Lake St. Martin Emergency Relief Channel
Monitoring and Development of Habitat Compensation
Physical Processes

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EXECUTIVE SUMMARY

Widespread record flooding throughout southern Manitoba during 2011 led to water levels in Lake Manitoba and Lake St. Martin that were several feet higher than desirable. As part of emergency relief measures, the Province of Manitoba, through Manitoba Infrastructure and Transportation (MIT), constructed Reach 1 and Reach 3 of the Lake St. Martin Emergency Outlet Channel System (LSMEOC). The Reach 1 Emergency Outlet Channel was completed in the fall of 2011 and operated until mid-November 2012. The channel was then operated a second time under another emergency condition from July 2014 to August 2015. The second channel, the Reach 3 Emergency Channel, was constructed during winter 2011/2012 but was not operated.

In response to the 2011/2012 operation of the LSMEOC, MIT retained North/South Consultants (NSC) and Kontzamanis Graumann Smith MacMillan Inc. (KGS Group) to undertake aquatic and environmental monitoring to determine what effects construction and operation of Reach 1 may have had on affected waterways downstream of the channel. These included the Buffalo Creek watershed, the lower Dauphin River, and Sturgeon Bay of Lake Winnipeg.

The Physical Processes report is Volume 2 of a 7 Volume series that document the results of the studies conducted by NSC and KGS Group. These included changes to erosion, sedimentation, vegetation cover, water quality, flow, and ice processes. Hydrometric data, total suspended solid concentrations, topographic and bathymetric surveys were used in conjunction with numerical hydraulic models to identify the potential effects of the operation of Reach 1 on the erosion and sediment deposition processes in the watershed.

Operation of Reach 1 resulted in high flows in Buffalo Creek during the 2011/2012 and 2014/2015 operation periods. The high flows in Buffalo Creek were accompanied with high velocities, which generated some erosion of the main channel and of the creek banks, as demonstrated with a comparison of creek cross sections prior to and after operation. The TSS measurements and the empirical model results indicated that some erosion also occurred in Reach 1 during its operation. As the flows from Reach 1 travelled through Big Buffalo Lake and the surrounding bog towards Buffalo Creek, the bulk of the suspended sediment deposited in the bog. The sediment that was then eroded in Buffalo Creek was transported in suspension into the lower Dauphin River and Lake Winnipeg.

The volume of suspended sediment released from Buffalo Creek as a result of the operation of Reach 1 was computed utilizing an empirical model with and without operation of Reach 1. It was estimated that the 2011/2012 operation resulted in an additional total volume of 8,900 m^3 of suspended sediment at the confluence between the lower Dauphin River and Buffalo Creek, plus another 2,200 m^3 during the closure period (2012-2014) and 8,600 m^3 during the 2014/2015 operation period. Analyses of the grain size distribution of the suspended solids showed that the material essentially constituted clays and silts.

The cross section comparison in Buffalo Creek computed a total volume of displaced material of 60,000 m^3 from 2011 to 2013 and 75,000 m^3 from 2013 to 2015. This represented the total volume of material that was eroded and displaced within Buffalo Creek. Some of this material went in suspension and contributed to the additional suspended sediment at the confluence between the lower Dauphin River and Buffalo Creek as computed with the empirical model.

Larger material could have been transported by bedload within the creek and may have left the system, however, measurements within the Dauphin River did not show an increase in bedload during operation of the LSMEOC. A review of the simulated velocities and shear stresses showed that most of the coarser material had deposited in the overbank areas or in reaches with lower velocities, as also confirmed by direct observations.

As simulated with the MIKE 21 2D model, the velocities in the Dauphin River were such that the suspended material would have been transported several hundred meters into Sturgeon Bay, with limited potential for deposition along the Dauphin River shoreline or in back eddies. Bathymetric comparisons in the Dauphin River showed no obvious or consistent patterns in changes to the riverbed. The difference in elevation appeared to occur randomly throughout the surveyed portion of the Dauphin River. In addition, there was no conclusive evidence of a correlation between erosion and deposition patterns within this reach of river and the operation and closure periods of the LSMEOC.

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1.0 INTRODUCTION

Widespread record flooding throughout southern Manitoba during 2011 led to water levels in Lake Manitoba and Lake St. Martin that were several feet higher than desirable, resulting in significant damage to hundreds of properties, restricted road access to several communities, and long-term evacuation of four First Nation communities in the vicinity of Lake St. Martin. As part of emergency relief measures, the Province of Manitoba, through Manitoba Infrastructure and Transportation (MIT), constructed the Lake St. Martin Emergency Outlet Channel (LSMEOC) System, which is comprised of two emergency channels. The Reach 1 Emergency Outlet Channel (Reach 1) begins at the northeast shore of the north basin of Lake St. Martin and extends approximately 6 km to the bog area surrounding Big Buffalo Lake. Water from Reach 1 inundates the bog area and then follows the natural Buffalo Creek Drainage System until flowing into the lower Dauphin River and ultimately into Sturgeon Bay (Figure 1 and Figure 2). Water began to flow through Reach 1 on November 1, 2011, and the channel was operated until November 21, 2012.

Computer models of potential water levels at the mouth of the Dauphin River indicated that there was a significant risk of major flooding of the Dauphin River communities in spring 2012. This risk was due to the potential formation of frazil ice jams combined with unprecedented winter flows that resulted from the Fairford River Water Control Structure (FRWCS) running at full capacity all winter. Consequently, a second channel (Reach 3 Emergency Channel; Reach 3) was constructed during winter 2012. Reach 3 was designed to divert excess flow from Reach 1 and Buffalo Creek away from the lower Dauphin River. The outlet of Reach 3 was designed to daylight gradually with the existing ground surface after which water exiting the channel would flow overland to Sturgeon Bay northwest of Willow Point (Figure 2). It was determined that operation of Reach 3 prior to the spring break up, in combination with the construction of dikes along the banks of the Dauphin River, should substantially reduce the risk of flooding for the Dauphin River communities.

Due to extremely mild winter conditions in 2011/2012, ice effects on both Reach 1 and the Dauphin River were much less severe than forecasted. With the continuous extreme mild conditions, updated flood forecasts indicated that the estimated discharge in the lower Dauphin

River during ice break up would be well below the capacity of the Dauphin River community dikes. Consequently, the proposed operation of Reach 3 was no longer required.

Heavy precipitation during winter 2013/2014 and spring 2014 again elevated water levels in Lake Manitoba and Lake St. Martin, prompting MIT to re-open Reach 1 at the beginning of July 2014. The channel was re-opened in two stages. The first occurred during in July 2014 when approximately 35 m of the berm closing Reach 1 was removed. The second stage occurred in November 2014, when an additional 10 m of the closure berm was removed to allow additional flow into the channel. Flow into Reach 1 was halted in late August 2015.

In response to the 2011/2012 operation of the LSMEOC, MIT retained North/South Consultants (NSC) and Kontzamanis Graumann Smith MacMillan Inc. (KGS Group) to undertake aquatic and environmental monitoring to determine what effects construction and operation of Reach 1 may have had on affected waterways downstream of the channel. These included studies to document changes to the physical environment (e.g., measurement of water flow through Reach 1 and the Dauphin River; sedimentation and erosion studies) and possible subsequent effects to the biological environment (e.g., possible change to fish community in Buffalo Creek). Environmental studies began in August 2011 and continued until September 2015 and included the Buffalo Creek watershed, the lower Dauphin River, and Sturgeon Bay of Lake Winnipeg.

This report accounts for the studies conducted by NSC and KGS Group, that occurred up to September 2015, and covers the 2011/2012 operation of the LSMEOC System, the closure period (2012 to 2014), and the 2014/2015 operation.

1.1 DESCRIPTION OF PHYSICAL PROCESSES REPORT

The Physical Processes report is Volume 2 of a 7 Volume series that documents the results of the current project. It summarizes data collected from studies and monitoring programs initiated to document changes to the physical environment related to construction and operation of the LSMEOC System. Potential physical environment impacts of the Project identified included changes to erosion, sedimentation, vegetation cover, water quality, flow, and ice processes. A brief overview of the physical processes assessed within the report is listed below. The details of each component, including a summary of data collected, methodology, analysis, and results are discussed in this report.

Hydrometric Data - Water level data was collected during discrete periods on Reach 1, Big Buffalo Lake and Buffalo Creek between the fall of 2012 until the late summer of 2015. Periodic flow metering events were conducted at Reach 1 and at a station in the lower reaches of Buffalo Creek (BCTM) between November 2011 and September 2015. In addition, an ice reconnaissance survey of the Dauphin River was conducted to visually assess ice conditions in the river. The hydrometric data was used to compute daily flows and was incorporated into the analyses and modeling described in this report.

Water Quality Data - Water samples were collected along the length of the LSMEOC System and regionally in water bodies and watercourses within the drainage basin from the beginning of Reach 1 construction, during the 2011/2012 operation and continued until the late summer of 2015. Water samples were analyzed for general water quality parameters to determine potential impacts of the Project on the aquatic ecosystem. The water quality data was also incorporated into the analyses and modeling described in this report.

Buffalo Creek Vegetation Cover Survey – A vegetation cover survey was conducted in the summer of 2013 to assess impacts to the vegetation cover and riparian community as well as erosion along Buffalo Creek following operation of the LSMEOC System. In total 31 transects were surveyed at the same location as the pre-operation vegetation survey. Results were compared between the pre- and post-operation surveys. A follow-up survey was conducted in June 2014 to attain a more appropriate estimate of vegetation cover regrowth along Buffalo Creek after a full growing season.

Buffalo Creek Cross Section Survey – Cross section surveys were conducted prior and after the 2011/2012 and the 2014/2015 operation of the LSMEOC at 30 established transect locations along Buffalo Creek to compare pre- and post-operation conditions. Data was used to identify and measure areas of erosion and deposition along Buffalo Creek. Results of the survey were also compared to the modeling results.

Dauphin River Bathymetric Survey – Bathymetric surveys of the Dauphin River were conducted prior to, during, and after the 2011/2012 and the 2014/2015 operation of the LSMEOC System. Surveys aimed to assess impacts of the Project on the Dauphin River, in particular identifying potential areas of erosion and deposition and associated effects on fish habitat in the lower Dauphin River. Surveys emphasized the area extending from slightly upstream of the confluence with Buffalo Creek and downstream into Sturgeon Bay. Results of the survey were also compared to the modeling results.

Hydraulic Modeling – Modeling was conducted to analyze flow patterns and sediment transport, and to predict sediment erosion and deposition along the LSMEOC System, including Reach 1, Buffalo Creek and Dauphin River, during operation of the Emergency Channel, as well as the post operation period. Three different models were used for the analysis, including a spreadsheet calculation model ("empirical" model) of the LSMEOC System, a HEC RAS Sediment Transport model of Buffalo Creek, and a 2D hydraulic and sediment transport model of the Dauphin River. Together, the models were used to identify areas of potential deposition and/or scour and predict sediment load along the LSMEOC System to determine potential impacts as well as identify sediment transport trends.

FIGURE 1-1
THE LOCATION OF MAJOR WATERBODIES AND WATERWAYS AFFECTED BY FLOODING IN SOUTHERN MANITOBA DURING SPRING, 2011

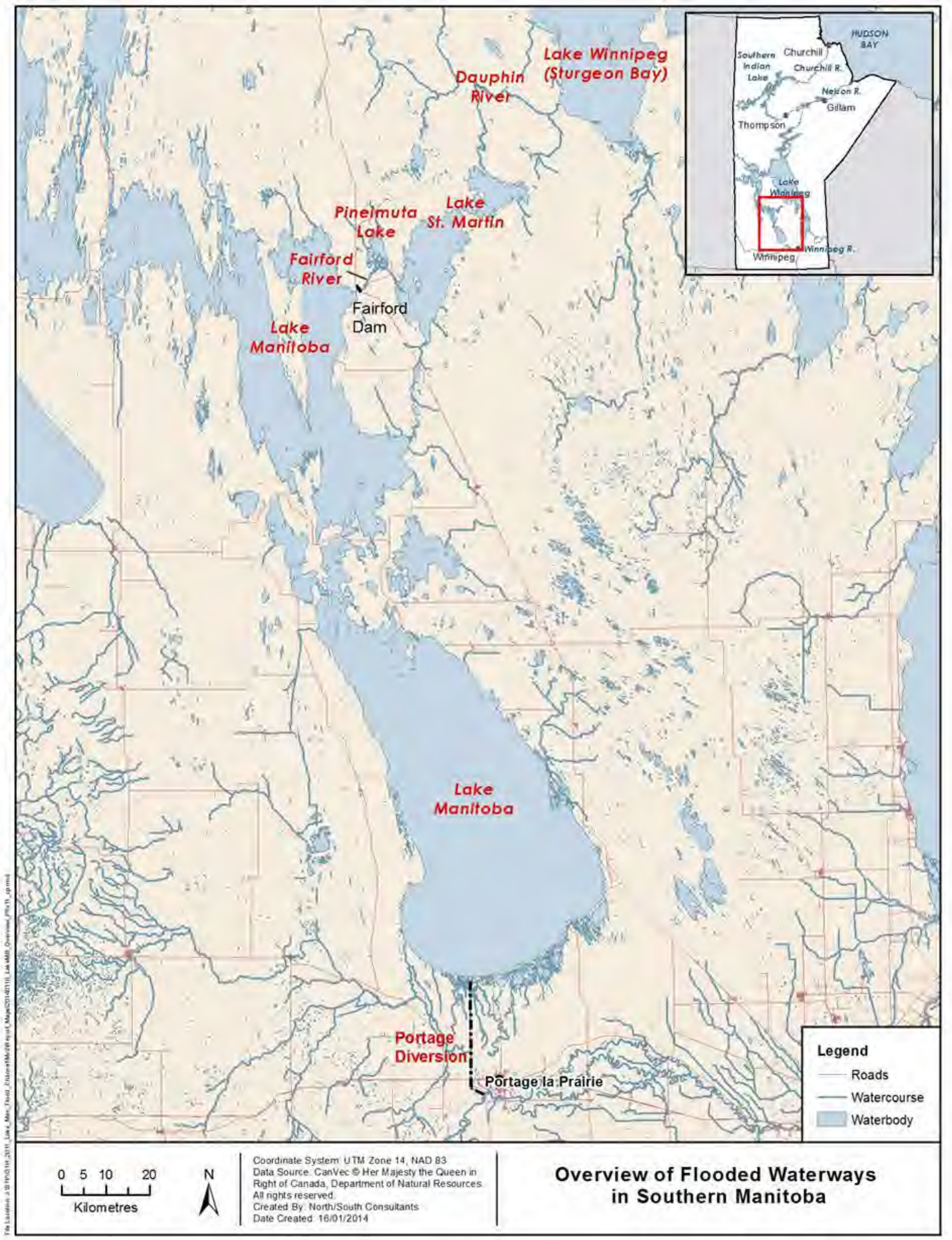


FIGURE 1-2
LOCATION OF THE REACH 1 EMERGENCY OUTLET CHANNEL, THE REACH 3 EMERGENCY CHANNEL, AND THE BUFFALO CREEK DRAINAGE SYSTEM IN RELATION TO LAKE ST. MARTIN,THE DAUPHIN RIVER, AND STURGEON BAY

2.0 PROJECT DESCRIPTION AND STUDY AREA

2.1 PROJECT DESCRIPTION

Infrastructure constructed to support the emergency reduction of Lake Manitoba and Lake St. Martin water levels included two channels designed to lower water levels on Lake St. Martin. The first channel, the Reach 1 Emergency Outlet Channel, was completed in fall of 2011 and operated until mid-November 2012. The channel was then operated a second time under another emergency condition from July 2014 to August 2015. The second channel, the Reach 3 Emergency Channel, was constructed during winter 2011/2012 but was not operated. Additional details pertinent to each of the channels are presented in the following sections.

2.1.1 Reach 1 Emergency Outlet Channel

As previously stated, Reach 1 was constructed to help lower water levels on Lake St. Martin. The inlet to Reach 1 is located along the northeast shore of the Lake St. Martin north basin. The channel extends north east for approximately 6 km to a bog area surrounding Big Buffalo Lake. Water from Reach 1 flowed through the bog area and Big Buffalo Lake into Buffalo Creek, and then flowed down Buffalo Creek to its confluence with the lower Dauphin River, approximately 4 km upstream of Sturgeon Bay.

The inlet of Reach 1 consisted of a fixed-level invert with a sill at an elevation of 243.1 m above sea level (mASL). The sill was designed to convey the desired flow of 142 m^3/s at a Lake St. Martin level of 244.1 mASL and was 120 m in length, had a bottom width of 60 m, and 3:1 side slopes. At the onset of operation, flow through Reach 1 was estimated to be approximately 170m^3/s at a Lake St. Martin level of 245.2 mASL based on a flow metering conducted about two weeks after the opening of the channel.

Reach 1 was operated from November 1, 2011 until November 21, 2012, at which time the inlet to Reach 1 was sealed with a rock berm. Post-closure, monitoring programs continued until June 2014. In July 2014, another emergency condition resulted in the channel to be operated for a second time. The berm was removed through a staged-opening process up to approximately three quarters of its discharge capacity. The 2014/2015 operation of the LSMEOC continued from July 3, 2014 to August 13, 2015.

2.1.2 Reach 3 Emergency Channel

Water level projections indicated that there was a substantial risk for major flooding in the Dauphin River communities in spring 2012 due to unprecedented flows along the Dauphin River downstream of Buffalo Creek and the increased potential for frazil ice jamming at the mouth of the Dauphin River. It was determined that the construction of an additional channel to divert Reach 1 flows away from the Dauphin River and construction of dikes along the banks of the lower Dauphin River prior to spring breakup was necessary to reduce the risk of flooding in the communities.

Following a review of configuration options, the Reach 3 Emergency Channel was constructed. Reach 3 originates at Buffalo Creek about 8 km downstream of Big Buffalo Lake (Figure 1-2), is approximately 6 km in length, and terminates in a lowland area 3 km inland of Sturgeon Bay. From the outlet of Reach 3, water would flow overland towards Sturgeon Bay, entering the bay through a proposed shoreline breach structure, which was to be constructed through the beach ridge to the west of Willow Point.

It was expected that Reach 3 would only operate for a short period of time during the spring freshet in 2012 to remove the threat of flooding along the lower Dauphin River. However, an exceptionally mild winter in 2011/2012 allowed sufficient drainage from Lake Manitoba and Lake St. Martin to reduce water levels to a point where risk of frazil ice jamming and flooding at Dauphin River communities became negligible. Consequently, Reach 3 was not operated. During the 2014/2015 period, Reach 3 was also not operated.

2.2 STUDY AREA

The emphasis of aquatic monitoring is to determine what effects construction and operation of Reach 1 may have had on affected waterways downstream of the channel. These include the Buffalo Creek watershed, the lower Dauphin River, and Sturgeon Bay. However, these waterways are also affected by conditions occurring upstream of Reach 1 and, in some instances, fish move between areas upstream and downstream of Reach 1. Consequently, some components of the aquatic monitoring program (water quality monitoring and fisheries investigations) include waterways upstream of Reach 1.

Local hydrology is affected by water flow from across the province. The main water inflows into Lake Manitoba are from the Whitemud River, the Waterhen River (including Lake Winnipegosis and Dauphin Lake), and the Portage Diversion, which routes excess flows from the Assiniboine River into the south end of Lake Manitoba (Figure 1-1). Water flows out of Lake Manitoba through the Fairford River and Lake Pineimuta into Lake St. Martin, and then through the Dauphin River to Sturgeon Bay.

The Buffalo Creek watershed is situated between Lake St. Martin to the south and the Dauphin River and Sturgeon Bay to the north. Prior to operation of Reach 1, the watershed was isolated and did not receive water from other waterways; all flow was due to local runoff. The headwaters of the watershed are comprised of a bog complex including Big Buffalo Lake (0.55 km^2) and several other ponds. Buffalo Creek originates in Big Buffalo Lake and flows through the bog complex before entering into a more defined creek channel with greater gradient and greater habitat diversity. The creek discharges into the lower Dauphin River approximately 4 km upstream of Sturgeon Bay on Lake Winnipeg.

Additional descriptions of the biophysical environments and flow regulation on Lake Manitoba, Fairford River, Lake Pineimuta, Lake St. Martin, Dauphin River and Sturgeon Bay are provided in North/South Consultants Inc. (November 2013).

3.0 DATA COLLECTION, ANALYSIS & RESULTS

3.1 HYDROMETRIC DATA (STA-1)

Hydrometric data was collected along the LSMEOC System to support the sediment transport models discussed in this report. Water level and flow data that was collected as part of the sediment transport Analysis and Modeling task (STA-1) of this project between October 2012 and September 2015 is discussed in this Section. Hydrometric data that was collected prior to November 2012 during operation of Reach 1 was obtained from the Analysis & Monitoring of Discharges & Ice Processes Report (KGS Group 2014) of the Emergency Reduction of Lake Manitoba and Lake St. Martin Water Levels Project.

3.1.1 Methodology

KGS Group conducted a hydrometric monitoring program to obtain water level and discharge data along the LSMEOC System. All monitoring locations are identified on Drawing 1. The program included the following components:

- Installation of an array of pressure loggers in Reach 1, Big Buffalo Lake and Buffalo Creek in the fall of 2012 to document changes in water level prior to, during, and following closure of Reach 1, as well as during the 2014/2015 operation period;
- Installation of a temporary hydrometric station on Buffalo Creek in the spring of 2013 to obtain a continuous recording of water levels in the Creek;
- Flow metering events on Reach 1 and Buffalo Creek to obtain a flow record along the LSMEOC System; and
- Ice reconnaissance survey of the Dauphin River in December 2012 and in December 2013.

During the 2011/2012 operation, pressure loggers were installed by NSC in late October 2012 to document changes in water level prior to, during, and following closure of Reach 1. The loggers collected data until their retrieval date between December 2012 and June 2013 depending on location. Details of the methods of installation, location and results of these pressure loggers are provided in Volume 6 - Reach 1 Closure Report.

In June 2014, pressure loggers were re-installed along the LSMEOC System to measure changes in water level for the 2014/2015 operation period. The loggers collected data until their retrieval date in September 2015. Details of the methods of installation and location are provided in the Field Inspection Forms (Task 13 & 18) provided in Appendix A1.

The temporary hydrometric station on Buffalo Creek was installed on May 14, 2013 at BC-TM. The location of BC-TM was selected to be a sufficient distance upstream of the Dauphin River where backwater effects were determined to be negligible. At the station, HOBO pressure loggers (Model U20-001-01, Onset Corporation) were installed to obtain a continuous recording of water levels at the site. One logger was installed under water on the creek channel bed to measure the pressure of water (water level logger), while two loggers were installed on a tree near the bank of the channel to measure the barometric pressure (barometric loggers). Data from the barometric loggers was used to calibrate the data from the water level logger. The loggers were set to record pressure every 15 minutes. Data from the loggers was then retrieved on subsequent site visits. The methodology for installation, servicing and retrieving data from the loggers is described in detail in the Field Inspection Forms (Task 13 & 18) provided in Appendix A1.

Global Positioning System (GPS) survey equipment was used during the installation of the pressure loggers to obtain the starting geodetic water elevation at the BC-TM site. A staff gauge was also installed in the creek to obtain relative water level elevation during future site visits. The zero elevation of the gauge was surveyed with the GPS equipment.

Flow metering measurements were conducted on Reach 1 between November 2011 and September 2015. Flows were recorded using a Teledyne RDI RiverRay – 600 kHZ Acoustic Doppler Current Profiler (ADCP). The ADCP was either connected to a boat or to the cableway system that was installed approximately 2 km downstream from the inlet of Reach 1. Flow readings at Reach 1 occurred on the following dates:

- November 18, 2011 following the opening of Reach 1 (2011/2012 Operation);
- March 21, April 17, and August 9, 2012 during operation of Reach 1 (2011/2012 Operation);
- November 15, 2012, immediately prior to closure Reach 1 (2011/2012 Operation);
- September 6, 2014 (2014/2015 Operation);
- November 18, 2014 (2014/2015 Operation);

- May 1, 2015 (2014/2015 Operation); and,
- June 11, 2015 (2014/2015 Operation).

The data listed above was supplemented with flow metering data conducted by MIT during the 2014/2015 Operation.

Flow metering was also carried out on Buffalo Creek at the BC-TM station using a Sontek Flow Tracker Acoustic Doppler Velocimeter (ADV) or the ADCP equipment on the following dates:

- May 14, 2013, during the spring freshet (closure period);
- August 14, 2013 (closure period);
- October 16, 2013 (closure period);
- May 15, 2014 (closure period);
- June 17, 2014, prior to the re-opening of Reach 1 (closure period); and,
- September 14, 2015 (2014/2015 post-operation).

Collection and processing of the flow metering data followed the widely accepted Water Survey of Canada (WSC) (Government of Canada 1999; Water Survey of Canada 2004) and United States Geological Survey (USGS) (Mueller and Wagner 2006; Mueller and Wagner 2009) Guidelines for hydrometric surveys.

On Dauphin River, hydrometric daily flow records are available from WSC at the hydrometric station No. 05LM006 (Dauphin River near Dauphin River). A field program to collect hydrometric data on the Dauphin River was therefore not necessary for this study. The location of the WSC gauge on Dauphin River is shown on Drawing 1.

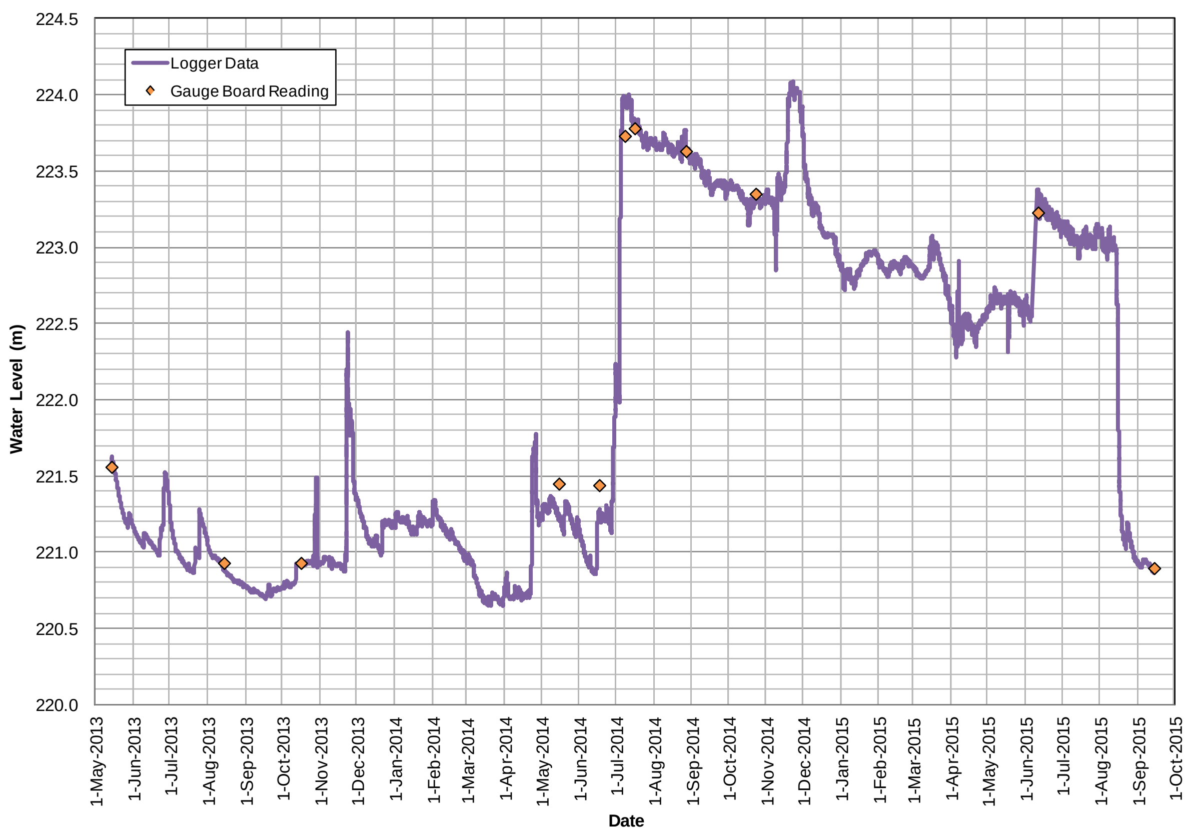
An ice reconnaissance survey was also conducted along the LSMEOC, emphasizing the upper Dauphin River, to supplement the WSC data during the winter period. The purpose of the survey was to assess the ice conditions in the Dauphin River and confirm the location and type of ice cover that caused restrictions in flows on the Dauphin River at the outlet of Lake St. Martin. Information on ice conditions is necessary to determine winter discharges in the Dauphin River.

Two surveys were conducted for this study and took place on December 20, 2012 as well as on December 12, 2013. The surveys were conducted by helicopter and documented with photos while flying over the LSMEOC system. The continuous log of photos taken during both surveys is provided in Appendix B.

3.1.2 Data Analysis and Results

Data from the water level and barometric pressure loggers were extracted and converted to relative water level using HOBOware Pro, a software package provided by Onset Corporation. An electronic copy of the data is provided in Appendix D. Relative water level was then converted to geodetic elevations based on the surveyed water levels obtained from the staff gauges during the field visits. The water level on Buffalo Creek at BC-TM measured by the pressure logger and recorded during the field visits are shown in Figure 3.1-1.

FIGURE 3.1-1
WATER LEVEL ON BUFFALO CREEK MEASURED AT BC-TM



The flow metering data was processed using the Teledyne RDI WinRiver II software for data collected with the ADCP and the Sontek Flow Tracker V2.3 software for data collected with the ADV. Results of the flow meterings are summarized in Table 3.1-1. Flow meterings from previous studies (KGS Group, 2014) are also included in the Table. Summary sheets and other details of the flow meterings that were conducted for the current study, generally including site photos, screenshots of typical ADCP transects and Flow Tracker results are provided in Appendix C.

TABLE 3.1-1
METERED DISCHARGE AND WATER LEVEL ON REACH 1 AND BUFFALO CREEK

Date	Location	Discharge (m^3/s)
18-Nov-11	RC-1	172
21-Mar-12	RC-1	158
17-Apr-12	RC-1	129
9-Aug-12	RC-1	115
21-Nov-12	RC-1	46
14-May-13	BC-TM	9.5
14-Aug-13	BC-TM	1.0
16-Oct-13	BC-TM	0.7
15-May-14	BC-TM	6.4
17-Jun-14	BC-TM	5.6
6-Sep-14	RC-1	112
18-Nov-14	RC-1	88
1-May-15	RC-1	94
11-Jun-15	RC-1	91
14-Sep-15	BC-TM	0.5

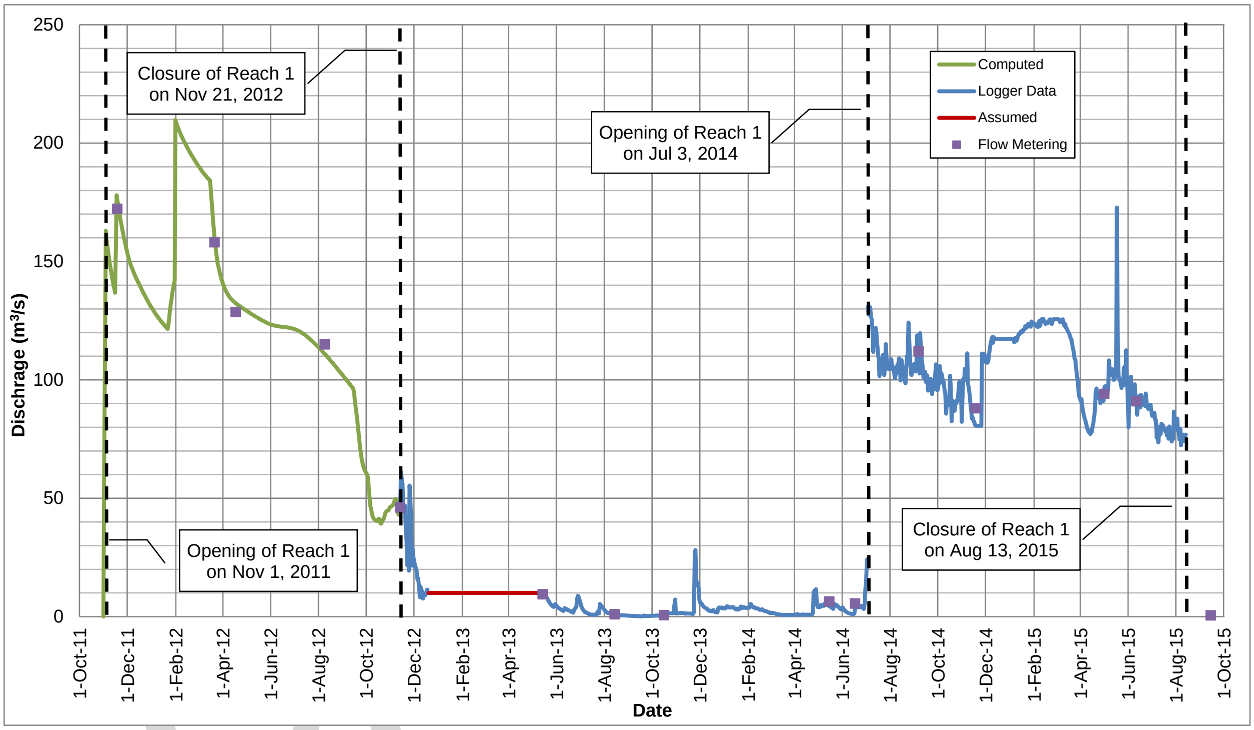
A flow hydrograph of Buffalo Creek was developed for this study. Prior to closure of Reach 1, the flows in Buffalo Creek were assumed to equal flows in Reach 1. Flows in Reach 1 were estimated based on data and results from the Analysis & Monitoring of Discharges & Ice Processes Report (KGS Group 2014) and the flow metering of November 15, 2012. For the period that extended between the closure of Reach 1 in November 2012 to the formation of ice in Buffalo Creek in mid-December 2012, flows in Buffalo Creek were estimated based on the flow metering of November 15, 2012 as well as data from the array of pressure loggers in Reach 1, Big Buffalo Lake and Buffalo Creek that were installed in the fall of 2012 (data provided and discussed in Volume 6 - Reach 1 Closure Report).

By mid-December 2012, ice had started to form in many locations along the LSMEOC and flows had receded due to the closure of Reach 1. Several of the pressure loggers were retrieved for analysis. Therefore, flows in Buffalo Creek during the winter of 2012-2013 were assumed to equal an average value of 10 m^3/s based on known flows in the creek immediately prior and after the winter. This assumed flow was deemed conservative for the purposes of the sediment transport analyses discussed in Section 4.0. In reality is likely that the flows receded to a lower value until the beginning of the spring freshet, due to sub-zero temperatures and limited runoff during the winter. From May 14, 2013, to July 3, 2014 flows in Buffalo Creek were estimated based on the results of the pressure loggers at BC-TM and the stage-discharge relationship outlined above.

During the 2014/2015 Operation period, from July 3, 2014 to August 13 2015, flows in Buffalo Creek were assumed to equal the flows in Reach 1. Flows in Reach 1 were based on the various flow meterings conducted by KGS Group and MIT at the cableway, combined with WSC recordings of water levels on Lake St. Martin and pressure logger data at the cableway.

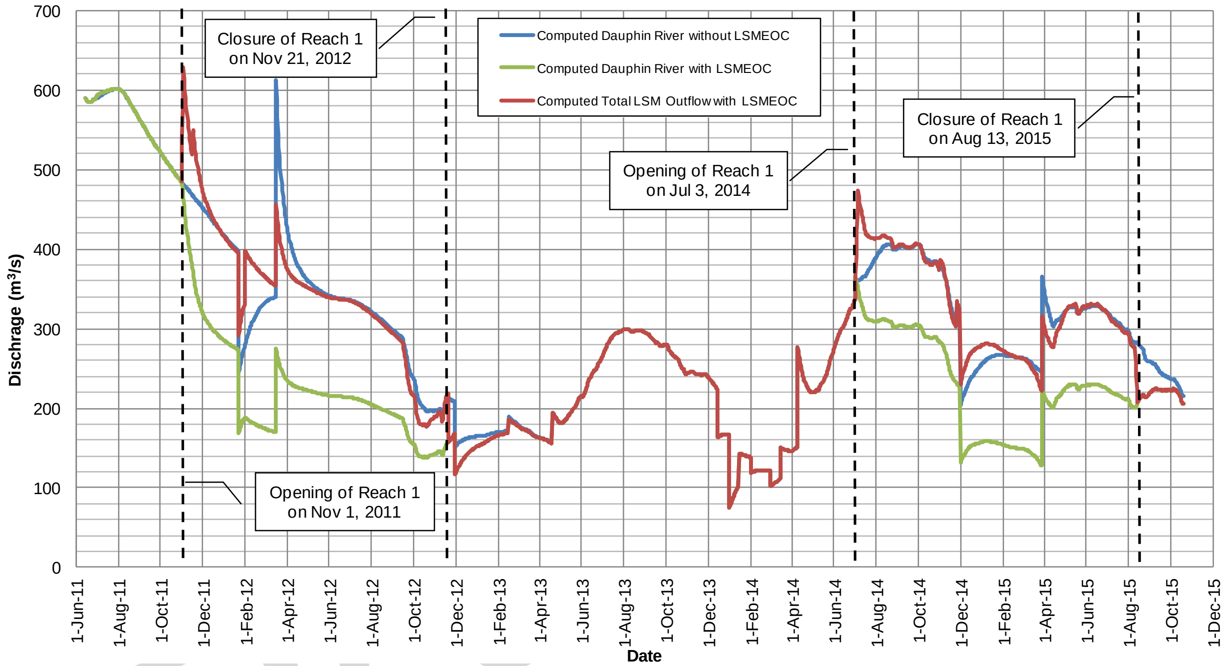
The estimated flow hydrograph on Buffalo Creek prior to and post closure of Reach 1 is provided in Figure 3.1-2.

FIGURE 3.1-2
BUFFALO CREEK FLOWS PRE- AND POST-OPERATION



Data obtained from WSC at Gauge No. 05LM006 (Dauphin River near Dauphin River) combined with knowledge of ice conditions from the Upper Dauphin River Ice Reconnaissance Survey and results from the Analysis & Monitoring of Discharges & Ice Processes Report (KGS Group, 2014), extended to 2015, was used to develop a flow hydrograph for the Dauphin River upstream of Buffalo Creek. This was necessary because the hydrometric data available on Dauphin River from WSC can be affected by ice conditions in the river during the winter. The computed flows on Dauphin River upstream of Buffalo Creek prior to and post closure of Reach 1 is provided in Figure 3.1-4. The total Lake St. Martin outflow during operation of the LSMEOC, which is the summation of the Buffalo Creek and Dauphin River discharges, is also shown on Figure 3.1-3.

FIGURE 3.1-3
DAUPHIN RIVER FLOWS PRE- AND POST-OPERATION



The Dauphin River sediment transport analysis (discussed in Section 4.0) required the development of a synthetic flow hydrograph of the Dauphin River assuming that the LSMEOC System was not operated. This had already been developed by KGS Group for the Analysis & Monitoring of Discharges & Ice Processes Report (KGS Group, 2014) from November 2011 to July 2012. The results from the previous analysis (KGS Group, 2014) were extended to October 2015 based on the additional data collected for this study. The synthetic flow hydrograph is a prediction of what flows would have occurred in the Dauphin River without operation of Reach 1 should all other conditions (e.g. inflow to Lake St. Martin, ice conditions in Dauphin River, etc.) remain the same. The computed synthetic flow hydrograph on Dauphin River without operation of the LSMEOC System is provided in Figure 3.1-3.

Duration curves of computed flows on Buffalo Creek and Dauphin River were prepared for comparison purposes and to assist with the sediment transport analyses discussed in Section 4.0. The duration curves of the computed outflow were prepared for three different time periods:

1. From November 1, 2011 to November 21, 2012 - opening of the LSMEOC;

2. From November 22, 2012 to July 2, 2014 – post closure of the LSMEOC; and

3. From July 3, 2014 to August 13, 2015 – opening of the LSMEOC.

FIGURE 3.1-4
DURATION CURVE OF COMPUTED FLOWS ON BUFFALO CREEK

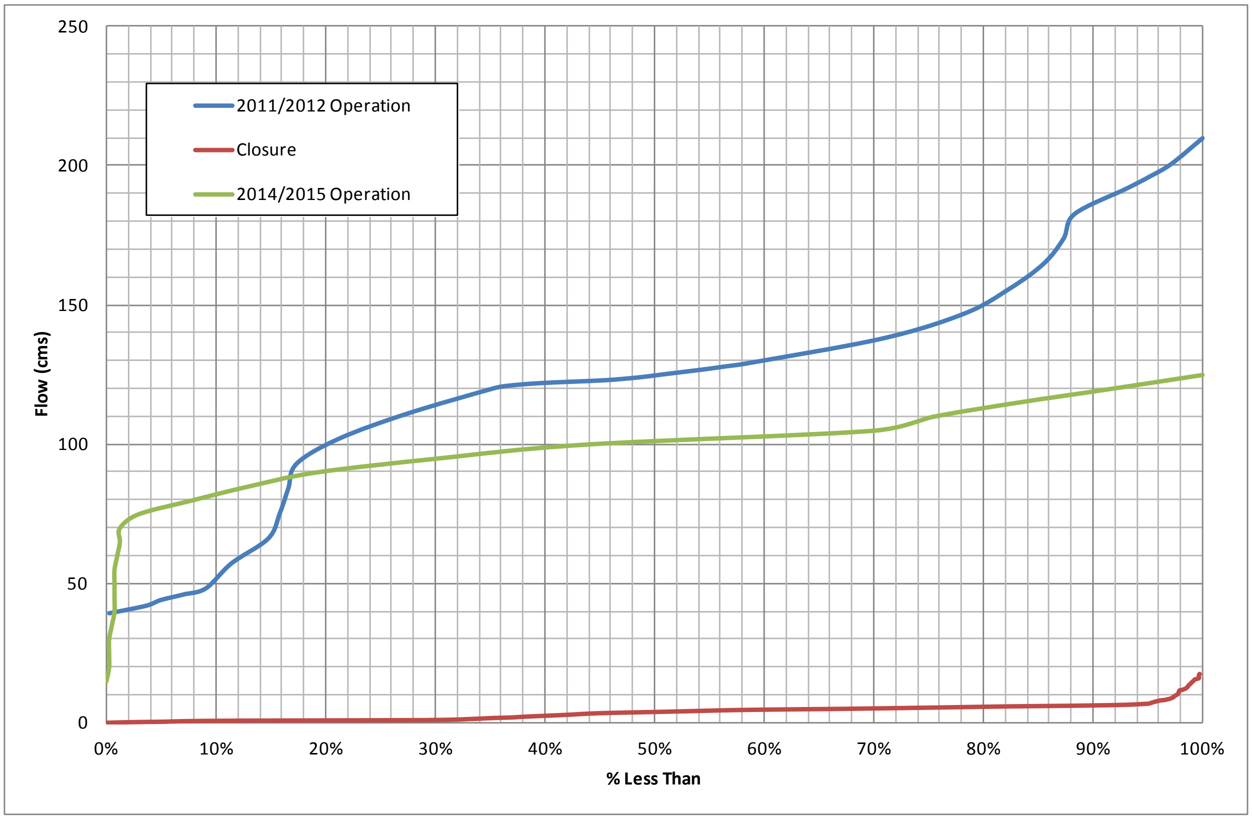


Figure 3.1-4 shows the duration curves for Buffalo Creek. The 10th, 50th, and 90th percentile flows as well as the estimated minimum and maximum flows for each operating period are summarized in Table 3.1-2.

TABLE 3.1-2
OUTFLOW CONDITIONS ON BUFFALO CREEK

Description	Minimum Flow (cms)	10% Flow (cms)	50% Flow (cms)	90% Flow (cms)	Maximum Flow (cms)
2011/2012 Operation Period	40	45	125	185	210
2012-2014 Closure Period	0	1	4	8	18
2014/2015 Operation Period	15	82	101	120	125

Dauphin River duration curves of the total Lake St. Martin outflow (Dauphin River outflow plus LSMEOC outflow) are shown on Figure 3.1-6. Duration curves are shown for conditions with operation of the LSMEOC and also for conditions assuming that the LSMEOC System was not operated. The 10th, 50th, and 90th percentile flows for the three operating periods are summarized in Table 3.1-3.

FIGURE 3.1-5
DURATION CURVES OF COMPUTED TOTAL OUTFLOW FROM LAKE ST. MARTIN

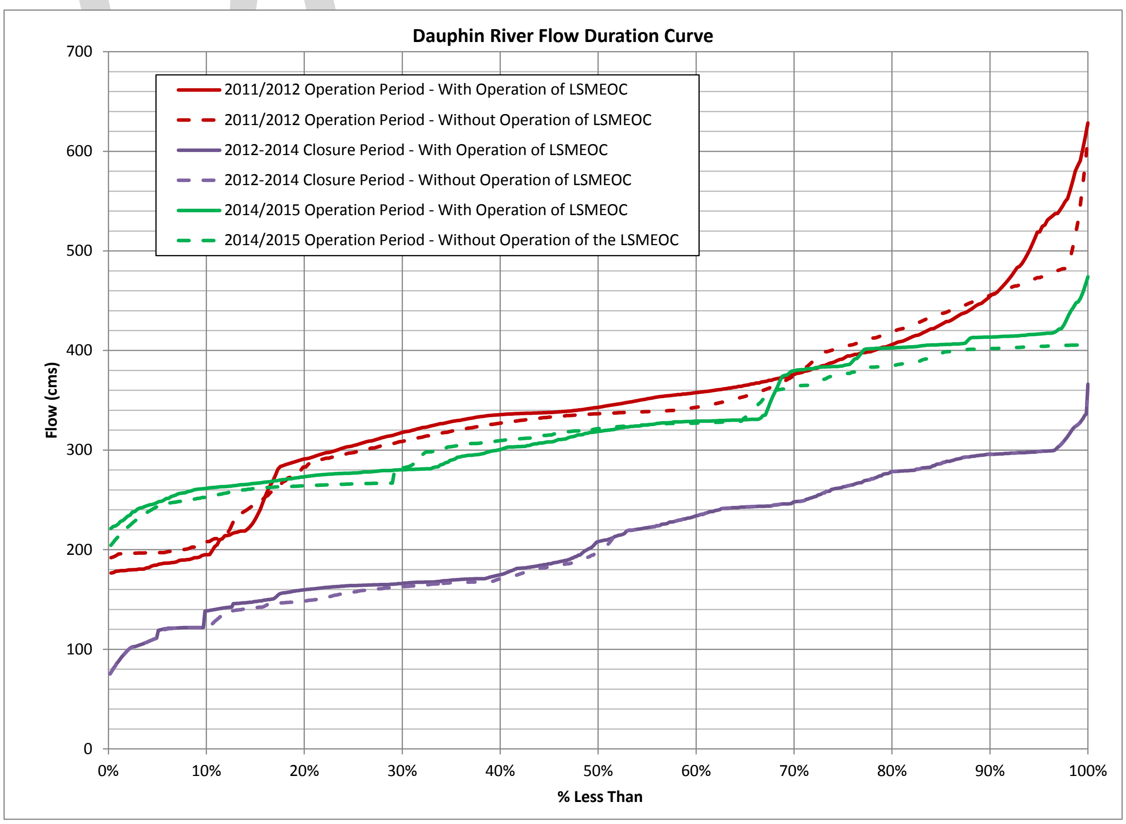


TABLE 3.1-3
FLOW CONDITIONS ON DAUPHIN RIVER

Description	LSMEOC Operating Scenario	10% Flow (cms)	50% Flow (cms)	90% Flow (cms)
2011/2012 Operation Period	With	195	335	455
	Without	210	340	455
2012-2014 Closure Period	With	120	200	295
	Without	140	210	295
2014/2015 Operation Period	With	260	320	415
	Without	255	320	400

As demonstrated by the Dauphin River flow hydrographs (Figure 3.1-4), and the Dauphin River duration curves (3.1-6) the discharge in the Dauphin River was influenced by the Buffalo Creek discharge from operation of the LSMEOC in both the 2011/2012 operation and the 2014/2015 operation periods. However, if the diversion of flow into Buffalo Creek had not occurred with the opening of the LSMEOC, the water level on Lake St. Martin would have staged accordingly to a higher level such that the total inflow to Lake St. Martin would have been released down the Dauphin River and the discharge on the river downstream from the Buffalo Creek confluence would have been approximately the same with or without the LSMEOC in operation. The potential influence of the Buffalo Creek discharge on the lower Dauphin River during operation of the LSMEOC is discussed further in Section 4.3 (Dauphin River Flow Pattern and Sediment Transport Analysis) of this report.

3.2 WATER QUALITY DATA (WQ-1, WQ-2 AND ESH-1)

Water quality monitoring of the LSMEOC System has been ongoing since early construction of Reach 1. This monitoring program was broken into three phases. The first phase was the 2011 Construction Monitoring, which began during construction in September 2011 and continued until just after initial operation of Reach 1 in November 2011 and focused on examining direct impacts on Buffalo Creek and the Dauphin River from construction and initial operation of Reach 1 (AECOM 2011a and 2011b). The second phase was the 2012 Water Quality program with continued monitoring of the LSMEOC System during the 2011/2012 operation period of Reach 1, as well as monitoring during the construction and potential operation of Reach 3 (KGS

Group, November 2013). The third phase contained the closure period from November 2012 to June 2014 as well as the 2014/2015 operation period, which included periodic sample events as described in the sections that follow.

NSC conducted a regional water quality (WQ-1) program, which examined additional water bodies and watercourses within the drainage basin extending from Lake Manitoba downstream to Lake Winnipeg at Sturgeon Bay. KGS Group conducted the LSMEOC System water quality monitoring (WQ-2) program that specifically monitored water quality within Reach 1, the Buffalo Creek Drainage System and the lower Dauphin River. These water quality monitoring programs were a continuation of the 2011 monitoring program that was established by AECOM during the construction and initial operation of Reach 1. KGS Group also conducted continuous turbidity monitoring in Reach 1, Buffalo Creek and the lower Dauphin River to support the sediment transport model as part of the Erosion, Sediment and Habitat (ESH-1) program.

3.2.1 Methodology

The 2012 to 2015 water quality monitoring program generally followed the protocols established during the 2011 Construction Monitoring Program. These protocols included special consideration in assessment of concentrations of total suspended solids (TSS) and dissolved oxygen (DO) to determine the potential impacts on aquatic organisms as a result of project activities. Any deviations from the 2011 protocols and a description of the parameters analyzed, the locations where samples were collected (Drawing 1), the methodology used and analytical results as part of the regional (WQ-1) and LSMEOC System (WQ-2) monitoring programs are detailed in Volume 3 - Water Quality. A notable change was that in 2012, turbidity was added to the analytical data so that it could be correlated with insitu turbidity data measured in the field, and to potentially provide an alternate estimation of impacts from suspended solids.

Two turbidity meters, one in Buffalo Creek near its outlet and the other within the lower Dauphin River, were installed in the fall of 2012 and in the spring of 2013 to collect long-term insitu data between the discrete water quality monitoring sampling events during the LSMEOC closure period (2012 to 2014). Two additional turbidity meters were then installed in June 2014, one in Reach 1 and the other in Buffalo Creek near its inlet, to collect additional data during the 2014/2015 operation period. Water quality data was also collected and analyzed at each turbidity meter location to verify the long-term insitu data and compare the turbidity readings to analytical data for TSS in support of the sediment transport analysis data. All monitoring station locations are shown on Drawing 1.

The Buffalo Creek Turbidity Meter (BC-TM) location was selected to be a sufficient distance upstream of the Dauphin River to avoid backwater effects during the monitoring and is shown on Drawing 1. In 2012, the turbidity meter was located approximately 700 m upstream of the BC-TM monitoring location. The turbidity meter at BC-TM was installed for the following periods:

- October 23, 2012 to November 13, 2012;
- May 14, 2013 to October 16, 2013;
- May 15, 2014 to October 23, 2014;
- November 14, 2014 to June 10, 2015 (data not retrievable due to winter damage); and
- June 10, 2015 to September 14, 2015.

The Dauphin River Turbidity Meter (DR-TM) location was selected upstream of the confluence with Buffalo Creek to provide background conditions. The turbidity meter at DR-TM was installed for the following periods:

- May 14, 2013 to October 16, 2013;
- May 15, 2014 to October 22, 2014; and
- June 10, 2015 to September 15, 2015.

The turbidity meter in Reach 1 was situated near the outlet of the Emergency Channel (at station EC-2) to measure turbidity of water leaving the emergency channel. The turbidity meter at EC-2 was installed for the following periods:

- June 25, 2014 to October 22, 2014; and
- November 14, 2014 to June 11, 2015.

The turbidity meter at BC1 was installed at the upstream end of Buffalo Creek immediately after water departs the large bog area surrounding Big Buffalo Lake. This site serves as a baseline for Buffalo Creek near its headwaters and also provides insight into how much deposition occurs through the bog complex. The turbidity meter at BC1 was installed for the following periods:

- June 25, 2014 to October 22, 2014.

Suitable locations to install the turbidity meters were selected based on an initial visual survey of site conditions, including stable banks and channel bottoms, as well as sufficient depth and flow. Additional details about installation methodology, servicing, and logger removal are described in the Field Inspection Forms (Task 13 & 18) provided in Appendix A1.

Bedload Sampling

To support the water quality data, bedload sampling was conducted on the Dauphin River to assess the quantity and composition of sediment transport along the river bottom. Bedload sampling occurred on the following dates:

- July 3, 2014;
- July 17, 2014;
- July 29, 2015; and
- September 15, 2015.

Sampling was conducted 1.9 km downstream from the confluence of the Buffalo Creek. A transect was established perpendicular to the river and sampling occurred at five locations equally distributed across this transect. Sampling included sediment collection with a bedload sampler, water velocity measurements with a current meter, water sample collection and water depth measurement. Details of the sampling methodology are provided within the Field Inspection Forms (Task 13 & 18) provided in Appendix A1.

3.2.2 Data Analysis and Results

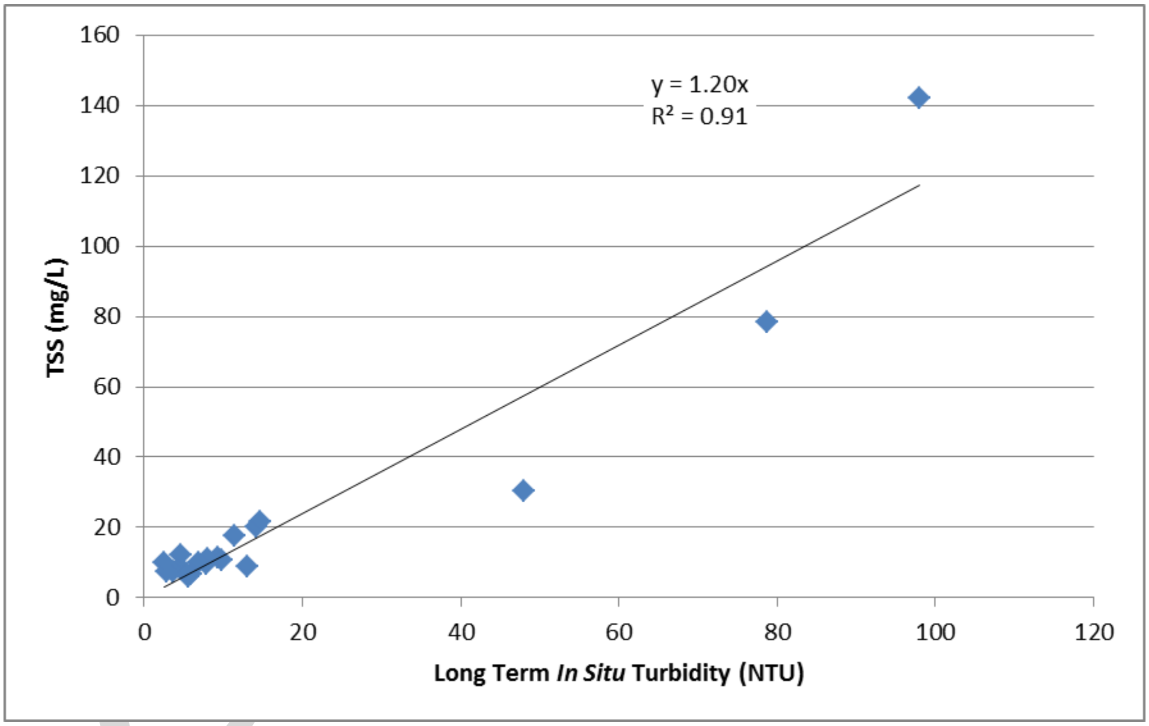
The data analysis for most of the water quality monitoring (WQ-1 and WQ-2) is described in Volume 3 Water Quality, whereas the data analysis of TSS and turbidity as it relates to the sediment transport analysis are described in this section of the report.

To assess the relationships between turbidity and TSS, the long-term insitu turbidity data was imported into an excel spreadsheet for processing and data analysis. In order to verify readings from the long term insitu turbidity logger, readings were also taken with a handheld turbidity meter and samples were also collected for laboratory analysis. The laboratory analyzed turbidity was more accurate than the turbidity meter data and, therefore, the long-term insitu turbidity data was adjusted as required to be representative of the laboratory results. As such, adjustment factors were developed for each of the turbidity meters for the long-term insitu data based on average differences between the lab analyzed turbidity value and the measured value from the turbidity meter at the nearest time. Based on this analysis, the raw long-term insitu turbidity data was adjusted by approximately 0 to 12 NTU depending on time and location. Due to uncontrollable field circumstances between field calibration events or data collection surveys while the turbidity meters were in operation (e.g. debris getting caught in the equipment or displacement of the equipment under water), there were a few instances where the data collected had unrealistic fluctuations between high and low turbidity values and exaggerated high level readings. Where this was the case, the raw long-term insitu turbidity data was either adjusted by a percentage representative of the laboratory data, or dismissed if there was no apparent correlation with the laboratory data.

To estimate TSS concentrations (mg/L) using the measured long-term insitu turbidity values (NTU), linear regressions were completed to correlate turbidity data to laboratory analyzed TSS or turbidity. Due to the evolving nature of the project that required periodic reporting and updates to the sediment transport empirical model, the turbidity/TSS relationships were also updated on numerous occasions. Preliminary relationships were used in the analysis based on the limited amount of data that was available during the closure period (2012-2014). These relationships were then updated during the 2014/2015 operation period based on the additional surveys and data points that became available. The most up-to date correlations between turbidity and TSS are provided below.

