PARISH aquatic services
A Division of Matrix Solutions Inc.

MEMORANDUM

TO: Jacques Robichaud, P.Eng., Department of Fisheries and Oceans Regional Engineer Small Craft Harbours, Maritime Region

FROM: Amanda McKay, B.Eng., E.I.T., Karen Hofbauer, M.A.Sc., P.Eng., and Ron Jenkins, EP, AScT, Matrix Solutions Inc.

SUBJECT: Hydraulic Assessment of the Little Southwest Miramichi River at Johnston's Pit at the Oxbow

DATE: April 20, 2016

1 INTRODUCTION

PARISH Aquatic Services, A Division of Matrix Solutions Inc. (PARISH; formerly PARISH Geomorphic Ltd.) was retained by Fisheries and Oceans Canada (DFO) to complete a detailed hydrometric survey of the Little Southwest Miramichi River upstream and downstream of a location of significant erosion and to complete conceptual design to stabilize the river bank at the site. The location of the erosion is locally known as Johnston's Pit at the Oxbow (herein referred to as the Oxbow). The Oxbow site is located in the downstream section of the Little Southwest Miramichi River as depicted on Figure 1.

A hydraulic analysis of existing and proposed conditions and a functional assessment of the preliminary stabilization design have been completed to ensure the proposed works will not cause unacceptable impacts to other areas of the river. This report details the methodology and results of the hydraulic assessment.

1.1 Background Information

The Little Southwest Miramichi River joins the Northwest Miramichi River just downstream of the Oxbow site. The Oxbow site is located on private land across and adjacent to the Metepenagiag First Nations community in Red Bank, New Brunswick and currently experiences substantial erosion issues. Significant efforts have been undertaken to understand the rate of erosion of the bank and the consequences of the sedimentation coming off the bank on the downstream riverbed. To this end, many topographic surveys have been completed since 2002, including LiDAR data collection. However, these previous studies have focused mainly on the area of the Oxbow with little information obtained above and below the site.

2 FIELD ASSESSMENT

To understand the current conditions of the Oxbow, a detailed field investigation was undertaken in November 2015 by PARISH. Two crews worked simultaneously to collect bathymetric and topographic information. One crew used total station survey equipment to survey the edge of water and channel banks, while the second crew used a River Surveyor Acoustic Doppler Current Profiler (ADCP) Unit mounted on the side of a small boat to collect bathymetric data.

2.1 Topographic Survey

The bank and edge of channel survey was undertaken by establishing temporary control points along the shoreline for use of a total station survey unit. From these locations, the edge of the bank at the waterline and the topography above this elevation was surveyed to provide the required boundary conditions above water for both the bathymetric base plan and the hydraulic model.

2.2 Bathymetric Survey

For the bathymetric survey, an ADCP unit was mounted on a small pontoon raft, which in turn, was mounted to an outrigger attached to an Aluminum boat (Figure A). In certain upstream and downstream river sections within the Oxbow site, access via boat was not feasible. In these locations, the ADCP unit and pontoon raft were attached to ropes of a length long enough to span the channel. Two personnel then used the ropes to move the ADCP unit and raft across the channel. The ADCP unit was linked to an RTK GPS system that allowed the depth soundings to be compiled as geodetic coordinates. The ADCP Unit was radio linked to a laptop computer, which served as the data collector for the survey. After setting up the base RTK station in an open area upstream of the survey site, the ADCP and rover RTK were calibrated and prepared for deployment.

The ADCP unit was towed around the study area to collect depth information. Combining the GPS data with the sonar data, the unit collected 3D coordinates of the channel bed for use in generating a bathymetric surface. A number of maneuvering patterns were used at a relatively constant rate of speed. Initially data was collected as a series of cross-sections, which ran from near the edge of water to the edge of water on the opposite bank. Transects were spaced as evenly as possible, averaging 25 m between each transect. In addition to the cross-sectional transects, four longitudinal transects were run from one end of the survey area to the other. These transects ran roughly parallel to the banks.

Figure A ADCP Unit for data collection

2.3 Data Processing

The collected field data was downloaded and subjected to a quality assurance/quality control (QA/QC) process to ensure any erroneous data were not carried through to the analysis phase. During this review, the RTK signal for the ADCP unit caused vertical error in the data. To correct this issue, average water surface elevation upstream, midstream, and downstream of the Oxbow site were calculated from the total station survey. The RTK vertical error was then corrected by separating the data into the corresponding upstream, midstream, and downstream segments and the erroneous water surface elevations were replaced with the average water elevations.

Additionally, as the elevations recorded at the Miramichi site are so close to sea level, some of the coordinates below the water surface recorded negative elevations. To maintain positive numbers for compatibility with the hydraulic model, all elevations were increased by 100 m.

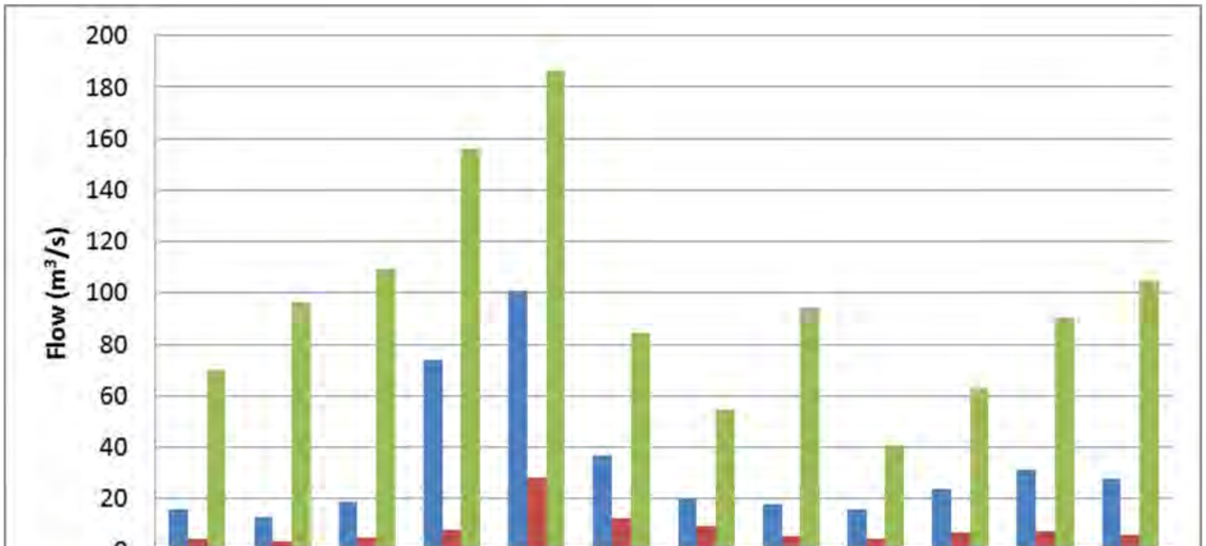
In addition to bathymetry and topographic surveys, LiDAR data for the site was obtained from Anqotum Resource Management. The initial tie-in of the LiDAR data with the recent survey information suggested that corrections would be needed to align the LiDAR with the total station surveyed topography. To understand the potential difference in elevation, 171 survey points taken during the field survey were compared with adjacent LiDAR information. The comparison showed an average elevation difference of 1.5 m between the LiDAR and the surveys, with the LiDAR being lower. As uncorrected LiDAR information would be unusable for the hydraulic model, creating a “ledge” between the surveys and LiDAR, and thus creating instabilities, the LiDAR data was raised by 1.5 m to align with the surveyed topography. LiDAR was then subjected to a second review and confirmed to be representative of the existing conditions. The data was then prepared for use in the bathymetric mapping and hydraulic modelling. Results of the topographic/bathymetric survey and LiDAR are presented on Figures 2-A to 2-C.

At the time of the survey, flow in the channel was measured using the ADCP and estimate a flow of 34 m^3/s. During this time, the channel maintained an average width of 50 m upstream and downstream of the Oxbow, with the channel width expanding up to 115 m at the site of the proposed bank restoration. Depths in the channel during the survey were measured as deep as 4 m in some locations. The shallowest depths were observed at the downstream portions of the Oxbow area and the greatest channel depths were observed at the site of the proposed bank restoration.

3 HYDROLOGY

Water Survey of Canada (WSC) has recorded more than 60 years of streamflow data for the Little Southwest Miramichi River at Lyttleton (Station 01BP001) which is located approximately 6 km upstream of the Oxbow site. Discharge at the station has been continuously monitored since 1952. The drainage area for the monitoring station is 1,340 km^2. A delineation of the drainage area at the Oxbow site estimated 1,354 km^2, only 14 km^2 larger than the WSC station (Figure 1). Therefore, the Little Southwest Miramichi River at Lyttleton (Station 01BP001) station was considered to provide a good representation of the flow at the Oxbow site.

The WSC station flow records were examined to determine trends in monthly flows of the Little Southwest Miramichi River. Mean, maximum, and minimum monthly flows are shown on Figure B. The highest monthly flow occurs during the spring melt in April and May. Flow declines into the summer months and increases again in October, November, and December before freeze up from January to March.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	15.9	13.0	18.9	74.3	100.7	36.6	19.9	17.6	15.9	24.0	31.5	27.7
Min	4.3	3.6	4.9	7.8	28.1	12.6	9.2	5.6	4.4	7.1	7.7	6.1
Max	70.0	96.5	109.3	156.0	186.5	84.6	54.5	94.5	40.5	63.0	90.6	104.7

Figure B Estimated Monthly Flows at the Little Southwest Miramichi River at Lyttleton

3.1 Frequency Analysis

A peak flow analysis using the annual extremes and several frequency distributions is outlined on Figure C. Based on the analysis, the Pearson Type 3 distribution was selected to estimate the return frequency flows for the Little Southwest Miramichi River. Table A highlights the 1, 2, 5, 10, 20, and 50-year return period flows.

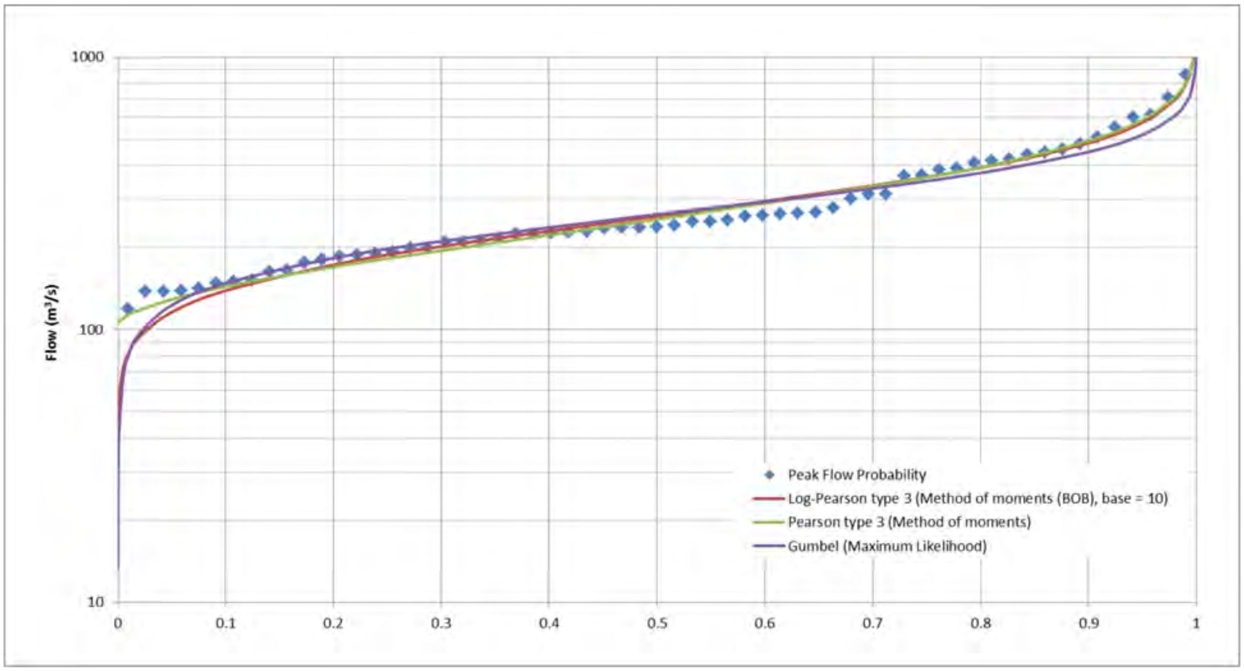


Figure C Peak Flow Frequency Distribution from the Little Southwest Miramichi River at Lyttleton

Table A Return Periods Flows for the Little Southwest Miramichi River (Pearson Type 3)

Return Period	Peak Flow Estimate (m^3/s)
Q_1	105[1]
Q_2	254
Q_5	394
Q_{10}	493
Q_{20}	589
Q_{50}	714

Notes:
[1] Annual peak flow ranges from 105 to 144 m^3/s dependant on Q_1 definition

In addition to the monthly and peak flow analysis, daily flow on the Little Southwest Miramichi River over the most recently available 5 years (2008 to 2012) are shown on Figure D. Flows consistently exceed 100 m^3/s several times throughout a given year. The highest flow during this 5-year period surpassed the Q_{10} estimate, reaching 533 m^3/s on December 14, 2010.

