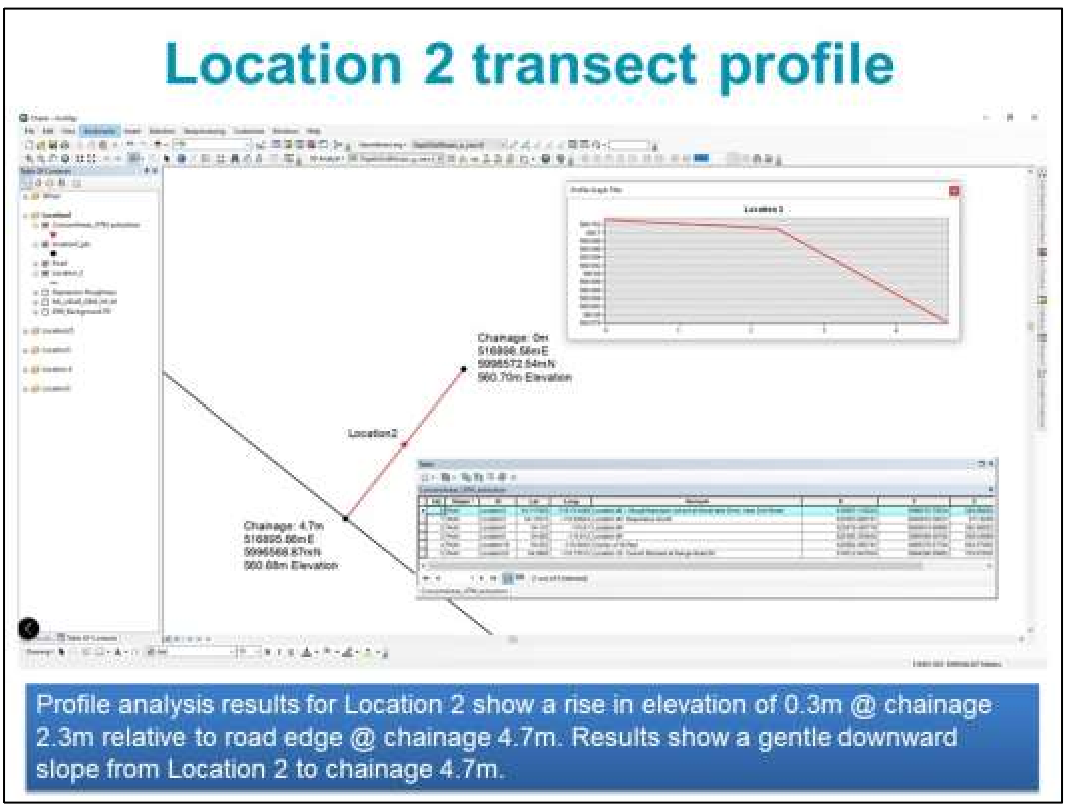
APPENDIX D. LIST OF POTENTIAL IMPOUNDMENT LOCATIONS FROM STREAM PROFILE ANALYSIS

