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NIAGARA RIVER AOC

Lyons Creek East Sediment Transport Study

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REPORT

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1.0 INTRODUCTION AND BACKGROUND

Studies conducted in Lyon's Creek East have identified elevated concentrations of some contaminants in sediment. In particular, elevated levels of PCBs in sediments of Lyons' Creek East were identified as a beneficial use impairment in the Niagara River Area of Concern. Subsequent studies conducted by Golder and Dillon Consulting noted that risks to human health and ecological receptors were negligible to marginal, and that due to the importance of the area as a Provincially Significant Wetland, Monitored Natural Recovery was the preferred remedial option. Study and result details from these studies can be found in Golder's report on Niagara River AOC Phase IV: Sediment Management Options for Lyon's Creek East and West (August 2008).

Golder Associates Ltd. (Golder) was retained in 2009 to provide an assessment of the potential for sediment re-suspension and transport in Lyon's Creek East, and verify the assumptions upon which the selection of the preferred management option was based.

- The purpose of the current study was to: Quantify the sediment input to Lyon's Creek East, in the section from the Welland Canal By-pass to Hwy 140, to assess the rate of accumulation, and to predict the period of time required to accumulate a given depth of sediment; and
- Determine the maximum flow velocity in the system that could be sustained without re-suspending bottom sediments, and potentially exposing PCB contaminated sediment to erosion.

In order to address the contaminated sediment concerns, and move towards de-listing of the area as an Area of Concern, there is a need to consider the remedial options that could be implemented at the site. The remedial options need to be appropriate for the risks identified, and need to provide suitable mitigation of the identified risks. Since various levels of risk have been identified across the site, the risk management options need to accommodate a range of different options at each site.

1.1 Site History

Lyons Creek East is the lower section of a small watershed near Welland, Ontario, which was severed by the construction of the Welland Canal By-Pass in the 1970's (Figure 1). The construction of the canal by-pass cut roughly across the middle of the historic watershed; flows from the remaining upper remnant watershed are collected at the lower end of Lyons Creek West and drain into the canal on the west side. Water from the canal is in turn pumped into the upper reaches of Lyons Creek East using a set of pumps.

The remaining catchment east of the Welland Canal draining to Lyons Creek East is a mix of agricultural and industrial properties, with some residential areas along Ridge Road and Highway # 140. Historically there have been some light and heavy industrial operations along the south side of Lyons Creek East; however these sites are no longer in use. During the excavation of the Welland Canal By-Pass, a large amount of fill was deposited to the north of the site adjacent to the canal. Roughly 40 ha, locally known as the Transport Canada Lands, of the fill pile lies in the East Lyons Creek catchment.

Elevated levels of PCBs have been found in both Lyons Creek East and West. Relatively uncontaminated sediments, ranging in depth between 20 cm and 30 cm, lie on top of the contaminated sediments in Lyons Creek East (Golder, 2005), which suggests that most of the deposition occurred historically.

1.2 Review of Previous Studies

Background reports reviewed for this study include:

- Niagara River Area of Concern, Contaminated Sediment, Site Assessment, Phase I and Phase II, by Golder Associates, May 2004; and
- Niagara River Area of Concern, Contaminated Sediment, Site Assessment, Phase III, by Golder Associates, May 2005.

1.3 Areas of Contaminated Sediment

Areas of PCB contaminated surface sediments are shown on Figure 2, taken from the May 2005 Phase III report (Golder, 2005). This figure shows an amalgam of sediment quality results from previous sampling programs.

Generally, surface concentrations are highest at the upstream end of the creek adjacent to the pump inlets from Welland Canal. Surface concentrations in this area range between 0.1 µg/L (taken at the canal pump outlet by Golder in 2005) to 15 µg/L (taken approximately 40 m downstream of the canal pump outlet by the MOE in 2002). The highest surface concentrations of PCBs in the sediment are generally at the upstream end of the creek, with surface concentrations becoming progressively lower moving in a downstream direction. This trend in turn reverses itself at the downstream end of the section, just before the Highway 140 culvert, with peak surface concentrations of PCBs in the sediments of 19 µg/L immediately upstream of the Highway #140 culvert.

2.0 DATA COLLECTION AND ANALYSIS

2.1 Hydrology

The primary inflows to Lyons Creek East are pumping from the Welland Canal and runoff from the contributing catchments east of the Welland Canal. Instantaneous flow measurements were taken in Lyons Creek East between October 2009 and July 2010, at seven locations shown on Figure 3. Measured flows included inflows at the upstream end of the creek (where the pumps from the Welland Canal discharge into the creek), at five tributaries discharging into the creek upstream of the Highway 140 culvert, and at the Lyons Creek culvert at Highway 140.

2.1.1 Inflows

The main source of inflow to Lyons Creek East is water pumped from the Welland Canal. Lyons Creek is divided by the canal and the east portion of the creek is fed by a pump house located on the canal. Several small tributaries that capture local runoff drain to Lyons Creek East augmenting its moderated flow rate during rainfall events and spring melt conditions.

According to previous reports (Acres, 1970), the pump rate from the Welland Canal to the upper reaches of Lyons Creek East varies depending on the season. From April to November, during the shipping season when the canal is full, the pumping rate is reported to be approximately 10 cfs (cubic feet per second), or 0.283 m^3/s. From December to March, when sections of the canal are drained, the flow is reportedly reduced to approximately 5 cfs, or 0.142 m^3/s. Based on discussions with the St. Lawrence Seaway Authority, any information regarding the installation, maintenance, and calibration of the pump has been misplaced.

2.1.2 Local Runoff

Runoff from the contributing catchments East of the Welland Canal is generally from agricultural fields and wooded areas. There are some light residential areas throughout the catchment area as well as industrial facilities along Ridge Road. The majority of the catchment area used for industrial purposes drains to a water management pond. These ponds are located on the south side of Ridge Road at its west end. These ponds do not discharge to Lyons Creek under regular conditions.

2.1.3 Outflow

The outflow from the Lyons Creek East study area is at a culvert under Highway 140. Outflow is conveyed by the culvert as described in the following section.

2.1.3.1 Outflow Structure

The outflow structure for the Lyons Creek East study area is located at the Highway 140 crossing. Outflow is moderated by an elevation control point approximately 5 m upstream of the Highway 140 crossing. The elevation control point is an armoured section of the creek that represents the water surface elevation at which no flow occurs. The culvert is a corrugated pipe arch (CPA). The width of the culvert is approximately 3 m with a height of approximately 2.2 m. The culvert conveys flow east under Highway 140 where the creek continues to flow in a north-easterly direction.

A photograph of the outlet culvert under Highway 140 can be found in Appendix A.

Cross-sectional and bathymetry surveys were conducted throughout the study reach. The stream geometry data were used to evaluate hydraulic features and controls including the position of the outflow culvert under Highway 140.

2.1.4 Results and Analysis

Results from the flow monitoring are shown in Table 1 below. Flows measured at the inlet (downstream of the pump discharge from the Welland Canal) were within a narrow range of 0.181 m^3/s to 0.211 m^3/s, while flows at the outlet culvert under Highway 140 were measured from 0.205 m^3/s to 0.543 m^3/s. The small tributaries to the main creek showed only intermittent flows.

Table 1: Measured Flow Rates

Date	Inlet[1] (m³/s)	SW2 (m³/s)	SC[2] (m³/s)	SW3 (m³/s)	SW4 (m³/s)	SW5 (m³/s)	Outlet (m³/s)	Water Elevation[6] (m)
October 15, 2009	--[5]	0.00040	--[5]	0.00037	0.00017	0.0[3]	--[5]	--[5]
March 30, 2010	~0.181[7]	0.0021	0.00014	0.0035	0.0019	0.016	0.205	173.830
July 9, 2010	~0.211[7]	0.0[3]	0.0[3]	0.0[3]	0.0[4]	0.0[3]	0.211	--[5]
December 2, 2010	0.184	--[5]	--[5]	--[5]	--[5]	--[5]	0.543	174.047

Notes

1. *Measured at bridge.*
2. *Unnamed station added in March 2009, located Between SW2 and SW3*
3. *Standing water or non-detectable flow.*
4. *Dry.*
5. *Not measured.*
6. *Measured at outlet.*
7. *Estimated*

According to the Environment Canada meteorological (ID# 6139445) station at Welland, July 9 2010 saw 41 mm of rainfall; however flows at the tributaries were not observed during the field visit. According to the field notes, the field visit took place between local 10:00 AM and 12:30 PM, while a review of historic Environment Canada radar images from King City suggests that most of the rainfall that day occurred after local noon. Thus, it is assumed that the peak flow event from that day was not captured.

The peak instantaneous flow measurement taken in Lyons Creek East immediately downstream of the pump discharge from the canal indicated a flow rate of 0.211 m^3/s (July 9, 2010); this is approximately 75% of the reported shipping season pumping rate in section 2.1.1. The reduction in the flow rate may be the result of one or a combination of several factors, including:

- A replacement of the original pump,
- The original pump is still operating but was never designed to provide the recommended flow, or
- Wear of the pump impellor has gradually decreased the pumping rate over time.

2.1.4.1 Rating Curve

A rating curve that relates water surface elevation to flow rate was developed for Lyons Creek East at the culvert crossing under Highway 140 and includes an invert control point upstream of the culvert inlet. This rating curve was developed to provide a smooth transition of flows between various water levels in the River2D Model (see Section 3.2). The one-dimensional model, HEC-RAS, was used to model the outlet portion of Lyons Creek East for a range of flow rates. The model was based on surveyed outlet geometry. Roughness coefficients for the creek bed were estimated from literature values and calibrated to measured flow and water level data.

The water surface elevations evaluated in the rating curve correspond to the ponded water surface upstream of the confined rip-rap lined channel, located directly upstream of the outlet culvert. Model calibration was completed using measured flow rates taken at the upstream end of the culvert on March 30 and December 2, 2010. These were the only two dates where both flow and water level were recorded at the outflow.

The calibrated model was run for a range of flow rates that bound the measured flow rate of approximately 0.205 m^3/s and 0.543 m^3/s as well as the peak flows expected from extreme rainfall events (Section 2.4). The surface water elevations at the control point (approximately 5 m upstream of the culvert) were extracted from the HEC-RAS model as a rating curve (as shown on Figure 4). The rating curve was described in River2D as a look-up table. As a result, Figure 4 does not show an equation for the rating curve.

It should be reiterated that the primary source of Lyons Creek East is pumped water from the Welland Canal. The flow rate will remain relatively constant due to the pumped source with fluctuations due to runoff from rainfall events and spring melt.

2.2 Suspended Sediment Inputs

Water quality samples were collected from the Lyons Creek study reach and its corresponding tributary channels. The water quality samples were analyzed for total suspended solids and suspended grain size. Water quality samples were collected from the input streams to the study reach, the canal and the reach outlet. Water quality samples were collected at input streams following storm events in order to evaluate suspended solids contributions from storm runoff. Water quality samples were collected in the canal as ships passed by the Lyons Creek pump intake to determine suspended solids contributions from the canal. Water quality samples were also collected at the reach outlet to determine the total suspended solids discharging from the study reach of the creek.

2.2.1 Runoff Suspended Sediment

Water quality samples were collected on three events (December 10, 2009, March 30, and July 9, 2010). These sampling events followed a storm event which occurred within 48 hours of sampling. Water samples were collected from the streams contributing flow to the study reach. Water quality samples were also collected at the reach inlet (inlet pond where pump house discharges) and outlet (upstream of the culvert crossing Highway #140).

Water quality samples were collected at five inflow streams (collected only under flow conditions). An additional runoff channel was sampled on March 30, 2010. Sampling stations SW1 and SW2 are located on the north side of Lyons Creek at the crossing of the trail which generally follows the north shore of the creek. Sampling station SW3 is located at the discharge of the runoff pond on the north side of the creek. Sampling stations SW4 and SW5 are located along the road crossing on Ridge Road to the south of Lyons Creek as shown on Figure 3.

2.2.1.1 Measured Results and Data Analysis

Water quality samples collected at the above stations were analyzed for total suspended solids (TSS) and suspended grain size analysis. The TSS results vary with station and magnitude of runoff. The stations SW1, SW3 and SW5 generally recorded higher TSS than the other stations sampled. The greater the discharge rates of runoff the greater the TSS levels carried by the streams. The most substantial flow rates and TSS concentrations in the stream were observed during the December 10, 2009 sampling event (27.5 mm of rainfall in the 48 hours prior to sampling).

During the March 30, 2010 sampling round minor discharge rates from the input streams (9.9 mm of rainfall in the 48 hours prior to sampling) were observed. The input stream at SW1 was found to be dry during this sampling period. However an additional station labelled "SC" located between SW2 and SW3, which was carrying overland flow was sampled. The TSS levels during this sampling round were found to be significantly less than those measured on December 10, 2009.

The sampling conducted on July 9, 2010 showed very low to zero discharge rates from the input streams, despite significant rainfall on the sampling date (41 mm of rainfall on July 9, 2010). As mentioned above, this is likely due to sampling occurring before the majority of rainfall that day.

The TSS values from the input streams can be found in Table 2.

Table 2: Total Suspended Solids in Input Streams

Station	Units	Sampling Date		
		December 10, 2009	**March 30, 2010**	**July 9, 2010**
Rainfall (48 hr)[1]	mm	27.5	9.9	41.0
IN	mg/L	<10	<10	<10
SW1	mg/L	296	Dry	Dry
SW2	mg/L	60	25	Dry
SC	mg/L	--	8	Dry
SW3	mg/L	55	6	Dry
SW4	mg/L	26	<10	Dry
SW5	mg/L	95	15	Stagnant
OUT	mg/L	24	10	<10

Notes

1. *Measured at Welland.*

The suspended solids grain size analysis was conducted on approximately half of the samples in Table 2. The results from the suspended solids grain size analysis are consistent with all samples collected at different stations and on different dates. The analysis results report the majority of suspended solids are fine grained and within the grain size of 11 µm to 1 µm. All samples reported 80% to 95% of suspended solids at all stations within this grain size range.

Laboratory results for TSS and suspended solid grain size analysis can be found in Appendix B.

2.2.2 Welland Canal

During the site inspection visit on September 3, 2009, it was observed that passing ships in the Welland Canal (Photograph #8 in Appendix A) created a noticeable amount of suspended sediment in their wake. Since the upstream flow for Lyons

Creek is pumped from the canal, it was appropriate to determine the potential sediment load from the Welland Canal to Lyons Creek.

2.2.2.1 Methodology

Suspended sediment data were collected in the Welland Canal at the pumphouse to Lyons Creek. Two types of data were collected;

- Continuous turbidity above the intake using a YSI metre (See Photograph #9 in Appendix A) to provide a continuous record of turbidity in the canal (1 to 3 second interval). The measurements were initiated as each ship approached the monitoring location and were continued for approximately 20 minutes (until the visible turbidity plume from the passing ship had dissipated), and
- Water samples were collected for suspended sediment and particle size analysis. The suspended sediment measurements were used to develop a relationship between the measured turbidity and suspended sediment.

2.2.2.2 Results and Analysis

Data regarding suspended sediment events from passing ships were collected on two dates (November 5, 2009 and July 22, 2010) and successfully obtained data for three passing ships. The analysis of the data was undertaken in the following steps;

- Develop a relationship between turbidity reading and measured suspended sediment concentration,
- Estimate the sediment loads to Lyons Creek for each passing ship, and
- Estimate the annual sediment load to Lyons Creek from ship traffic and background suspended sediment concentrations.

The relationships between turbidity and suspended sediment concentration are shown on Figure 5. The data showed that the relationship between turbidity and suspended sediment was different on each of the two days. The difference between the two relationships could be the result of many factors such as seasonal effects, size of passing ship and proximity of the passing ship to the monitoring location. For the subsequent analysis, the turbidity measurements were converted to a suspended sediment concentration using the relationship for the appropriate date.

The estimated suspended sediment concentrations for each of the passing ships are shown on Figure 6. The figure shows that the turbidity plumes measured in Nephelometric Turbidity Units (NTU) from the passing ships dissipated to background conditions within 20 minutes. The figure also shows than the background suspended sediment concentration was approximately 8 mg/L. Particle size analysis of the samples indicated that the suspended sediment in the Welland Canal is silt and clay sized (See Appendix C).

