Environment

Prepared for:
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November 1, 2012

Tagish River Erosion Analysis

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1.0 Introduction

One of the projects identified for the Yukon Energy Corporation's (YEC) key energy development and enhancement requires the raising of Marsh Lake's full supply level by 0.3 m to store additional water for winter power production at the Whitehorse Rapids Generating Station (WRGS). Numerical modeling was conducted to estimate the potential magnitude of shoreline erosion along the Tagish River (connecting Marsh Lake with Tagish Lake) due to currents and higher lake levels, which might arise due to this increase in the levels of the two lakes. The main purpose of this report is to compare the shear stresses along the Tagish River shoreline obtained from the numerical modeling with the threshold shear stress required for incipient sediment motion. This investigation will assist in:

1. Understanding the environmental conditions that are contributing to the erosion currently observed along the Tagish River.
2. Understanding the role that fluvial processes have in erosion along the Tagish River.
3. Providing a tool for assessing what changes may occur in Tagish River erosion as a result of changing the water management regime on Marsh Lake.

The numerical modeling was performed using HEC-RAS, which is a hydraulic modeling software package developed by the Hydrological Engineering Center of the U.S. Army Corps of Engineers (USACE). Boundary conditions for the model were flow data, water level data, and sediment size information for the riverbed. The boundary conditions for the flow data and the water level data for the model were monthly averaged values. The numerical modeling results for the comparison were obtained from the technical report *Assessment of Fluvial Erosion in M'Clintock River and Tagish River*, which is included as Appendix A.

2.0 Methodology

The critical shear stress for sediment motion was calculated using Equation 1[1]:

$$\frac{\tau_{wc}}{\tau_c} = cos\,\varphi_1 \sqrt{1 - \left(\frac{tan\,\varphi_1}{tan\,\theta}\right)^2}$$

Equation 1

In Equation 1,

t_{wc}	Critical shear stress for sediment particle on riverbank
t_c	Critical shear stress for sediment particle on riverbed
φ	Angle of side slopes of riverbank
θ = 37 degrees	Angle of repose for sediment.

τ_c in Equation 1 is given by Equation 2:

$$\tau_c = \frac{c_1 a_1}{c_2 a_2}(\gamma_s - \gamma) d_s \tan\theta$$

Equation 2

In Equation 2,

$\gamma = \rho_w g$	Specific weight of sediment
$\gamma_s = \rho_s g$	Specific weight of water
ρ_w = 1000 kg/m^3	Density of water
ρ_s = 2650 kg/m^3	Density of soil
g = 9.81 m/s^2	Gravitational acceleration
d_s	Mean sediment size
a_1, c_1	Coefficient that takes into account particle shape and packing
a_2, c_2	Coefficient that takes into account geometry, packing of the grains, and the variation of drag coefficient.

[1] Source: Vanoni, V.A. 1975. *Sedimentation Engineering, Manual and Report No. 54*, American Society of Civil Engineers, New York, N.Y. Equation 2.127.

Experiments by White (1940), which were used in the derivation of the critical shear stress equation, show that the constant $\frac{c_1 a_1}{c_2 a_2}$ is equal to 0.18 and Equation 2 can be written as:

$$\tau_c = 0.18(\gamma_s - \gamma) d_s \tan\theta$$

Equation 3

For the purposes of this report, the Tagish River domain was divided into the Tagish River North reach and the Tagish River South reach, as shown in Figure 1. Stations from the numerical model that were considered for the Tagish River North reach are Station 16.54 and Station 640.59. Stations that were considered for the Tagish River South reach are Station 5805.69, Station 6426.78, and Station 7233.73.

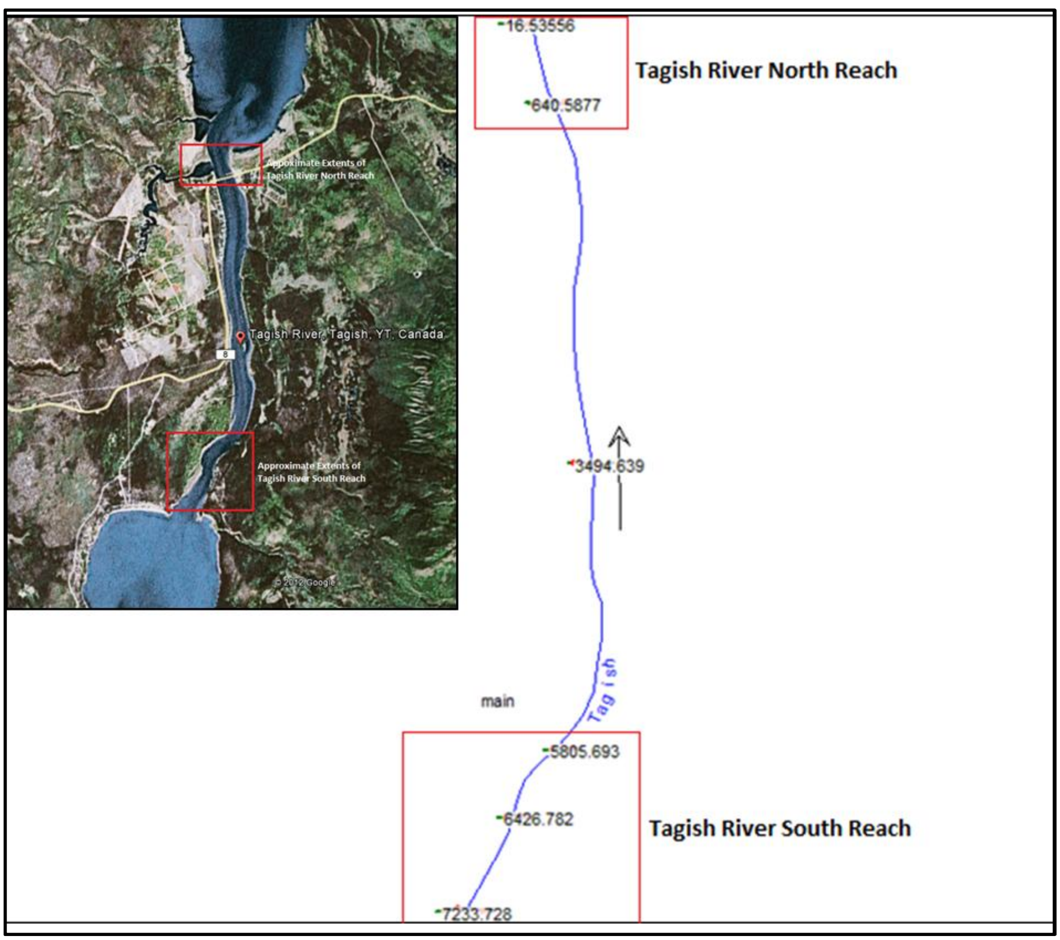

Figure 1 Tagish River Domain Used for Numerical Modeling (showing the stations considered for the Tagish River North and South reaches)

Since complete survey data were not available along the entire Tagish River shoreline, Survey 7 from the technical report titled *Marsh Lake Fall-Winter Storage Concept: 2011 Geomorphology Field and Associated Studies Report* (AECOM 2011) was assumed to be a representative cross-section for the Tagish River shoreline. Survey 7 together with field observations were used in selecting the slope for the threshold shear stress calculations. Figure 2 shows Survey 7.

Shallow slopes were observed on the west bank, and steep slopes were observed on the east bank for both stations investigated for the Tagish River North reach. For the Tagish River South reach, steep slopes were observed on the west bank, and shallow slopes were observed on the east bank for Station 5805.69. For Stations 6426.78 and 7233.73, steep slopes were observed for both east and west banks.

For the stations where steep slopes were observed, the steep slope shown in Figure 2 was used as the representative slope in calculating the threshold shear stress. For the stations where shallow slopes were observed, the shallow slope shown in Figure 2 was used as the representative slope for the threshold shear stress calculations.

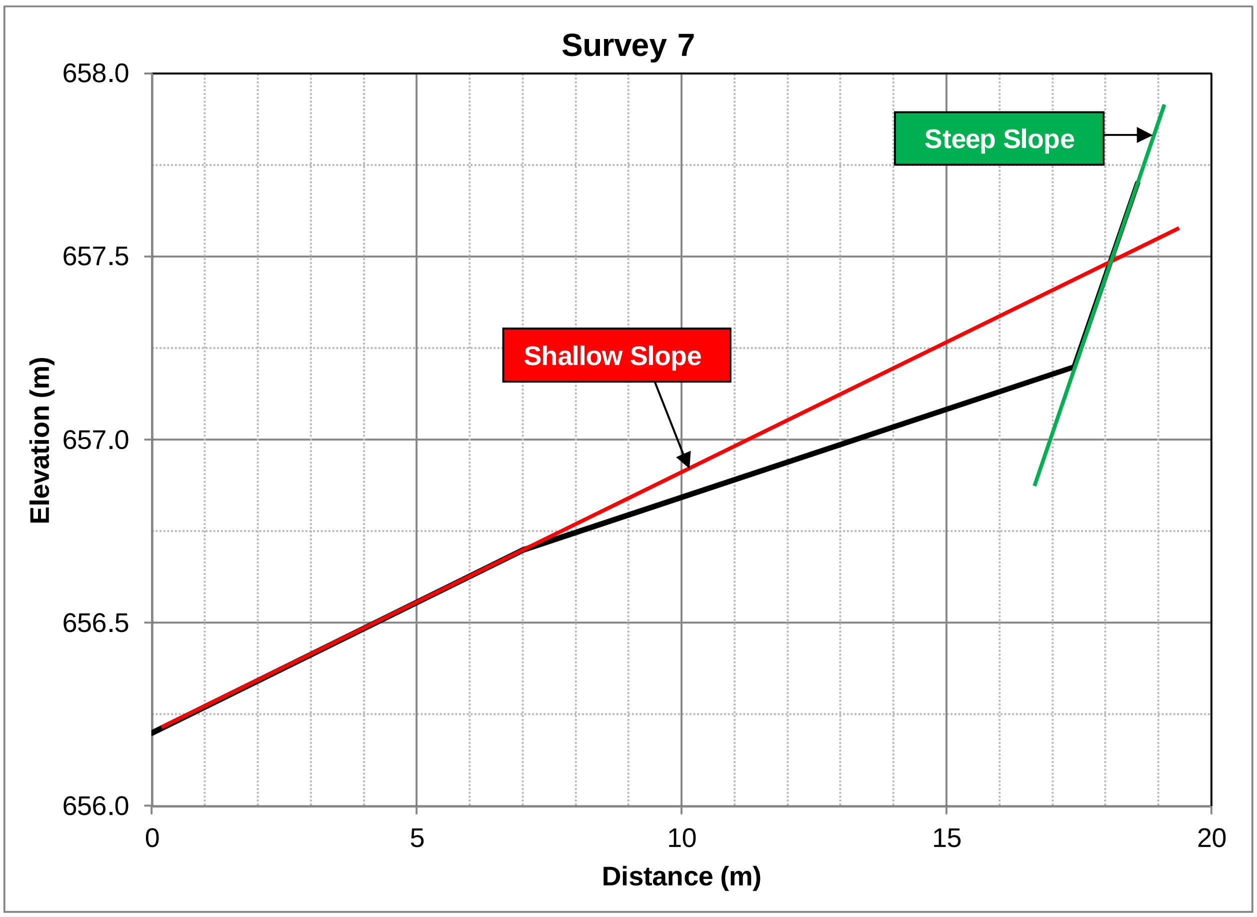

Figure 2 Survey 7, Used as Approximation for Shoreline Cross-section along Tagish River Shoreline

The sediment characteristic required for this analysis is the median grain size, D_{50}, which was calculated based on the sieve analysis data provided by ALS Canada Ltd. Sieve analysis sample SS30 was used as representative for the Tagish River North reach, and sieve analysis sample SS42 was used as representative for the Tagish River South reach. Figure 3 and Figure 4 show the sieve analysis results for the Tagish River North and South reaches, respectively. The sieve analyses show that D_{50} values for the Tagish River North and South reaches were 0.1 mm and 0.25 mm, respectively.