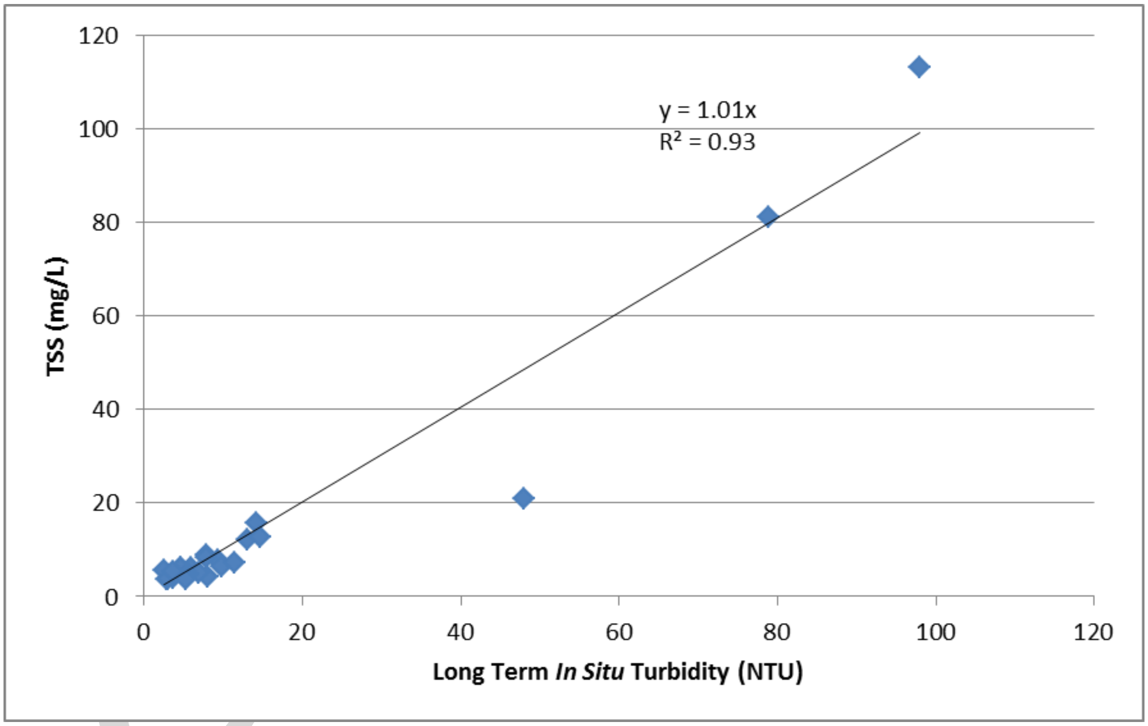
Within Buffalo Creek the insitu turbidity values measured at BC-TM correlated well (R^2 = 0.91) with TSS having a linear relationship of TSS = 1.20 x Turbidity as shown in Figure 3.2-1. The strength of this linear relationship would likely improve with more data points and if there was a greater range of turbidity and TSS concentrations. Regardless, the linear relationship and the strength of this relationship is comparable to other projects such as the Red River Floodway Expansion which started with a reasonably correlated relationship of TSS = 1.12 x Turbidity (R^2 of 0.50) that improved to TSS = 1.19 x Turbidity (R^2 = 0.81) with more sample points and concentration range.

FIGURE 3.2-1
CORRELATION OF INSITU TURBIDITY AND LABORATORY ANALYZED TSS MEASURED IN BUFFALO CREEK (BC-TM)



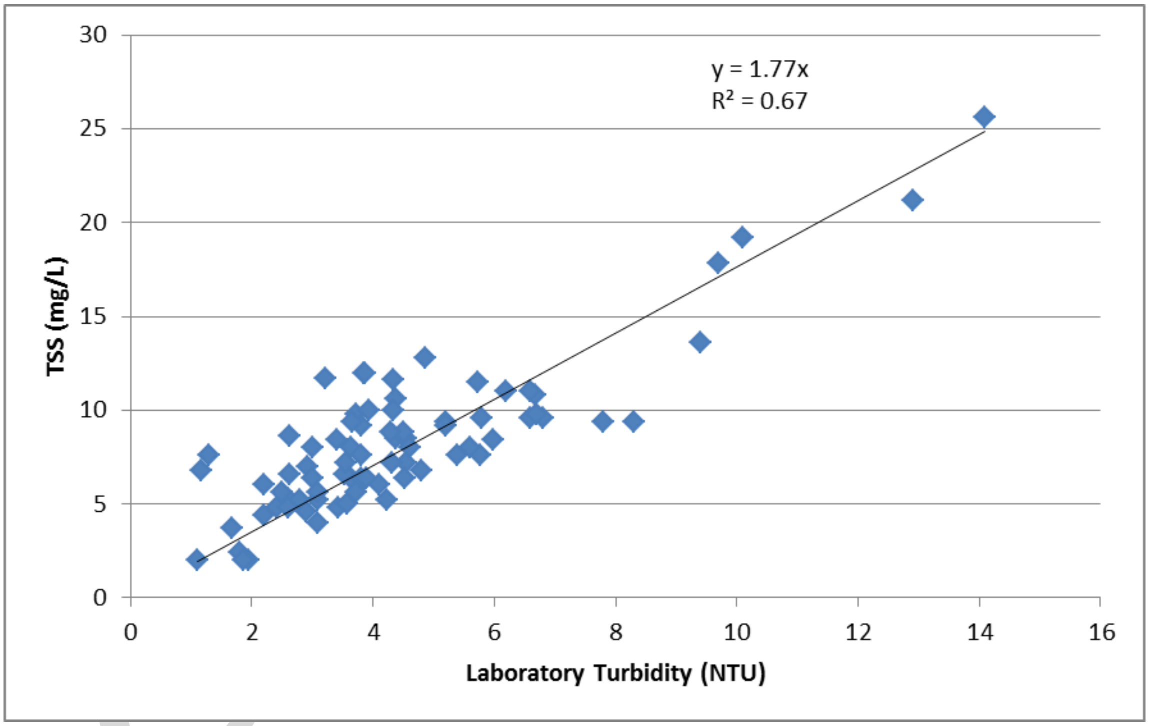
Within the lower Dauphin River the insitu turbidity values measured at DR-TM poorly correlated with TSS because there were too few TSS samples and the range of TSS and turbidity concentrations was too low. As such the laboratory analyzed turbidity was evaluated as a surrogate to the insitu turbidity data to develop a correlation between TSS and turbidity and then that relationship was used to estimate TSS from the insitu turbidity data. As discussed above, it was assumed that the laboratory analyzed turbidity would be more accurate than the long-term insitu turbidity data and therefore the raw data was adjusted accordingly. The adjusted insitu turbidity values measured at BC-TM and DR-TM were strongly correlated (R^2 = 0.93) with laboratory analyzed turbidity having a 1:1 linear relationship as shown in Figure 3.2-2. This confirmed that the insitu turbidity data was adjusted accurately to be equivalent to the laboratory analyzed turbidity data, which was therefore used to develop the relationship to estimate TSS using the long-term insitu turbidity data.

FIGURE 3.2-2
CORRELATION OF INSITU TURBIDITY AND LABORATORY ANALYZED TURBIDITY MEASURED IN BUFFALO CREEK (BC-TM) AND DAUPHIN RIVER (DR-TM)



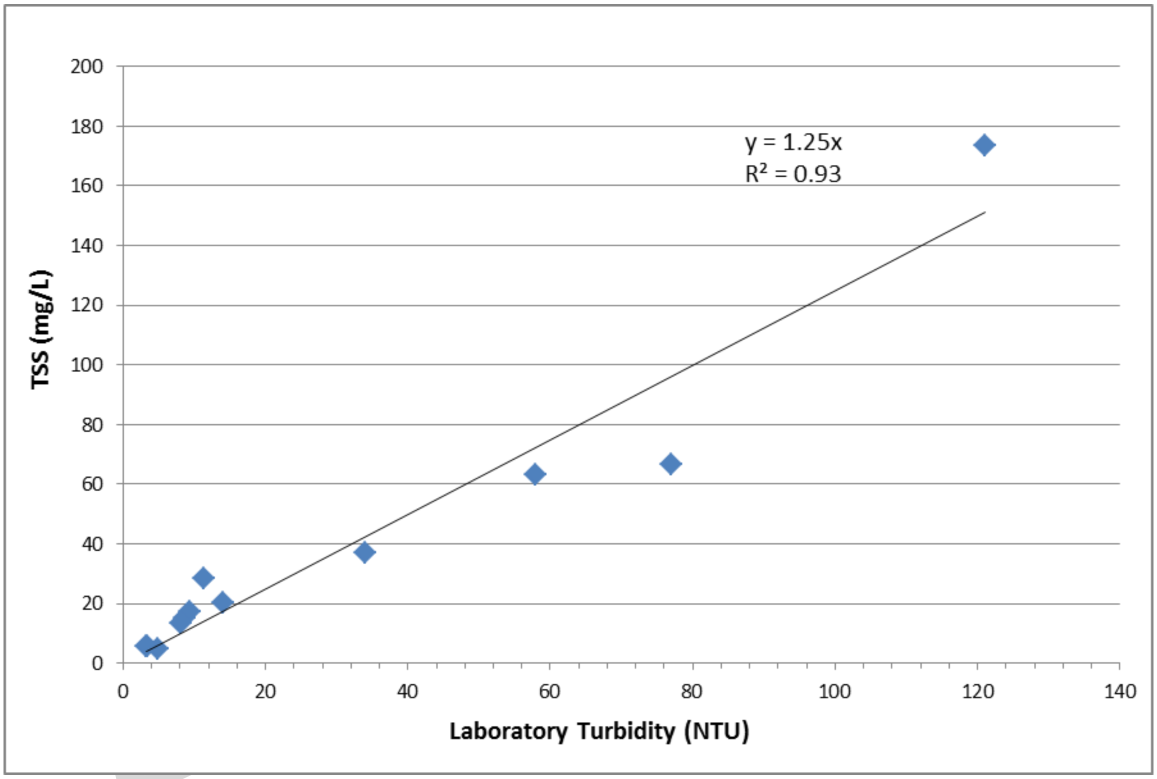
The linear regression completed to correlate laboratory analyzed turbidity and TSS within the Dauphin River also included data collected from the sample location DR1 to supplement the limited data collected at DR-TM. Since DR1 was located upstream of the confluence with Buffalo Creek in close proximity to DR-TM, it was assumed that it had representative conditions. In comparison, DR3 and DR2C, which are located downstream of the confluence point, were not used in the analysis as they could have been influenced by Buffalo Creek or Lake Winnipeg. Within the Dauphin River the laboratory turbidity values measured at DR-TM and DR1 correlated well (R2 = 0.67) with TSS having a linear relationship of TSS = 1.77 x Turbidity as shown in Figure 3.2-3. This linear relationship was used for estimating TSS concentrations (mg/L) from the long-term insitu turbidity based on the 1:1 relationship between laboratory analyzed turbidity and insitu turbidity.

FIGURE 3.2-3
CORRELATION OF LABORATORY ANALYZED TURBIDITY AND TSS MEASURED IN DAUPHIN RIVER (DR-TM & DR1)



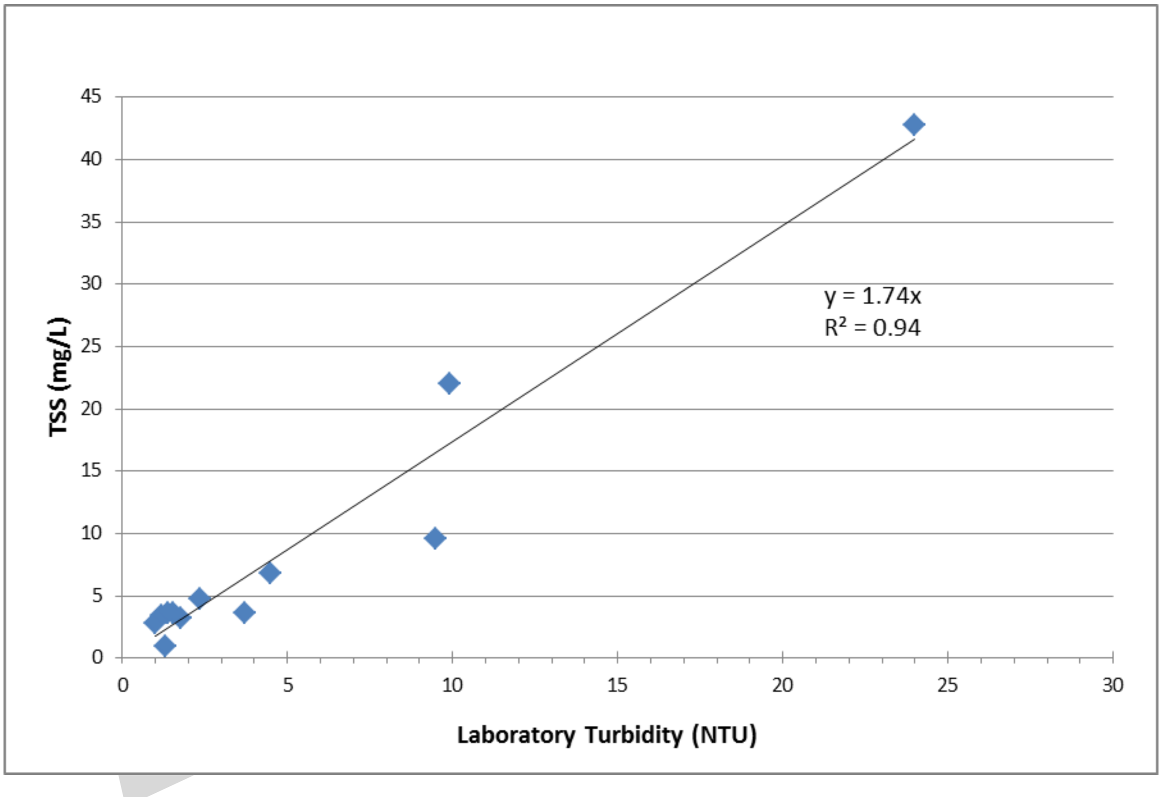
For the turbidity logger at EC-2 within Reach 1, a linear regression was generated between laboratory turbidity values and laboratory TSS values from water samples collected at EC-2. The plot generated correlated well (R^2 = 0.93) with TSS having a linear relationship of TSS = 1.25 x Turbidity as shown in Figure 3.2-4. This linear relationship was used for estimating TSS concentrations (mg/L) from the long-term insitu turbidity based on the 1:1 relationship between laboratory analyzed turbidity and insitu turbidity as justified above.

FIGURE 3.2-4
CORRELATION OF LABORATORY ANALYZED TURBIDITY AND TSS MEASURED AT EC-2



For the turbidity logger at BC-1, a linear regression was generated between laboratory turbidity values and laboratory TSS values from water samples collected at BC-1. The plot generated correlated well (R^2 = 0.94) with TSS having a linear relationship of TSS = 1.74 x Turbidity as shown in Figure 3.2-5. This linear relationship was used for estimating TSS concentrations (mg/L) from the long-term insitu turbidity based on the 1:1 relationship between laboratory analyzed turbidity and insitu turbidity as justified above.

FIGURE 3.2-5
CORRELATION OF LABORATORY ANALYZED TURBIDITY AND TSS MEASURED AT BC-1



Daily average TSS calculated from the Turbidity meter data was then used in the empirical model where applicable and was supplemented as required by interpolating between laboratory analyzed In-situ TSS data. The estimated TSS concentrations in Reach 1, Buffalo Creek and Dauphin River, are provided with the Empirical model results in Section 4.1. An electronic copy of the Turbidity data is provided in Appendix D.

Bedload Sampling

Laboratory results of the Bedload sampling events are provided in Appendix L. Table 3.2-1 summarizes the average dry weight per minute of all the samples collected during each of the surveys. The computed flow in the Dauphin River on the day of the survey is also reported, as well as the operating status of the LSMEOC.

TABLE 3.2-1
SUMMARY OF BEDLOAD SURVEY RESULTS

Date of Survey	LSMEOC Operating Condition	Average Dry Weight of Sample (g/min)	Approximate Flow in Lower Dauphin River (m^3/s)
July 3, 2014	Closed	1.6	330
July 17, 2014	Opened	0.8	415
July 29, 2015	Opened	0.6	295
September 15, 2015	Closed	0.05	220

The results of the survey indicated that there was a very small amount of material transported as bedload in the lower Dauphin River. Additionally, the survey did not show an increase in bedload in the lower Dauphin River at the sampling locations during operation of the LSMEOC. It is acknowledged, however, that bedload measurements under a wide range of flow conditions over many years are necessary to fully understand and quantify the extent of bedload that would be expected in this reach of River. The results presented above were incorporated into the Dauphin River erosion and deposition analysis discussed in Section 4.4.2.

3.3 BUFFALO CREEK VEGETATION COVER SURVEY (ESH-4)

KGS Group completed 31 vegetation survey transects along Buffalo Creek between Stations 13+000 m and 28+000 m. This was completed as part of the Buffalo Creek Watershed – Post-Project Evaluation (Task ESH-4). The purpose of the vegetation survey along Buffalo Creek was to assist in monitoring and assessing the impacts of the emergency channel operation and changes to the riparian vegetation community as well as erosion along the river. The survey included the recording of vegetation cover types and relative coverage of each vegetative type.

An initial survey was conducted in 2011 prior to construction and operation of the emergency channels. A subsequent survey was conducted in 2013 following the closure of the emergency channel. A third survey was conducted in 2014 in order to assess the continued recovery of the vegetative community following the 2011-2012 operation, but also to serve as a pre-operation survey prior to the 2014-2015 operation.

3.3.1 Methodology

Field work for the substrate cover surveys was completed on the following dates:

- Survey 1 – September 21-26, 2011;
- Survey 2 – July 3-5, 2013; and
- Survey 3 – June 17-19, 2014.

Survey findings are briefly summarized below, with more details provided within the 2011 Buffalo Creek Vegetation Cover Survey memo provided in Appendix F and the Field Inspection Forms (Task 16 – Buffalo Creek Vegetation Cover Surveys) provided in Appendix A2. The Buffalo Creek vegetation cover survey involved documenting the cover types while walking 100 m transects on both sides of and perpendicular to the creek. Sampling locations were established every 500 m along the length of Buffalo Creek beginning at Station 13+000 m and continuing to just upstream of the confluence with the Dauphin River at Station 28+000 (Drawings 2 and 3). The transect orientation was modified from perpendicular in locations where the meander of the creek resulted in an overlap with a transect from another location.

A general description of cover types, start and end distance of each cover type within the transect, and depth of soil organic layer were also recorded. Cover types were placed in four broad categories:

- Bare: exposed mineral soil with no vegetation or soil organic layer;
- Grass: vegetation cover consists of grass, sedge, or rush families;
- Shrub: vegetation cover consists of woody species which do not form distinct trunks or canopies of leaves, especially those which do not normally exceed 10 m in height; At times, a distinction was made between short herbaceous shrubs and taller woodier shrubs; and
- Treed: vegetation cover consists of woody species that form distinct trunks and leaf canopies, and which normally can or do exceed 10 m in height.

The four representative cover types are shown in Photos 1 to 4 below. Photos comparing the difference between survey periods are found within the field inspection forms provided in Appendix A2. Digital photograph logs of the surveys were compiled and are provided in Appendix E.

PHOTO 1
"BARE" SUBSTRATE OBSERVED AT 18+000

PHOTO 2
"GRASS" VEGETATION OBSERVED AT 13+500

PHOTO 3
"SHRUB" VEGETATION OBSERVED AT 26+000

PHOTO 4
"TREED" VEGETATION OBSERVED AT 25+000

The ground cover within areas of the transects was then subdivided into percentages (e.g. 50% area covered by grass; 50% area covered by shrubs). Due to plant morphology and habit, total percentages greater than 100% were possible.

Organic soil depths were measured in a representative location within each different ground cover areas identified within the transects (i.e. if substrate changes from grass to trees, a soil depth measurement was taken within the grass area and within the treed area). Areas of erosion or deposition of soils were also noted where evident. The soil organic layer depth was compared against pre-project observations as an indication of the quantity of organic fines that may have moved downstream.

3.3.2 Data Analysis and Results

Full records for each transect are provided in the 2011 Buffalo Creek Vegetation Cover Survey memo in Appendix F and the Field Inspection Forms in Appendix A2. Within the 2013 Field Inspection Form, the results of the 2011 (pre-operation) survey are compared to the results of the 2013 (post-operation) survey. Within the 2014 Field Inspection Form, the results of the 2013 survey are compared to the results of the 2014 survey. In addition, GAIM flight imagery taken in 2013 and 2014 occurred concurrently with the substrate cover surveys and was analyzed to compare and contrast transect locations and impacted areas (Appendix G).

As noted in the 2011 substrate cover memo (Appendix F), the vegetation data observed was found to be comparable to existing known broad level cover type data, taken from GeoBase 2000 data. Due to the accuracy of the GPS, and movement of creek banks as a result of varying water levels, detailed quantitative comparisons were not feasible. Rather, detailed GIS cross section surveys were conducting on Buffalo creek and are discussed in Section 3.4. A general description of observations from the Vegetation Cover survey is provided in the paragraphs that follow.

2011 Survey

In 2011, grass cover was predominantly adjacent to the creek bank which generally transitioned to shrubs and then trees. A small number of bare areas were noted near the creek bank. Minimal dead vegetation was observed in 2011. This may be partly attributable to the time of year of the survey. This survey occurred in September following a full growing season. Several beaver dams were present, which created backwater effects that inundated relatively large areas.

2013 Survey

In 2013, many bare areas were observed along the length of the creek where little or no vegetation was established. Signs of sediment erosion and deposition were fairly widespread. Grass was sparse with most of the grass previously observed in 2011 no longer present. Many dead shrubs and trees were also observed. At some transects, the vegetation dead zone extended beyond the 100 m transect length of this survey. Debris (branches, logs) had accumulated at several locations. Early successional grasses and shrubs were observed at many transects. A comparison between the 2011 and 2013 survey must also consider the different times of year in which the surveys were conducted. The 2013 vegetation cover survey was conducted in early July following a late spring whereas the 2011 survey was conducted at the end of a full growing season. None of the beaver dams previously observed were remaining.

2014 Survey

In general, the large areas of dead trees observed in 2013 remained similar in 2014. In some locations, dead trees had fallen over. While many of the shrubs were still dead, regeneration from the roots had resulted in the resurgence of shrubs in numerous locations, particularly willows. The branches from the dead shrubs were still present above the surface, but were more frequently found along the ground with new green vegetation growing through and above it. In some stretches trees that had appeared to be alive in 2013, appeared dead in 2014. Ground cover in 2014 near the creek bank was much thicker, taller and greener than what was observed in 2013. Several beaver dams were again present along the creek. An additional task conducted as part of the 2014 survey was the determination of the extent of dead tree stands ("Vegetation Impact Zone"). The results of this task assisted with the deadfall removal program that was conducted prior to the 2014 operation of the LSMEOC to reduce potential impacts to fishing nets in Lake Winnipeg.

Soils

Organic and inorganic soil depths were measured at several locations at each transect. Due to the natural variability of soils and the challenges of replicating exact locations, a comparison of soils between surveys is difficult. An additional challenge was that many areas were inundated in 2011 as a result of backwater effects due to numerous beaver dams. Despite these limitations, some general observations were made. In 2011, a layer of organic soil was observed at almost all locations. This varied in depth from very shallow (1-2 cm) to >30 cm. In

2013 many of the areas had inorganic soil deposition above the organic soils consisting predominantly of silt, but also sand, gravel, and cobble. When present, the inorganic soil depth was also measured. Inorganic soil depths varied from 1 cm to 15 cm. The inorganic soils were generally located closer to the creek, but at some transects appeared to be present along the entire length of the transect. Several areas also showed signs of erosion. Soils observed in 2014 were similar to what was observed in 2013. A thin layer of recently deposited organic soil was present at numerous locations above the inorganic soil deposition.

3.4 BUFFALO CREEK CROSS SECTION SURVEY (ESH-4)

KGS Group completed two geodetic topographic surveys of thirty cross sections on Buffalo Creek at the same location as the 30 cross sections that were initially surveyed in October 2011 prior to operation of the LSMEOC. The first survey was completed between July 3 and 7, 2013 after the 2011/2012 operation period. Details of the 2013 survey are provided in the Field. The second survey was completed between September 14 and 21, 2015 after the 2014/2015 operation period. Details of the 2013 and 2015 surveys, are provided in the Field Inspection Form (Task 16 – Topographic Cover Survey) attached in Appendix A3. Details of the 2011 survey are provided in Appendix H.

The purpose of the surveys was to compare pre and post operating conditions in Buffalo Creek. Plans showing the location of the cross sections are provided on Drawings 2 and 3. Comparisons between the cross sections are provided on Drawing 4.

To support the cross section survey comparison, GAIM imagery collected in 2011, 2013 and 2014 was also compared at the location of the cross sections. The comparison is provided in Appendix G.

3.4.1 Methodology

The topographic surveys were completed by multiple survey crews over a 5 to 7 day periods. Previously established horizontal and vertical controls were used where possible, and new control points were established as needed. Thirty transects were surveyed at approximately 500 m intervals along Buffalo Creek. Each transect extended a minimum of 100 m from the centerline of the creek. The upstream limit (Sta. 13+000) had been previously established based on accessibility as this station is near the edge of the bog area surrounding Big Buffalo Lake. The downstream limit of the survey investigation (Sta. 27+500) was approximately 150 m upstream of the confluence with the Dauphin River.

The surveys were completed in Universal Transverse Mercator (UTM) NAD83 CSRS and NAD 83 Zone 14 projection and using the CGVD28 Datum for the determination of all orthometric heights for elevation datum. The surveys were conducted using Global Positioning System (GPS) Real Time Kinematic (RTK) style surveying and a total station. Geodetic project control benchmarks were established using a GNSS L1/L2 GPS receiver to collect the static data, and static occupations on control networks were performed by L1/L2 dual constellation (GPS and GLONASS) receivers using post-processing procedures and confirmed using data from the Canadian Active Control System (CACS) available online. The absolute accuracy of the control networks were +/- 2.0 cm (horizontal) and +/- 2.0 cm (vertical) and the relative precision of each section was 1.0 cm.

At a few sections, field conditions were such that the surveyed cross sections could not follow the exact alignment of the 2011 survey. At those locations, new survey pins were installed, and the section alignments were re-established. This has been noted on the Drawings. The location of the survey controls and the cross section pins are shown on Drawing 3.

It should be noted that during the surveys, a layer of peat was present at the bottom of Buffalo Creek at many locations on either side of the riparian channel. Normal changes in the peat between survey events can result in slight differences when comparing cross sections. This has been noted on the Drawings.

3.4.2 Data Analysis and Results

The results of the comparison (Drawing 4) show that erosion has occurred in Buffalo Creek along most of its entire length. Typically, the erosion occurred within the main channel of Buffalo Creek, generally making it wider and deeper. There were also some localized areas that showed deposition. These were generally located in the overbanks, immediately adjacent to the main channel. Field observations indicated that the material deposited in these areas usually consisted of cobbles and gravels. As discussed in Section 3.3.2, deposition of fine inorganic material was also noted in the overbanks during the Vegetation Cover Surveys. Typically, this layer of deposition was relatively shallow (1 cm to 15 cm) and therefore is not necessarily visible on the Drawings when comparing cross sections.

Based on the survey comparisons, the total in-situ volume of material that was eroded from the channel was estimated to be approximately 60,000 m^3 between 2011 and 2013, and approximately 75,000 m^3 between 2013 and 2015. These quantities are approximated since interpolation was necessary between cross sections that were nearly 500m apart. For this analysis, it was assumed that each cross section was representative of conditions in the channel approximately 250m upstream and downstream. In reality, observations of conditions in the channel showed that the magnitude of erosion changes more frequently than at the 500 m intervals between sections. Therefore, it is likely that the actual volume of erosion would be different. As such, the 60,000 m^3 and 75,000 m^3 values should be used for comparison purposes only, and in conjunction with other results and modeling presented in this report.

3.5 DAUPHIN RIVER BATHYMETRIC SURVEY (ESH-3)

Operation of the LSMEOC may have caused an increase to the natural erosion and sedimentation processes along the lower reaches of the Dauphin River, causing an impact to fish habitat or navigation. To help determine the effects of the LSMEOC on fish habitat or navigation in the lower Dauphin River, bathymetric mapping was conducted from slightly upstream of the confluence with Buffalo Creek to downstream into Sturgeon Bay. KGS Group had previously performed bathymetric surveys in July 2011 (pre-operation) and in June 2012 during the 2011/2012 operation period. Additional surveys were completed in June/July 2013 and June 2014 (2012-2014 closure period), as well as August 2015 (post 2014/2015 operation). The extents of the surveys are shown on Drawing 5.

3.5.1 Methodology

Bathymetric surveys were conducted by KGS Group personnel using a sonar device mounted on the rear of a boat. A Lowrance HDS-8 chartplotter computer was used to power and log sonar data from a dual transducer configuration using survey grade narrow cone multi-beam sonar and a high frequency side scanner. The chartplotter was used to record a continuous log of sonar data from both transducers and stored the sonar traces on the chartplotter device. All sonar point locations were referenced by linking the sonar unit to a survey grade Topcon Global Positioning System (GPS) RTK receiver and positional data was recorded at an interval of 1 second. The objective of the survey was to capture changes in the river bottom over time. Survey data was collected along each river bank, the river centerline, and a crisscross pattern along the length of the Dauphin River. Survey controls were established for the bathymetric survey and are shown on Drawing 5. All controls established were set by completing a static GPS network for the entire project area and were referenced to known GPS 3D monuments set along PTH 6 from Lundar to Fairford and along PR 513.

The 2011 survey program was undertaken as part of the Emergency Reduction of Lake Manitoba and Lake St. Martin Water Levels project (KGS Group, 2014), along the entire Dauphin River during high flow conditions in the summer of the 2011 flood (July 1-4, 2011), prior to the operation of the Lake St. Martin Emergency Outlet Channel (LSMEOC). The survey was completed from the inlet of the Dauphin River at Lake St. Martin to the mouth of the river at Lake Winnipeg, adjacent to the Dauphin River First Nation community. All rapids and natural water drops were fully submerged at the time of the bathymetric survey and a continuous survey was able to be conducted along the complete reach length. Access along the banks of the river was limited during the survey. Most of the banks could not be captured as unknown flow conditions were occurring at the river's edge, as well as the presence of trees and submerged vegetation. Local knowledge of the area from the boat operator was essential for the safe navigation and capture of the Dauphin River bathymetry data. Details of the 2011 survey are provided in Appendix I

The 2012 survey program was also undertaken as part of the Emergency Reduction of Lake Manitoba and Lake St. Martin Water Levels project (KGS Group 2014). It extended from upstream of Buffalo Creek at Station 46+200 to the mouth of the river at Lake Winnipeg and included Sturgeon Bay, as shown on Drawing 5. The survey occurred on June 18-20, 2012 during operation of the LSMEOC, when river flows and water levels were significantly lower than in 2011. Details of the 2012 survey are provided in Appendix I.

The 2013 survey program extended from upstream of Buffalo Creek near Big Bend at Station 25+200 to the mouth of the river at Lake Winnipeg including Sturgeon Bay as shown on Drawing 5. The survey was initiated June 5-7, but as a result of the sonar transducer hitting a rock and needing repairs, the survey had to be completed at a later date. The survey crew returned July 22-23 to complete the survey. The portion upstream of the Buffalo Creek confluence was largely surveyed from June 5-7, while the portion downstream from the Buffalo Creek confluence was largely surveyed July 22-23. The purpose of this survey was to measure and record river bottom conditions after the closure of the LSMEOC, which occurred in November of 2012. Details of the 2013 survey are provided in the Field Inspection Form (Task 15 – Dauphin River Bathymetric Survey) attached in Appendix A4.

The 2014 survey program extended from upstream of Buffalo Creek at Station 25+600 to the mouth of the river at Lake Winnipeg including Sturgeon Bay as shown on Drawing 5. The survey occurred on June 17-21 to measure and record river bottom conditions immediately prior to the 2014/2015 operation of the LSMEOC. Details of the 2014 survey are provided in the Field Inspection Form (Task 15 – Dauphin River Bathymetric Survey) attached in Appendix A4.

The 2015 survey program extended from upstream of Buffalo Creek at Station 48+000 to the mouth of the river at Lake Winnipeg including Sturgeon Bay as shown on Drawing 5. The survey occurred on September 16 and 17, 2015 to measure and record river bottom conditions immediately after the 2014/2015 operation of the LSMEOC. Details of the 2015 survey are provided in the Field Inspection Form (Task 15 – Dauphin River Bathymetric Survey) attached in Appendix A4.

3.5.2 Data Analysis and Results

Bathymetric surveys were compiled and compared between years for the same length of the Dauphin River (i.e. from Lake Winnipeg to Station 46+250 or to the nearest station where data was available to be consistent with what was done in 2012). Differences between 2011 and 2012 have previously been provided in a letter report submitted to MIT in January 2013, which is enclosed in Appendix I. Bathymetric comparison between 2011 and 2013, between 2013 and 2014, and between 2014 and 2015 are provided in Drawings 6, 7, and 8 respectively. Riverbed elevation variations between the surveys are displayed using colour-coded depth ranges showing regions of increased and decreased riverbed elevation for the lower Dauphin River and Sturgeon Bay. Each set of drawings also show the locations of the sonar tracks, the river centreline and stationing, as well as surveyed water levels at various locations.

As discussed in Section 3.5.1, the position and elevation of each sonar depth sounding was obtained by Survey Grade GPS. The resultant accuracy for each discrete survey/sonar point was approximately 50 mm. From this survey data, a Digital Elevation Model (DEM) of the Dauphin River bathymetry was developed. Assumptions were made when developing the DEM, and interpolations were required between data points in the model. The accuracy of the DEM varied depending on the number of survey points collected and the proximity of the survey points between each other but was generally in the order of ± 0.5 m. Sudden changes in the riverbed or the presence of large cobbles and boulders were examples of conditions which may have affected the accuracy of the surface model. Caution should be exerted when comparing two different surfaces of the same area developed from two separate surveys, as the accuracy of the comparison is highly dependent on the proximity of the survey points collected between the two surveys. In locations of interpolations, the relative accuracy of the comparison was deemed to range between ± 0.5 m to 1.0 m.

However, an analysis of the raw data collected from one survey to the next, where individual survey points were located within 1m of each other, showed that differences in elevations obtained from bathymetric DEM comparisons were in the same range as the true differences of the individual survey points. Furthermore, the statistical distribution of points that showed riverbed increases and decreases in the DEM comparisons was consistent with the results of the comparisons of individual survey points. On this basis, the bathymetric DEMs were considered representative of the survey data for the purpose of determining overall trends, as is presented in this report.

As previously reported (Appendix I), the comparison in riverbed elevation from 2011 to 2012 showed some areas with increases and other areas with decreases in riverbed elevation. No obvious or consistent patterns in changes to the riverbed were observed; however, an area of degradation was noted at the mouth of the river (from just upstream of Station 52+000 to approximately 52+090) where a decrease in riverbed elevation greater than 1 m was observed. This area was only approximately 100 m long with bed elevations downstream from 52+100 to

53+000 generally higher in 2012 than in 2011. Likely, the formation of a hanging ice dam at this location in the winter during the 2011/2012 operation period would have resulted in high water velocities under the ice, which would have had the potential to erode the riverbed.

The comparisons between the 2011 and 2013 bathymetry (Drawing 6), between the 2013 and 2014 bathymetry (Drawing 7), and the 2014 and 2015 bathymetry (Drawing 8) also showed that there were areas that experienced an increase in the riverbed elevation while other areas experienced a decrease in riverbed elevation. However, no obvious or consistent patterns in changes to the riverbed were observed. The difference in elevation appeared to occur randomly throughout the surveyed portion of the Dauphin River and displayed normal variations in bed elevation that are expected when comparing DEMs generated from two separate surveys. In addition, there was no conclusive evidence of a correlation between erosion and deposition within this reach of river, and operation and closure periods of the LSMEOC.

As mentioned above, the apparent differences between elevations from one survey to the next were expected due to the interpolation between sonar tracks and relative accuracy of the DEMs generated. None-the-less, a trend towards an increase in riverbed elevation was likely a sign of sedimentation (or deposition of bed material) occurring in the Dauphin River and in Sturgeon Bay. Contrary, a trend towards a decrease in riverbed elevation was likely a sign that erosion was occurring.

Comparisons between the results of the bathymetric surveys and the results of the 2D hydraulic model on the Dauphin River, as well as to the sediment transport model are included in Sections 4.3 and 4.4 of the report.

4.0 HYDRAULIC MODELING

Operation of the LSMEOC System may have had impacts due to a change in sediment loads and sediment transport trends within the study area. As part of the hydraulic studies for the current project, MIT requested the development of sediment transport models to determine potential impacts as well as identify transport trends within the LSMEOC System. Modeling was conducted to analyze the extent and type of erosion and sedimentation that occurred within the study area, including Reach 1, Buffalo Lake, Buffalo Creek, Dauphin River, and Lake Winnipeg, to assess conditions pre, during and post-operation of the LSMEOC. To complete this analysis, the following three models were developed by KGS Group:

1. An **Empirical Model** was developed based on field measurements of TSS and turbidity and computed flows. The model included all reaches of the system and is documented in Section 4.1;
2. A **HEC-RAS Sediment Transport Model of Buffalo Creek** was developed based on surveyed cross sections of the creek and is documented in Section 4.2. The results were compared to the empirical model results as well as the Buffalo Creek Vegetation and Cross Section surveys discussed in Section 3.3 and 3.4; and
3. A **Two-Dimensional (2D) Hydraulic and Sediment Transport Model of the Dauphin River**, using DHI's MIKE 21 Hydrodynamic Model (HD) and the Mike 21 Mud Transport Module (MTM), was developed to analyze flow patterns on the Dauphin River, and to identify areas of potential deposition and/or scour along the river and in Sturgeon Bay. The Dauphin River flow pattern and sediment transport analyses are documented in Sections 4.3 and 4.4. The results of the 2D model were compared to the Dauphin River bathymetric surveys discussed in Section 3.5 as well as the results from the empirical and Buffalo Creek sediment transport models.

4.1 LSMEOC SEDIMENT TRANSPORT EMPIRICAL MODEL (STA-1)

To help quantify erosion through Reach 1, Buffalo Creek and the lower Dauphin River reaches of the LSMEOC System, an Empirical Model was developed as an Excel spreadsheet program. The model estimates cumulative volumes of suspended sediment transported in each reach (sediment inflow), and is indicative of the extent of erosion and deposition of smaller particles that occurred within each reach.

The empirical model was first developed in 2012, and has been documented in Emergency Reduction of Lake Manitoba & Lake St. Martin Water Levels: Sediment Transport Analysis LSM

Emergency Channel System Report (KGS Group 2012). The original model was updated and the modeling time period was extended for the current study. Modeling was completed for each reach of the LSMEOC and subdivided into the following three periods:

1. the 2011/2012 operation period;
2. the 2012-2014 closure period; and
3. and the 2014/2015 operation period.

4.1.1 Model Description

The empirical model combines discrete TSS concentration measurements, daily average TSS concentrations computed from turbidity meter data, and estimated discharges to calculate a daily volume of suspended sediment at a given location. Sediment concentrations were based on actual TSS measurements taken at various locations in the LSMEOC System prior to, during and post operation, and computed average daily TSS using the turbidity data collected by the long-term insitu turbidity meter loggers as described in Section 3.2. Discharges along the system were estimated based on a combination of observations, measurements, flow records and computations, as described in Section 3.1.

The empirical model utilized an average soil density value of 1400 kg/m³. The insitu or pre-excavation unit weight of the soil material within the Reach 1 Channel is estimated to range between 2000 kg/m³ and 2200 kg/m³ based on observations and engineering judgment. The post-construction surface within the limits of the Reach 1 Channel was disturbed from the excavation process, resulting in a loose and more exposed material that would be more vulnerable to riverine erosion than the insitu intact material. It is difficult to estimate a representative insitu density that would account for this disturbance; however, the unit weight that could be representative of this disturbed material is anticipated to be variable and in the range of 1100 to 1800 kg/m³, based on previous experience and engineering judgment. A sensitivity analysis was carried out to evaluate the potential impacts from this variability, and the selected value of 1400 kg/m³ is believed to be conservative.

Two monitoring locations were selected along each reach for the analysis. One location was selected near or at the upstream end to capture "baseline" conditions prior to entering the reach.

The second location was selected near the downstream end to capture "exit" conditions prior to exiting the reach. The net volume balance within a reach was assumed to be the difference in suspended sediment volume between the exit and the baseline conditions. Drawing 1 shows the location of these monitoring locations.

However, exit conditions have not been reported on the Dauphin River since flows from Buffalo Creek and the Dauphin River were not entirely mixing together before entering Sturgeon Bay and due to the variability that existed in the suspended sediment sampling location. Rather, an assessment of the sediment transport processes and of the transport of suspended sediment in the lower Dauphin River was carried out based on the 2-dimensional hydraulic model described in Sections 4.3 and 4.4.

To compare the actual effects of the operation of the LSMEOC on the amount of suspended sediment released from the system, cumulative suspended volumes were also calculated using the computed daily flows for the Dauphin River and Buffalo Creek assuming the LSMEOC had not been operated. As discussed in Section 3.1, the flows in the upper Dauphin River would have been greater if the LSMEOC had not been operated, therefore, transporting a greater volume of suspended sediment originating from Lake St. Martin. The comparison of the cumulative volumes downstream of the confluence of Buffalo Creek and the Dauphin River with and without operation of the LSMEOC provides the best estimate of the actual effects of the entire LSMEOC system on the volume of suspended sediment released at the exit of Buffalo Creek.

Reach 1

Baseline conditions in Reach 1 were based on TSS concentrations measured in Lake St. Martin (LSM1). During operation of Reach 1, it was assumed in the model that the TSS concentrations measured in the lake were representative of baseline conditions at the entrance of Reach 1. However, under normal conditions, the TSS concentrations measured in a standing body of water (i.e. Lake St. Martin) are generally lower than those in a moving body of water (i.e. Reach 1) and; therefore, this assumption was deemed conservative for this analysis.

Prior to January 17, 2012, TSS concentrations in Reach 1 were based on measurements taken at monitoring location EC1 that is situated near the midpoint between the Reach 1 inlet and

Buffalo Lake bog. Data was not collected at the end of Reach 1 at monitoring location EC2 and EC3 until this date and, therefore, could not be used in the model. As a result, the net suspended sediment volume balance calculated in the model up to this point may not be completely indicative of what occurred throughout Reach 1 in 2011/2012. However, since Buffalo Creek is located downstream of Reach 1, any potential erosion or deposition occurring between monitoring location EC1 and EC2 would contribute to the baseline measurements on Buffalo Creek and is captured elsewhere in the model.

After January 17, 2012, exit conditions in Reach 1 were based on measurements taken at monitoring location EC2 that is situated at the end of the Reach 1 Emergency Channel. Measured and estimated daily concentrations and the estimated balance of suspended sediment volumes after this date are therefore indicative of actual conditions in Reach 1. As discussed in Section 3.2, a turbidity logger was installed at this location in June 2014. Average daily TSS values calculated from the turbidity logger data, were used at this location after this date, and were supplemented with the measured TSS values as required.

Buffalo Creek

Prior to January 17, 2012, conditions near the upstream end of Buffalo Creek were based on measurements taken at monitoring location BC2 that is situated approximately 2 km downstream of the Buffalo Creek Inlet. Data was not continuously collected at monitoring location BC1 until this date and, therefore, could not be used to model conditions at the upstream end of Buffalo Creek. As a result, the net suspended sediment volume balance calculated in the model up to this point may not be completely indicative of what occurred throughout Buffalo Creek. However observations made after January 17 showed that conditions at BC2 were similar to those at BC1. As such, it was likely that conditions observed at BC2 were representative of baseline conditions in Buffalo Creek.

After January 17, 2012, conditions at the upstream end of Buffalo Creek were based on measurements taken at monitoring location BC1. Measured and estimated daily concentrations and estimated daily volumes after this date are indicative of actual conditions in the entire creek. As discussed in Section 3.2, a turbidity logger was installed at this location in June 2014. Average daily TSS values calculated from the turbidity logger data, were used at this location after this date, and were supplemented with the measured TSS values as required.

Exit conditions in Buffalo Creek were based on measurements taken at monitoring location BC3 and BC-TM. BC3 is situated on Buffalo Creek immediately upstream of the confluence with the Dauphin River, while BC-TM is situated an additional 2 km upstream of BC3 (to avoid the backwater effects of the Dauphin River for hydrometric data collection). BC-TM was used once the turbidity meter was installed on May 14, 2013. Average daily TSS values calculated from the turbidity logger data, as discussed in Section 3.2, were used at this location, and were supplemented with the measured TSS values as required.

Lower Dauphin River

Baseline conditions in the Dauphin River during and post operation of the LSMEOC System were based on measurements taken at monitoring location DR1 and DR-TM. DR1 was situated in the nearest accessible open water location on the south shore of the Dauphin River, approximately 500 m upstream of the confluence of Buffalo Creek and the Dauphin River. DR-TM is located on the north shore of the Dauphin River, approximately 200 m upstream of the confluence of Buffalo Creek and the Dauphin River. DR-TM was used once the turbidity meter was installed on May 14, 2013. Average daily TSS values calculated from the turbidity logger data, as discussed in Section 3.2, were used at this location and were supplemented with the measured TSS values as required.

4.1.2 Model Results – 2011/2012 Operation

Reach 1

Measured and interpolated daily TSS concentrations in Reach 1 during the 2011/2012 operation are provided in Figure 4.1-1. The calculated daily and cumulative volumes of suspended sediment inflow in Reach 1 during the 2011/2012 operation period are provided in Figures 4.1-2 and 4.1-3, respectively.

FIGURE 4.1-1
MEASURED AND INTERPOLATED DAILY TSS CONCENTRATION IN REACH 1 DURING 2011/2012 OPERATION

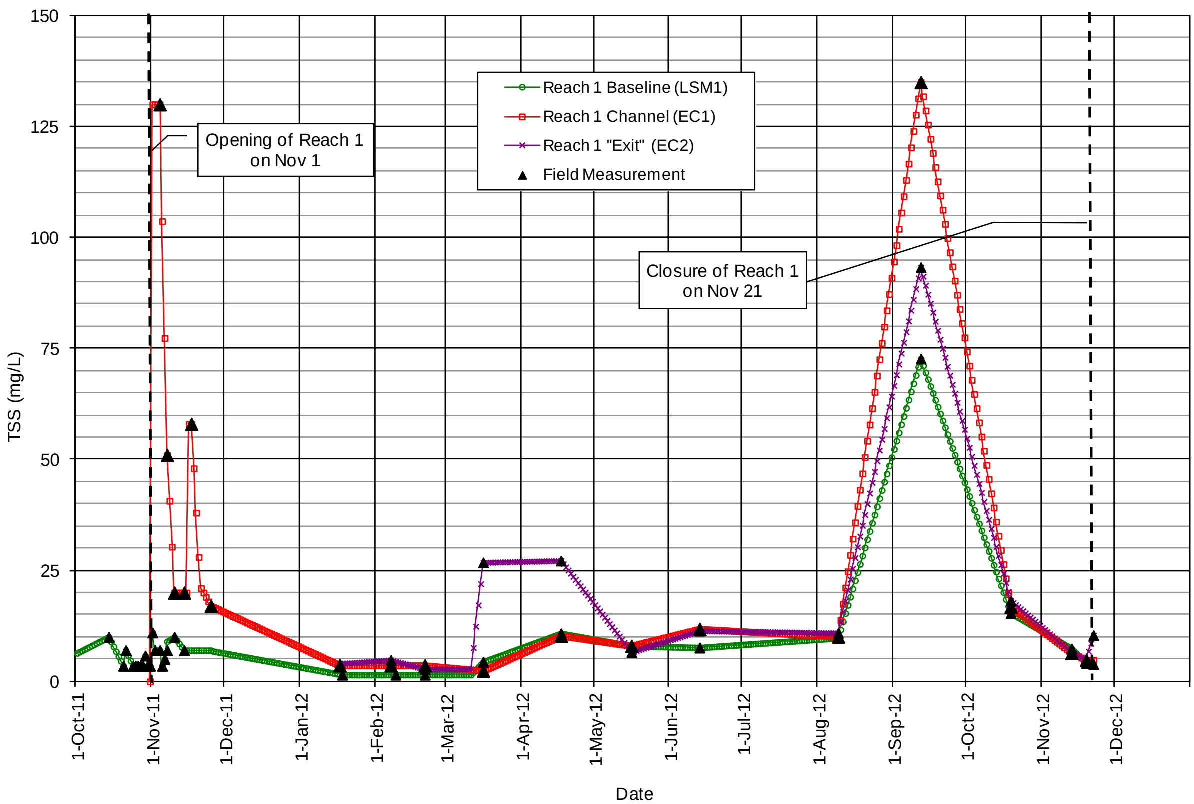
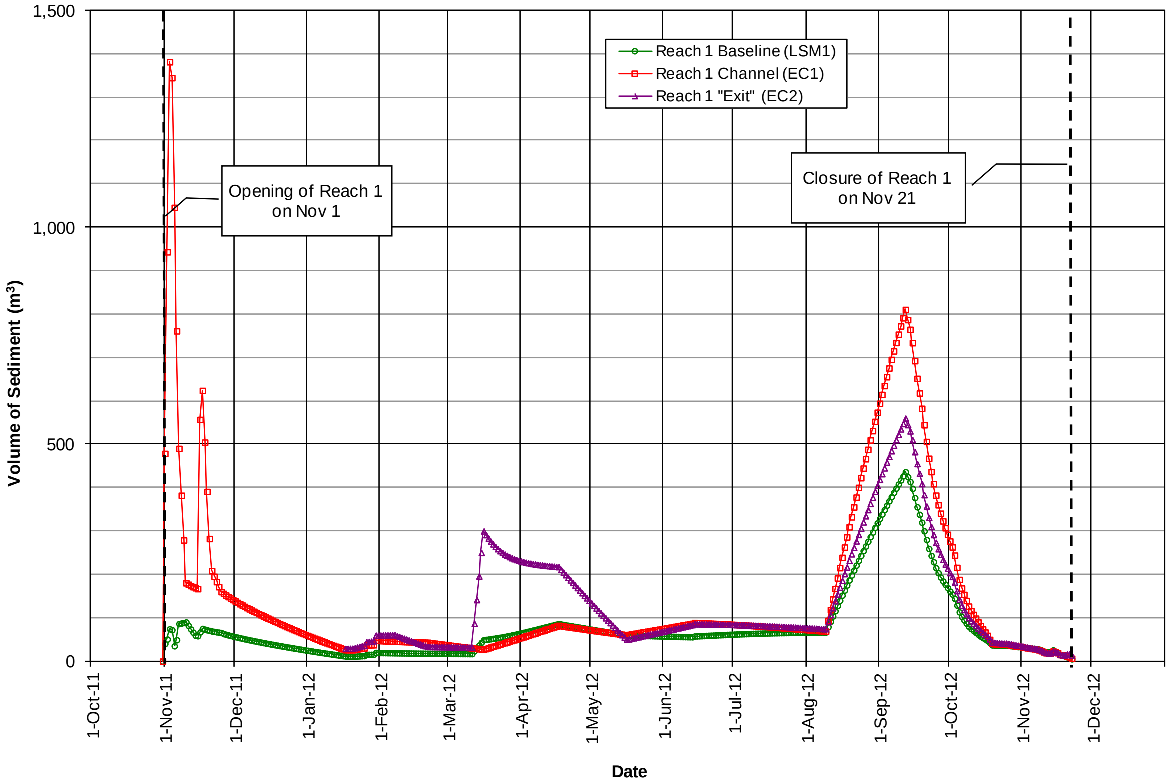
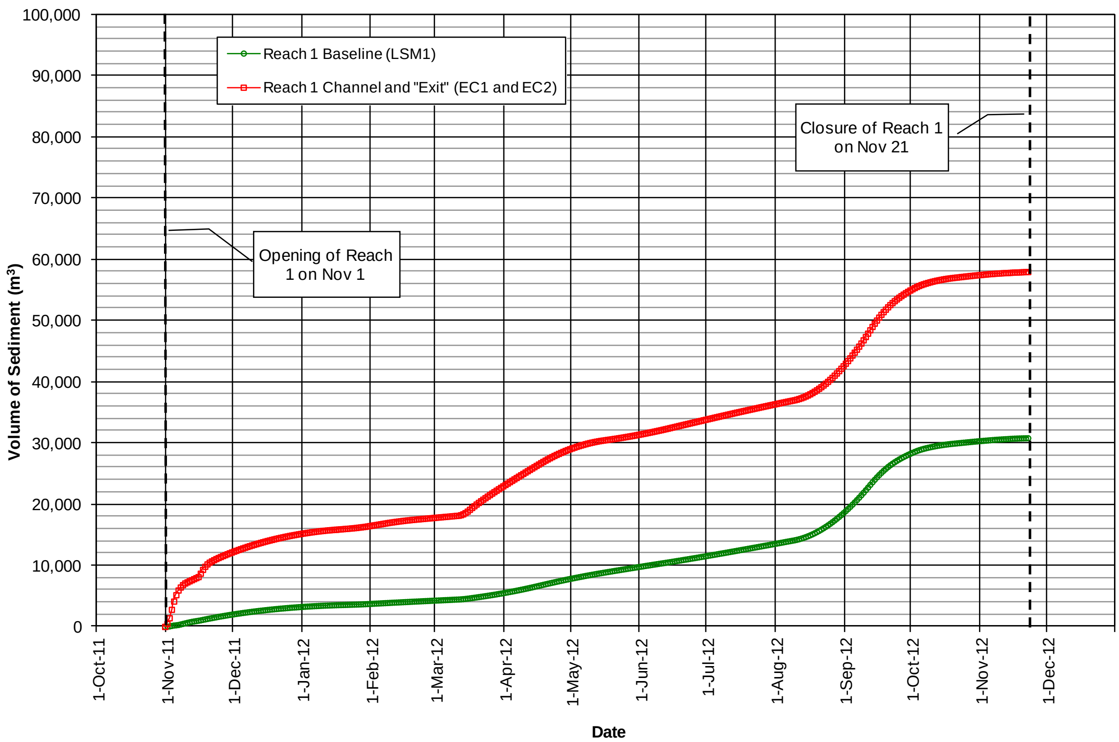


FIGURE 4.1-2
ESTIMATED DAILY SUSPENDED SEDIMENT VOLUMES IN REACH 1 DURING 2011/2012 OPERATION



KGS GROUP

FIGURE 4.1-3
ESTIMATED CUMULATIVE SUSPENDED SEDIMENT VOLUMES IN REACH 1 DURING 2011/2012 OPERATION



The suspended sediment volume balance calculated in Reach 1 during the 2011/2012 operation period is summarized in Table 4.1-1.

TABLE 4.1-1
REACH 1 SUSPENDED SEDIMENT VOLUME BALANCE DURING 2011/2012 OPERATION

Description	Cumulative Sediment Volume (m^3)
Baseline	30,900
Channel or "Exit"	58,000
Net Total	27,100

Buffalo Lake Bog

Based on the Reach 1 Channel or "Exit" conditions and the Buffalo Creek Baseline conditions, the suspended sediment volume balance calculated in the Buffalo Lake Bog area during the 2011/2012 operation period is summarized in Table 4.1-2.

TABLE 4.1-2
BUFFALO LAKE BOG SUSPENDED SEDIMENT VOLUME BALANCE DURING 2011/2012 OPERATION

Description	Cumulative Sediment Volume (m^3)
Reach 1 Channel or "Exit"	58,000
Buffalo Creek Baseline or near Entrance	17,000
Net Total	-41,000

Buffalo Creek

Measured and interpolated daily TSS concentrations in Buffalo Creek during operation are provided in Figure 4.1-4. The calculated daily and cumulative volumes of suspended sediment in Buffalo Creek during operation are provided in Figures 4.1-5 and 4.1-6, respectively.