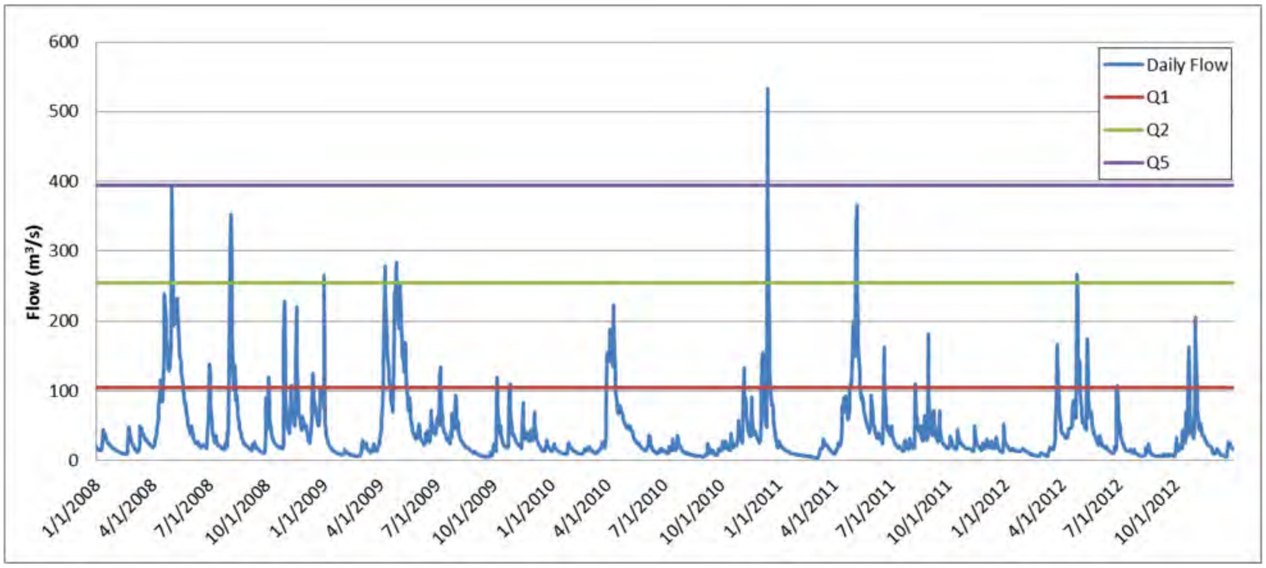


Figure D 5-year Daily Flow Record Little Southwest Miramichi River (2008 to 2012)

3.2 Flows for Use in Hydraulic Assessment

Local knowledge of the project site indicates that the critical flow for erosion at the Oxbow site occurs a few times per year. Higher flows bypass the Oxbow via a spill location across the floodplain. This spill point is seen in the imagery shown on Figure 3 as well as the LiDAR contours shown on Figures 2-A to 2-C. To further understand what flow would exceed the spill point, several flow conditions were evaluated in the hydraulic model (refer to Section 4 for details). These four steady state flow conditions included the following:

- 34 m^3/s, representing the conditions during the time of the survey
- 105 m^3/s, representing the annual return (Q_1) peak flow
- 254 m^3/s, representing the 2-year return period flow (Q_2)
- 392 m^3/s, representing the 5-year return period flow (Q_5)

Although higher flows such as the Q_{10} to Q_{50} could be represented with the hydraulic model and tied into the existing LiDAR data, the result of the modelling show that flows greater than the 1 in 5-year (Q_5) are likely to completely flood the Oxbow area, resulting in a wider flow path and thus dissipating the velocities acting on the banks. The flows selected for the hydraulic analysis provide an adequate assessment of existing and proposed channel conditions as they pertain to the current erosion issues.

4 HYDRAULIC MODELLING

River2D is a transient, 2D hydrodynamic model that has been specifically developed for the evaluation of velocity and depth distributions. It is intended for natural watercourses and is well suited to accommodate supercritical/subcritical flow transitions as well as variably wetted areas. 2D models have been developed and used in various studies and applications including habitat evaluation, diversion works, and for bridge design.

For this project, River2D was used to characterize existing conditions, as well as evaluate potential changes in the river, in and downstream of the Oxbow site, resulting from the proposed channel restoration. The model was used to assess potential changes by examining flow patterns, velocities, depth, and water level. The results of the hydraulic model have also been used to complete shear bed stress analyses (refer to Section 4).

4.1 Model Development

The developed River2D model utilized the location (easting and northing) and bed elevations for numerous points recorded within the channel and on the banks during the field assessment. Data recorded by the ADCP survey as well as the total station and LiDAR were used to develop the input file for the channel bed topography.

Channel roughness and substrate conditions were modelled based on field observations. Sandy substrate was observed at the erosion site and downstream at a deposition location. However, substrate in surrounding areas was characterized as cobble, gravel, and pebbles. Figure 3 details the location of substrate and channel details that were noted in the field.

4.1.1 Mesh Development

Point data were input into River2D to define the bed elevation, bed roughness, and used to outline the interior and exterior boundaries. From the point information, nodes were generated at a 4 m interval and represent the adjacent point information. Once defined, the nodes were triangulated to create a mesh of elements representing the surface of the hydraulic model. The mesh was modified and refined through adding, moving, and deleting nodes to meet the recommended quality index (QI) of the model, which ranges between 0.15 and 0.50. Elevations and roughness values in the mesh were assessed for QA/QC using contours and colour gradients. For the proposed design conditions, nodes representing the conceptual channel design were added and tied into the existing topographic information.

The upstream boundary condition required for a River2D model is channel flow input. For this study, steady state flows were selected based on the hydrology assessment (see Section 3). For the downstream boundary, a fixed water level elevation is required. The fixed water level used varied to correlate with the inflow condition. The boundary condition water level for the 34 m^3/s flow condition was set based on measurements taken during the field program. The boundary condition water levels for the other flow conditions were derived through Manning's equation based on known channel geometry. Table B summarizes the resulting flow area, wetted perimeter, and water levels that make up the model's downstream boundary conditions. The model was then run in steady state until convergence of solution change and mass balance was achieved.

Table B Modelled Flows and Boundary Conditions

Flow Condition (m^3/s)	Flow Area (m^2)	Wetted Perimeter (m)	Water Levels (m)
34	25.54	49.24	103.43
105	52.51	55.01	103.95
254	93.58	61.98	104.65
394	126.29	67.88	105.16

4.1.2 Calibration

Calibration of the model was completed by comparing the simulated upstream water level to the median upstream water level as measured during the field program (elevation 104.08 m including 100 m addition for modelling consistency). Table C outlines the calibration of the existing condition River2D model run under the 34 m^3/s steady state flow condition. The model is considered calibrated as the modelled water levels are within 5 cm of the observed, mass balance between the inflow and outflow is achieved and the solution change is minimal (less than 0.002).

Table C Existing Conditions River2D Model Calibration

Inflow (m^3/s)	Outflow (m^3/s)	Difference (%)	Solution Change	Downstream Elevation (Boundary Condition; m)	Target Upstream Elevation (Edge of Water Survey; m)	Modelled Upstream Elevation (m)	Difference from Calibration Target (m)
34	33.94	-0.18	1.52E-03	103.43	104.08	104.13	0.05

4.1.3 Limitations

As with any modelling tool, there are limitations to the input, output and interpretation of the physical settings. For example, River 2D allows for boundary controls (both interior and exterior to the model domain) but these must be defined by a single elevation. A second limitation is that the model only computes one average velocity for each grid cell. Any variations in velocities between the bottom of the channel or at the water surface are not explicitly accounted for. Although both of these items limit the models ability to fully simulate the physical conditions within the channel, 2D averaged depth models, including River2D, have been proven to simulate field observations of contraction scour and produce results similar to 3D modelling programs (Lai et al. 2010).

4.2 Hydraulic Assessment

The area of the proposed channel restoration is shown on Figures E and F. This area consists of steep, sandy banks and has been the main concern for erosion in the area. Upstream on the bend, an excavated area exists that fills with water during periods of higher flow (e.g. the annual peak flow [Q_1]). Depths at this part of the channel exceeded 4 m during the time of the bathymetric survey.

Figure E Proposed Channel Restoration Site

Another significant area of concern is the outer bank downstream of the proposed restoration site, as shown on Figures G and H. The banks in this area are steep and consist of sand, cobble, and gravel. Deposition of sand and gravel has occurred on the opposite (inner) bank, reducing the channel width at this section during average and low flows.

Figure F Outer Bank, Downstream of Oxbow Restoration Site

Figure G Downstream Banks

The evaluation of the channel conditions using the hydraulic model focuses on any impacts to these areas of concern and provides insight into the existing and potential velocities, water levels, and shear forces acting on the bed and banks from peak flows.

4.2.1 Modelled Existing Conditions

Existing conditions in the Oxbow were evaluated under the steady state flow conditions of 34 and 105 m^3/s, and 254 and 394 m^3/s, as determined from the hydrology assessment above. A summary of the model simulation details are provided in Table D, showing the convergence, mass balance, and solution change for each flow condition.

Table D Existing Conditions River2D Model Scenarios

Condition	Inflow (m^3/s)	Outflow (m^3/s)	Difference (%)	Solution Change	Downstream Elevation (Boundary Condition); (m)
November 4, 2015	34	33.94	-0.18%	1.52E-03	103.43
Q_1	105	104.90	-0.10%	1.33E-04	103.95
Q_2	254	251.87	-0.84%	1.24E-03	104.65
Q_5	394	392.18	-0.46%	5.87E-04	105.16

Figures 4 and 5 highlight the depths and velocities from the model simulations. As anticipated, depths and velocities increase within the channel with increase flow conditions. Flow is confined in the channel during the annual flow (Q_1) but spills into the Oxbow during the 2- and 5-year return periods. As shown in the LiDAR elevation, supplementary channels convey the flow across the Oxbow's floodplain and confluence with the main channel downstream of the model boundary. Based on the existing water levels during the Q_5 simulation, anything exceeding 394 m^3/s will likely flood the entire Oxbow floodplain area.