The sediment load to Lyons Creek for each passing ship was estimated by taking the area under the lines shown on Figure 6 (after the background concentrations were subtracted) and multiplying by the pumping rate to Lyons Creek. The flow rate measured at the inlet (Table 1) was assumed to be representative of the pumping rate. The resulting sediment loads to Lyons Creek for passing ships ranged from 1.1 to 2.2 kg with an average of 1.7 kg.

2.2.2.3 Estimated Sediment Load From Welland Canal

The annual estimated sediment load to Lyons Creek East from the Welland Canal was estimated for passing ships and background conditions.

Based on annual shipping traffic through the canal, the average total annual sediment load was estimated to be 5.9 tonnes. This estimate is based on ship traffic data from 2004 through 2009 and is summarized on Table 3.

Table 3: Annual Ship Traffic in Welland Canal

Year	Number of Canal Transits (Ships)[1]	Annual Sediment Load to Lyons Creek (tonnes)[2,3,4]
2004	3185	5.6
2005	3443	6.0
2006	3573	6.2
2007	~3670	6.4
2008	~3530	6.2
2009	2806	4.9
Average	**3368**	**5.9**

Notes

1. *Shipping traffic and season data obtained from St. Lawrence Seaway Annual Reports.*
2. *Annual sediment loads assume pumping rate of 0.183 m³/s (6.5 cfs).*
3. *Loads are above the background TSS concentration of 8 mg/L.*
4. *Assumes an average sediment load to Lyons Creek of 1.7 kg per ship.*

The background suspended sediment load to Lyons Creek East from the Welland Canal was estimated based on the background concentration of 8 mg/L and the measured pumping rate of 0.183 m³/s (6.5 cfs) during the shipping season (April through December). During the winter, the assumed pumping rate was reduced to 0.093 m³/s (3.3 cfs) based on information provided by NPCA (see Section 2.1.1). Table 4 provides a summary of the estimated background sediment loads.

Table 4: Estimated Background Sediment Load from Welland Canal

Period	Flow at Pumphouse	Duration (days)	Annual Sediment Load to Lyons Creek (tonnes)[3]
Winter	0.093 m³/s (3.3 cfs)[1]	90	5.8
Shipping (Summer)	0.184 m³/s (6.5 cfs)[2]	275	35.2
Annual	**0.162 m³/s (5.7 cfs)**	**365**	**40.9**

Notes

1. *Winter pumping rate assumed to be half the summer rate (Acres 1970).*
2. *Flow measured at inlet on December 2, 2010.*
3. *Sediment load assumes background suspended*

In total, the average annual sediment load to Lyons Creek East from the Welland Canal is expected to be approximately 46.8 tonnes. Of this total, 87% is the result of background suspended sediment and only 13% is attributed to re-suspension of sediments in the Welland Canal due to passing ships.

2.3 Lyons Creek Sediment Data

The Lyons Creek East study reach was analyzed to determine the sediment properties. Sediment was evaluated using sediment traps installed throughout the study reach and an in-situ flume which was operated at a number of different locations throughout the reach.

2.3.1 Sediment Traps

The sediment traps are designed to collect sediment that accumulates on the channel bed of the study reach. The sediment trap consist of a glass jar, which is set in to the bed sediment in a square steel rim, which prevents the trap from sinking into the sediment (Photograph #6, Appendix A). The sediment traps were installed at eight different cross sections within the study reach, on both of the banks (approximately 1 to 5 m from shore).

Sediment traps were originally installed on November 25, 2009 and were retrieved on March 31, 2010. Only two samples were successfully collected on March 31, 2010 because the majority of the sediment traps were broken due to freezing over the winter period. All of the sediment traps were re-installed on March 31, 2010. An attempt was made to retrieve the sediment traps on August 17, 2010; however due to heavy vegetation throughout the study reach only the sediment traps at cross section six were retrieved. These sediment traps were not re-installed. The majority of the remaining sediment traps were retrieved on November 24, 2010. The complete record of sediment trap sampling periods can be found in Table 5.

Table 5: Sediment Trap Sampling Periods

Station	Unconsolidated Sediment Collected (cm)[1]	
	Nov 25, 2009 to Mar 31, 2010	Mar 31, 2010 to Nov 24, 2010
XS6 LB	na[2]	nm[4]
XS6 RB	na[2]	nm[4]
XS7 LB	na[2]	10
XS7 RB	na[2]	8
XS9 LB	na[2]	27
XS9 RB	na[2]	19
XS12 LB	na[2]	na[2]
XS12 RB	na[2]	6
XS14 LB	na[2]	na[2]
XS14 RB	na[2]	24
XS16 LB	na[2]	19
XS16 RB	na[2]	31
XS17 LB	na[2]	29
XS17 RB	21	21
OUT LB	4	na[2]
OUT RB	na[2]	31
Duration – Days	126	238
Average - Accumulated	12.5	20.5
Accumulation Rate (mm/day)	0.99	0.86
Accumulation Rate (cm/year)	36.2	31.4

Notes

1. *Accumulated amount unconsolidated sediment adjusted for jar opening width.*
2. *Not available – collection jar broken.*
3. *Collection jar could not be located.*
4. *Not measured.*

2.3.1.1 Sediment Accumulation Rates

The majority of the sediment trap collected sediment over the period from March 31, 2010 to November 24, 2010 (238 days). This period collected sediment from the majority of the year under non-freezing conditions. The average depth of unconsolidated sediment that accumulated over the study reach based on the retrieved sediment traps under non-freezing conditions was approximately 21 cm (0.9 mm per day). This rate suggests an annual deposition rate of approximately 31 cm per year

The sediment accumulation data collected over the period from (November 25, 2009 to March 31, 2010 (126 days) was considered representative of freezing conditions. The average depth of unconsolidated sediment that accumulated this period was approximately 13 cm (0.1 mm per day). This rate suggests an annual deposition rate of approximately 36 cm per year; however, the data collected during the freezing period were not considered reliable since only 2 of the 16 sample jars were retrieved.

The sediment that was collected in the sediment traps had a high void ratio and was very lightly consolidated. Due to the design of the sediment traps once the sediment is collected in the trap there is little opportunity for re-suspension. The sediment on the channel bed has a greater opportunity to be re-suspended and move downstream. For this reason the accumulation rates from the sediment traps may be greater than that of the channel bed. However based on the River2D modelling exercise (see Section 4.2) it is unlikely that there will be any significant sediment re-suspension in any of the events except for the extreme events.

2.3.1.2 Particle Size Distribution

A particle size distribution analysis was conducted on seven samples from the sediment traps. The diameter (D_{50}) of all the sediment samples analyzed was found to average approximately 0.01 mm, with diameters (D_{50}) ranging from approximately 0.008 to 0.017 mm. The majority of the sediment collected in the traps was found to be within silt and clay size.

Laboratory results of this analysis can be found in Appendix D.

2.3.1.3 Volatile Organic Compound Analysis

Volatile organic compound (VOC) analysis was conducted on sediment samples collected from cross section seven, nine and seventeen. These three samples were selected in order to generate an average distribution of the study reach and to screen for any potential new contaminants. All samples reported below detection limit for all parameters measured, with the exception of one parameter at one location. The sample collected from the left bank of cross section nine (XS9 on Figure 3) reported a Toluene value of 0.5 µg/g (the detection limit for this analysis was 0.1 µg/g). Laboratory results can be found in Appendix D.

Since there were no new contaminants identified, the VOC data were not used in any subsequent analysis.

2.3.2 Critical Shear Velocity

To identify the point at which the channel sediment will erode, the critical shear velocity of the in-situ sediments was measured. The critical shear velocity is a measure of steepness of the velocity profile at which the channel sediment initiates erosion. The level of resistance sediment has to erosion is dependent on a series of sediment characteristics. The critical shear velocity changes with sediment grain size, orientation, consolidation and cohesiveness.

Grain size affects sediment erosion because the larger the particles the more energy required to transport them. When grain size is the only characteristic considered, the larger sediments have a greater erosion resistance than that of sand or silt. In addition, the cohesive nature of very fine sediments can help to resist erosion. Although sediment grain size affects erosion it needs to be considered with other characteristics.

The orientation of a sediment particle can also affect the resistance it has to erosion. This can affect sediment particles which have non spherical shapes. In the case of clays the particles are typically long and flat and they usually are aligned horizontally in consolidated clays. When the particles are aligned this way the surface is relatively smooth. However if the orientation is disturbed the particles can create a rougher surface and the particles can act like sails in the current, increasing the erosion vulnerability.

Sediments that have been consolidated have a greater resistance to erosion than unconsolidated sediments of the same material. This is because as sediment is consolidated, void spaces within the sediment are reduced. Consolidated sediment has less interconnected water pathways through the material which can erode as the water flows through it. Also as the material gets consolidated the more the sediment particles interact with each other and it is the particle interaction that is responsible for the cohesiveness of the sediment. Consolidation and cohesiveness are characteristics that are usually attributed to sediment with silt or clay. Sediments can become consolidated through stratification, when sediments are consolidated due to the weight of layers of sediment on top of them. For this reason sediments in sub-surface layers usually have greater erosion resistance than surface layers.

Critical shear velocities can be determined in laboratories following collection and transportation of samples. The properties of the sediment discussed above can be altered through sample collection, transportation or laboratory set-up. For these reasons an in-situ sediment flume was selected to evaluate the sediment.

2.3.2.1 Methodology - In-Situ Measurement

In order to estimate the critical shear velocity within the study reach the channel bed sediment needed to be evaluated. An in-situ flume design was developed to evaluate the sediment. The flume utilizes a velocity enhancer that is operated through a range of current velocities by a rheostatic control. Corresponding sediment re-suspension/mobilization was assessed through visual observations, turbidity measurements and water quality samples collected (subsequently analyzed for Total Suspended Solids and suspended solids grain size distribution). A detailed experimental methodology, results and photographs are included in Appendix E.

Channel sediment was evaluated, at eleven different locations within the reach, using the flume. The results and data summary for the flume experiments can be found in Section 2.3.2.2 and 2.3.2.4.

2.3.2.2 In-Situ Flume Results

The in-situ flume experiments were conducted at eleven different locations; however only nine of them successfully eroded the channel sediment. The locations that did not experience sediment erosion could not evaluated for critical shear velocities since critical shear velocity was greater than the maximum applied shear velocity (locations three and nine did not suspend sediment). A plot of measured velocities from the successful flume experiments are shown on Figure 7.

The critical shear velocities for the above experiment locations were estimated using the line of best fit to the data found on Figure 7. Calculations used to estimate critical shear velocities can be found in Appendix E. The values of critical shear velocities and critical shear stresses obtained from these data are summarized in Table 6.

The critical shear velocities (T_c) estimated at the above locations range from 0.009 m/s to 0.107 m/s. The average critical shear velocity from the above estimated values within the study reach is 0.058 m/s. The critical shear stresses estimated in Table 6 range from 0.07 N/m^2 to 11.55 N/m^2, with an average of 4.3 N/m^2.

Table 6: Critical Shear Velocities and Stresses from Flume Experiments

Location[1]	Measurement Location from Upstream Boundary (m)	Critical Shear Velocity u^* (m/s)	Critical Shear Stress, T_c (N/m^2)
1	1,346	0.071	5.10
2	1,239	0.032	1.02
11	1,028	0.009	0.07
4	922	0.107	11.6
10	812	0.046	2.16
5	620	0.060	3.64
6	530	0.050	2.52
7	311	0.044	1.97
8	201	0.104	10.9

Notes

1. *Flume measurement locations shown on Figure 3.*

2.3.2.3 Literature Values

Critical shear velocities from literary sources are largely based on empirical laboratory data and were compared to the values developed with the in-situ flume. The sediment evaluated within the study reach is not completely represented in much of the literature; however specific characteristics of the reach sediment have been evaluated within the literature. The data in Table 7 present sediment grain sizes and their corresponding typical parameter values. Based on the grain size analysis conducted on the channel sediment suspended by the flume the median grain size is approximately 0.02 mm in diameter (D_{50}). The critical shear velocity (u^*) for this grain size listed in Table 7, is 0.0080 m/s. The minimum and average critical shear velocity estimated from the flume calculations was found to be 0.009 m/s and 0.058 m/s, respectfully. The differences between the values from Table 7 and those from the flume study can be attributed to differences in data collection and handling. Empirical laboratory data to determine critical shear velocity typically report values more conservatively than those of in-situ data estimates; however, the estimates determined from the in-situ flume experiments generally compare well to that of the values from the literature below.

Table 7: Threshold Conditions for Uniform Material at 20 °C (Julien, 2010)

Class name	Median Grain Size d_{50} (mm)	Dimensionless Particle Diameter d_*	Angle of Repose Φ (deg)	Critical Shear Stress T_c (N/m²)	Critical Shear Velocity u^*_c (m/s)
Boulder					
Very Large	> 2,048	51,800	42	1790	1.33
Large	> 1,024	25,900	42	895	0.94
Medium	> 512	12,950	42	447	0.67
Small	> 256	6,475	42	223	0.47
Cobble					
Large	> 128	3,235	42	111	0.33
Small	> 64	1,620	41	53	0.23
Gravel					
Very coarse	> 32	810	40	26	0.16
Coarse	> 16	404	38	12	0.11
Medium	> 8	202	36	5.7	0.074
Fine	> 4	101	35	2.71	0.052
Very Fine	> 2	50	33	1.26	0.036
Sand					
Very coarse	> 1	25	32	0.47	0.0216
Coarse	> 0.5	12.5	31	0.27	0.0164
Medium	> 0.25	6.3	30	0.194	0.0139
Fine	> 0.125	3.2	30	0.145	0.0120
Very Fine	> 0.0625	1.6	30	0.11	0.0105
Silt					
Coarse	> 0.031	0.8	30	0.083	0.0091
Medium	> 0.016	0.4	30	0.065	0.0080

The greater the clay content in the sediment the more it resists erosion, as shown by the thick black line on Figure 8. However as clay content increases the greater the effect void ratio has on the critical shear velocity. The void ratio in most clay is an indication of cohesiveness of the sediment and more cohesive material has a higher critical shear velocity. Although the sediment in the study reach has a significant clay content, the upper layers of sediment have little cohesiveness and a high estimated void ratio of 4.6 (as observed in sediment traps) and therefore the clay content does little to increase critical shear velocity at the surface.

The empirical laboratory data presented on Figure 8 show depth averaged velocities and not shear velocities. For this reason it is estimated that the velocities are approximately 40% higher than that of the critical shear velocities (Graf, 1984). This correction between the critical depth averaged velocity and critical shear velocity is based on assumption of a log velocity profile through the flow field. Using the values in Figure 8 and the study data the estimated grain size can be directly compared. The data in Figure 8 present a range of velocities between erosion and sedimentation, labelled transportation. This transportation area represents a range of velocities in which sediments may or may not erode or deposit, depending on flow conditions and sediment characteristics. The average velocities in Figure 8 are greater than those critical shear velocities estimated in the study. The estimated velocities of the study fall in the higher level of the transportation region of Figure 8. Although the study estimated velocities are not in the erosion range of the figure under the specific conditions of the study they do represent the critical shear velocities. This difference between observed in-situ experiment results and the literature values is likely attributed to the observed high void ratio of the in-situ surficial sediments. Despite the differences between the study results and values found in Figure 8, the study estimated velocities are in the high level of the transportation range and the two provide a useful comparison.

After comparing the critical shear velocity estimates from the in-situ study to the literature values discussed above it can be seen that the in-situ estimates are consistent with those from the literature and greater than some estimated empirical data (Lane, 1955). This supports the understanding that laboratory estimates of critical shear velocity can be conservatively high.

3.0 MODELLING

The Lyons Creek East Sediment Transport Study used two modelling packages:

- SEDCAD was used to model runoff flows and sediment delivery into Lyons Creek and,
- River2D was used to predict the shear velocity within Lyons Creek for various observed and modelled extreme flow events.