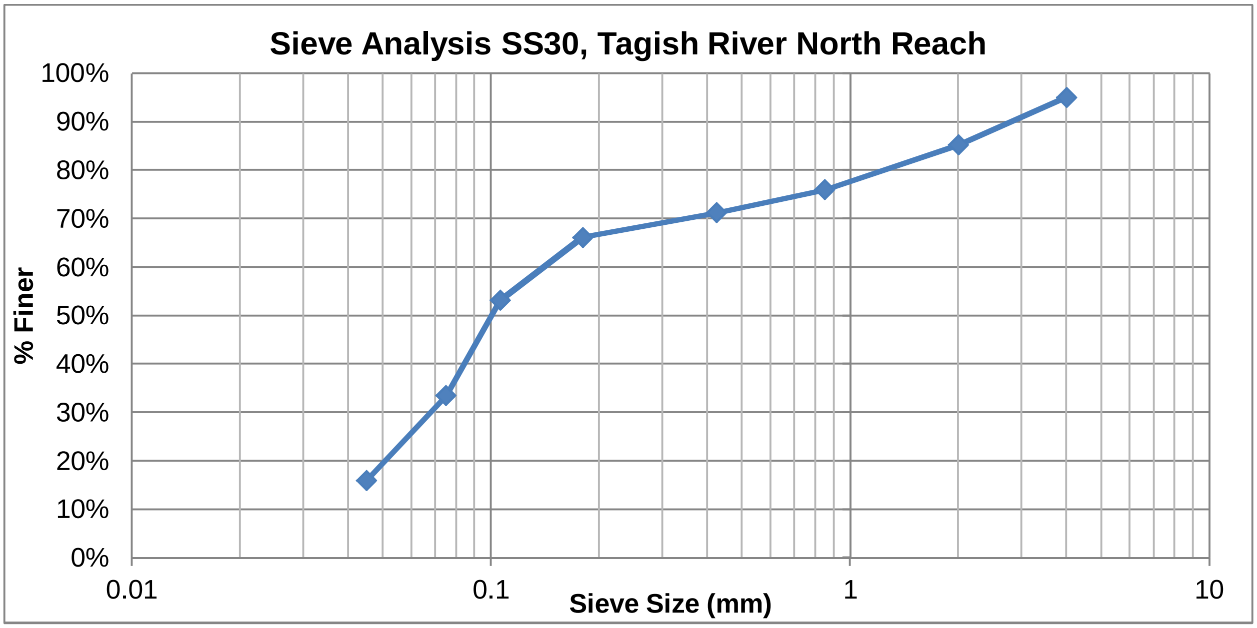

Figure 3 Sieve Analysis Results for Representative Sediment Sizes at Tagish River North Reach

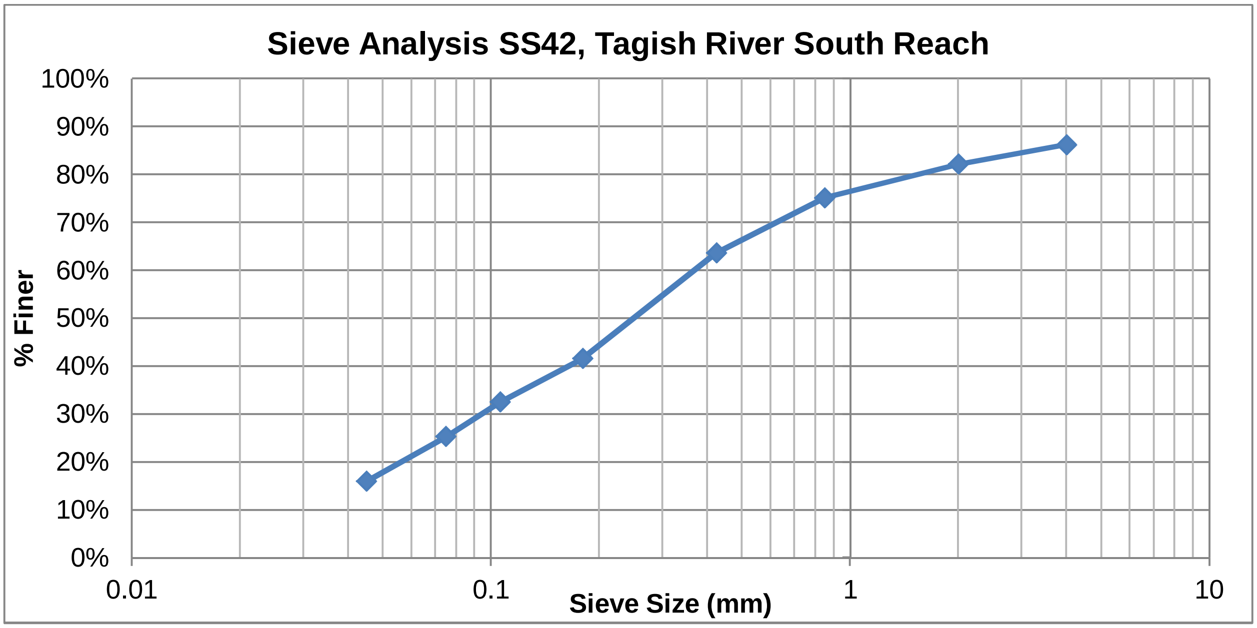

Figure 4 Sieve Analysis Results for Representative Sediment Sizes at Tagish River South Reach

3.0 Results

The critical shear stresses for the stations with shallow banks (shallow slope), calculated based on the methodology described above, were 0.22 N/m^2 and 0.54 N/m^2 for the Tagish River North and South reaches, respectively. The critical shear stresses for the stations with steep banks (steep slope) were 0.17 N/m^2 and 0.42 N/m^2 for Tagish River North and South reaches, respectively.

The threshold shear stresses for the Tagish River North and South reaches were compared to the numerical model results. The numerical model shear stress results presented here for comparison to the threshold shear were obtained from the numerical model study titled *Assessment of Fluvial Erosion in M'Clintock River and Tagish River* (AECOM 2012), included as Appendix A. Bank erosion is expected to occur when the shear stress predicted by the model exceeds the threshold shear stress. The comparisons between the model-predicted shear stresses and the threshold shear stresses for Tagish River North and South reaches are presented below.

3.1 Tagish River North Reach

Figure 5 and Figure 6 present the numerical model results showing the monthly variation of shear stresses for one calendar year, together with the threshold shear stress for the steep and shallow bank stations of the Tagish River North reach, respectively.

The highest shear stresses were observed during the months of June through August. From Figure 5, it can also be seen that the model predicts erosion occurring for the right overbank (east bank), primarily during the months of June through August when the river velocities are the greatest and not during the rest of the year. For the left overbank (west bank) of the Tagish River North reach, the model does not predict any erosion, as seen in Figure 6.

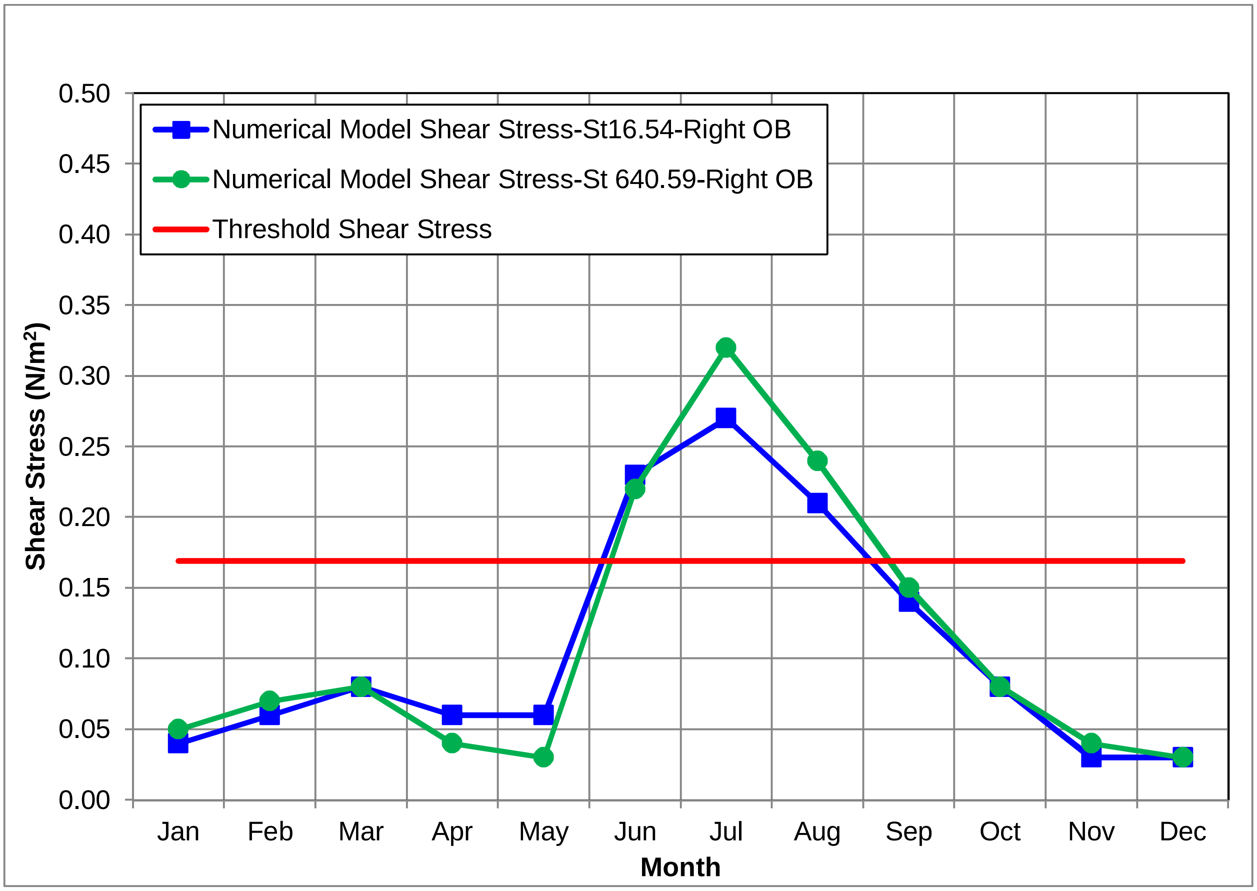

Figure 5 Comparison of Threshold Shear Stress to Numerical Model Shear Stress Results for Tagish River North Reach Stations with Steep Banks

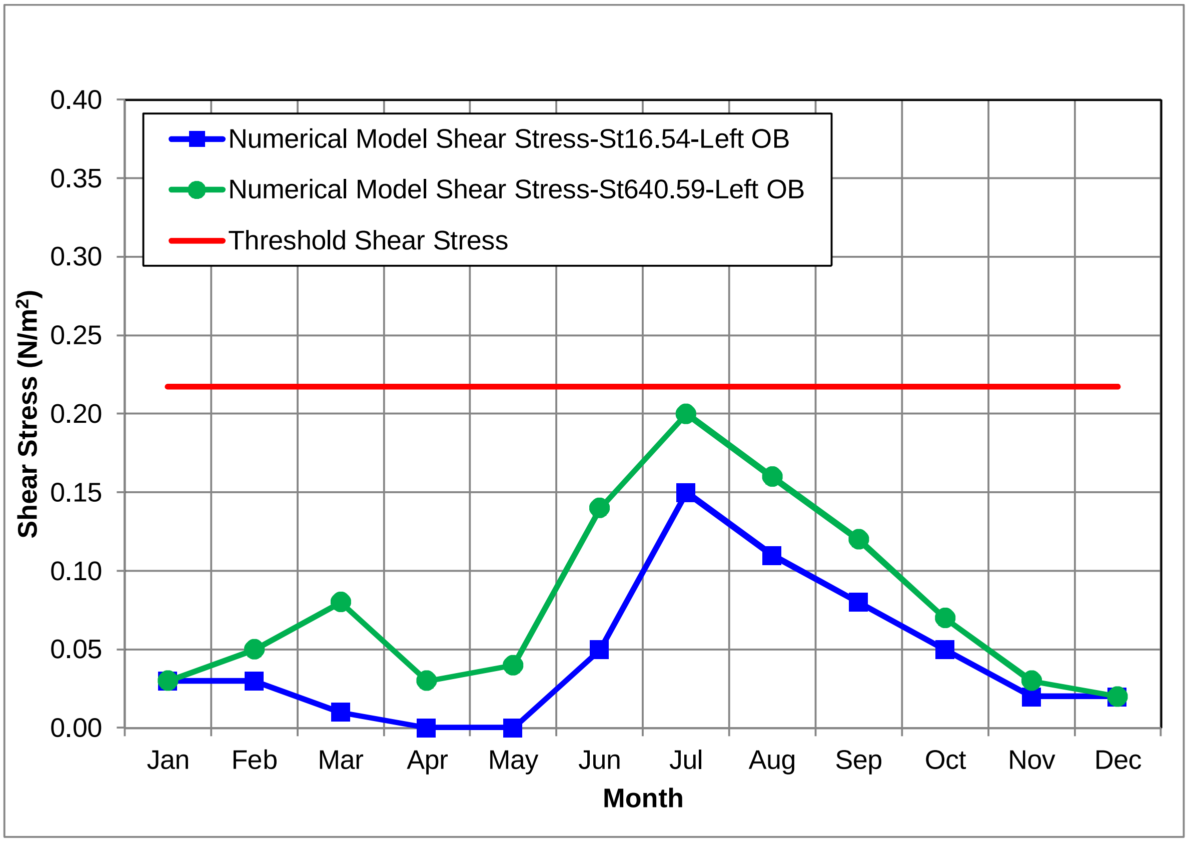

Figure 6 Comparison of Threshold Shear Stress to Numerical Model Shear Stress Results for Tagish River North Reach Stations with Shallow Banks

3.2 Tagish River South Reach

Figure 7 and Figure 8 present the numerical model results showing the monthly variation of shear stresses for one calendar year, together with the threshold shear stress for the steep and shallow bank stations of the Tagish River South reach, respectively.

The highest shear stresses were seen during the months of June through August. From Figure 7, it can also be seen that the numerical model predicts the majority of the erosion occurring at the right overbank (east bank) and left overbank (west bank) at Station 6426.78. Figure 7 also shows that erosion occurs at the left overbank (west bank) of Station 5805.69 during the months of July and August. The numerical model does not predict erosion for the rest of the Tagish River South reach locations investigated, as the shear stresses predicted by the model are lower than the threshold shear stress.