To assess specific areas of the channel, Figure 6 shows two areas at the restoration site and at the downstream banks where the model simulation results can easily be compared between flow conditions.

Assessment Area 1 – Figure 7

As measured in the field, modelled depths (existing conditions) were greatest in the area of the proposed channel restoration; however, velocities in this area were low and generally less than 1 m/s. The flow direction near the proposed channel restoration is opposite the channel gradient, formed by an eddy created against the downstream bank. Water circulates slowly in this area forming a deep, slow moving pool. Water enters the excavated area during the Q_2 and Q_5 flows but again with minimal velocities minimizing potential for erosion at this location.

Assessment Area 2 – Figure 8

Downstream of the proposed restoration, velocities increase as the channel contracts both in width and depth. The highest velocities are maintained in the channel centre, which limits the forces acting on the banks. A comparison of the maximum velocities on the downstream bank between the Q_2 and Q_5 condition shows a reduction in velocities during the higher Q_5 event. This is due to the increased spilling from the Oxbow area, which dissipates the flow.

The highest velocities in the channel are seen in the downstream section of the channel, refer to Figures 5 and 6. The depth of the channel in this area is reduced, which further increases the velocities through this section. The direction of flow follows the channel gradient and again, limited the forces are found to be acting on the bank.

4.2.2 Modelled Proposed Channel Restoration

The proposed channel restoration was evaluated against the same steady state flows as the existing condition. This enables evaluation of any change in depth, velocity, and water levels resulting from the restoration works. The centre Oxbow area was removed from the post-processing data analysis to concentrate on the effects in the channel and on the outer banks. A summary of the model simulation details for the proposed conditions are provided in Table E, showing the convergence, mass balance, and solution change for each flow condition.

Table E Proposed Conditions River2D Model Scenarios

Condition	Inflow (m^3/s)	Outflow (m^3/s)	Difference (%)	Solution Change	Downstream Elevation Boundary Condition (m)
November 4, 2015	34	33.92	-0.24%	4.01E-03	103.43
Q_1	105	104.89	-0.11%	3.97E-03	103.95
Q_2	254	251.45	-1.01%	2.97E-03	104.65
Q_5	394	390.95	-0.78%	6.89E-05	105.16

Figures 9 and 10 highlight the potential changes in depth and velocity under the Q_5 (394 m^3/s) scenario. During the Q_5, differences in depth between the existing and proposed conditions were minimal, affecting less than 3% of the channel area. Increases in depth are seen where the proposed channel restoration will infill some of the existing pool. This change does not influence the depths upstream or downstream of the design area.

Changes in velocities within the channel resulting from the proposed works are generally less than 0.1 m/s. Both increases and decreases in velocity are seen in the proposed restoration area. Downstream of the proposed restoration there are some changes in velocities both in the channel and along the outer channel banks, although these are generally less than 0.01 m/s, which is considered within the numerical limitations of the model.

4.2.3 Shear Stress and Sediment Transport

Sediment transport, which relates to channel scour and deposition, is the result of the erosive action of flowing water, which excavates and carries away material from the bed and banks of stream. This movement of sediment within a channel resulting from flow, velocity, roughness and channel gradient are summarized in a parameter called shear stress (Trenhaile 2007). Substrate begins to move when the shear stress exceeds the critical stress of a particle (the stress at which a particle of a given size starts to move). The bed shear stress can be represented throughout the channel by Equation 1, using depth, velocity and roughness as simulated by the hydraulic model.

Equation 1 Keulegan Bed Shear Stress Equation (SI Units):

$$\tau_o = \frac{\rho \bar{u}^2}{\left\{\left(5.75 \log\left[\frac{12.2y}{k_s}\right]\right)\right\}^2}$$

where: τ_o = bed shear stress (N/m^2)

$\bar{u}$ = depth averaged velocity (m/s)

ρ= density of water (1000 kg/m^3)

y = depth (m)

The critical shear stress of a bed or bank particle is determined using Shield's parameter, a dimensionless value that represents the particles force ratio of entrainment to stabilization (Trenhaile 2007) and the median particle size. The equation (Equation 2) for critical shear stress is used to determine when particles would reach the potential for entrainment.

Equation 2 Critical Shear Stress:

$$\tau_c = \Theta^*(s-1)\rho g d_{50}$$

where: τ_o = critical bed shear stress (N/m^2)

Θ^*= Shield's parameter (based on particle size – dimensionless)

ρ= density of water (1000 kg/m^3)

s = specific particle gravity (based on particle weight - dimensionless)

g = constant for acceleration of gravity (m/s^2)
d_{50} = median particle size (m)

The ratio of bed shear stress to critical shear stress provides a dimensionless parameter, which indicates if a particle has been entrained. By dividing the bed shear stress by the critical shear stress, the shear bed intensity is determined (see Equation 3; Lacey and Millar 2001). A shear bed intensity value greater than 1 indicates potential entrainment where a value less than 1 indicates potential for deposition.

Equation 3 Shear Bed Intensity:

$$\tau_{intensity} = \frac{\tau_o}{\tau_c}$$

Streams can be classified according to the dominant size of the sediment on their beds. Accurate determination of the particle size distribution of bed material requires sampling and analysis, particularly for coarse bed material, but for most bed material distributions, rough approximations can be derived from visual observation. Table F indicates the particle size ranges, shields parameter, and critical bed shear stress associated with each particle class.

Table F Sediment Size Class, Shield Parameter and Critical Bed Shear Stress

Particle Class	Particle Size (mm)	Shields Parameter (Dimensionless)	Critical Bed Shear Stress (n/m^2)
Silt	0.00 to 0.009	0.165 to 0.3	0.038 to 0.083
Sand	0.01 to 5	0.044 to 0.065	0.083 to 2.7
Gravel	5 to 64	0.044 to 0.052	2.7 to 54
Cobble	64 to 256	0.054	54 to 112
Boulder/Bedrock	256+	0.054	112 to 223

Note:
Adapted from Berenbrock and Tranmer 2008

Using Equations 1, 2, and 3, the values listed in Table F, the output from the hydraulic model, and the observation of bed and bank particle size, an evaluation and comparison of shear bed intensity was completed. Figures 11 and 12 highlight the shear bed stress for the existing and proposed channel conditions, and Figure 13 outlines a differential map of shear bed intensity. As shown, during the peak flow scenario (394 m^3/s) shear bed intensity remains unchanged within the majority (99% percent) of the channel. Decreases in shear intensity are seen in the area of proposed channel restoration, and align with the decreases in velocity. While there are some marginal increases (i.e. within 0.05 of existing) in shear stress intensity, the variations at these locations are not likely to increase sediment transport, as these particles were already entrained during the existing conditions. Shear intensity does not increase along the bank areas during the Q_5 scenario. There are no areas within the channel where shear intensity will cause particles to be entrained in the proposed conditions, which were not entrained in the existing conditions (i.e., in no location do the proposed works cause the shear intensity to cross the threshold of 1.0).

5 CONCLUSION

A hydraulic assessment was used to evaluate and compare channel conditions for the Oxbow site under existing and proposed channel restoration conditions. Four flow scenarios were evaluated based on a hydrology assessment from and upstream WSC station gauge. The flow scenarios provided a range of conditions that include both in and out of channel flows for both the existing and proposed conditions. The findings from this assessment are as follows:

- Negligible changes in depths were observed throughout the channel, with the exception of the channel restoration area, which infilled the existing scour pool.

- Variations in velocity gradient showed acceptable changes resulting from the proposed works.

- Comparison of shear stress intensity presented limited potential for the design to increase erosion or scour within the channel.

Therefore, there are no unacceptable impacts anticipated due to the proposed works. And advancement of the proposed design is recommended.

We trust this assessment meets with your approval. If you have any questions, please contact Ron Jenkins at 506.472.8440.

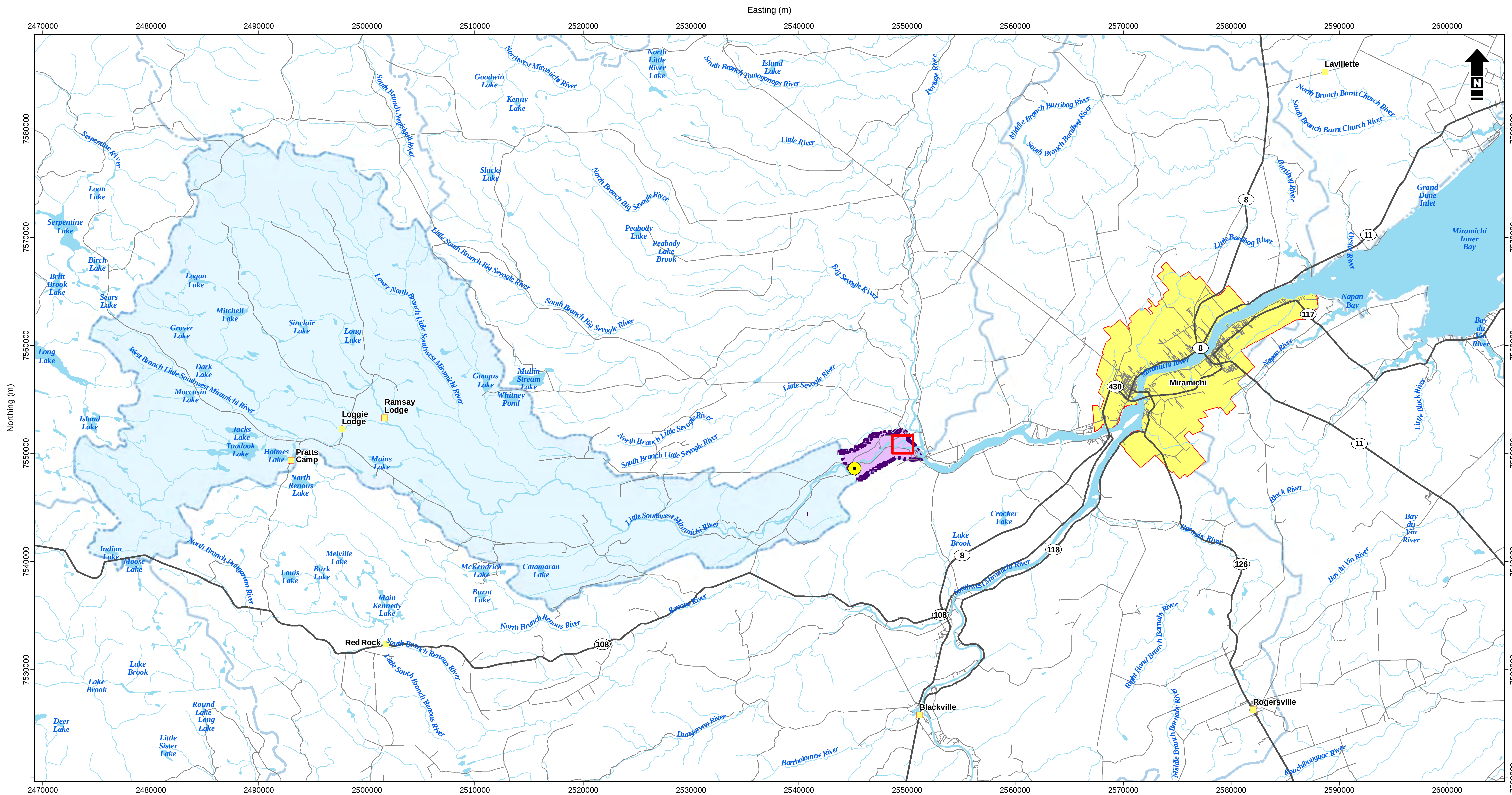
REFERENCES

Berenbrock, Charles, and Tranmer, A.W. 2008. *Simulation of flow, sediment transport, and sediment mobility of the Lower Coeur d'Alene River*. Idaho: U.S. Geological Survey Scientific Investigations Report 2008–5093, 164 p.