3.1 Hydrology and Sediment Model - SEDCAD

In order to better estimate runoff flows and sediment erosion and delivery (wash-off) from the areas surrounding Lyons Creek, a hydrologic model for the system was developed using the SEDCAD software package. This software allows users to estimate flows and sediment loads from sub-catchment networks for rainfall events up to twenty four hours in length. Runoff flows are estimated using Soil Conservation Service (SCS) hydrology methods, while sediment loads are based on a combination of calculated flows, rainfall characteristics, vegetation and land use, topography, and soil characteristics. The model was used to estimate sediment loads contributed from the catchments over an average year (based on a number of large storm events), as well as flows and sediment loads during return period storm events.

3.1.1 Description of SEDCAD

SEDCAD is a comprehensive hydrology and sedimentology package, useful for runoff and sediment control design calculations. Initially released in 1987, SEDCAD (Sediment, Erosion, Discharge by Computer Aided Design) is a comprehensive program that includes hydrology, hydraulics, and design and evaluation of erosion and sediment control measures. The current Version 4 has been upgraded by incorporating applied research from universities and government research facilities, feedback from users, and advances in operating systems, CAD software and computer capabilities.

SEDCAD uses the SCS Curve Number (CN) method for hydrology calculations, while most of the sediment control procedures have been developed based on extensive applied research conducted at the University of Kentucky. Verification studies for sediment ponds, silt fences and check dams have been completed both under controlled laboratory and field conditions, encompassing measurement of inflow and effluent stormwater, sediment concentrations, and particle size distributions.

3.1.2 Model Setup and Configuration

The SEDCAD model was constructed using the subcatchments areas from previous studies (NPCA, 2011). Small sub-catchments that drained into Lyons Creek by the same outlet were lumped together into larger subcatchments. In total all the subcatchments west of Highway 140 were grouped into 18 larger catchments (Figure 9). Parameters including drainage areas, drainage lengths, average slopes, imperviousness, and soil types were entered into the model. Additionally, the grain size distributions from the field work were also entered, as were estimates for erosion factors in each catchment. A full accounting of hydrologic and sediment parameters used in the model can be found in Table 8.

Table 8: SEDCAD Model Parameters

Catchment ID	Drainage Length (m)	Drainage Area (ha)	Curve Number	Time of Concentration[1] (hrs)	Erosion Slope Length (ft)	Erosion Slope (%)	Erosion C-Factor[2]
1	200	2.1	86	0.11	100	9	0.05
2	900	12.4	86	0.44	305	8	0.05
3	140	1.2	86	0.09	70	6	0.05
4	100	0.4	91	0.09	50	3	0.05
5	400	5.5	86	0.22	122	7	0.05
6	470	12.7	86	0.24	235	7	0.05
7	270	3.7	85	0.15	135	7	0.05
8	1200	29.5	83	0.69	122	2	0.03
9	400	48.6	75	0.60	122	3	0.02
10	670	34.9	84	0.31	305	7	0.05
11	250	14.5	73	0.42	122	4	0.02
12	1140	28.7	87	0.66	122	2	0.05
13	70	1.6	85	0.24	35	3	0.01
14	140	1.4	80	0.09	70	5	0.03
15	340	4.7	60	0.52	122	6	0.01
16	70	0.1	92	0.05	35	15	0.05
17	270	2.8	89	0.19	122	3	0.05
18	400	12.1	85	0.22	122	4	0.04

Notes
1. *Calculated based on formulas recommended in the MTO Drainage Manual (MTO, 1997).*
2. *Recommended values in SEDCAD Users Manual (Warner and Schwab, 2008).*

3.1.3 Grain Size Distribution

The grain size distribution, taken from the in-stream sediment traps on March 31, 2010 was used, by the SEDCAD model, to estimate settling rates and sediment trapping efficiencies in Lyon's Creek. The grain size distribution used in the model is shown in Table 9 below, and detailed results are found in Appendix D.

Table 9: Grain Size Distribution at XS7RB (March 31, 2010)

Grain Size (mm)	% Passing
10	100
5	100
2	100
1	100
0.5	95
0.2	88
0.1	85
0.05	70
0.02	54
0.01	35
0.005	22
0.002	13
0.001	10

3.1.4 Annual Inputs

The SEDCAD model was also used to estimate the average annual sediment delivery to the Lyons Creek system as a result of rainfall / erosion.

Literature suggests that the majority of soil erosion occurs during large storm events (Edwards and Owens, 1991). In order to estimate the annual sediment yield, the large storms from the available data were run in SEDCAD. This is assumed to represent a conservatively low estimate of sediment delivery to Lyons Creek, since it does not include all possible erosion events in a given year.

The selection of the meteorological station used in this study was based on the proximity of the station to the study area as well as the availability of continuous data. As a result, the hourly precipitation data from November 2005 to July 2010 at Welland-Pellham station were obtained from Environment Canada Climate Services, and the 24-hour rainfall depths were estimated. The partial years (2005 and 2010) were eliminated, as was 2006, which had a data gap between May and October. The 2007 year, which has no data from September 19 to November 19 (a total of 61 days), was still included to provide a minimum of the three years of data. The 24-hour events with the top 5% of rainfall depths for the remaining 2007, 2008, and 2009 data were then selected. Details of these events are shown below in Table 10 Runoff and sediment loading to Lyons Creek during these events was then simulated using SEDCAD.

Table 10: Selected Rainfall Events

Year	Date	Rainfall Depth (mm)
2007	January 5, 2007	21.9
	July 18, 2007	26.8
	July 19, 2007	25.1
	September 8, 2007	27.3
	November 21, 2007	45.6
2008	February 5, 2008	22.2
	March 4, 2008	26.8
	April 11, 2008	20.0
	July 19, 2008	22.7
	August 12, 2008	25.8
	September 5, 2008	34.3
	September 13, 2008	23.3
	October 15, 2008	23.5
	December 9, 2008	20.2
	December 26, 2008	22.0
2009	February 11, 2009	29.8
	March 7, 2009	37.7
	March 10, 2009	22.4
	April 3, 2009	36.4
	April 19, 2009	25.2
	June 17, 2009	43.7
	July 1, 2009	34.5
	July 22, 2009	22.6
	August 8, 2009	40.7
	September 28, 2009	25.8
	November 30, 2009	22.1
	December 9, 2009	28.8

The SEDCAD results for the aforementioned top 5% of 24-hour rainfall events are shown in Table 11. In the table, the peak outflow is the peak flow at the Highway 140 culvert of all the events in the given year, 'Sediment In' is the sum of all modelled sediment loads being delivered to the creek from the large rainfall events in the given year and does not include the sediment input from the Welland Canal due to pumping, 'Sediment Out' is the sum of all modelled sediment loads leaving the system through the Highway 140 culvert for all of the large events in that year, and 'Sediment Stored' is the net sum of all modelled sediment loads stored for the large events in that year. The removal efficiency of the system ('Sediment Stored' divided by 'Sediment In', shown as a percentage) is also included to show the effect of the creek storage volume and retention time in the model.

Table 11: Estimated Annual Sediment Load from Runoff

Year	Number of Storms	Peak Flow (m^3/s)	Total Sediment In[1](Tonnes)	Total Sediment Out (Tonnes)	Total Sediment Stored (Tonnes)	Sediment Deposition Rate (mm)	Removal Efficiency (%)
2007	5	0.276	191.2	27.8	163.4	6.8	85%
2008	10	0.159	199.8	21.2	178.6	7.4	89%
2009	12	0.339	539.4	77.2	462.2	19.1	86%
Average	**-**	**-**	**310.1**	**42.1**	**268.1**	**11.1**	**87%**

Notes

1. *Does not include the sediment contributions from Welland Canal discussed in Section 2.2.2.3.*
2. *Sediment deposition rate assumes that the sediment density is 1,000 kg/m³ (Julien, 2010) and the sediment is evenly distributed over the entire study area (2.42 ha).*

Generally, the storms simulated for 2007 and 2008 produce similar results in terms of sediment delivery. By contrast, the large storms in 2009 generated more than twice the mass of sediment of either of the single previous years. This is likely the result of the increased precipitation during the summer (Jun-Jul-Aug) 2009, which saw more precipitation (352 mm) in those months compared to previous years (108 mm and 237 mm for 2007 and 2008, respectively). Higher precipitation during these months is thought to have contributed directly to the greater number of high intensity thunderstorm events, which in turn generated greater sediment load to the creek.

The average sediment stored in the creek was assumed to be equivalent to the amount of sediment deposited in the creek annually. Assuming deposition occurs over the creek area of 2.42 ha and the density of deposited sediment is 1,000 kg/m^3 (Julien, 2010), the annual rate of sediment deposition was estimated to range from 6.8 to 19.1 mm per year with an average rate of approximately 11 mm per year.

3.1.5 Model Calibration and Verification

Because of the lack of continuous flow and TSS monitoring data in Lyons Creek during runoff events, the model cannot be calibrated for individual storm events. However, using the estimated depth of 'clean' sediment overtop of the sediment with elevated levels of PCB (20 cm to 30 cm of 'clean' sediment, from Section 1.1) and an estimate of the historic timeframe of higher PCB delivery to the system (prior to the construction of the new Welland Canal (by-pass) roughly 40 years ago), the historic rate of sediment deposition in the creek can be estimated at 5 mm to 7.5 mm per year. This estimate is less than the 11 mm per year deposition rate from the SEDCAD results, indicating the model may be generating slightly (3.5 mm/yr to 6 mm/yr) higher average rate of deposition than is actually occurring. The differences may also be attributed to variations in annual sediment loads or consolidation of sediment over time.

3.1.6 Peak Storm Inputs

In order to evaluate the model under high flow conditions, runoff and sediment response to extreme rainfall events were modelled in SEDCAD. These storm events represent a range of rainfall depths and durations (12 and 24-hours). The flow responses from the model were used to evaluate erosion potential in the River 2D model (described in section 3.2), while sediment modelling was used to estimate deposition rates from individual storms.

Extreme flow events, modelled using SEDCAD, were as follows (in order of increasing rainfall depth):

- The 2-yr, 5-yr, 10-yr, 25-yr, 50-yr, and 100-yr return period storms (based on the City of Welland IDF standards and a 24-hr duration SCS storm),
- Hurricane Hazel (the local regional storm event, reflecting the last 12-hours of the recorded storm and AMC III or 'saturated' antecedent soil moisture conditions), and
- Two Probable Maximum Precipitation (PMP) 12-hour storms (reflecting the theoretical limit for intense rainfall resulting from both a tropical storm and a thunderstorm event (Bruce, 1961).

In general, the increasing rainfall depth (mm) through this storm list is mirrored by increasing peak rainfall intensity (mm/hour).

The results of the extreme storm runs from the SEDCAD model are shown in Table 12 below. The table shows rainfall for the entire duration of each rain event, the peak outflow at the Highway 140 culvert, the total sediment being delivered to the Lyons Creek study reach from the land surfaces ('Sediment In') the total sediment leaving the system through the Highway 140 culvert ('Sediment Out') and the total sediment stored in the system ('Sediment Stored'). Generally, the flows and sediment delivery rates show an expected increasing trend which follows the increase in rainfall and rainfall intensity. The removal efficiency of the system ('Sediment Stored' divided by 'Sediment In', shown as a percentage) is also included to show the effect of the creek storage volume in the model.

Table 12: Sediment and Runoff Estimates for Extreme Storms

Event	Rainfall (mm)	Peak Outflow (m^3/s)	Sediment In (Tonnes)	Sediment Out (Tonnes)	Sediment Stored (Tonnes)	Removal Efficiency (%)
2-yr	58	0.4	237	50	187	79%
5-yr	70	0.6	335	73	262	78%
10-yr	80	0.7	432	98	334	77%
25-yr	96	1.6	576	148	428	74%
50-yr	109	2.4	723	197	526	73%
100-yr	120	2.9	845	238	607	72%
Hurricane Hazel	211	9.1	1,266	343	922	73%
PMP (Tropical Storm)	330	12.6	2,738	838	1,900	69%
PMP (Thunderstorm)	420	14.6	3,587	1,149	2,437	68%

Generally, the flows and sediment delivery rates show an expected increasing trend for larger storm events. This is the result of the larger rainfall depths increasing flows in the creek, and the higher overland flow rates in the model carrying more sediment to the creek. By comparison, the removal efficiencies decrease with increasing rainfall depths. This decrease is the result of higher flows and lower retention times within the creek, which prevent some of the smaller particles from settling to the bottom of the creek.

The modelled mass of sediment in storage is significant compared to the expected rate of sediment accumulation. Using the existing surface area of the creek (2.42 ha) and an assumed density of deposited sediment (1000 kg/m^3, Julien 2010), the resulting deposition rate in the creek is roughly 4.2 mm of sediment for every 100 tonnes of sediment stored. This ratio results in large storm depositions ranging from 7.8 mm (2-yr storm) to 38.4.0 mm (Hurricane Hazel) and as high as 101.5 mm (thunderstorm PMP).

As mentioned in previous sections, the SEDCAD model does not model re-suspension of sediments; this may lead to an overestimation of the final mass of sediment in storage, particularly in high-flow events. Occurrence of erosion and re-suspension during high flow events was further studied using the River 2D model described in Section 3.2.

3.2 Hydrodynamic Model

River2D is a two-dimensional (2D) depth-averaged hydrodynamic model intended for use on natural streams and rivers and has special features for supercritical/subcritical flow transitions, ice covers, and variable wetted area. River2D (Version 0.95a) was used for the Lyons Creek East sediment transport study. It was developed by the University of Alberta and is freely available (Steffler and Blackburn, 2002).

The variables solved for were water depth and depth-averaged velocities in two dimensions/directions. Input data for River2D model were channel bed bathymetry, roughness height, transverse eddy viscosity distributions, boundary conditions and initial flow conditions.

The objectives and scope of the River2D modelling study were as follows:

- Predict water levels and shear velocities in the study reach;
- Develop an understanding of flow conditions under flood flow scenarios; and
- Provide shear velocity distributions for comparison with critical shear velocities estimated using flume experiments.

3.2.1 Model Setup and Configuration

The model was setup and calibrated to simulate existing hydraulic conditions in the river. The Lyons creek study area was considered to be between the Ridge Road bridge and outlet culvert under Hwy No. 140. The following sections outline the model setup with respect to bathymetry, mesh generation and bed roughness.

3.2.1.1 Bathymetry

The bathymetry of Lyons Creek was based on;

- GPS reference depth measurements for 18 cross-sections taken during December 2009 and 6 cross-sections taken during March 2010,
- An additional 11 profile points between cross-sections were also measured as depth below the water surface to refine the bathymetry, and
- Digital terrain information obtained from NCPA.

Since the section of Lyons Creek 300 meters upstream of the culvert was inaccessible due to vegetation, 6 interpolated cross-sections were created to ensure a reasonable mesh generation. Manual modifications to the bathymetric data were also undertaken to prevent the mesh generation program from creating artificial features during the interpolation of the data. The final digital elevation model used in River2D is shown in Figure 10.

3.2.1.2 Mesh Generation

A well generated mesh system or spatial discretization ensures numerical accuracy in a model. The model boundary was extended 4 meters higher than the measured elevation of the water edge boundary to accommodate for higher flow simulations corresponding to different scenarios (see section 4.0 for more details). The final mesh system with triangular finite elements for numerical modelling, is shown on Figure 11

Additional considerations during the River2D mesh generation included:

- Computational domain was defined by the exterior boundaries set in the elevation range 176.5 to 178.0 m.;
- The extent (shown in red lines on Figure 11) was defined by considering;
  - River2D requirement of minimum resolution (4 to 10 cells in each direction);
  - Flood flow conditions;
- Breaklines were applied at the thalwegs and toe of the river banks (show in blue lines); and
- Grid size was set to 5 m in the middle and wider sections of the creek, and refined to 1 m at the inlet and outlet.