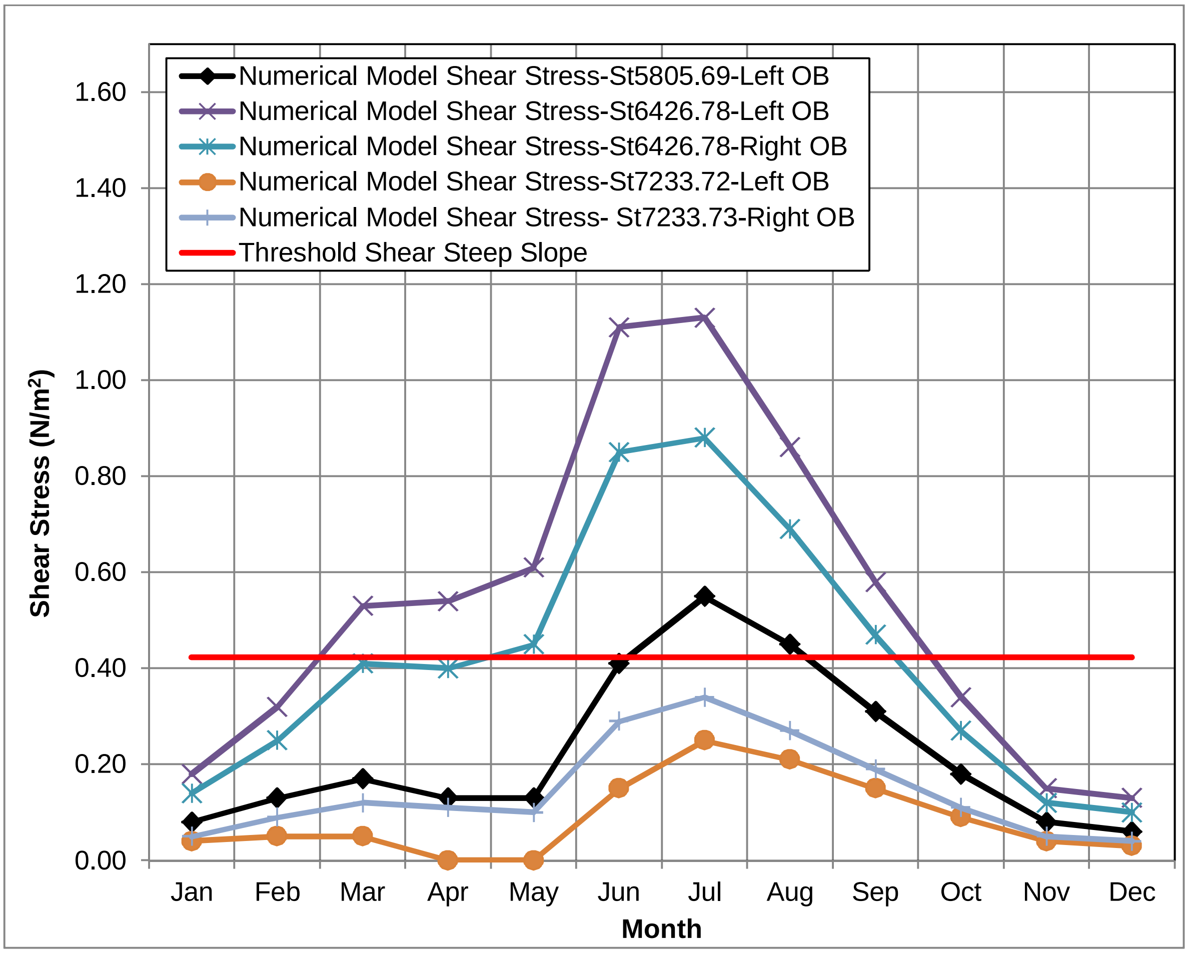

Figure 7 Comparison of Threshold Shear Stress to Numerical Model Shear Stress Results for Tagish River South Reach Stations with Steep Banks

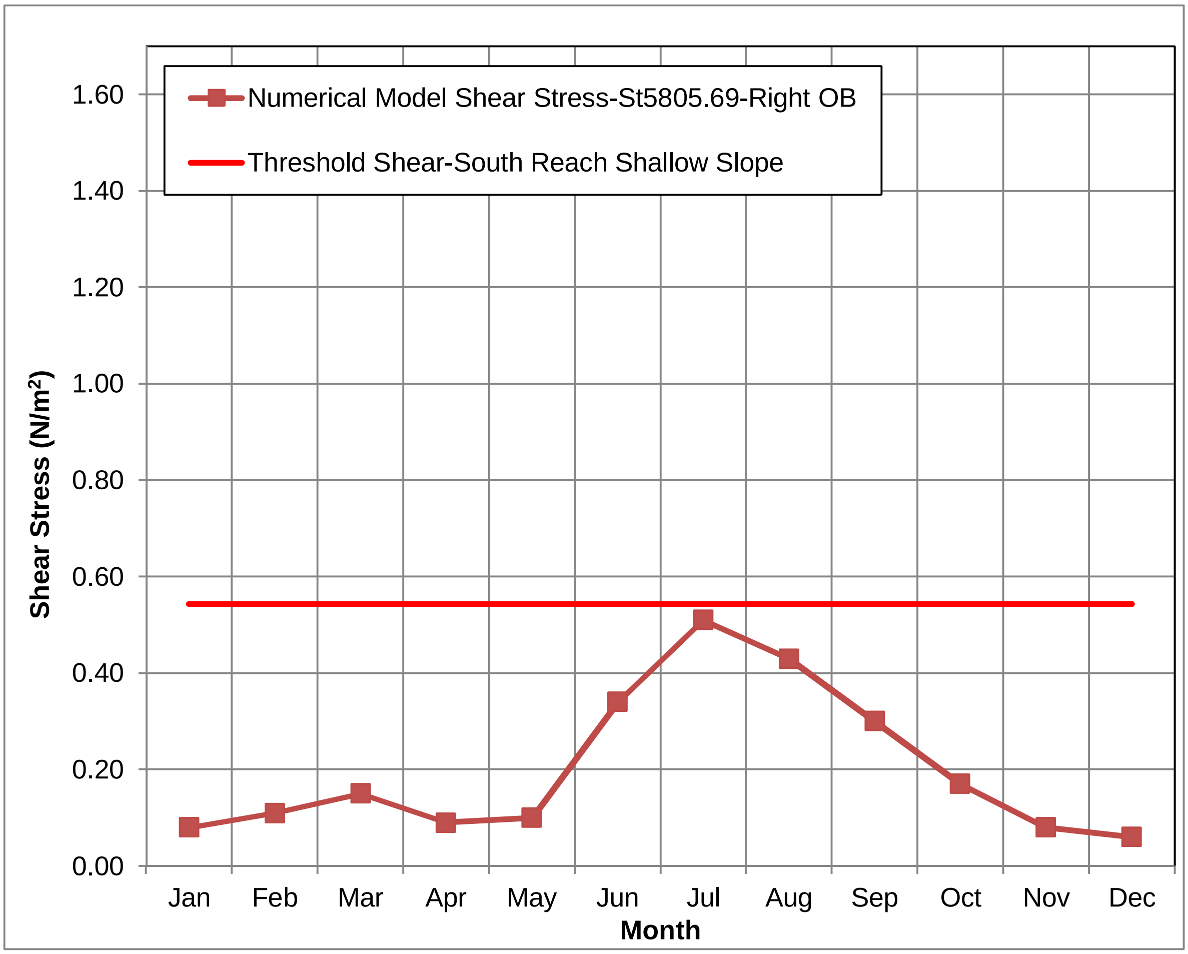

Figure 8 Comparison of Threshold Shear Stress to Numerical Model Shear Stress Results for Tagish River South Reach Stations with Shallow Banks

4.0 Conclusion

Numerical model results for shear stresses along the Tagish River were compared to the threshold shear stress to investigate the erosion potential along the Tagish River.

For the Tagish River North reach, shear stresses exceeded the threshold shear during the months of June through August for the right over bank (east bank) for both locations investigated. This indicates the occurrence of erosion at the investigated locations during these months, based on the model-predicted shear stresses. The predicted shear stresses for the remainder of the open water months do not exceed the threshold shear stress for the Tagish River North reach. Field observations of the Tagish River North reach show erosion occurring just upstream of Station 640.59 mainly during the months of July and August when the river velocities are the greatest. This is in agreement with the numerical model predictions when compared with the threshold shear.

For the Tagish River South reach, the majority of the erosion was predicted for Station 6426.78. For this station the model-predicted shear stresses exceeded the threshold shear during the months of May through September for the right overbank (east bank) and March through September for the left overbank (west bank). The model results also predicted erosion for the left overbank of Station 5805.69, mainly during the months of July and August. The remainder of the locations investigated for the Tagish River South reach did not exceed the threshold shear. Field observations of the Tagish River South reach show high cut banks and the greatest erosion on the west side of the river at or near Station 6426.78. This is in agreement with the numerical model prediction for erosion. Field observations also show erosion at the west bank near Station 5805.69, which is in agreement with the numerical model prediction. At the turn near the east end of California beach (Station 7233.73), the model does not predict any erosion. Erosion observed at this location may be due to lake waves and is only expected to occur when the lake level is very high.

5.0 References

AECOM. 2011. *Marsh Lake Fall-Winter Storage Concept: 2011 Geomorphology Field and Associated Studies Report*. AECOM Technical Report.

AECOM. 2012. *Assessment of Fluvial Erosion in M'Clintock River and Tagish River*. AECOM Technical Report. Prepared by Ashraful Islam and Joe Orlins.

Vanoni, V.A. 1975. *Sedimentation Engineering, Manual and Report No. 54.* American Society of Civil Engineers, New York, N.Y.

Appendix A

Assessment of Fluvial Erosion in M'Clintock River and Tagish River

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September 2012

Assessment of Fluvial Erosion in M'Clintock River and Tagish River

Prepared By Ashraful Islam, PhD, PE

Reviewed By Joe Orlins, PhD, PE, DWRE

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1.0 Introduction

Yukon Energy Corporation (YEC) owns the Whitehorse Rapids Dam and Power Plant, located on the Yukon River at the City of Whitehorse, approximately 40 km downstream from the Marsh Lake outlet. A control structure at the Marsh Lake outlet, Lewes Dam, operates in conjunction with the power plant, regulating the water level during fall and winter months to provide additional winter power generation. AECOM is assisting YEC for the key energy development and enhancement projects as part of YEC's 20-year resource plan. One of the projects identified in the resource plan envisions raising the full supply level (FSL) of Marsh Lake by 0.3 m to store additional water for winter power production at the Whitehorse Rapids Generating Station (WRGS)

Marsh Lake and its surrounding water bodies may experience increased shoreline erosion due to the higher water levels. The erosion can be caused by fluvial and wind actions. This report focuses on the prediction of fluvial erosion of the M'Clintock and Tagish Rivers, both tributaries to the Marsh Lake. The objectives of the study were to:

1) Estimate the potential magnitude of M'Clintock River bank erosion due to river currents and higher lake water levels.
2) Estimate the potential magnitude of Tagish River bank erosion due to river currents and higher lake water levels.

The study was conducted using the one dimensional (1-D) hydraulic modeling software package, HEC-RAS. The mobile bed sediment transport module of HEC-RAS was used to estimate the bed level change of the rivers over the simulation period of one year.

2.0 Software Description

HEC-RAS is a hydraulic modeling software package developed by Hydrologic Engineering Center of the U.S. Army Corps of Engineers (USACE). The HEC-RAS system contains four one-dimensional river analysis components for: (1) steady flow water surface profile computations; (2) unsteady flow simulation; (3) movable boundary sediment transport computations; and (4) water quality analysis. A key element is that all four components use a common geometric data representation and common geometric and hydraulic computation routines. In addition to the four river analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed.

The HEC-RAS sediment transport module is intended for the simulation of one-dimensional sediment transport/movable boundary calculations resulting from scour and deposition over specified time periods. The sediment transport potential is computed by grain size fraction, thereby allowing the simulation of hydraulic sorting and armoring. Major features include the ability to model a full network of streams, channel dredging, various levee and encroachment alternatives, and the use of several different equations for the computation of sediment transport. The model is designed to simulate long-term trends of scour and deposition in a stream channel that might result from modifying the frequency and duration of the water discharge and stage, or modifying the channel geometry. This system can be used to evaluate deposition in reservoirs, design channel contractions required to maintain navigation depths, predict the influence of dredging on the rate of deposition, estimate maximum possible scour during large flood events, and evaluate sedimentation in fixed channels.

3.0 Model Development

The M'Clintock River and the Tagish River are the two major tributaries to Marsh Lake, which forms the headwaters of the Yukon River. An aerial view of this interconnected network of rivers and lakes is shown in Figure 3-1. To reduce the size of the computational domain, the study was conducted separately for two rivers. Marsh Lake was used as the downstream boundary in both models.

In HEC-RAS, the computational domain is represented by the stream network along with its associated cross section information. At each cross-section, HEC-RAS uses the following input parameters to describe the shape, elevation, and relative location along the stream:

1. River station (cross-section) number
2. Lateral and elevation coordinates for each terrain point
3. Left and right bank station locations *("left" and "right" designations are as used in the model and this report are oriented while looking downstream)*
4. Reach lengths between adjacent cross-sections
5. Manning's roughness coefficients for the channel and left and right overbank areas
6. Channel contraction and expansion coefficients
7. Geometric description of any hydraulic structures

The geometry information for each of the models was prepared in ArcGIS using an automation tool, HEC-GeoRAS (GeoRAS). Input parameters for GeoRAS were georeferenced aerial photo and digital terrain model (DTM) of the project area. The DTM of the project area encompassing the part of the M'Clintock River and the Marsh Lake was supplied by AECOM Canada whereas the DTM for the Tagish River was prepared from bathymetric survey data collected by Northwest Hydraulic Consultants (NHC). A series of line themes, such as river centerline, bank, flow paths for two banks and the centerline, and the cross sectional transects were created by on screen digitization of the aerial photo. GeoRAS processed these line themes and the DTM to prepare the required geometry files to be used in the RAS models.