FIGURE 4.1-4
MEASURED AND INTERPOLATED DAILY TSS CONCENTRATION IN BUFFALO CREEK DURING 2011/2012 OPERATION

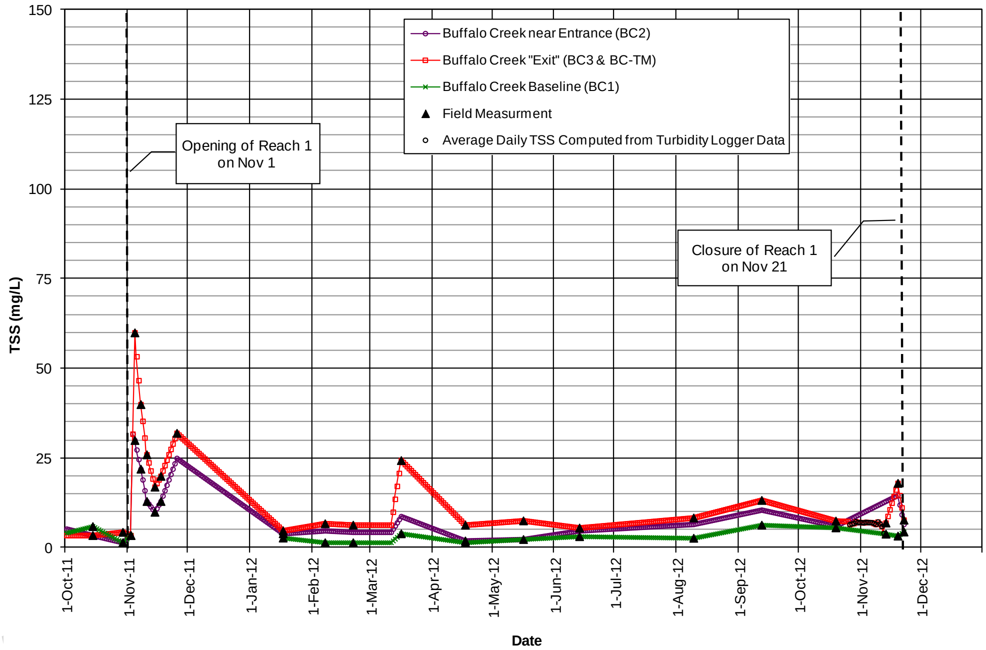


FIGURE 4.1-5
ESTIMATED DAILY SUSPENDED SEDIMENT VOLUME IN BUFFALO CREEK DURING 2011/2012 OPERATION

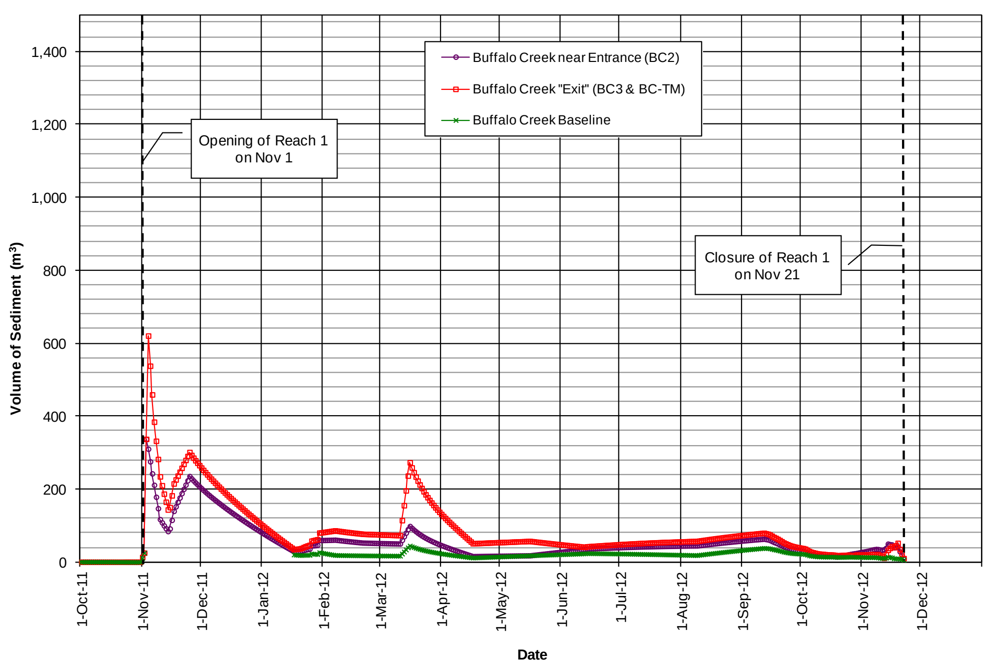
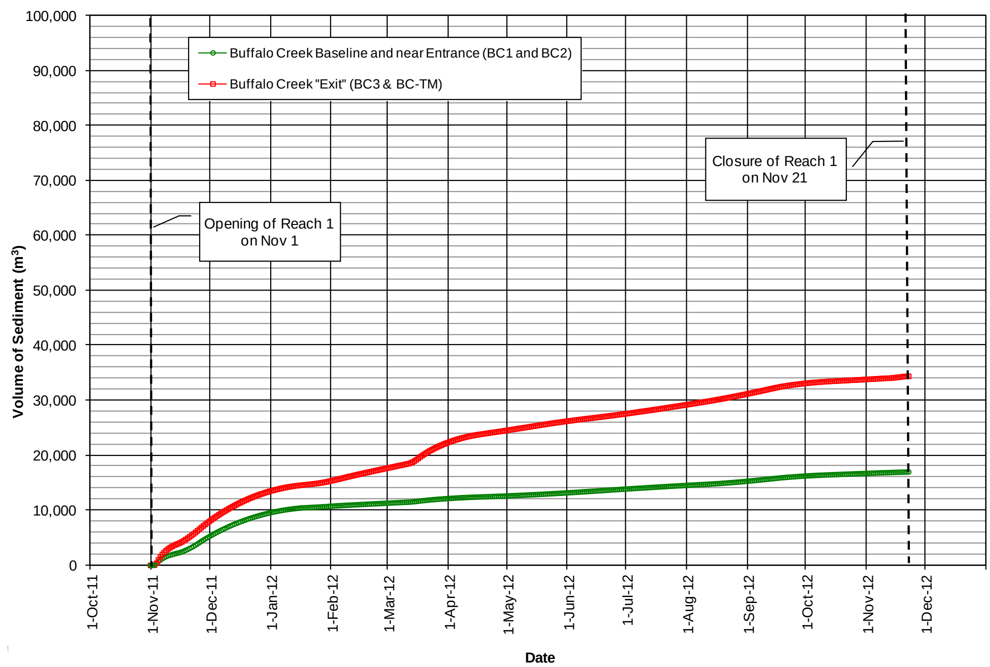


FIGURE 4.1-6
ESTIMATED CUMULATIVE SUSPENDED SEDIMENT VOLUME IN BUFFALO CREEK DURING 2011/2012 OPERATION



The suspended sediment volume balance calculated in Buffalo Creek during operation is summarized in Table 4.1-3.

TABLE 4.1-3
BUFFALO CREEK SUSPENDED SEDIMENT VOLUME BALANCE DURING 2011/2012 OPERATION

Description	Cumulative Sediment Volume (m^3)
Baseline or near Entrance	17,000
Exit	34,400
Net Total	17,400

Reach 1 to Buffalo Creek

The suspended sediment volume balance which occurred within the LSMEOC System from the entrance of Reach 1 to the exit of Buffalo Creek during the 2011/2012 operation is summarized in Table 4.1-4.

TABLE 4.1-4
LSMEOC FROM REACH 1 (ENTRANCE) TO BUFFALO CREEK (EXIT) – SUSPENDED SEDIMENT VOLUME BALANCE DURING 2011/2012 OPERATION

Description	Cumulative Sediment Volume (m^3)
Reach 1 Baseline	30,900
Buffalo Creek Exit	34,400
Net Total	3,500

Lower Dauphin River

Measured and interpolated daily TSS concentrations during the 2011/2012 operation are also available for the lower Dauphin Reach upstream of the confluence with Buffalo Creek and are shown in Figure 4.1.7. Suspended sediment volumes computed for this location are shown in Figure 4.1-8.

FIGURE 4.1-7
MEASURED AND INTERPOLATED DAILY TSS CONCENTRATION IN LOWER DAUPHIN RIVER DURING 2011/2012 OPERATION

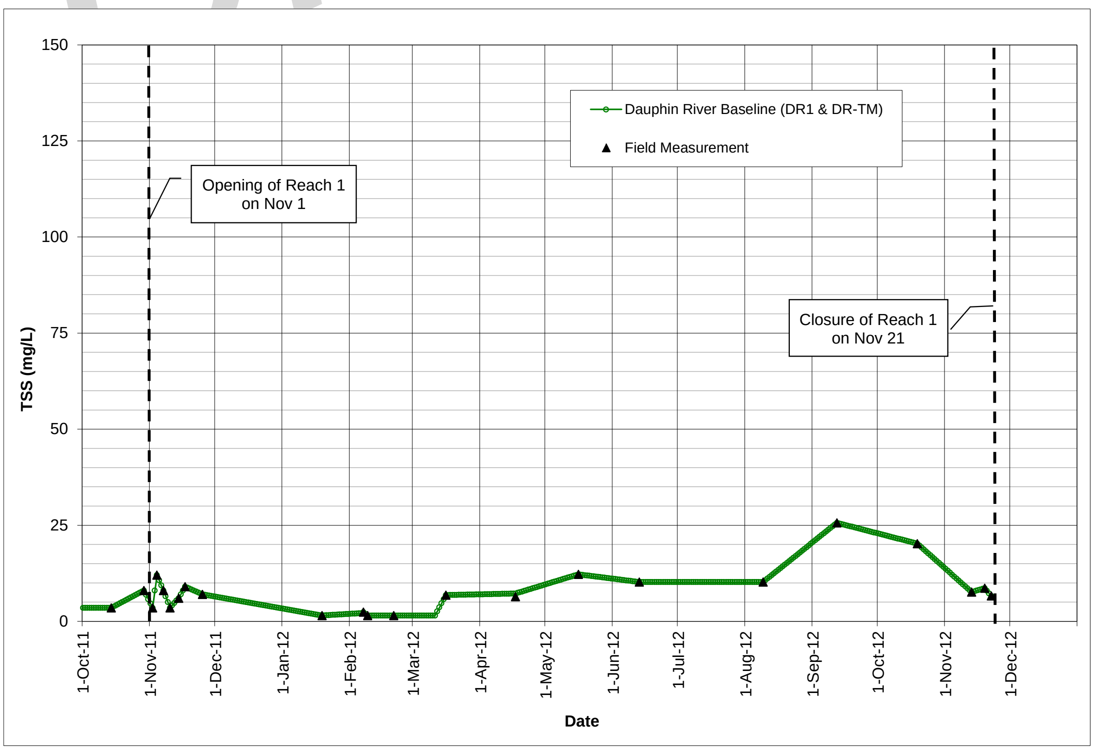
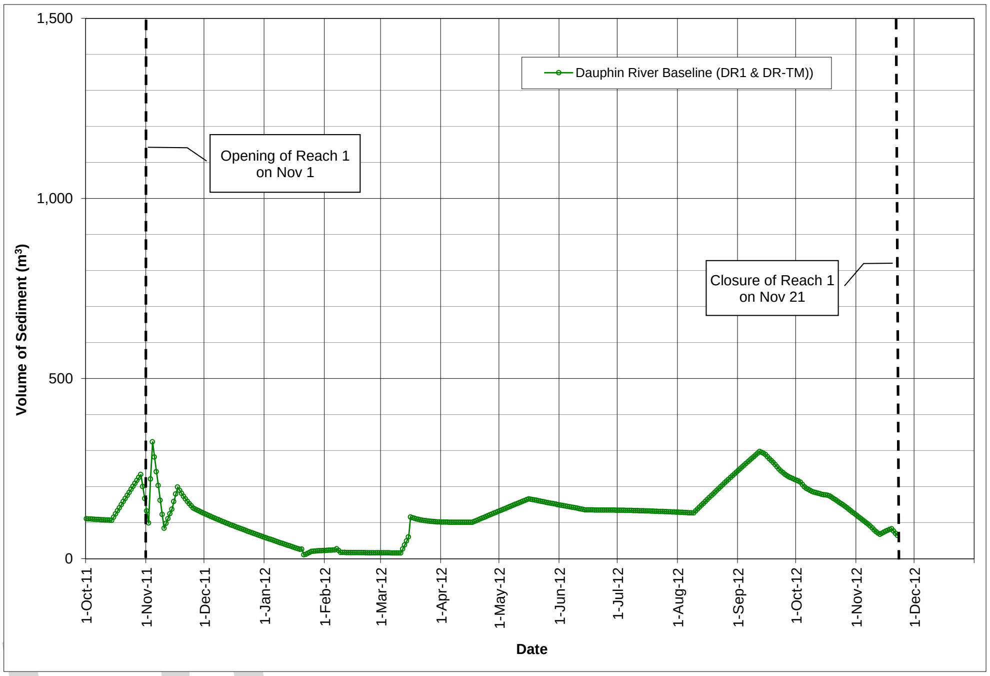
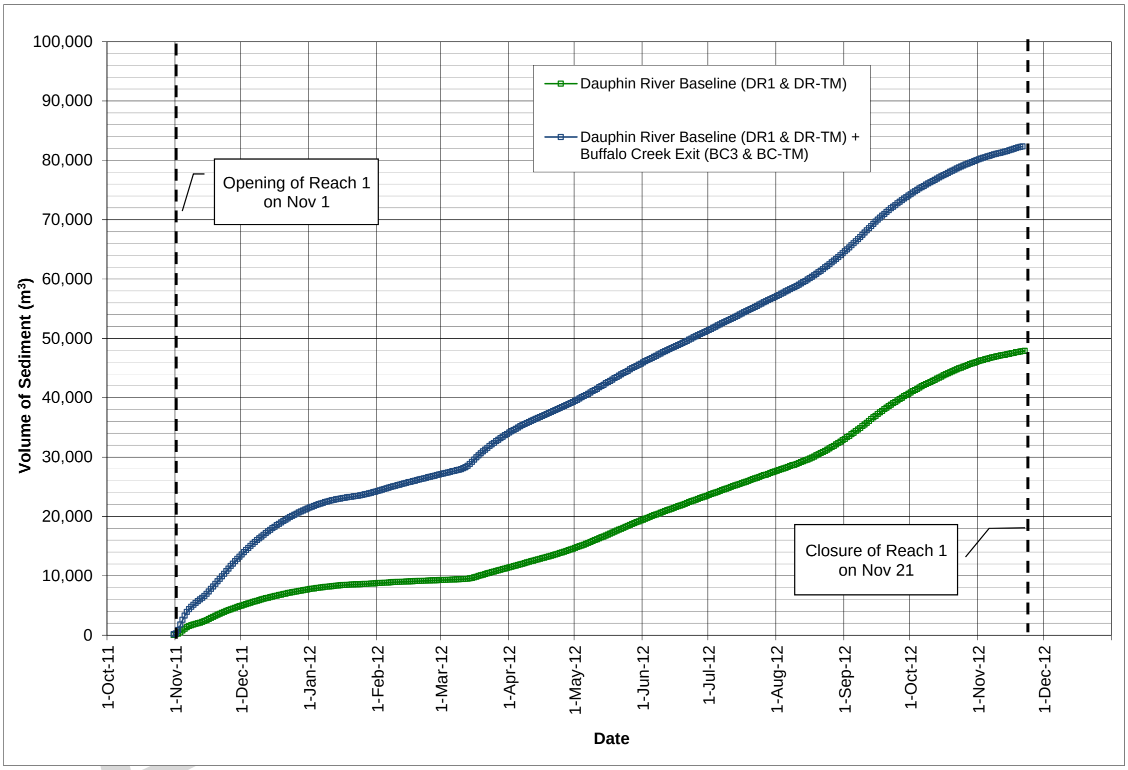


FIGURE 4.1-8
ESTIMATED DAILY SUSPENDED SEDIMENT VOLUME
IN LOWER DAUPHIN RIVER DURING 2011/2012 OPERATION



Cumulative suspended sediment volumes were computed upstream of the confluence with Buffalo Creek, and are shown in Figure 4.1-9. Also included on the figure are values that combine both the Buffalo Creek Exit and Dauphin River Baseline as a single sediment inflow volume to the lower Dauphin River. The combined volumes allow for a comparison of conditions with and without operation of the LSMEOC and provide the best estimate of the actual effects of the entire LSMEOC system on the volume of suspended sediment released at the exit of Buffalo Creek.

FIGURE 4.1-9
ESTIMATED CUMULATIVE SUSPENDED SEDIMENT VOLUME IN LOWER DAUPHIN RIVER DURING 2011/2012 OPERATION



The cumulative combined volume of suspended sediment in the lower Dauphin River during operation is summarized in Table 4.1-5.

TABLE 4.1-5
LOWER DAUPHIN RIVER CUMULATIVE SEDIMENT VOLUME DURING 2011/2012 OPERATION

Description	Cumulative Sediment Volume (m^3)
Dauphin River Baseline	47,800
Buffalo Creek Exit	34,400
Combined Dauphin River Baseline & Buffalo Creek Exit	82,200

To assess the effects of operation of the LSMEOC on the volume of suspended sediment in the Dauphin River downstream of Buffalo Creek, the same volume was computed using the empirical model with Dauphin River flows obtained from the routing model assuming the

LSMEOC had not been operated. The cumulative sediment inflow at the Buffalo Creek Exit would have been substantially less, since the upper Dauphin River flows would have been significantly greater without operation of the emergency channel. However, the cumulative volume of suspended sediment on the Dauphin River upstream of Buffalo Creek would have been significantly more. The comparison of cumulative combined volume of suspended sediment in the lower Dauphin River with and without the LSMEOC is summarized in Table 4.1-6. The net total is the estimated volume of suspended sediment increase that the operation of the LSMEOC contributed to the Dauphin River downstream of the confluence with Buffalo Creek.

TABLE 4.1-6
LOWER DAUPHIN RIVER CUMULATIVE SEDIMENT VOLUME WITH AND WITHOUT OPERATION OF THE LSMEOC FOR 2011/2012 OPERATION PERIOD

Description	Cumulative Sediment Volume (m^3)
With Operation of the LSMEOC	82,200
Without Operation of the LSMEOC	73,300
Net Increase	8,900

4.1.3 Model Results – Closure Period (2012-2014)

Reach 1 and Buffalo Lake Bog

There was no flow in Reach 1 during the closure period (2012-2014) and therefore the empirical model did not apply for this period along Reach 1 and the Buffalo Lake Bog area.

Buffalo Creek

Measured and interpolated daily TSS concentrations in Buffalo Creek during the closure period (2012-2014) are provided in Figure 4.1-10. The calculated daily and cumulative volumes of suspended sediment in Buffalo Creek are provided in Figures 4.1-11 and 4.1-12, respectively.

FIGURE 4.1-10
MEASURED AND INTERPOLATED DAILY TSS CONCENTRATION IN BUFFALO CREEK DURING CLOSURE PERIOD (2012-2014)

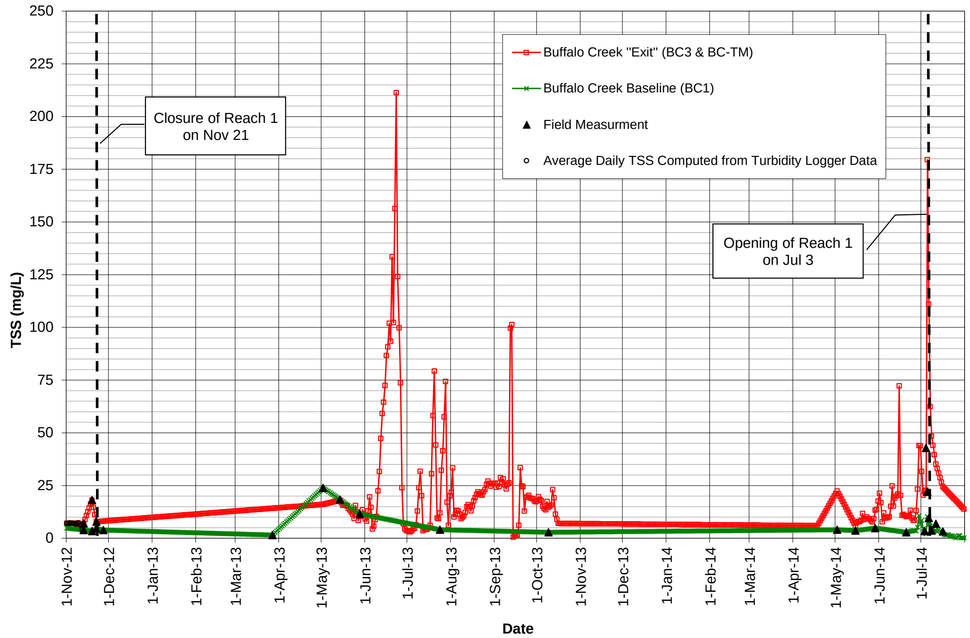


FIGURE 4.1-11
ESTIMATED DAILY SUSPENDED SEDIMENT VOLUMES IN BUFFALO CREEK DURING CLOSURE PERIOD (2012-2014)

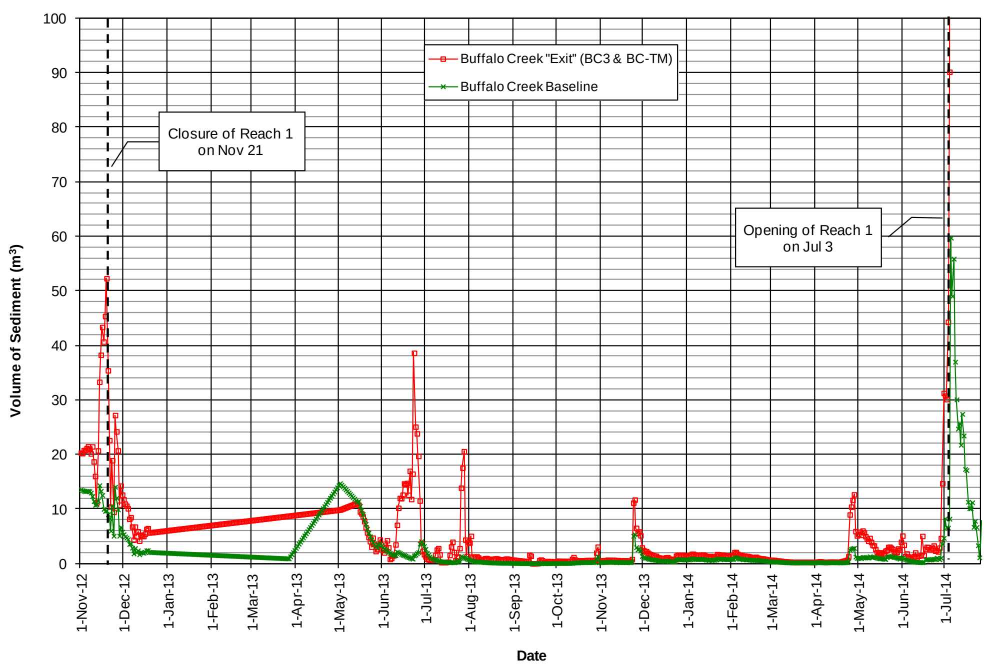
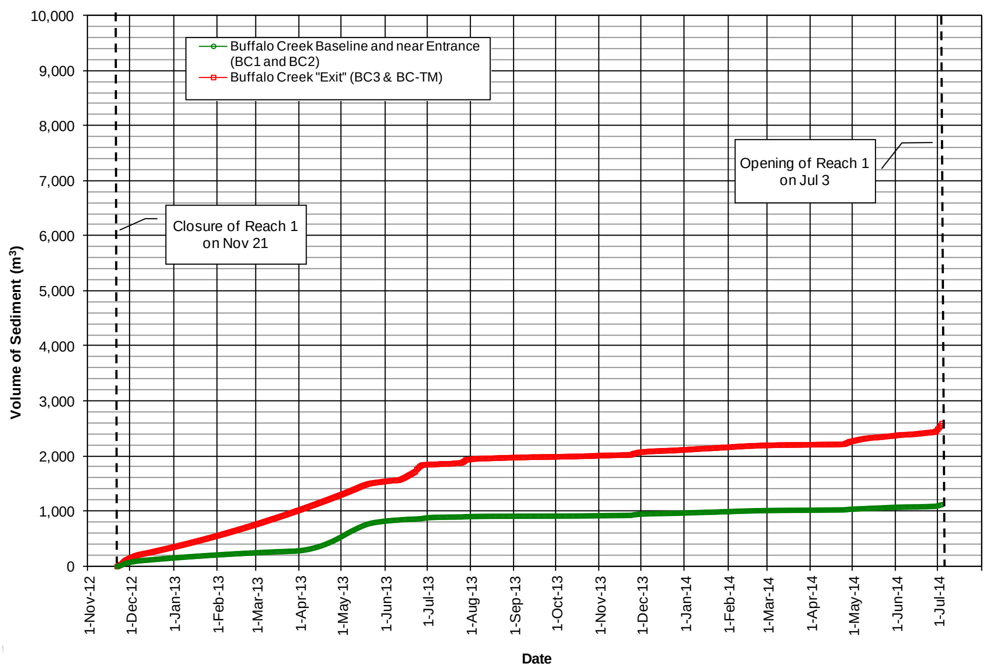


FIGURE 4.1-12
ESTIMATED CUMULATIVE SUSPENDED SEDIMENT VOLUMES IN BUFFALO CREEK DURING CLOSURE PERIOD (2012-2014)



The balance of suspended sediment volumes calculated in Buffalo Creek during the closure period (2012-2014) is summarized in Table 4.1-7 below.

TABLE 4.1-7
BUFFALO CREEK SUSPENDED SEDIMENT VOLUME BALANCE DURING CLOSURE PERIOD (2012-2014)

Description	Cumulative Sediment Volume (m^3)
Baseline or near Entrance	1,100
Exit	2,600
Net Total	1,500

Lower Dauphin River

Measured and interpolated daily TSS concentrations in the lower Dauphin River during the closure period (2012-2014) are provided in Figure 4.1-13. The daily suspended sediment volumes calculated in the lower Dauphin River during the closure period (2012-2014) are provided in Figures 4.1-14.

FIGURE 4.1-13
MEASURED AND INTERPOLATED DAILY TSS CONCENTRATION IN LOWER DAUPHIN RIVER DURING CLOSURE PERIOD (2012-2014)

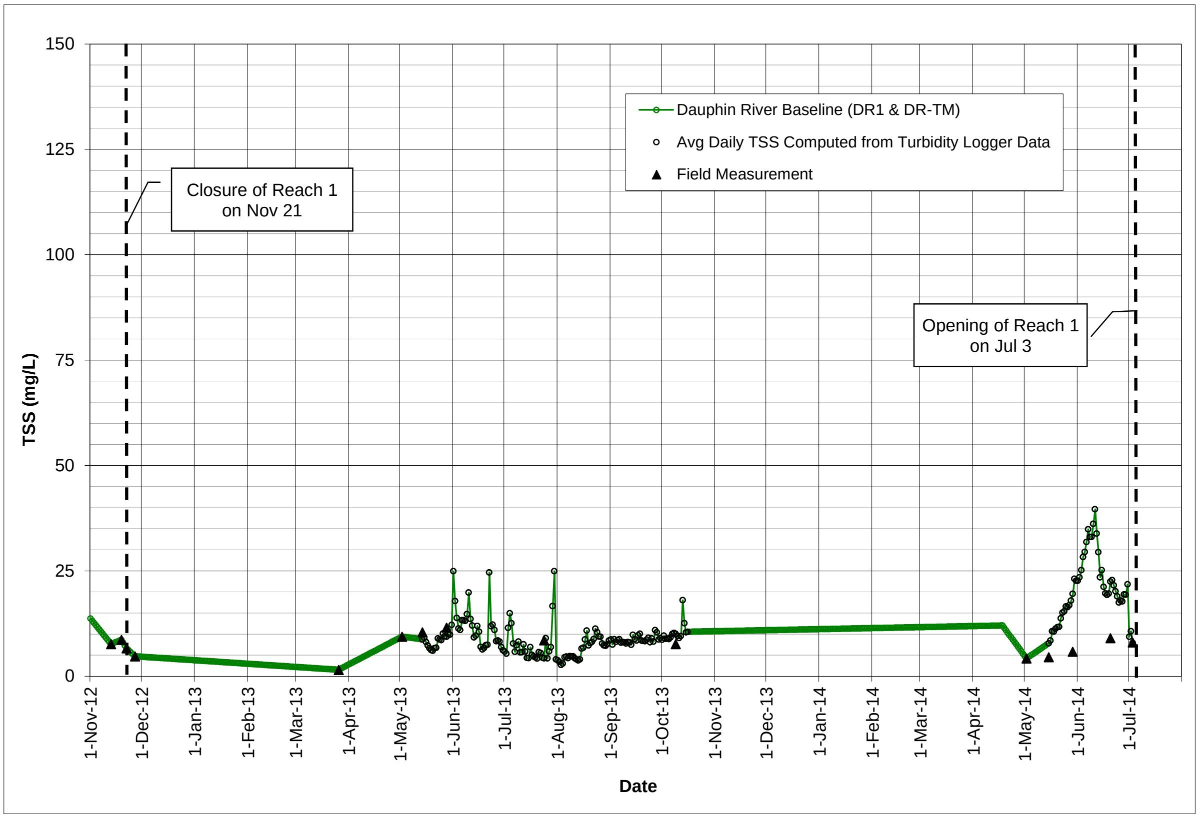
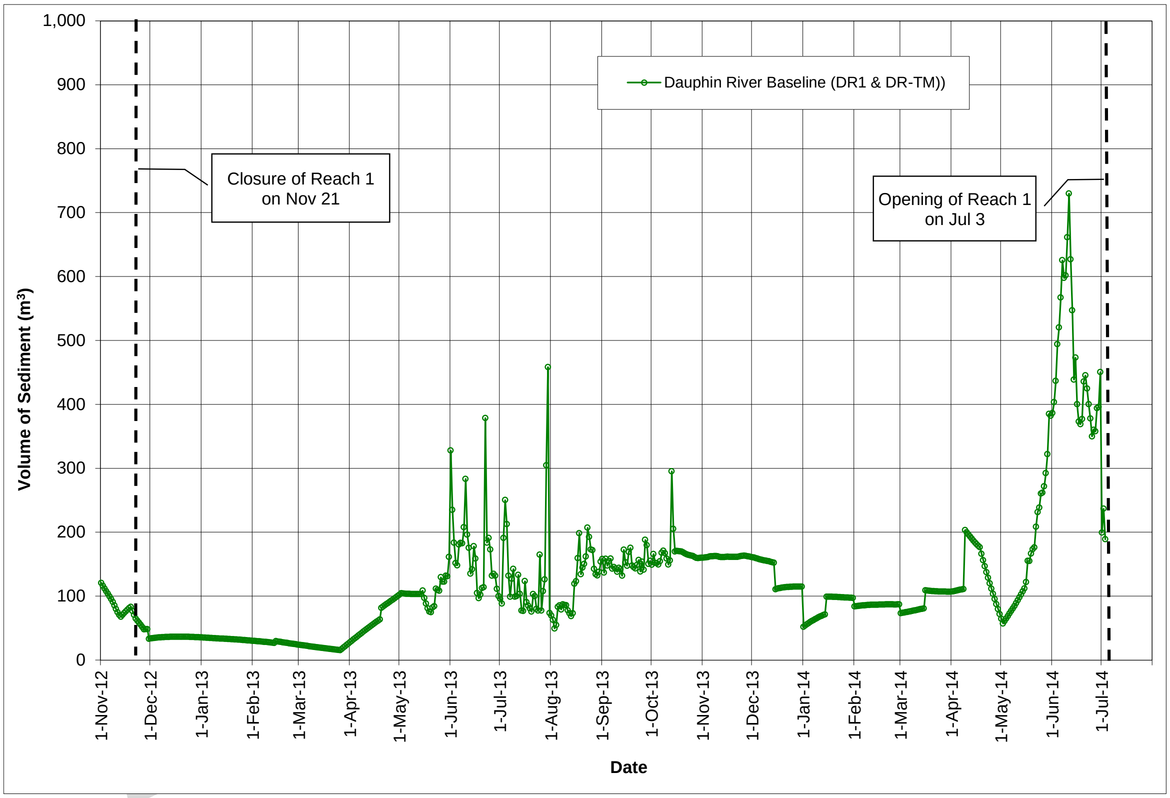
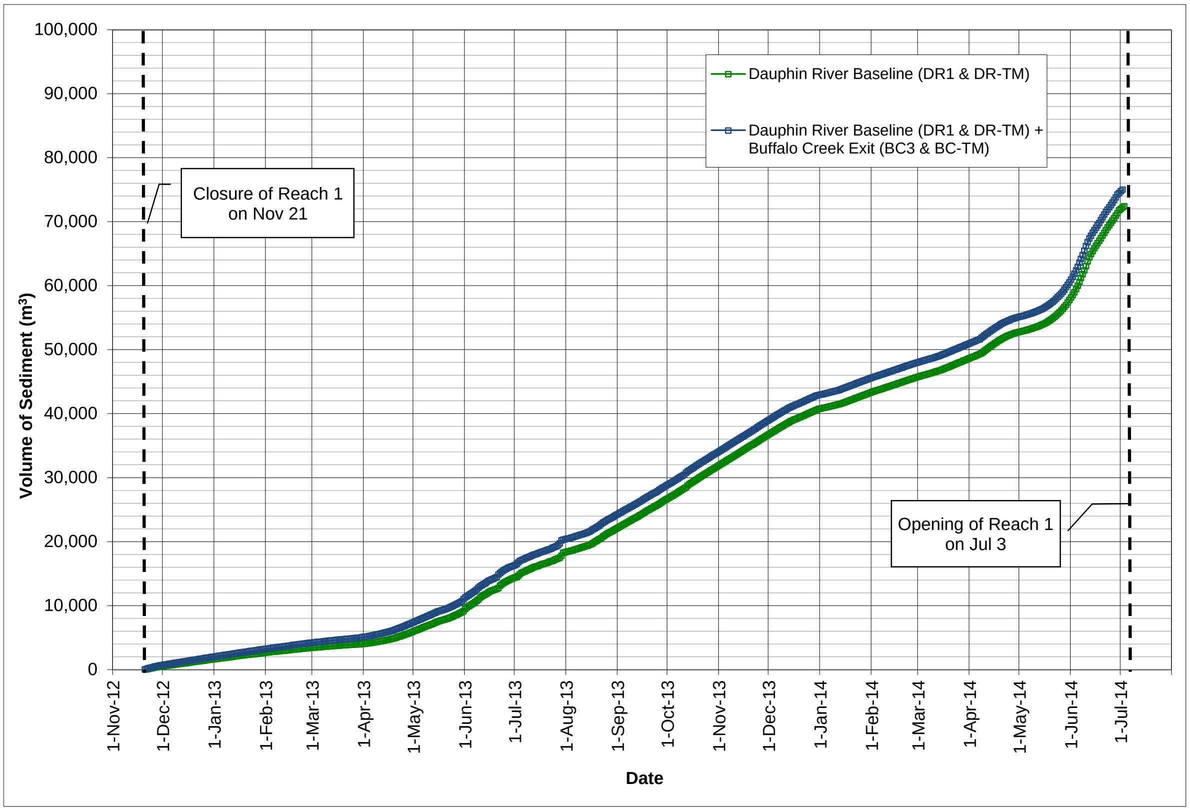


FIGURE 4.1-14
ESTIMATED DAILY SUSPENDED SEDIMENT VOLUMES IN LOWER DAUPHIN RIVER DURING CLOSURE PERIOD (2012-2014)



Cumulative suspended sediment volumes in the Dauphin River were computed upstream of the confluence with Buffalo Creek, and are shown in Figure 4.1-15. Also included on the figure are values that combine both, Buffalo Creek Exit and Dauphin River Baseline as a single sediment inflow volume to the lower Dauphin River. The combined volumes allows for a comparison of conditions with and without operation of the LSMEOC and provides the best estimate of the actual effects of the entire LSMEOC system on the volume of suspended sediment released at the exit of Buffalo Creek.

**FIGURE 4.1-15
ESTIMATED CUMULATIVE SUSPENDED SEDIMENT VOLUMES
IN LOWER DAUPHIN RIVER DURING CLOSURE PERIOD (2012-2014)**



The cumulative combined volume of suspended sediment in the lower Dauphin River during the closure period is summarized in Table 4.1-8.

**TABLE 4.1-8
LOWER DAUPHIN RIVER CUMULATIVE VOLUME OF SUSPENDED SEDIMENT
DURING CLOSURE PERIOD (2012-2014)**

Description	Cumulative Sediment Volume (m^3)
Dauphin River Baseline	72,200
Buffalo Creek Exit	2,600
Combined Dauphin River Baseline & Buffalo Creek Exit	74,800

To assess the effects of the operation of the LSMEOC on the volume of suspended sediment in the Dauphin River downstream of Buffalo Creek, the same volume was computed using the empirical model with Dauphin River flows obtained from the routing model assuming the LSMEOC had not been operated. In the model it was conservatively assumed that without operation of the LSMEOC, flows in Buffalo Creek during the closure period would have been negligible. The comparison of cumulative combined volume of suspended sediment in the lower Dauphin River with and without the LSMEOC is summarized in Table 4.1-9. The net total is the estimated volume of suspended sediment increase that the operation of the LSMEOC contributed to the Dauphin River downstream of the confluence with Buffalo Creek.

TABLE 4.1-9
LOWER DAUPHIN RIVER CUMULATIVE SEDIMENT VOLUME WITH AND WITHOUT OPERATION OF THE LSMEOC FOR 2011/2012 OPERATION PERIOD

Description	Cumulative Sediment Volume (m^3)
With Operation of the LSMEOC	74,800
Without Operation of the LSMEOC	72,600
Net Increase	2,200

4.1.4 Model Results – 2014/2015 Operation

Reach 1

Measured and interpolated daily TSS concentrations in Reach 1 during 2014/2015 operation are provided in Figure 4.1-16. The calculated daily and cumulative volumes of suspended sediment inflow in Reach 1 during operation are provided in Figures 4.1-17 and 4.1-18, respectively.

FIGURE 4.1-16
MEASURED AND INTERPOLATED DAILY TSS CONCENTRATION IN REACH 1 DURING 2014/2015 OPERATION

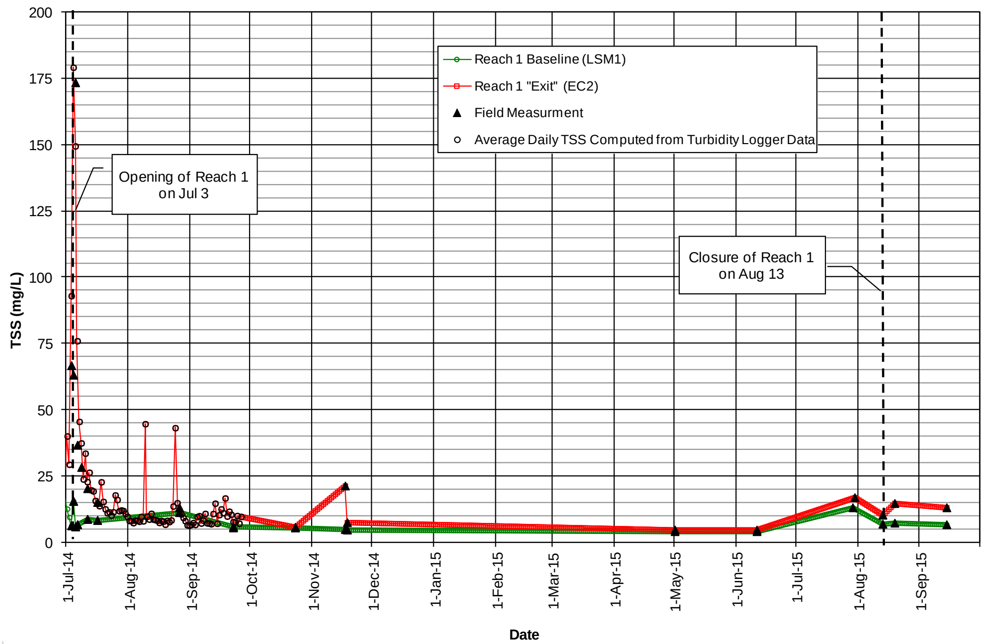
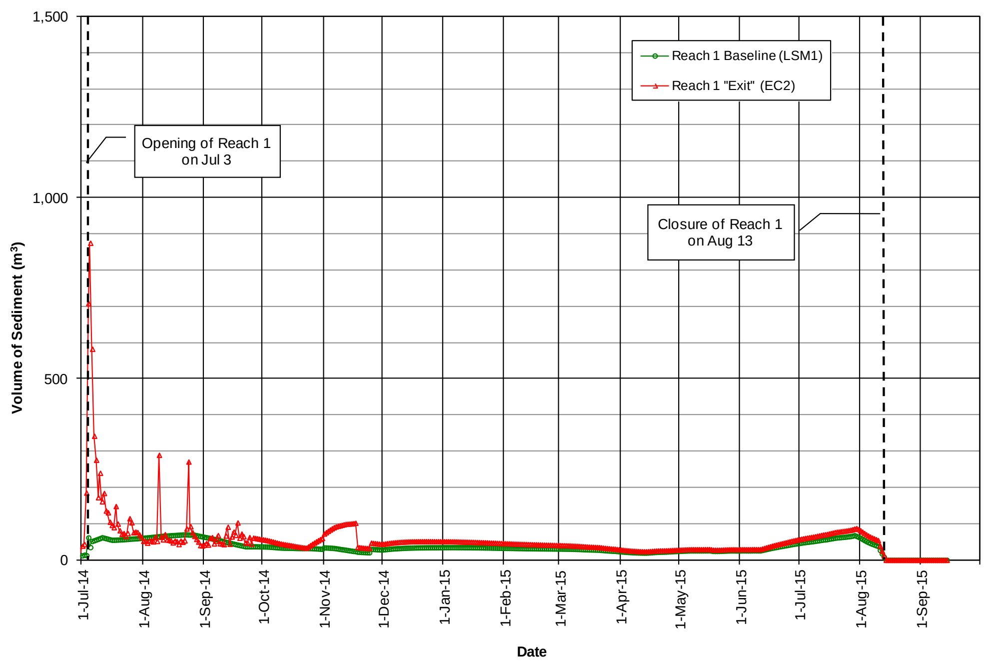
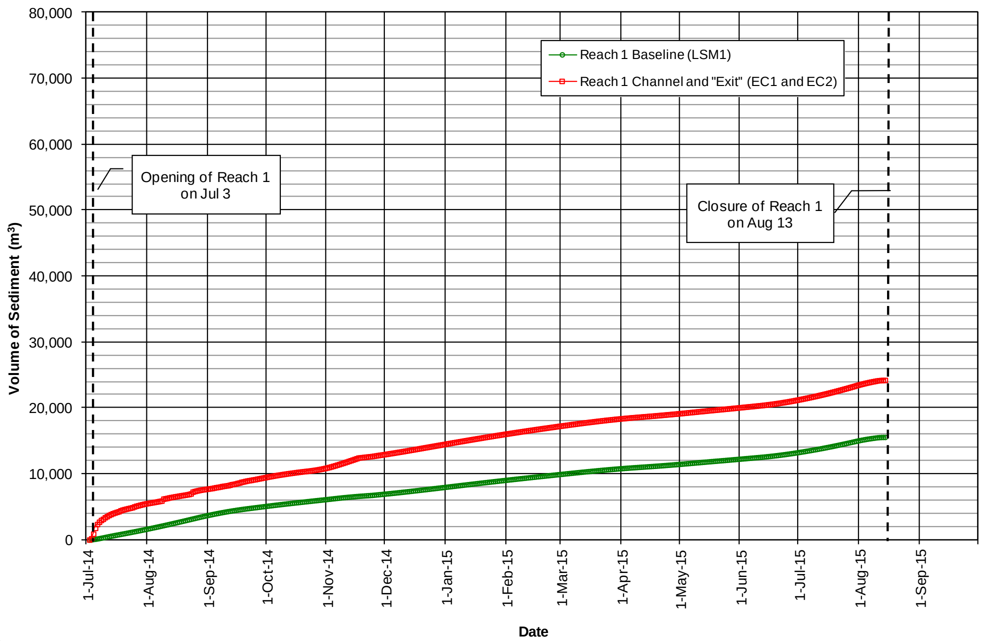


FIGURE 4.1-17
ESTIMATED DAILY SUSPENDED SEDIMENT VOLUMES IN REACH 1 DURING 2014/2015 OPERATION



KGS GROUP

FIGURE 4.1-18
ESTIMATED CUMULATIVE SUSPENDED SEDIMENT VOLUMES IN REACH 1 DURING 2014/2015 OPERATION



The suspended sediment volume balance calculated in Reach 1 during the 2014/2105 operation is summarized in Table 4.1-10.

TABLE 4.1-10
REACH 1 SUSPENDED SEDIMENT VOLUME BALANCE DURING 2014/2015 OPERATION

Description	Cumulative Sediment Volume (m^3)
Reach 1 Baseline	15,600
Reach 1 Channel or “Exit”	24,200
Net Total	8,600

Buffalo Lake Bog

Based on the Reach 1 Channel or “Exit” conditions and the Buffalo Creek Baseline conditions, the suspended sediment volume balance calculated in the Buffalo Lake Bog area during the 2014/2015 operation period is summarized in Table 4.1-11.

TABLE 4.1-11
BUFFALO LAKE BOG SUSPENDED SEDIMENT VOLUME BALANCE DURING 2014/2015 OPERATION

Description	Cumulative Sediment Volume (m^3)
Reach 1 Channel or "Exit"	24,200
Buffalo Creek Baseline or near Entrance	6,400
Net Total	-17,800

Buffalo Creek

Measured and interpolated daily TSS concentrations in Buffalo Creek during the 2014/2015 operation period are provided in Figure 4.1-19. The calculated daily and cumulative volumes of suspended sediment in Buffalo Creek during operation are provided in Figures 4.1-20 and 4.1-21, respectively.

FIGURE 4.1-19
MEASURED AND INTERPOLATED DAILY TSS CONCENTRATION IN BUFFALO CREEK DURING 2014/2015 OPERATION

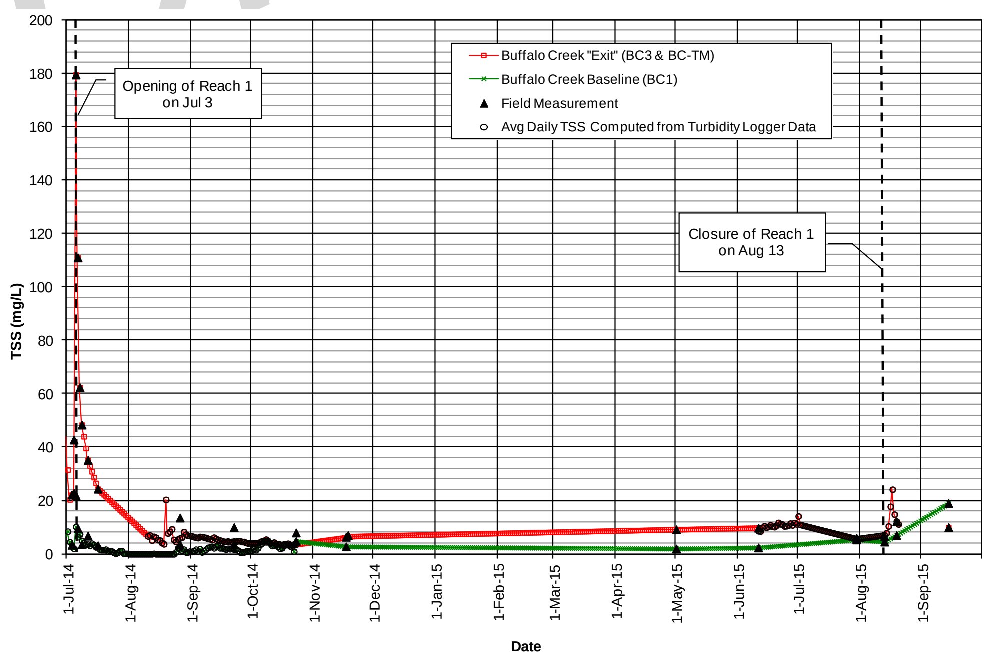


FIGURE 4.1-20
ESTIMATED DAILY SUSPENDED SEDIMENT VOLUME IN BUFFALO CREEK DURING 2014/2015 OPERATION OF THE LSMEOC

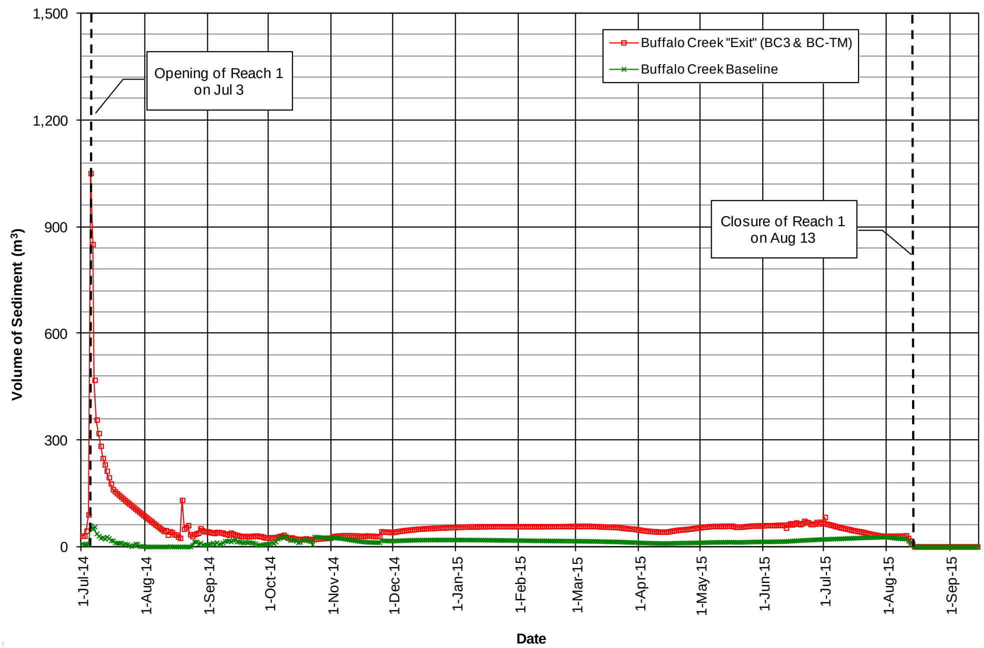
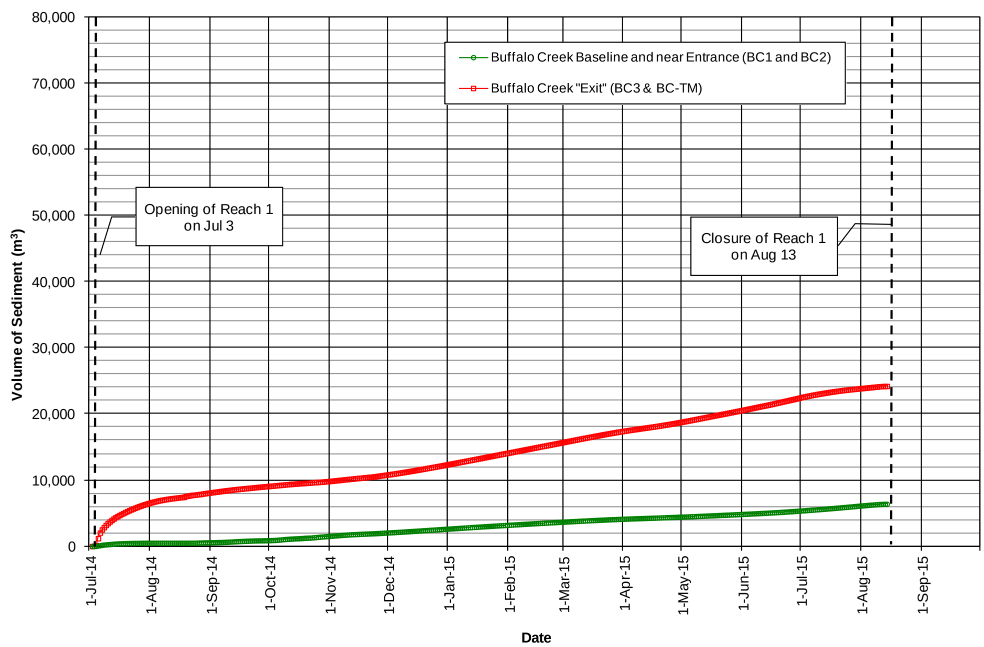


FIGURE 4.1-21
ESTIMATED CUMULATIVE SUSPENDED SEDIMENT VOLUME IN BUFFALO CREEK DURING 2014/2015 OPERATION



The suspended sediment volume balance calculated in Buffalo Creek during the 2014/2015 operation period is summarized in Table 4.1-12.

TABLE 4.1-12
BUFFALO CREEK SUSPENDED SEDIMENT VOLUME BALANCE DURING 2014/2015 OPERATION

Description	Cumulative Sediment Volume (m^3)
Baseline or near Entrance	6,400
Exit	24,200
Net Total	17,800

Reach 1 to Buffalo Creek

The suspended sediment volume balance that occurred within the LSMEOC System from the entrance of Reach 1 to the exit of Buffalo Creek during the 2014/2015 operation is summarized in Table 4.1-13.

TABLE 4.1-13
LSMEOC FROM REACH 1 (ENTRANCE) TO BUFFALO CREEK (EXIT) SUSPENDED SEDIMENT VOLUME BALANCE DURING 2014/2015 OPERATION

Description	Cumulative Sediment Volume (m^3)
Reach 1 Baseline	15,600
Buffalo Creek Exit	24,200
Net Total	8,600

Lower Dauphin River

Measured and interpolated daily TSS concentrations during the 2014/2015 operation are also available for the lower Dauphin River upstream of the confluence with Buffalo Creek and are shown in Figure 4.1.22. Suspended sediment volumes computed for this location are shown in Figure 4.1-23.

FIGURE 4.1-22
MEASURED AND INTERPOLATED DAILY TSS CONCENTRATION IN LOWER DAUPHIN RIVER DURING 2014/2015 OPERATION

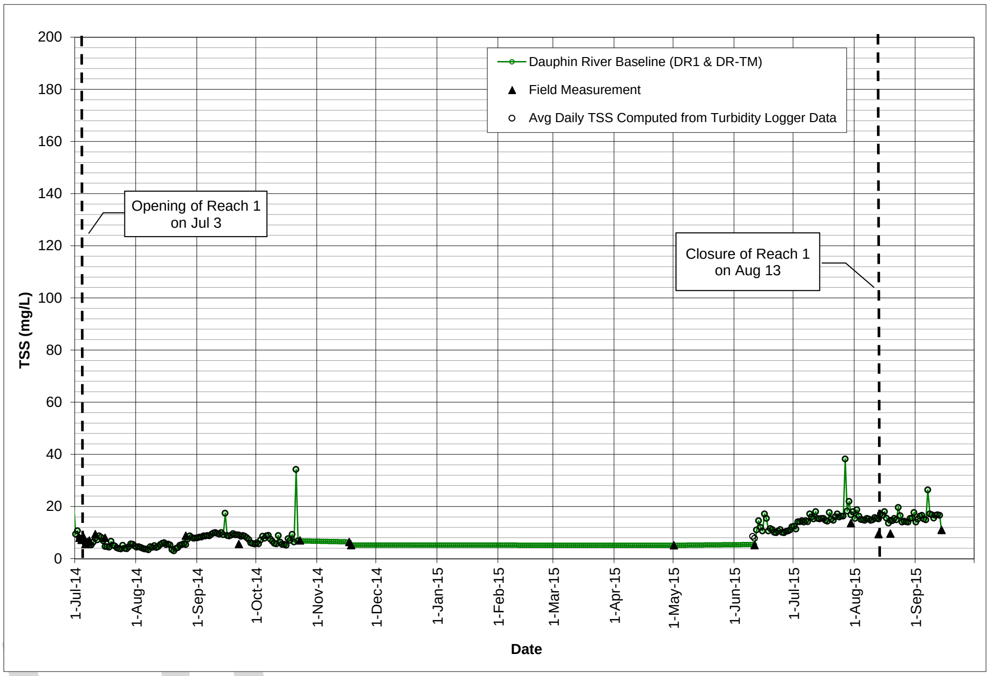
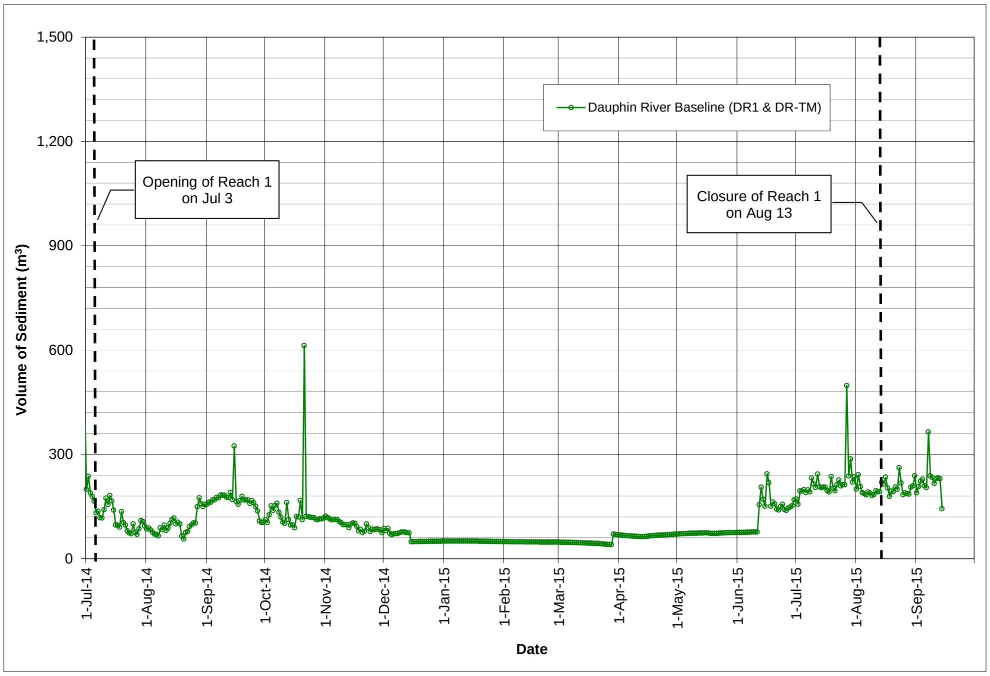
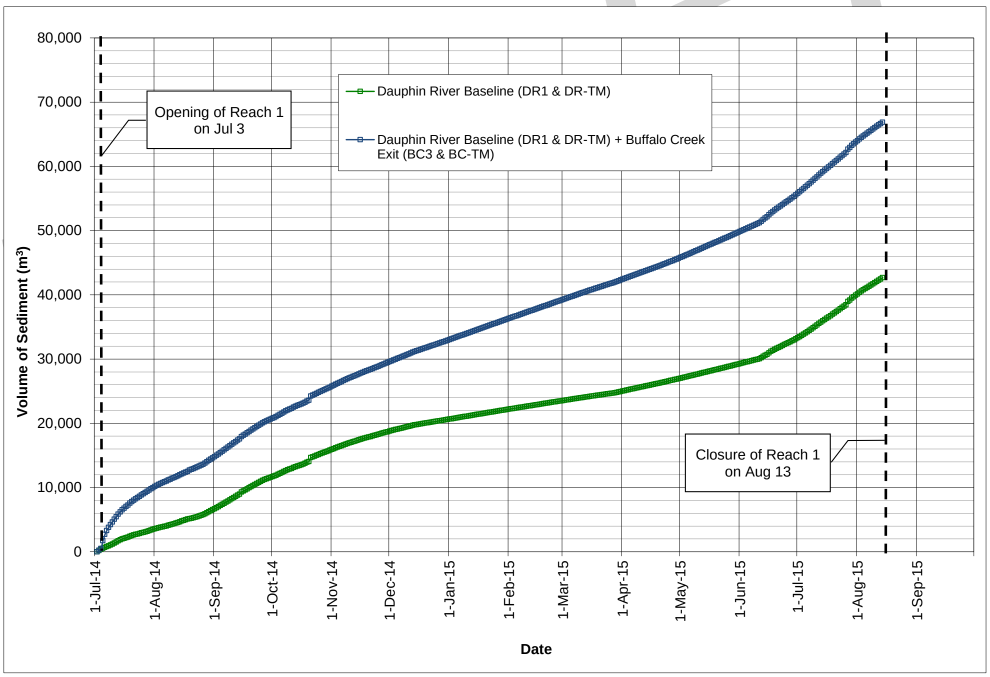


FIGURE 4.1-23
ESTIMATED DAILY SUSPENDED SEDIMENT VOLUME IN LOWER DAUPHIN RIVER DURING 2014/2015 OPERATION



Cumulative suspended sediment volumes in the Dauphin River were computed upstream of the confluence with Buffalo Creek and are shown in Figure 4.1-24. Also included on the figure are values that combine both the Buffalo Creek Exit and the Dauphin River Baseline as a single sediment inflow volume to the lower Dauphin River. The combined volumes allow for a comparison of conditions with and without operation of the LSMEOC and provide the best estimate of the actual effects of the entire LSMEOC system on the volume of suspended sediment released at the exit of Buffalo Creek.

FIGURE 4.1-24
ESTIMATED CUMULATIVE SUSPENDED SEDIMENT VOLUME IN LOWER DAUPHIN RIVER DURING 2014/2015 OPERATION



The cumulative combined volume of suspended sediment in the lower Dauphin River during operation is summarized in Table 4.1-14.