3.2.1.3 River Bed Roughness

According to the field survey, the river bed along the banks was mostly covered with cattails. Towards the downstream end of the creek, the banks were surrounded by trees. During the summer months, 70% of the creek was found to be covered with dense cattails and other emergent vegetation not only at the banks but also at the center of the channel. The initial estimate of roughness distribution (k_s) was based on these observations. These values were adjusted during the model calibration process to match the measured and simulated (using HEC-RAS) water surface profiles.

3.2.2 Model Calibration and Verification

3.2.2.1 Approach

The numerical model was calibrated using the water level measured on December 2010 by adjusting bed roughness height until the simulated water level and flow matched the observed field data at the outlet

3.2.2.2 Measured Flow Data

Measurements for flow discharges were carried out in March and December 2010 at inlet and outlet. Water surface elevation was measured at 14 points along the creek on December 2010. The flow rate measured at the outlet was used as the discharge from the system for calibration simulations.

River discharge was specified as the inflow condition at the upstream and water level was specified as the outflow downstream boundary.

Table 12 shows the set of data used for calibration and verification. Data for December 2010 were used for calibration and the data for March 2010 were used for verification.

Table 13: Available data for model calibration and verification

Date	Discharge (m^3/s)	Upstream Water Level (m)	Downstream Control Point Water Level (m)	Comments
December 2010	0.543	174.090	174.060	Calibration
March 2010	0.205	173.930	173.830	Validation

3.2.2.3 Calibration

A roughness height of 0.616 m, corresponding to a manning's n = 0.050 for a channel that is winding with some pools and stones, was found to show minimum deviation (0.003 m) between observed and simulated water surface profiles. The calibration is summarized in Table 13 and on Figure 12.

Table 14: Model Calibration and Verification Details

Parameter	Calibration	Verification
Measured Total Inflow	0.543 m^3/s	0.205 m^3/s
Measured Total Outflow	0.543 m^3/s	0.205 m^3/s
Measured Water Surface Elevation at Inlet	174.090 m	173.930 m
Measured Water Surface Elevation at Outlet (Control Point)	174.058 m	173.830 m
Bed Roughness	0.616 m	0.616 m
Time of the Year	December 2010	March 2010

3.2.2.4 Verification

The calibrated roughness height of 0.616 m was applied to the creek and verified against the two water surface elevation points measured in March 2010 as well as a water surface profile generated using HECRAS. The profile agreed with the verification data.

The profile showed good agreement with the measured profile. The difference between simulated and measured water levels was in the range of ± 1.5 cm.

Other parameters relevant to the model are the x, y and z eddy viscosity coefficients. The values for these parameters were kept at default values given in Table 15. A comparison of the predicted and measured water elevations are shown on Figure 13.

The calibration and validation results with a bed roughness (k_s) of 0.616 m suggest that the model is reliable for simulations of a range of flow events. 2yr, 5yr, 10 yr, 25 yr, 50 yr and 100 yr storm discharges were obtained from the SEDCAD model results. These discharges were used as input to the River2D model. Shear velocities obtained from these simulations were compared with critical shear velocities measured from the flume experiments.

Table 15: Default parameters for Model Calibration

Variable	Value
Upwinding Coefficient (0.0 – 1.0)	0.5
Eddy Viscosity Coefficient Parameters:	
Epsilon 1	0
Epsilon 2	0.5
Epsilon 3	0

4.0 SCENARIOS

4.1 Scenario Development and Selection

Scenario selection was based on the peak flow conditions from the SEDCAD modelling, which included the 2- year to 100-year return period storms, the regional storm (Hurricane Hazel), and the two PMP storm events outlined in Section 3.1.6. The model, which was run for steady state conditions, used the peak flow rates in the creek, and for the inflowing tributaries, which were predicted using SEDCAD and are provided in Table 11.

4.2 Scenario Assessments

The results from the scenario assessment are shown in Table 15 and 16 below, and Figures 14 through 28. Generally, for the return period storms (2 year through 50 year return period storm events), the modelled shear velocities were lower than the estimated critical shear velocities required to re-suspend sediments.

Each of these events is briefly discussed in the following paragraphs.

2-Year Event – Figure 14: During an event that is expected to occur regularly (e.g. once every two years on average), the highest predicted shear velocities occur in the narrow upstream sections and in the vicinity of the outflow. On Figure 14, the areas of highest shear velocity are shown in light blue and correspond to the areas with highest measured critical shear velocity. This is expected since any sediment deposited in these areas during low flow periods would be routinely moved during high flow events such as the 2-year event.

5-Year Event – Figure 15: The predicted shear velocities shown in Figure 15 for the 5-year event are similar to the results shown for the 2-year event (Figure 14). This was not unexpected since the effects on the 25% increase in flow between the 2-year and 5-year events are offset by an increase in water level of 4.5 cm. The increase in water level is the result of the discharge geometry and rating curve shown in Figure 4.

10-Year Event – Figure 16: The predicted shear velocities shown in Figure 16 for the 10-year event are similar to the results shown for the 2-year event (Figure 14) and the 5-year event (Figure 15). Once again, this was not unexpected since the effects on the 60% increase in flow between the 2-year and 10-year events are offset by an increase in water level of almost 10 cm. The increase in water level is the result of the discharge geometry and rating curve shown in Figure 4.

25-Year Event – Figure 17: This is the highest frequency (lowest return period) event where elevated shear velocities are predicted for the majority of the study area. Shear velocities are predicted to increase regardless of the increased water level (30 cm higher than the 2-year event). Figure 17 also shows that the 25-year event is the most frequent event where the rise in water level resulted in flooding of the surrounding land. Re-suspension of the bed sediments is not expected to occur during the 25-year event since the predicted shear velocities are still below the measured critical velocities at all the locations.

50-Year Event – Figure 18: Figure 18 shows that during the 50-year event there is more flooding than that predicted for the 25-year event (Figure 17) but the distribution of the elevated shear velocities is similar to that of the 25-year event. Table 17 shows that the predicted shear velocity at Location 4 is approaching the critical shear velocity of 0.009 m/s.

100-Year Event – Figures 19, 20 and 21: As shown on Table 17, the 100-year event is the highest frequency (lowest return period) event predicted to exceed the measured critical shear velocity at any location. The increase in flow from the 50-year event (2.395 m^3/s) to the 100-year event (2.927 m^3/s) only increases the water level by 3 cm and is predicted to produce shear velocities that will cause sediment re-suspension only at Location 4.

Figures 20 and 21 are provided as enlargements of the 100-year event (Figure 19) to show the elevated predicted shear velocities in the narrow upstream sections (Figure 20) and the near the outflow (Figure 21).

Hurricane Hazel Event – Figure 22: Figure 22 shows significantly more flooding for the Hurricane Hazel event than the 100-year event (Figure 19) due to the three fold increase in flow between the two events. During the Hurricane Havel event the water level is predicted to be approximately 1 m higher than the 100-year event and 1.5 m higher than the 2-year event. As a result, as shown in Table 17, the shear velocities in the upper sections of Lyons Creek are expected to increase while the shear velocities in the lower sections are expected to decrease. As with the 100-year event, sediment re-suspension is expected to occur at Location 4.

Tropical Storm and Thunderstorm Probable Maximum Precipitation Events – Figures 23 and 24: The tropical storm and thunderstorm PMP events both have predicted water levels that are 2 m or greater above the 2-year event and have predicted flows that are in excess of 10 m^3/s. At all the locations, the predicted shear velocities are the same or less than the shear velocities predicted for the Hurricane Hazel event. As with the 100-year event, sediment re-suspension is expected to occur at Location 4.

4.3 Summary of Assessment Scenarios

For the larger storm events (100-year, Hazel, Tropical Storm PMP and Thunderstorm PMP), velocities are shown to exceed minimum re-suspension shear velocity at Location 4 (approximately 920 m downstream of the inlet). This was the only one of the nine bed shear measurement locations where the model velocities exceeded the measured critical shear velocities. Model velocities may be sufficient for re-suspension to occur in other sections of the creek where critical shear was not measured.

Table 16: Model Input Details

Storm Event	Inflow and Outflow Discharge (m^3/s)	Downstream Water Surface Elevation (m) – From Rating Curve
2 Year	0.449	174.013
5 Year	0.557	174.057
10 Year	0.714	174.107
25 Year	1.625	174.325
50 Year	2.395	174.476
100 Year	2.927	174.541
Hurricane Hazel	9.131	175.440
Thunder PMP	12.644	175.970
Tropical Storm PMP	14.610	176.340

Table 17: Shear Velocities Exceeding Critical Shear Velocities

Location[1]	Measurement Location from upstream boundary	Measured Critical Shear Velocity from Flume Experiments	Calibration	Validation	2yr	5yr	10yr	25yr	50yr	100yr	Hazel	Tropical Storm PMP	Thunder Storm PMP
	(m)	(m/s)	(m/s)	(m/s)	(m/s)	(m/s)	(m/s)	(m/s)	(m/s)	(m/s)	(m/s)	(m/s)	(m/s)
1	1,346	0.071	0.003	0.003	0.003	0.003	0.004	0.005	0.006	0.006	0.007	0.006	0.006
2	1,239	0.032	0.004	0.003	0.004	0.004	0.005	0.006	0.007	0.008	0.009	0.008	0.008
11	1,028	0.104	0.004	0.004	0.004	0.005	0.005	0.007	0.008	0.008	0.009	0.009	0.008
4	922	0.009	0.005	0.004	0.005	0.005	0.006	0.007	0.008	**0.009**	**0.010**	**0.009**	**0.009**
10	812	0.044	0.005	0.003	0.004	0.005	0.005	0.008	0.009	0.009	0.011	0.011	0.010
5	620	0.107	0.007	0.006	0.007	0.007	0.007	0.009	0.010	0.011	0.010	0.008	0.007
6	530	0.046	0.010	0.009	0.009	0.010	0.011	0.013	0.013	0.014	0.012	0.011	0.010
7	311	0.060	0.020	0.026	0.023	0.020	0.021	0.027	0.029	0.030	0.022	0.018	0.016
8	201	0.050	0.022	0.017	0.022	0.023	0.025	0.030	0.032	0.034	0.029	0.026	0.022

Notes

1. *Flume measurement locations shown on Figure 3.*
2. *Bold values indicate exceedances of the measured critical shear velocity at that location.*

5.0 CONCLUSIONS

5.1 Sediment Accumulation

As noted in Section 1, an objective of the study was to quantify the sediment input, and assess the accumulation rate in order to predict the time required to accumulate a given depth of sediment. The studies conducted confirm that there are a number of sources of sediment to the creek, including small tributary streams along both the north and south sides of the creek that combined contribute approximately 85% of the sediment load to the creek. The remaining 15% is contributed from the Canal By-Pass due to re-suspension of canal sediments by passing ships and background levels originating from Lake Erie.

Sediment load estimates indicate that the total load to the creek is approximately 324 tonnes/yr, of which:

- 277 tonnes/year (85% of the total load) is contributed from runoff during rainfall events;
- 40.9 tonnes/year (13% of the total load) is related to the background suspended sediment in the Welland Canal; and
- 5.9 tonnes/year (2% of the total load) is from sediment re-suspension in the canal from ship passage.

As well, the data indicate that approximately 86% of the sediment load contributed to this section of the creek from runoff and the canal is retained within the creek, with 14% being transported downstream via the culvert at Hwy 140. Based on the sediment trap studies, an average deposition rate of rate of 0.9 mm/day (31 cm/yr) as unconsolidated sediments is estimated. The actual accumulation rate is likely to be lower, since ice cover in the winter will limit sediment accumulation during the winter months. As well, it should be noted that sediment depth will decrease over time as the material becomes consolidated.

Comparison of the calculated accumulation rate with the amount of sediment that has accumulated historically (on average, the higher concentrations in sediment were found to occur in the 30-40 cm depths) indicate that actual, consolidated sediment accumulation since 1971 (i.e., over 30 years) when the canal by-pass was completed would be approximately 1 cm/yr. SEDCAD modelling results indicate an annual accumulation rate of approximately 11 mm/yr, which corresponds well with the measured accumulation rate of 1 cm/yr. The studies therefore confirm that there are sources of sediment to the creek, that these sediments are currently contributing to continued burial of more contaminated sediments, and that the selected remedial option will be effective in isolating the more contaminated sediments over time, generally reducing the concentrations of PCBs to which biota could be exposed in the surficial sediment layers.

It should be noted that the estimates of sediment accumulation are likely to be conservatively low since they only include top 5% of rainfall/runoff events. Nonetheless, when seasonality and consolidation of sediments is taken into account, sediment deposition estimates are consistent with observed burial rates.

5.2 Flow Velocities

The second objective of the study was to determine the flow velocities that could result in re-suspension of bed sediments, which could result in exposure of deeper, more contaminated sediments. As the data presented illustrates, potential for sediment re-suspension varies depending on the location.

Based on the in-situ flume studies, under normal flow conditions, there is negligible potential for sediments to be eroded and re-suspended. The data and modelling results indicate that of the measured locations, potential for re-suspension during major storm events (i.e., on the scale of a 1 in 100 years storm) is confined to one location (Location 4).

Sediment PCB concentrations at surface at Location 4 were measured by MOE (2002) as 1.6 µg/g (identified by MOE as station LC12). While sediment cores are not available at this location, results from the nearest upstream (T6, reported in Golder 2008) and downstream locations (T7, reported in Golder 2008) were in the range of 20.8 µg/g at T6 and 7.2 µg/g at T7 (both in the 25-50 cm depths) indicating that sediment concentrations at depth at Location 4 (LC 12) would be somewhere between these two values. By comparison, sediment concentrations in the upper 25 cm (0-25 cm depth) were generally around the mean value of 5 µg/g for surficial sediments in this section of the creek. The data indicate that a significant, prolonged erosional event that resulted in the re-suspension of a 25 cm depth of sediments would be required before there was potential for exposure of sediments with higher PCB concentrations at depth. The likelihood of such an event occurring is considered to be low.

The measured critical shear velocities are consistent with literature values. Where values higher than those reported in the literature were observed, these are likely related to organic content, vegetation and the differences between in-situ and laboratory sediment samples. Model resolution was insufficient to accurately evaluate the likelihood of re-suspension in the immediate area of the inflows as the model was unable to accurately represent small inflow channels. Nonetheless, the model provided conservative estimates since all the inflows were placed at the upstream boundary, and indicated that re-suspension of sediments is expected to occur during the 1 in 100 year or greater events, and only at Location 4.

5.3 Uncertainties

The above conclusions are based on the available data, and include a number of assumptions. As well, there are inherent limitations in the models used. In order to increase the accuracy of the predictions, additional data would be required. These would include;

- Determination the actual pumping rate from the canal to Lyon's Creek;
- Evaluation the internal solids loading due to macrophyte growth;
- Additional flume study to identify the critical shear velocities for the sediments at areas predicted by the model to have high shear velocities; and
- Establishment of an automated, event driven turbidity and water quality monitoring system at the outflow to verify suspended sediment and contaminant losses from Lyon's Creek. This system should also include a water level gauge for flow monitoring.