Stream ID	Subwatershed	Description	East_UTMZ12	North_UTMZ12	Depth(m)	Chainage(m)	Comments	Impoundment Category	Information Source
ML1	Muriel Lake	Elevation rise of 1m @ 430m	527016.41	5988521.38	591.88	430	Profile analysis results for ML1 indicate obstruction to water flow @ chainage 430m (0.7m rise from chainage 380m)	Natural	Stream profile analysis
ML2	Muriel Lake	Elevation rise of 1m @ 2320m	525643.76	5993942.64	564.90	2320	Profile analysis results for ML2 indicate obstruction to water flow within wetland @ chainages 2320m (1m rise)	Natural	Stream profile analysis
ML2	Muriel Lake	Elevation rise of 1.8m @ 2610m	525566.83	5994188.76	564.81	2610	Profile analysis results for ML2 indicate obstruction to water flow within wetland @ chainages 2610m (1.8m rise)	Natural	Stream profile analysis
ML2	Muriel Lake	Elevation rise of 6.3m @ 3070m	525448.19	5994539.16	567.96	3070	6.3m rise is elevation @ road intersection – chainage 3070m	Road intersection	Stream profile analysis
ML2-1	Muriel Lake	Elevation fall of 1.2m @ 3030m	528213.04	5994053.44	594.55	3030	Profile analysis result indicate an elevation difference of 1.2m between chainges 3030m and 3060m. Locate within a marsh and fen wetland complex	Natural	Stream profile analysis
ML2-1	Muriel Lake	Elevation fall of 2.5m @ 5950m	526026.28	5992902.78	575.69	5950	Profile analysis results for ML2-5 stream segment show a depression of 2.1m @ 5950m between chainages 5920m &	Natural	Stream profile analysis
ML2-2	Muriel Lake	Elevation fall of 4.4m @ 350m	527561.21	5993334.23	622.98	350	Profile analysis results for ML2-2 stream segment show a depression of 4.4m @ 390m relative to chainage 350m.	Natural	Stream profile analysis
ML2-4	Muriel Lake	Elevation fall of 0.5m @ 100m	533301.78	5995238.14	635.10	100	Profile analysis results for ML2-4 stream segment show a depression of 0.5m @ 100m relative to chainage 0m.	Natural	Stream profile analysis
ML2-5	Muriel Lake	Elevation fall of 0.5m @ 4140m	534106.86	5995631.05	632.78	4140	Profile analysis results for ML2-5 stream segment show a depression of 0.5m @ 4140m relative to chainage 4100m.	Natural	Stream profile analysis
ML2-5	Muriel Lake	Elevation fall of 0.5m @ 4210m	534099.63	5995699.71	632.64	4210	Depression of 0.5m @ 4210m relative to 4160m (located in	Natural	Stream profile analysis
ML2-5	Muriel Lake	Road intersection @ 11670m	529671.31	5995640.26	606.29	11670	Road intersection @ 11670m - height difference of 1.4m (relative to 11650m) and 1.7m (@11720m)	Road intersection	Stream profile analysis
ML3	Muriel Lake	Elevation rise of 2.4m @ 5970m	526302.04	5997213.74	592.45	5970	2.4m rise in elevation @ road intersection – chainage 5970m	Road intersection	Stream profile analysis
ML3	Muriel Lake	Elevation rise of 1.4m @ 6690m	525822.29	5996831.79	588.48	6690	Profile analysis results for ML3 show obstruction to water flow @ chainage 6690m (1.4m rise)	Possible culvert / natural	Stream profile analysis
ML3-1	Muriel Lake	Road intersection @ 710m	527437.35	5996945.32	606.69	710	Stream profile analysis for ML3-1 segment show a 2.0m rise in elevation @ a road intersection (chainage 710m)	Road intersection	Stream profile analysis
ML3-1	Muriel Lake	Elevation fall @ chainage 1390m	526892.81	5996790.17	600.56	1390	Profile analysis show a depression of 0.4m @ chainage 1390m (in relation to chainage 1360m)	Natural	Stream profile analysis
ML3-1	Muriel Lake	Elevation fall @ chainage 1760m	526575.83	5996613.65	597.59	1760	Depression of 0.9m @ chainage 1760m - in relation to	Natural	Stream profile analysis
ML3-1	Muriel Lake	Road intersection @ 2750m	525811.55	5996785.07	592.57	2750	Stream profile analysis for ML3-1 segment show a 5.4m rise in elevation @ a road intersection (chainage 2750m)	Road intersection	Stream profile analysis
ML5	Muriel Lake	Elevation rise of 1.3m @ 760m	514322.05	5997791.38	561.49	760	Profile analysis show height difference of 0.8m between chainages 650m and 760m	Natural	Stream profile analysis
ML5	Muriel Lake	Depression of 0.8m @ 790m	514294.13	5997781.22	560.66	790	Profile analysis show height difference of 0.8m between chainages 760m and 790m	Natural	Stream profile analysis
ML6	Muriel Lake	Elevation rise of 1.4m @ 550m	530098.29	6003419.15	588.66	550	Profile analysis results for ML6 stream segment indicate obstruction to water flow between chainages 480m &	Natural	Stream profile analysis
ML6	Muriel Lake	Depression of 3.3m @ 620m	530031.36	6003438.03	585.44	620	Profile analysis results for ML6 stream segment indicate obstruction to water flow between chainages 480m &	Natural	Stream profile analysis
ML6	Muriel Lake	Depression of 0.6m @ 910m	529798.30	6003371.19	583.75	910	Profile analysis results for ML6 stream segment show obstruction to waterflow between chainage 880m & 930m	Natural	Stream profile analysis
ML6	Muriel Lake	Elevation rise of 2.2m @ 2480m	528621.63	6002782.54	578.99	2480	Profile analysis results for ML6 stream segment indicate obstruction to water flow @ chainages 2450m & 2480m. Edge of open water	Possible culvert / natural	Stream profile analysis
ML7	Muriel Lake	Elevation rise of 2m @ 1610m	521392.50	5994281.19	572.99	1610	Profile analysis results for ML7 stream segment indicate obstruction to water flow @ chainage 1610m (2m rise)	Possible culvert / natural	Stream profile analysis
ML8	Muriel Lake	Elevation rise of 0.8m @ 1100m	525679.26	6003372.36	571.72	1110	Profile analysis results for ML8 stream segment indicate obstruction to water flow between chainage 1050m and	Natural	Stream profile analysis