Lacey, R.W.J., and R.G. Millar. 2001. *Application of a 2-dimensional hydrodynamic model for the assessment and design of instream channel restoration works*. Province of British Columbia, Ministry of Water, Land and Air Protection, and Ministry of Forests. Watershed Restoration Management Report No. 9: 70p.

Lai, Yong G. and Greimann, Blair P. 2010. "Predicting contraction scour with a two-dimensional depth-averaged model." *Journal of Hydraulic Research 48(3)*: 383—387 pp.

Trenhaile, A.S., 2007. *Geomorphology: A Canadian Perspective, Third Edition*. Oxford: Oxford University Printing Press.



- Oxbow Site
- Delineated Catchment Area
- Little Southwest Miramichi Drainage Area
- Drainage Area
- Community
- Water Body
- Watercourse
- Highway
- Road
- 01BP001 Station Location

Reference: Data obtained from GeoBase® and GeoGratis © Department of Natural Resources Canada (all rights reserved) used under license.

1:350,000
3,500 0 3,500 7,000 m
NAD 1983 CSRS New Brunswick Stereographic

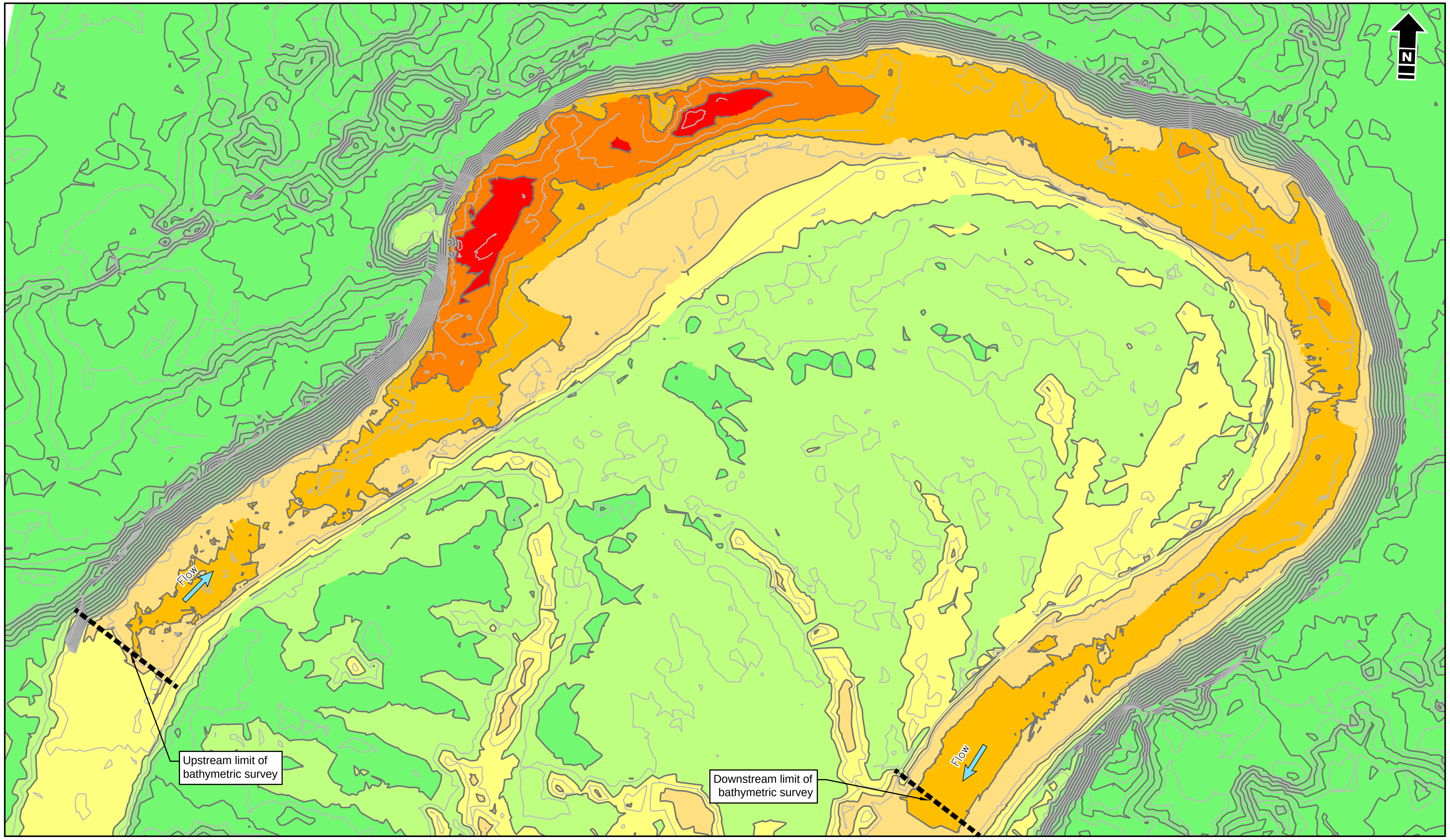
Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

Small Craft Harbours
Technical Memo

Little Miramichi Southwest River Drainage Area

Date:	Project:	Technical:	Reviewer:	Drawn:
20 Apr 2016	22751	A. McKay	R. Jenkins	C. Curry

Figure 1



Bathymetry Legend	
(red)	100 - 101m
(orange)	101 - 102m
(amber)	102 - 103m
(light orange)	103 - 104m
(yellow)	104 - 105m
(light green)	105 - 106m
(green)	> 106m

Notes:

1. Total Station survey of shore and top of bank completed by Matrix Solutions Inc. on November 3, 5, 2015.
2. Bathymetric survey completed by Matrix Solutions Inc. on November 3, 4, 5, 2015.
3. Elevations displayed on figure are based on meters above sea level +100m.

1:2500 Meters
25 0 25 50
Datum

PARISH aquatic services
A Division of Matrix Solutions Inc.

Small Craft Harbours

Little Southwest Mirimachi River Existing Channel Bathymetry Full Plan

REVISION					
01	20 04 2016	Draft for client review	ESD	RJ	ESD
No.	DATE	DESCRIPTION	BY	CHK.	DRN.

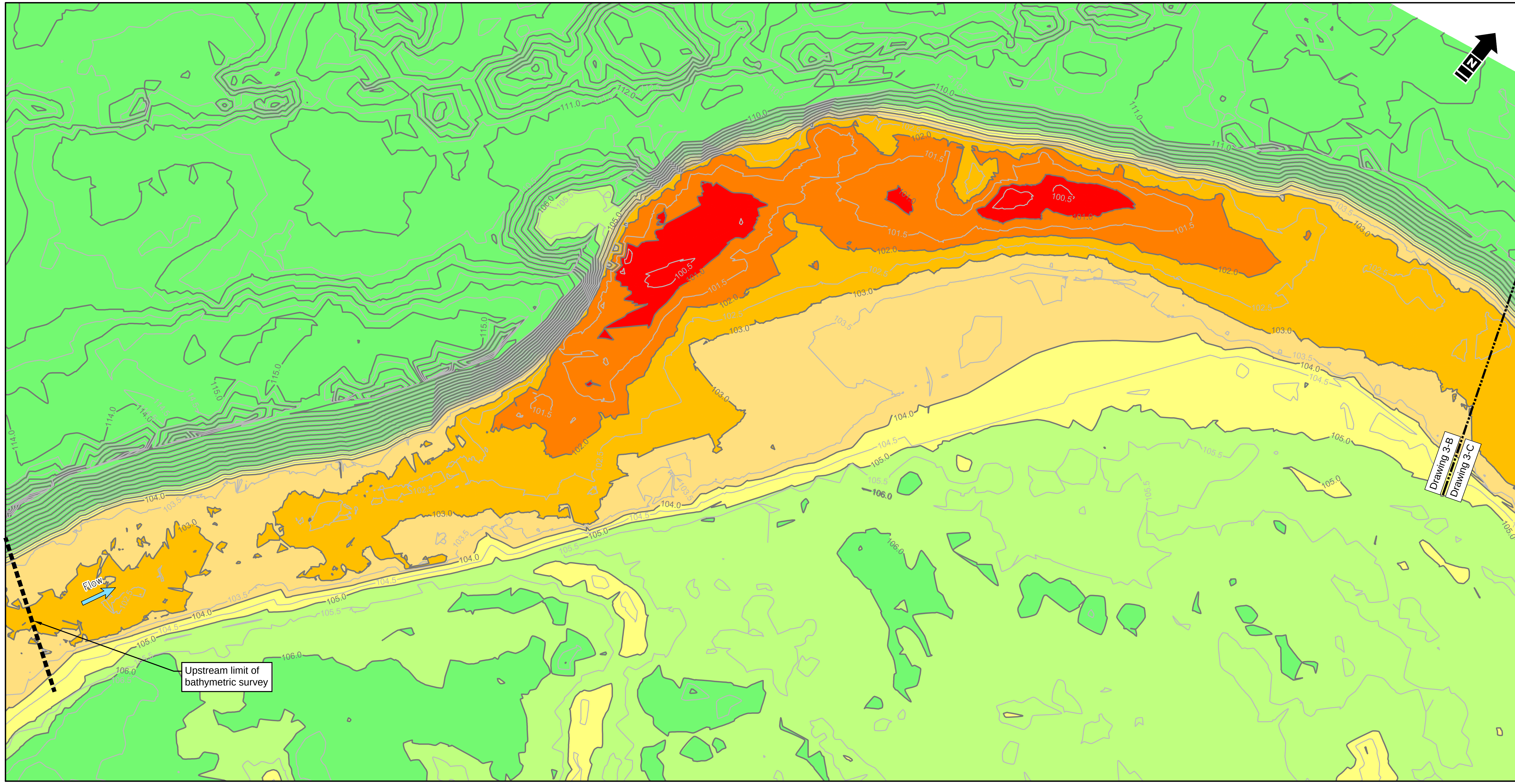
Date:	Project:	Technical:	Reviewer:	Drawn:
20 04 2016	22751	E. Drost	R. Jenkins	E. Drost

Figure 2-A

Note: Drawing(s) must be used in conjunction with the attached technical memorandum dated April 8, 2016 and is subject to the limitations and conditions stated in the report.