TABLE 4.1-14
LOWER DAUPHIN RIVER CUMULATIVE SEDIMENT VOLUME DURING 2014/2015 OPERATION

Description	Cumulative Sediment Volume (m^3)
Dauphin River Baseline	42,700
Buffalo Creek Exit	24,200
Combined Dauphin River Baseline & Buffalo Creek Exit	66,900

To assess the effects of the operation of the LSMEOC on the volume of suspended sediment in the Dauphin River downstream of Buffalo Creek, the same volume was computed with the empirical model using Dauphin River flows obtained from the routing model assuming the LSMEOC had not been operated. Although the cumulative sediment inflow at the Buffalo Creek Exit would have been substantially less, since the upper Dauphin River flows would have been significantly greater without operation of the emergency channel. However, the cumulative volume of suspended sediment on the Dauphin River upstream of Buffalo Creek would have been significantly more. The comparison of cumulative volume of suspended sediment in the lower Dauphin River (Combined Dauphin River Baseline & Buffalo Creek Exit) with and without the LSMEOC is summarized in Table 4.1-15. The net total is the estimated volume of suspended sediment increase that the operation of the LSMEOC contributed to the Dauphin River downstream of the confluence with Buffalo Creek.

TABLE 4.1-15
LOWER DAUPHIN RIVER CUMULATIVE SEDIMENT VOLUME WITH AND WITHOUT OPERATION OF THE LSMEOC FOR 2014/2015 OPERATION PERIOD

Description	Cumulative Sediment Volume (m^3)
With Operation of the LSMEOC	66,900
Without Operation of the LSMEOC	55,800
Net Increase	8,100

4.2 BUFFALO CREEK SEDIMENT TRANSPORT ANALYSIS (STA-1)

4.2.1 Background

A Sediment Transport model of Buffalo Creek was previously developed in 2012 and has been documented in the report by KGS Group (August 2012). The model used the sediment transport subroutine in the program HEC-RAS V.4.1.0, from the US Army Corps of Engineers. The purpose of the model was to provide a preliminary assessment of the potential for erosion in Buffalo Creek during the proposed operation period of the LSMEOC at the time. This model has been updated for the current study based on new survey and hydrometric data that is now available.

The HEC-RAS program is a one-dimensional model that uses empirical theory to estimate scour, sediment transport and deposition. The methods used in HEC-RAS to model scour and deposition were developed for non-cohesive river sediments, which considers whether the shear stress in the channel is large enough to lift the particles off the river bed. When applied to sediments in the clay and silt size range (cohesive sediments), the model generally overstates the erosion potential by as much as 2-3 degrees of magnitude, since the submerged unit weight of the fine particle size is too low to resist the scour force in the absence of cohesive forces.

Since the results of the Buffalo Creek substrate survey indicated an abundance of clay and silt material, a cohesive approach was used in 2012 to attempt to estimate the erosion. However, based on observations of conditions in Buffalo Creek after operation of the LSMEOC, it was determined that the substrate in the creek was not typical of cohesive soils. In light of this, a revised approach was taken for the current study and the model was updated such that all particles are treated as though they are non-cohesive.

4.2.2 Model Setup

The Laursen (Copeland) transport method was selected in HEC-RAS for the analysis. This method was preferred over other methods as it obtains better results than other HEC-RAS methods for soil types that extend into the silt range.

Exner 5 was selected as the sorting method for the analysis since it considers the influences of bed armoring by using a more complex three layer system. Report 12 was selected as the fall velocity method due to its iterative approach. These methods were preferred over other sorting and fall velocity methods available in HEC-RAS as it was determined that they would provide better results for this analysis.

Default parameters defined by HEC-RAS were maintained in the model, unless there was a specific reason to change the values based on model calibration or sensitivity analysis, as specified in the following sections.

The 2012 model utilized cross sections obtained from a combination of LiDAR and surveyed field data. This was updated in the current model by replacing the LiDAR sections with cross sections surveyed prior to the operation of the channel. The surveyed cross sections are more accurate than the LiDAR sections since certain details, such as the Buffalo Creek riparian channel, were not captured by the LiDAR.

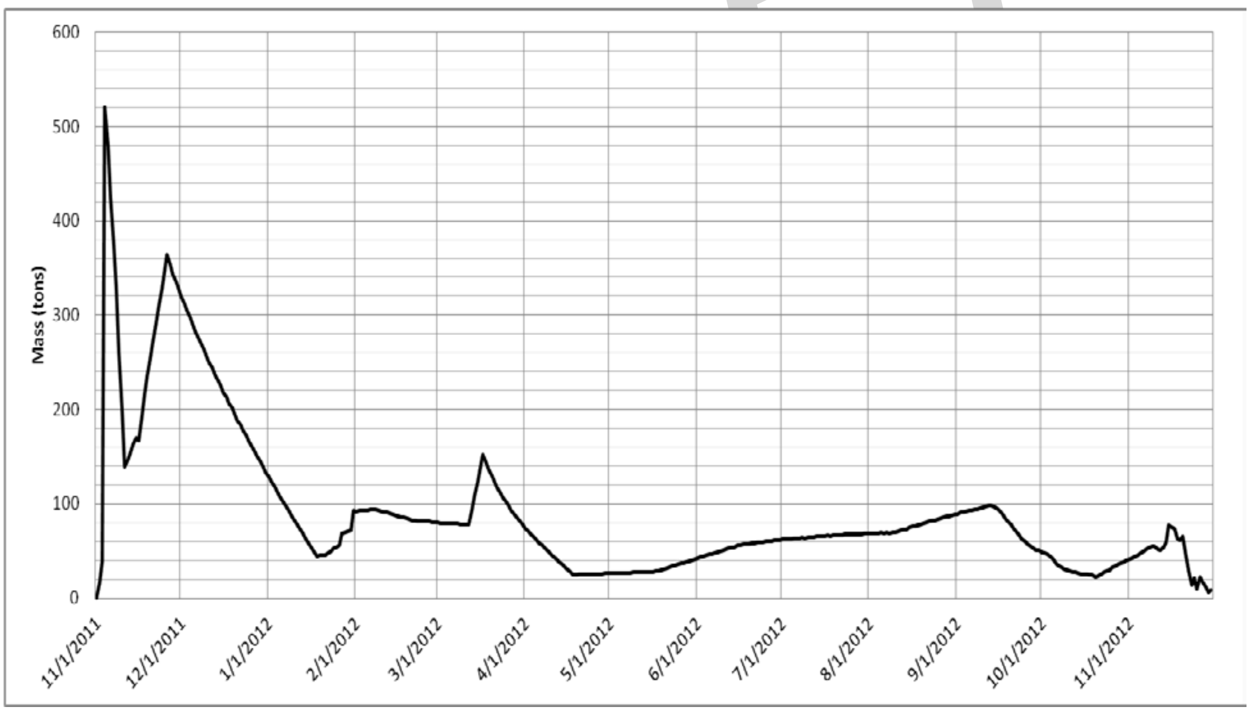
The surveyed cross sections were located approximately 500 m apart. To obtain better hydraulic stability in the model, additional cross sections were interpolated at approximately 75 m intervals and added in the model. Also, four cross sections were added outside of the study area to the upstream end of the model. These sections were generated based on the most upstream cross section in Buffalo Creek, and maintained the same slope as the upstream reach of the channel. The additional sections were included to allow the sediment model to stabilize outside of the study area, thereby improving the sediment erosion results in Buffalo Creek.

For the sediment transport model, it was necessary to define the erosion limits on each cross section. These were defined based on the results of the 2013 survey. However, the maximum depth of erosion was set to a high value of 10m, such that the extents of erosion computed by the model would be based on the hydraulic conditions in the creek and the properties of the bed material (self-armouring) rather than being limited by the user.

In the hydraulic model, the Buffalo Creek daily flow hydrograph, previously discussed in Section 3.1.2 and provided on Figure 3.1-3, was input as the upstream boundary condition. A normal water depth of flow, based on a slope of 0.001, was input as the downstream boundary condition.

In the sediment transport model, a sediment load was input as an upstream boundary condition. The sediment load was calculated based on the flow hydrograph outlined above and the TSS data collected at the upstream end of Buffalo Creek, as previously discussed in Section 4.1.1. The Buffalo Creek inflow Sediment Load is provided on Figure 4.2-1

FIGURE 4.2-1
BUFFALO CREEK DAILY SEDIMENT LOAD INFLOW



To improve the performance of the model, various computation time steps were simulated. It was determined that a time step of one day provided the best results.

Properties of the Buffalo Creek bed material defined in the model were based on substrate surveys conducted by KGS Group in September 2011 along the channel overbanks. Details and results of the survey are summarized in a memo attached in Appendix J. The grain size distribution of the material that was used for the analysis is shown on Table 4.2-1. The class and diameter size of the material shown in the table were defined by the laboratory where the substrate material was tested, and were adopted for the Buffalo Creek analysis.

TABLE 4.2-1
GRAIN SIZE DISTRIBUTION OF BUFFALO CREEK SUBSTRATE

Class	Diameter	% Finer
Clay	0.002 - 0.005	49.1
Silt	0.005 - 0.075	69.9
Sand	0.075 - 4.75	93.3
Gravel	4.75 - 75	99.3
Cobble	75 - 250	100

A grain size distribution was also input for the sediment load inflow referenced in Figure 4.2-1. The grain size was determined based on laboratory results of suspended solids from two water samples collected on January 17, 2012 along the LSMEOC; one on Buffalo Creek and the other on the Dauphin River. A copy of the laboratory results is provided in Appendix K, and the grain size distribution of the suspended solids is summarized in Table 4.2-2. Additional samples were also collected on July 24, 2014 and the laboratory results are also provided in Appendix K.

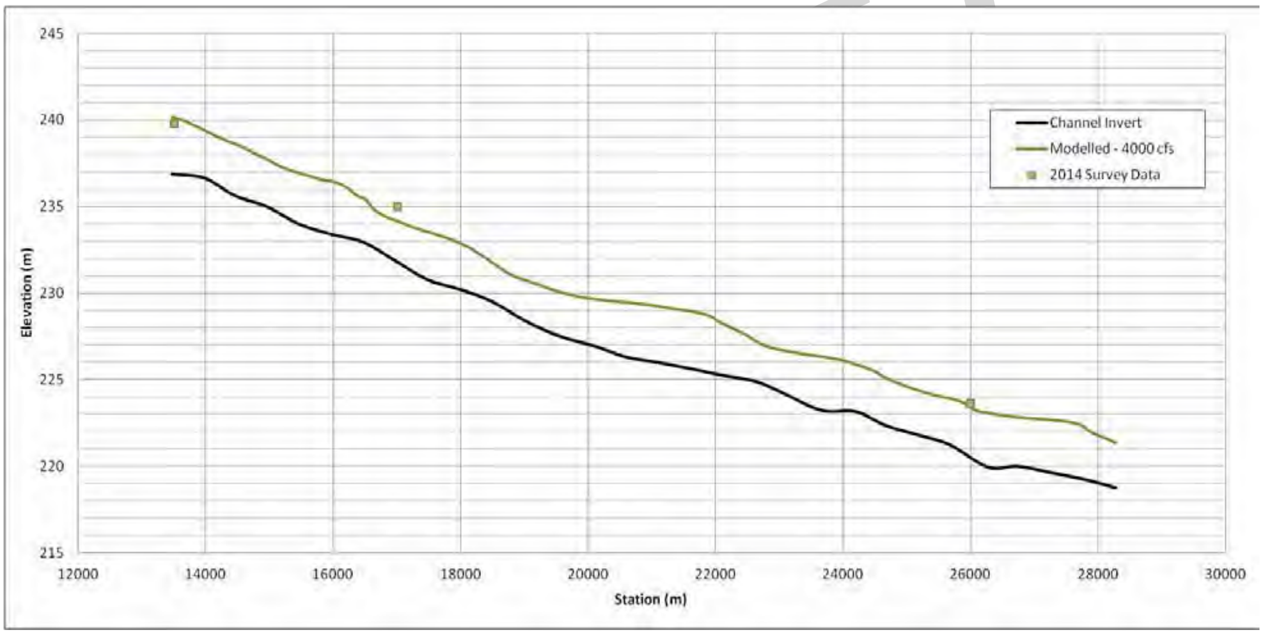
TABLE 4.2-2
GRAIN SIZE DISTRIBUTION OF SUSPENDED SOLIDS

Class	Diameter (mm)	% Finer
Clay	0.002 - 0.005	16
Silt	0.005 - 0.075	93
Sand	0.075 - 4.75	100
Gravel	4.75 - 75	100
Cobble	75 - 250	100

4.2.3 Hydraulic Model Calibration

Limited survey data was available on Buffalo Creek during the 2011/2012 operation of the LSMEOC to calibrate the hydraulic model. Therefore, a Manning's 'n' value of 0.03 for the main channel and 0.08 for the overbank sections was selected based on experience and knowledge of the channel characteristics. The model was then simulated using the selected channel roughness values, and the resulting water surface profile was compared to surveyed water levels, which were measured when the channel was flowing at approximately 113 cms (4,000 cfs). This comparison, shown in Figure 4.2-2, demonstrates that there is good agreement between measured and modelled water levels and that the selected channel roughness values are suitable for this application.

FIGURE 4.2-2
2014 WATER SURFACE PROFILE



An analysis was completed to test the model's sensitivity to changes in channel roughness. The model was simulated for a range of channel and overbank roughness values smaller and greater than the selected values previously identified. The analysis indicated that although changes in channel roughness result in a notable change in water levels, resultant changes to velocities and shear stress were not sufficient to impact the results of the sediment transport analysis discussed in the subsequent sections of this report. Since the purpose of the model is to conduct a sediment transport analysis and define the potential for erosion in Buffalo Creek, and not on defining water levels, further refinements to the model calibration was not necessary.

4.2.4 Sediment Transport Theoretical Analysis

The initiation of particle movement occurs when the shear stress in the channel exceeds the critical shear stress of the particle. U.S. Geological Survey (USGS) has published theoretical critical shear values for a range of sediment grain sizes (USGS, 2008). The critical shear stress values corresponding to the grain classes used for this analysis are shown in Table 4.2-3.

TABLE 4.2-3
CRITICAL SHEAR STRESS FOR EROSION

Class	Diameter (mm)	Minimum Critical Shear Stress for Erosion (N/m^2)
Clay	0.002 - 0.005	-
Silt	0.005 - 0.075	0.03
Sand	0.075 - 4.75	0.11
Gravel	4.75 - 75	3.3
Cobble	75 - 250	64

Shear stress is a function of the river bed roughness, water depth and flow velocity. Therefore, potential for sediment erosion and deposition can also be determined by comparing water velocities in the channel to critical velocities for erosion and deposition, such as defined by Hjulstrom and provided on Figure 4.2-3. The Hjulstrom curve takes into account the cohesive properties of clay and silt particles, resulting in increasing critical erosion velocities with decreasing grain sizes for very small materials. However, as discussed previously, the clays and silts in Buffalo Creek are mostly non-cohesive in nature and will likely start eroding before sand and gravel particles. Therefore, Hjulstrom's critical erosion velocities for silts and clays were excluded from the analysis. Values from the Hjulstrom curve corresponding to the grain classes used for this analysis are shown in Table 4.2-4.

FIGURE 4.2-3
HJULSTROM CURVE

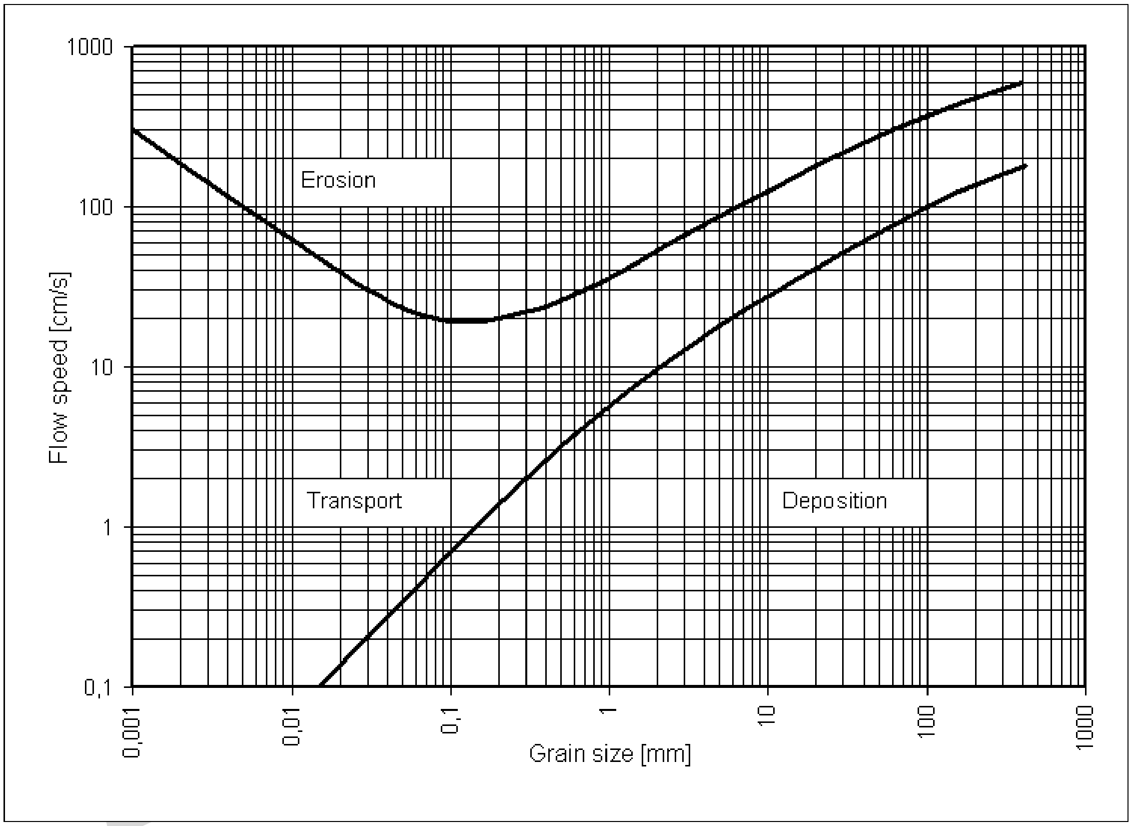


TABLE 4.2-4
CRITICAL VELOCITY FOR DEPOSITION AND EROSION

Class	Diameter (mm)	Maximum Critical Velocity for Deposition (m/s)	Minimum Critical Velocity for Erosion (m/s)
Clay	0.002 - 0.005	<0.001	-
Silt	0.005 - 0.075	0.005	-
Sand	0.075 - 4.75	0.18	0.20
Gravel	4.75 - 75	0.85	0.85
Cobble	75 - 250	1.5	3.2

A steady state hydraulic model was simulated for the minimum, median and maximum flow of 40 cms (1400 cfs), 125 cms (4400 cfs) and 210 cms (7400 cfs), respectively, during the 2011/2012 operation period presented in Section 3.1.2. Average shear stress and velocities obtained from the model were compared to the critical values for deposition and erosion outlined above. Results in the overbanks of the creek were analyzed separately from results in the main channel due to the wide range of expected values within a cross section. The resulting average shear stresses in the main channel and in the overbanks are shown in Figures 4.2-4 and 4.2-5, respectively, and are compared to the critical shear stress for erosion of the different grain classes. The resulting average velocities in the main channel and in the overbanks are shown on Figures 4.2-6 and 4.2-7, respectively, and are compared to the minimum critical velocity for erosion of the different grain classes. Figures 4.2-8 and 4.2-9 show the resulting average velocities in the main channel and in the overbanks compared to the maximum critical velocity for deposition of the different grain classes.

FIGURE 4.2-4
SHEAR STRESS PROFILE IN THE MAIN CHANNEL
COMPARED TO CRITICAL SHEAR STRESS FOR EROSION

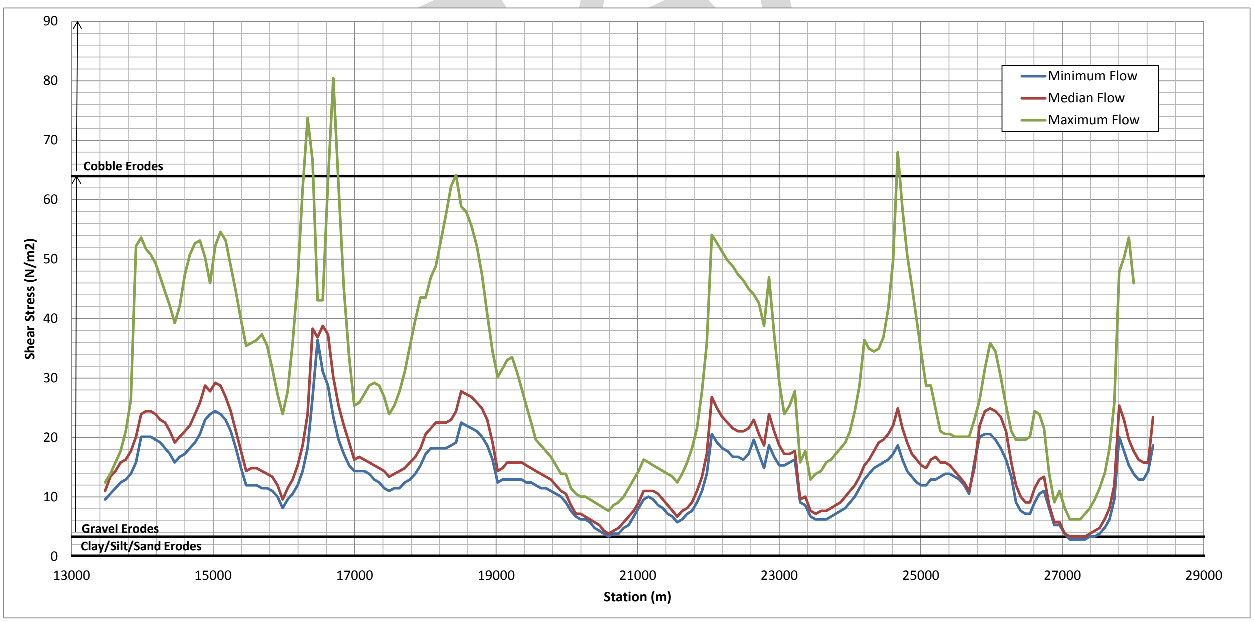


FIGURE 4.2-5
SHEAR STRESS PROFILE IN THE OVERBANKS
COMPARED TO CRITICAL SHEAR STRESS FOR EROSION

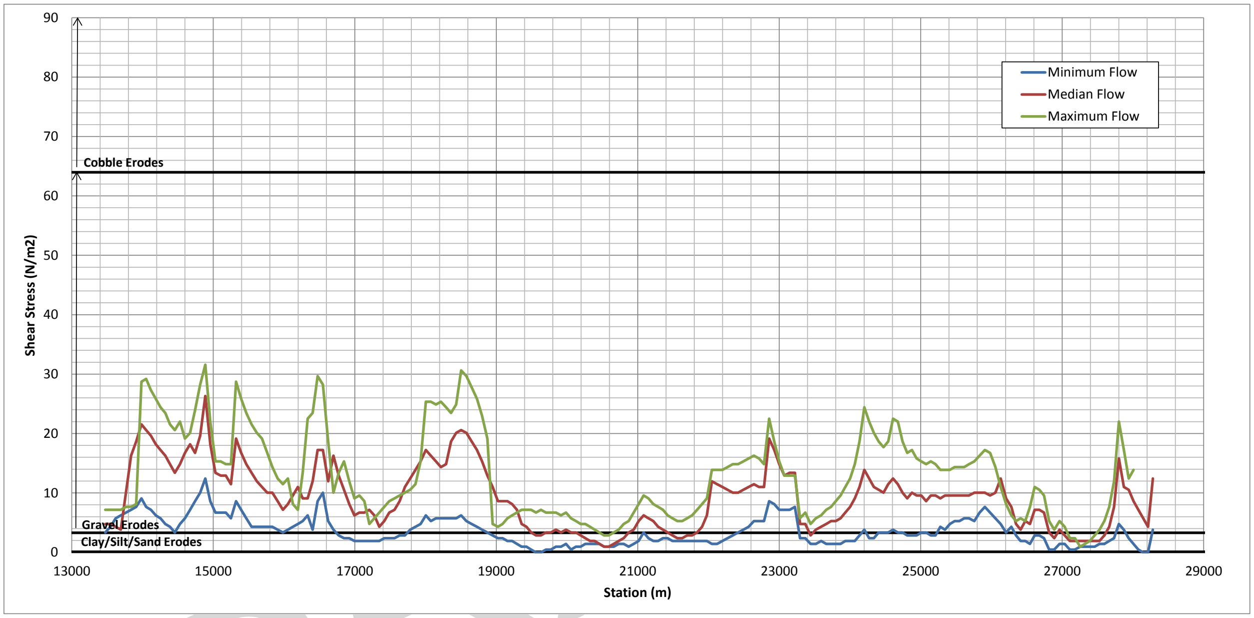


FIGURE 4.2-6
VELOCITY PROFILE IN THE MAIN CHANNEL
COMPARED TO MINIMUM CRITICAL VELOCITY FOR EROSION

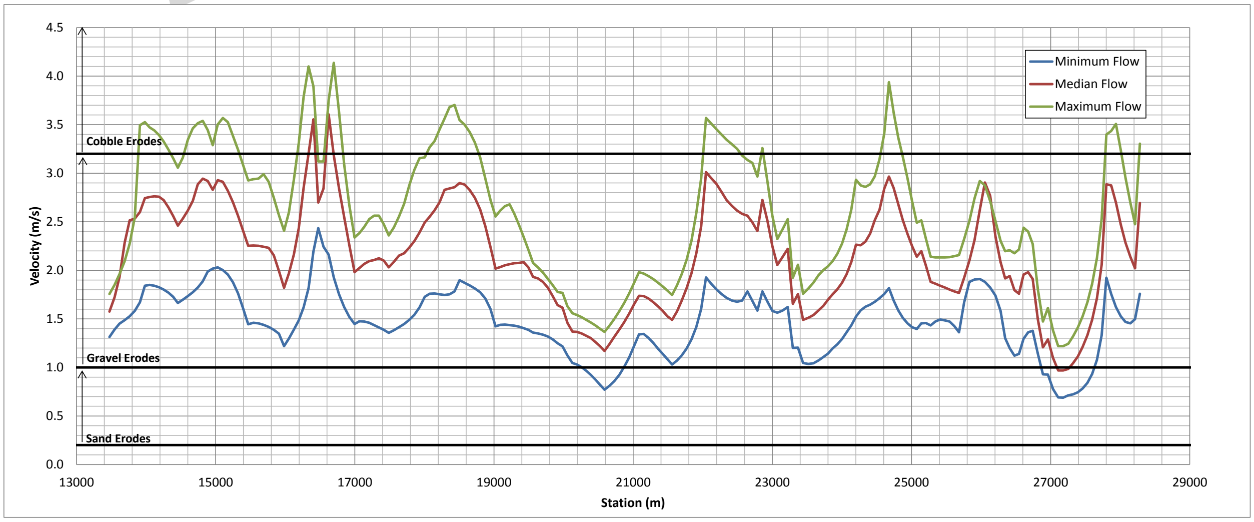


FIGURE 4.2-7
VELOCITY PROFILE IN THE OVERBANKS
COMPARED TO MINIMUM CRITICAL VELOCITY FOR EROSION

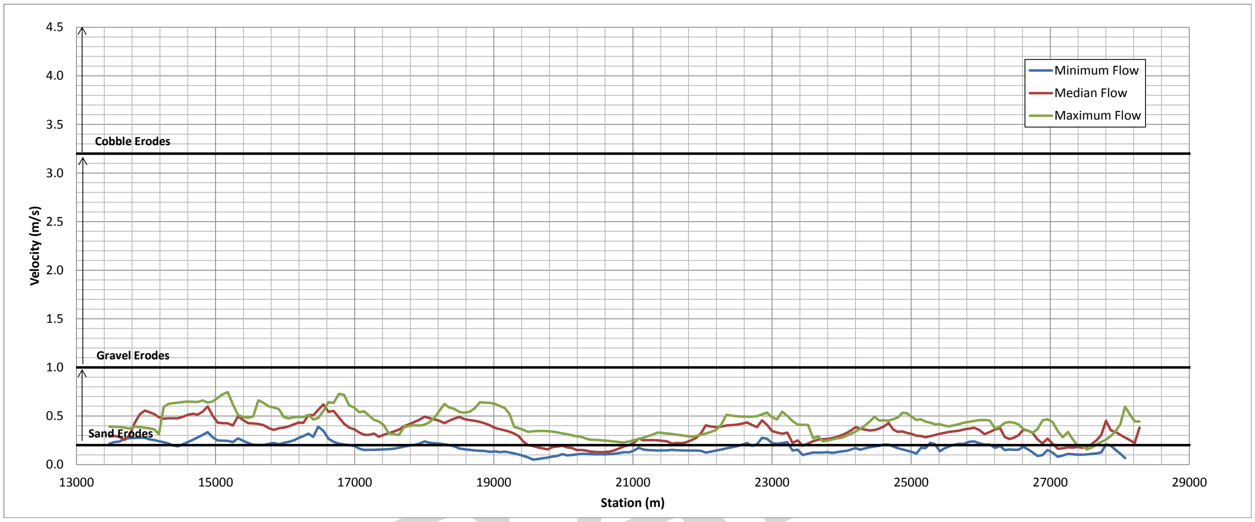


FIGURE 4.2-8
VELOCITY PROFILE IN THE MAIN CHANNEL
COMPARED TO MAXIMUM VELOCITY FOR DEPOSITION

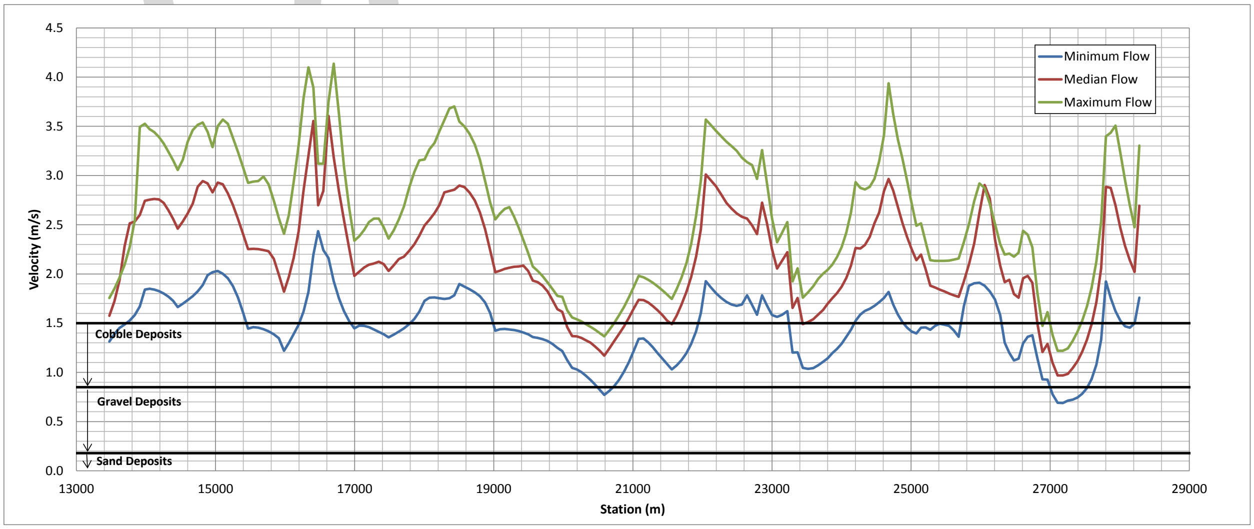
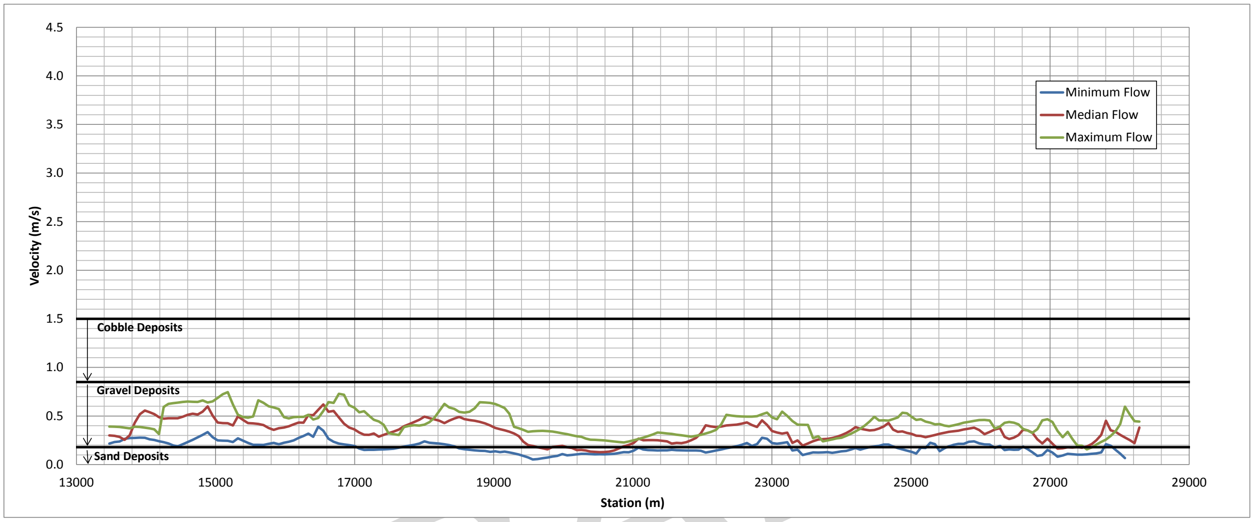


FIGURE 4.2-9
VELOCITY PROFILE IN THE OVERBANKS
COMPARED TO MAXIMUM VELOCITY FOR DEPOSITION



It is evident from Figures 4.2-4, 4.2-5, 4.2-6 and 4.2-7 that the velocities and shear stresses that were present in the main channel and in the overbanks of Buffalo Creek during operation of the LSMEOC, even for the minimum flow, were large enough to induce the movement of gravel size materials or smaller. In the main channel, the results also indicate that there were areas where cobble size materials were subject to erosion. These results are consistent with cross section comparisons of pre and post operating conditions in Buffalo Creek, as discussed in Section 3.4.2. The cross section comparisons showed that erosion had occurred in Buffalo Creek, and that the erosion was concentrated in the main channel.

Once in movement, Figure 4.2-8 shows that for the flows that occurred during operation of the LSMEOC, there was a low potential for gravel size sediments or smaller to deposit in the main channel. When flows exceeded median conditions, cobble size materials also had a low potential for deposition. However, at the minimum flow, there are many locations where cobbles had a high potential for deposition.

In the overbanks, Figure 4.2-9 shows that gravel size sediments had a high potential for deposition during operation of the LSMEOC. The figure also shows that there were many areas where sand size sediments had the potential to deposit at the minimum flow.

These results on potential for deposition are also consistent with the pre and post cross section comparisons. As discussed in Section 3.4.2, the comparisons showed that deposition generally occurred in the overbanks, immediately adjacent to the main channel, and that the material deposited usually consisted of cobbles and gravels. The results are also consistent with the vegetation cover survey, discussed in section 3.3, which showed that a layer of fine sediments could be found in the overbanks of the channel.

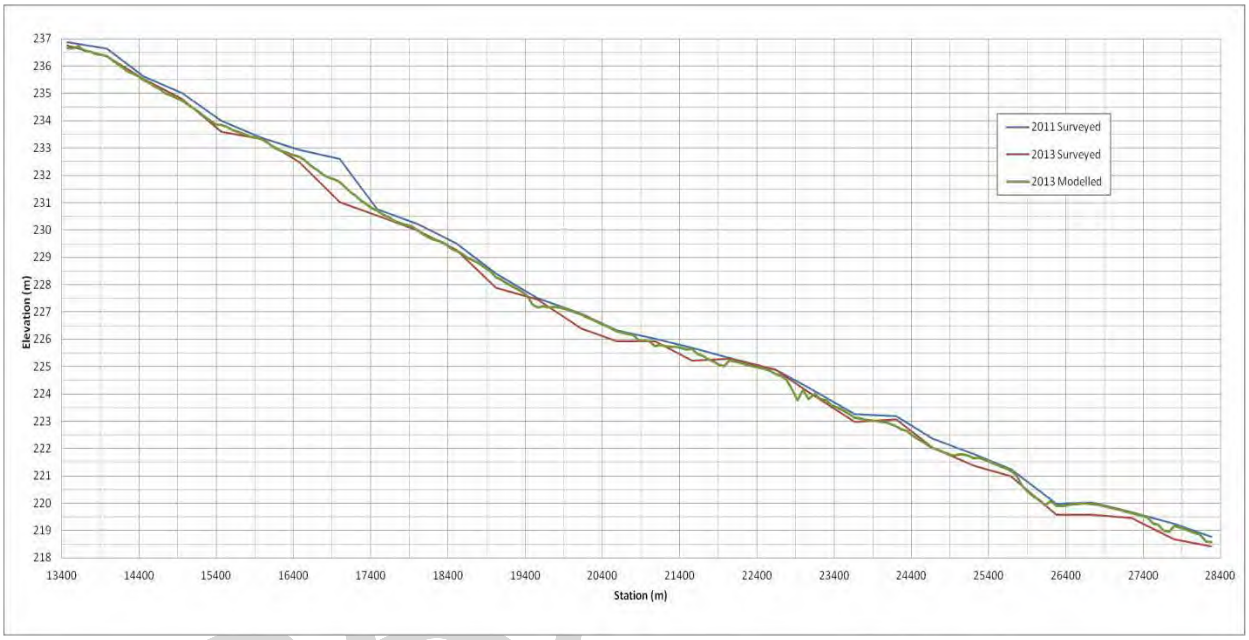
4.2.5 Sediment Transport Modeling

The HEC RAS Sediment Transport Model was used to simulate conditions in Buffalo Creek during operation of the LSMEOC from November 1, 2011 to November 21, 2012. The model was optimized to best replicate the extent of physical erosion that occurred within the channel, by comparing the computed Buffalo Creek profile and cross sections at the end of the simulation to the surveyed profile and cross sections obtained in 2013, post-operation of the LSMEOC. The following measures were undertaken to optimize the sediment transport model:

- A sensitivity analysis of the critical Shield's number, which is an adjustable parameter of the Laursen method, was undertaken. The Shield's number is used to calculate the initiation of sediment movement. Literature (Richardson, 2008) suggests the Shield's number can range between 0.03 and 0.1, with the optimal value being 0.039. This optimal value is also the HEC RAS default. Based on the results of the sensitivity analysis, the HEC RAS default was maintained; and
- Computation options and tolerances were adjusted to provide a better fit between modelled and observed data. In particular, the number of cross sections used for averaging hydraulic properties upstream and downstream were adjusted, as well as the weighting assigned to the hydraulic properties at the main cross section versus the upstream and downstream sections.

The results of the model are shown on Figure 4.2-10, which compares the surveyed channel invert to the modelled invert.

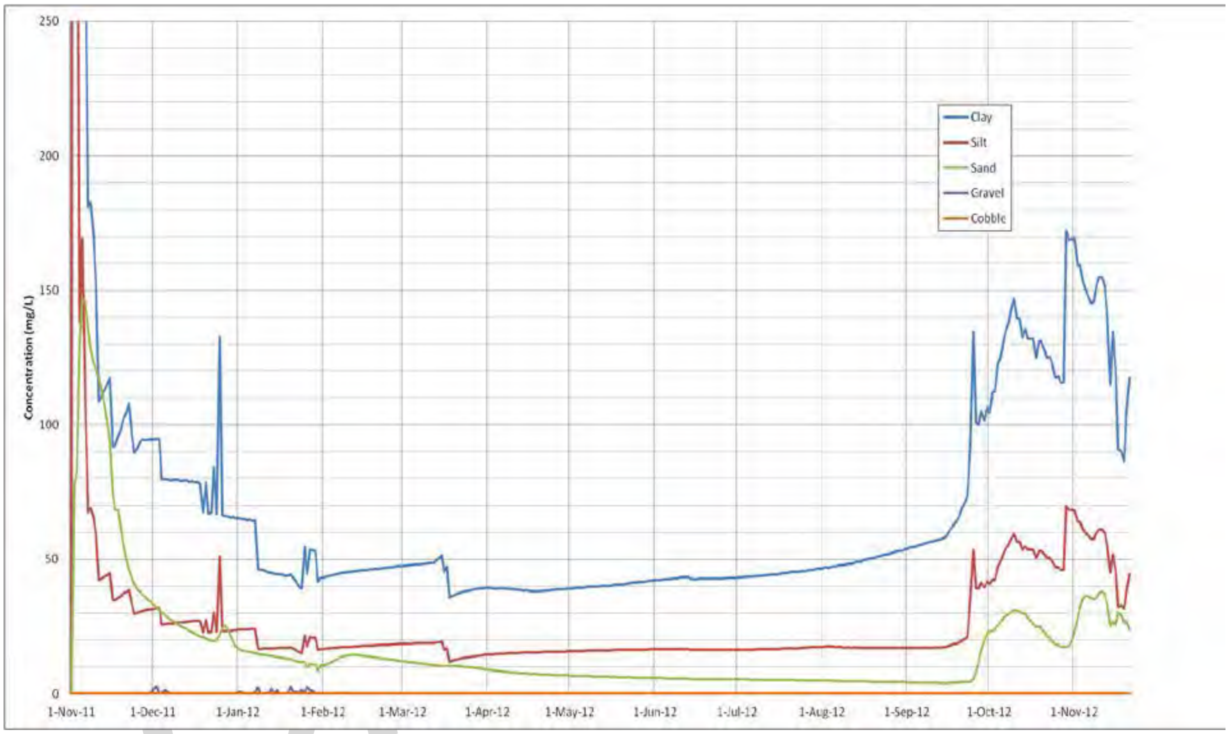
FIGURE 4.2-10
COMPARISON OF MODELLED AND SURVEYED CHANNEL PROFILE



Generally, the model was able to simulate the trend in channel erosion relatively well throughout the channel. This was further confirmed by comparing the estimated total volume of in-situ material that was eroded from the channel based on a comparison of the 2011 and 2013 cross sections. As discussed in Section 3.4.2, based on the surveyed cross sections, the total in-situ volume of material that was eroded from the channel was estimated to be approximately 60,000 m^3. A comparison of the modelled cross sections resulted in similar value of approximately 50,000 m^3.

In addition to the profile and cross section comparison, the sediment concentration was also evaluated. The results of the model at the channel outlet are shown in Figure 4.2-11.

FIGURE 4.2-11
SEDIMENT CONCENTRATION AT CHANNEL OUTLET



The model showed that nearly all of the suspended sediment consisted of clay, silt, and sand particles. This is expected as larger size material would typically be transported as bedload and HEC-RAS does not have the capability to simulate the movement of sediments as bedload. When comparing the simulated sediment concentration at the outlet of Buffalo Creek with the modelled concentrations, the modelled concentrations were significantly higher than those that were measured. It is therefore possible that some of the erosion that occurred in Buffalo Creek was transported as bedload. However, bedload measurements taken in the Dauphin River downstream of Buffalo Creek before, during and after the 2014/2015 operation, as discussed in Section 3.2.2, were inconclusive in suggesting that eroded material in Buffalo Creek was transported via bedload downstream in the Dauphin River.

4.3 LOWER DAUPHIN RIVER FLOW PATTERN ANALYSIS (ESH -1)

To study the changes to the physical environment and the possible subsequent effects to the biological environment in the lower Dauphin River and Sturgeon Bay, a 2D hydrodynamic model was developed to numerically investigate the flow patterns in the lower Dauphin River and identify areas with a potential for erosion and sediment deposition.

4.3.1 Lower Dauphin River Model Description

The MIKE 21 software with Flexible Mesh (MIKE 21), developed by DHI Group in Denmark, is a two dimensional model simulating free surface flows. The model solves the depth-averaged 2D Navier-Stokes equations using a cell-centered finite volume solution technique to simulate flows in rivers, lakes, estuaries, bays, coastal areas, and overland flooding. MIKE 21 FM is commercial software widely used in the industry in North America with many possible applications in river engineering.

The MIKE 21 model encompassed a reach of the lower Dauphin River located between Station 47+800 (upstream of Buffalo Creek) to Station 53+200 (in Sturgeon Bay) as shown in Figure 4.3-1. A digital elevation model (DEM) was built for this analysis with data obtained from different sources. The bathymetry data in the Dauphin River and Lake Winnipeg was derived from the sonar survey data conducted in 2011 and 2012 by KGS Group (Section 3.5). The topographic data outside of the river and the lake was obtained from the LiDAR data completed in June/July 2011. The integrated DEM for 2011 included the river bathymetry data based on a sonar survey in 2011 and the LIDAR data completed in 2011. The DEM for 2012 was built based on the river bathymetry sonar survey in 2012 and the LIDAR data completed in 2011. The 2011 and 2012 DEM are shown on Figures 4.3-2 and 4.3-3, respectively.

FIGURE 4.3-1
2D MODEL STUDY AREA FOR LOWER DAUPHIN RIVER DOWNSTREAM OF BUFFALO CREEK
(FROM STATION 47+800 TO 53+100)

FIGURE 4.3-2
2011 DIGITAL ELEVATION MODEL BUILT BASED ON 2011 RIVER SONAR SURVEY DATA AND 2011 LIDAR SURVEY DATA

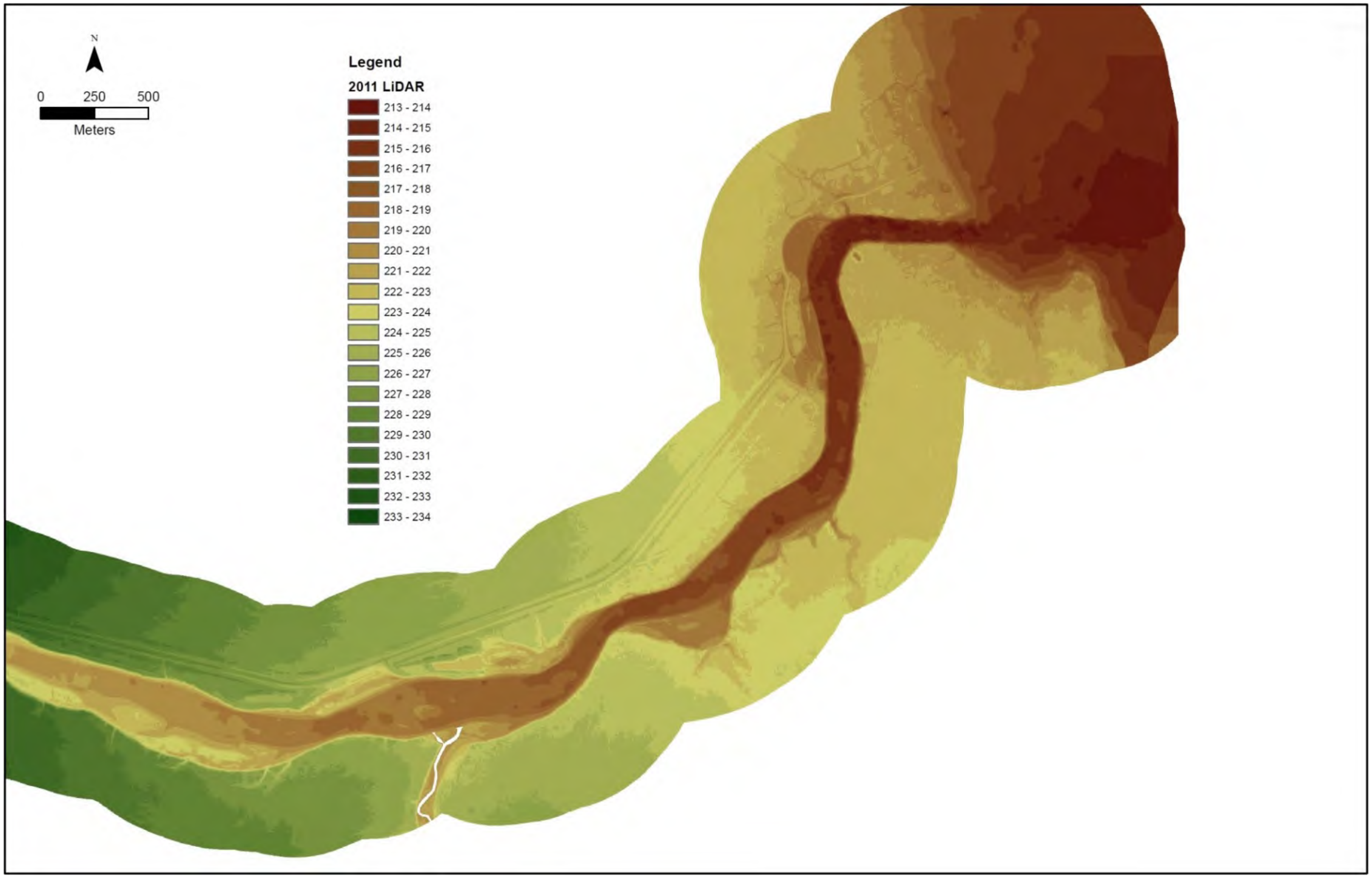
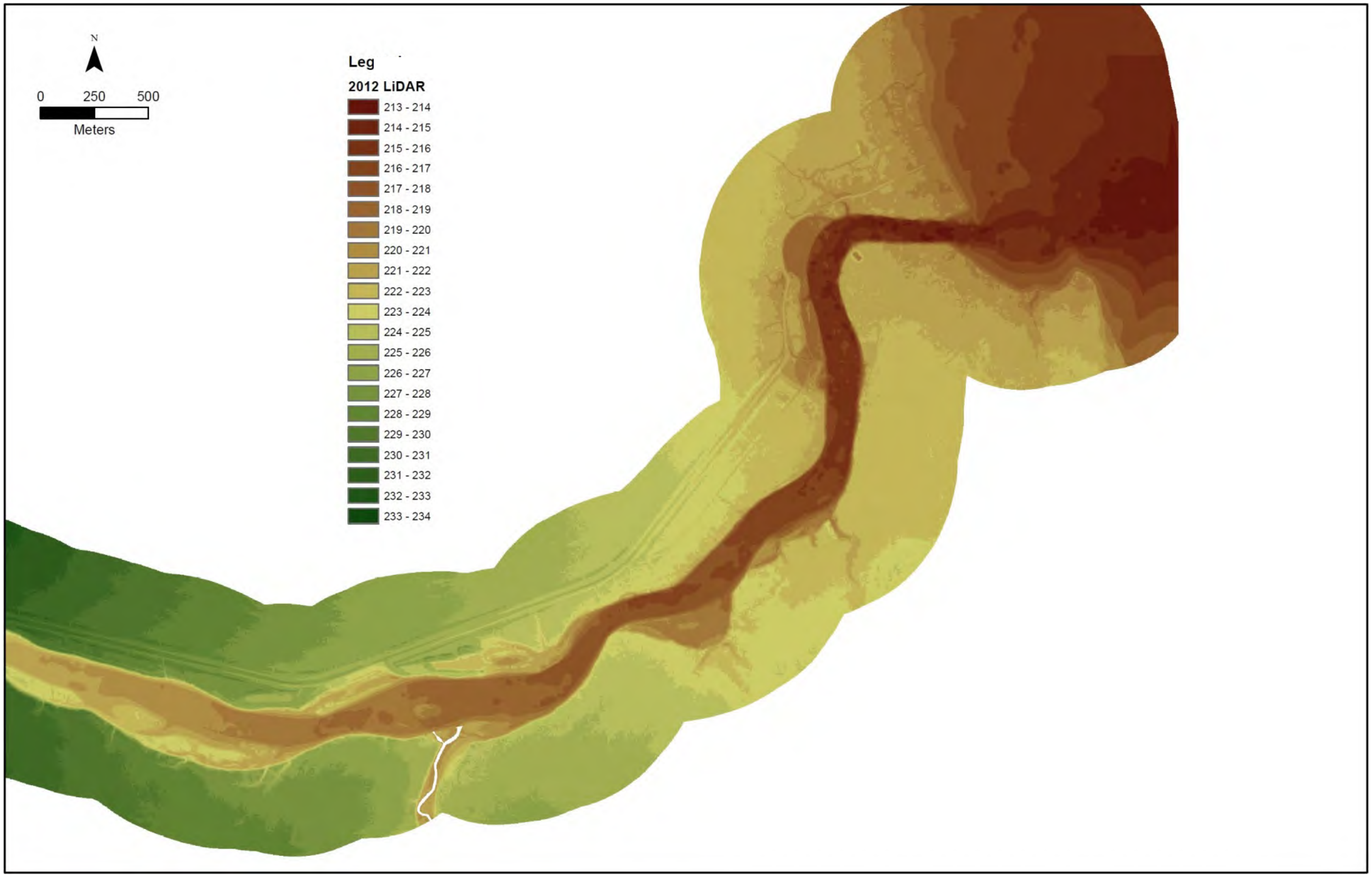


FIGURE 4.3-3
2012 DIGITAL ELEVATION MODEL BUILT BASED ON 2012 RIVER SONAR SURVEY DATA AND 2011 LIDAR SURVEY DATA

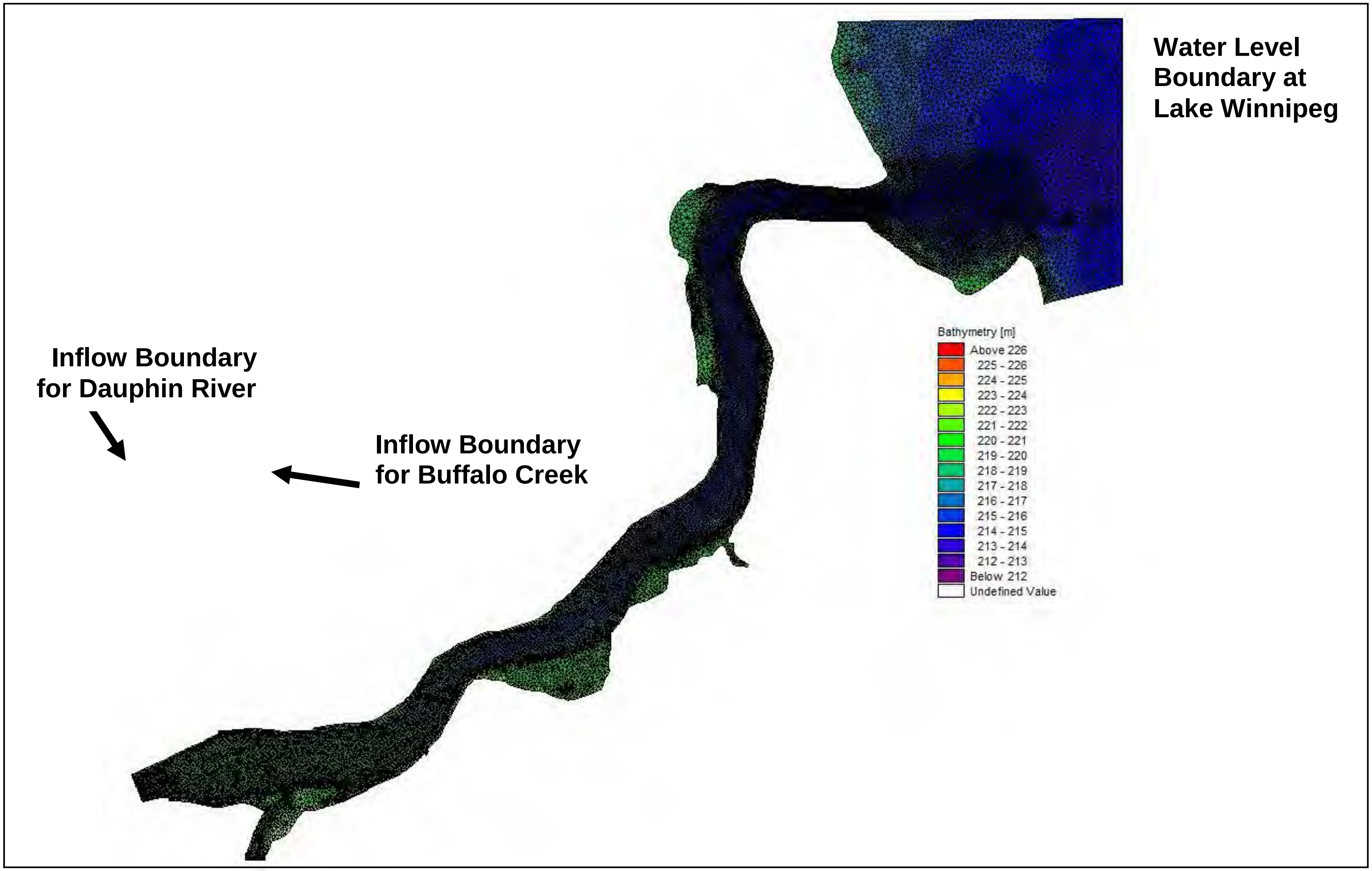


The computational mesh was diligently designed with a combination of quadrangular and triangular elements. The quadrangular mesh was only used in Buffalo Creek to adequately represent the narrow river channel, while the triangular mesh was applied to the rest of the study area. A refined mesh was used on Buffalo Creek, the Dauphin River and Sturgeon Bay. A coarser mesh was used in Lake Winnipeg away from shore.

Once the appropriate mesh sizing was established, the digital elevation data exported from the DEM was imported into the MIKE 21 model for mesh interpolation. Mesh interpolation is the process of draping the computational mesh onto the topographic and bathymetric data to assign the elevation data to the mesh. The mesh development incorporated the features captured in the DEM to facilitate the interpolation of the DEM to the mesh. The model geometry for the 2011 and 2012 MIKE 21 models were developed based on the DEM of the corresponding year. Figure 4.3-4 shows the mesh development and the location of model boundaries in the study area for 2011 and is typical of what would be shown for 2012.

The upstream boundary conditions of the MIKE 21 model consisted of inflow hydrographs at the on Dauphin River and Buffalo Creek. A water level was applied at the downstream boundary of the model on Lake Winnipeg.

FIGURE 4.3-4
MESH DESIGN WITH 2011 RIVER BATHYMETRY AND LOCATION OF MODEL BOUNDARIES



4.3.2 Model Calibration

The MIKE 21 model was calibrated to the hydraulic conditions observed during the summer of 2011 and 2012. The riverbed roughness coefficient (Manning's 'n' value) distribution in the model was adjusted in the study area to represent the July 2, 2011 and June 20, 2012 conditions, defined as follows:

- July 2, 2011

  Dauphin River inflow of 568 m³/s, as recorded at the WSC hydrometric Station 05LM006
  Buffalo Creek inflow of 2 m³/s, assumed in the absence of available data.

  Lake Winnipeg Water Level at El. 218.17 m, as surveyed by KGS Group.

- June 20, 2012

  Dauphin River inflow of 215 m³/s, as recorded at the WSC hydrometric Station 05LM006
  Buffalo Creek inflow of 122 m³/s, as computed with the routing model of the LSMEOC system.

  Lake Winnipeg Water Level at El. 217.74 m, as surveyed by KGS Group.