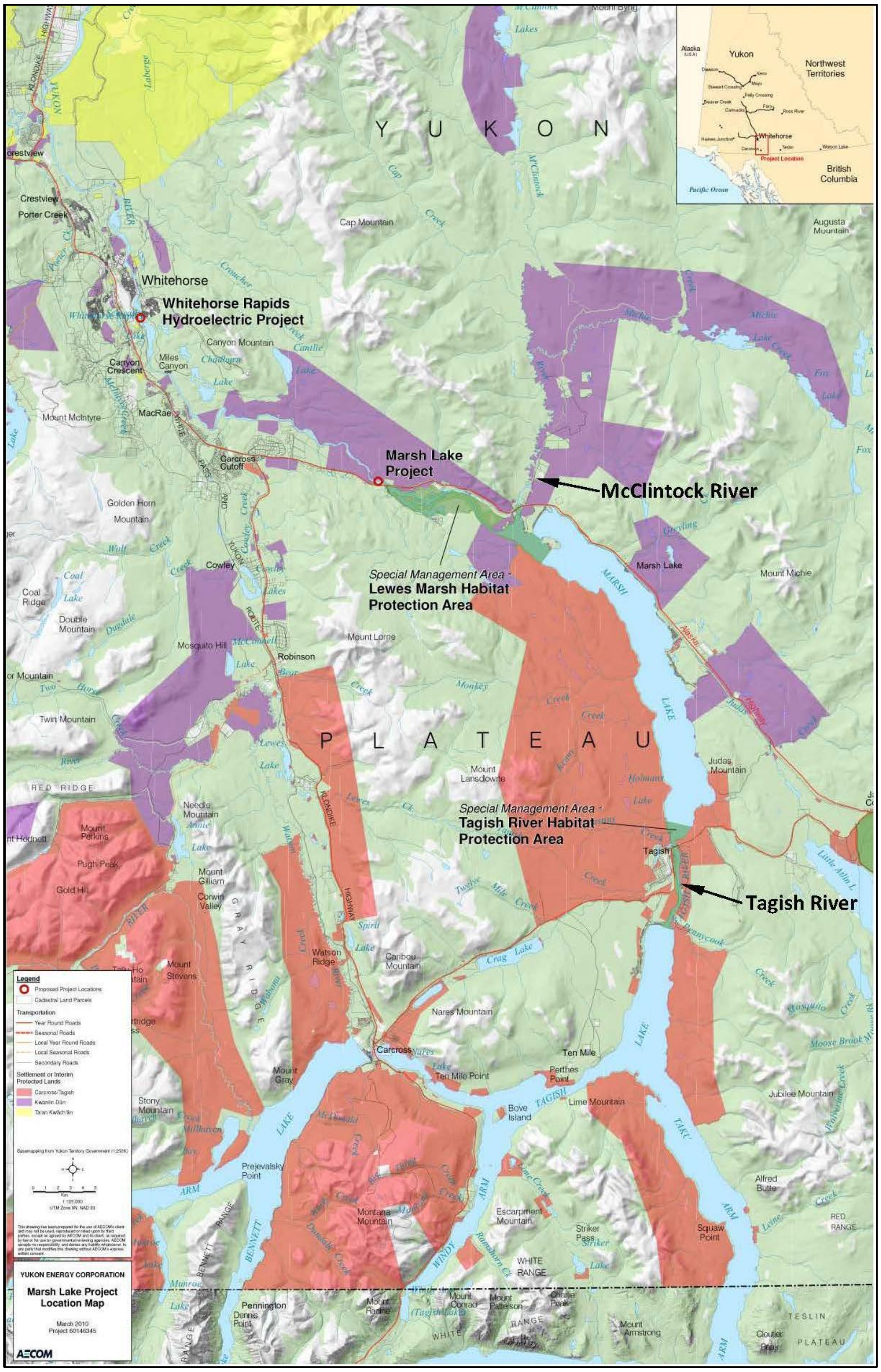

Figure 3-1: Study Area

Figure 3-2 shows the 3,620-m long M'Clintock River reach and its cross sectional transects used in the HEC-RAS model. Note that the available DTM only covered the portion of the river downstream of the Alaskan Highway. Therefore, the portion of the river reach upstream of the Highway was approximated by the upstream-most cross section extracted from the DTM. As the purpose of the study was to assess the shoreline erosion adjacent to the Marsh Lake, this approximation is unlikely to affect the model results. Cross section cut lines were located along the stream centerline at points that represent the average geometry of a stream segment, and at changes in geometry, slope, channel, overbank roughness, and discharge. Available aerial photographs and contour information were used to layout the cross section locations. The average distance between cross sections varied from 28 m to 127 m, with less distance between cross sections around the areas of abrupt changes in channel geometry.

A schematic of the 7,235-m long Tagish River and its cross sectional transects is shown in Figure 3-3. As shown in Figure 3-1, the Tagish River extends from Tagish Lake to Marsh Lake and the river reach does not have any significant bends. Therefore, six cross sections were considered enough to represent the geometry of the total length

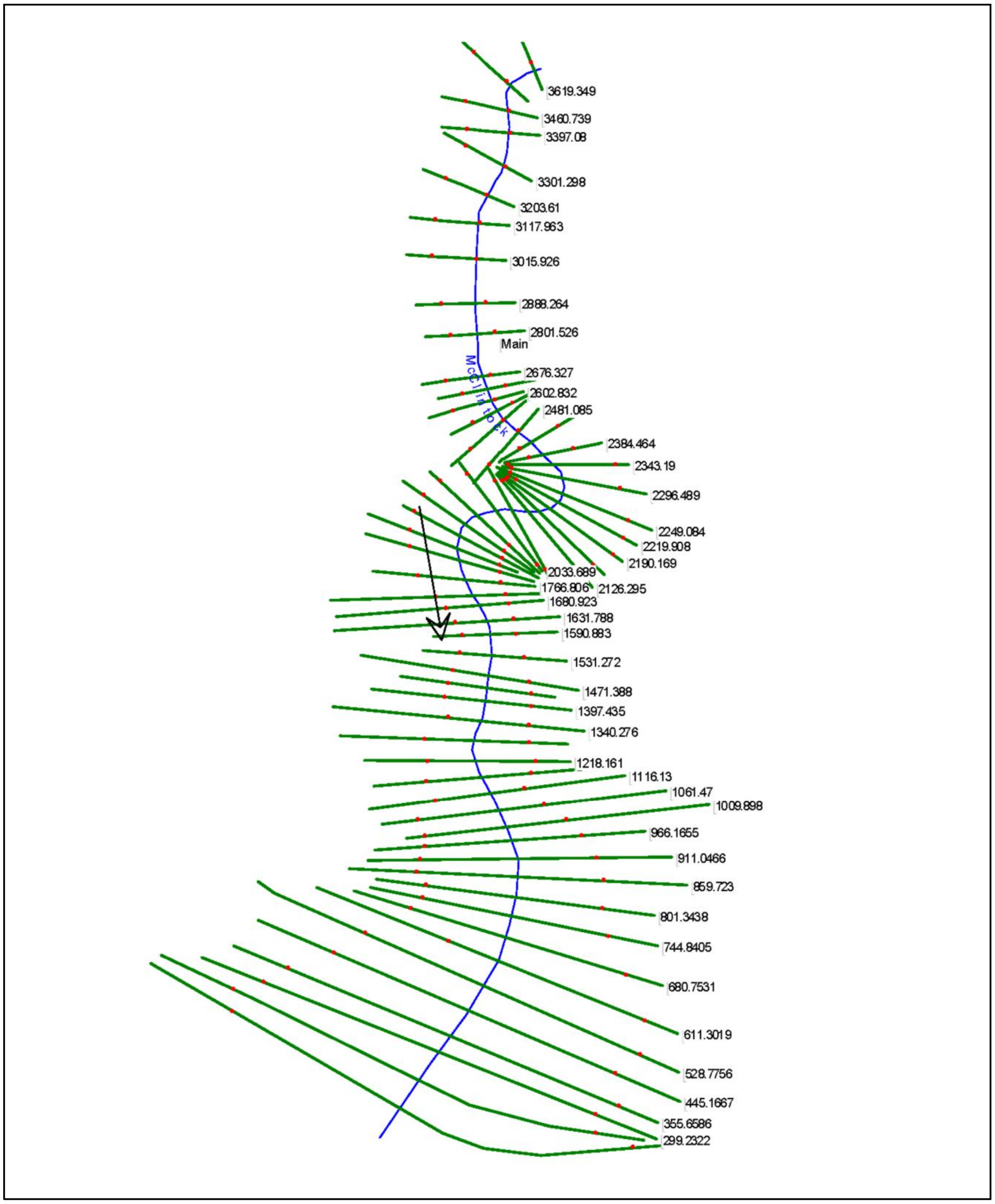

Figure 3-2: Cross Section Locations for M'Clintock River Model

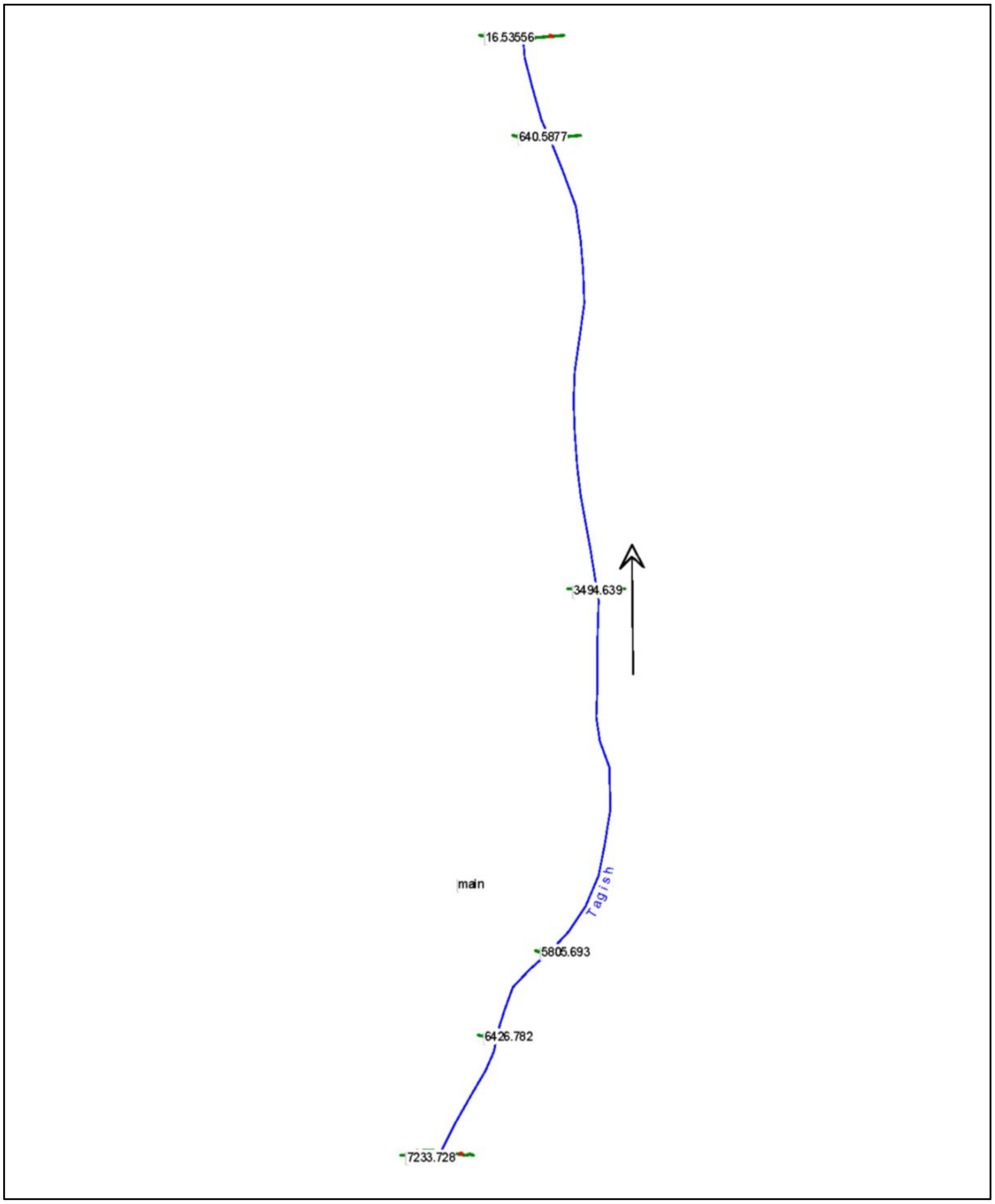

Figure 3-3: Cross Section Locations for Tagish River Model

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4.0 Boundary Conditions

Boundary conditions for the models were flow data, water level data, and sediment size information for the river bed. The sediment transport module of HEC-RAS is based on quasi-steady state hydraulics which approximates a flow hydrograph by a series of steady flow profiles of smaller durations. The model study was conducted for one calendar year by approximating the varying flow as constant for each month. The time series of flow rate was specified at the upstream end while a water level time series was specified at the downstream boundary location, which was the Marsh Lake for both models. Figure 4-1shows the flow and water level boundary data used for the M'Clintock River model, Figure 4-2 shows the flow and water level boundary data for the Tagish River model.

AECOM conducted several reconnaissance surveys to assess the erosive potential of the shoreline. Sieve analysis of the soil samples collected from the study area were used to define the bed material of the channel bed and banks. Figure 4-3 and Figure 4-4 show the grain size distributions of the bed material for the M'Clintock and Tagish Rivers, respectively.