Plot 1:1 = Tabloid (L)

F:\22751\CAD\22751 - Craft Harbours -Combined - 04-05-2016.dwg - FULL PLAN - Wednesday, April 20, 2016 11:29:29 AM - Eric Drost



Bathymetry Legend
100 - 101m
101 - 102m
102 - 103m
103 - 104m
104 - 105m
105 - 106m
> 106m

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1:1500 Meters
15 0 15 30
Datum

REVISION

No.	DATE	DESCRIPTION	BY	CHK.	DRN.
01	20 04 2016	Draft for client review	ESD	RJ	ESD

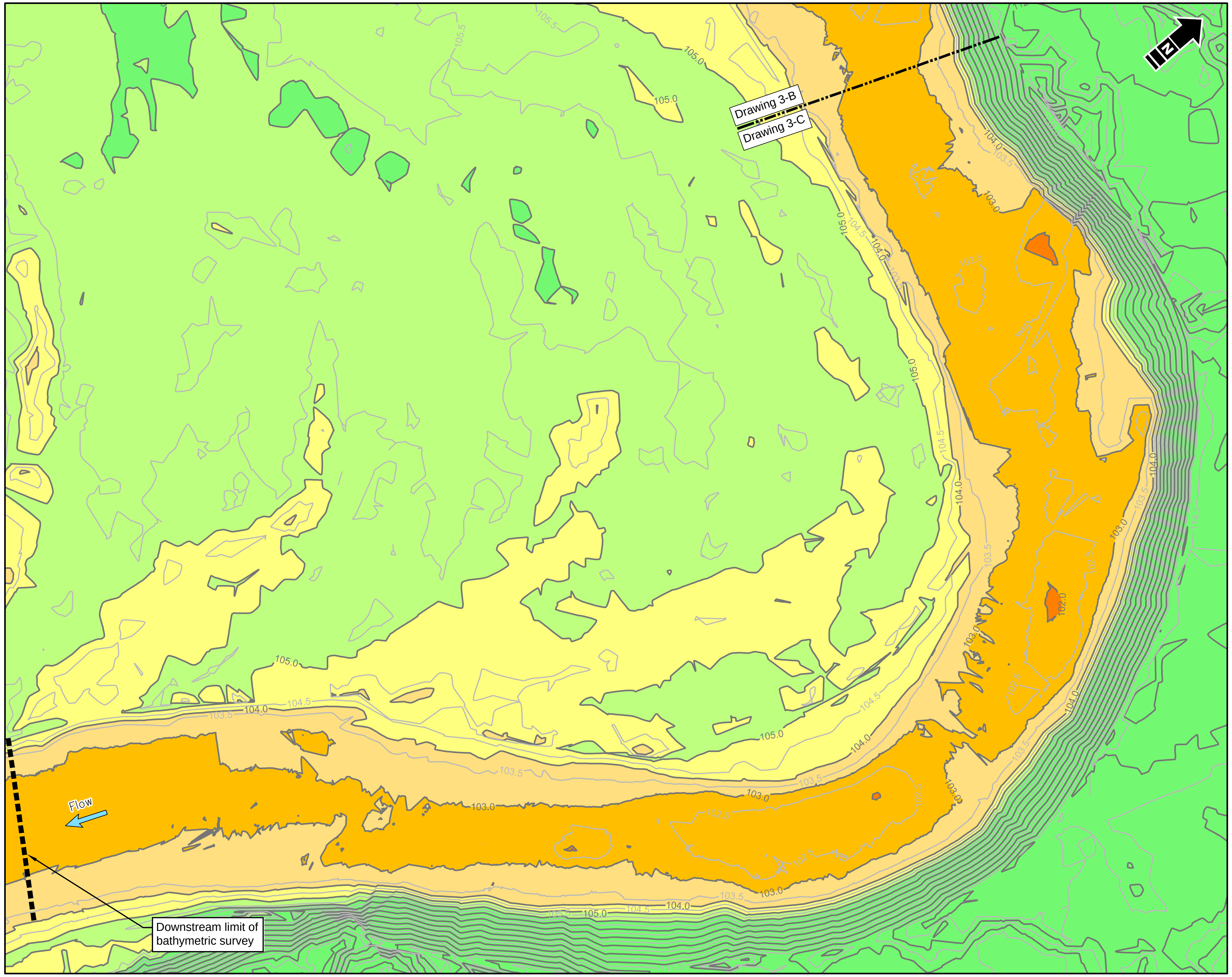
PARISH aquatic services — A Division of Matrix Solutions Inc.

Small Craft Harbours

Little Southwest Mirimachi River Existing Channel Bathymetry Upstream Plan

Date:	Project:	Technical:	Reviewer:	Drawn:
20 04 2016	22751	E. Drost	R. Jenkins	E. Drost

Figure 2-B



Bathymetry Legend	
(red)	100 - 101m
(dark orange)	101 - 102m
(orange)	102 - 103m
(light orange)	103 - 104m
(yellow)	104 - 105m
(light green)	105 - 106m
(green)	> 106m

Notes:

1. Total Station survey of shore and top of bank completed by Matrix Solutions Inc. on November 3, 5, 2015.
2. Bathymetric survey completed by Matrix Solutions Inc. on November 3, 4, 5, 2015.
3. Elevations displayed on figure are based on meters above sea level +100m.

1:1500 Meters
15 0 15 30
Datum

Note: Drawing(s) must be used in conjunction with the attached technical memorandum dated April 8, 2016 and is subject to the limitations and conditions stated in the report.

REVISION					
01	20 04 2016	Draft for client review	ESD	RJ	ESD
No.	DATE	DESCRIPTION	BY	CHK.	DRN.

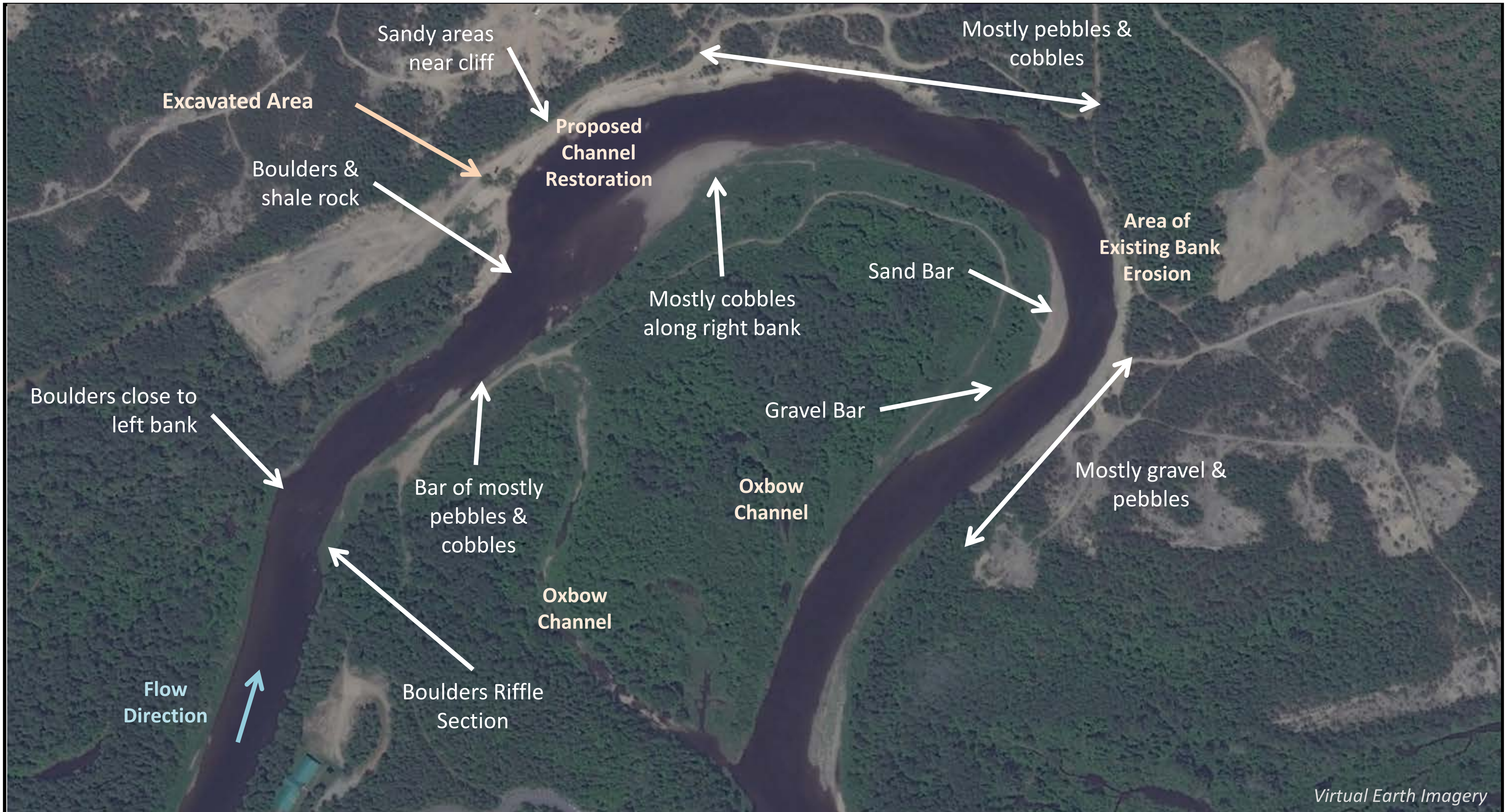
PARISH aquatic services — A Division of Matrix Solutions Inc.

Small Craft Harbours

Little Southwest Mirimachi River Existing Channel Bathymetry Downstream Plan

Date:	Project:	Technical:	Reviewer:	Drawn:
20 04 2016	22751	E. Drost	R. Jenkins	E. Drost

Figure 2-C



Notes:

1. Based on observations made during the November 2015 field work

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Small Craft Harbours
Technical Memo

Oxbow Site Conditions

Date:	Project:	Technical:	Reviewer:	Drawn:
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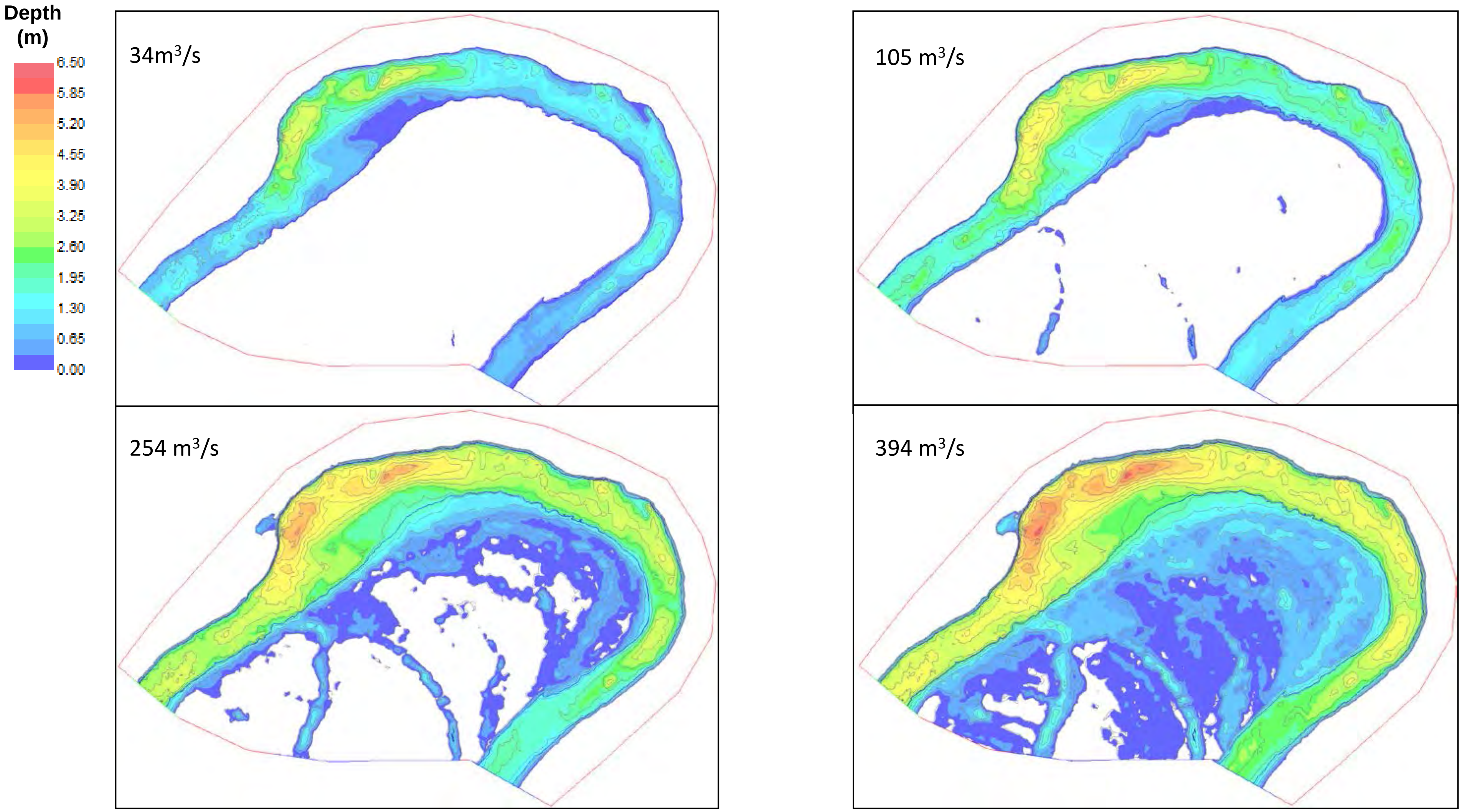
Figure
3