Report Signature Page

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CMD/CD/SK/gf/ch

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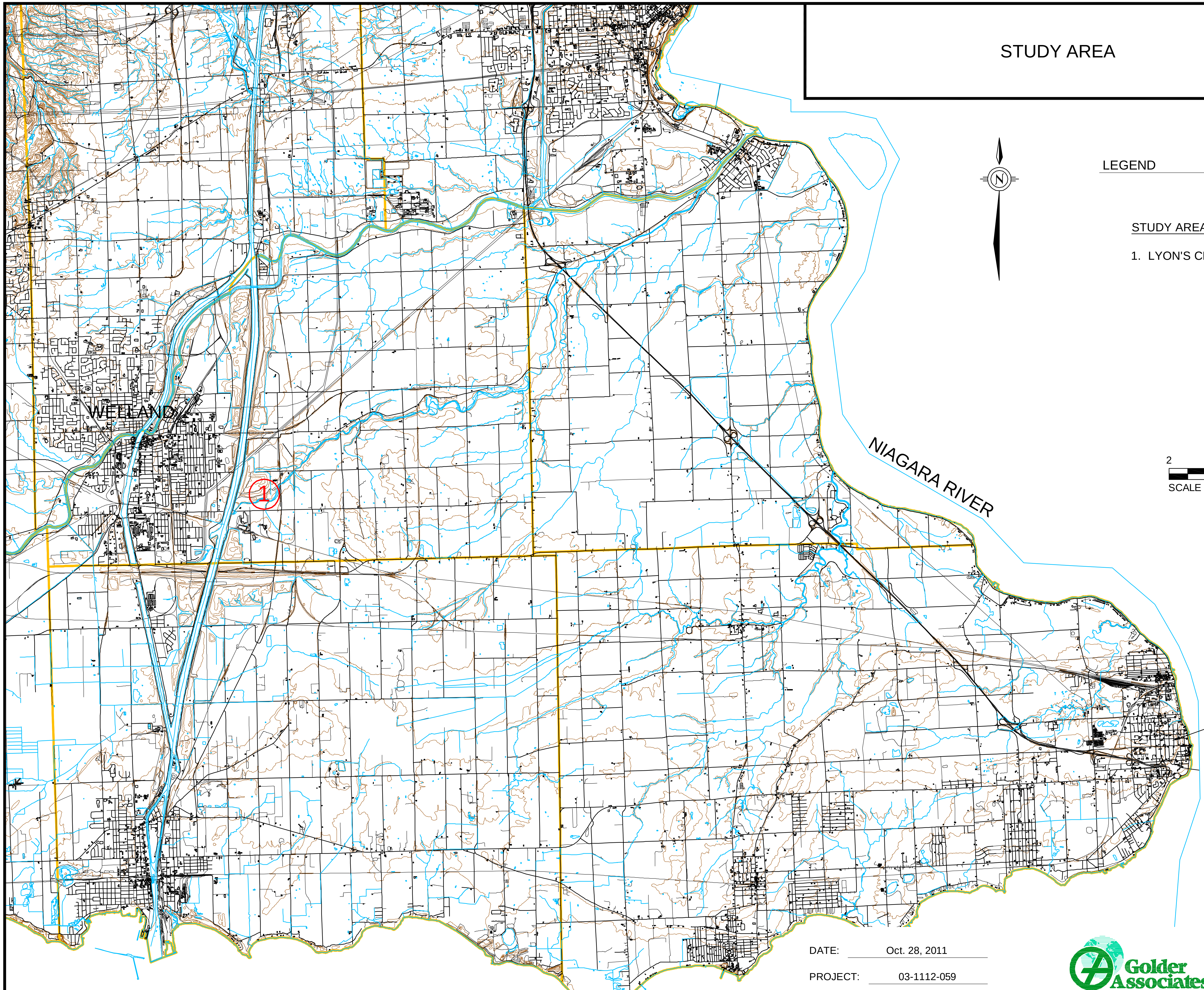
Warner, R.C. and Schwab, P.J. ***SEDCAD 4 for Windows: Design Manual and User's Guide***. Civil Software Design, LLC. 2008.

FIGURES

STUDY AREA

FIGURE 1



N

LEGEND

STUDY AREA LOCATION

1. LYON'S CREEK EAST

2 0 2 4

SCALE 1:100000 KM

DATE: Oct. 28, 2011

PROJECT: 03-1112-059

Golder Associates

CAD: KD\DD

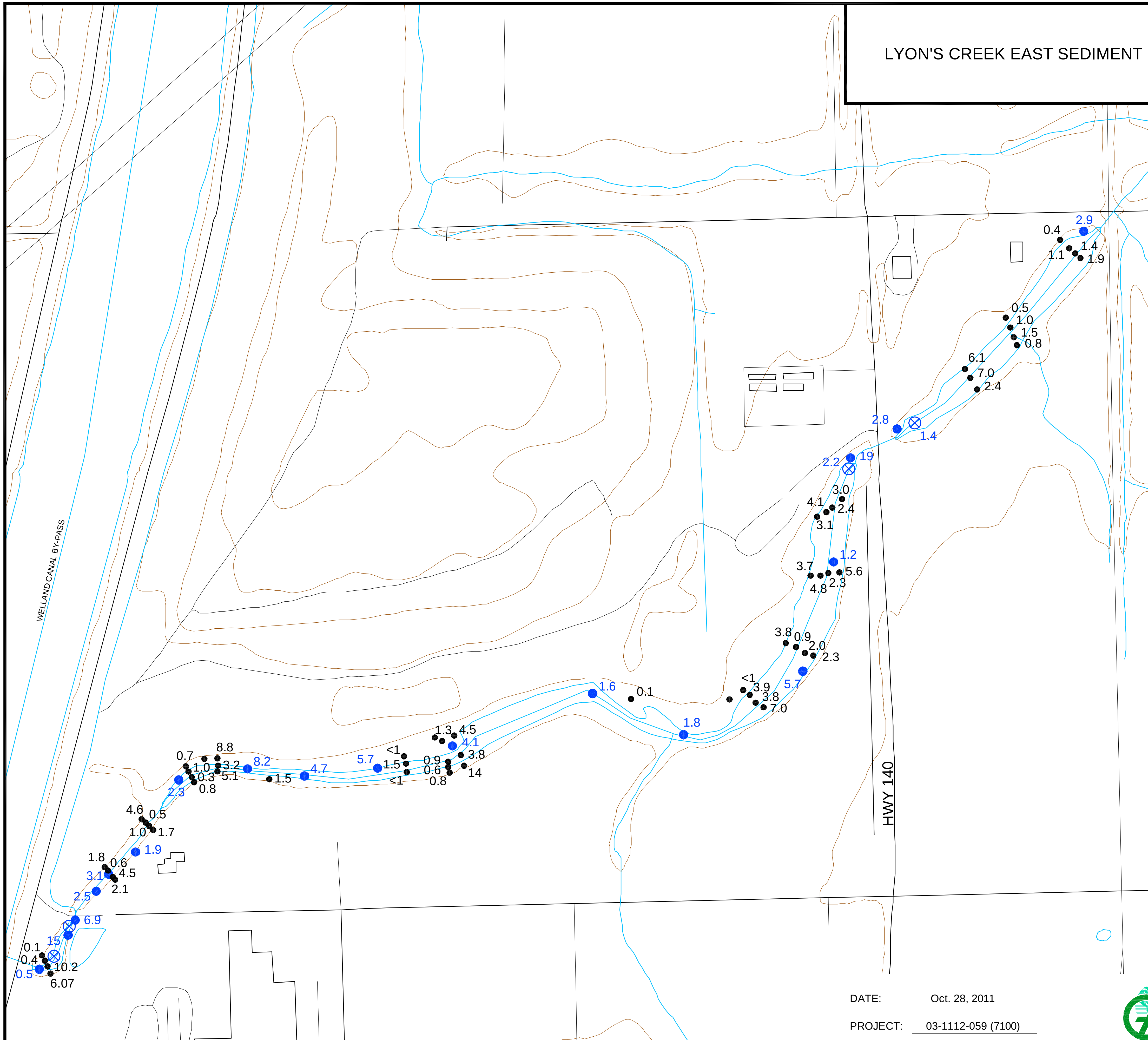
CHK: RJ

PLOT DATE: October 28, 2011

FILENAME: T:\Projects\2003\03-1112-059 (NPCA, Niagara)\-FB- (7100)\031112059FB001.dwg

LYON'S CREEK EAST SEDIMENT PCB CONCENTRATIONS

FIGURE 2



LEGEND

- ⊗ MOE 2002-3 (CORES)
- ● MOE 2002-3 (GRABS)
- • GOLDER - DILLON 2005 SAMPLING POINTS

NOTE

PCB CONCENTRATIONS IN µg/g

TO BE READ IN CONJUNCTION WITH ACCOMPANYING REPORT.

120 0 120 240

SCALE 1:6000 METRES

DATE: Oct. 28, 2011

PROJECT: 03-1112-059 (7100)

Golder Associates

CAD: KD/DD

CHK: RJ

PLOT DATE: October 28, 2011

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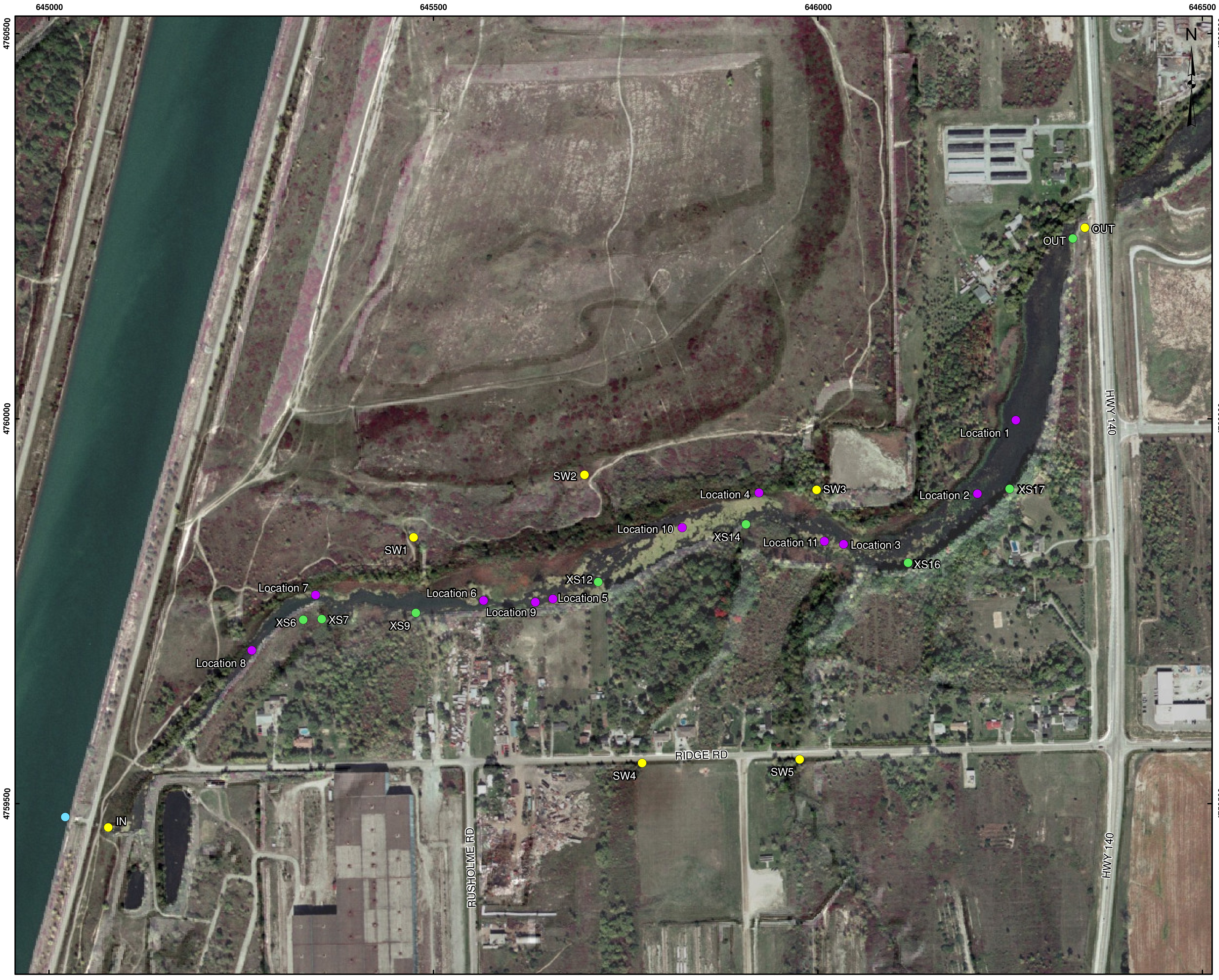
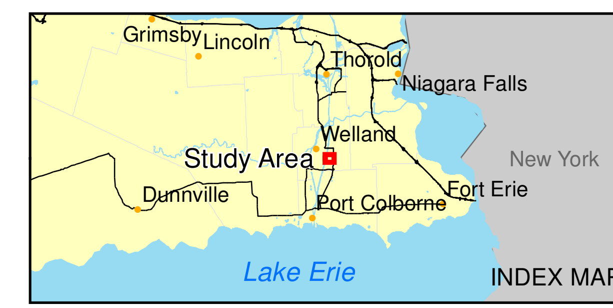


LEGEND

- Flume Test
- Sediment Trap
- TSS & Flow Measurement
- TSS Measurements

TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING REPORT



REFERENCE

Base Data - MNR NRVIS, obtained 2004, CANMAP v2008.4
Imagery: Bing Maps © 2009 Microsoft Corporation and its data suppliers
Produced by Golder Associates Ltd under licence from Ontario Ministry of Natural Resources, © Queens Printer 2008
Projection: Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 17

100 50 0 100 200 300
SCALE 1:5,000 METRES

PROJECT

LYON'S CREEK

TITLE

SURFACE WATER LOCATIONS

Golder Associates
Mississauga, Ontario

PROJECT NO. 03-1112-059			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	15 Oct. 2009		
GIS	PRM	27 Oct. 2011		
CHECK	CD	27 Oct. 2011		
REVIEW	GVA	27 Oct. 2011		

FIGURE: 3

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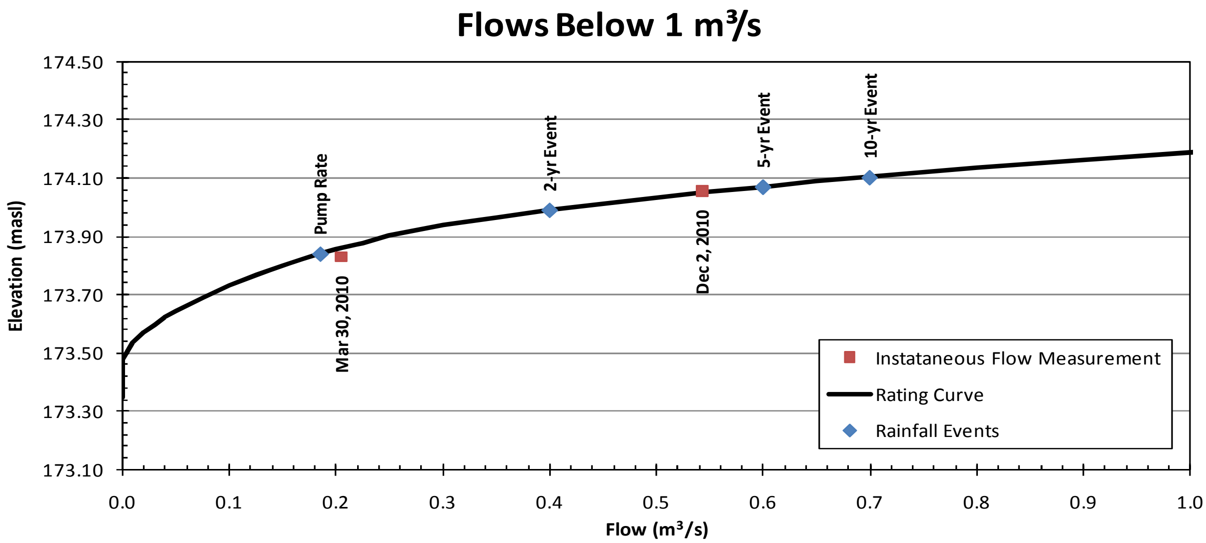
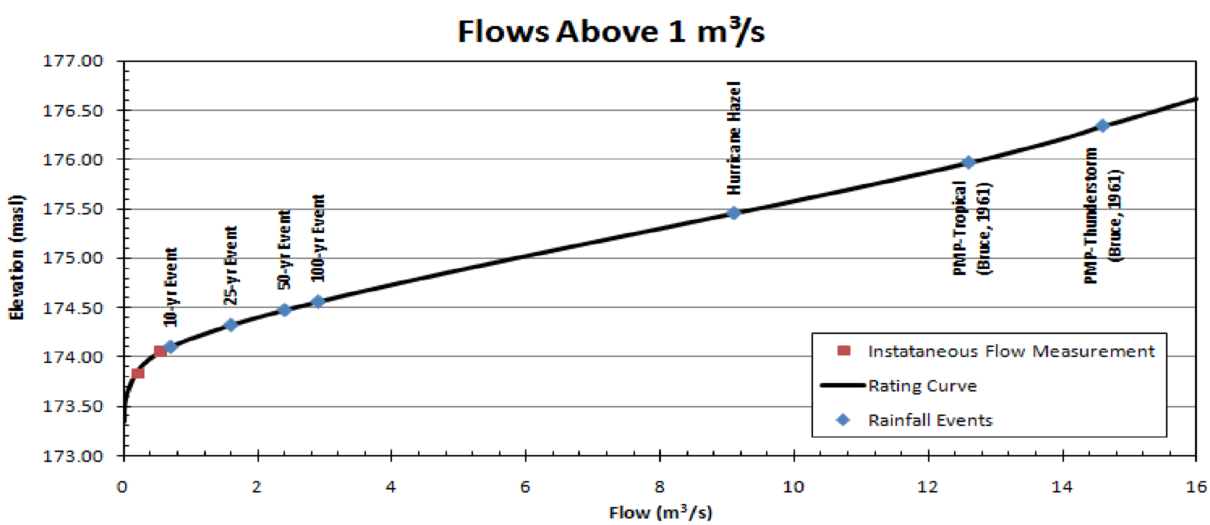
Rating Curve for Outlet Flow	Figure 4





note: elevations are expressed in metres above sea level (masl).