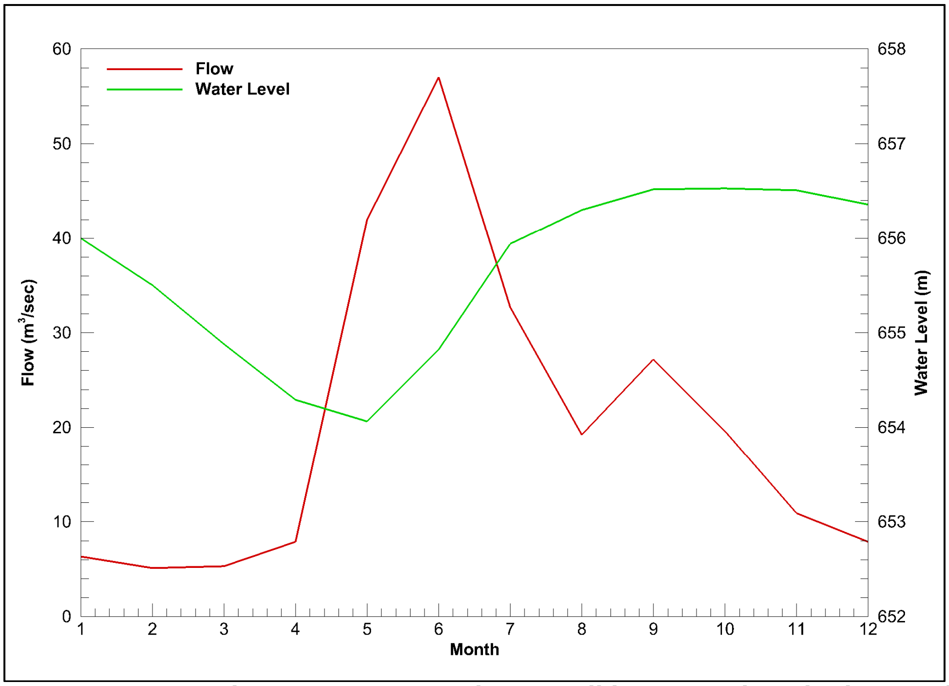


Figure 4-1: Flow and Water Level Boundary Conditions - M'Clintock River Model

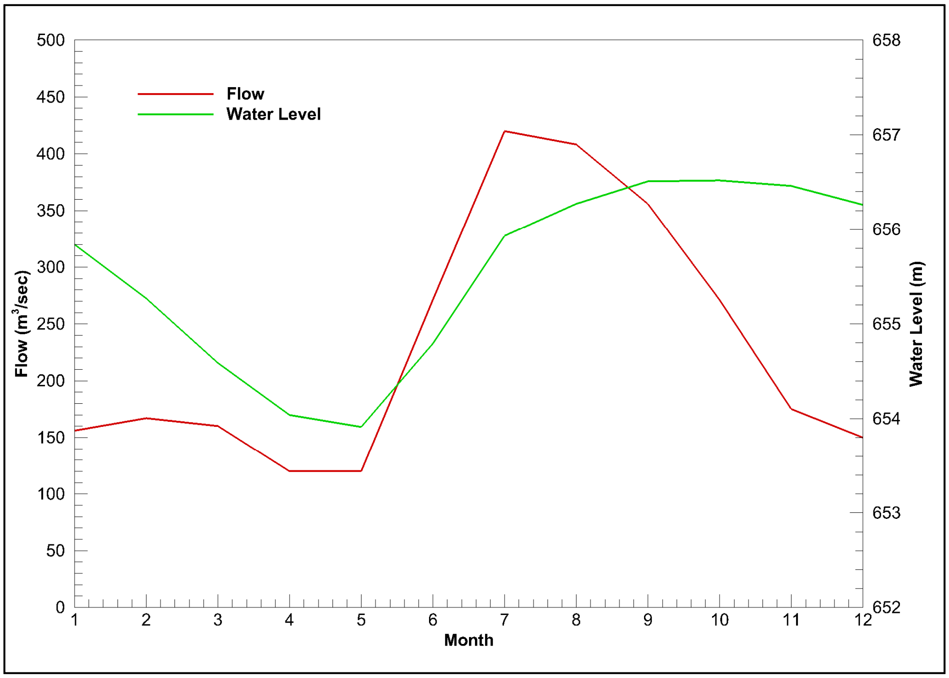


Figure 4-2: Flow and Water Level Boundary Conditions - Tagish River Model

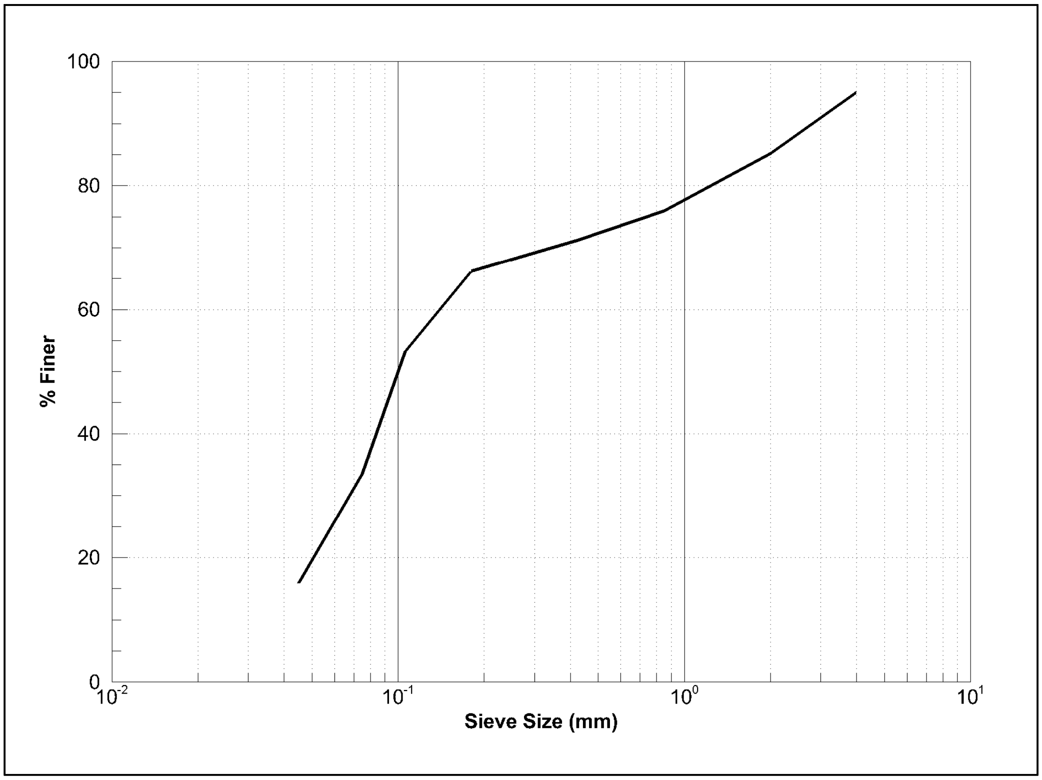


Figure 4-3: Sediment Grain Size Distribution - M'Clintock River

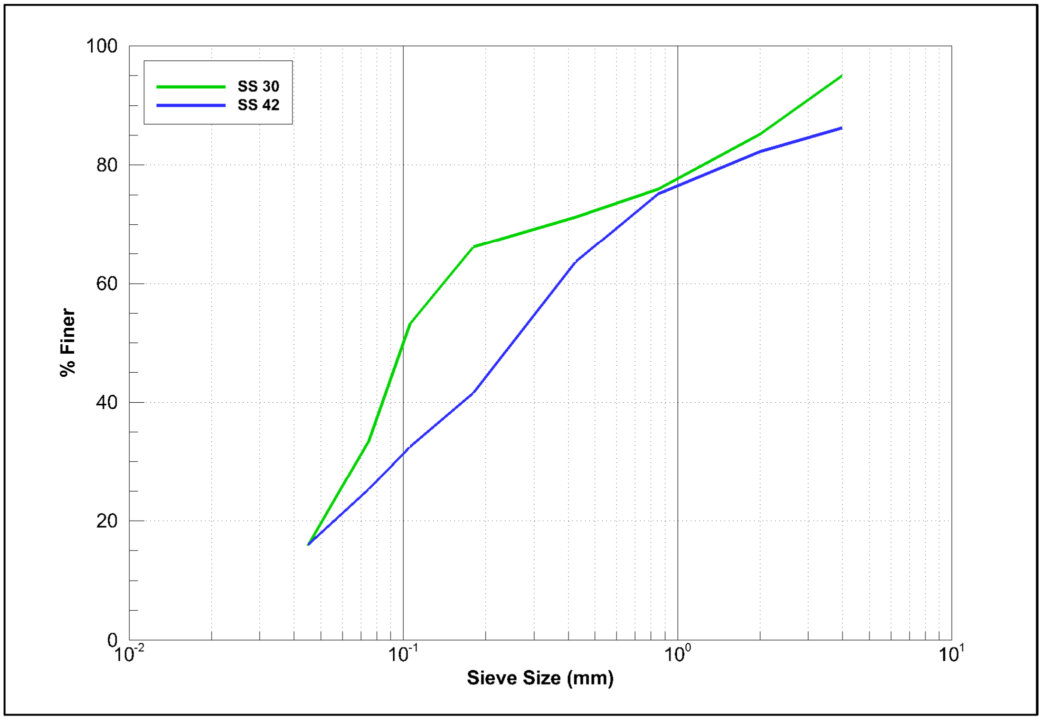
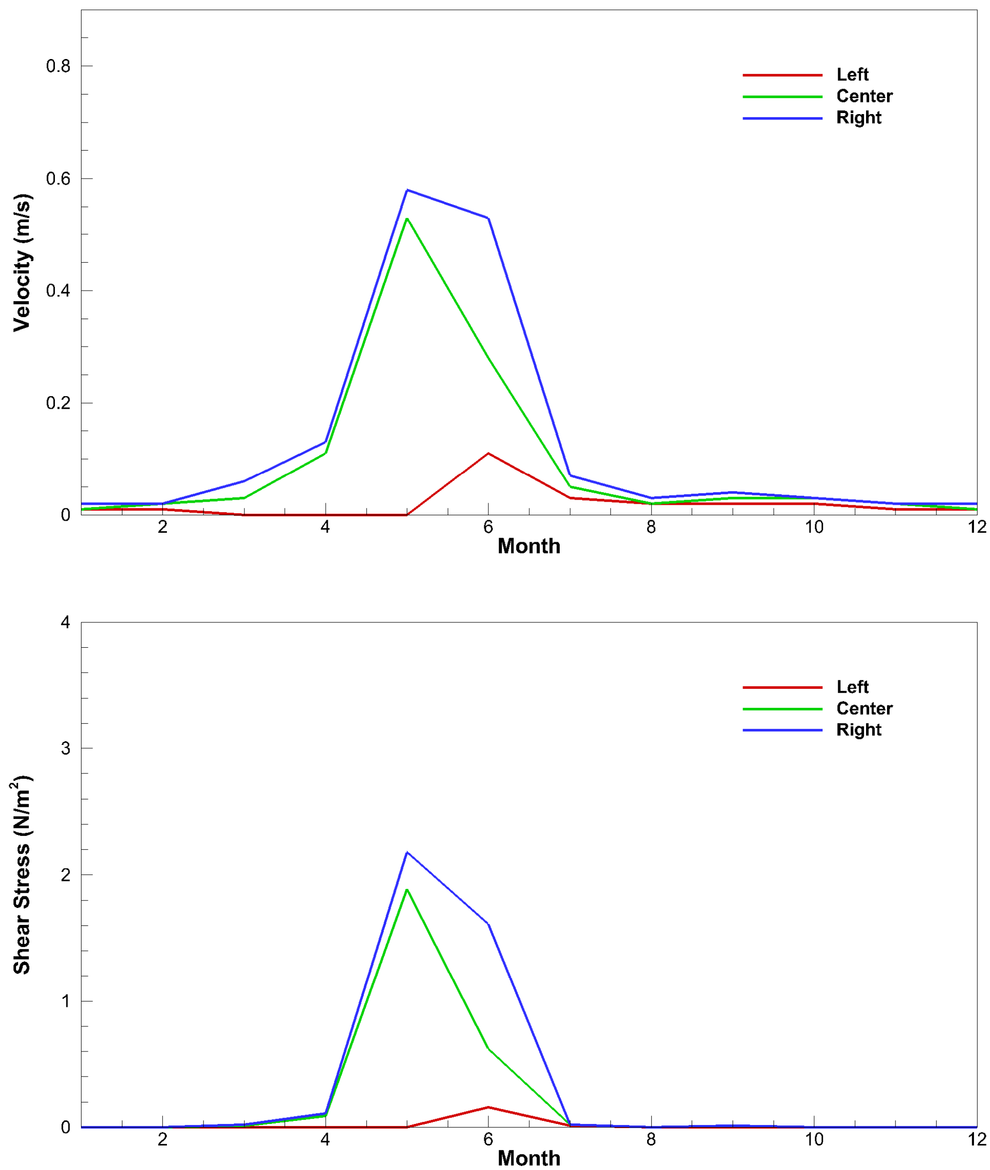


Figure 4-4: Sediment Size Distribution - Tagish River

5.0 Results

The models were run to predict the amount of bed load transported at each model transect and evaluate the corresponding long term deposition and erosion trends in the reach over the simulation period of one year. With the variation of cross sectional area along the length of the models, the cross-sectional averaged velocity varied widely with a corresponding variation in the bed shear stress that defines the erosion/depositional potential of a particular section. Velocity and shear stress distributions at five cross sections of the downstream portion of the M'Clintock River near Marsh Lake are shown in Figure 5-1 through Figure 5-5. At each cross section, the results are shown for the main channel, the right overbank area, and the left overbank area for the twelve-month simulation period. Figure 5-6 summarizes the erosion and deposition at each section along the length of the river.

The velocity and shear stress distributions at the six transects of the Tagish River are shown in Figure 5-7 through Figure 5-12.