Notes:

1. River2D output for each flow scenario
2. 0.5 m depth contours are shown

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Small Craft Harbours
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Existing Conditions – River 2D Simulation
Depth (m)

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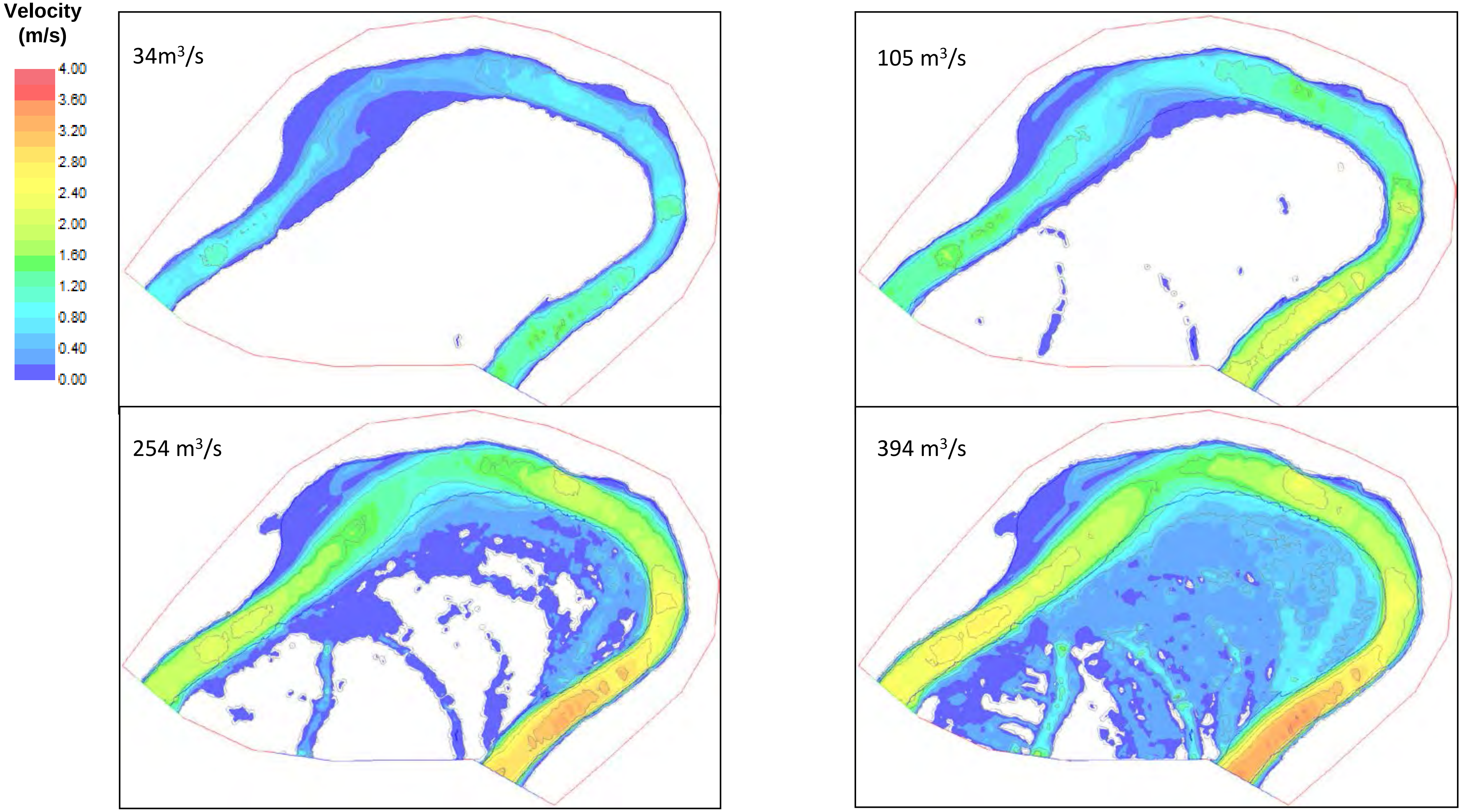
Figure
4



Notes:

1. River2D output for each flow scenario
2. 0.5 m/s velocity contours are shown

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Small Craft Harbours
Technical Memo

Existing Conditions – River 2D Simulation Velocity (m/s)

Date:	Project:	Technical:	Reviewer:	Drawn:
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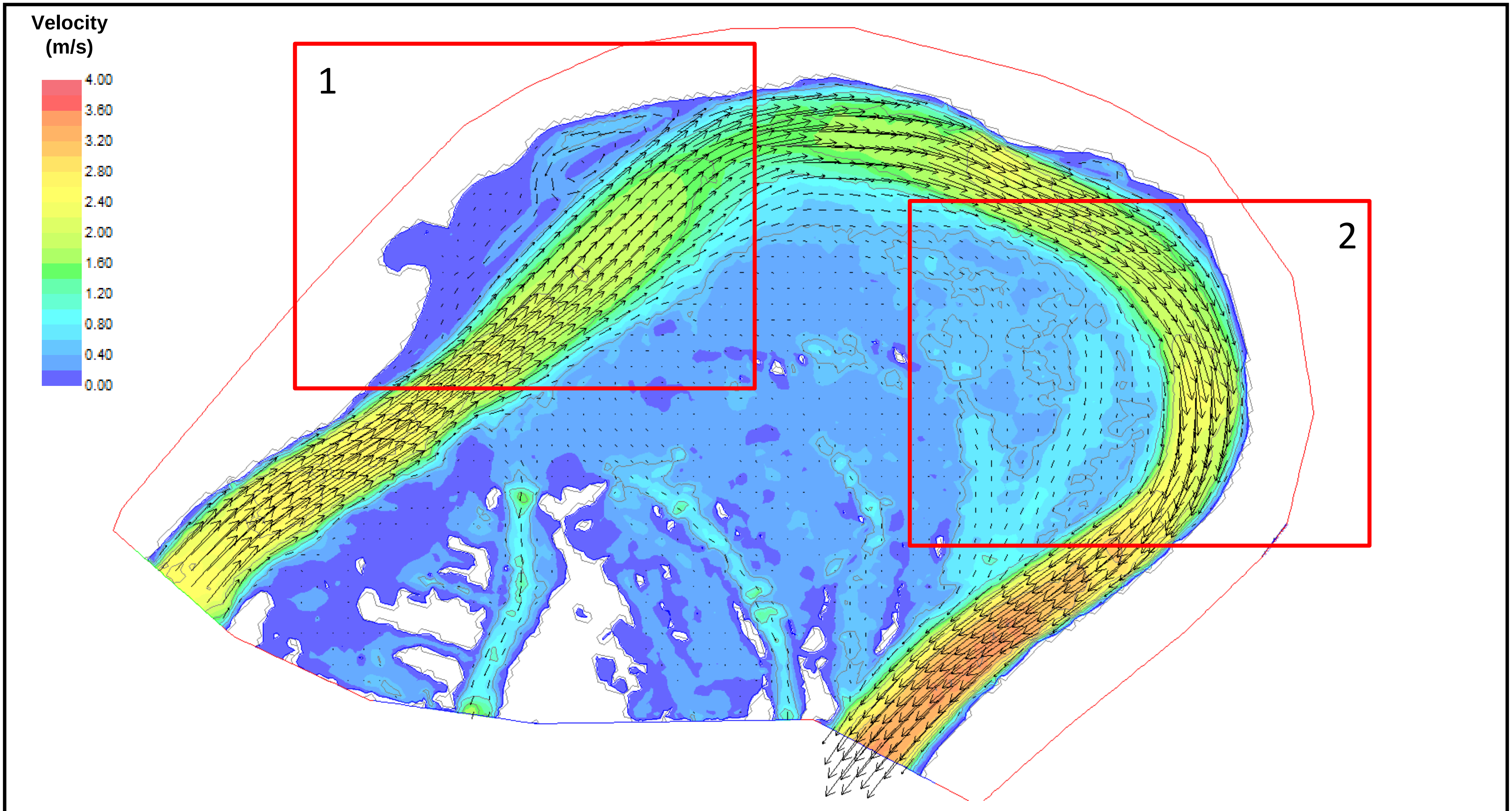
Figure 5



Notes:

1. River2D output for the existing 394 m^3/s flow scenario
2. 0.5 m/s velocity contours are shown
3. Velocity magnitude and direction arrows are shown

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Small Craft Harbours
Technical Memo

Existing Conditions – River 2D Simulation
Assessment Areas 1 and 2

Date:	Project:	Technical:	Reviewer:	Drawn:
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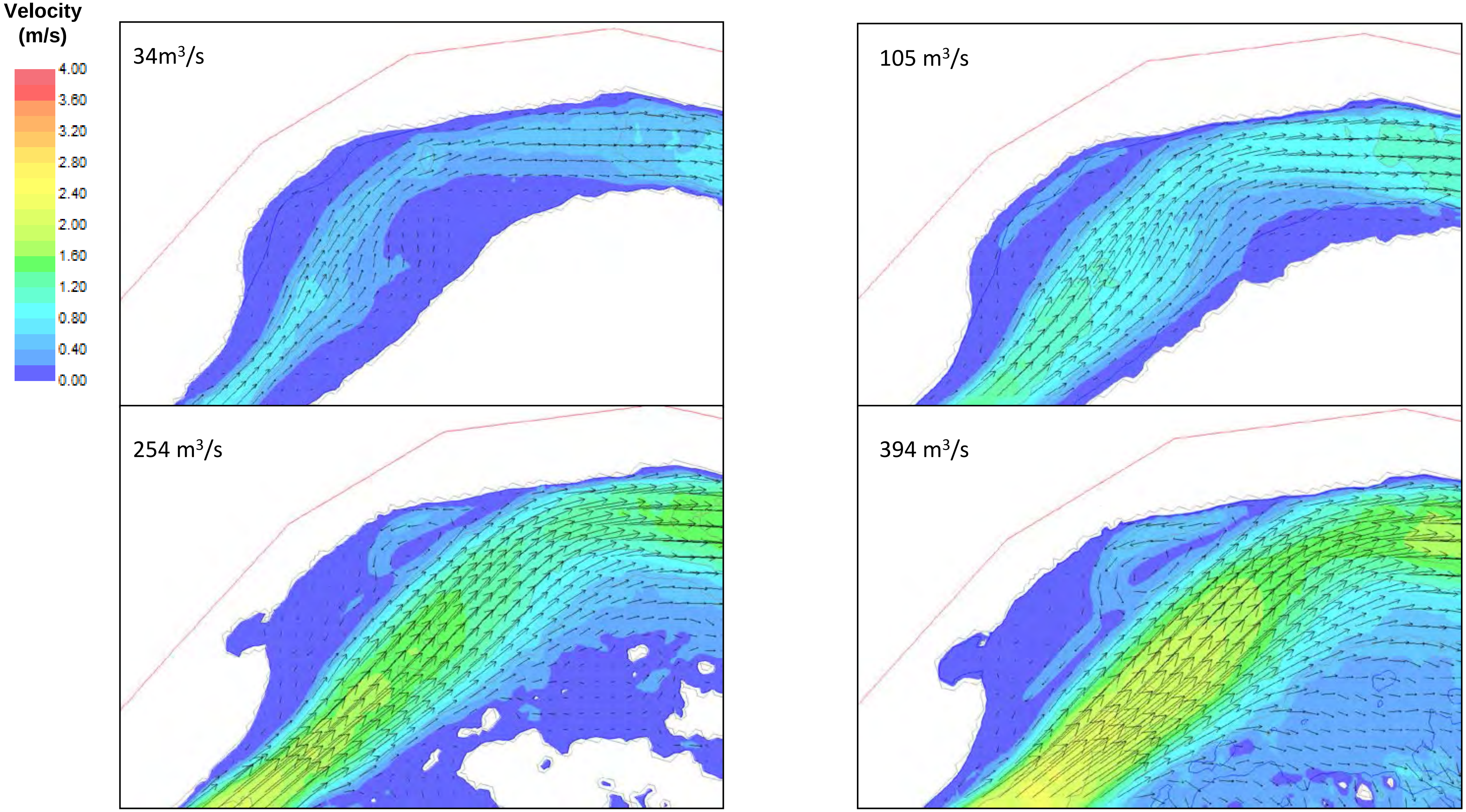
Figure 6