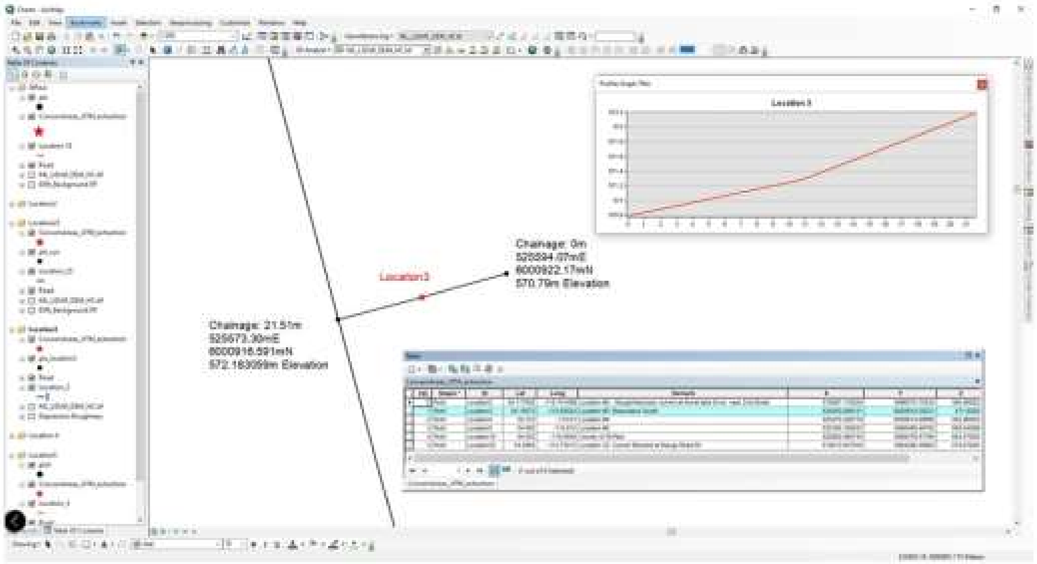
Stream ID	Subwatershed	Description	East_UTMZ12	North_UTMZ12	Depth(m)	Chainage(m)	Comments	Impoundment Category	Information Source
ML8	Muriel Lake	Elevation rise of 1m @ 1480m	525395.14	6003232.35	570.92	1480	Profile analysis results for ML8 stream segment indicate obstruction to water flow between 1460m & 1490m	Natural	Stream profile analysis
ML11	Muriel Lake	Depression of 2.8m @ 370m	516423.07	6002265.72	573.12	370	Profile analysis results for ML11 stream segment show obstruction to stream flow between chainage 340m & 400m	Natural	Stream profile analysis
ML11	Muriel Lake	Depression of 2.1m @ 470m	516516.69	6002232.00	571.36	470	Profile analysis results for ML11 stream segment show obstruction to stream flow @ chainage 470m (between	Natural	Stream profile analysis
GL3	Garnier Lake	2.5m rise @ chainage 760m	527683.98	5983851.86	597.00	760	Result of profile analysis show a 2.5m rise @ chainage 760m in comparison to chainages 730m & 790m respectively. Potential blockage needing validation.	Natural	Stream profile analysis
GL3	Garnier Lake	0.8m rise @ chainage 1230m	527735.38	5984267.74	591.30	1230	Result of profile analysis show a 0.8m rise @ chainage 1230m in comparison to chainages 1200m & 1280m respectively. Potential blockage needing validation.	Natural	Stream profile analysis