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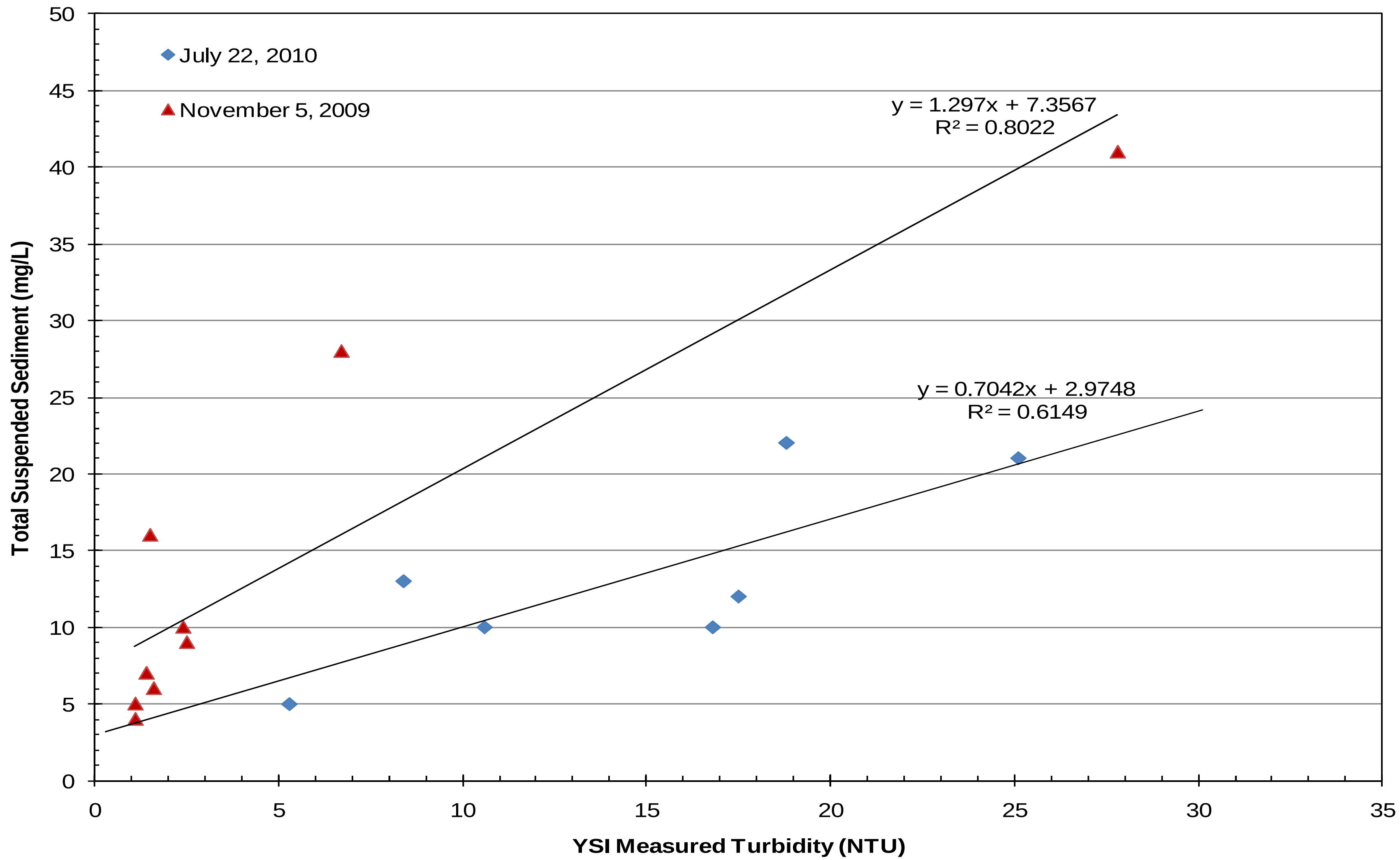
Relationships Between Turbidity and Suspended Sediment Concentration for Passing Ships in Canal	Figure 5



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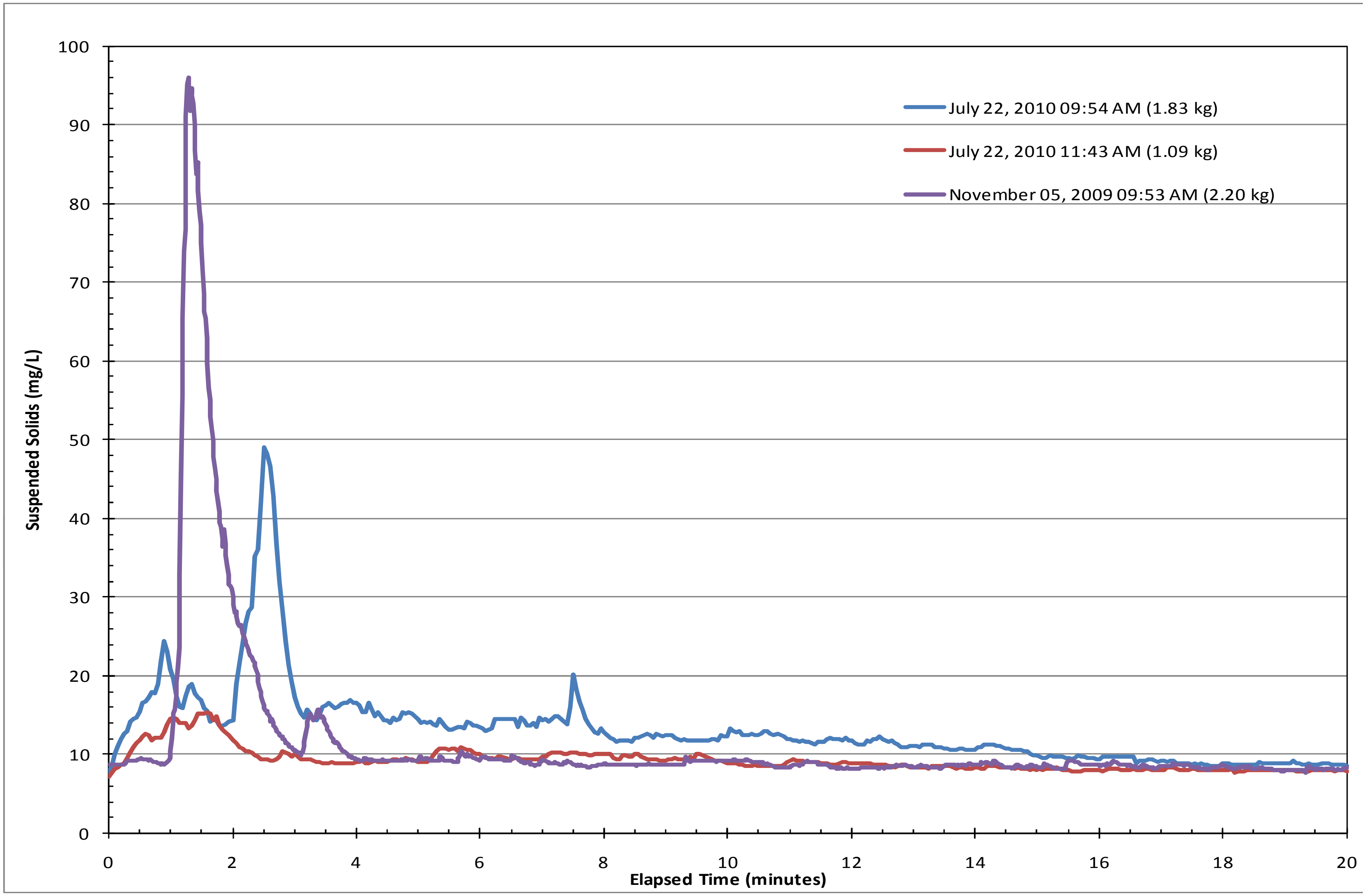
Measured Suspended Sediment from Passing Ships	Figure 6



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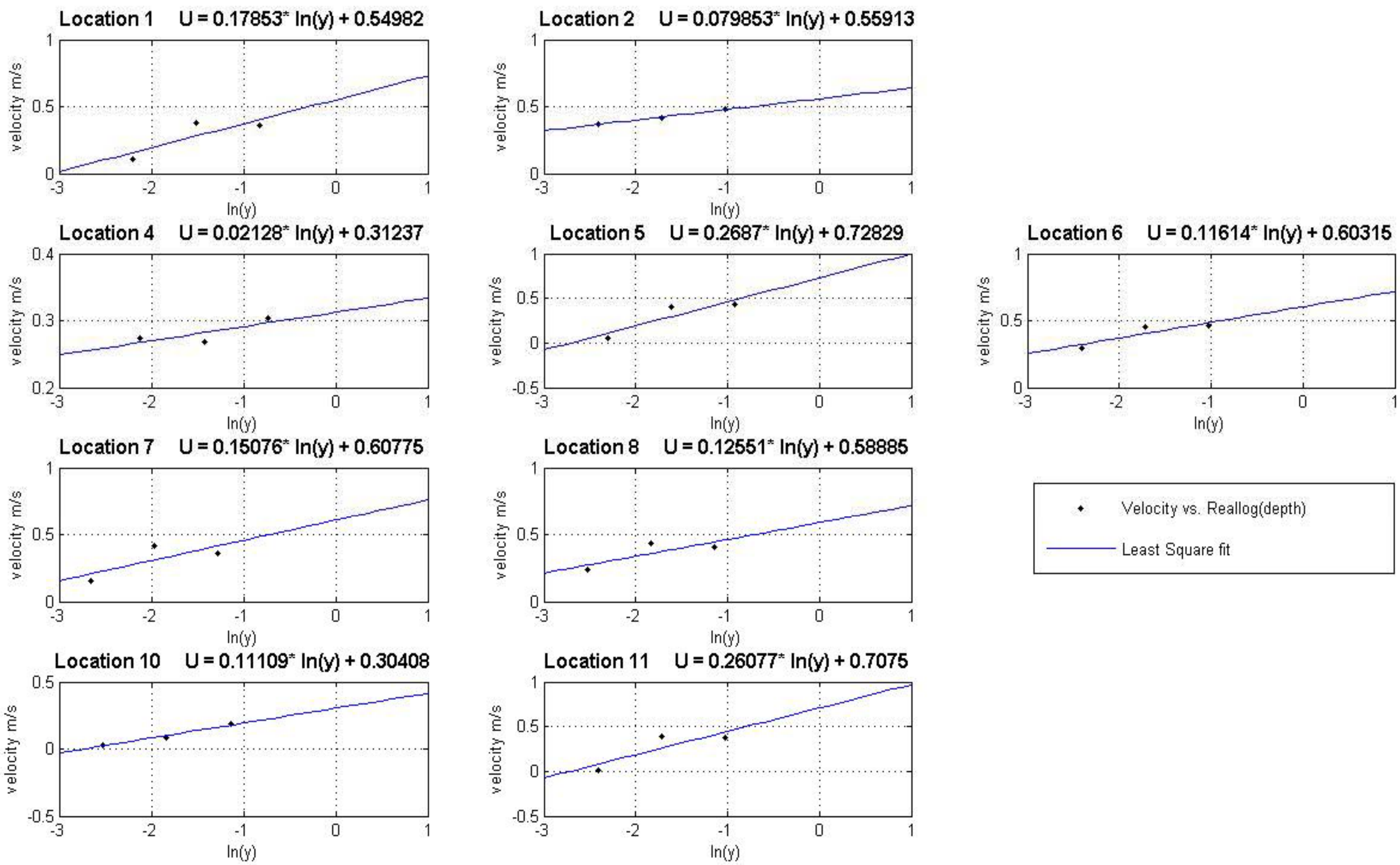
Measured Velocities Versus Depth of All Locations

Figure 7



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DATE: March 2011

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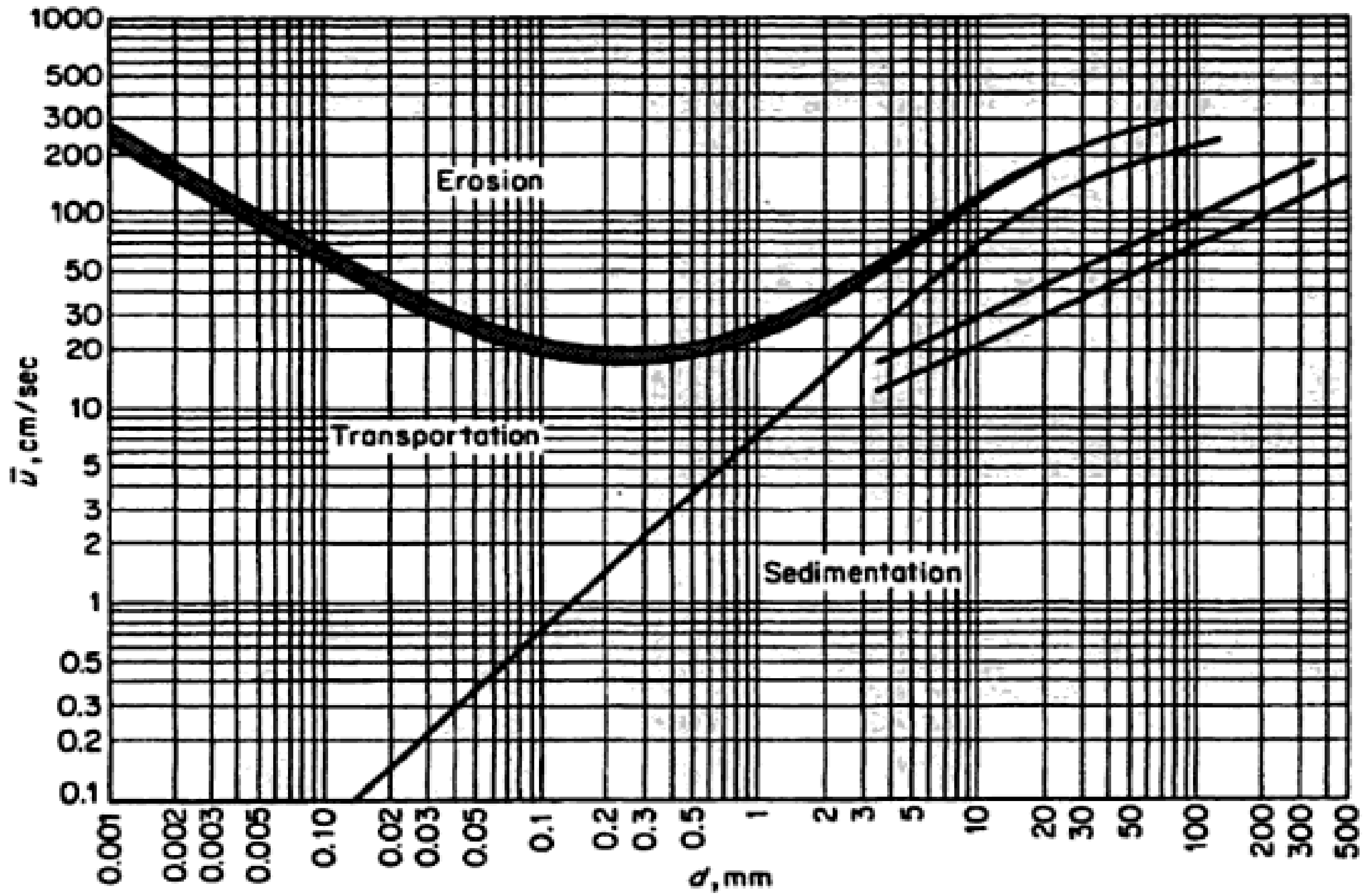
Erosion-Deposition Criteria for Uniform Particles (Graf, 1984)	Figure 8