"Left" and "right" designations are oriented looking downstream

Figure 5-1: Velocity and Shear Stress at M'Clintock RS 1061.47

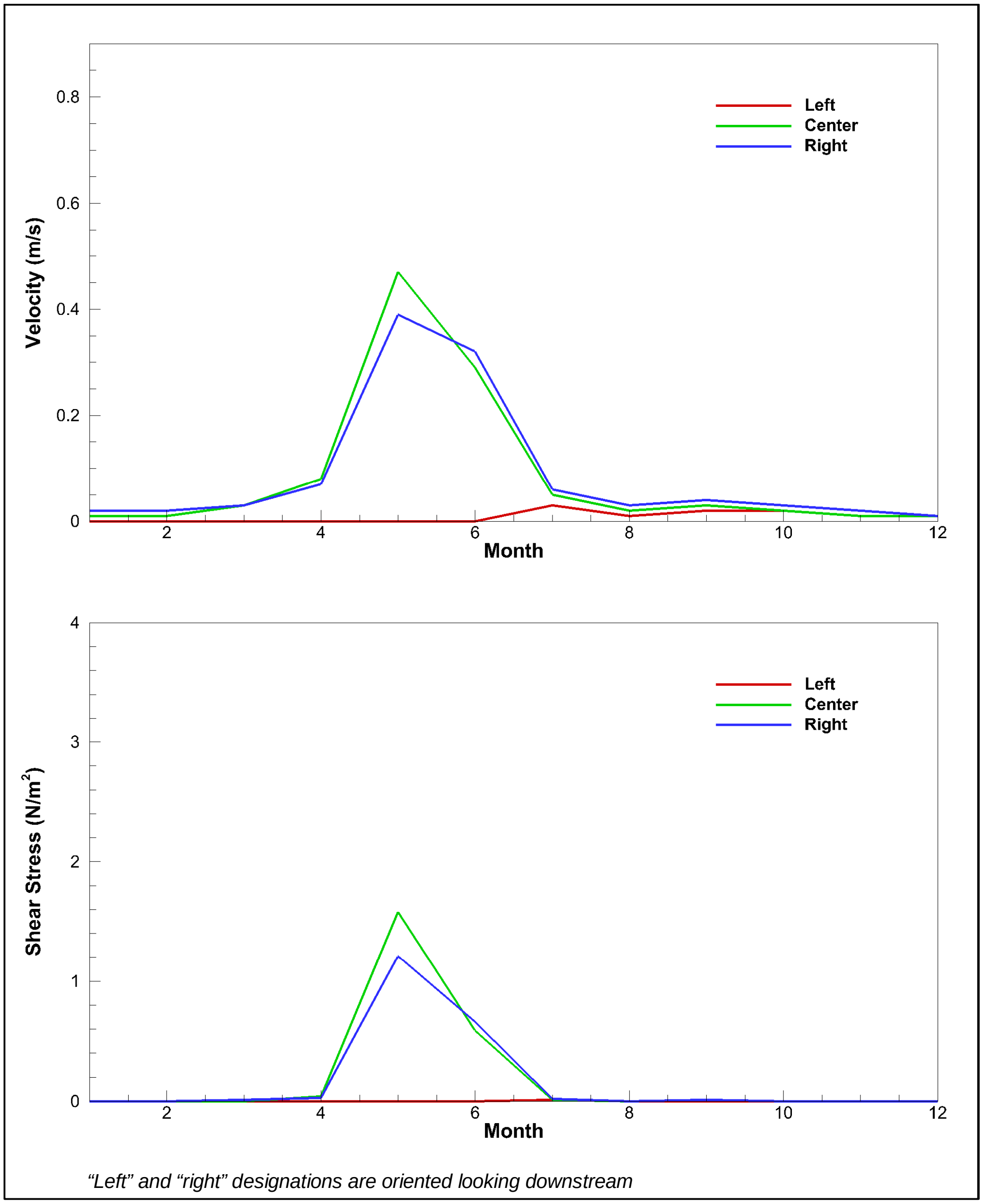
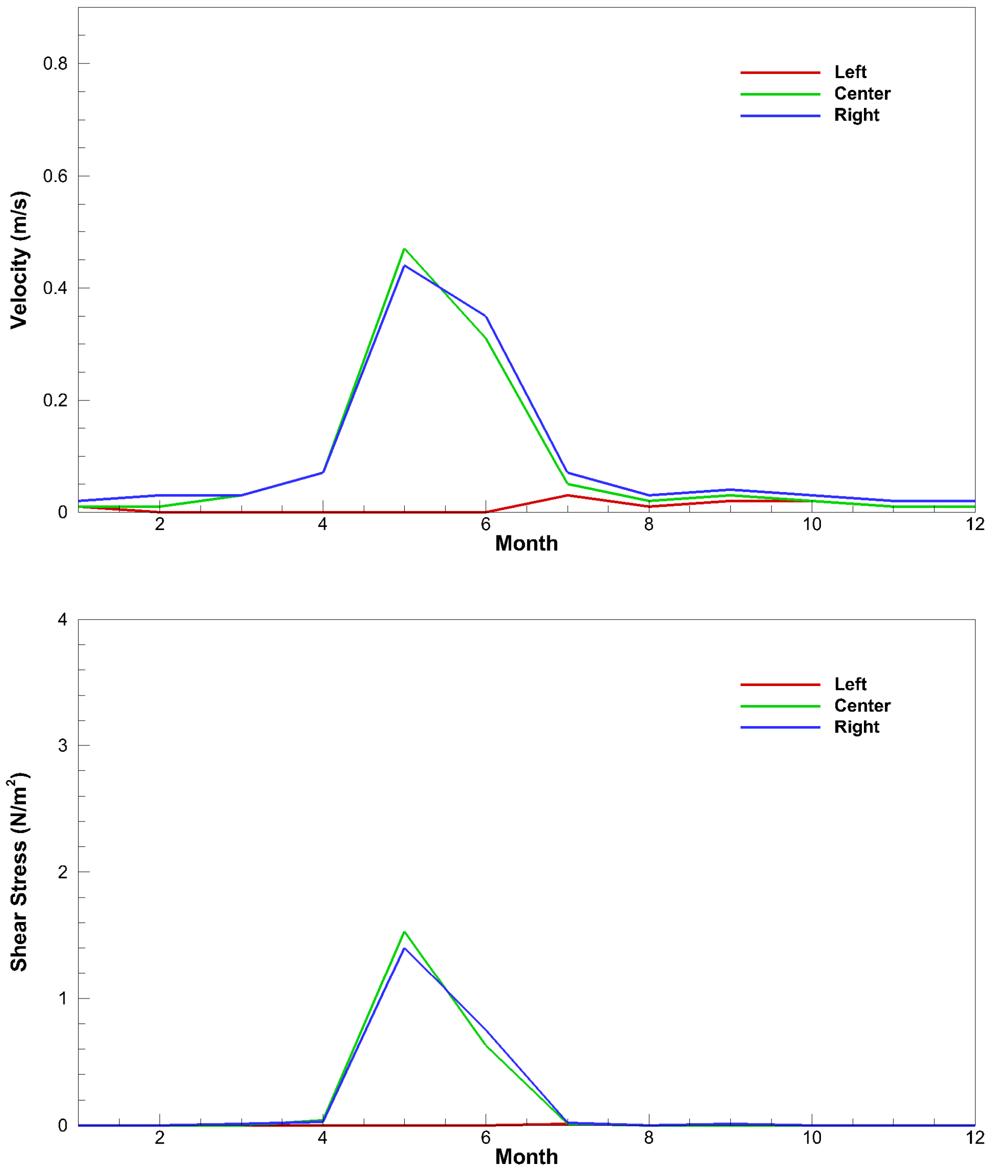