Notes:

1. River2D output for each flow scenario
2. 0.5 m/s velocity contours are shown
3. Velocity magnitude and direction arrows are shown

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Small Craft Harbours
Technical Memo

Existing Conditions – River 2D Simulation
Area 1 Velocity (m/s)

Date:	Project:	Technical:	Reviewer:	Drawn:
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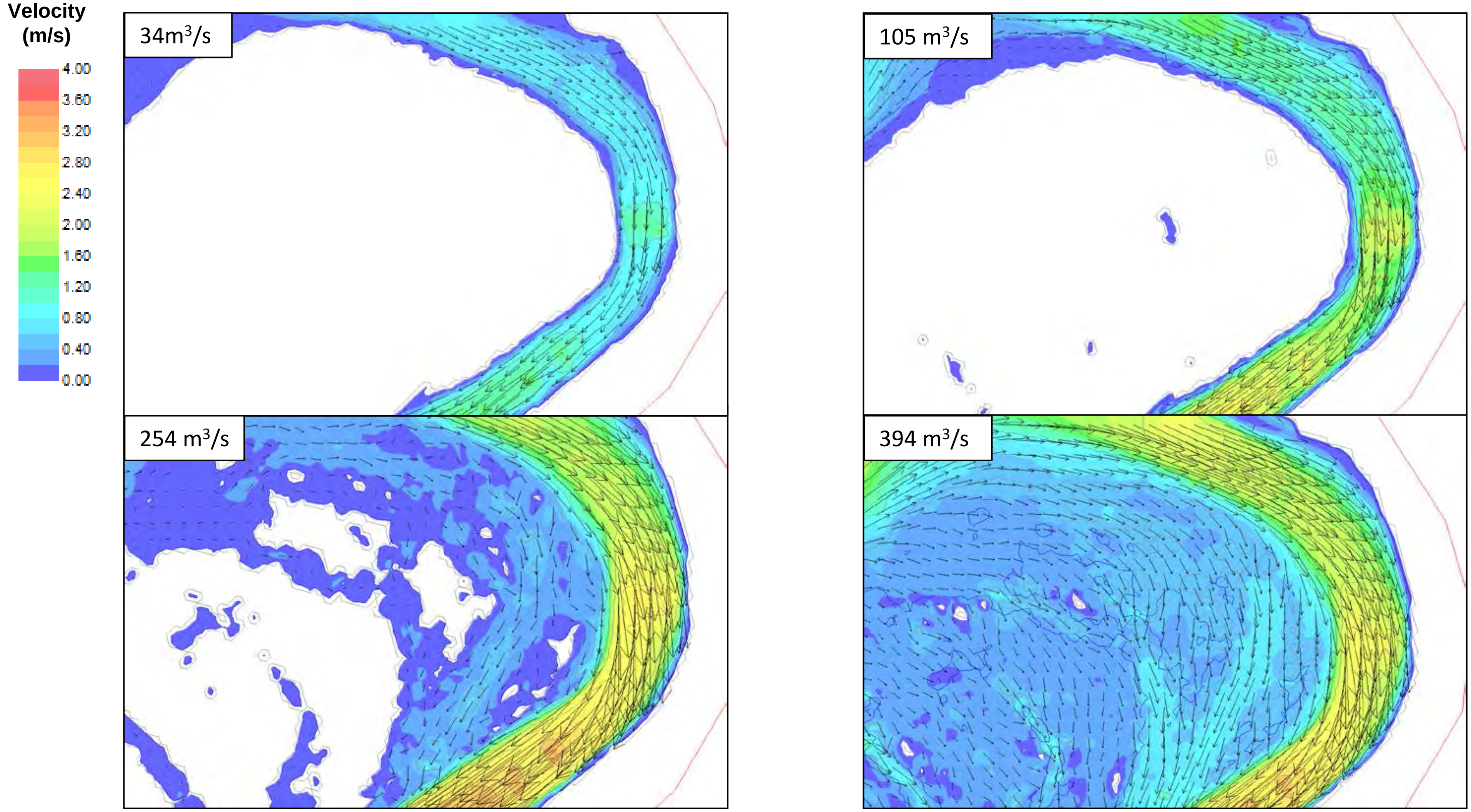
Figure
7



Notes:

1. River2D output for each flow scenario
2. 0.5 m/s velocity contours are shown
3. Velocity magnitude and direction arrows are shown

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Small Craft Harbours
Technical Memo

Existing Conditions – River 2D Simulation
Area 1 Velocity (m/s)

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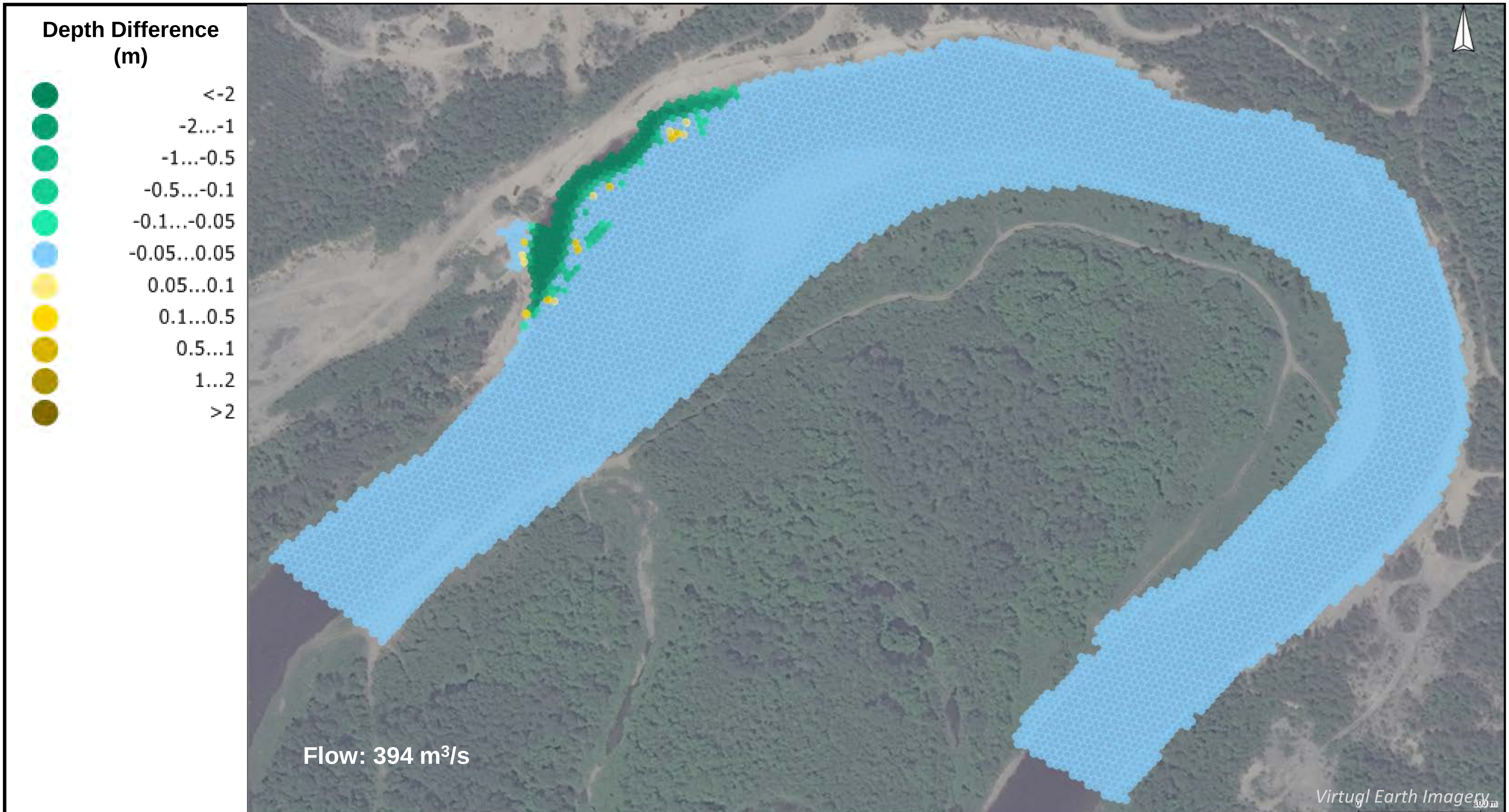
Figure **8**



Notes:

1. Differences are developed by subtracting the proposed conditions from existing. Positive numbers indicate an increase in parameter, negative numbers indicate a decrease in parameter.
2. Gaps in the difference comparisons are due to variation in in mesh refinement between the existing and proposed model surfaces.
3. Depth differences less than 5 cm were considered no change between proposed and existing conditions.