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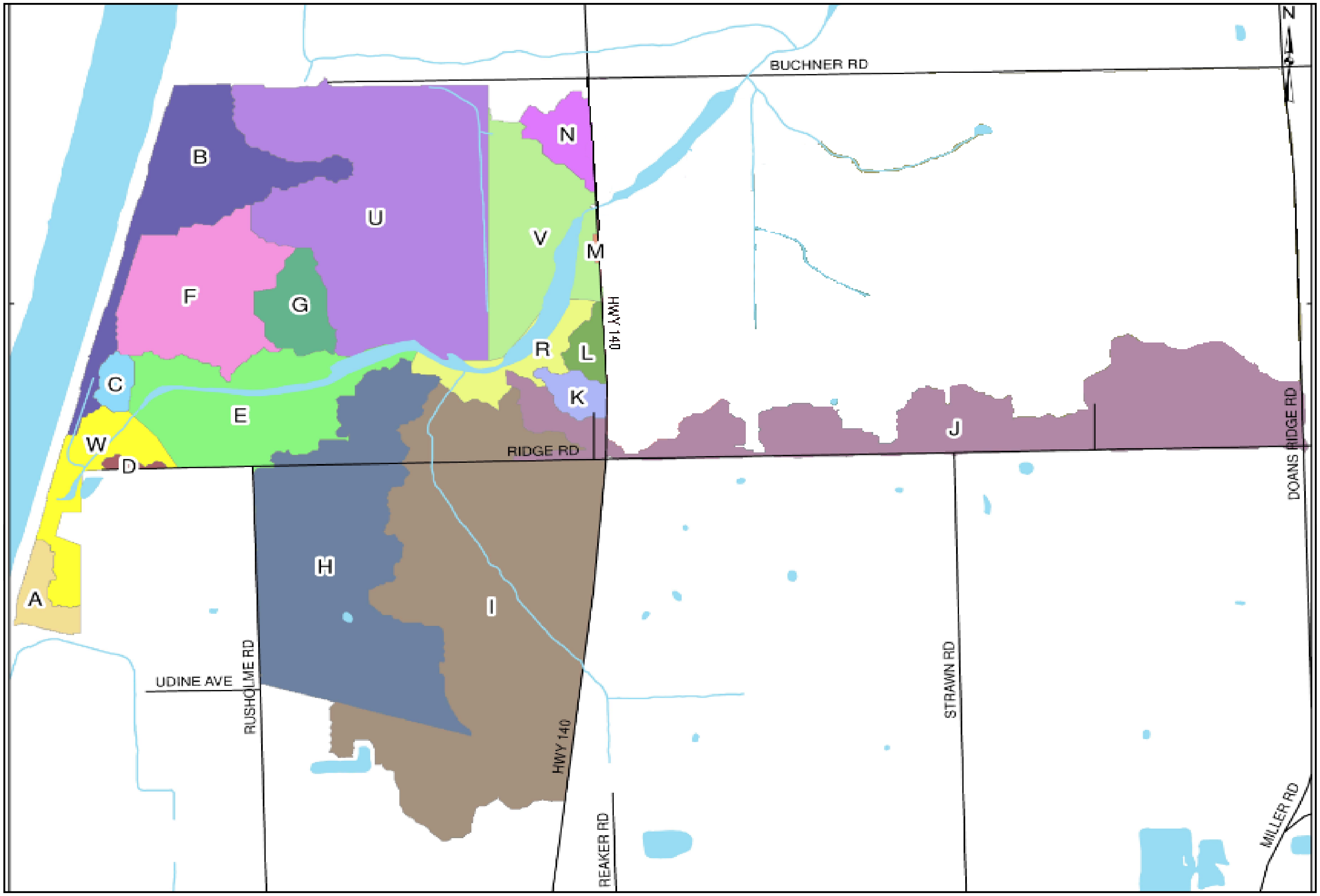
Lyons Creek East Drainage Sub-Catchments Used in SEDCAD	Figure 9



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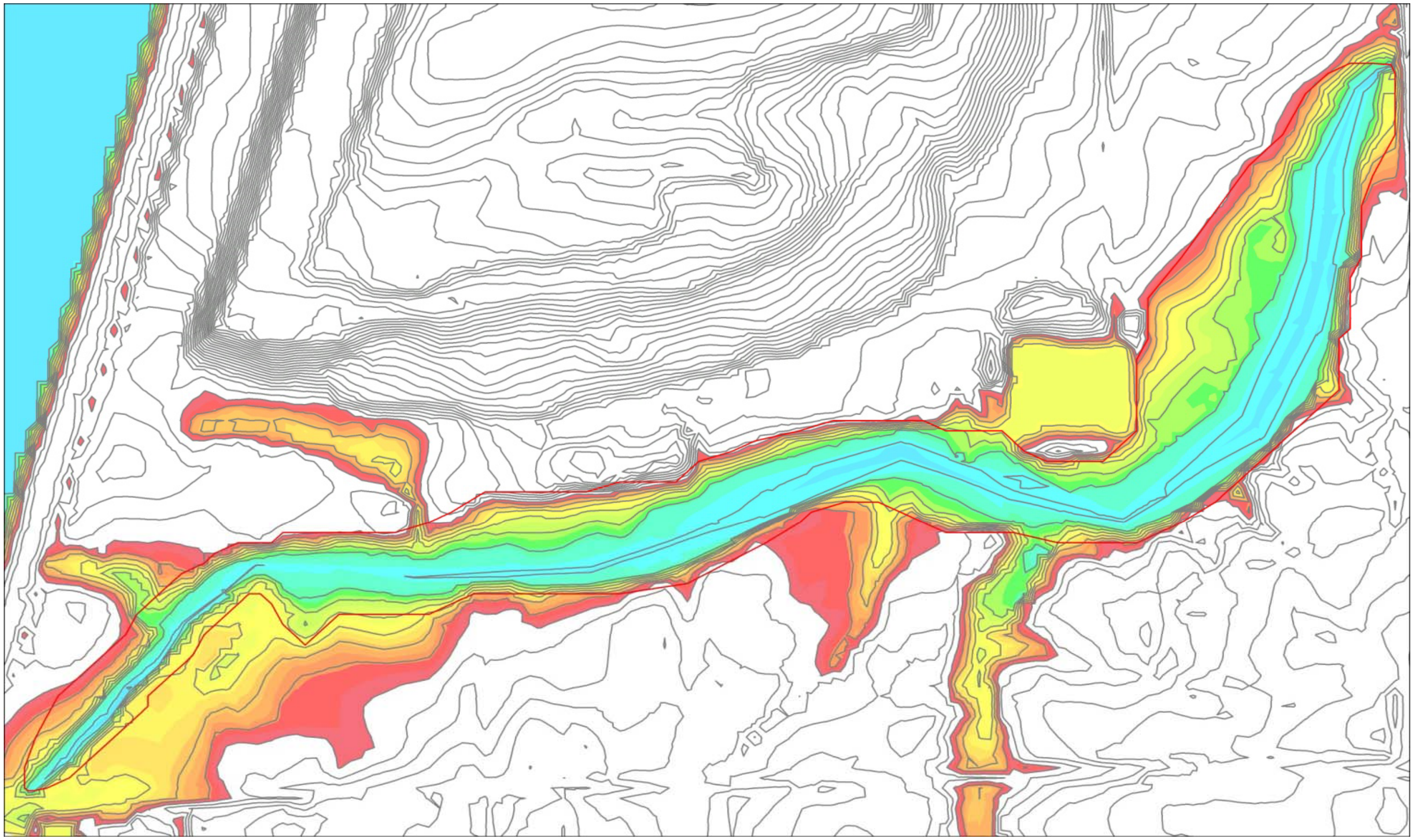
Final Bed Topography and Model Boundary for River2D

Figure 10



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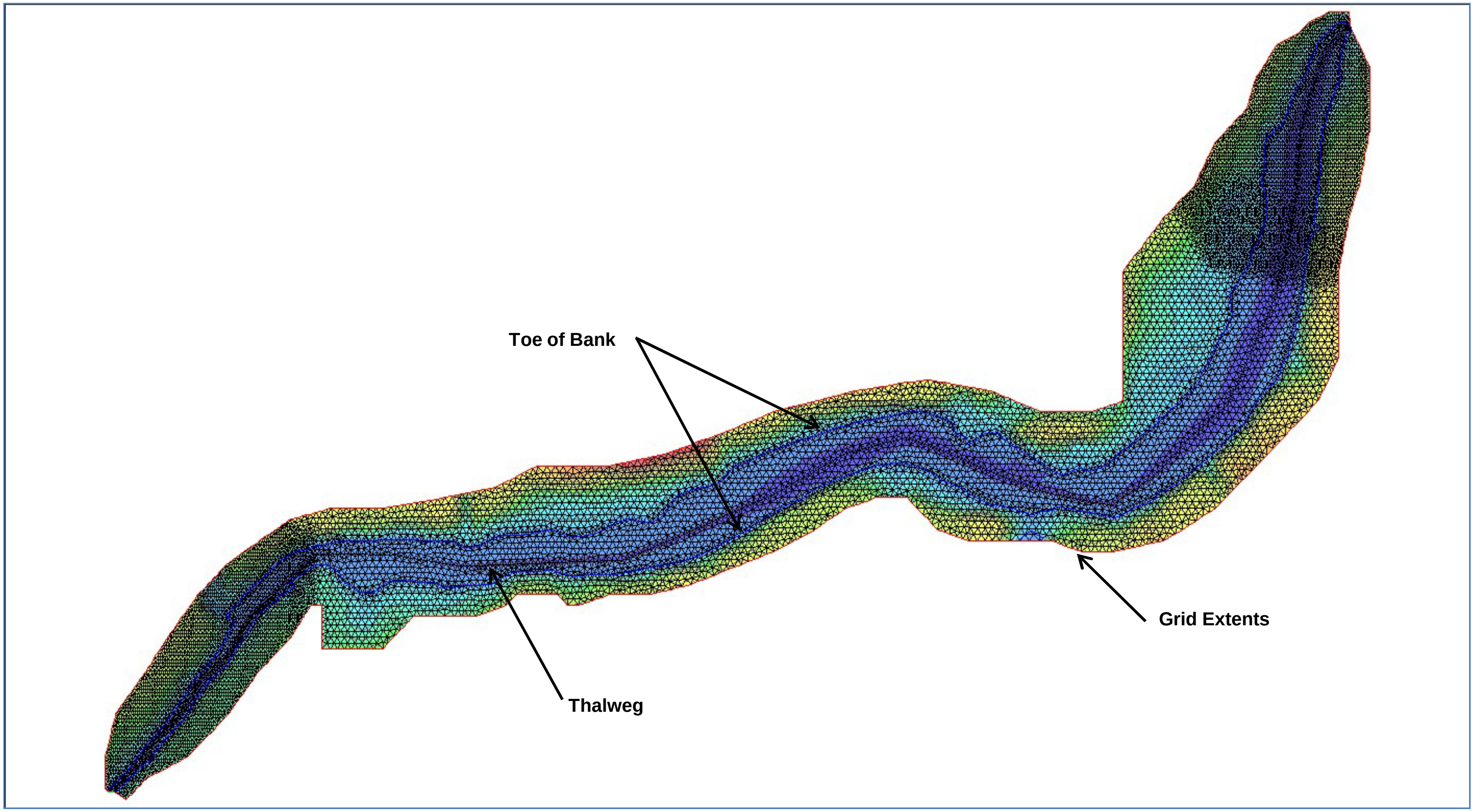
Final River2D Model Mesh	Figure 11



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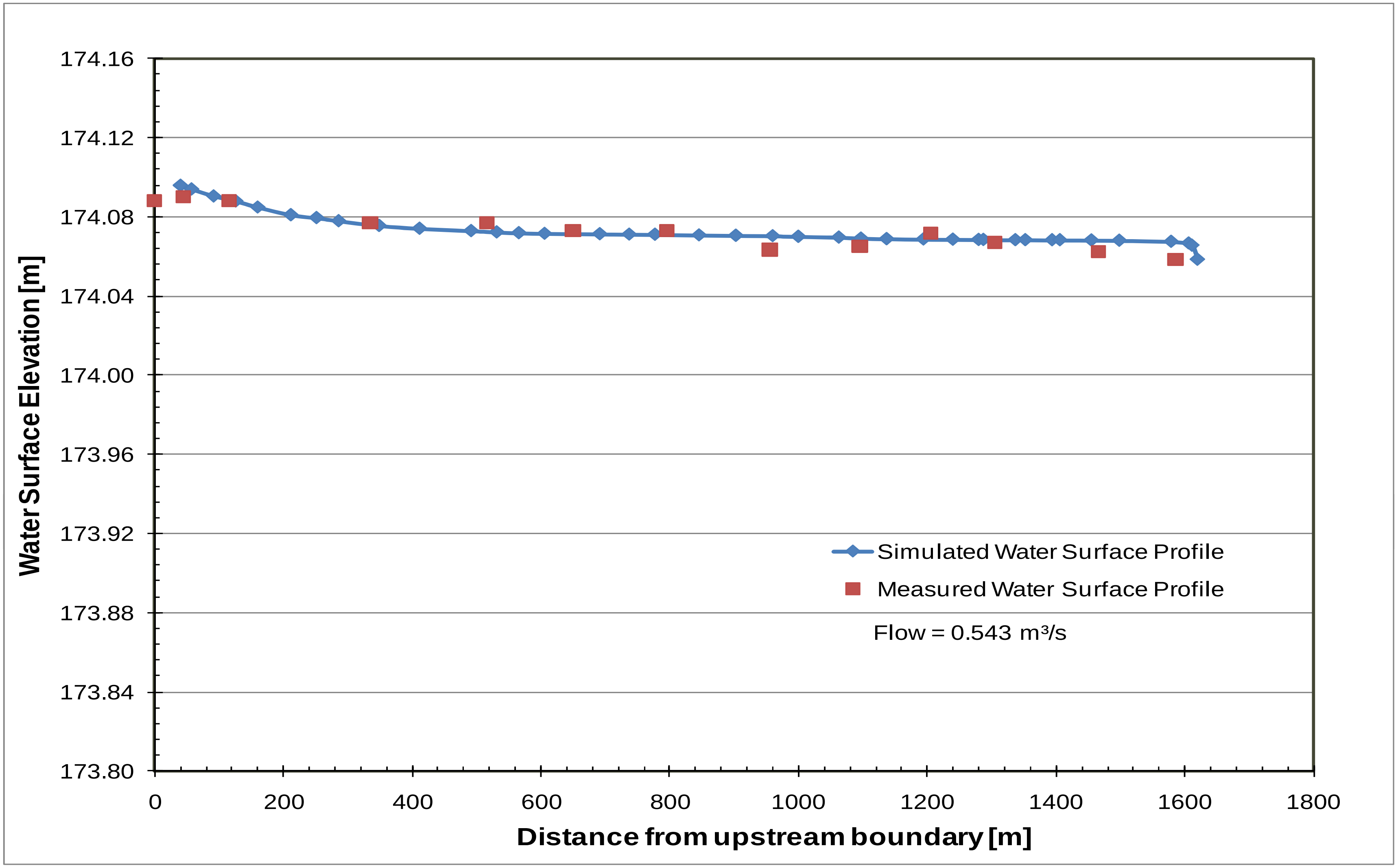
River2D Water Elevation Calibration	Figure 12