Figure 5-2: Velocity and Shear Stress at M'Clintock RS 1009.9



"Left" and "right" designations are oriented looking downstream

Figure 5-3: Velocity and Shear Stress at M'Clintock RS 966.17

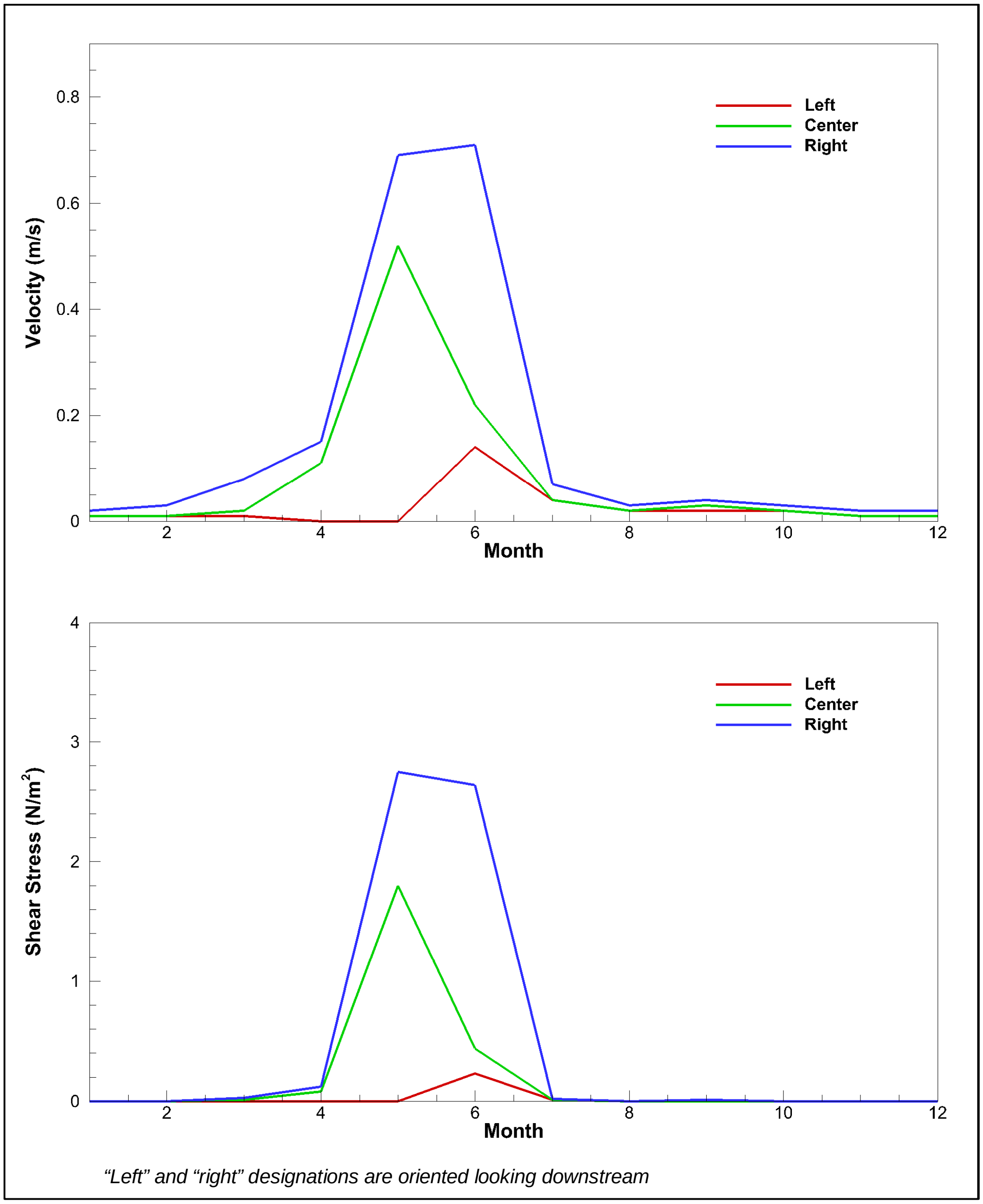


Figure 5-4: Velocity and Shear Stress at M'Clintock RS 911.05

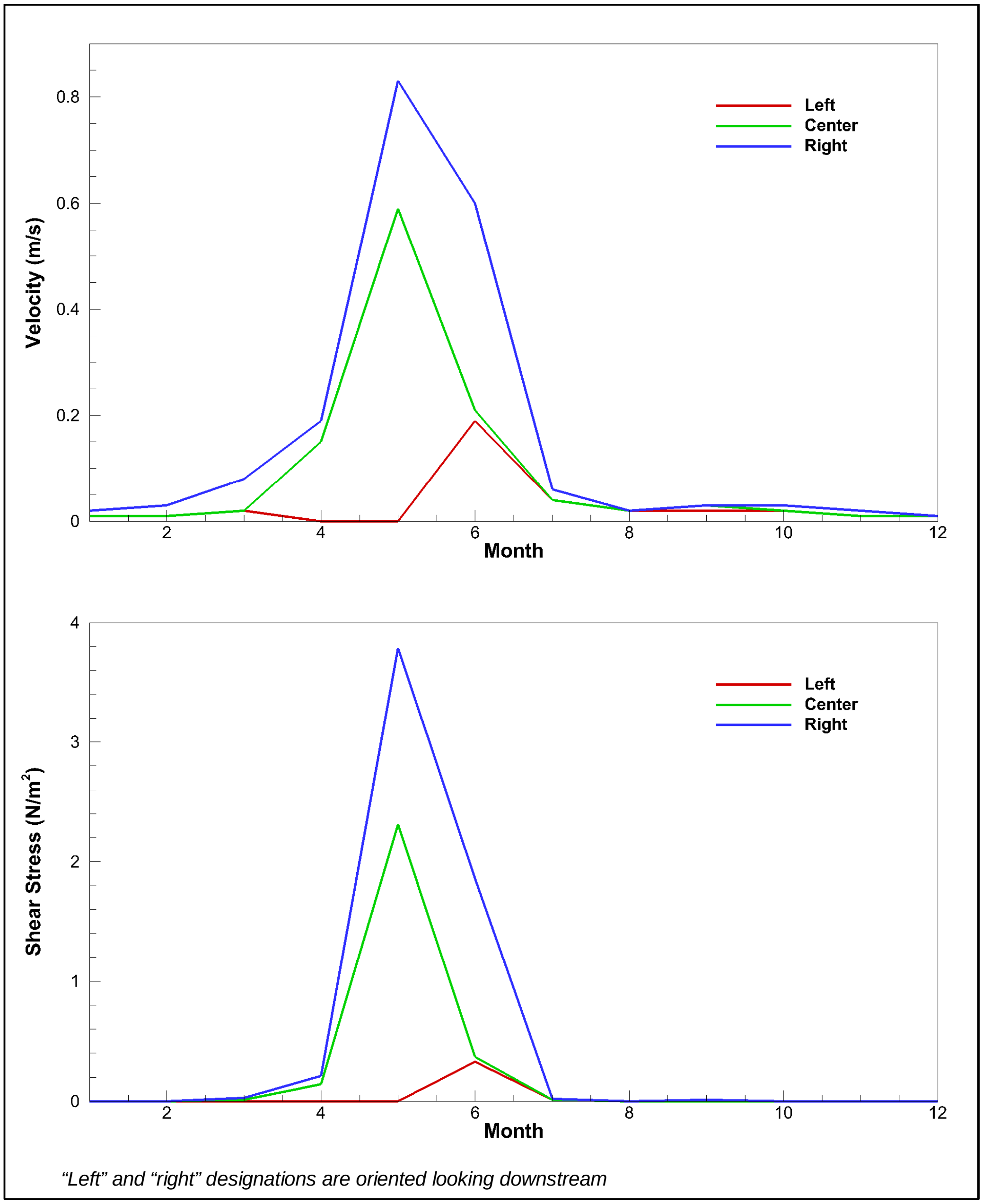


Figure 5-5: Velocity and Shear Stress at M'Clintock RS 859.72

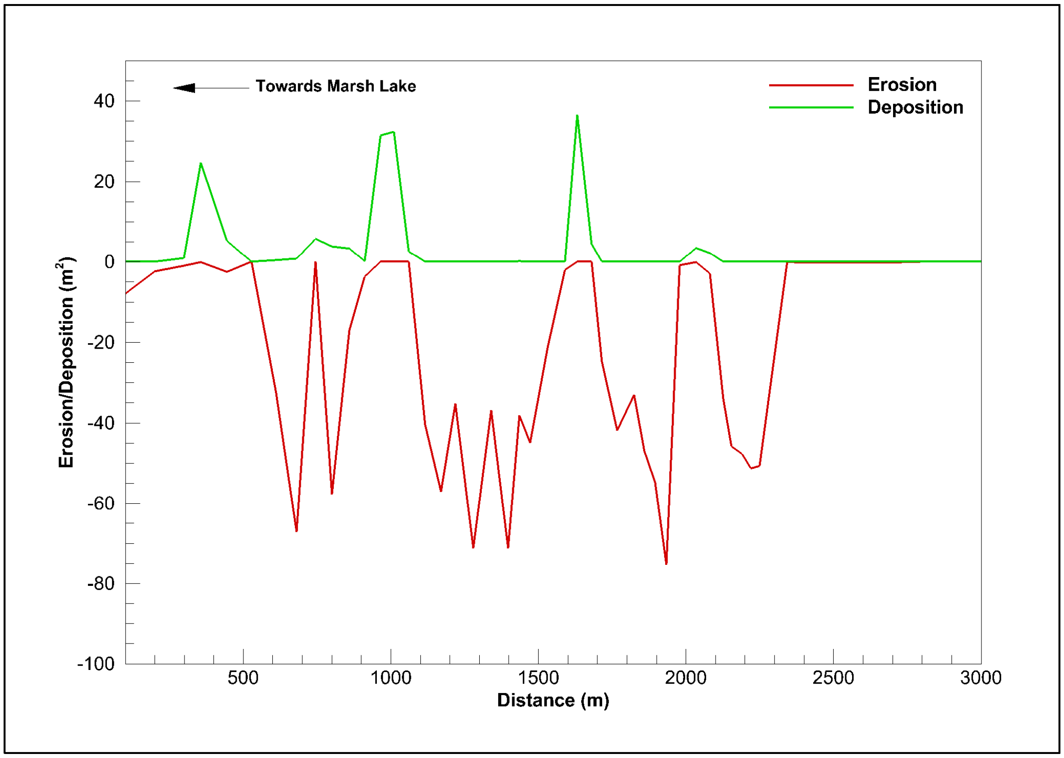
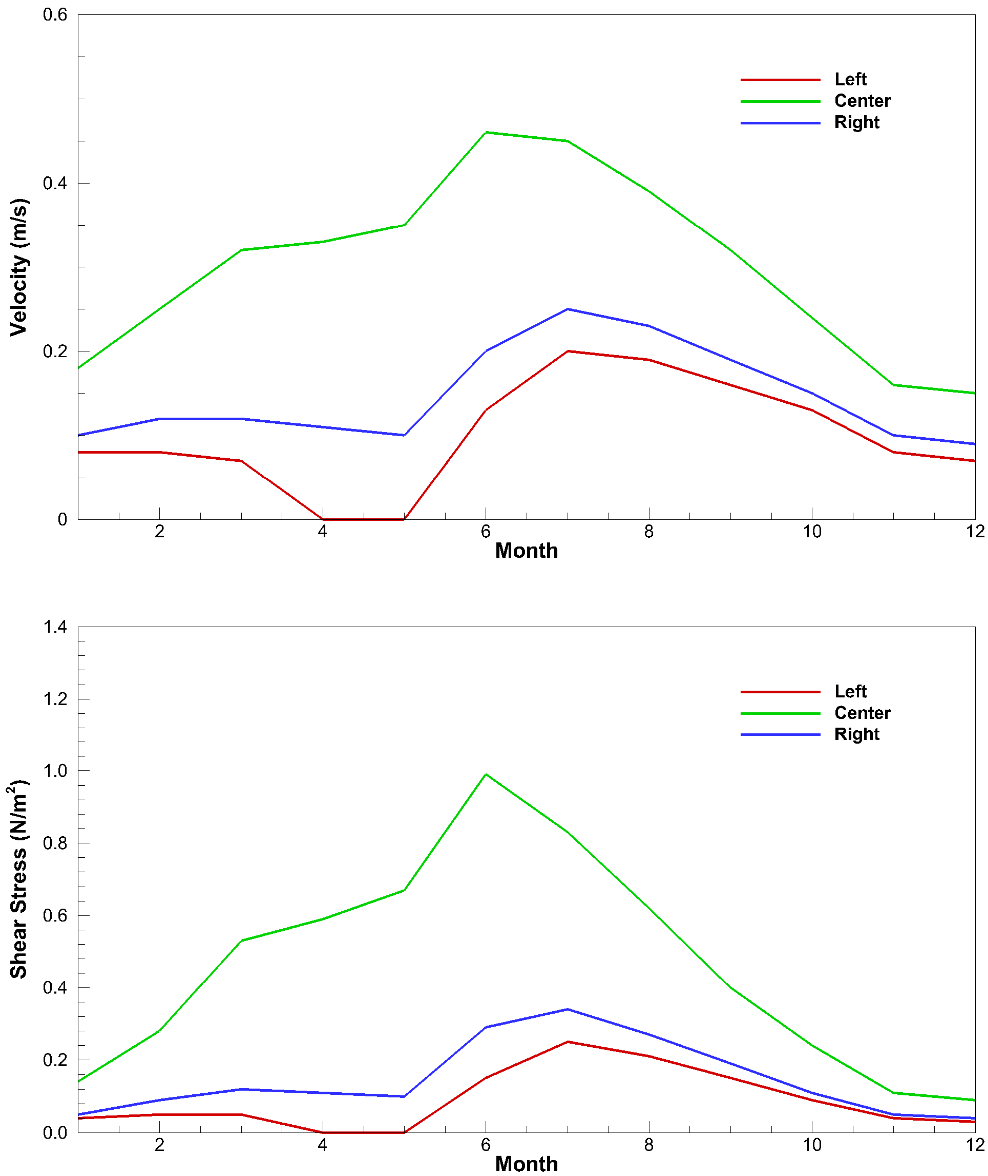
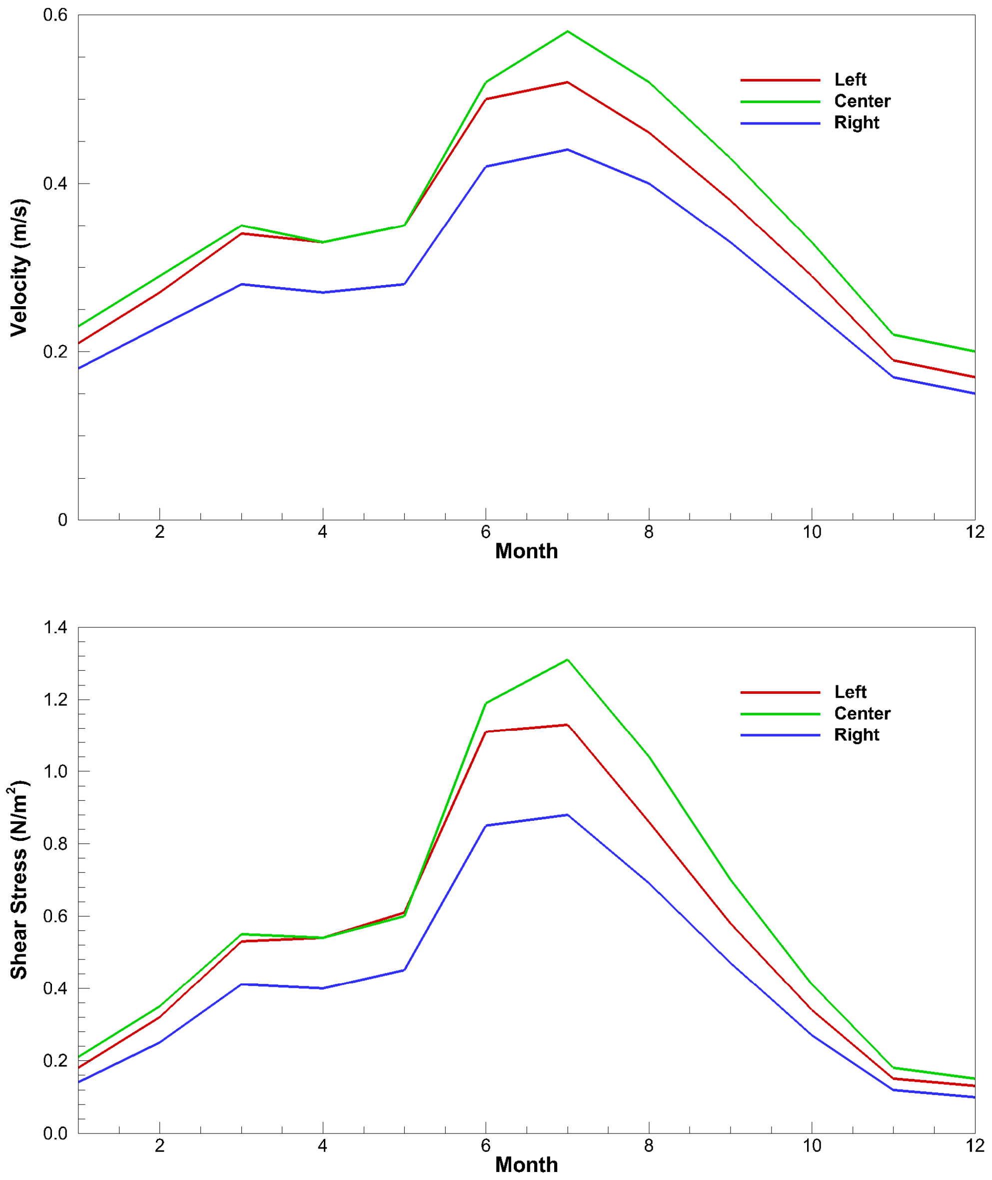


Figure 5-6: Erosion / Deposition Along M'Clintock River



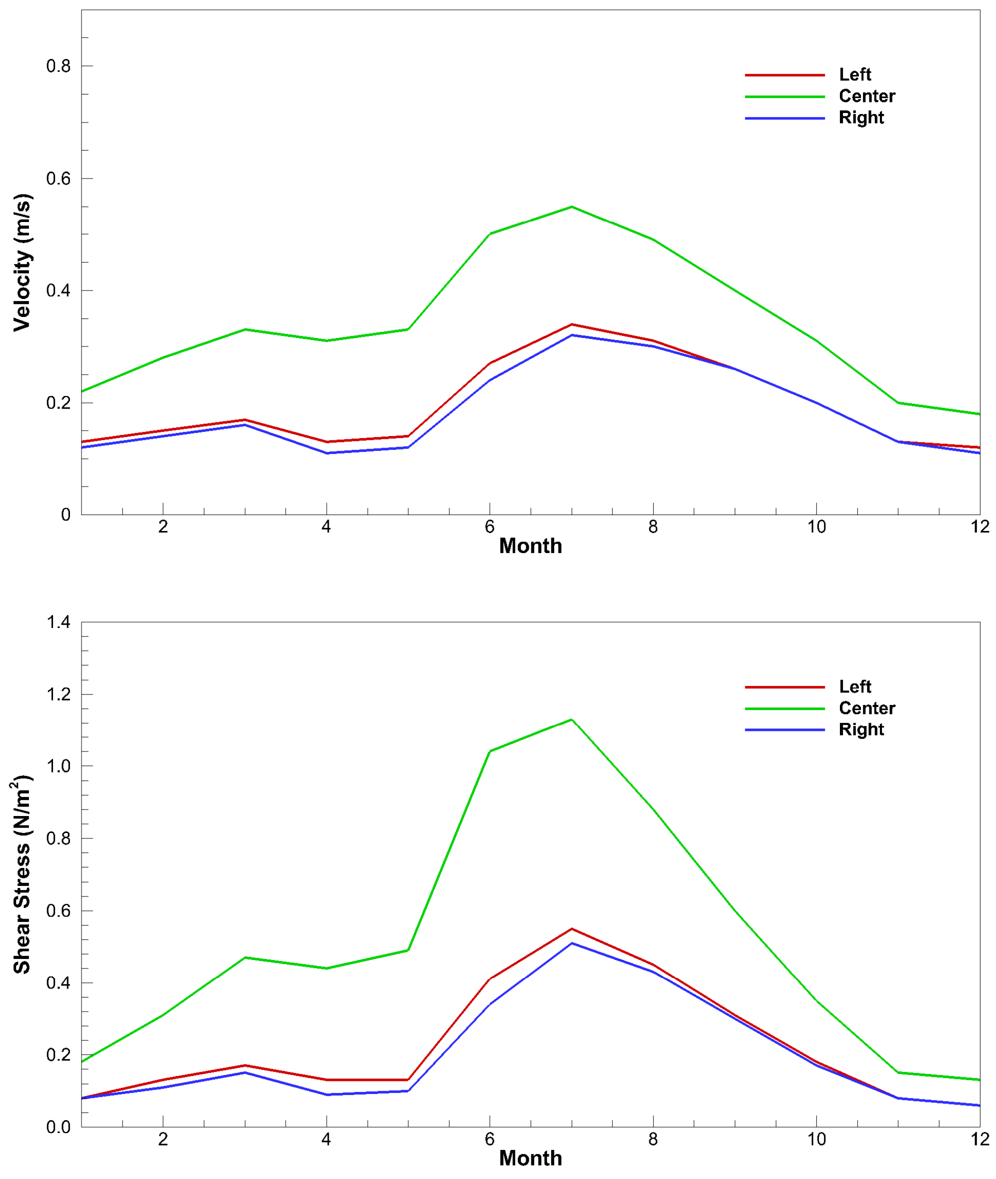
"Left" and "right" designations are oriented looking downstream