Surveyed water levels recorded in July 2011 and June 2012 (see Figures 4.3-5 and 4.3-6, respectively) were compared with the simulated water surface profiles from the MIKE 21 model with various roughness coefficients ranging from 0.016 to 0.020. The simulated water levels using a Manning's number of 0.018 were determined to give the best representation of the surveyed conditions.

FIGURE 4.3-5
LOWER DAUPHIN RIVER MIKE 21 MODEL CALIBRATION USING 2011 SUMMER FLOW

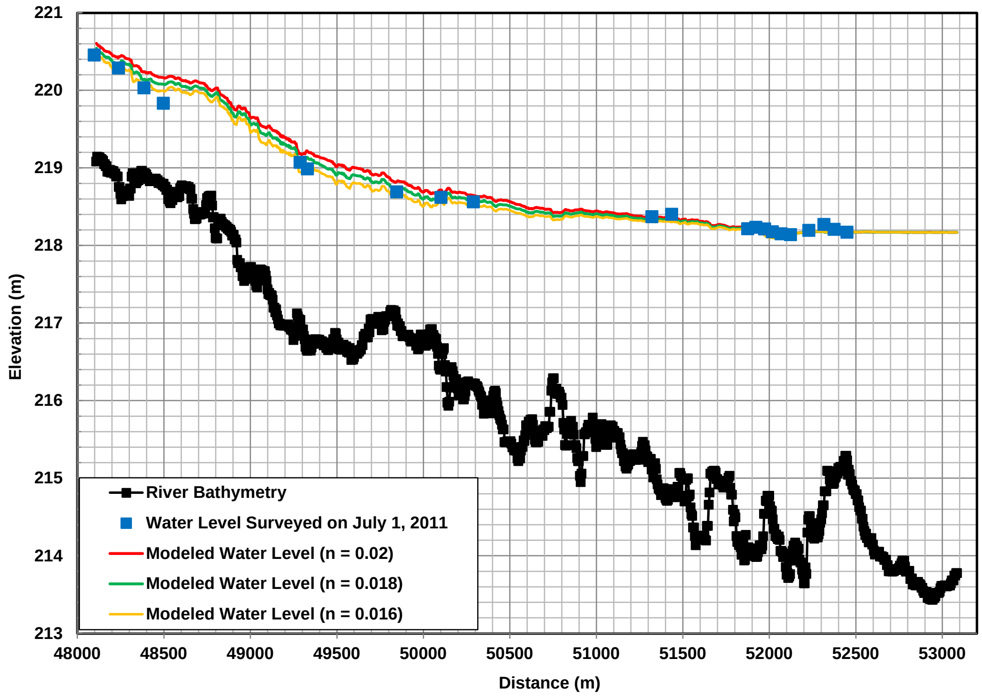
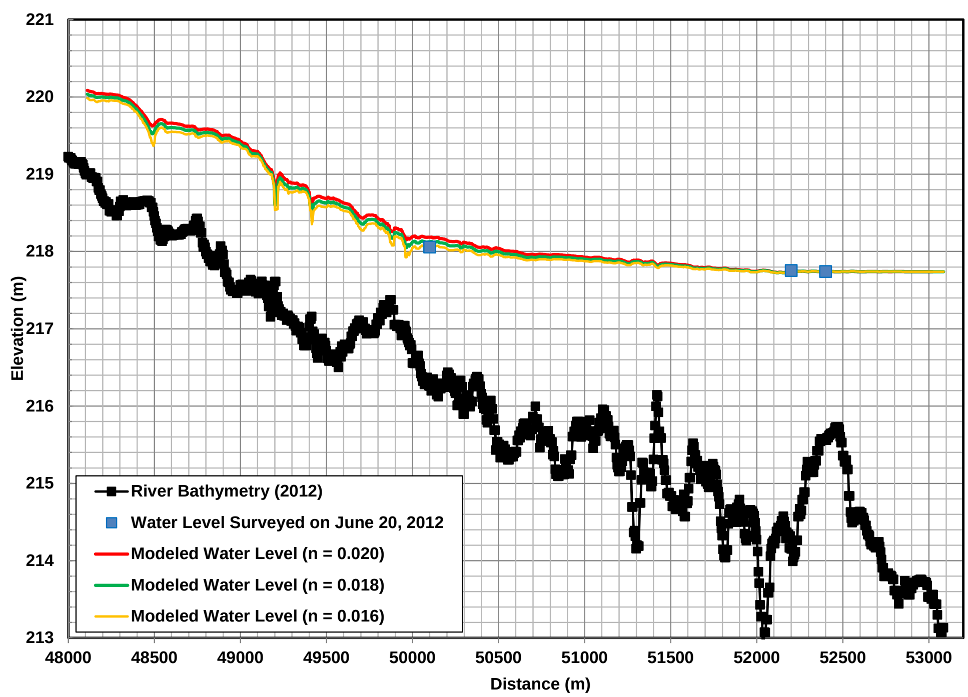


FIGURE 4.3-6
LOWER DAUPHIN RIVER MIKE 21 MODEL CALIBRATION USING 2012 SUMMER FLOW



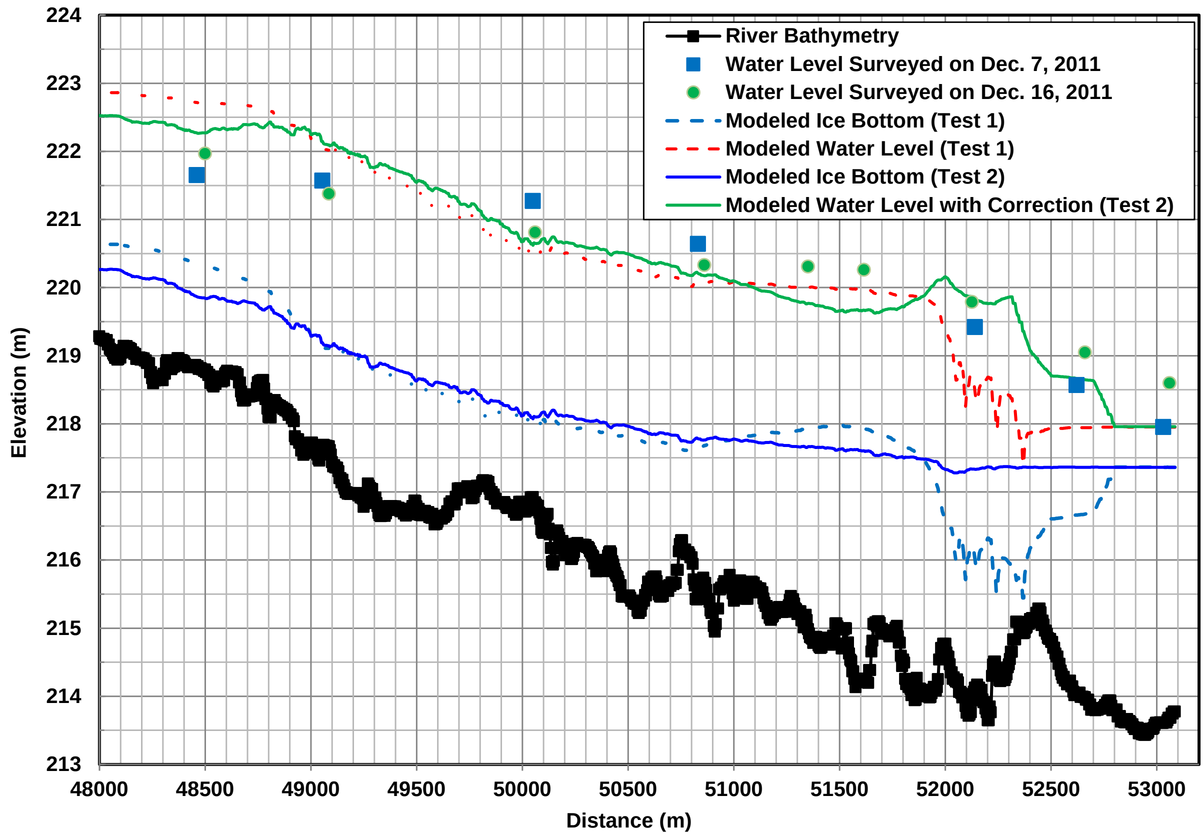
Ice covered conditions were also simulated with the MIKE 21 model. The calibration of the MIKE 21 model with presence of an ice cover was completed by adjusting the roughness coefficient of the ice-cover. The value of the ice-cover roughness coefficient can be defined as a variable dependant on its thickness.

The ice processes on the Dauphin River are fairly complex. The steep river slope existing on the lower Dauphin River is prone to the formation of frazil ice pans that generally accumulate to form an ice dam. Upstream velocities are then reduced due to the backwater effect resulting from the presence of the ice dam, which helps the formation of a stable ice cover. When the ice dam reaches a certain height, the accumulated ice is pushed further downstream as a result of the difference in head across the ice dam, leading to a decrease of the water level on its upstream side. Typically by the middle of the winter, an ice cover is formed and the water levels in the river tend to stabilize.

Water levels were surveyed by KGS Group between November 20 and December 17, 2011 as well as January 6, 2012. The surveyed water levels reached a maximum on December 10, 2011 due to the accumulation of frazil ice, and then the river adjusted itself to relatively stable water levels after December 15, 2011.

Calibration of the 2D model was done using a variable ice-cover roughness distribution computed from an independent 1D numerical ice model based on observed conditions as well as a uniform ice-cover with a constant thickness. The simulated water surface profiles obtained with both methods were compared with the water levels surveyed on December 7 and 16, 2011 with a Dauphin River flow of 446 m^3/s. A uniform ice cover of 0.65 m with a roughness of 0.038 was determined to achieve both numerical stability of the model and a good representation of the average ice conditions in winter on the lower Dauphin River. A comparison of the simulated and surveyed water levels is shown in Figure 4.3-7.

FIGURE 4.3-7
LOWER DAUPHIN RIVER
ICE MODELING TESTS USING MIKE 21 MODEL OF THE DAUPHIN RIVER



4.3.3 Lower Dauphin River Model Simulations

The calibrated MIKE 21 model based on the 2011 DEM was developed to analyse the flow characteristics in the Dauphin River. Three flow conditions, representing approximately the 10th percentile, 50th percentile and 90th percentile flows, were selected for simulation according to the flow duration curve with and without operation of the LSMEOC for the period from July 2011 to July 2012 and the flow hydrograph of the Dauphin River as described in Section 3.1.2. Lake Winnipeg Water levels that occurred during the 2011 to 2012 period under similar flow conditions were taken from WSC Gauge Station 05SD002.

Table 4.3.1 summarizes the flows and water levels for six simulations that were developed. Based on the Dauphin River Hydrograph, Cases 1, 2, 5 and 6 were simulated under open water conditions. Cases 3 and 4 were simulated under the winter since the 50th percentile flow condition mostly occurred during the 2011/2012 winter period.

TABLE 4.3.1
MIKE 21 SIMULATIONS AND RELATED FLOW CONDITIONS

Case No.	Total Flow (m³/s)	Operation of the LSMEOC	Dauphin River Flow (m³/s)	Buffalo Creek Flow (m³/s)	Lake Winnipeg Level (m)
1	340 (10th percentile)	With Operation	220	120	217.75
2		Without Operation	338	2	217.75
3	430 (50th percentile)	With Operation	299	131	217.57
4		Without Operation	428	2	217.57
5	590 (90th percentile)	With Operation	431	159	217.77
6		Without Operation	588	2	217.77

4.3.4 Flow Pattern Analysis

The flow velocity is a key parameter to evaluate the flow characteristics in the river. For each flow condition, a plate was produced to show the flow velocities in the Dauphin River with and without operation of the LSMEOC and the flow velocity differences between the two cases. For example, Drawing 9 shows the flow velocities in the Dauphin River for the 10th percentile flow with (Case 1) and without (Case 2) operation of the LSMEOC and the flow velocity differences between Cases 1 and 2. Similarly, Drawing 10 shows the flow velocities and velocity differences for the 50th percentile flow (Cases 3 and 4) and Drawing 11 shows the flow velocities and velocity differences for the 90th percentile flow (Cases 5 and 6).

For the 10th percentile flow, Drawing 9 shows that flow from Buffalo Creek enters the Dauphin River at very high velocities (>3 m/s) with operation of the LSMEOC. In the Dauphin River, the flow velocities were greater than 1 m/s for nearly the entire reach with velocities greater than 1.5 m/s from Station 48+800 to 50+200, just downstream of the Buffalo Creek junction. Near the junction area, the flow patterns differ between simulations with and without operation of the LSMEOC. This is due to the difference in flow distribution between the Dauphin River and Buffalo Creek, with and without operation of the LSMEOC. The Dauphin River flow rates without operation of the LSMEOC are higher than flows with operation of the LSMEOC, which results in higher flow velocities in the Dauphin River near and upstream of the junction. Flow velocities then become identical between simulations with and without operation of the LSMEOC, downstream of Station 49+200 in the Dauphin River (far right map on Drawing 9). This indicates that the flow pattern in the Dauphin River downstream of Station 49+200 was not affected by the operation of LSMEOC.

Similar flow velocity features can be found in the model results for the 50^{th} (Drawing 10) and 90^{th} percentile (Drawing 11) flows. However, velocities in the Dauphin River increased as the flow rates increased. The flow pattern in the Dauphin River downstream of Station 49+200 was nearly unaffected by the operation of LSMEOC (far right map on Drawings 10 and 11).

4.4 DAUPHIN RIVER SEDIMENT TRANSPORT ANALYSIS (STA-1)

Erosion and sediment deposition in the Dauphin River were analyzed based on the flow characteristics mentioned in Section 4.3 and the riverbed substrates documented in Volume 4 – Fish Habitat. The results of this analysis are documented in the sub-sections that follow.

4.4.1 Riverbed Substrates and Gradations

Preliminary substrate surveys conducted by NSC in 2011 and 2013 (see Volume 4) indicate that the riverbed material downstream of Station 50+500 was comprised of areas of gravel and sand (called sandy gravel hereafter). From Station 51+200 to Lake Winnipeg and into Sturgeon Bay, a high percentage of the substrate was gravel and sand. Upstream from Station 50+500, however, riverbed materials were comprised of more compact materials and contained cobble/gravel (called gravelly cobble hereafter), and boulder/cobble. After reviewing the background information (including the sample photos) and the unified soil classification system SCS, the following gradation for “sandy gravel” was adopted:

- Gravel (64 – 2 mm): 45% - 60%;
- Sand (2 – 0.063 mm): 30% - 25%; and
- Silt and Clay (less than 0.063 mm): 10% - 20%.

The following gradation was adopted for "gravelly cobble":

- Cobble (256 – 64 mm): 10% - 15%;
- Gravel (64 – 2 mm): 40% - 50%;
- Sand (2 – 0.063 mm): 15% - 20%; and
- Silt and Clay (less than 0.063 mm): 5% - 20%.

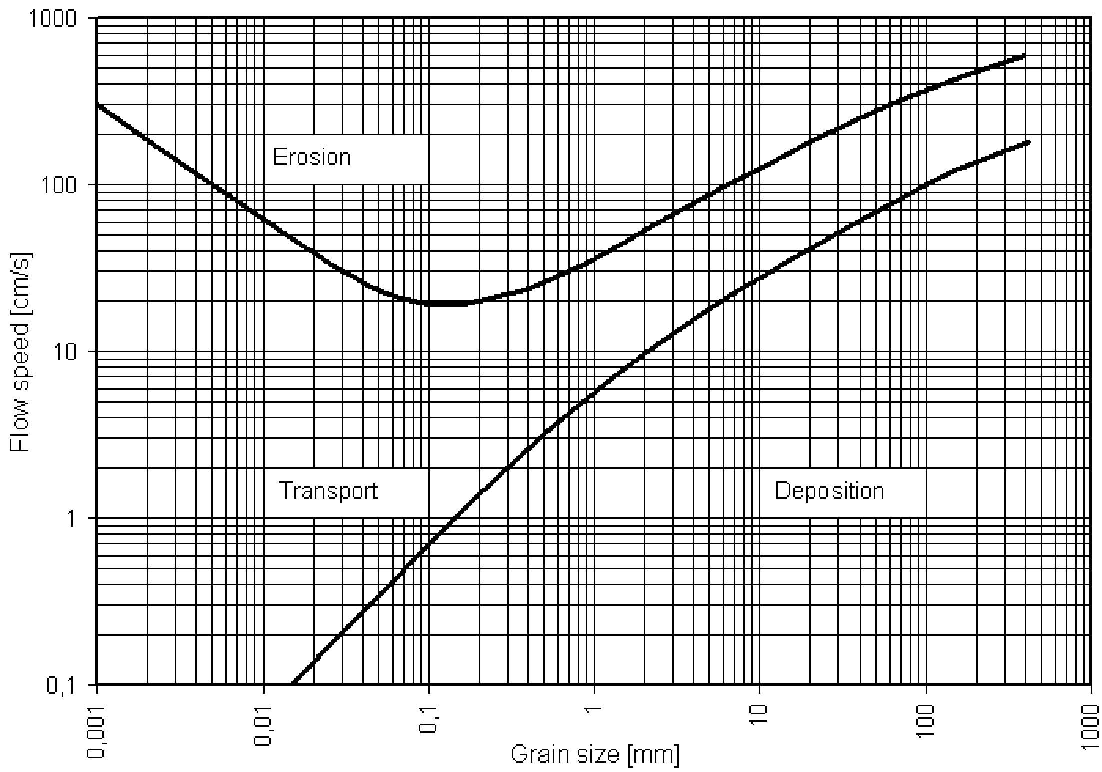
4.4.2 Erosion and Deposition Analysis Based on River Hydrodynamics

To assess whether the Dauphin River erodes, transports or deposits sediment, Table 4.4-1 was developed based on the Hjulstrom curve (Figure 4.4-1) and listed the critical velocities for erosion or deposition with different particle sizes.

TABLE 4.4-1
CRITICAL FLOW VELOCITIES FOR DEPOSTION AND EROSION

Grain Material	Grain Size Upper Limit (mm)	Critical Flow Velocity for Deposition (m/s)	Critical Flow Velocity for Erosion (m/s)
Silt/Clay	0.063	0.004	0.21
Sand	2	0.1	0.52
Gravel	64	0.77	2.98
Cobble	256	1.47	5.09

FIGURE 4.4-1
HJULSTROM CURVE



Sediment Deposition

At first, the sediment deposition in the Dauphin River was assessed for the various flow conditions mentioned in Section 4.3. Drawing 12 was generated based on the modelled flow velocities for the 10^{th}, 50^{th} and 90^{th} percentile flows using the scales of critical flow velocity for deposition listed in Table 4.4-1. The maps shown on the Drawing show that:

- For the 10^{th} percentile flow, the flow velocities in the Dauphin River are mostly higher than 0.77 m/s. Therefore the sediment from upstream of either the Dauphin River or Buffalo Creek with particle sizes < 2 mm, such as silt/clay and sand, would likely be transported in the river flow and deposited in Lake Winnipeg far from the river mouth area where the flow velocities are less than 0.1 m/s. The sediment with particle sizes between 2 mm to 64 mm, such as gravel, would likely be deposited near the shoreline from Station 50+800 to Station 51+600 or in Lake Winnipeg near the river mouth area where the flow velocities are less than 0.77 m/s. The sediment with particle sizes between 64 mm and 256 mm, such as cobble, would likely be deposited upstream of Station 48+800 and downstream of Station 50+200 in the Dauphin River where the flow velocities are less than 1.47 m/s;

- For the 50th percentile flow, the flow velocities in the Dauphin River are higher than 0.77 m/s. The sediment from upstream of either the Dauphin River or Buffalo Creek with particle sizes < 64 mm, such as silt/clay, sand and gravel, would likely be transported in the river flow and deposited in Lake Winnipeg near the river mouth area where the flow velocities are less than 0.77 m/s. The sediment with particle sizes between 64 mm and 256 mm, such as cobble, would likely be deposited upstream of Station 48+800 or downstream of Station 50+200 in the river or in Lake Winnipeg near the river mouth area where the flow velocities are less than 1.47 m/s; and
- For the 90th percentile flow, the flow velocity distribution in the Dauphin River is similar to the 50th percentile flow. Therefore the sediment deposition trends are similar to the 50th percentile flow.

Although the 10th, 50th and 90th percentile flow conditions were based on the July 2011 to July 2012 period (based on the dates of the bathymetric surveys), these flows are likely representative of the flow characteristics of both operating periods of the LSMEOC (2011/2012 and 2014/2015) due to the wide range of flows considered in the analysis and similarity in operating conditions. During the closure period (2012-2014), flows were generally less in the Dauphin River and, therefore, only the 10th percentile condition would be considered representative for this period.

Based on the sediment deposition analysis of the 2D model results for the 10th, 50th and 90th percentile flows, it can be concluded that:

- Sediment with particle sizes < 2 mm, such as silt/clay and sand, is likely to be transported in the river flow and deposited in Lake Winnipeg far from the river mouth area. The sediment was unlikely to deposit in the Dauphin River;
- Sediment with particle sizes between 2 mm and 64 mm, such as gravel, has the potential to be deposited near the shoreline from Station 50+800 to Station 51+600 for low flows and/or in Lake Winnipeg near the river mouth area for high flows; and
- Sediment with particle sizes between 64 mm and 256 mm, such as cobble, has the potential to be deposited upstream of Station 48+800 and downstream of Station 50+200 in the Dauphin River and in Lake Winnipeg.

As mentioned in Section 4.2 (Table 4.2.2), the water quality was continuously monitored after September 2011 in different phases and a gradation of TSS was tested in the Laboratory for selected samples. The lab tests showed that the particles in the TSS samples were all less than 0.1 mm. Based on the flow velocity characteristics in the Dauphin River, all of the TSS sediment from either the Dauphin River or Buffalo Creek would have likely been transported to Lake

Winnipeg and deposited in the areas far from the river mouth, and would likely not have been deposited in the Dauphin River channel.

As also discussed in section 4.2, the results of bedload surveys prior to, during and after the 2014 flood indicated that there was a very small amount of material transported as bedload in the lower Dauphin River. Since some of this material was greater than 2mm in diameter, some of this material could have been deposited within the Dauphin River Channel. However, based on the results of the bedload survey, it could not be concluded that there was an increase in the Dauphin River bedload due to operation of the LSMEOC.

Riverbed Erosion

To assess riverbed erosion in the Dauphin River, Drawing 13 was generated based on the modelled flow velocities for the 10th, 50th and 90th percentile flows using the scales of critical flow velocity for erosion listed in Table 4.4-1. Since the flow velocities in the Dauphin River are higher than 0.52 m/s for all of the 10th, 50th and 90th percentile flows, the bed materials including silt/clay, sand and gravel with particle sizes < 64 mm can be eroded in the Dauphin River. The bed material for cobbles with particle sizes between 64 mm to 256 mm can be eroded in the very limited areas where the flow velocities are higher than 2.98 m/s, as is the case near the Buffalo Creek entrance for all of the 10th, 50th and 90th percentile flows or near Station 49+200 in the Dauphin River for the 90th percentile flow only (far right map on Drawing 13).

The gradation of gravel is in a wide range from 2 mm to 64 mm and the related critical velocities for erosion vary from 0.52 m/s to 2.98 m/s. To further analyze the gravel erosion in the river, Table 4.4-2 was developed based on the Hjulstrom curve to show specifically the critical velocities of erosion and deposition for different grain sizes of gravel.

TABLE 4.4-2
CRITICAL FLOW VELOCITIES FOR DEPOSITION AND EROSION FOR VARIOUS GRAVELS

Grain Material	Grain Size Upper Limit (mm)	Critical Flow Velocity For Deposition (m/s)	Critical Flow Velocity For Erosion (m/s)
Very coarse gravel	64	0.77	2.98
Coarse gravel	32	0.54	2.23
Medium gravel	16	0.36	1.54
Fine gravel	8	0.24	1.11
Very fine gravel	4	0.15	0.76

Drawing 14 was generated based on the modelled flow velocities for the 10th, 50th and 90th percentile flows using the scales of critical flow velocity for erosion listed in Table 4.4-2. Based on Drawing 14, it was found that:

- Gravel on the riverbed with sizes between 2 mm and 8 mm has the potential to be eroded almost everywhere in the river since the flow velocity is greater than 0.52 m/s in the river for all of the 10th, 50th and 90th percentile flows;
- Gravel on the riverbed with sizes between 8 mm and 16 mm has the potential to be eroded upstream of Station 50+800 and the partial area downstream of Station 50+800 in the river channel for the 10th percentile flows and almost everywhere in the entire river for the 50th and 90th percentile flows, where the flow velocity is greater than 1.11 m/s;
- Gravel on the river bed with a sizes between 16 mm and 32 mm has the potential to be eroded in the river channel from Station 48+400 and the partial area downstream of Station 50+000 for the 10th percentile flows. Erosion also has the potential to occur almost everywhere in the river channel upstream of Station 50+800 and in the centre of the river channel downstream of Station 50+800 for the 50th and 90th percentile flows where the flow velocity is greater than 1.54 m/s; and
- Gravel on the riverbed with sizes between 32 mm and 64 mm has the potential to be eroded only in small areas in the river channel near the Station 49+000 for the 10th percentile flows and in a short reach from Station 48+800 to Station 50+00 for the 50th and 90th percentile flows where the flow velocity is greater than 2.23 m/s.

Based on the erosion analysis of the 2D model results for the 10th, 50th and 90th percentile flows, it can be concluded that in the Dauphin River:

- Material with particle sizes < 8 mm, such as silt/clay, sand, very fine gravel and fine gravel, has the potential to be eroded from the riverbed almost in the entire reach; and
- Material with particle sizes of 8 mm and bigger than 8 mm, such as medium gravel, coarse gravel, very coarse gravel and cobble has the potential to be eroded from the riverbed in some river reaches depending on the flow rates of the river.

As discussed in Section 3.1, high flows (and therefore velocities) in this reach of the river would have occurred regardless of operation of the LSMEOC. Therefore, any erosion that may have occurred within this reach is a result of natural processes and cannot be attributed to operation of the LSMEOC alone.

Comparison to Bathymetric Survey Results

Considering the results of the 2D model summarized above, it can be concluded that erosion and sediment deposition processes occur naturally on this reach of the Dauphin River and that they are highly dynamic. Erosion can be defined by conditions at the site, but deposition depends on a source of material to deposit. The latter is impossible to predict on theoretical grounds alone and would require years of suspended sediment and bedload measurements under a wide range of flow conditions to quantify.

The river bathymetry surveys that were conducted throughout the duration of project, as discussed in Section 3.5, showed no obvious or consistent patterns in changes to the riverbed. The difference in elevation appeared to occur randomly throughout the surveyed portion of the Dauphin River. In addition, there was no conclusive evidence of a correlation between erosion and deposition within this reach of river, and operation and closure periods of the LSMEOC.

The results of the bathymetric survey comparison are generally consistent with the results of the 2D model. Areas of erosion were expected due to the high velocities present in the river. However, the special variability of composition of the bed material, the self-armoring effects of the riverbed (i.e. the formation of a coarser and harder to move layer at the surface of the channel bed) over decades of natural morphological changes, and the potential movement of larger size particles via bedload would all have contributed to random variability in deposition and erosion that was observed in the Dauphin River.

4.4.3 Sediment Transport Modeling

To further confirm the erosion and deposition analysis based on the flow patterns, a sediment transport model was developed using MIKE 21 Mud Transport Module (MTM). The MIKE 21 Mud Transport Module, developed by DHI Group, is an add-on module to MIKE 21 FM. It is used to simulate erosion, transport and deposition processes of mud or sand/mud mixture under the action of currents and waves.

The input parameters for MTM include the properties of sediment in the water (such as settling velocity, critical shear stress for deposition, density, etc.) and the properties of the riverbed (such as critical shear stress for erosion, erosion coefficient, dry density, etc.). Those parameters have to be well calibrated/verified using detailed survey data. Although a substantial amount of data was collected as part of the project, specific details that were required prior to the 2011 flood to calibrate and verify the model such as river bedload data and river substrate samples were not available. Additionally, as discussed in Section 3.5, assumptions were made when developing the Digital Elevation Model (DEM) of the Dauphin River, and interpolations were required between data points in the model that resulted in accuracy between interpolation points in the order of ± 0.5 m. Due to the limited amount of survey data available prior to the 2011 flood and the limitations associated with the DEM, the MTM was not able to be thoroughly calibrated for the 2011/2012 operation period. Therefore, only the preliminary model results are provided based on the data that was available.

The MIKE21 model with MTM continuously simulated the flows with operation of the LSMEOC from July 1, 2011 to June 20, 2012 initially based on the 2011 bathymetry. The flows of the Dauphin River and Buffalo Creek in the same period were estimated based on the hydrographs presented in Section 3.1 and used as the inflow boundary conditions. The water level boundary data for Lake Winnipeg was obtained from the WSC Gauge Station 05SD002. The ice cover with a uniform thickness of 0.65 m, as described in Section 4.3.1, was added to the model during the winter time.

The monitored TSS data (Section 3.2) was used as the boundary condition for the sediment from the Dauphin River and the Buffalo Creek. The riverbed material was defined based on the substrate surveys conducted by NSC in 2011 (Volume 4 – Fish Habitat). Other input parameters for MTM related to the properties of sediment and riverbed were estimated based on the substrate survey data and experience.

Drawing 15 shows the modelled bed level changes in the Dauphin River from July 1, 2011 to June 20, 2012. Since the model could not be calibrated, as noted previously, the results cannot be used to quantify the volume of erosion or deposition that occurred in the lower Dauphin River. Rather, the results provide an indication of areas that have a potential for erosion or deposition and should be used only with other analyses and results presented in this report.

The results of the model indicated a potential for erosion in the Dauphin River near Station 50+600 and in the reach from Station 51+000 to Station 52+200. As well, it indicated a potential for erosion at the exit of Buffalo Creek due to the high flow velocities from the creek during operation of the LSMEOC. The model results also showed that there was a potential for deposition in Lake Winnipeg near the mouth area due to the reduction in flow velocities. It also indicated a potential for minor deposition along the shorelines of the Dauphin River downstream of Station 51+000. The trends for erosion and deposition depicted by the model were consistent with the results of the Erosion and Deposition Analysis discussed in Section 4.4.2.

5.0 SUMMARY

Data collected from studies and monitoring programs that were initiated to document changes to the physical environment and potential impacts related to construction and operation of the LSMEOC System have been documented in this report. These included changes to erosion, sedimentation, vegetation cover, water quality, flow, and ice processes. Hydrometric data, total suspended solid concentrations, topographic and bathymetric surveys were used in conjunction with numerical hydraulic models to identify the potential effects of the operation of Reach 1 on the erosion and sediment deposition processes in the watershed.

Operation of Reach 1 resulted in high flows in Buffalo Creek during the 2011/2012 and the 2014/2015 operation periods. The high flows in Buffalo Creek were accompanied with high velocities, which generated some erosion of the main channel and of the creek banks, as demonstrated with a comparison of creek cross sections prior to and after operation. The TSS measurements and the empirical model results indicated that some erosion also occurred in Reach 1 during its operation. As the flows from Reach 1 travelled through Buffalo Lake and the surrounding bog towards Buffalo Creek, the bulk of the suspended sediment deposited in the bog. The sediment that was then eroded in Buffalo Creek was transported in suspension into the lower Dauphin River and Lake Winnipeg.

The volume of suspended sediment released from Buffalo Creek as a result of the operation of Reach 1 was computed utilizing the empirical model with and without operation of Reach 1. It was estimated that the 2011/2012 operation resulted in an additional total volume of 8,900 m^3 of suspended sediment at the confluence between the lower Dauphin River and Buffalo Creek, plus another 2,200 m^3 during the closure period (2012-2014) and 8,600 m3 during the 2014/2015 operation period. Analyses of the grain size distribution of the suspended solids showed that the material essentially constituted of clays and silts.

The cross section comparison in Buffalo Creek computed a total volume of displaced material of 60,000 m^3 from 2011 to 2013 and 75,000 m3 from 2013 to 2015. This represented the total volume of material that was eroded and displaced within Buffalo Creek. Some of this material went in suspension and contributed to the additional suspended sediment at the confluence between the lower Dauphin River and Buffalo Creek as computed with the empirical model.

Larger material could have been transported by bedload within the creek and may have left the system, however, measurements within the Dauphin River did not show an increase in bedload during operation of the LSMEOC. A review of the simulated velocities and shear stresses showed that most of the coarser material had deposited in the overbank areas or in reaches with lower velocities, as also confirmed by direct observations.

As simulated with the MIKE 21 2D model, the velocities in the Dauphin River are such that the suspended material would be transported several hundred meters into Sturgeon Bay, with limited potential for deposition along the Dauphin River shoreline or in back eddies. Bathymetric comparisons in the Dauphin River showed no obvious or consistent patterns in changes to the riverbed. The difference in elevation appeared to occur randomly throughout the surveyed portion of the Dauphin River. In addition, there was no conclusive evidence of a correlation between erosion and deposition patterns within this reach of river, and the operation and closure periods of the LSMEOC.

6.0 STATEMENT OF LIMITATIONS AND CONDITIONS

6.1 THIRD PARTY USE OF REPORT

This report has been prepared for North/South Consultants Inc. and Manitoba Infrastructure and Transportation to whom this report has been addressed and any use a third party makes of this report, or any reliance on or decisions made based on it, are the responsibility of such third parties. KGS Group accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions undertaken based on this report.

7.0 REFERENCES

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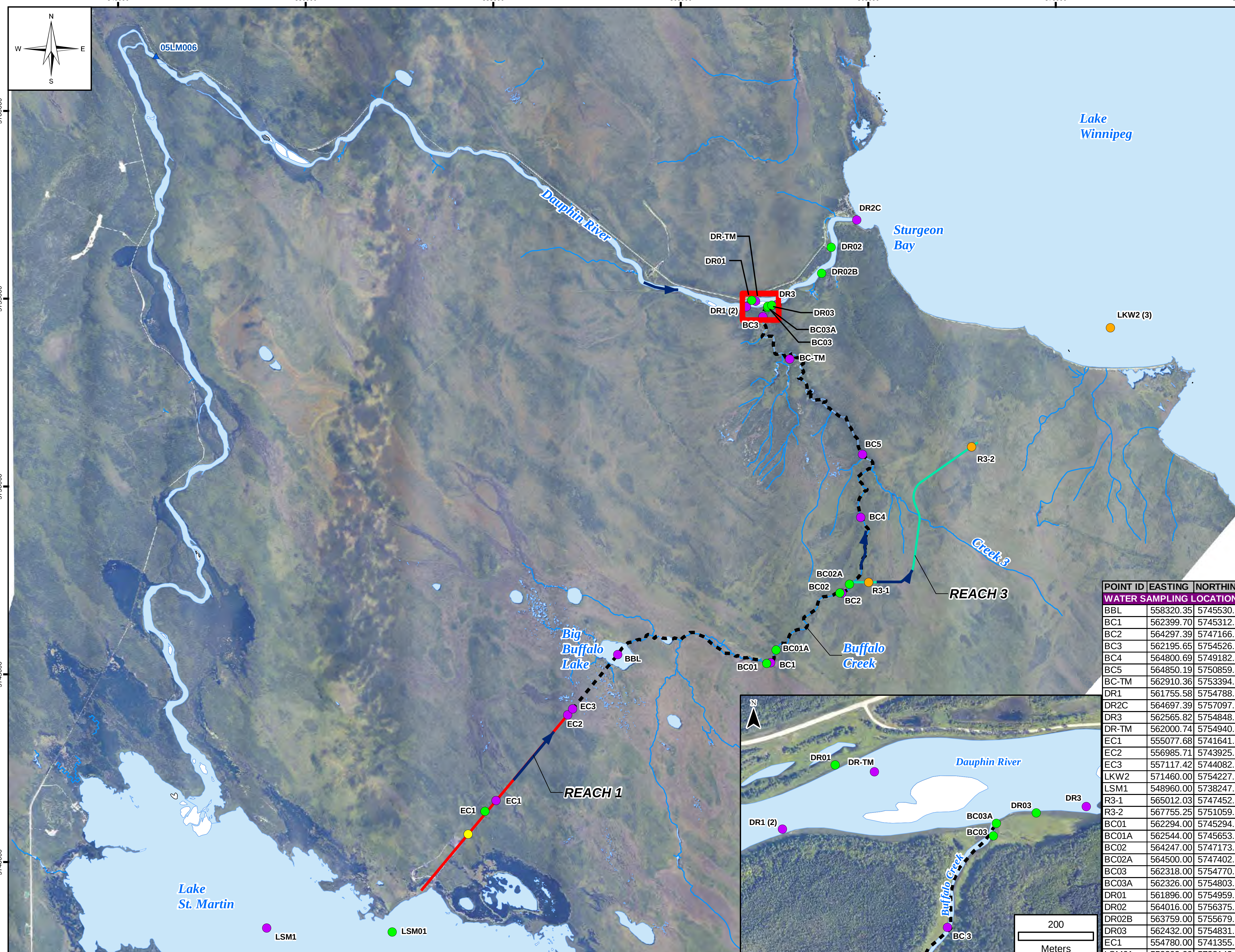
DRAWINGS



POINT ID	EASTING	NORTHING
WATER SAMPLING LOCATIONS		
BBL	558320.35	5745530.07
BC1	562399.70	5745312.28
BC2	564297.39	5747166.04
BC3	562195.65	5754526.07
BC4	564800.69	5749182.43
BC5	564850.19	5750859.47
BC-TM	562910.36	5753394.79
DR1	561755.58	5754788.03
DR2C	564697.39	5757097.77
DR3	562565.82	5754848.01
DR-TM	562000.74	5754940.44
EC1	555077.68	5741641.48
EC2	556985.71	5743925.77
EC3	557117.42	5744082.54
LKW2	571460.00	5754227.00
LSM1	548960.00	5738247.00
R3-1	565012.03	5747452.78
R3-2	567755.25	5751059.60
BC01	562294.00	5745294.00
BC01A	562544.00	5745653.00
BC02	564247.00	5747173.00
BC02A	564500.00	5747402.00
BC03	562318.00	5754770.00
BC03A	562326.00	5754803.00
DR01	561896.00	5754959.00
DR02	564016.00	5756375.00
DR02B	563759.00	5755679.00
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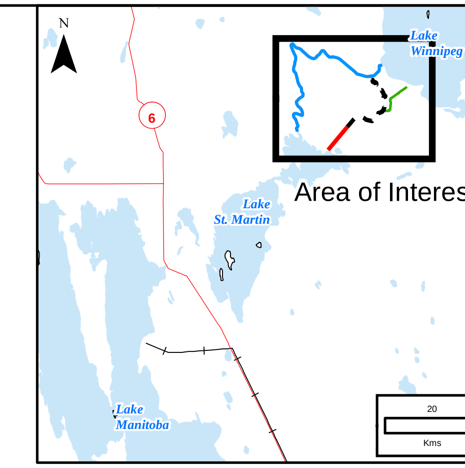

LEGEND:

- Water Survey of Canada Gauge
- Water Sampling Locations
  - Construction & Operations Monitoring
  - Proposed Reach 3 Operation Monitoring
  - 2011 Construction Monitoring
  - Reach 1 Cableway
- Direction of Surface Water Flow
- Water Feature
- Buffalo Creek Drainage System
- Reach 1 Emergency Outlet Channel
- Reach 3 Emergency Channel
- Water Feature
- Island

NOTES:

1. Aerial Imagery: July 2011.
2. This Station was continually relocated as ice staging changes on Dauphin River.
3. These Sample Stations were used as part of North/South Consultants delineation of Sturgeon Bay for the Regional Water Quality Program.
4. Due to safety concerns and/or ice cover, some Sample Stations had become inaccessible. Field crews attempted to choose appropriate surrogate Sample Stations when possible.

DRAFT

1 0 1 2 3 4
Kms

SCALE: 1:100,000 METRIC 11"x17"

All units are metric and in metres unless otherwise specified.
Transverse Mercator Projection, NAD 1983, Zone 14
Elevations are in metres above sea level (MSL)

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/01	ISSUED WITH DRAFT REPORT	PAL	MSW
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT	PAL	

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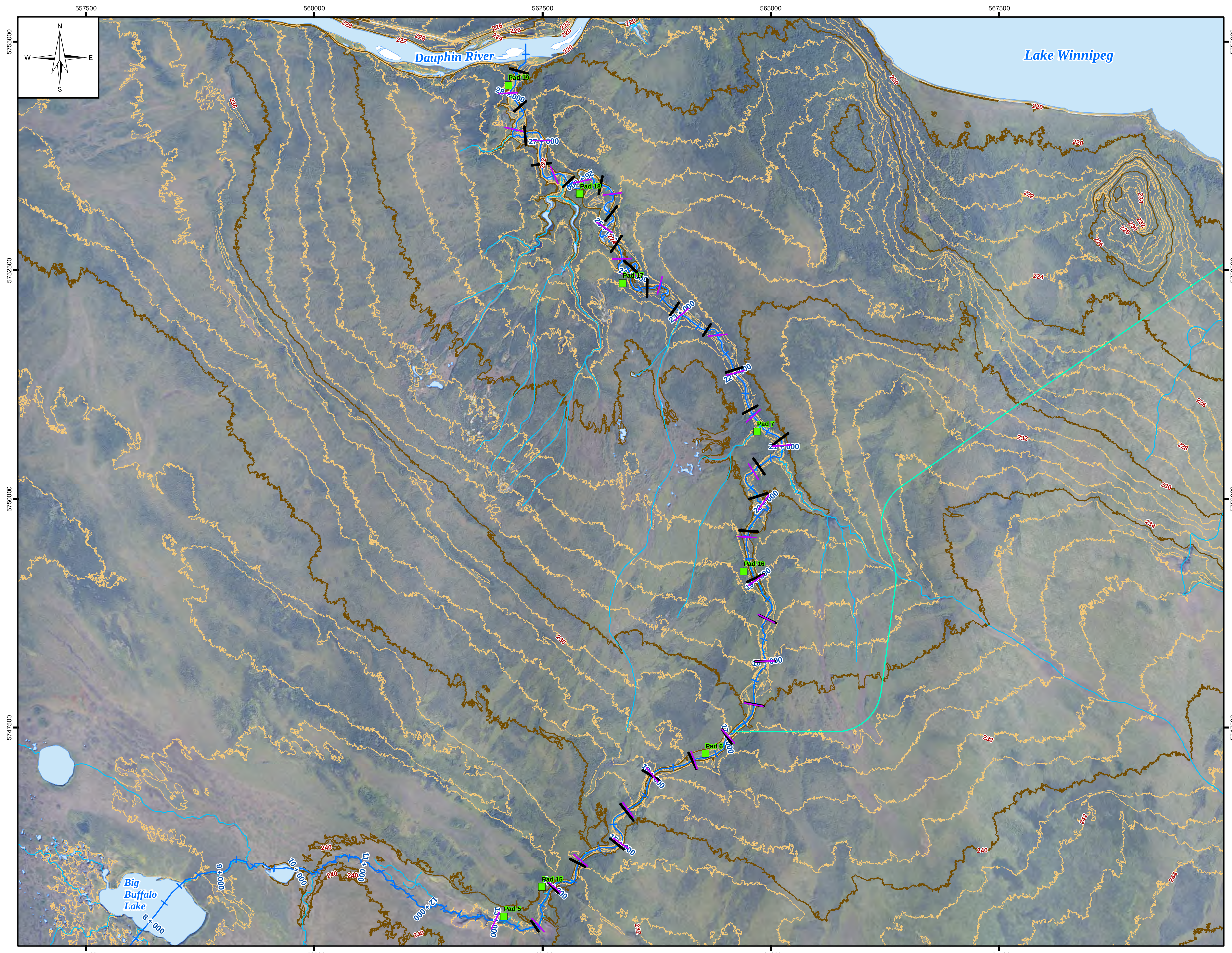
Manitoba INFRASTRUCTURE AND TRANSPORTATION
North/South Consultants Inc. Aquatic Environment Specialists

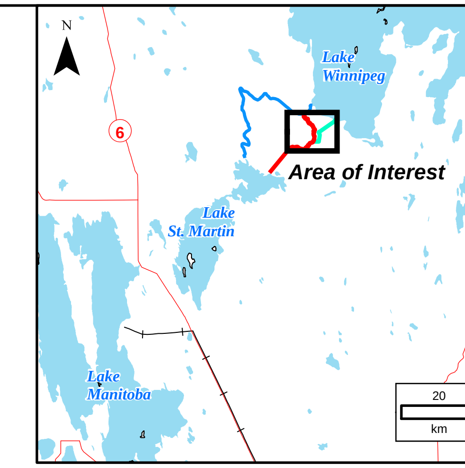
LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

LAKE ST. MARTIN EMERGENCY OUTLET CHANNEL SYSTEM – OVERVIEW OF MONITORING LOCATIONS

MARCH 2016 | DRAWING 1 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001_Fig01_RevB.mxd
11"x17" PLOT SCALE 1:1





LEGEND:

- Constructed Helicopter Landing Pad
- Vegetation Survey Transect
- Cross Section
- Buffalo Creek Centreline
- Reach 3
- 5m Index Contour
- 1m Contour
- Water Feature
- Water Feature
- Island

DRAFT

0 500 1,000 1,500 2,000
Metres

SCALE: 1:40,000 METRIC 11"x17"

All units are metric and in metres unless otherwise specified.
Transverse Mercator Projection, NAD 1983, Zone 14
Elevations are in metres above sea level (MSL)

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	STO
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT	PAL	

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LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

LOCATIONS OF BUFFALO CREEK CROSS SECTIONS AND VEGETATION COVER TRANSECTS

MARCH 2016 | DRAWING 2 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001_Fig02_RevB.mxd
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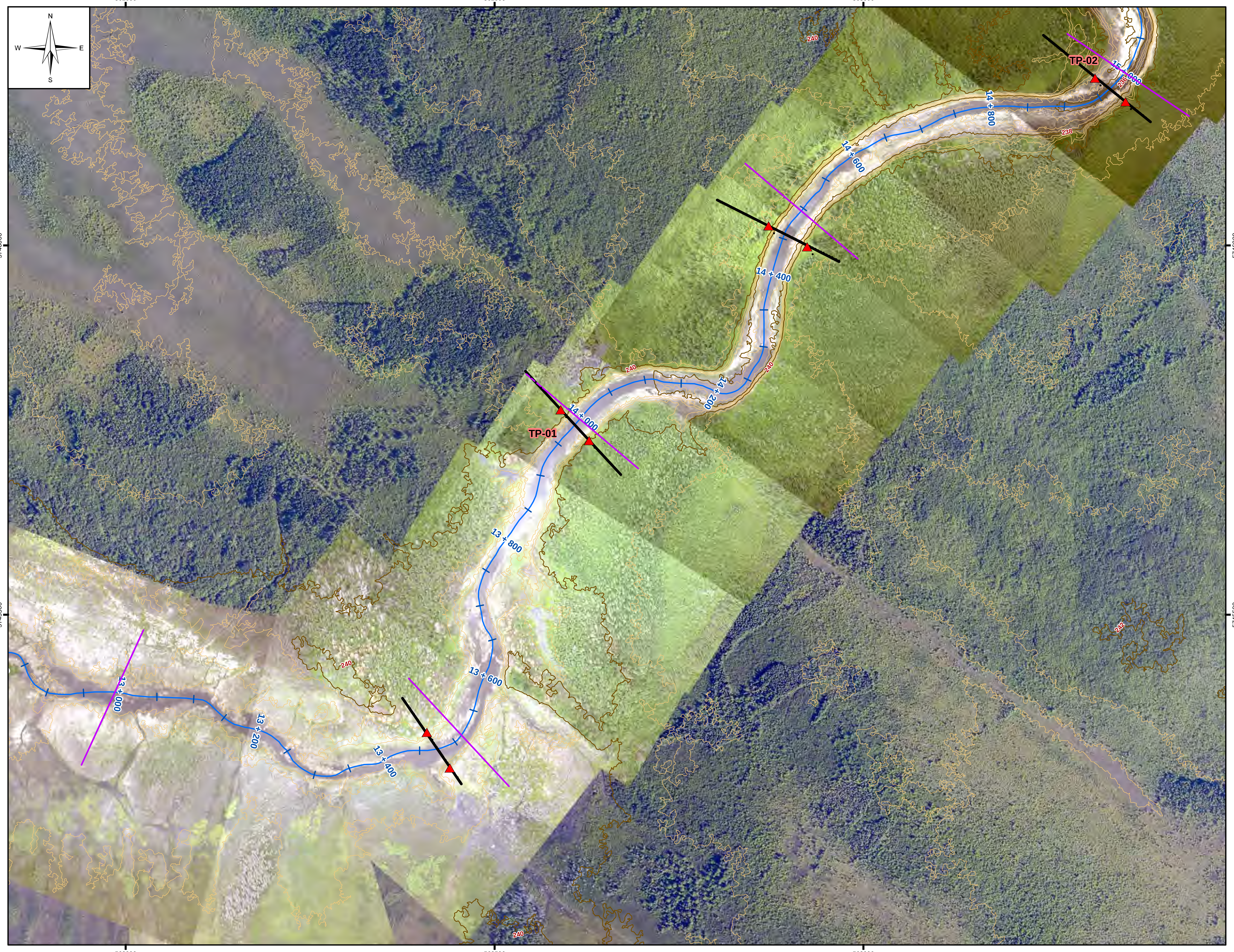

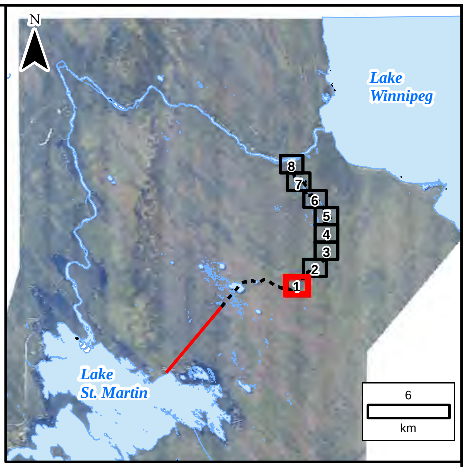

LEGEND:

- Test Pit
- KGS X-Section Survey
- Survey Point
- X-Section Pin
- Survey Control
- X-Section
- Vegetation Survey Transect
- Buffalo Creek Centreline
- 2m Index Contour
- 0.5m Contour

NOTES:

1. Georeferenced Aerial Imaging and Mapping (GAIM) flown by TAIGA Air Services Ltd on July 7th, 2013.
2. Background Satellite Image provided by Atlis Geomatics, July 2011
3. Original ground surface based on LiDAR provided by Atlis Geomatics (June/July 2011)
4. All units are metric and in metres unless otherwise specified. Transverse Mercator Projection, NAD 1983, Zone 14. Elevations are in metres above sea level (MSL)

DRAFT

50 0 50 100 150 200
Metres

SCALE: 1:5,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT	PAL	

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LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

DETAILED LOCATION PLAN OF CROSS SECTIONS, VEGETATION COVER SURVEYS AND TILL SURVEY ON BUFFALO CREEK. (SHEET 1 OF 8)

MARCH 2016 | DRAWING 3.1 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig03_RevB.mxd
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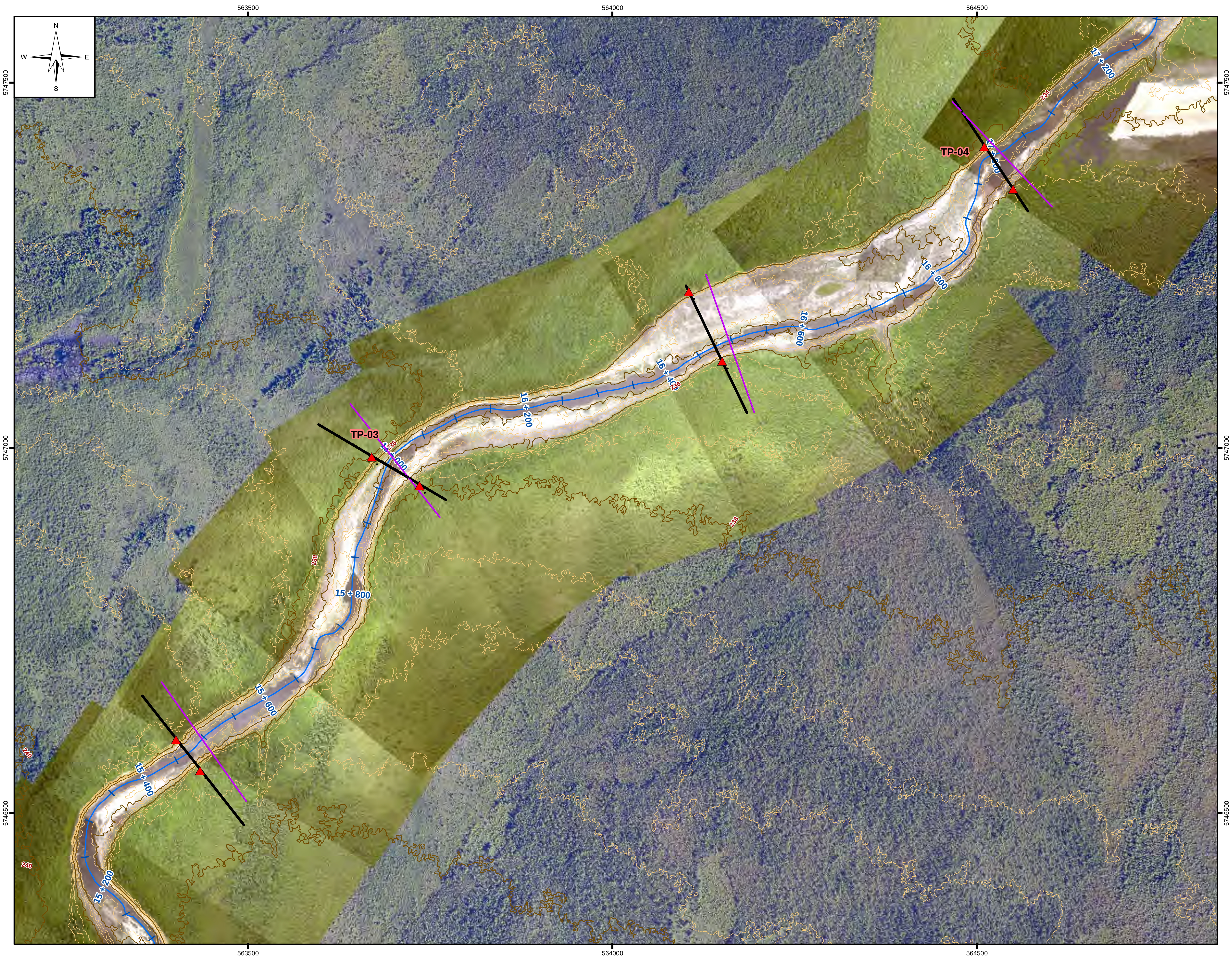

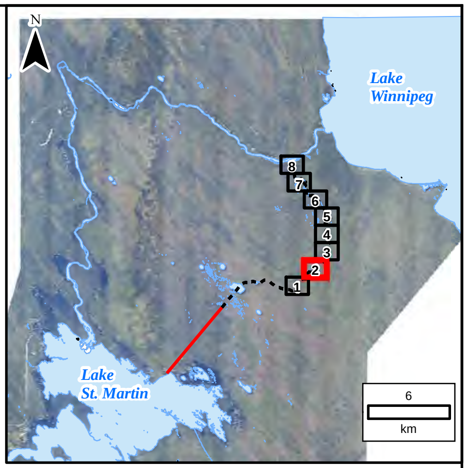

LEGEND:

- Test Pit
- KGS X-Section Survey
- Survey Point
- X-Section Pin
- Survey Control
- X-Section
- Vegetation Survey Transect
- Buffalo Creek Centreline
- 2m Index Contour
- 0.5m Contour

NOTES:

1. Georeferenced Aerial Imaging and Mapping (GAIM) flown by TAIGA Air Services Ltd on July 7th, 2013.
2. Background Satellite Image provided by Atlis Geomatics, July 2011
3. Original ground surface based on LiDAR provided by Atlis Geomatics (June/July 2011)
4. All units are metric and in metres unless otherwise specified. Transverse Mercator Projection, NAD 1983, Zone 14. Elevations are in metres above sea level (MSL)

DRAFT

50 0 50 100 150 200
Metres

SCALE: 1:5,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW

NO.	YY/MM/DD	DESCRIPTION	BY
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT	PAL

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LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

DETAILED LOCATION PLAN OF CROSS SECTIONS, VEGETATION COVER SURVEYS AND TILL SURVEY ON BUFFALO CREEK. (SHEET 2 OF 8)

MARCH 2016 | DRAWING 3.2 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig03_RevB.mxd
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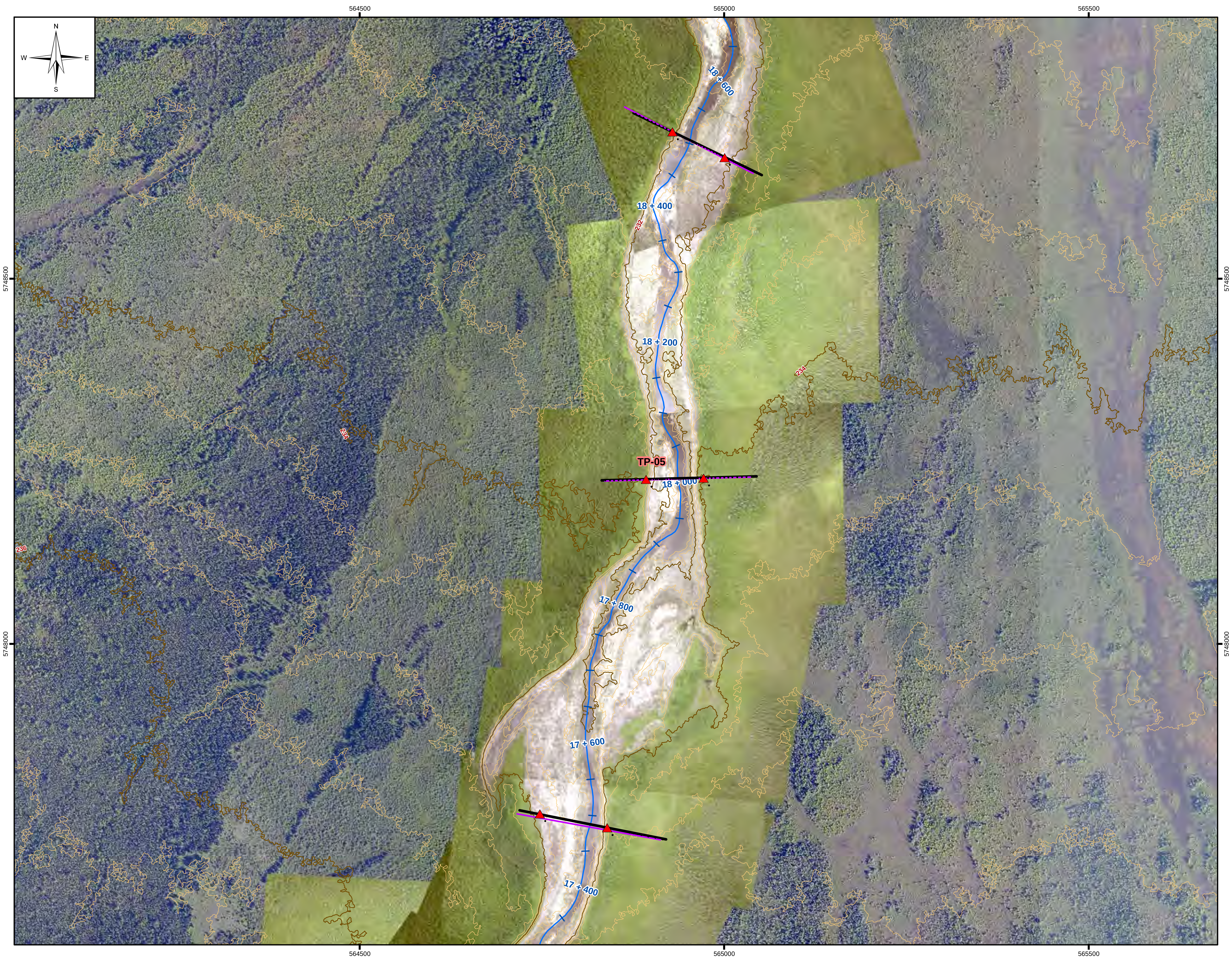