APPENDIX E. TRANSECT PROFILE RESULTS



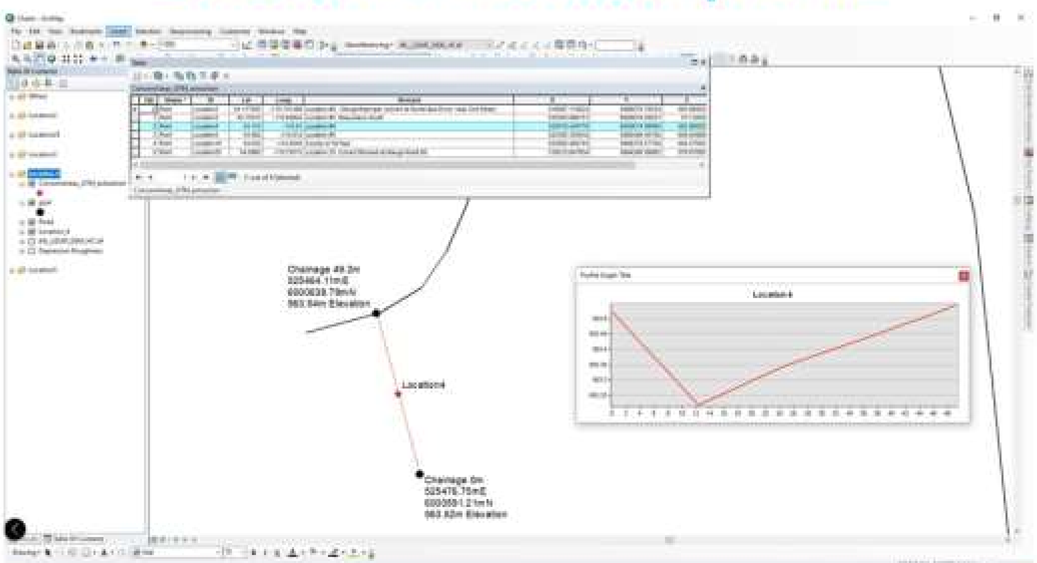


Location 3 transect profile



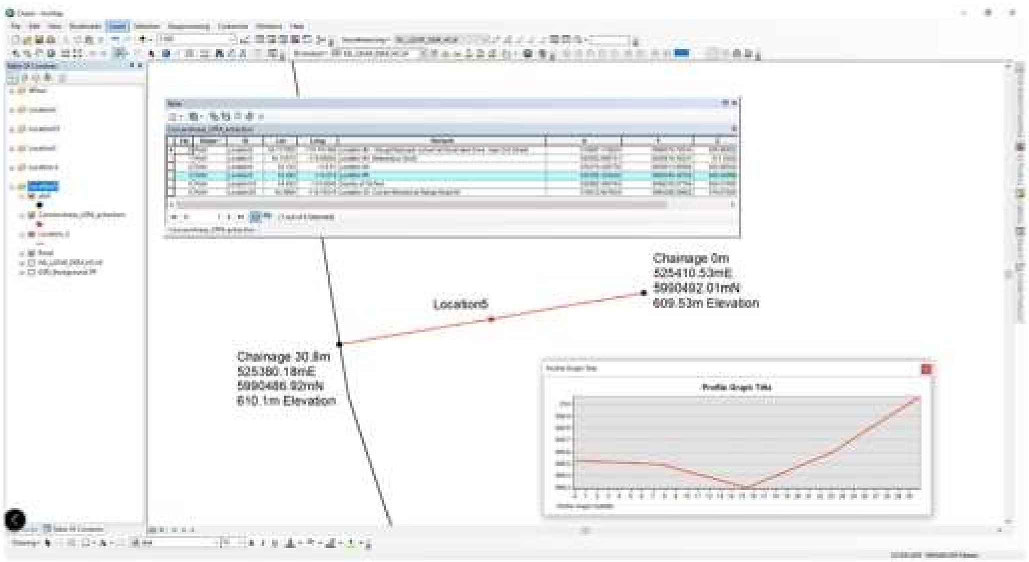
Profile analysis results for Location 3 show a rise in elevation of 0.2m @ chainage 10.8m relative to road edge @ chainage 21.5m. The results show a gentle upward slope direction from Location 3 to Chainage 21.5m