Figure 5-7: Velocity and Shear Stress at Tagish RS 7233



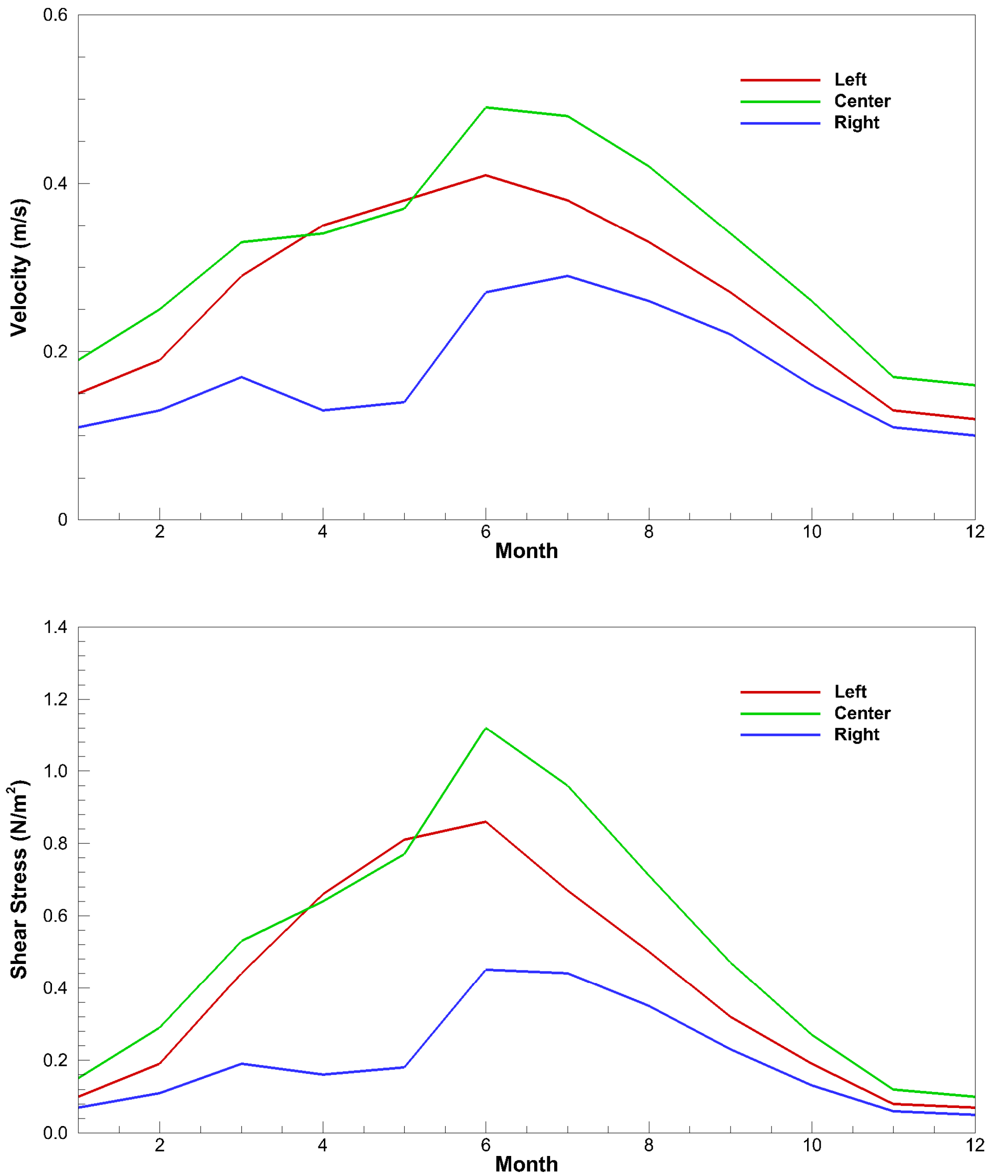
"Left" and "right" designations are oriented looking downstream

Figure 5-8: Velocity and Shear Stress at Tagish RS 6427



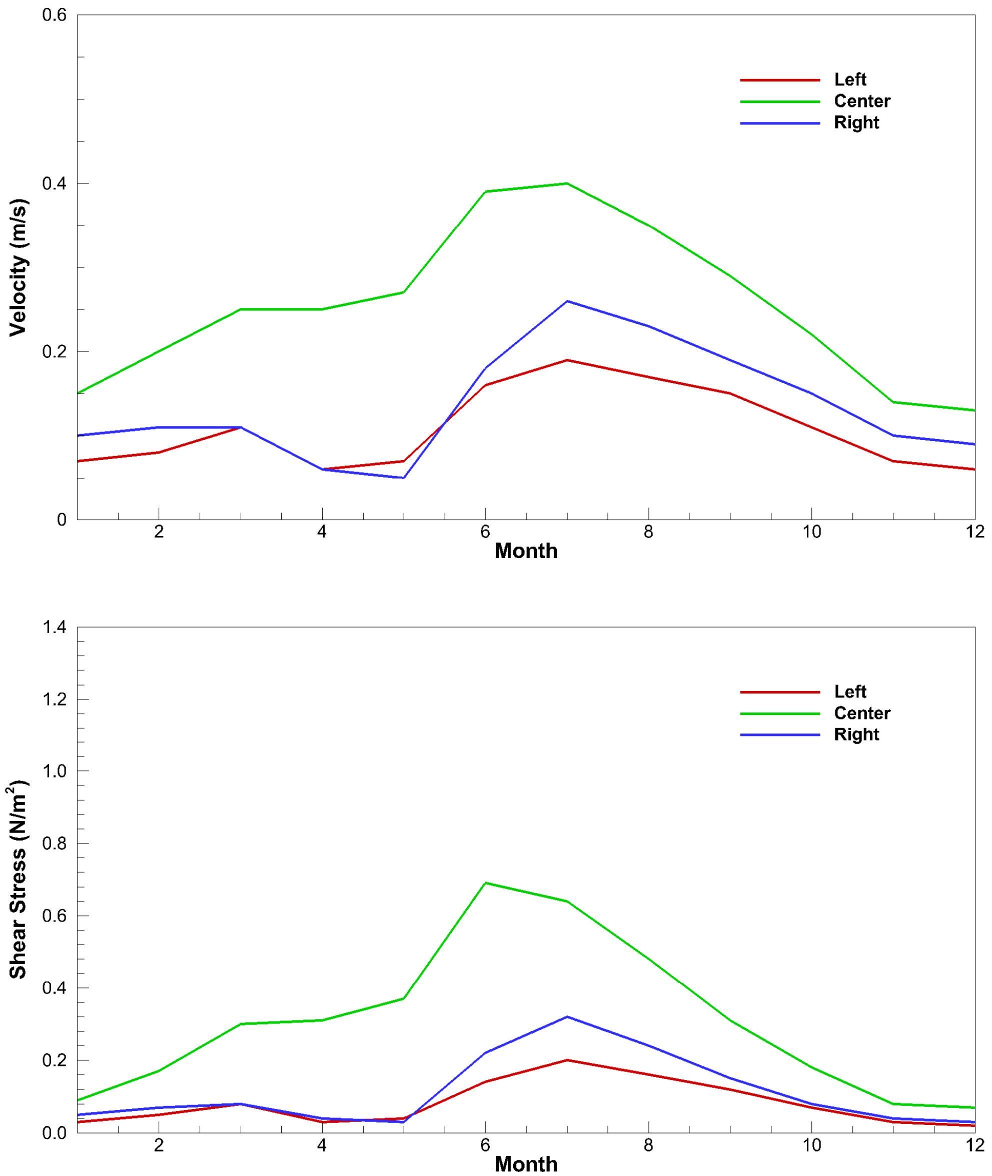
"Left" and "right" designations are oriented looking downstream

Figure 5-9: Velocity and Shear Stress at Tagish RS 5806



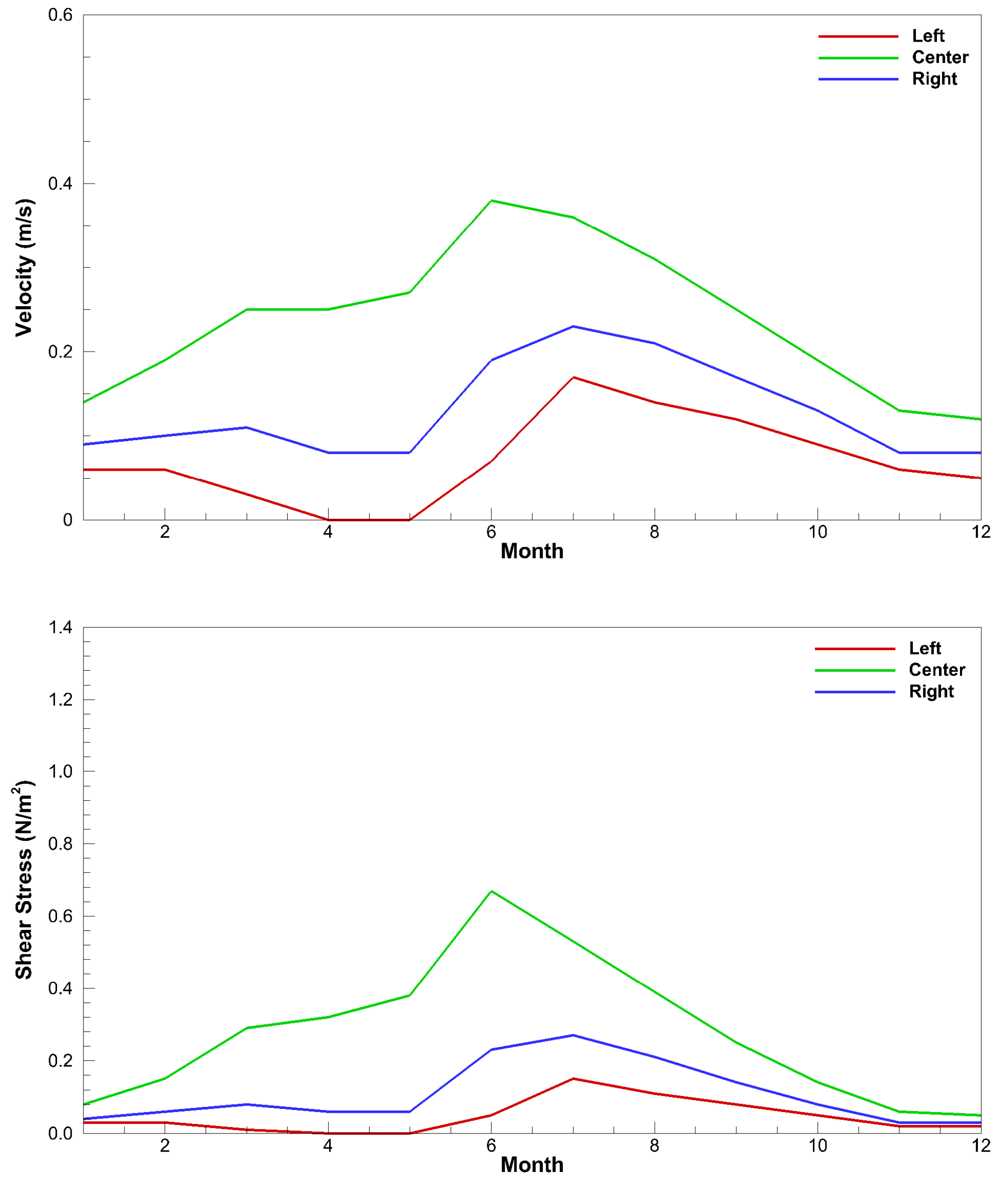
"Left" and "right" designations are oriented looking downstream

Figure 5-10: Velocity and Shear Stress at Tagish RS 3495



"Left" and "right" designations are oriented looking downstream

Figure 5-11: Velocity and Shear Stress at Tagish RS 641



"Left" and "right" designations are oriented looking downstream

Figure 5-12: Velocity and Shear Stress at Tagish RS 17