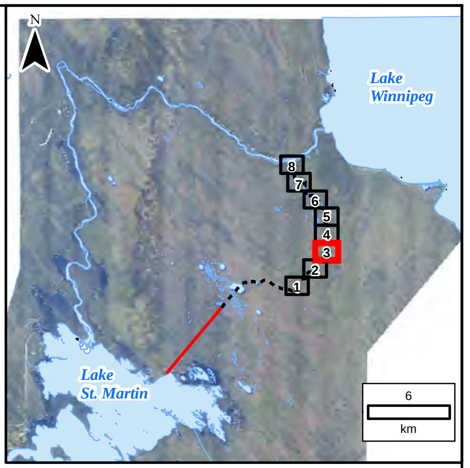

LEGEND:

- Test Pit
- KGS X-Section Survey
- Survey Point
- X-Section Pin
- Survey Control
- X-Section
- Vegetation Survey Transect
- Buffalo Creek Centreline
- 2m Index Contour
- 0.5m Contour

NOTES:

1. Georeferenced Aerial Imaging and Mapping (GAIM) flown by TAIGA Air Services Ltd on July 7th, 2013.
2. Background Satellite Image provided by Atlis Geomatics, July 2011
3. Original ground surface based on LiDAR provided by Atlis Geomatics (June/July 2011)
4. All units are metric and in metres unless otherwise specified. Transverse Mercator Projection, NAD 1983, Zone 14. Elevations are in metres above sea level (MSL)

DRAFT

50 0 50 100 150 200

Metres

SCALE: 1:5,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT		PAL

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LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

DETAILED LOCATION PLAN OF CROSS SECTIONS, VEGETATION COVER SURVEYS AND TILL SURVEY ON BUFFALO CREEK. (SHEET 3 OF 8)

MARCH 2016 | DRAWING 3.3 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig03_RevB.mxd
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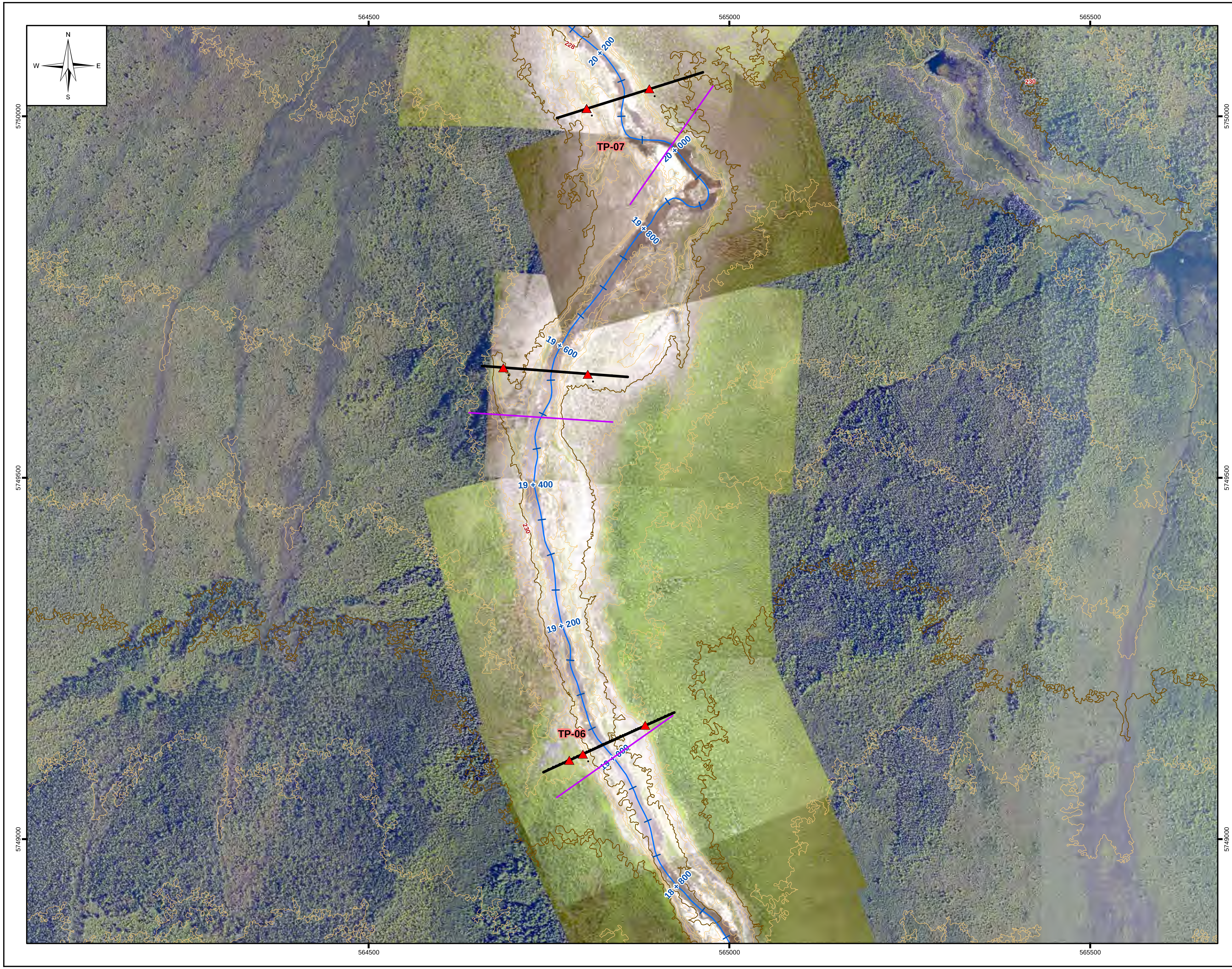

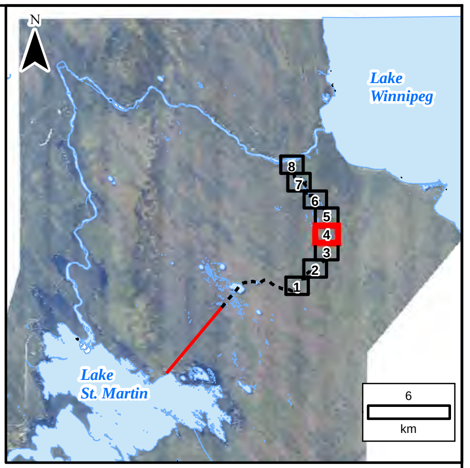

LEGEND:

- Test Pit
- KGS X–Section Survey
- Survey Point
- X–Section Pin
- Survey Control
- X–Section
- Vegetation Survey Transect
- Buffalo Creek Centreline
- 2m Index Contour
- 0.5m Contour

NOTES:

1. Georeferenced Aerial Imaging and Mapping (GAIM) flown by TAIGA Air Services Ltd on July 7th, 2013.
2. Background Satellite Image provided by Atlis Geomatics, July 2011
3. Original ground surface based on LiDAR provided by Atlis Geomatics (June/July 2011)
4. All units are metric and in metres unless otherwise specified. Transverse Mercator Projection, NAD 1983, Zone 14. Elevations are in metres above sea level (MSL)

DRAFT

50 0 50 100 150 200

Metres

SCALE: 1:5,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT		PAL

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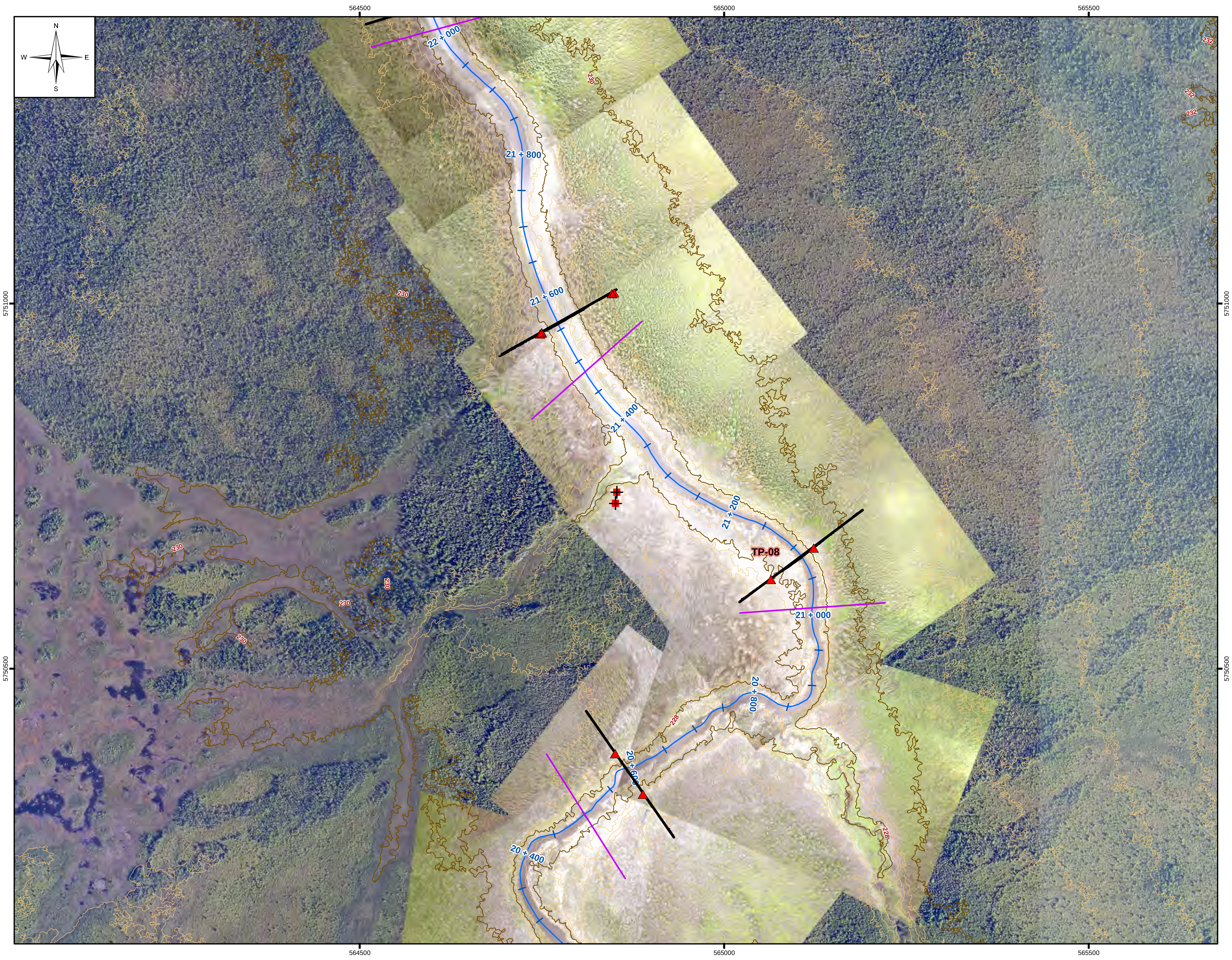
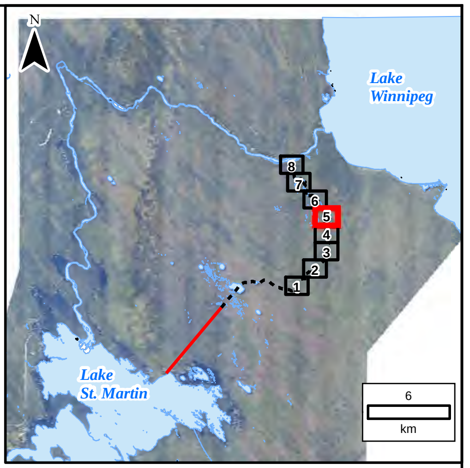
LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

DETAILED LOCATION PLAN OF CROSS SECTIONS, VEGETATION COVER SURVEYS AND TILL SURVEY ON BUFFALO CREEK. (SHEET 4 OF 8)

MARCH 2016 | DRAWING 3.4 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig03_RevB.mxd
11"x17" PLOT SCALE 1:1





LEGEND:

- Test Pit
- KGS X-Section Survey
  - Survey Point
  - X-Section Pin
  - Survey Control
  - X-Section
- Vegetation Survey Transect
- Buffalo Creek Centreline
- 2m Index Contour
- 0.5m Contour

NOTES:

1. Georeferenced Aerial Imaging and Mapping (GAIM) flown by TAIGA Air Services Ltd on July 7th, 2013.
2. Background Satellite Image provided by Atlis Geomatics, July 2011
3. Original ground surface based on LiDAR provided by Atlis Geomatics (June/July 2011)
4. All units are metric and in metres unless otherwise specified. Transverse Mercator Projection, NAD 1983, Zone 14. Elevations are in metres above sea level (MSL)

DRAFT

50 0 50 100 150 200

Metres

SCALE: 1:5,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT		PAL

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LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

DETAILED LOCATION PLAN OF CROSS SECTIONS, VEGETATION COVER SURVEYS AND TILL SURVEY ON BUFFALO CREEK. (SHEET 5 OF 8)

MARCH 2016	DRAWING 3.5	REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig03_RevB.mxd
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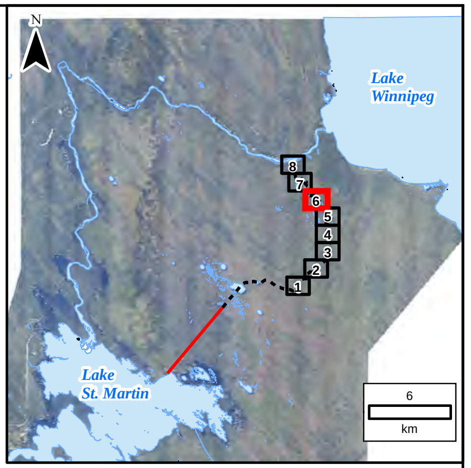

LEGEND:

- Test Pit
- KGS X–Section Survey
- Survey Point
- X–Section Pin
- Survey Control
- X–Section
- Vegetation Survey Transect
- Buffalo Creek Centreline
- 2m Index Contour
- 0.5m Contour

NOTES:

1. Georeferenced Aerial Imaging and Mapping (GAIM) flown by TAIGA Air Services Ltd on July 7th, 2013.
2. Background Satellite Image provided by Atlis Geomatics, July 2011
3. Original ground surface based on LiDAR provided by Atlis Geomatics (June/July 2011)
4. All units are metric and in metres unless otherwise specified. Transverse Mercator Projection, NAD 1983, Zone 14. Elevations are in metres above sea level (MSL)

DRAFT

50 0 50 100 150 200

Metres

SCALE: 1:5,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT		PAL

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Manitoba INFRASTRUCTURE AND TRA

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LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

DETAILED LOCATION PLAN OF CROSS SECTIONS, VEGETATION COVER SURVEYS AND TILL SURVEY ON BUFFALO CREEK. (SHEET 6 OF 8)

MARCH 2016 | DRAWING 3.6 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig03_RevB.mxd
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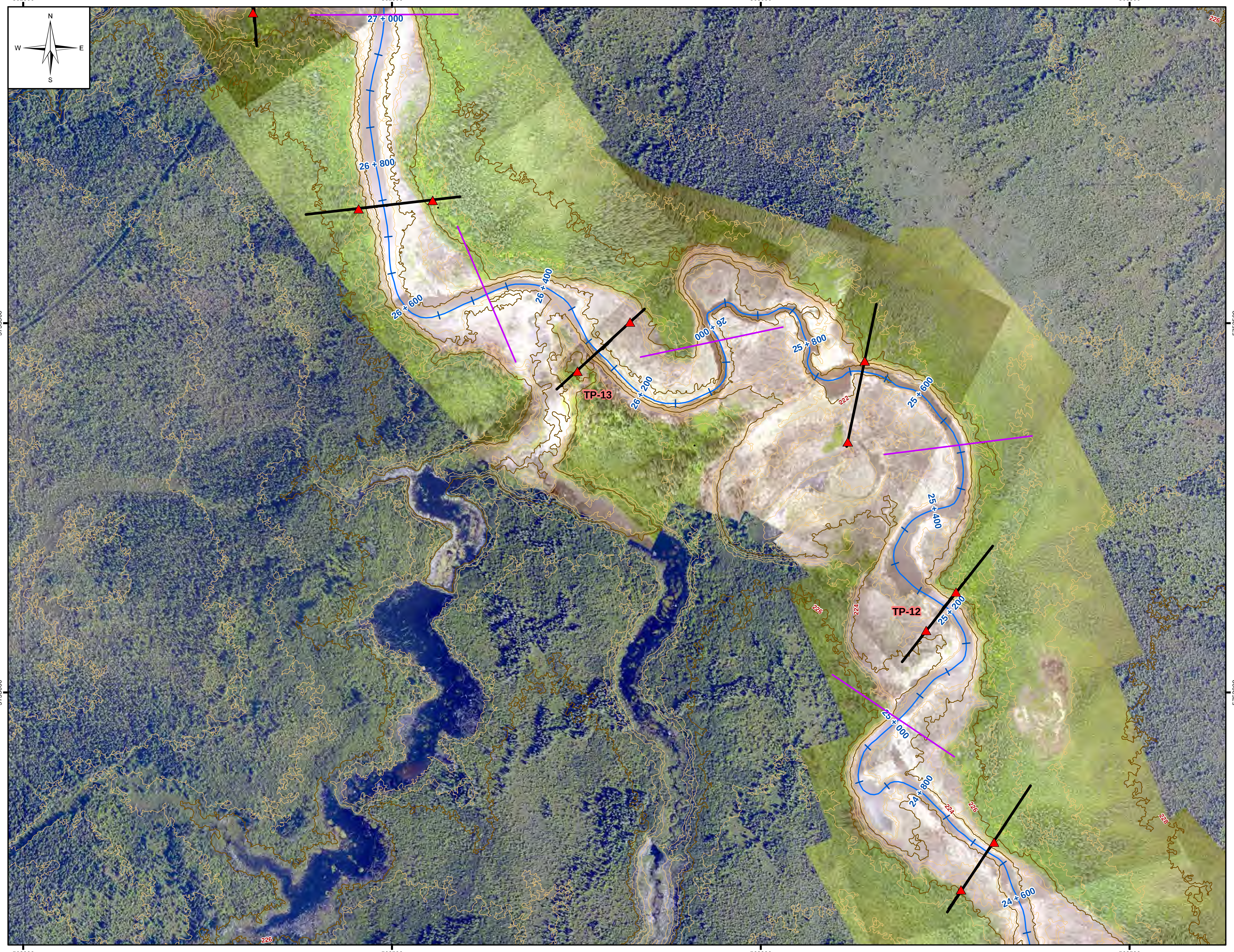

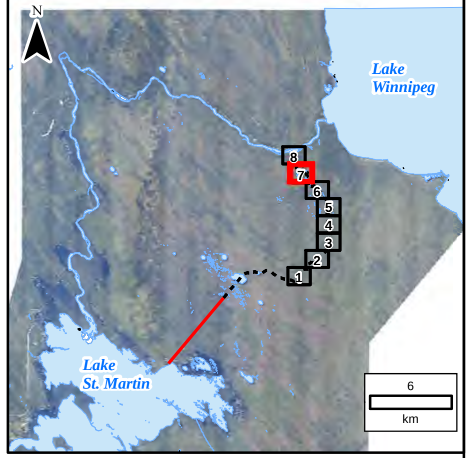

LEGEND:

- Test Pit
- KGS X–Section Survey
- Survey Point
- X–Section Pin
- Survey Control
- X–Section
- Vegetation Survey Transect
- Buffalo Creek Centreline
- 2m Index Contour
- 0.5m Contour

NOTES:

1. Georeferenced Aerial Imaging and Mapping (GAIM) flown by TAIGA Air Services Ltd on July 7th, 2013.
2. Background Satellite Image provided by Atlis Geomatics, July 2011
3. Original ground surface based on LiDAR provided by Atlis Geomatics (June/July 2011)
4. All units are metric and in metres unless otherwise specified. Transverse Mercator Projection, NAD 1983, Zone 14. Elevations are in metres above sea level (MSL)

DRAFT

50 0 50 100 150 200

Metres

SCALE: 1:5,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT	PAL	

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Manitoba INFRASTRUCTURE AND TRA

North/South Consultants Inc. Aquatic Environment Specialists

LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

DETAILED LOCATION PLAN OF CROSS SECTIONS, VEGETATION COVER SURVEYS AND TILL SURVEY ON BUFFALO CREEK. (SHEET 7 OF 8)

MARCH 2016 | DRAWING 3.7 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig03_RevB.mxd
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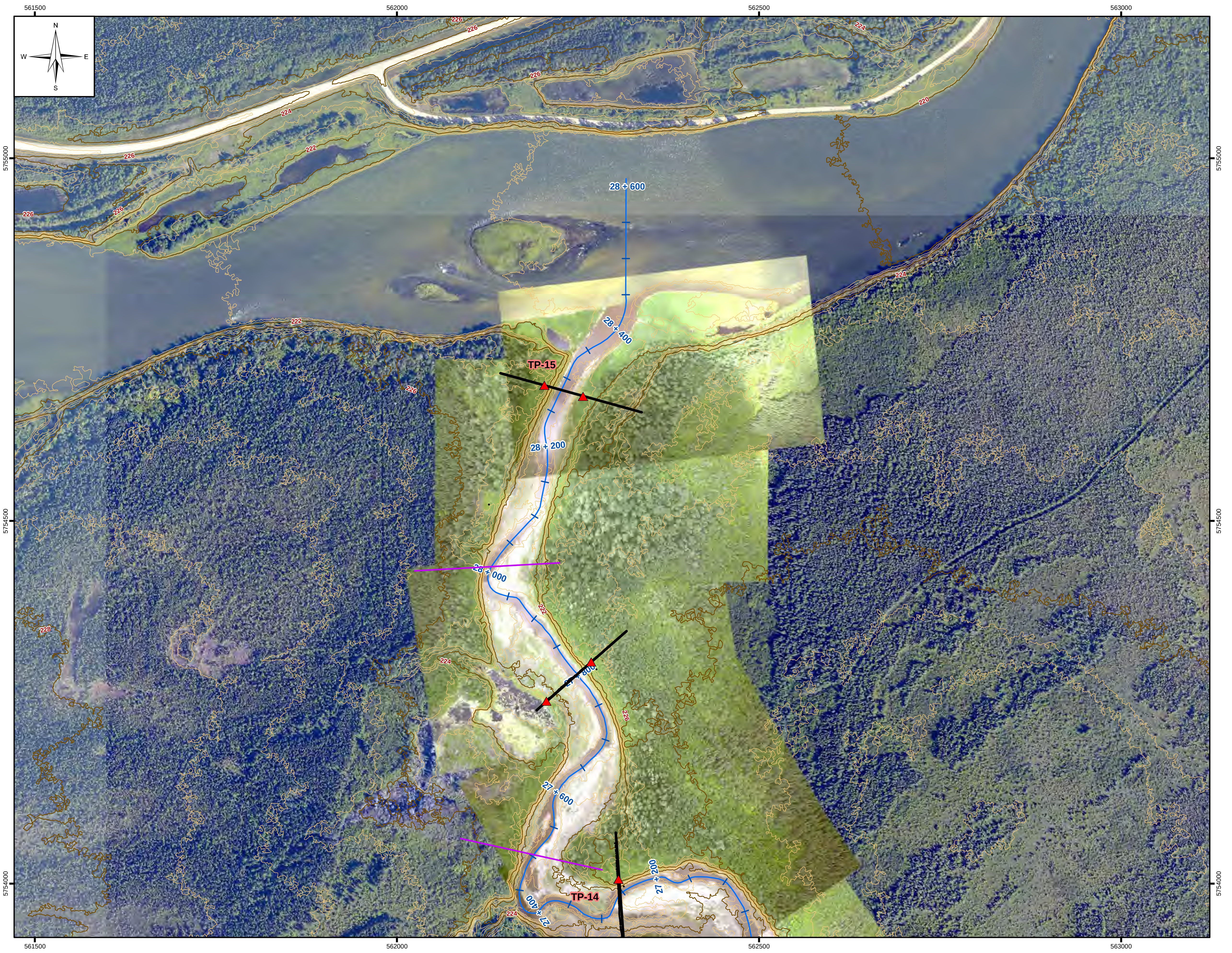

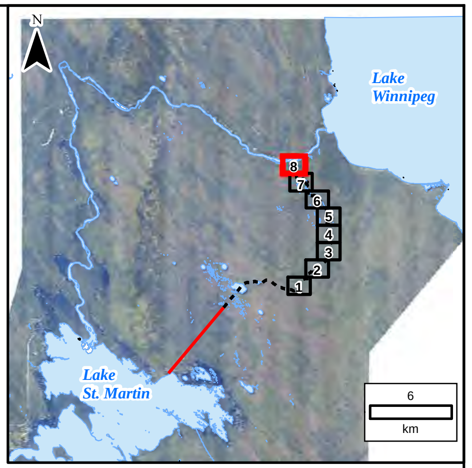

LEGEND:

- Test Pit
- KGS X–Section Survey
- Survey Point
- X–Section Pin
- Survey Control
- X–Section
- Vegetation Survey Transect
- Buffalo Creek Centreline
- 2m Index Contour
- 0.5m Contour

NOTES:

1. Georeferenced Aerial Imaging and Mapping (GAIM) flown by TAIGA Air Services Ltd on July 7th, 2013.
2. Background Satellite Image provided by Atlis Geomatics, July 2011
3. Original ground surface based on LiDAR provided by Atlis Geomatics (June/July 2011)
4. All units are metric and in metres unless otherwise specified. Transverse Mercator Projection, NAD 1983, Zone 14. Elevations are in metres above sea level (MSL)

DRAFT

50 0 50 100 150 200

Metres

SCALE: 1:5,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW

NO.	YY/MM/DD	DESCRIPTION	BY
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT	PAL

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Manitoba INFRASTRUCTURE AND TRA

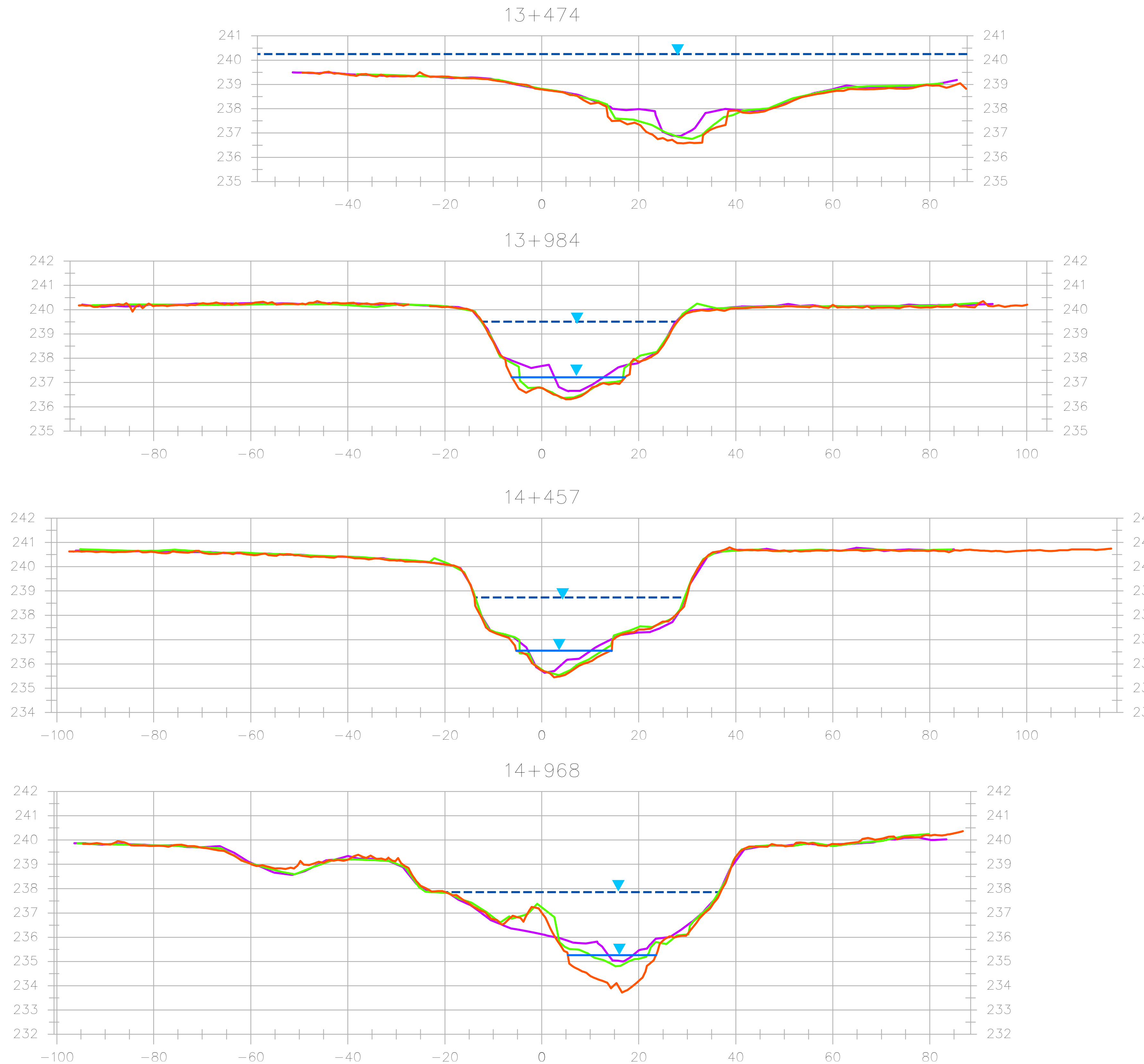
North/South Consultants Inc. Aquatic Environment Specialists

LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

DETAILED LOCATION PLAN OF CROSS SECTIONS, VEGETATION COVER SURVEYS AND TILL SURVEY ON BUFFALO CREEK. (SHEET 8 OF 8)

MARCH 2016 | DRAWING 3.8 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig03_RevB.mxd
11"x17" PLOT SCALE 1:1



LEGEND:

- 2011 Survey
- 2013 Survey
- 2015 Survey
- 2015 Surveyed Water Level
- Average Water Level during 2012 operation of LSMEOC (computed)

GENERAL NOTES:

1. See Drawings 2 or 3 for Cross Section locations.
2. Sections are orientated looking downstream.
3. Normal changes in the peat between surveys can result in slight differences when comparing cross sections.

CROSS SECTION NOTES:

4. 2015 section was slightly offset due to debris / beaver dam in creek. Survey data shown with dotted line is projected on section, (see sheet 2 & 3).
5. 2011 survey data superimposed on section. Alignment was relocated for the 2013 and 2015 surveys due to field conditions, (see sheet 5 & 6).
6. Data was not collected during the 2011 Survey at this location due to field conditions, (see sheet 5 & 7).
7. The 2011 survey was done in September / October, 2013 survey was done in July, and the 2015 survey was done in September by KGS Group.

DRAFT

2 0 2 4 6 8
Metres

VERTICAL SCALE: 1:200 (5x Vertical Exaggeration)

10 0 10 20 30 40
Metres

HORIZONTAL SCALE: 1:1,000 (5x Vertical Exaggeration)

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT	PAL	

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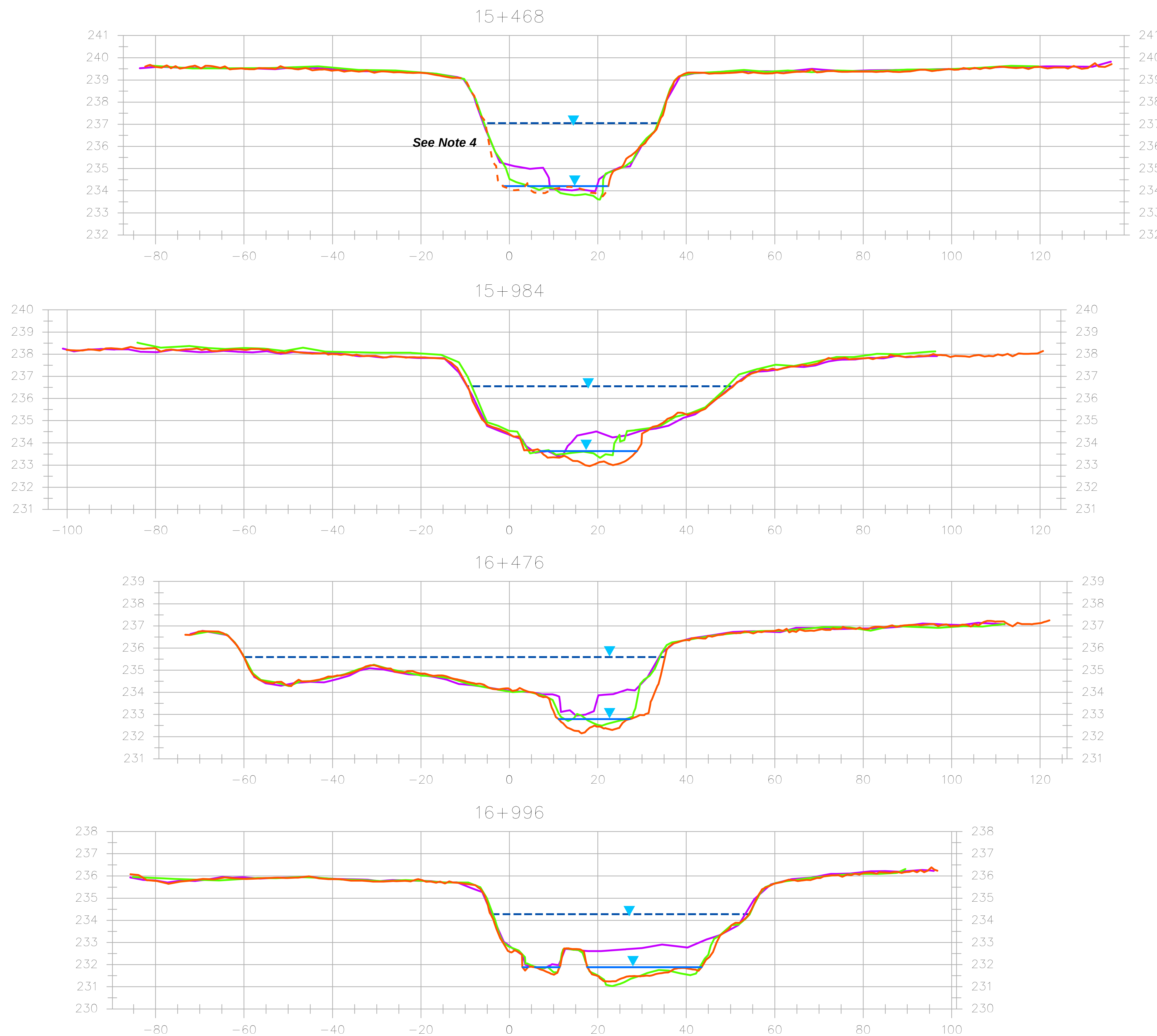
LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

BUFFALO CREEK CROSS SECTIONS
SHEET 1 OF 8

MARCH 2016 | DRAWING 4.1 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig04_RevB.mxd
11"x17" PLOT SCALE 1:1



LEGEND:

- 2011 Survey
- 2013 Survey
- 2015 Survey
- 2015 Surveyed Water Level
- Average Water Level during 2012 operation of LSMEOC (computed)

GENERAL NOTES:
1. See Drawings 2 or 3 for Cross Section locations.
2. Sections are orientated looking downstream.
3. Normal changes in the peat between surveys can result in slight differences when comparing cross sections.

CROSS SECTION NOTES:
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DRAFT

2 0 2 4 6 8
Metres
VERTICAL SCALE: 1:200 (5x Vertical Exaggeration)

10 0 10 20 30 40
Metres
HORIZONTAL SCALE: 1:1,000 (5x Vertical Exaggeration)

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT	PAL	

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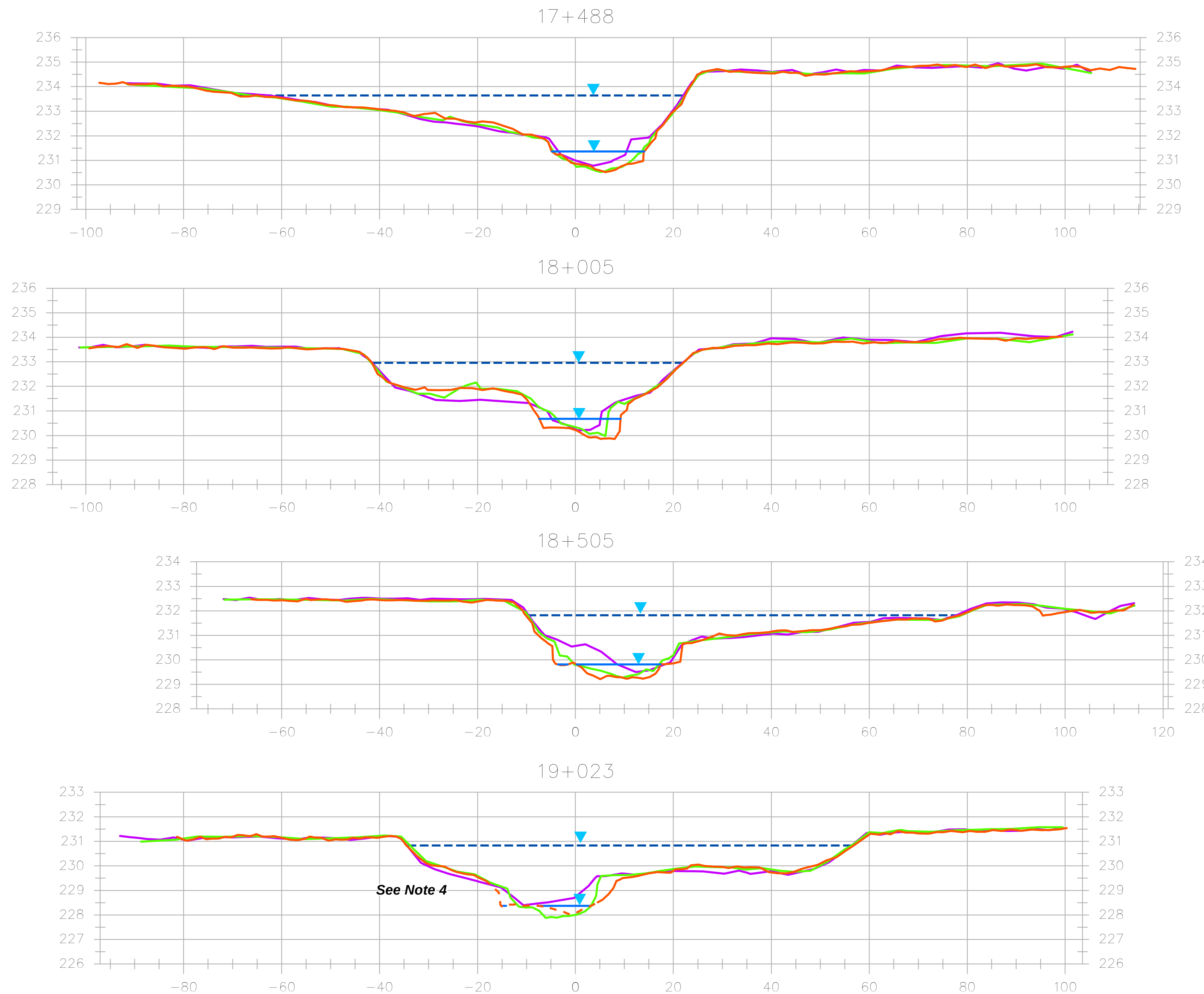
LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

BUFFALO CREEK CROSS SECTIONS SHEET 2 OF 8

MARCH 2016 | DRAWING 4.2 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig04_RevB.mxd
11"x17" PLOT SCALE 1:1

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig04_RevB.mxd
11"x17" PLOT SCALE 1:1



LEGEND:

- 2011 Survey
- 2013 Survey
- 2015 Survey
- 2015 Surveyed Water Level
- Average Water Level during 2012 operation of LSMEOC (computed)

GENERAL NOTES:
1. See Drawings 2 or 3 for Cross Section locations.
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7. The 2011 survey was done in September / October, 2013 survey was done in July, and the 2015 survey was done in September by KGS Group.

DRAFT

2 0 2 4 6 8
Metres
VERTICAL SCALE: 1:200 (5x Vertical Exaggeration)

10 0 10 20 30 40
Metres
HORIZONTAL SCALE: 1:1,000 (5x Vertical Exaggeration)

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT	PAL	

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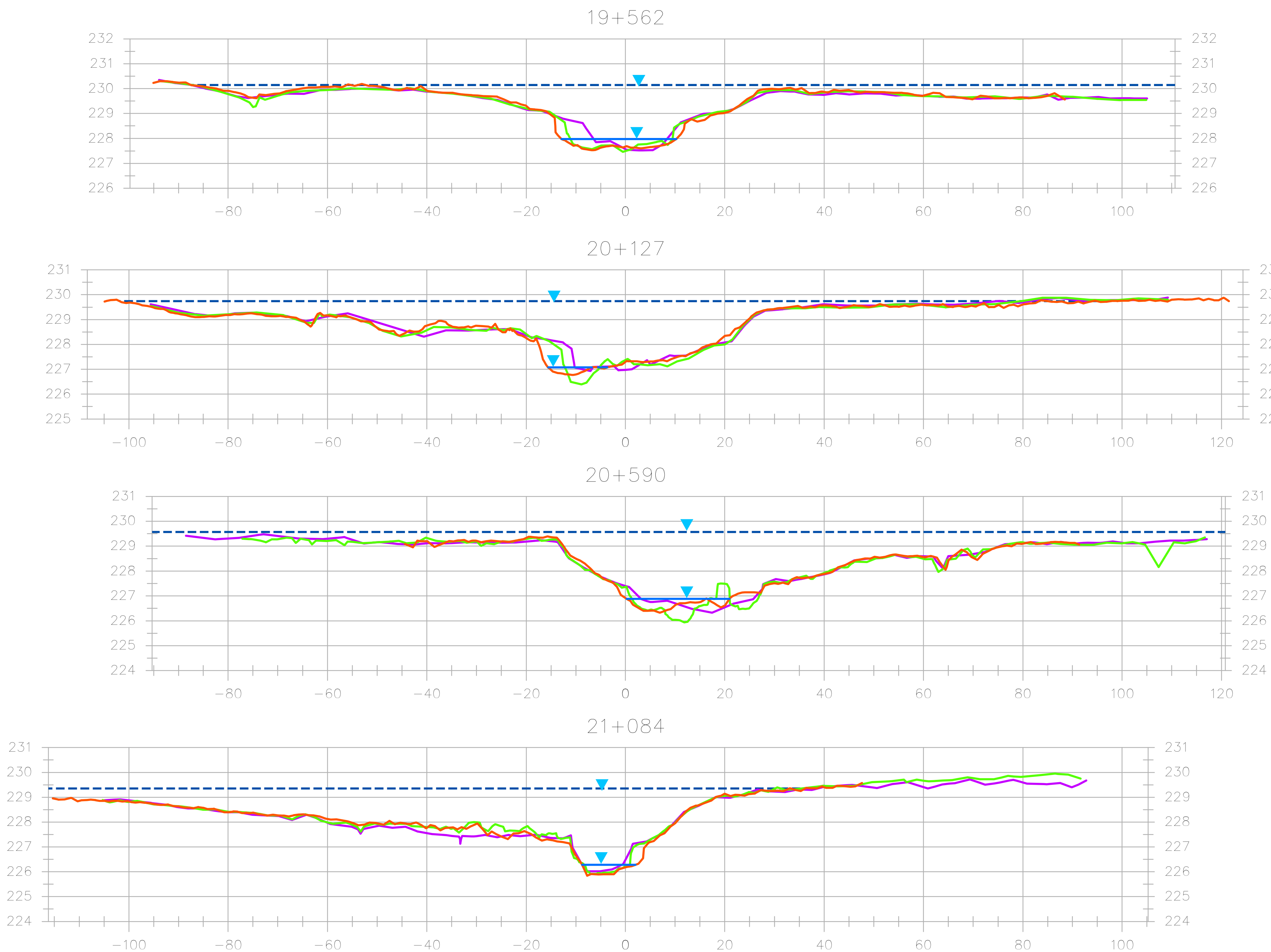
LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

BUFFALO CREEK CROSS SECTIONS
SHEET 3 OF 8

MARCH 2016 | DRAWING 4.3 | REV: B



LEGEND:

- 2011 Survey
- 2013 Survey
- 2015 Survey
- 2015 Surveyed Water Level
- Average Water Level during 2012 operation of LSMEOC (computed)

GENERAL NOTES:

1. See Drawings 2 or 3 for Cross Section locations.
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DRAFT

2 0 2 4 6 8
Metres
VERTICAL SCALE: 1:200 (5x Vertical Exaggeration)

10 0 10 20 30 40
Metres
HORIZONTAL SCALE: 1:1,000 (5x Vertical Exaggeration)

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT		PAL

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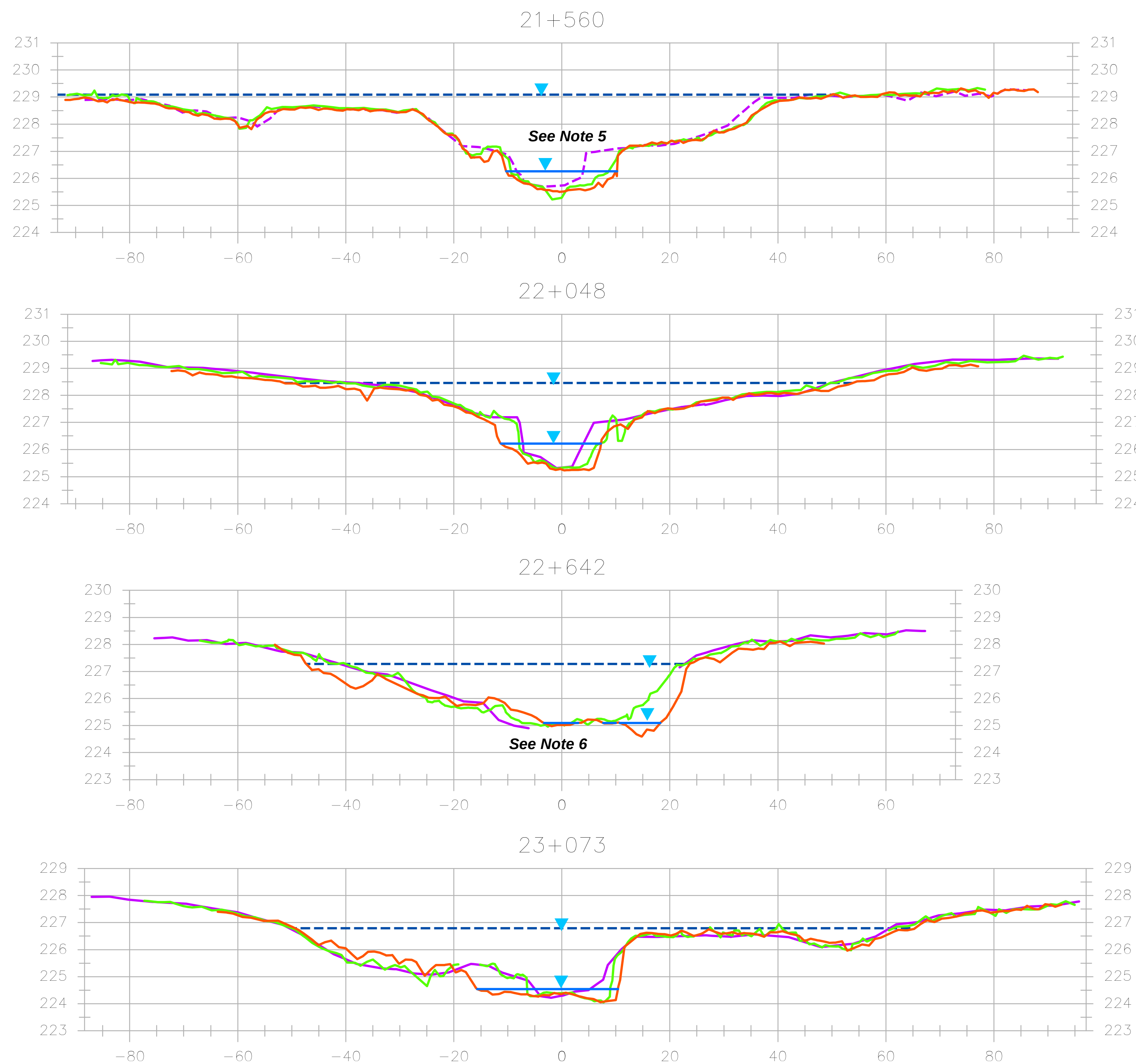
BUFFALO CREEK CROSS SECTIONS
SHEET 4 OF 8

MARCH 2016 | DRAWING 4.4 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig04_RevB.mxd
11"x17" PLOT SCALE 1:1



LEGEND:

- 2011 Survey
- 2013 Survey
- 2015 Survey
- 2015 Surveyed Water Level
- Average Water Level during 2012 operation of LSMEOC (computed)

GENERAL NOTES:
1. See Drawings 2 or 3 for Cross Section locations.
2. Sections are orientated looking downstream.
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4. 2015 section was slightly offset due to debris / beaver dam in creek. Survey data shown with dotted line is projected on section, (see sheet 2 & 3).
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DRAFT

2 0 2 4 6 8
Metres
VERTICAL SCALE: 1:200 (5x Vertical Exaggeration)

10 0 10 20 30 40
Metres
HORIZONTAL SCALE: 1:1,000 (5x Vertical Exaggeration)

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW

NO.	YY/MM/DD	DESCRIPTION	BY
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT	PAL

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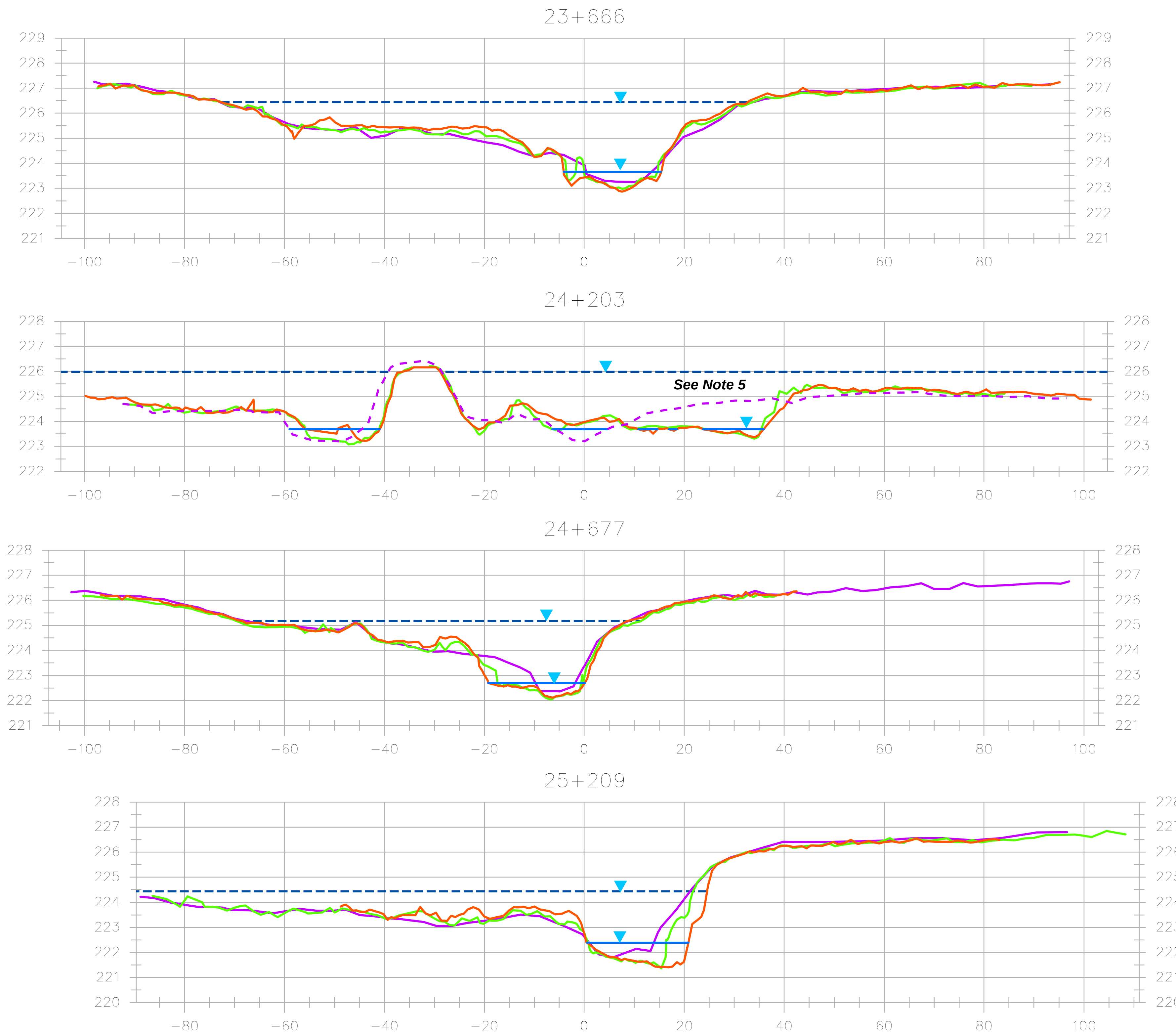
BUFFALO CREEK CROSS SECTIONS
SHEET 5 OF 8

MARCH 2016 | DRAWING 4.5 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig04_RevB.mxd
11"x17" PLOT SCALE 1:1



LEGEND:

- 2011 Survey
- 2013 Survey
- 2015 Survey
- 2015 Surveyed Water Level
- Average Water Level during 2012 operation of LSMEOC (computed)

GENERAL NOTES:
1. See Drawings 2 or 3 for Cross Section locations.
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DRAFT

2 0 2 4 6 8
Metres
VERTICAL SCALE: 1:200 (5x Vertical Exaggeration)

10 0 10 20 30 40
Metres
HORIZONTAL SCALE: 1:1,000 (5x Vertical Exaggeration)

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT		PAL

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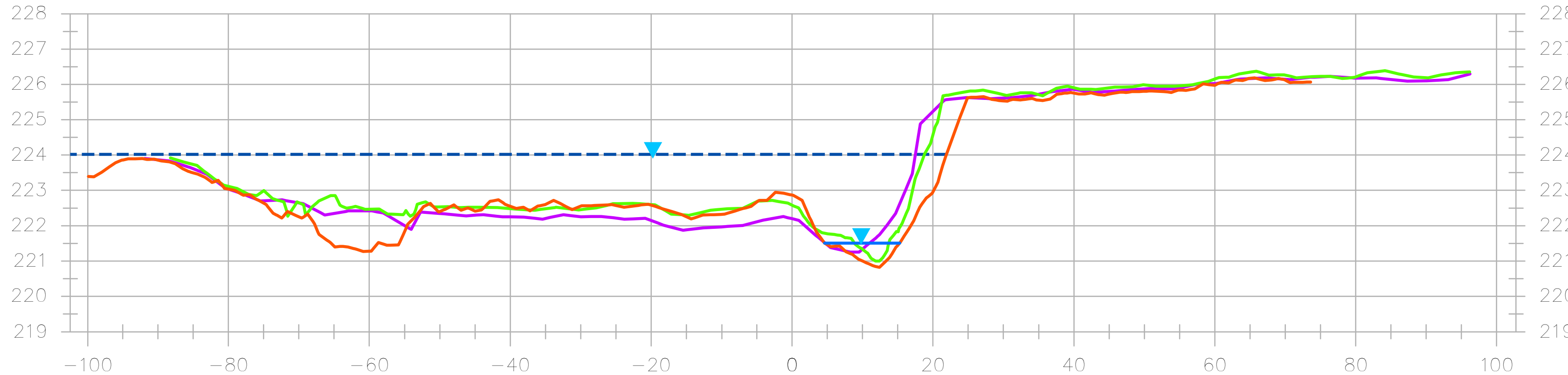
BUFFALO CREEK CROSS SECTIONS
SHEET 6 OF 8

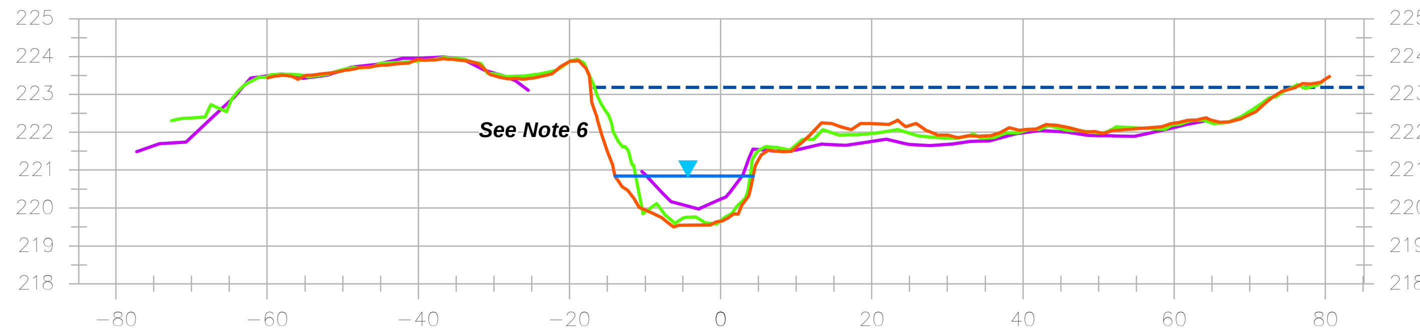
MARCH 2016 | DRAWING 4.6 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig04_RevB.mxd
11"x17" PLOT SCALE 1:1