Location 4 transect profile



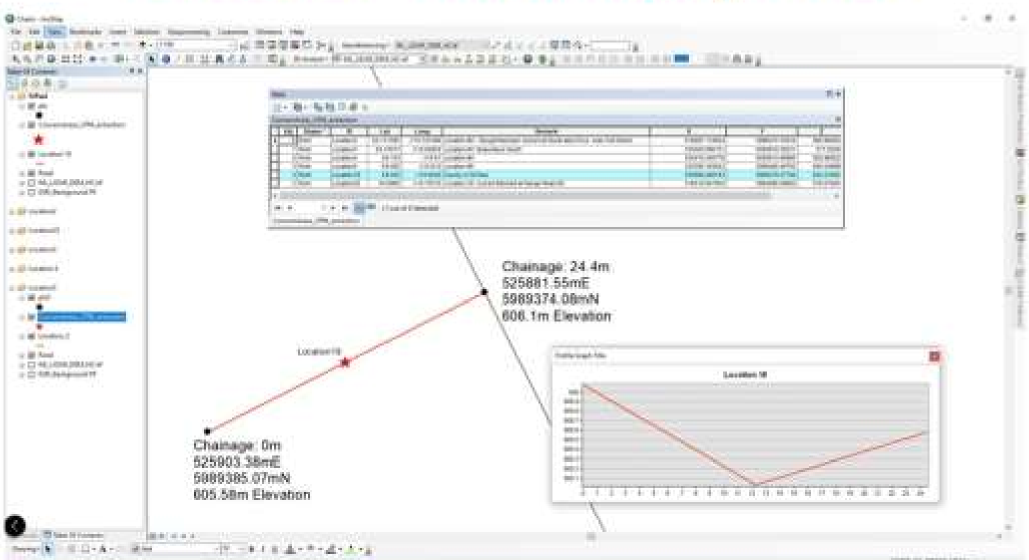
Profile analysis results for Location 4 show a depression of 0.6m @ chainage 24.6m relative to road edge @ chainage 49.2m. At chainage 12.2m (approx.), depression is observed. This might result in standing water – needs to be field verified.

Location 5 transect profile



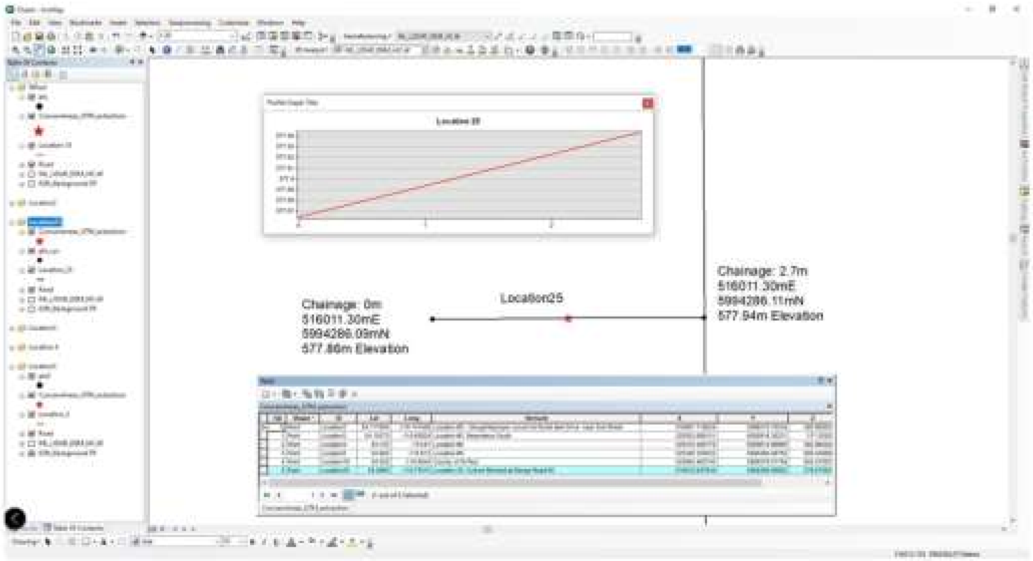
Profile analysis results for Location 5 shows a depression @ chainage 15.4m. Field verification of the location is recommended.

Location 18 transect profile



Profile analysis results for Location 18 show an elevation difference of 1.5m between chainage 12.2m and road edge @ chainage 24.4m. Depression @ chainage 12.5m – needs to be field verified.

Location 25 transect profile



Profile analysis results for Location 25 shows a gentle upward slope from chainage 0 to 2.7m.