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Technical Memo

River 2D Simulation Depth Difference between Proposed and Existing Conditions

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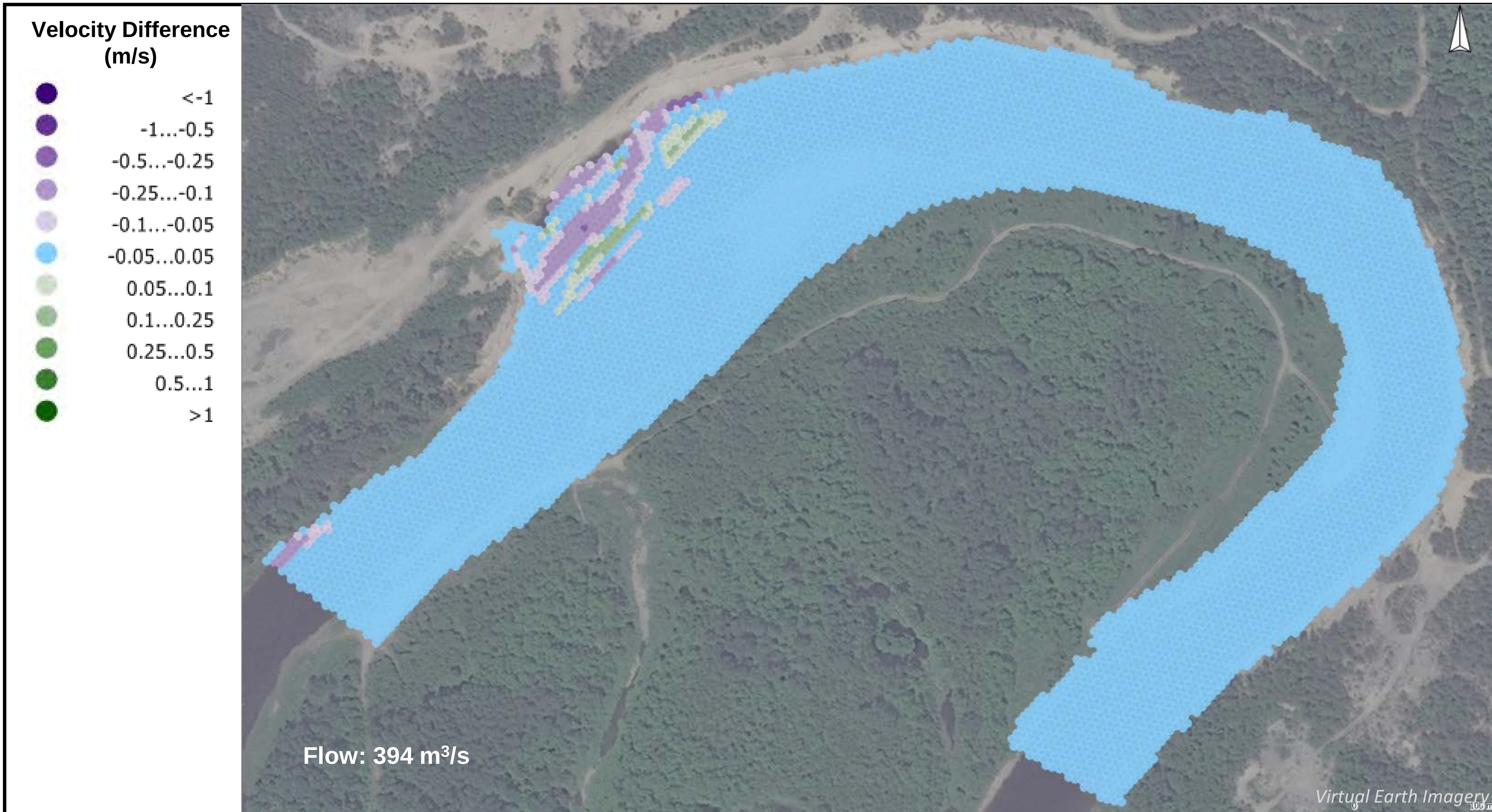
Figure 9



Notes:

1. Differences are developed by subtracting the proposed conditions from existing. Positive numbers indicate an increase in parameter, negative numbers indicate a decrease in parameter.
2. Gaps in the difference comparisons are due to variation in in mesh refinement between the existing and proposed model surfaces.
3. Velocity differences less than 0.05 m/s were considered no change between proposed and existing conditions.

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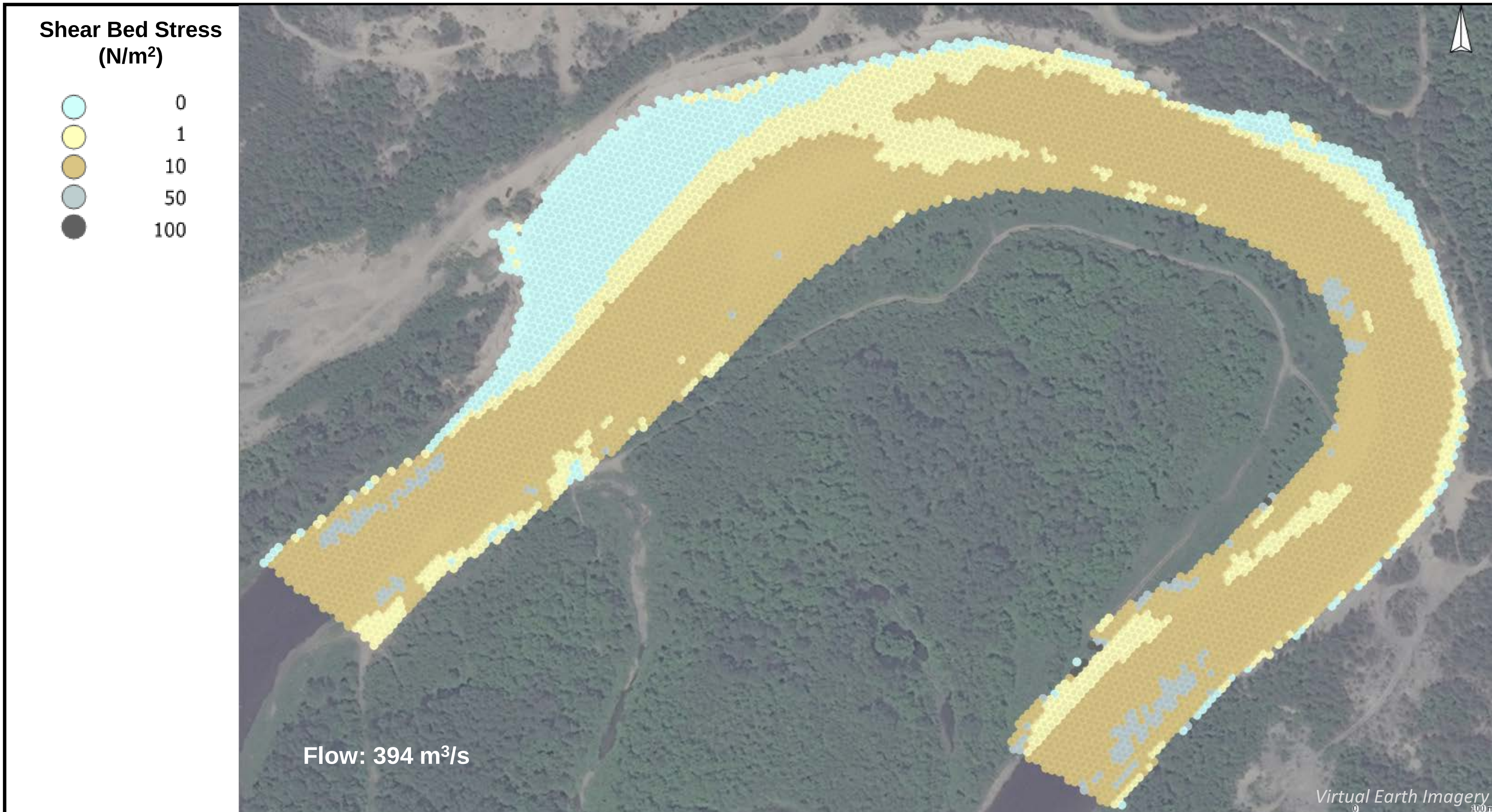
River 2D Simulation Velocity Difference between Proposed and Existing Conditions

Date:	Project:	Technical:	Reviewer:	Drawn:
April 20, 2016	22751-522	A. McKay	R. Jenkins	A. McKay

Figure **10**



Notes:

1. Shear bed stress was calculated using velocity and depth output from the River2D simulation and observed substrate conditions.

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Small Craft Harbours
Technical Memo

Existing Conditions - Shear Bed Stress (N/m^2)

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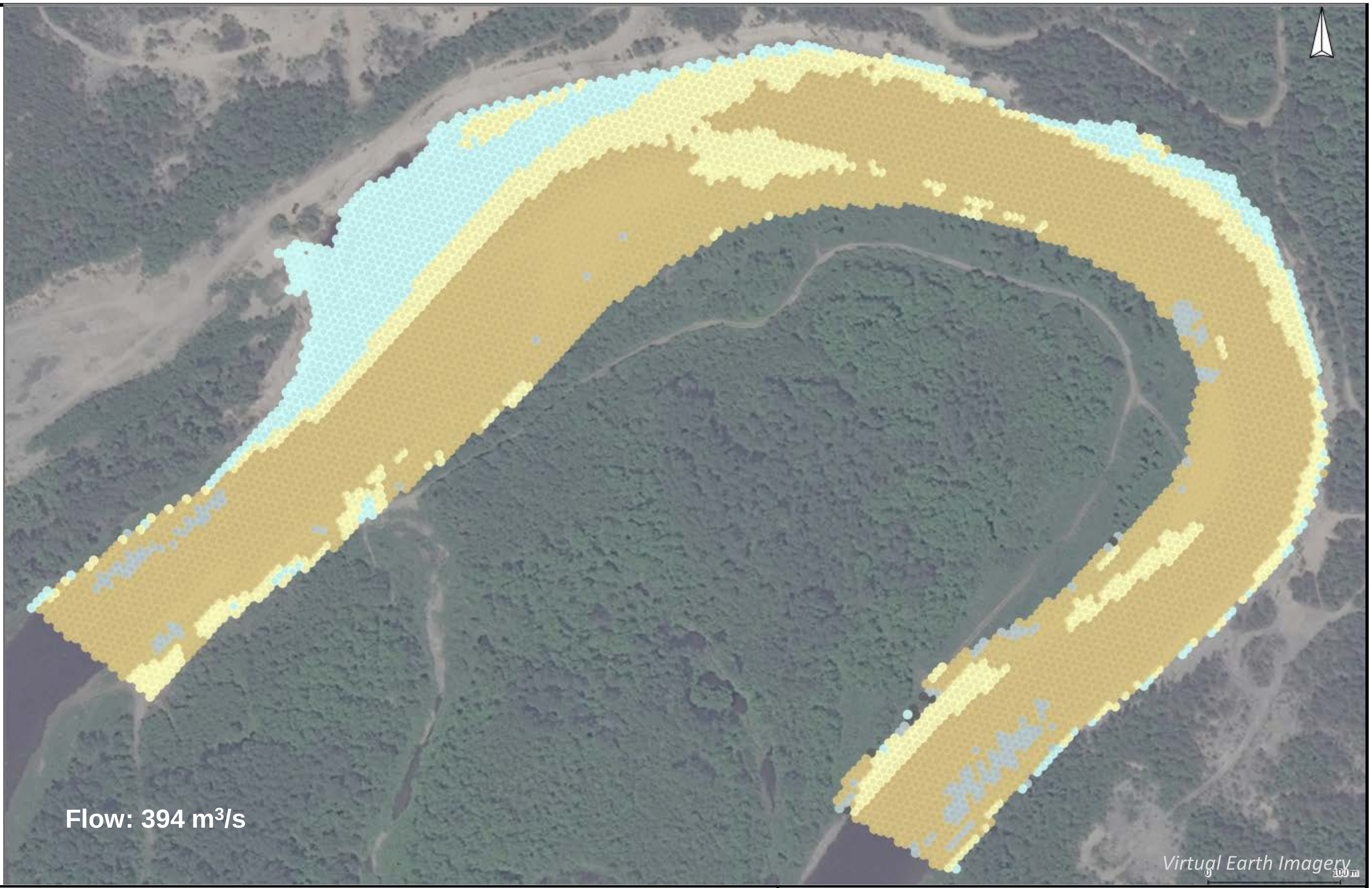
Figure **11**

Shear Bed Stress (N/m²)

(light blue)	0
(light yellow)	1
(tan)	10
(grey-blue)	50
(dark grey)	100



Notes:

1. Shear bed stress was calculated using velocity and depth output from the River2D simulation and observed substrate conditions.

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Small Craft Harbours
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Existing Conditions - Shear Bed Stress (N/m²)

Date:	Project:	Technical:	Reviewer:	Drawn:
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Figure **12**

Notes:

1. Differences are developed by subtracting the proposed conditions from existing. Positive numbers indicate an increase in parameter, negative numbers indicate a decrease in parameter.
2. Gaps in the difference comparisons are due to variation in mesh refinement between the existing and proposed model surfaces.
3. Shear intensity differences less than 0.01 were considered no change between proposed and existing conditions.

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Small Craft Harbours
Technical Memo

River 2D Simulation Shear Intensity Difference between Proposed and Existing Conditions

Date:	Project:	Technical:	Reviewer:	Drawn:
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Figure 13