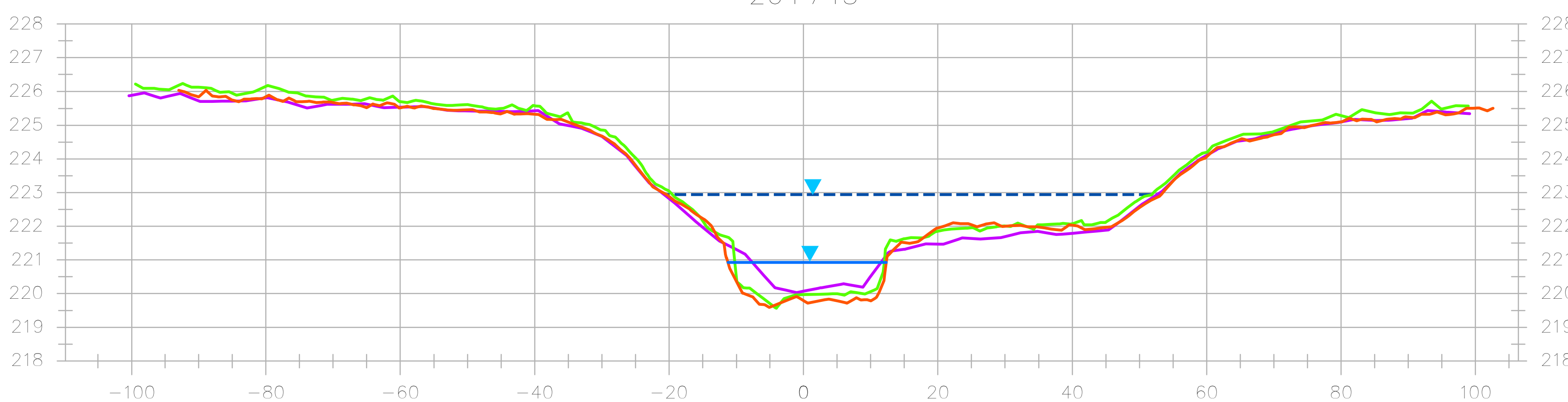
25+683



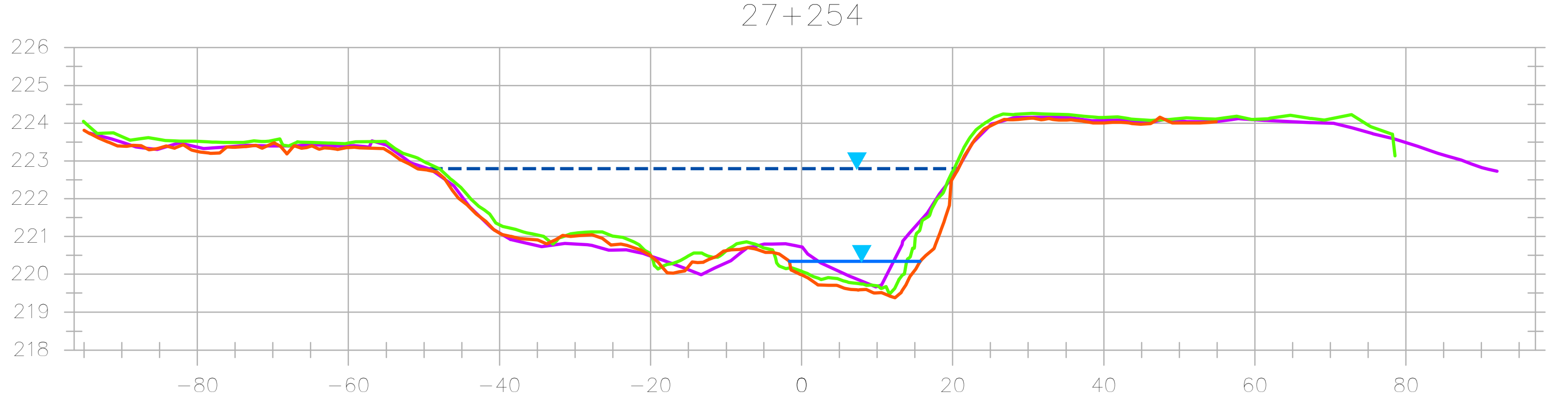
26+281



26+743



27+254



LEGEND:

- 2011 Survey
- 2013 Survey
- 2015 Survey
- 2015 Surveyed Water Level
- Average Water Level during 2012 operation of LSMEOC (computed)

GENERAL NOTES:

1. See Drawings 2 or 3 for Cross Section locations.
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DRAFT

2 0 2 4 6 8
Metres

VERTICAL SCALE: 1:200 (5x Vertical Exaggeration)

10 0 10 20 30 40
Metres

HORIZONTAL SCALE: 1:1,000 (5x Vertical Exaggeration)

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW
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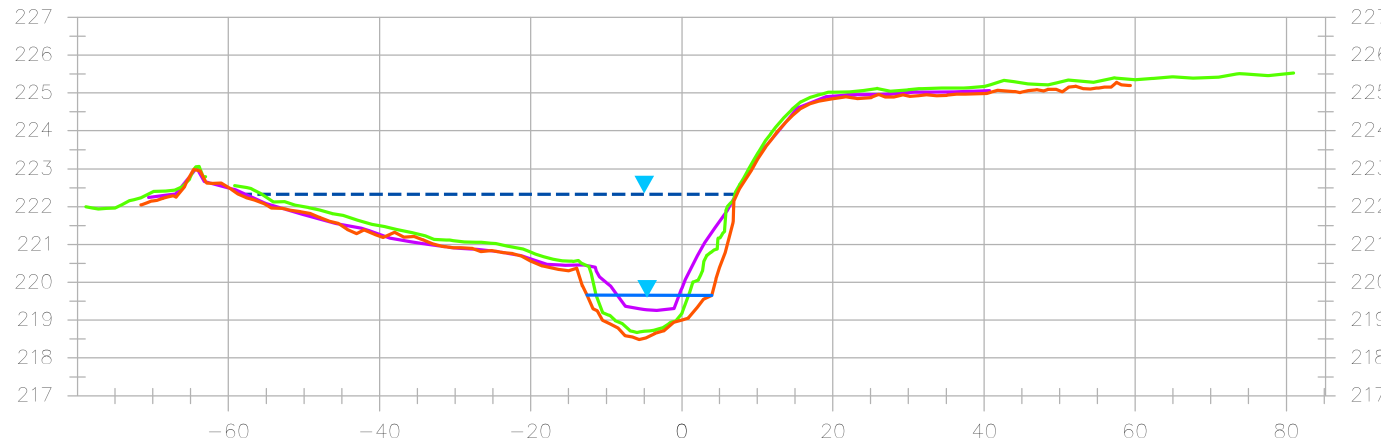
BUFFALO CREEK CROSS SECTIONS SHEET 7 OF 8

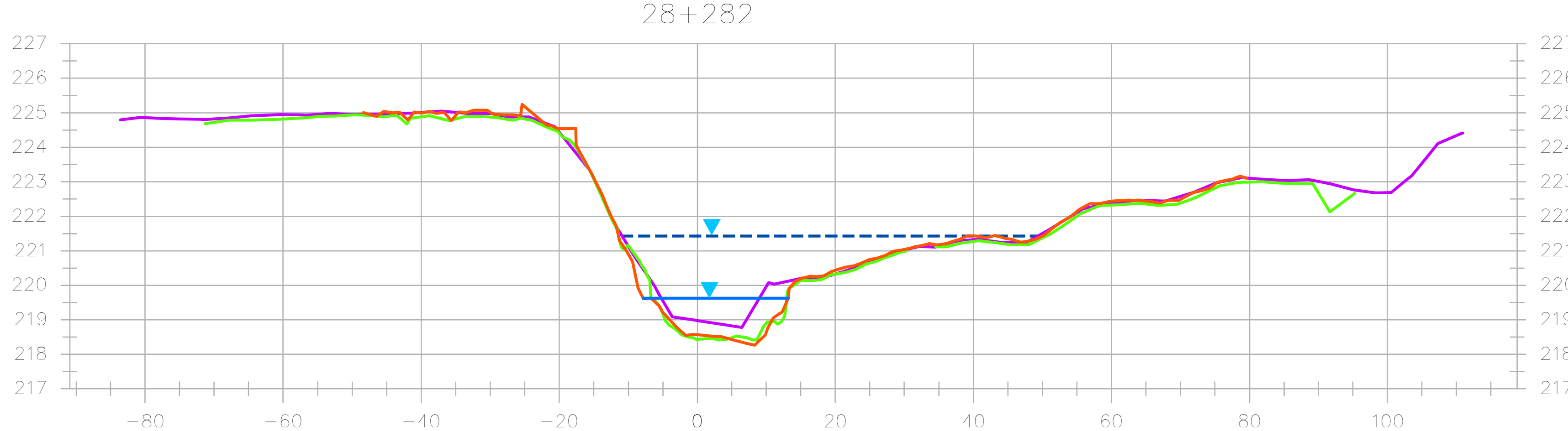
MARCH 2016 | DRAWING 4.7 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig04_RevB.mxd
11"x17" PLOT SCALE 1:1

27+802



28+282



LEGEND:

- 2011 Survey
- 2013 Survey
- 2015 Survey
- 2015 Surveyed Water Level
- Average Water Level during 2012 operation of LSMEOC (computed)

GENERAL NOTES:
1. See Drawings 2 or 3 for Cross Section locations.
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DRAFT

2 0 2 4 6 8
Metres

VERTICAL SCALE: 1:200 (5x Vertical Exaggeration)

10 0 10 20 30 40
Metres

HORIZONTAL SCALE: 1:1,000 (5x Vertical Exaggeration)

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT	PAL	

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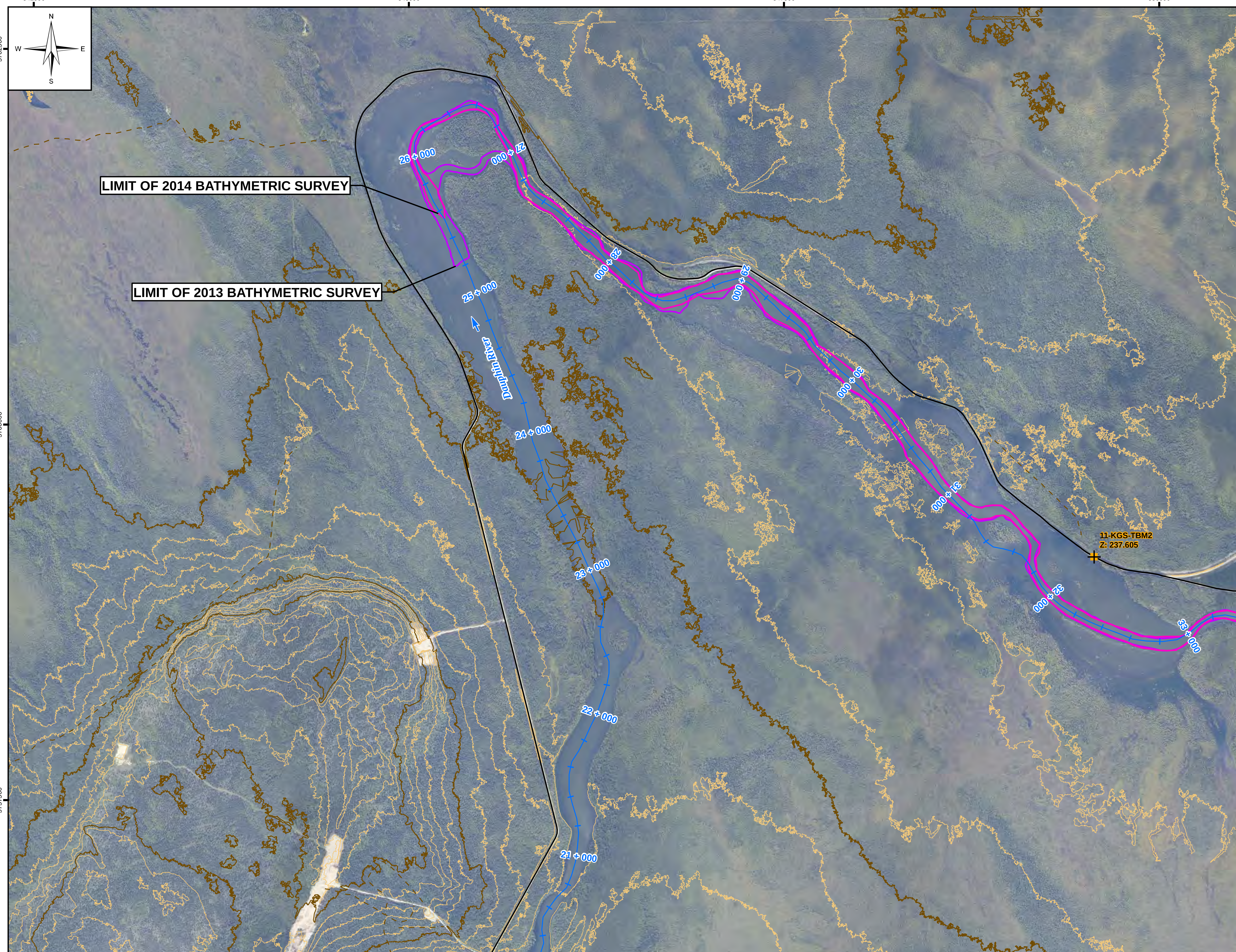
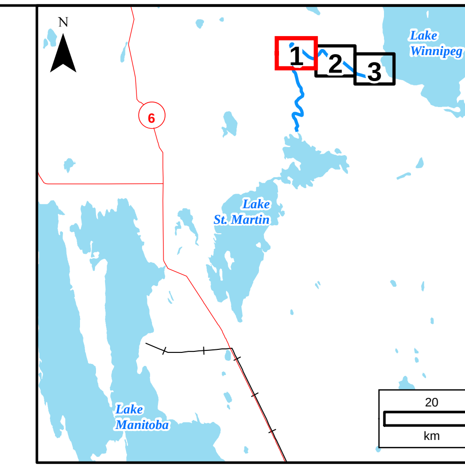
BUFFALO CREEK CROSS SECTIONS
SHEET 8 OF 8

MARCH 2016 | DRAWING 4.8 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig04_RevB.mxd
11"x17" PLOT SCALE 1:1





LEGEND:

- Survey Control 2011
- Survey Control 2012
- Survey Control 2013
- Survey Control 2014
- Survey Control 2015
- Limit of 2012 Bathymetric Survey
- Limit of 2013 Bathymetric Survey
- Limit of 2014 Bathymetric Survey
- Limit of 2015 Bathymetric Survey
- Dauphin River Centreline

TRANSPORTATION

- Gravel Road
- Trail

LIDAR CONTOURS

- 5m Index Contour
- 1m Contour

NOTES:

1. 2012 Sonar completed by KGS Group on June 20, 2012. 2013 Sonar completed by KGS Group on June 5–7, and July 22–23, 2013. 2014 Sonar completed by KGS Group on June 17–21, 2014. 2015 Sonar completed by KGS Group on Sept 16 –17, 2015.
2. Satellite image provided by Atlis Geomatics, July 2011
3. Original ground surface based on LiDAR provided by Atlis Geomatics (June/July 2011)
4. All units are metric and in metres unless otherwise specified
   Transverse Mercator Projection, NAD 1983, Zone 14
   Elevations are in metres above sea level (MSL)

DRAFT

250 0 250 500 750 1,000
Metres

SCALE: 1:25,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT	PAL	

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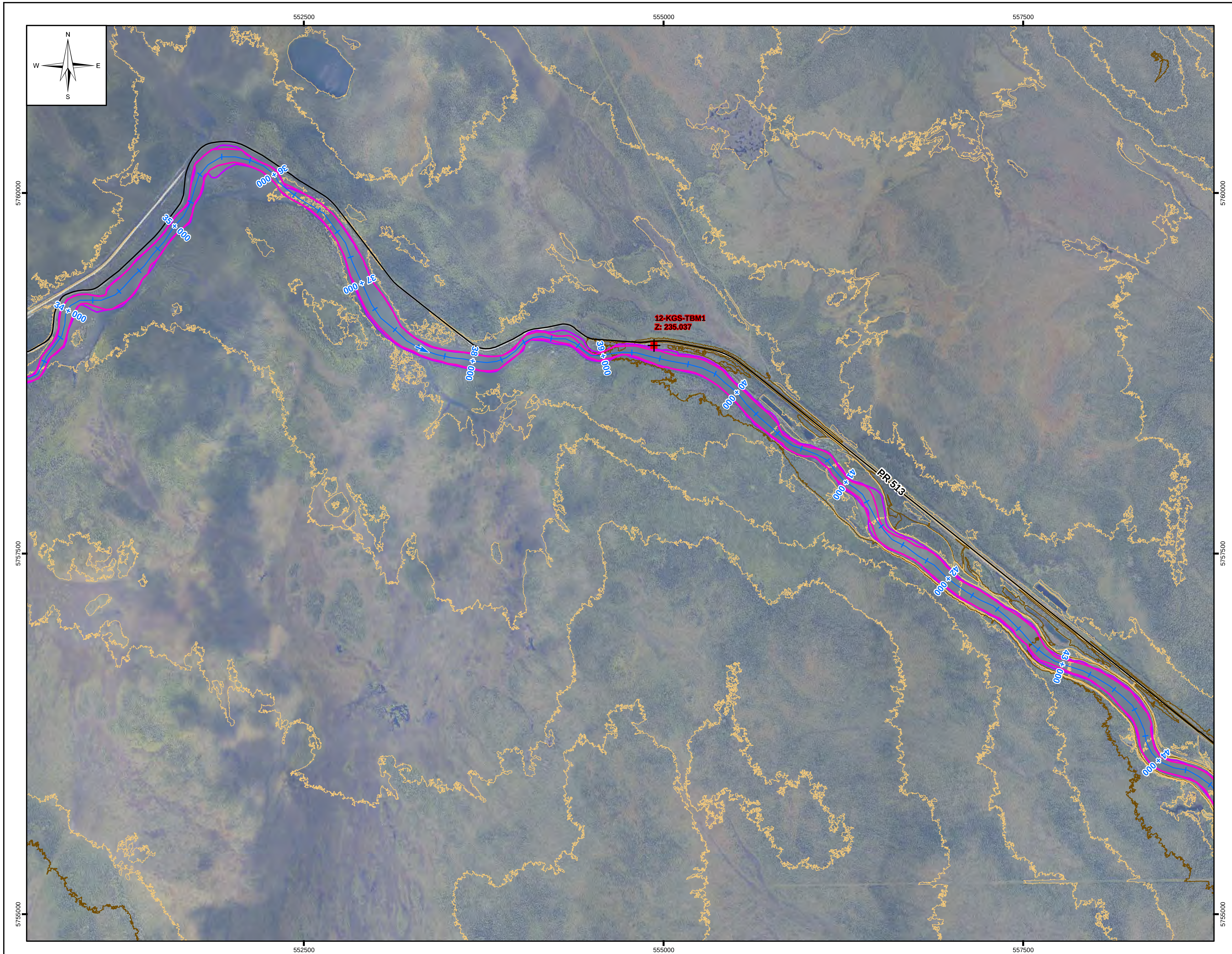
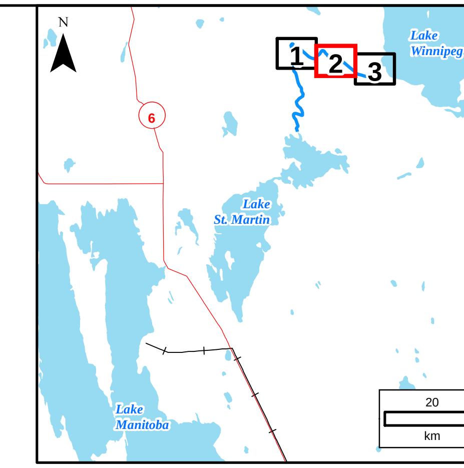
LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

LOWER DAUPHIN RIVER BATHYMETRY OVERVIEW. (SHEET 1 OF 3)

MARCH 2016 | DRAWING 5.1 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig05_RevB.mxd
11"x17" PLOT SCALE 1:1





LEGEND:

- Survey Control 2011
- Survey Control 2012
- Survey Control 2013
- Survey Control 2014
- Survey Control 2015
- Limit of 2012 Bathymetric Survey
- Limit of 2013 Bathymetric Survey
- Limit of 2014 Bathymetric Survey
- Limit of 2015 Bathymetric Survey
- Dauphin River Centreline

TRANSPORTATION

- Gravel Road
- Trail

LIDAR CONTOURS

- 5m Index Contour
- 1m Contour

NOTES:

1. 2012 Sonar completed by KGS Group on June 20, 2012. 2013 Sonar completed by KGS Group on June 5–7, and July 22–23, 2013. 2014 Sonar completed by KGS Group on June 17–21, 2014. 2015 Sonar completed by KGS Group on Sept 16 –17, 2015.
2. Satellite image provided by Atlis Geomatics, July 2011
3. Original ground surface based on LiDAR provided by Atlis Geomatics (June/July 2011)
4. All units are metric and in metres unless otherwise specified
Transverse Mercator Projection, NAD 1983, Zone 14
Elevations are in metres above sea level (MSL)

DRAFT

250 0 250 500 750 1,000
Metres

SCALE: 1:25,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT		PAL

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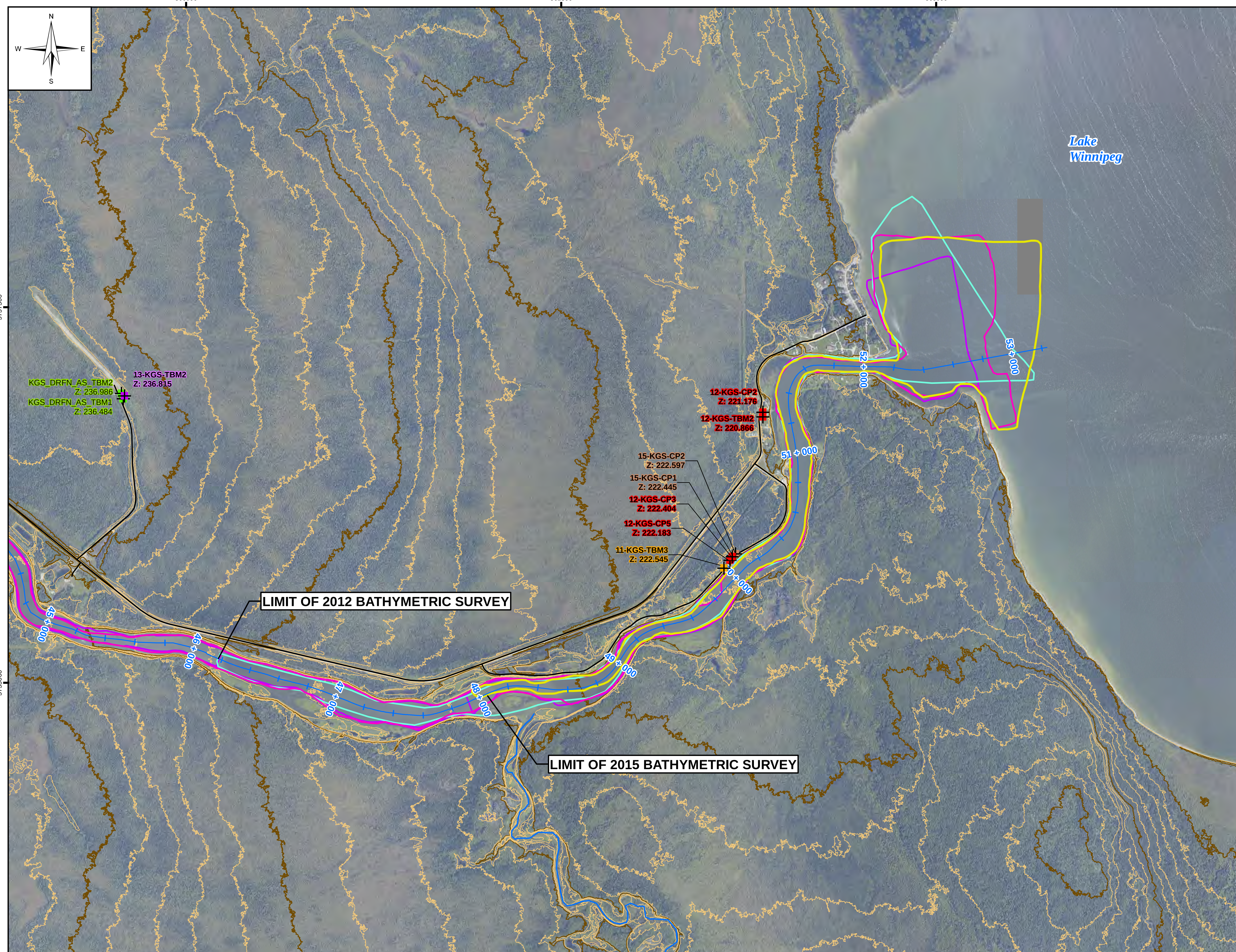
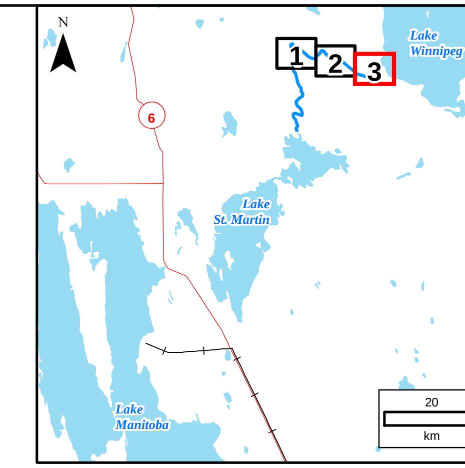
LOWER DAUPHIN RIVER BATHYMETRY OVERVIEW. (SHEET 2 OF 3)

MARCH 2016 | DRAWING 5.2 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDS\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig05_RevB.mxd
11"x17" PLOT SCALE 1:1

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig05_RevB.mxd
11"x17" PLOT SCALE 1:1





LEGEND:

- Survey Control 2011
- Survey Control 2012
- Survey Control 2013
- Survey Control 2014
- Survey Control 2015
- Limit of 2012 Bathymetric Survey
- Limit of 2013 Bathymetric Survey
- Limit of 2014 Bathymetric Survey
- Limit of 2015 Bathymetric Survey
- Dauphin River Centreline

TRANSPORTATION

- Gravel Road
- Trail

LiDAR CONTOURS

- 5m Index Contour
- 1m Contour

NOTES:

1. 2012 Sonar completed by KGS Group on June 20, 2012. 2013 Sonar completed by KGS Group on June 5–7, and July 22–23, 2013. 2014 Sonar completed by KGS Group on June 17–21, 2014. 2015 Sonar completed by KGS Group on Sept 16 –17, 2015.
2. Satellite image provided by Atlis Geomatics, July 2011
3. Original ground surface based on LiDAR provided by Atlis Geomatics (June/July 2011)
4. All units are metric and in metres unless otherwise specified
   Transverse Mercator Projection, NAD 1983, Zone 14
   Elevations are in metres above sea level (MSL)

DRAFT

250 0 250 500 750 1,000
Metres

SCALE: 1:25,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT		PAL

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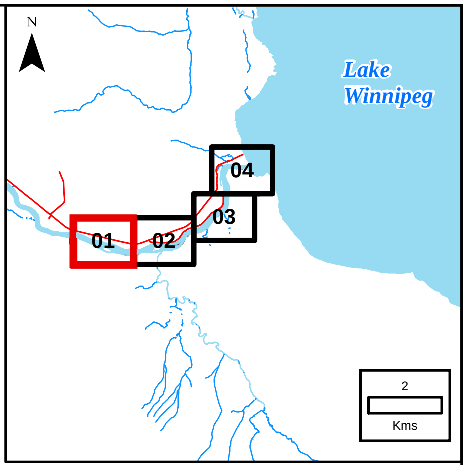
LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

LOWER DAUPHIN RIVER BATHYMETRY OVERVIEW. (SHEET 3 OF 3)

MARCH 2016 | DRAWING 5.3 | REV: B



LEGEND:

- 2013 Sonar Point
- 2011 Sonar Point
- Water Level 2013
- Survey Control 2011 (See Note 3 Below)
- Dauphin River Centreline

TRANSPORTATION

- Gravel Road
- Trail
- Edge of Water (LiDAR)

From 2011 to 2013
Elevation Variation (m)

- < −2
- −2.0 − −1.5
- −1.5 − −1.0
- −1.0 − −0.5
- −0.5 − 0.5
- 0.5 − 1.0
- 1.0 − 1.5
- 1.5 − 2.0
- > 2.0

* SEE NOTE 1 FOR EXPLANATION

NOTES:

1. Negative elevation values indicates erosion and positive indicates deposition.
2. 2011 Sonar completed by KGS Group on June 29 − July 2, 2011.
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DRAFT

50 0 50 100 150 200
Metres

SCALE: 1:5,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/01	ISSUED WITH DRAFT REPORT	PAL	MSW

NO.	YY/MM/DD	DESCRIPTION	BY
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT	PAL

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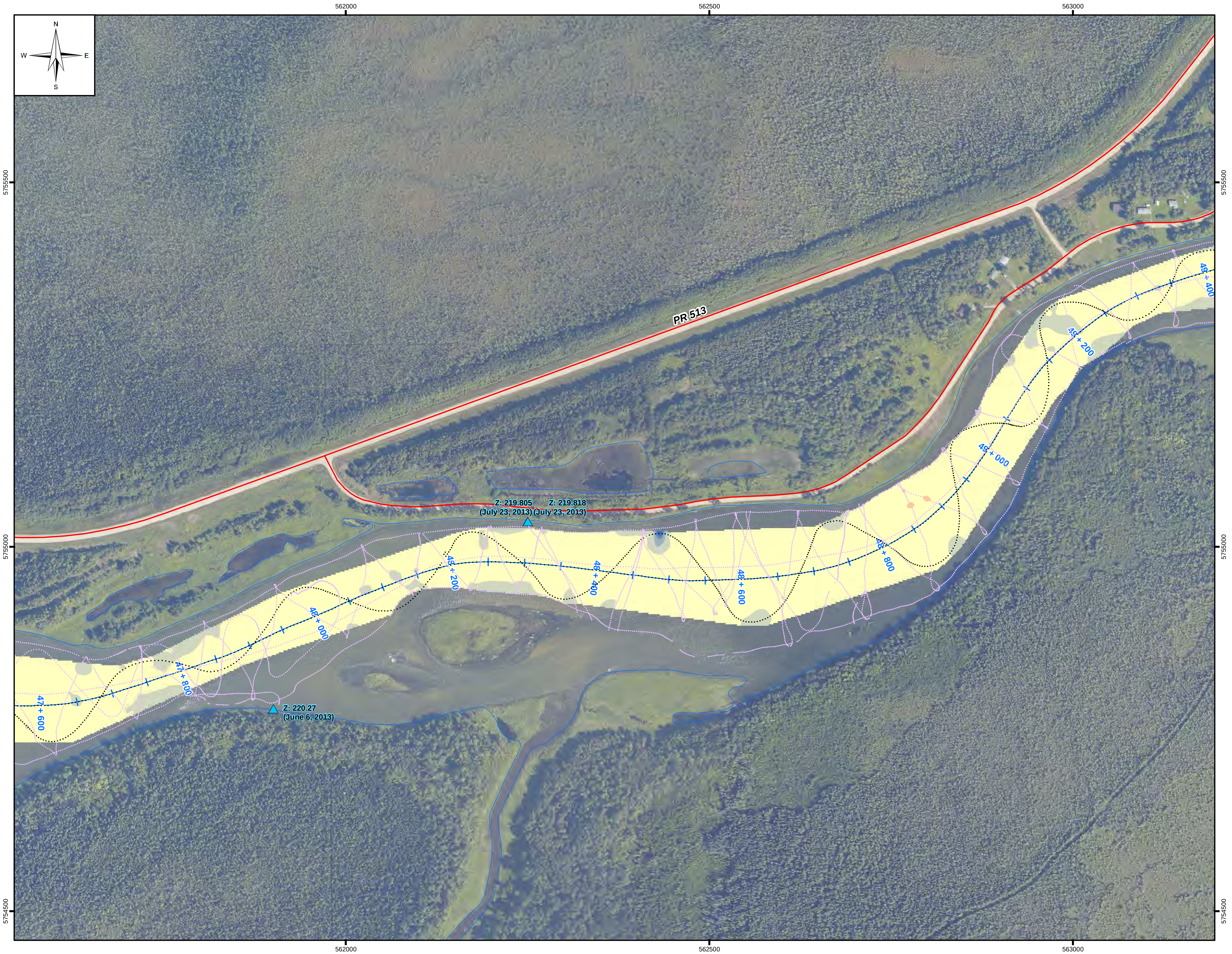
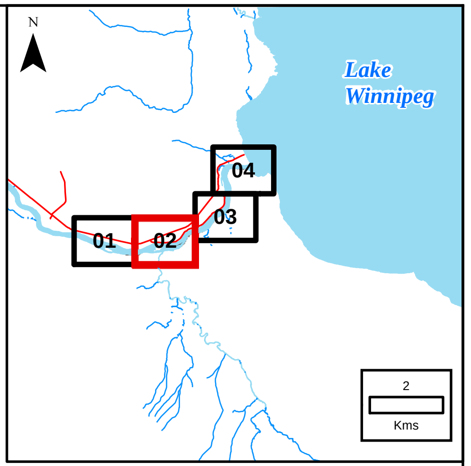
KGS GROUP — Manitoba Infrastructure and Transportation — North/South Consultants Inc. Aquatic Environment Specialists

LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

LOWER DAUPHIN RIVER BATHYMETRY DIFFERENCES OF 2011 TO 2013 (SHEET 1 OF 4)

MARCH 2016 | DRAWING 6.1 | REV: B





LEGEND:

- 2013 Sonar Point
- 2011 Sonar Point
- Water Level 2013
- Survey Control 2011 (See Note 3 Below)
- Dauphin River Centreline

TRANSPORTATION

- Gravel Road
- Trail
- Edge of Water (LiDAR)

From 2011 to 2013

Elevation Variation (m)

- < −2
- −2.0 − −1.5
- −1.5 − −1.0
- −1.0 − −0.5
- −0.5 − 0.5
- 0.5 − 1.0
- 1.0 − 1.5
- 1.5 − 2.0
- > 2.0

* SEE NOTE 1 FOR EXPLANATION

NOTES:

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DRAFT

50 0 50 100 150 200

Metres

SCALE: 1:5,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/011	ISSUED WITH DRAFT REPORT	PAL	MSW
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT		PAL

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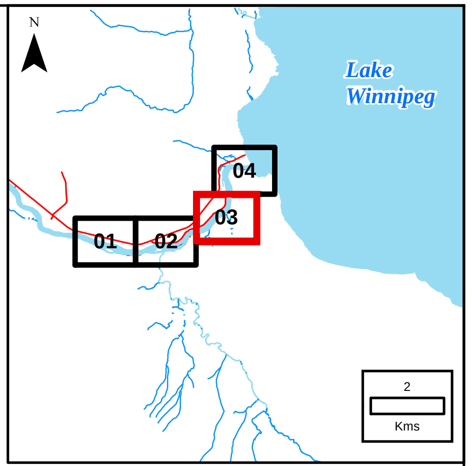
North/South Consultants Inc.
Aquatic Environment Specialists

LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

LOWER DAUPHIN RIVER BATHYMETRY DIFFERENCES OF 2011 TO 2013 (SHEET 2 OF 4)

MARCH 2016 | DRAWING 6.2 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig06_RevB.mxd
11"x17" PLOT SCALE 1:1



LEGEND:

- 2013 Sonar Point
- 2011 Sonar Point
- Water Level 2013
- Survey Control 2011 (See Note 3 Below)
- Dauphin River Centreline

TRANSPORTATION

- Gravel Road
- Trail
- Edge of Water (LiDAR)

From 2011 to 2013
Elevation Variation (m)

- < −2
- −2.0 − −1.5
- −1.5 − −1.0
- −1.0 − −0.5
- −0.5 − 0.5
- 0.5 − 1.0
- 1.0 − 1.5
- 1.5 − 2.0
- > 2.0

* SEE NOTE 1 FOR EXPLANATION

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DRAFT

50 0 50 100 150 200
Metres

SCALE: 1:5,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/011	ISSUED WITH DRAFT REPORT	PAL	MSW
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT	PAL	

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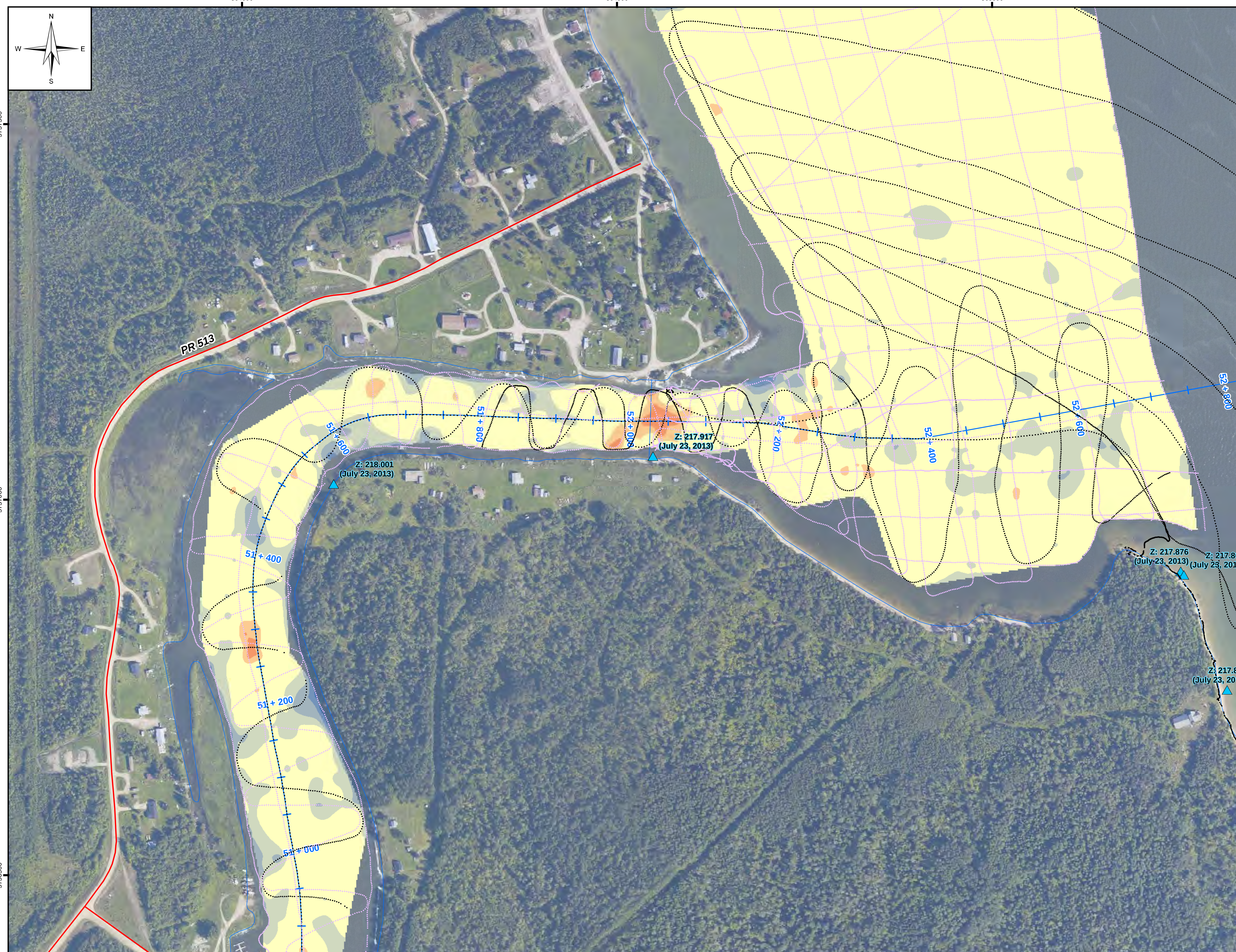
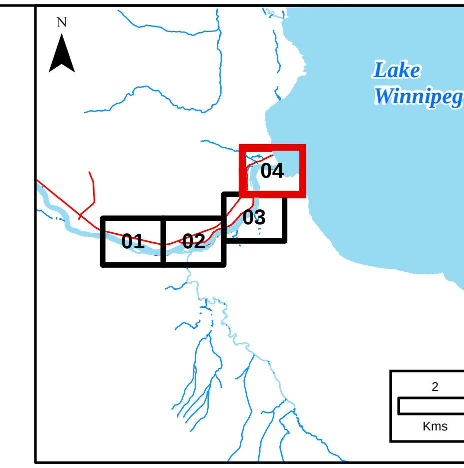
LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

LOWER DAUPHIN RIVER BATHYMETRY DIFFERENCES OF 2011 TO 2013 (SHEET 3 OF 4)

MARCH 2016 | DRAWING 6.3 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig06_RevB.mxd
11"x17" PLOT SCALE 1:1





LEGEND:

- 2013 Sonar Point
- 2011 Sonar Point
- Water Level 2013
- Survey Control 2011 (See Note 3 Below)
- Dauphin River Centreline

TRANSPORTATION

- Gravel Road
- Trail
- Edge of Water (LiDAR)

From 2011 to 2013
Elevation Variation (m)

- < −2
- −2.0 – −1.5
- −1.5 – −1.0
- −1.0 – −0.5
- −0.5 – 0.5
- 0.5 – 1.0
- 1.0 – 1.5
- 1.5 – 2.0
- > 2.0

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DRAFT

50 0 50 100 150 200
Metres

SCALE: 1:5,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/01	ISSUED WITH DRAFT REPORT	PAL	MSW
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT	PAL	

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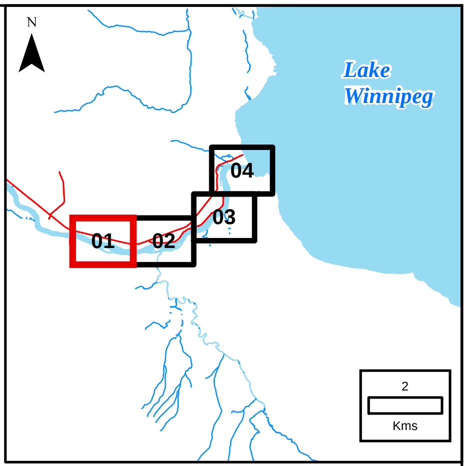
LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

LOWER DAUPHIN RIVER BATHYMETRY DIFFERENCES OF 2011 TO 2013 (SHEET 4 OF 4)

MARCH 2016 | DRAWING 6.4 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig06_RevB.mxd
11"x17" PLOT SCALE 1:1



LEGEND:

- 2014 Sonar Point
- 2013 Sonar Point
- Water Level (June 17–21, 2014)
- Dauphin River Centreline

TRANSPORTATION

- Gravel Road
- Trail
- Edge of Water (LiDAR)

From 2013 to 2014 Elevation Variation (m)

- < -2
- -2.0 – -1.5
- -1.5 – -1
- -1.0 – -0.5
- -0.5 – 0.5
- 0.5 – 1.0
- 1.0 – 1.5
- 1.5 – 2.0
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DRAFT

50 0 50 100 150 200

Metres

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B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT		PAL

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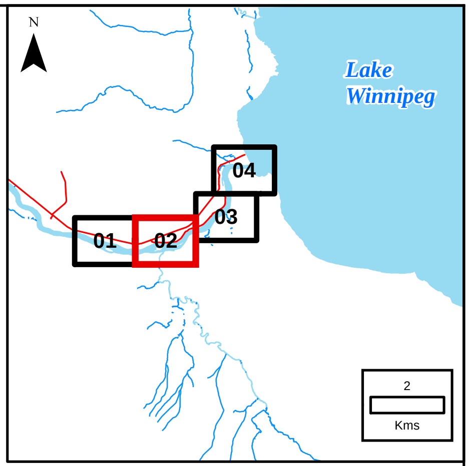
LOWER DAUPHIN RIVER BATHYMETRY DIFFERENCES OF 2013 TO 2014 (SHEET 1 OF 4)

MARCH 2016 | DRAWING 7.1 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig07_RevB.mxd
11"x17" PLOT SCALE 1:1



LEGEND:

- 2014 Sonar Point
- 2013 Sonar Point
- Water Level (June 17–21, 2014)
- Dauphin River Centreline

TRANSPORTATION

- Gravel Road
- Trail
- Edge of Water (LiDAR)

From 2013 to 2014
Elevation Variation (m)

- < −2
- −2.0 – −1.5
- −1.5 – −1
- −1.0 – −0.5
- −0.5 – 0.5
- 0.5 – 1.0
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DRAFT

50 0 50 100 150 200
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SCALE: 1:5,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
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A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT	PAL	

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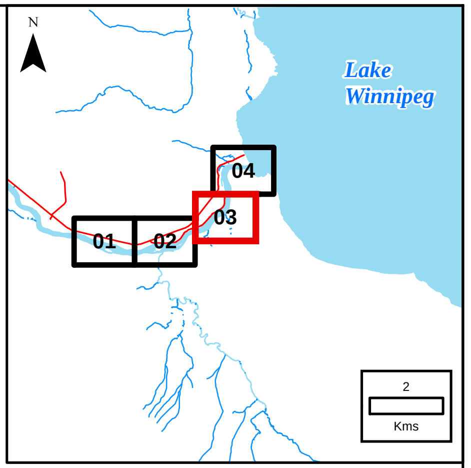
LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

LOWER DAUPHIN RIVER BATHYMETRY DIFFERENCES OF 2013 TO 2014 (SHEET 2 OF 4)

MARCH 2016 | DRAWING 7.2 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig07_RevB.mxd
11"x17" PLOT SCALE 1:1



LEGEND:

- 2014 Sonar Point
- 2013 Sonar Point
- Water Level (June 17–21, 2014)
- Dauphin River Centreline

TRANSPORTATION

- Gravel Road
- Trail
- Edge of Water (LiDAR)

From 2013 to 2014

Elevation Variation (m)

- < −2
- −2.0 − −1.5
- −1.5 − −1
- −1.0 − −0.5
- −0.5 − 0.5
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DRAFT

50 0 50 100 150 200

Metres

SCALE: 1:5,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT	PAL	

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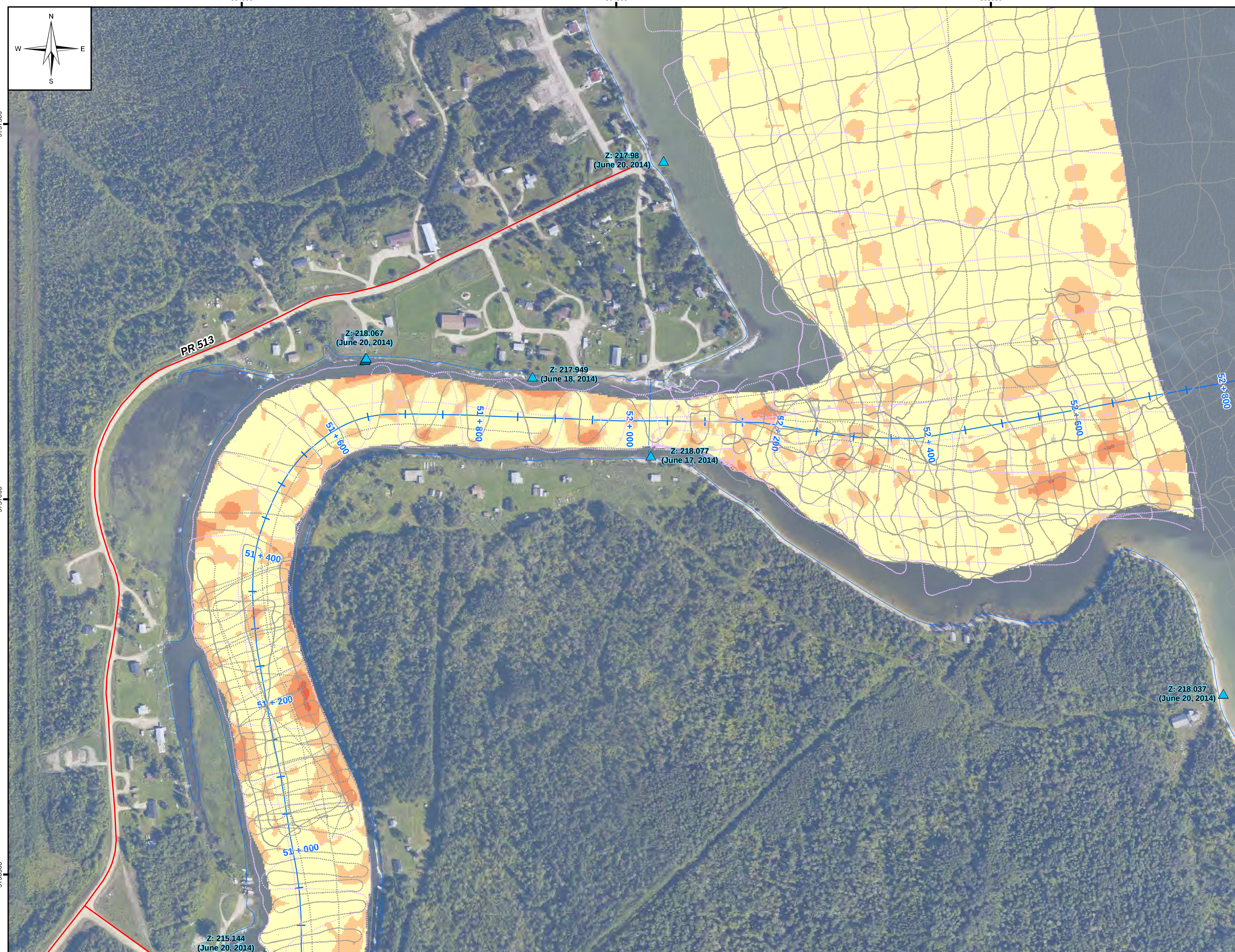
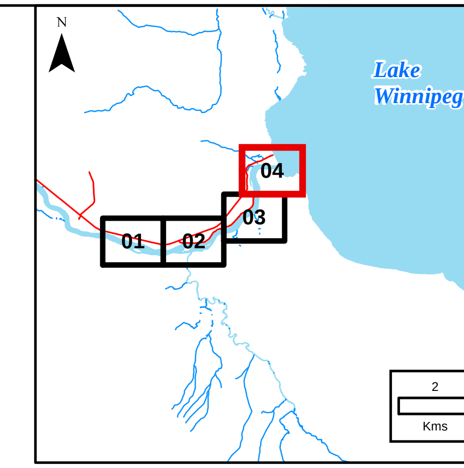
LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

LOWER DAUPHIN RIVER BATHYMETRY DIFFERENCES OF 2013 TO 2014 (SHEET 3 OF 4)

MARCH 2016 | DRAWING 7.3 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig07_RevB.mxd
11"x17" PLOT SCALE 1:1





LEGEND:

- 2014 Sonar Point
- 2013 Sonar Point
- Water Level (June 17–21, 2014)
- Dauphin River Centreline

TRANSPORTATION

- Gravel Road
- Trail
- Edge of Water (LiDAR)

From 2013 to 2014
Elevation Variation (m)

- < −2
- −2.0 – −1.5
- −1.5 – −1
- −1.0 – −0.5
- −0.5 – 0.5
- 0.5 – 1.0
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DRAFT

50 0 50 100 150 200
Metres

SCALE: 1:5,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
B	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW

NO.	YY/MM/DD	DESCRIPTION	BY
A	14/10/17	ISSUED WITH PRELIMINARY DRAFT REPORT	PAL

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Manitoba INFRASTRUCTURE AND TRANSPORTATION

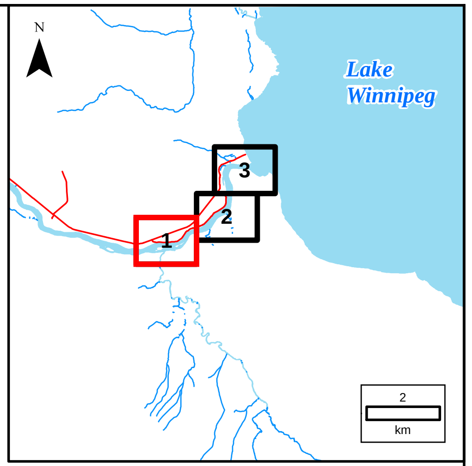
North/South Consultants Inc.

LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

LOWER DAUPHIN RIVER BATHYMETRY DIFFERENCES OF 2013 TO 2014 (SHEET 4 OF 4)

MARCH 2016 | DRAWING 7.4 | REV: B

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevB\Draft_Report_20160304\Physical_Process\13-0431-001-Fig07_RevB.mxd
11"x17" PLOT SCALE 1:1



LEGEND:

- Water Level (Sept 16–17, 2015)
- Water Level (June 17–21, 2014)
- 2015 Sonar Point
- 2014 Sonar Point
- Dauphin River Centreline

TRANSPORTATION

- Gravel Road
- Trail
- Edge of Water (LiDAR)

From 2014 to 2015 Elevation Variation (m)

- < −2
- −2.0 − −1.5
- −1.5 − −1
- −1.0 − −0.5
- −0.5 − 0.5
- 0.5 − 1.0
- 1.0 − 1.5
- 1.5 − 2.0
- > 2.0

NOTES:

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DRAFT

50 0 50 100 150 200

Meters

SCALE: 1:5,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
A	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW

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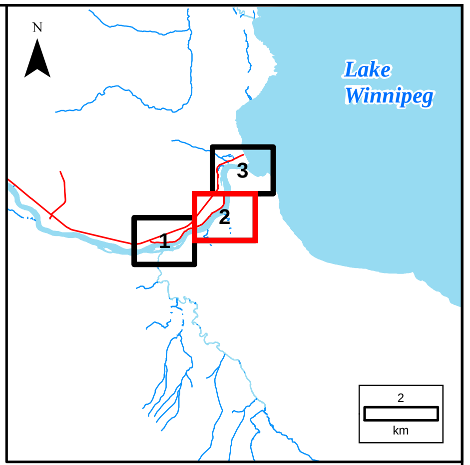
North/South Consultants Inc. Aquatic Environment Specialists

LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

LOWER DAUPHIN RIVER BATHYMETRY DIFFERENCES OF 2014 TO 2015 (SHEET 1 OF 3)

MARCH 2016 | DRAWING 8.1 | REV: A

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevA\DR_Bathy_2015\13-0431-001_Fig08_RevA.mxd
11"x17" PLOT SCALE 1:1



LEGEND:

Yellow triangle	Water Level (Sept 16–17, 2015)
Blue triangle	Water Level (June 17–21, 2014)
·	2015 Sonar Point
·	2014 Sonar Point
Blue line	Dauphin River Centreline

TRANSPORTATION

Red line	Gravel Road
Dashed line	Trail
Blue outline	Edge of Water (LiDAR)

From 2014 to 2015 Elevation Variation (m)

- < -2
- -2.0 – -1.5
- -1.5 – -1
- -1.0 – -0.5
- -0.5 – 0.5
- 0.5 – 1.0
- 1.0 – 1.5
- 1.5 – 2.0
- > 2.0

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DRAFT

50 0 50 100 150 200
Meters

SCALE: 1:5,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
A	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW

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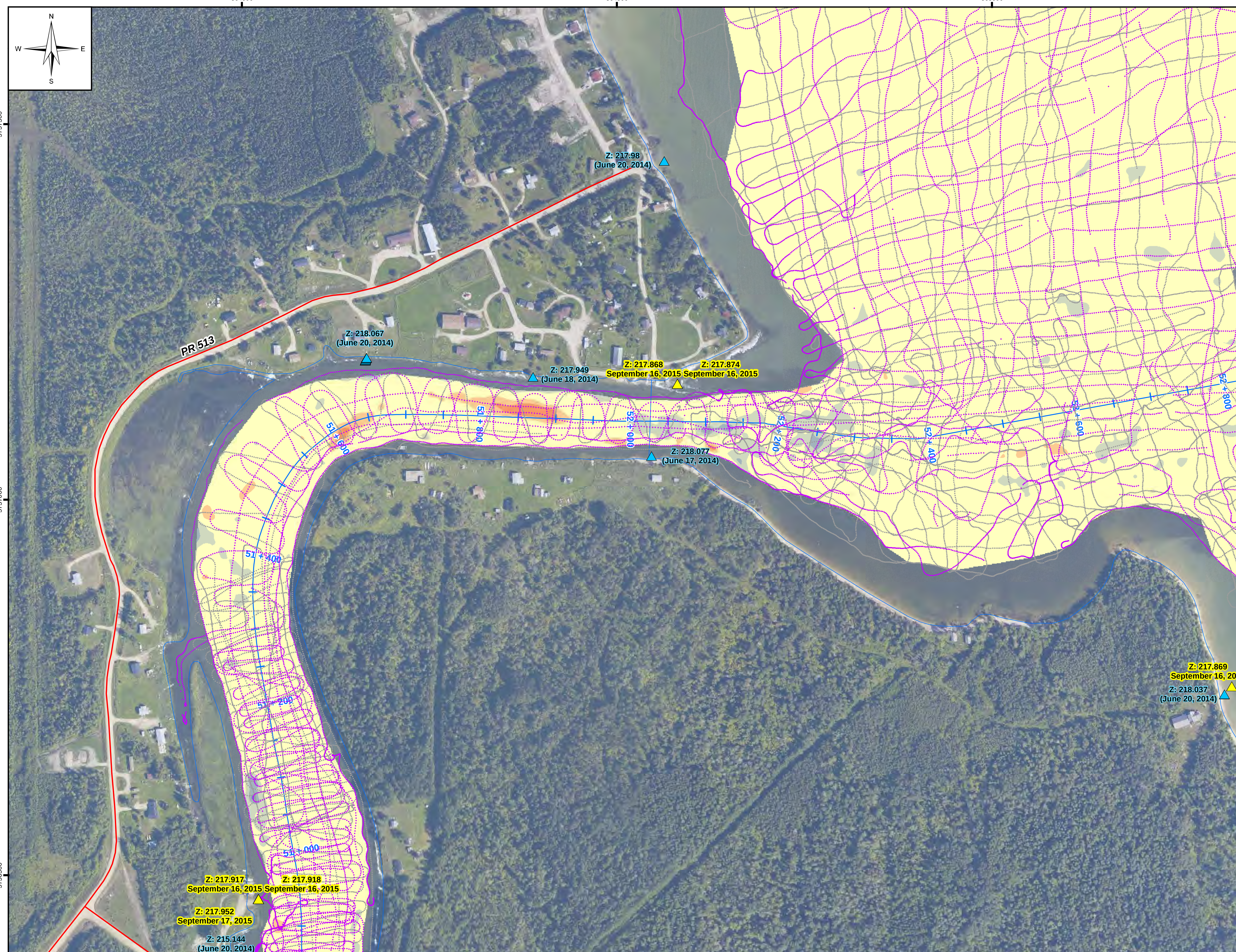
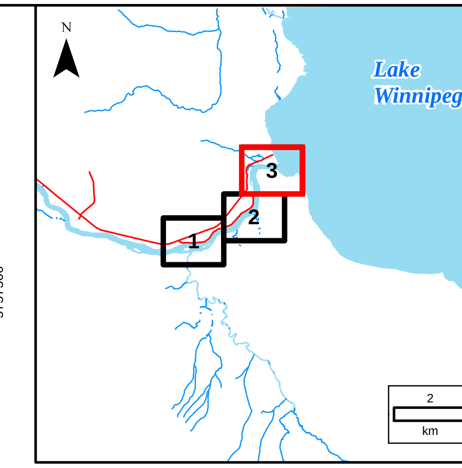
LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

LOWER DAUPHIN RIVER BATHYMETRY DIFFERENCES OF 2014 TO 2015 (SHEET 2 OF 3)

MARCH 2016 | DRAWING 8.2 | REV: A

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevA\DR_Bathy_2015\13-0431-001_Fig08_RevA.mxd
11"x17" PLOT SCALE 1:1





LEGEND:

- Water Level (Sept 16–17, 2015)
- Water Level (June 17–21, 2014)
- 2015 Sonar Point
- 2014 Sonar Point
- Dauphin River Centreline

TRANSPORTATION

- Gravel Road
- Trail
- Edge of Water (LiDAR)

From 2014 to 2015 Elevation Variation (m)

- < −2
- −2.0 – −1.5
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DRAFT

50 0 50 100 150 200
Meters

SCALE: 1:5,000 METRIC 11"x17"

NO.	YY/MM/DD	DESCRIPTION	ISSUED BY	CHECK BY
A	16/03/11	ISSUED WITH DRAFT REPORT	PAL	MSW

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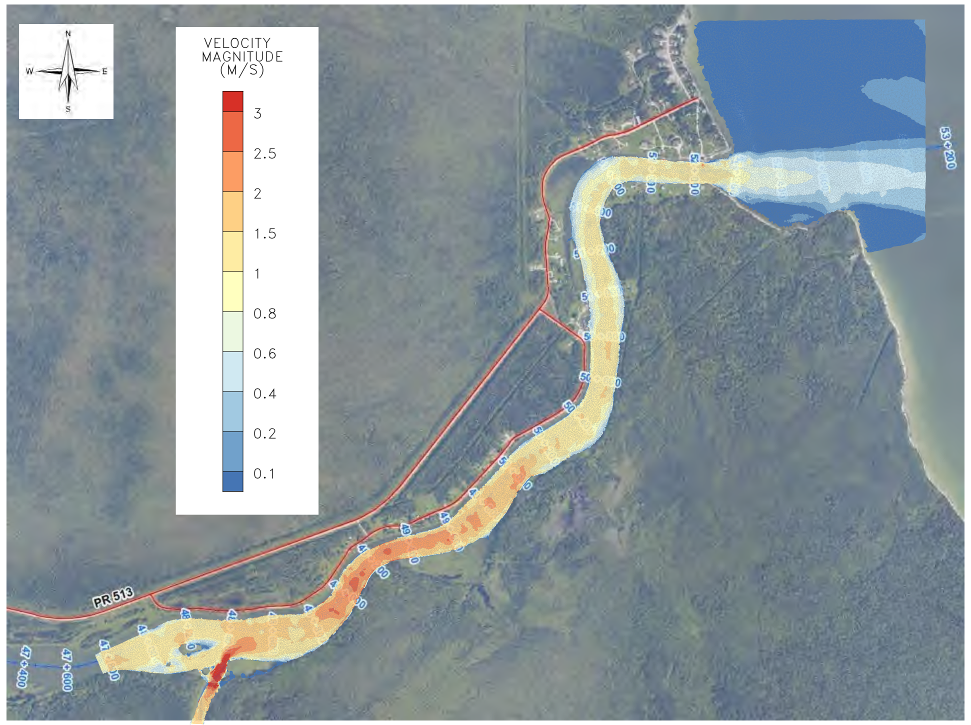
LOWER DAUPHIN RIVER BATHYMETRY DIFFERENCES OF 2014 TO 2015 (SHEET 3 OF 3)

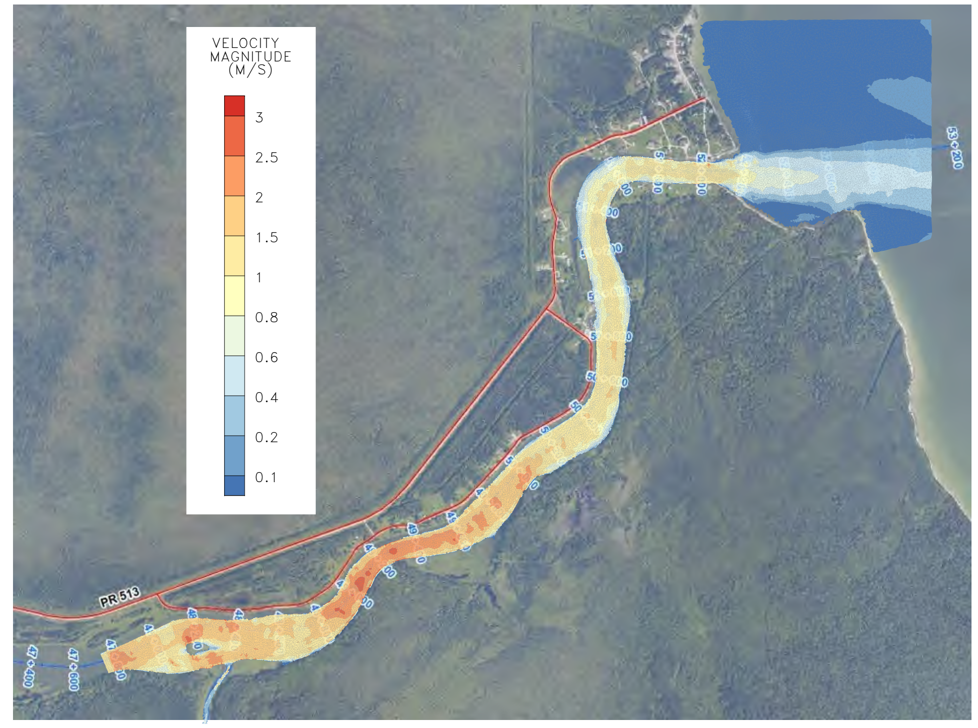
MARCH 2016 | DRAWING 8.3 | REV: A

FileName: P:\Projects\2013\13-0431-001\Dwg\GIS\MXDs\RevA\DR_Bathy_2015\13-0431-001_Fig08_RevA.mxd
11"x17" PLOT SCALE 1:1



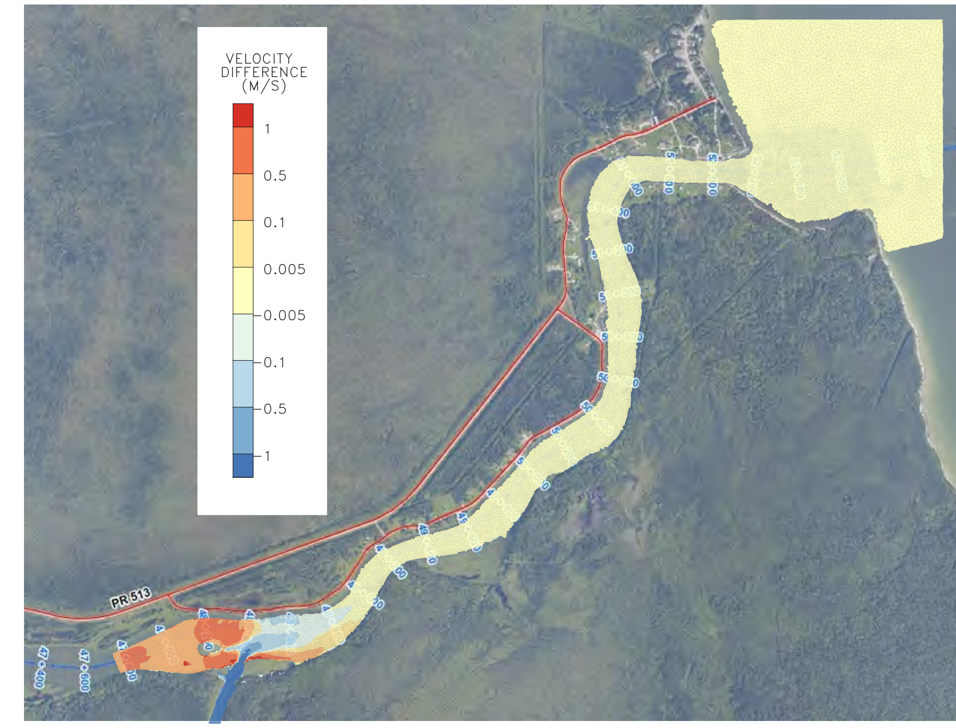
FLOW VELOCITY WITH LSMEOC OPERATION

FLOW CONDITIONS WITH LSMEOC:
DAUPHIN RIVER FLOW: 220 M^3/S
BUFFALO CREEK FLOW: 120 M^3/S
WINNIPEG LAKE LEVEL: 217.75 M



FLOW VELOCITY WITHOUT LSMEOC OPERATION

FLOW CONDITIONS WITHOUT LSMEOC:
DAUPHIN RIVER FLOW: 338 M^3/S
BUFFALO CREEK FLOW: 2 M^3/S
WINNIPEG LAKE LEVEL: 217.75 M



VELOCITY DIFFERENCE (WITHOUT – WITH)

200 0 200 400 600

SCALE: 1:20,000 METRES (11" X 17")

NOTES:
1. ALL UNITS ARE METRIC AND IN METRES UNLESS OTHERWISE SPECIFIED.
2. DATA SHOWN REPRESENTS THE AVERAGE HYDRAULIC CONDITIONS OF MIKE21 FM SIMULATION RESULTS.
3. THE 10TH PERCENTILE FLOW WAS DEFINED BASED ON THE DURATION CURVE OF THE OUTFLOWS FROM LAKE ST. MARTIN DURING THE PERIOD FROM JULY 2011 TO JULY 2012

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LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

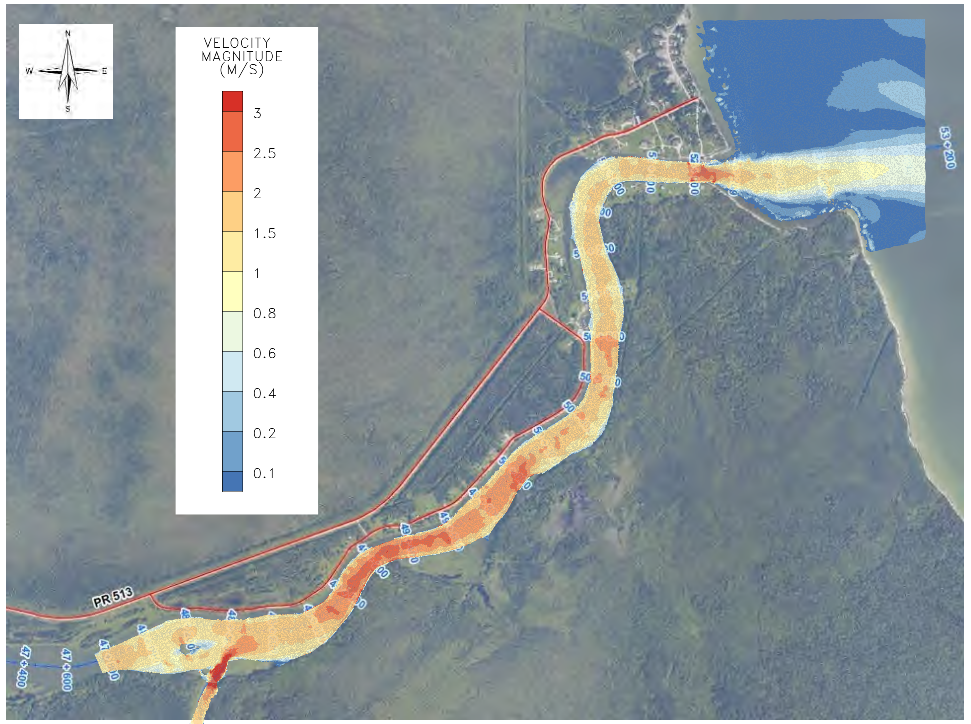
2D MODEL OF DAUPHIN RIVER DOWNSTREAM OF BUFFALO CREEK 10TH PERCENTILE FLOW

MARCH 2016 | DRAWING 9 | REV: A

Drawn with Tecplot 360 2013R1

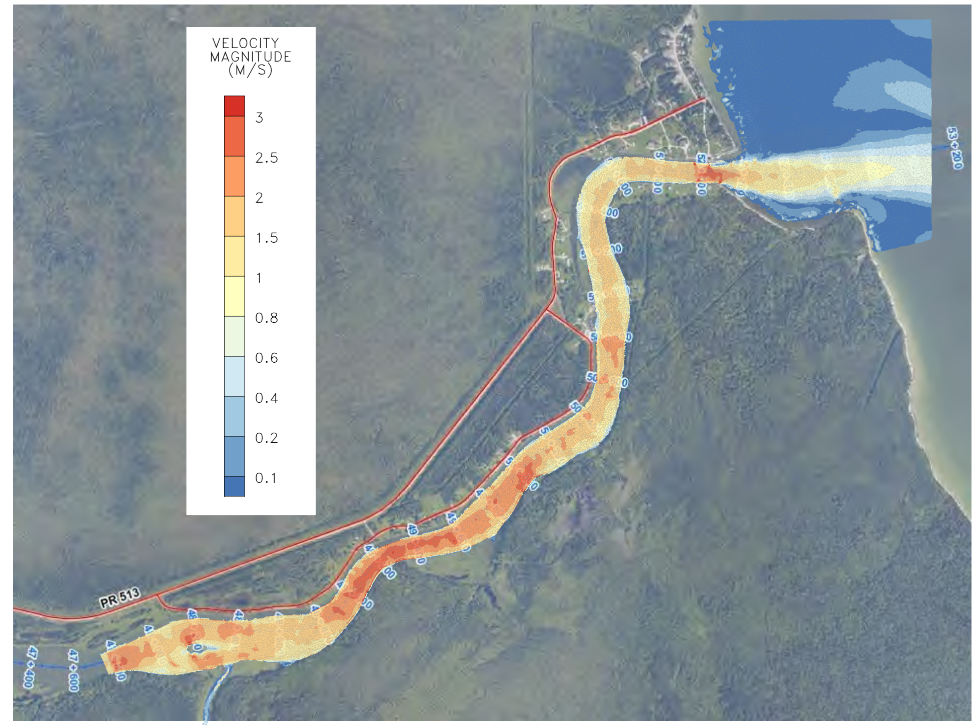
FileName: V:13-0431-001 DauphinRiverMIKE21 Mud ModelInlTestsInlTest43 Q340WithoutInlTest43_03.m21fm - Result Files13-0431-001_W09_Rev A.PDF
11"x17"

Drawn with Tecplot 360 2013R1



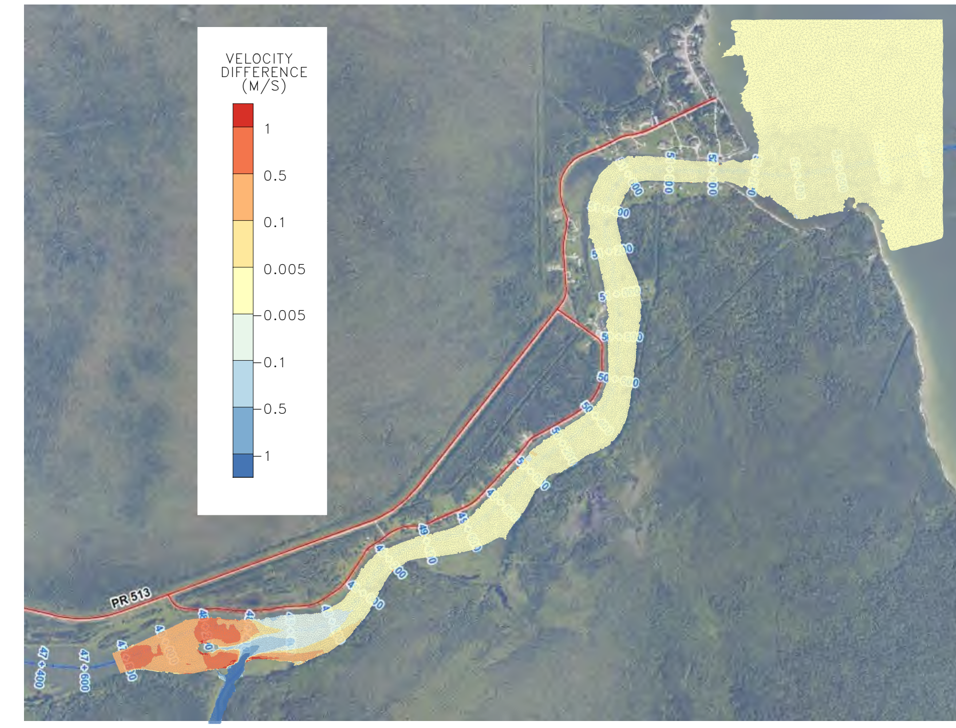
FLOW VELOCITY WITH LSMEOC OPERATION

FLOW CONDITIONS WITH LSMEOC:
DAUPHIN RIVER FLOW: 299 M^3/S
BUFFALO CREEK FLOW: 131 M^3/S
WINNIPEG LAKE LEVEL: 217.57 M



FLOW VELOCITY WITHOUT LSMEOC OPERATION

FLOW CONDITIONS WITHOUT LSMEOC:
DAUPHIN RIVER FLOW: 428 M^3/S
BUFFALO CREEK FLOW: 2 M^3/S
WINNIPEG LAKE LEVEL: 217.57 M



VELOCITY DIFFERENCE (WITHOUT – WITH)

200 0 200 400 600

SCALE: 1:20,000 METRES (11" X 17")

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NOTES:
1. ALL UNITS ARE METRIC AND IN METRES UNLESS OTHERWISE SPECIFIED.
2. DATA SHOWN REPRESENTS THE AVERAGE HYDRAULIC CONDITIONS OF MIKE21 FM SIMULATION RESULTS.
3. THE 10TH PERCENTILE FLOW WAS DEFINED BASED ON THE DURATION CURVE OF THE OUTFLOWS FROM LAKE ST. MARTIN DURING THE PERIOD FROM JULY 2011 TO JULY 2012

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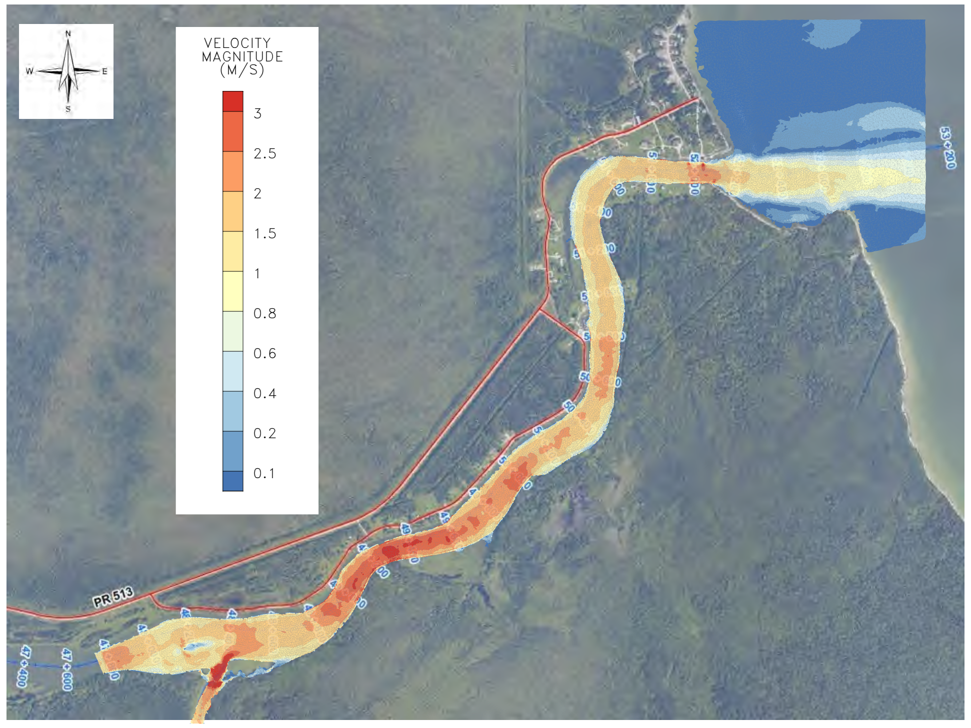
LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

2D MODEL OF DAUPHIN RIVER DOWNSTREAM OF BUFFALO CREEK 50TH PERCENTILE FLOW

MARCH 2016 | DRAWING 10 | REV: A

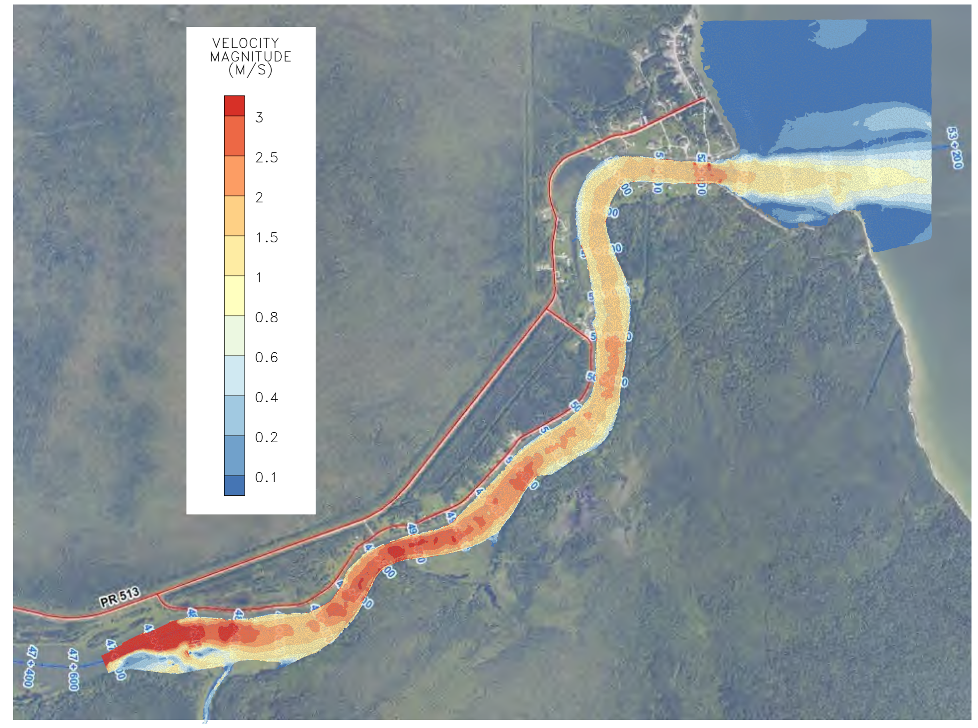
FileName: V:13-0431-001 DauphinRiverMIKE21 Mud ModelInitTestsInitTest45 0430WithoutInitTest45.m21fm – Result Files13-0431-001_W10_Rev A.PDF
11"x17"

Drawn with Tecplot 360 2013R1



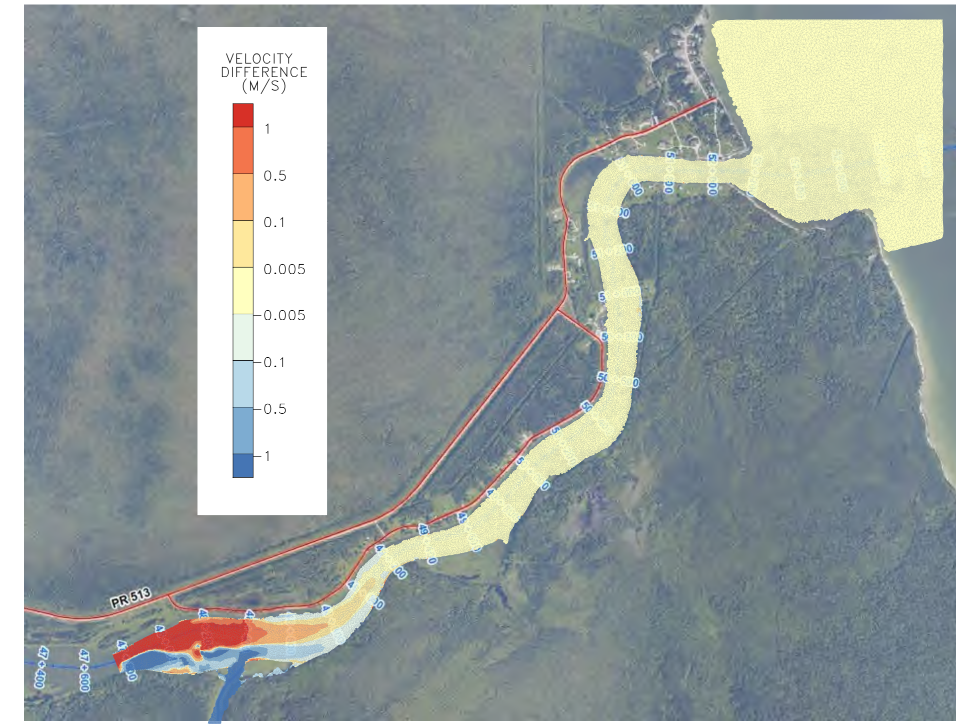
FLOW VELOCITY WITH LSMEOC OPERATION

FLOW CONDITIONS WITH LSMEOC:
DAUPHIN RIVER FLOW: 431 M^3/S
BUFFALO CREEK FLOW: 159 M^3/S
WINNIPEG LAKE LEVEL: 217.77 M



FLOW VELOCITY WITHOUT LSMEOC OPERATION

FLOW CONDITIONS WITHOUT LSMEOC:
DAUPHIN RIVER FLOW: 588 M^3/S
BUFFALO CREEK FLOW: 2 M^3/S
WINNIPEG LAKE LEVEL: 217.77 M



VELOCITY DIFFERENCE (WITHOUT − WITH)

200 0 200 400 600

SCALE: 1:20,000 METRES (11" X 17")

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NOTES:
1. ALL UNITS ARE METRIC AND IN METRES UNLESS OTHERWISE SPECIFIED.
2. DATA SHOWN REPRESENTS THE AVERAGE HYDRAULIC CONDITIONS OF MIKE21 FM SIMULATION RESULTS.
3. THE 10TH PERCENTILE FLOW WAS DEFINED BASED ON THE DURATION CURVE OF THE OUTFLOWS FROM LAKE ST. MARTIN DURING THE PERIOD FROM JULY 2011 TO JULY 2012

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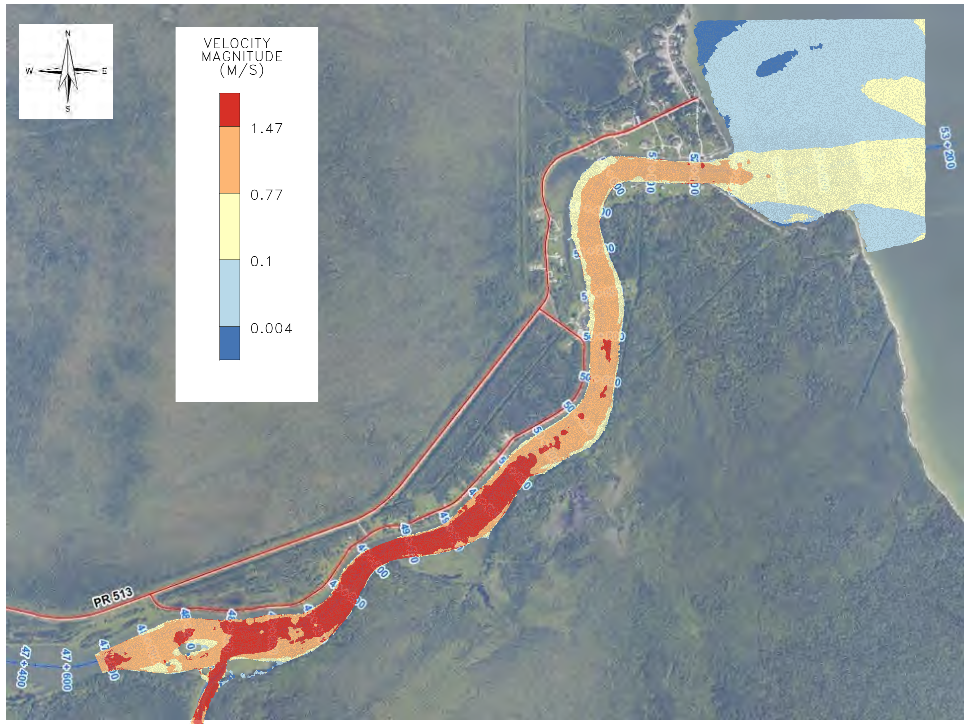
LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

2D MODEL OF DAUPHIN RIVER DOWNSTREAM OF BUFFALO CREEK 90TH PERCENTILE FLOW

MARCH 2016 | DRAWING 11 | REV: A

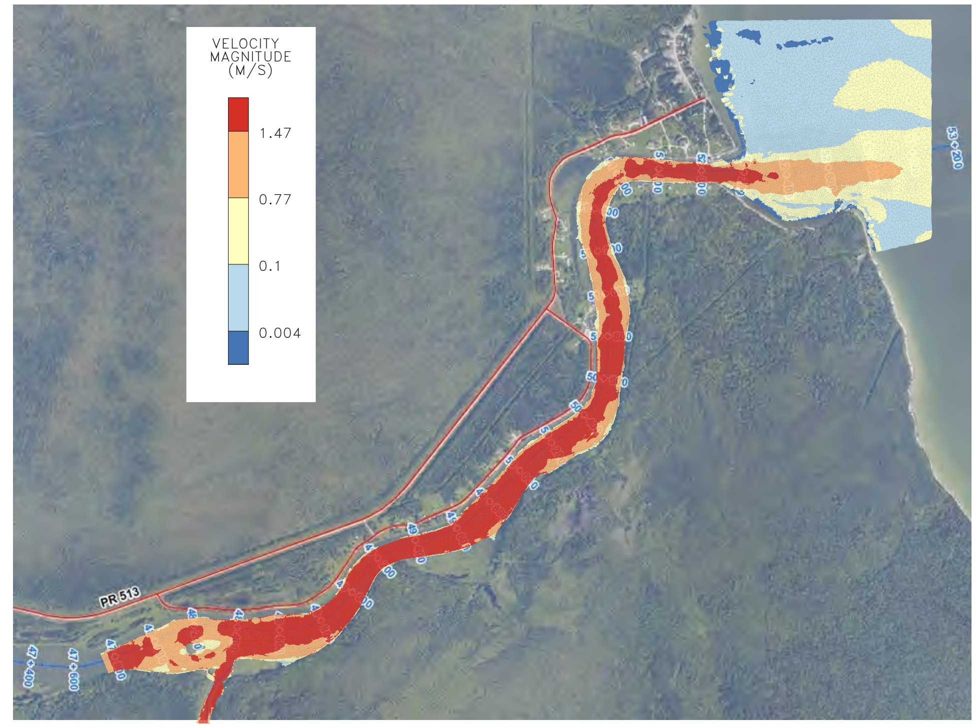
FileName: V:13-0431-001 DauphinRiverMIKE21 Mud ModelIniTestsIniTest47 Q590WithoutIniTest47.m21fm - Result Files13-0431-001_W11_Rev A.PDF
11"x17"

Drawn with Tecplot 360 2013R1



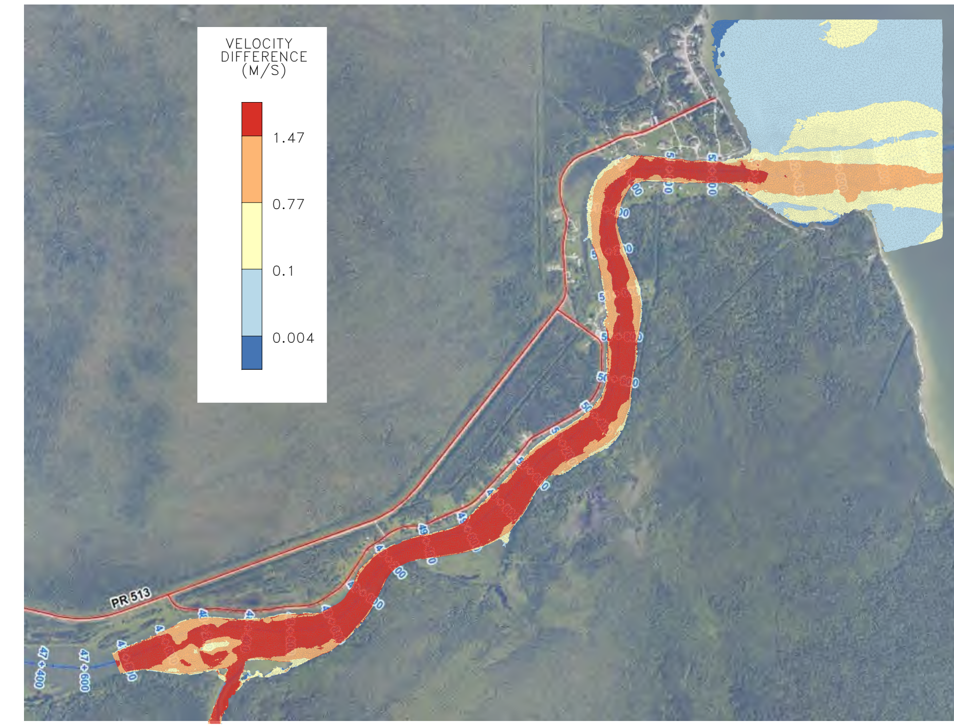
FLOW VELOCITY FOR 10TH PERCENTILE FLOW WITH LSMEOC OPERATION

FLOW CONDITIONS WITH LSMEOC:
DAUPHIN RIVER FLOW: 220 M^3/S
BUFFALO CREEK FLOW: 120 M^3/S
WINNIPEG LAKE LEVEL: 217.75 M



FLOW VELOCITY FOR 50TH PERCENTILE FLOW WITH LSMEOC OPERATION

FLOW CONDITIONS WITH LSMEOC:
DAUPHIN RIVER FLOW: 299 M^3/S
BUFFALO CREEK FLOW: 131 M^3/S
WINNIPEG LAKE LEVEL: 217.57 M



FLOW VELOCITY FOR 90TH PERCENTILE FLOW WITH LSMEOC OPERATION

FLOW CONDITIONS WITHOUT LSMEOC:
DAUPHIN RIVER FLOW: 431 M^3/S
BUFFALO CREEK FLOW: 159 M^3/S
WINNIPEG LAKE LEVEL: 217.77 M

200 0 200 400 600

SCALE: 1:20,000 METRES (11" X 17")

NOTES:
1. ALL UNITS ARE METRIC AND IN METRES UNLESS OTHERWISE SPECIFIED.
2. DATA SHOWN REPRESENTS THE AVERAGE HYDRAULIC CONDITIONS OF MIKE21 FM SIMULATION RESULTS.
3. THE 10TH PERCENTILE FLOW WAS DEFINED BASED ON THE DURATION CURVE OF THE OUTFLOWS FROM LAKE ST. MARTIN DURING THE PERIOD FROM JULY 2011 TO JULY 2012
4. SCALE BASED ON CRITICAL VELOCITY FOR DEPOSITION OF DIFFERENT GRAIN MATERIAL TYPES (0.004 M/S – SILT/CLAY, 0.1 M/S – SAND, 0.77 M/S – GRAVEL, 1.47 M/S – COBBLE)

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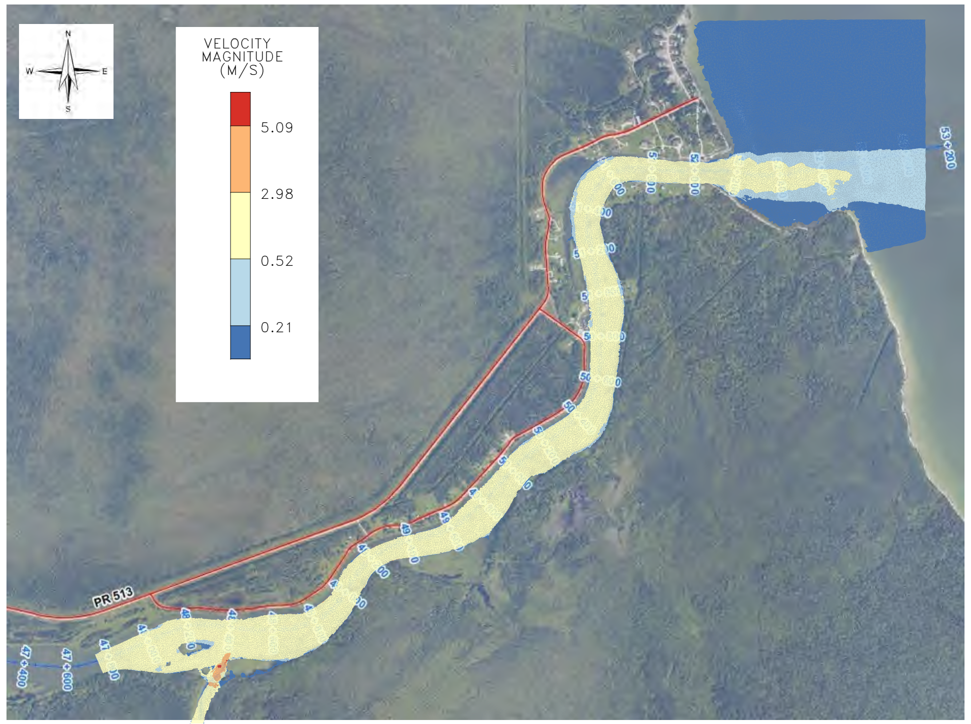
LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

2D MODEL OF DAUPHIN RIVER DOWNSTREAM OF BUFFALO CREEK VELOCITY FOR DEPOSITION

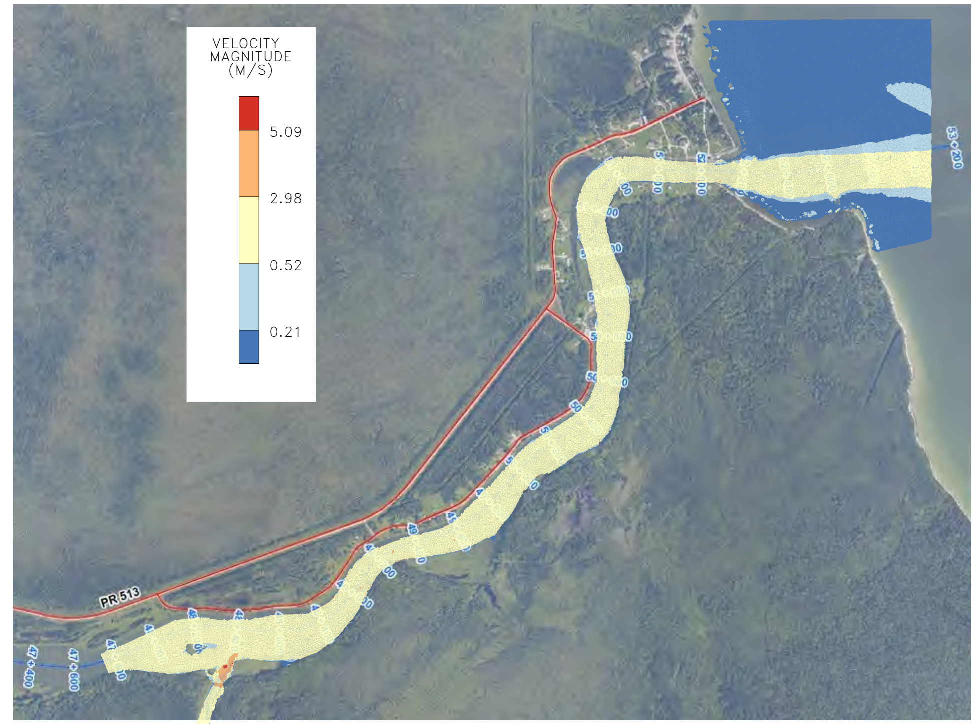
MARCH 2016 | DRAWING 12 | REV: A

FileName: V:13-0431-001 DauphinRiverMIKE21 Mud ModelIniTestsIniTest47 Q590WithoutIniTest47.m21fm – Result Files13-0431-001_W12_Rev A.PDF
11"x17"



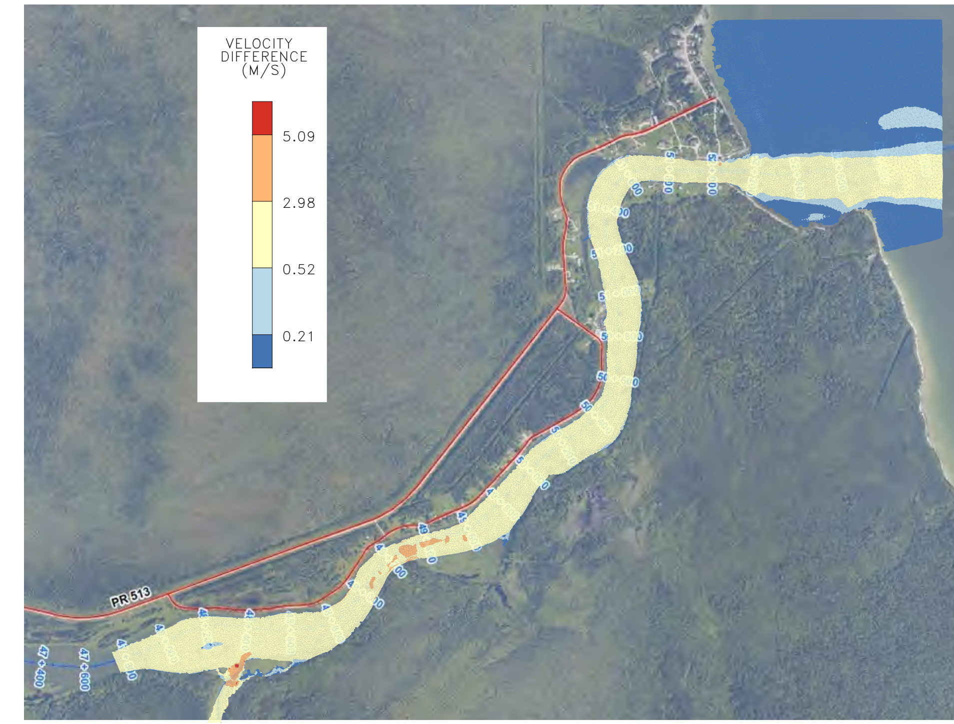
FLOW VELOCITY FOR 10TH PERCENTILE FLOW WITH LSMEOC OPERATION

FLOW CONDITIONS WITH LSMEOC:
DAUPHIN RIVER FLOW: 220 M^3/S
BUFFALO CREEK FLOW: 120 M^3/S
WINNIPEG LAKE LEVEL: 217.75 M



FLOW VELOCITY FOR 50TH PERCENTILE FLOW WITH LSMEOC OPERATION

FLOW CONDITIONS WITH LSMEOC:
DAUPHIN RIVER FLOW: 299 M^3/S
BUFFALO CREEK FLOW: 131 M^3/S
WINNIPEG LAKE LEVEL: 217.57 M



FLOW VELOCITY FOR 90TH PERCENTILE FLOW WITH LSMEOC OPERATION

FLOW CONDITIONS WITH LSMEOC:
DAUPHIN RIVER FLOW: 431 M^3/S
BUFFALO CREEK FLOW: 159 M^3/S
WINNIPEG LAKE LEVEL: 217.77 M

200 0 200 400 600

SCALE: 1:20,000 METRES (11" X 17")

NOTES:
1. ALL UNITS ARE METRIC AND IN METRES UNLESS OTHERWISE SPECIFIED.
2. DATA SHOWN REPRESENTS THE AVERAGE HYDRAULIC CONDITIONS OF MIKE21 FM SIMULATION RESULTS.
3. THE 10TH PERCENTILE FLOW WAS DEFINED BASED ON THE DURATION CURVE OF THE OUTFLOWS FROM LAKE ST. MARTIN DURING THE PERIOD FROM JULY 2011 TO JULY 2012
4. SCALE BASED ON CRITICAL VELOCITY FOR EROSION OF DIFFERENT GRAIN MATERIAL TYPES (0.21 M/S – SILT/CLAY, 0.52 M/S – SAND, 2.98 M/S – GRAVEL, 5.09 M/S – COBBLE)

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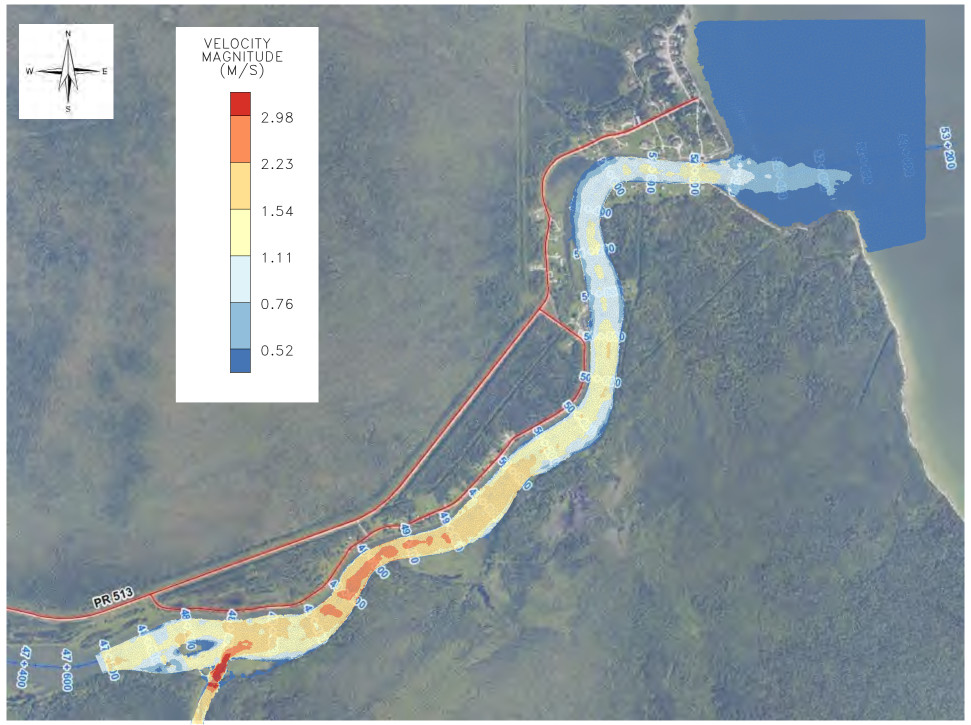
LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

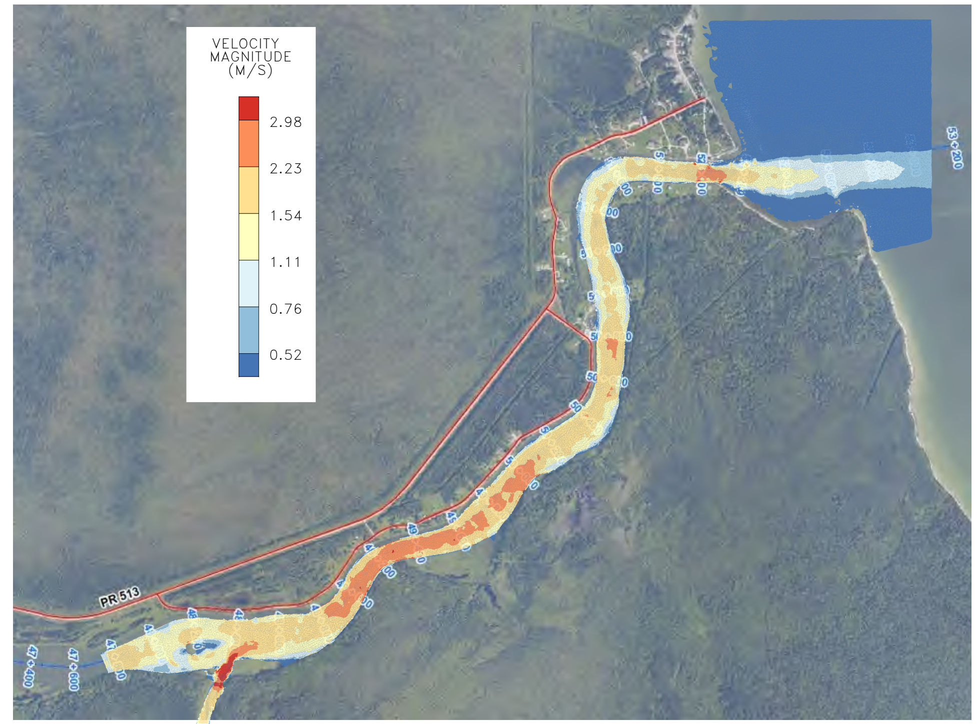
2D MODEL OF DAUPHIN RIVER DOWNSTREAM OF BUFFALO CREEK FLOW VELOCITY FOR EROSION

MARCH 2016 | DRAWING 13 | REV: A



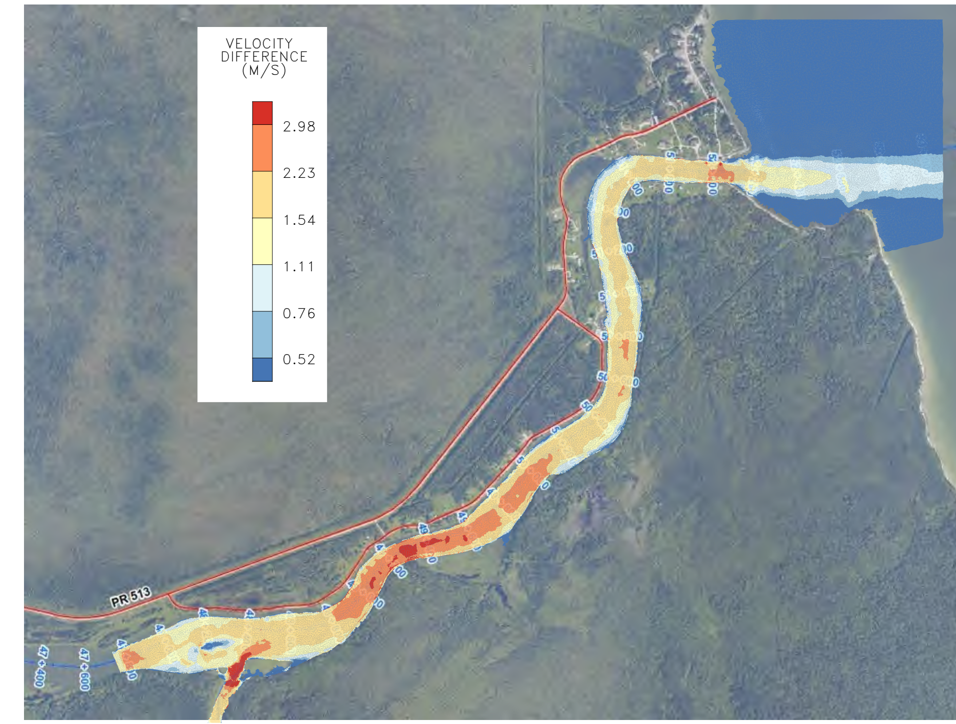
FLOW VELOCITY FOR 10TH PERCENTILE FLOW WITH LSMEOC OPERATION

FLOW CONDITIONS WITH LSMEOC:
DAUPHIN RIVER FLOW: 220 M^3/S
BUFFALO CREEK FLOW: 120 M^3/S
WINNIPEG LAKE LEVEL: 217.75 M



FLOW VELOCITY FOR 50TH PERCENTILE FLOW WITH LSMEOC OPERATION

FLOW CONDITIONS WITH LSMEOC:
DAUPHIN RIVER FLOW: 299 M^3/S
BUFFALO CREEK FLOW: 131 M^3/S
WINNIPEG LAKE LEVEL: 217.57 M



FLOW VELOCITY FOR 90TH PERCENTILE FLOW WITH LSMEOC OPERATION

FLOW CONDITIONS WITH LSMEOC:
DAUPHIN RIVER FLOW: 431 M^3/S
BUFFALO CREEK FLOW: 159 M^3/S
WINNIPEG LAKE LEVEL: 217.77 M

200 0 200 400 600

SCALE: 1:20,000 METRES (11" X 17")

NOTES:
1. ALL UNITS ARE METRIC AND IN METRES UNLESS OTHERWISE SPECIFIED.
2. DATA SHOWN REPRESENTS THE AVERAGE HYDRAULIC CONDITIONS OF MIKE21 FM SIMULATION RESULTS.
3. THE 10TH PERCENTILE FLOW WAS DEFINED BASED ON THE DURATION CURVE OF THE OUTFLOWS FROM LAKE ST. MARTIN DURING THE PERIOD FROM JULY 2011 TO JULY 2012
4. SCALE BASED ON CRITICAL VELOCITY FOR EROSION OF GRAVEL (0.76 M/S – VERY FINE GRAVEL, 1.54 M/S – MEDIUM GRAVEL, 2.98 M/S – VERY COARSE GRAVEL)

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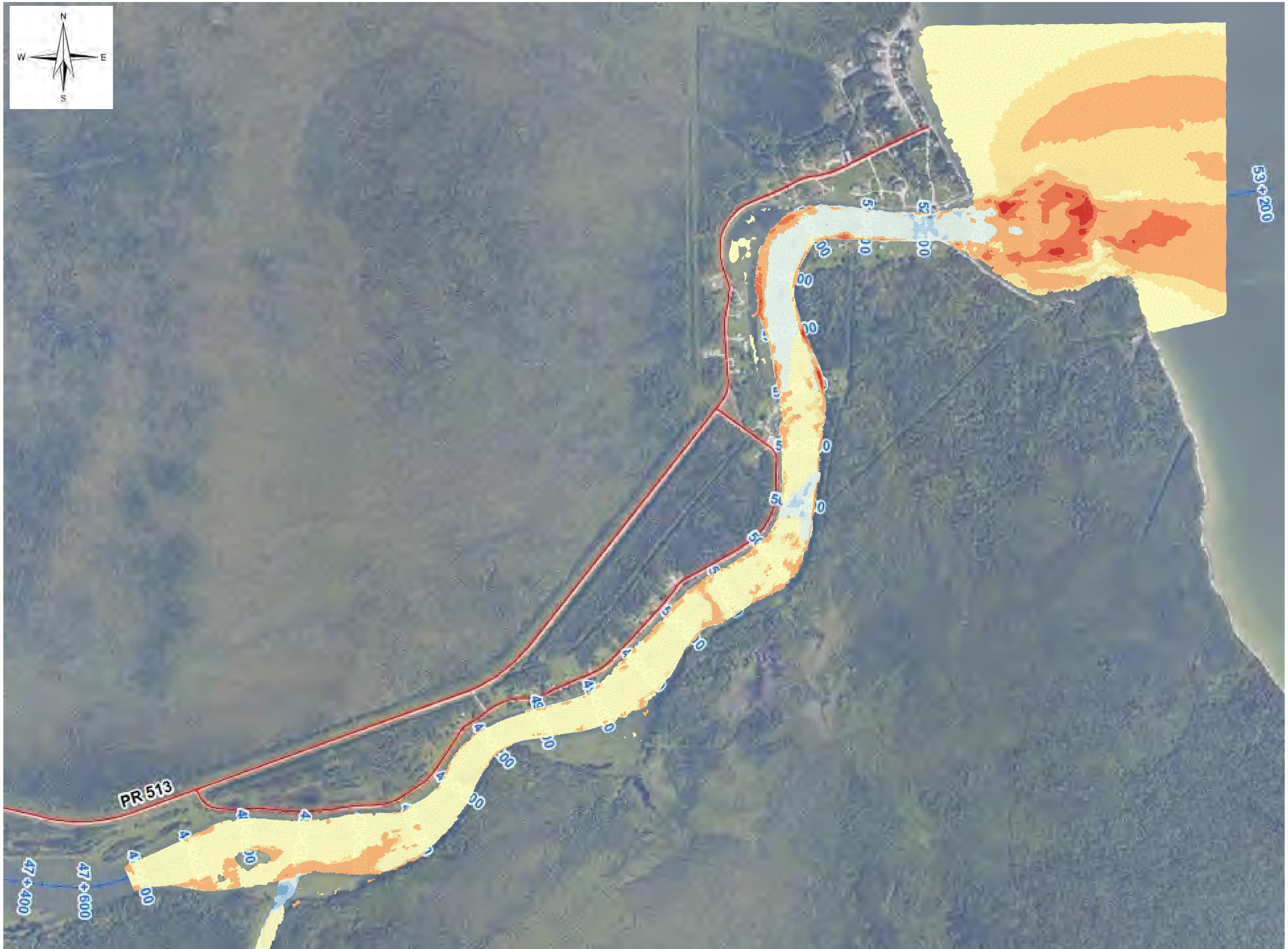
LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

2D MODEL OF DAUPHIN RIVER DOWNSTREAM OF BUFFALO CREEK VELOCITY FOR GRAVEL EROSION

MARCH 2016 | DRAWING 14 | REV: A

Drawn with Tecplot 360 2013R1

FileName: V:13-0431-001 DauphinRiverMIKE21 Mud ModelInitTestsInitTest47 Q590WithoutInitTest47.m21fm – Result Files13-0431-001_W14_Rev A.PDF
11"x17"



BED LEVEL CHANGES FROM 2011 TO 2012 (M)

1
0.5
0.01
0
-0.01
-0.5
-1
-1.5

DRAFT

NOTES:
1. ALL UNITS ARE METRIC AND IN METRES UNLESS OTHERWISE SPECIFIED.
2. DATA SHOWN REPRESENTS THE AVERAGE BED LEVEL CHANGES FROM JULY 2011 TO JUNE 2012 BASED ON THE MODEL SIMULATION OF MIKE21 FM MODEL WITH MUD TRANSPORT MODULE.

100 0 100 200 300 400

SCALE: 1:10,000 METRES (11" X 17")

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LSM EMERGENCY RELIEF CHANNEL MONITORING & DEVELOPMENT OF HABITAT COMPENSATION

2D MODEL OF DAUPHIN RIVER DOWNSTREAM OF BUFFALO CREEK BED LEVEL CHANGES

MARCH 2016 | DRAWING 15 | REV: A

Drawn with Tecplot 360 2013R1

FileName: V:13-0431-001 DauphinRiverMIKE21 Mud ModelRun13 2011MudRun13_01.m21fm ~ Result Files13-0431-001_W15_Rev A.PDF
11"x17"

APPENDICES