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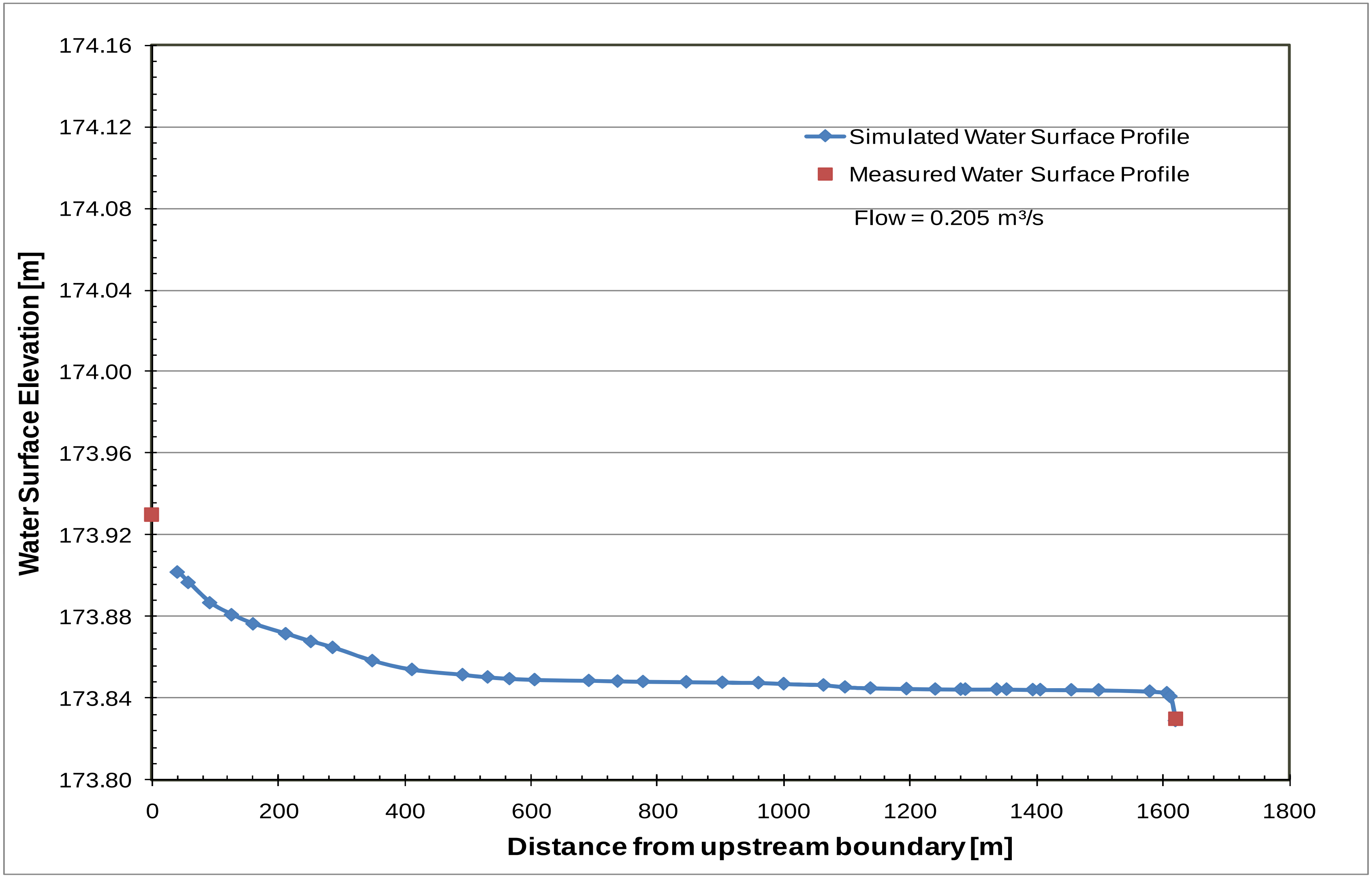
River2D Water Elevation Verification	Figure 13



PROJECT: 03-1112-059
DATE: November 2011

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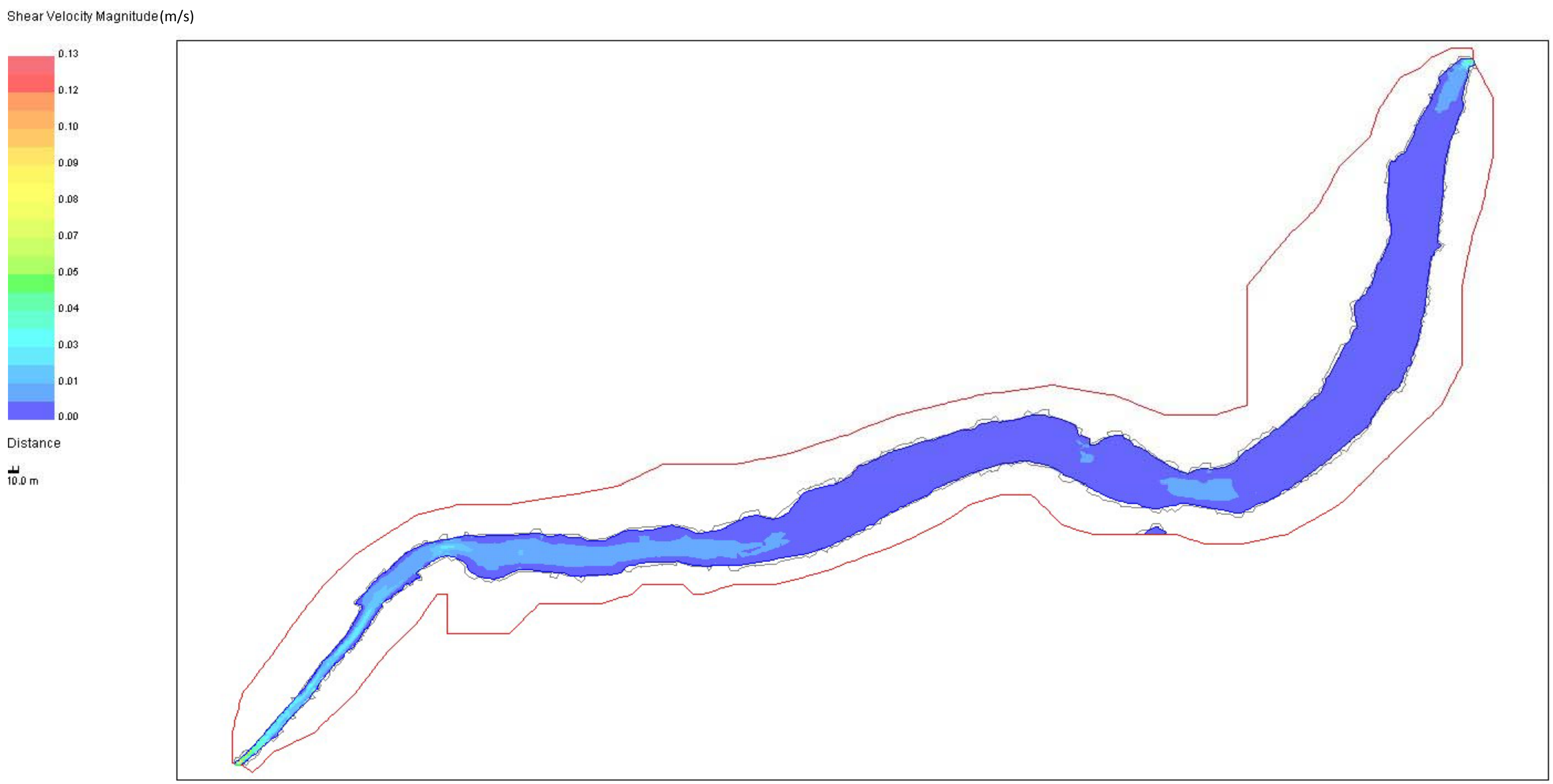
Contour Map of Shear Velocity Distribution - 2 Year Event	Figure 14



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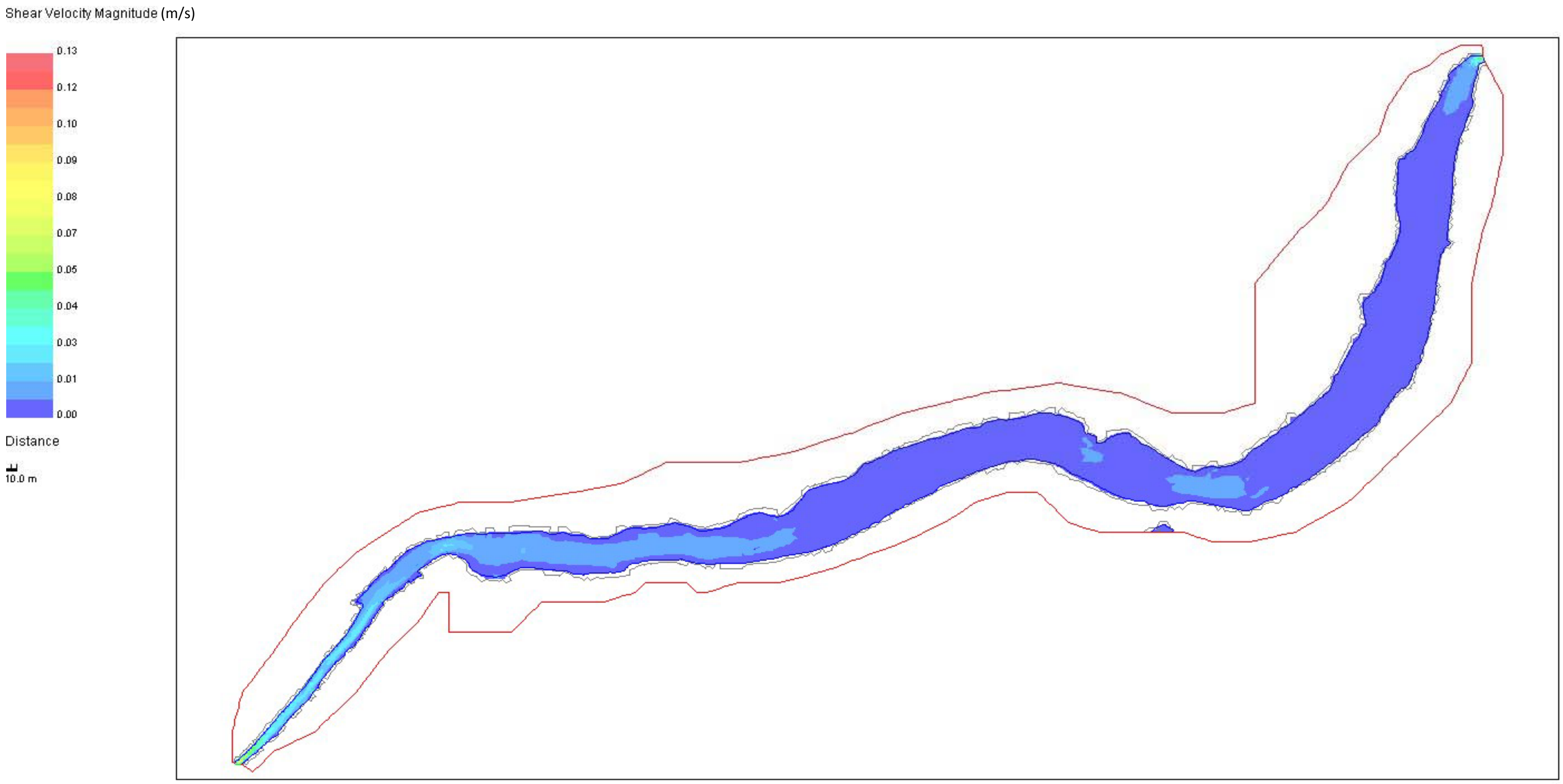
Contour Map of Shear Velocity Distribution - 5 Year Event	Figure 15



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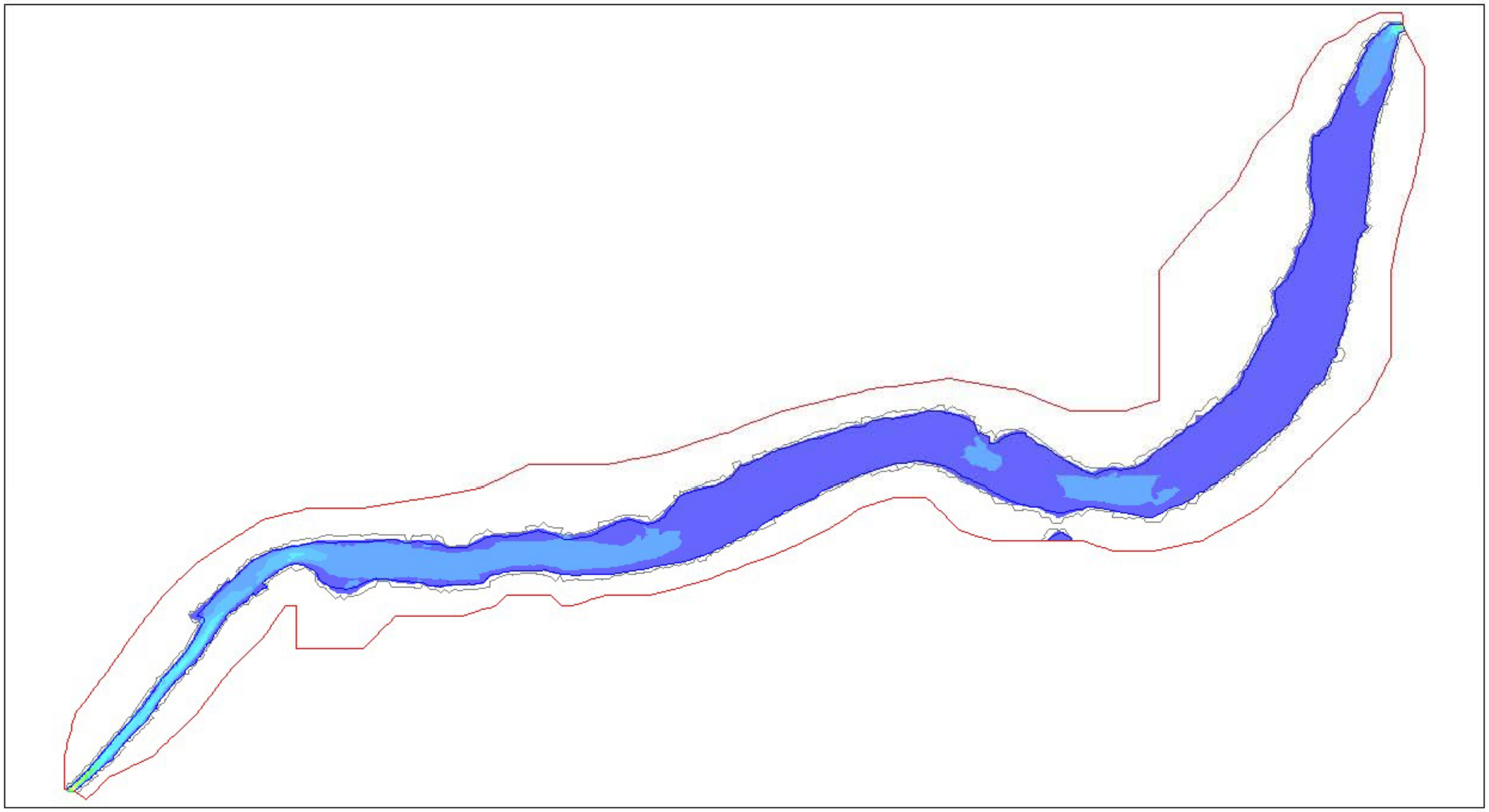
Contour Map of Shear Velocity Distribution - 10 Year Event	Figure 16

Shear Velocity Magnitude (m/s)

0.13
0.12
0.10
0.09
0.08
0.07
0.05
0.04
0.03
0.01
0.00

Distance

10.0 m



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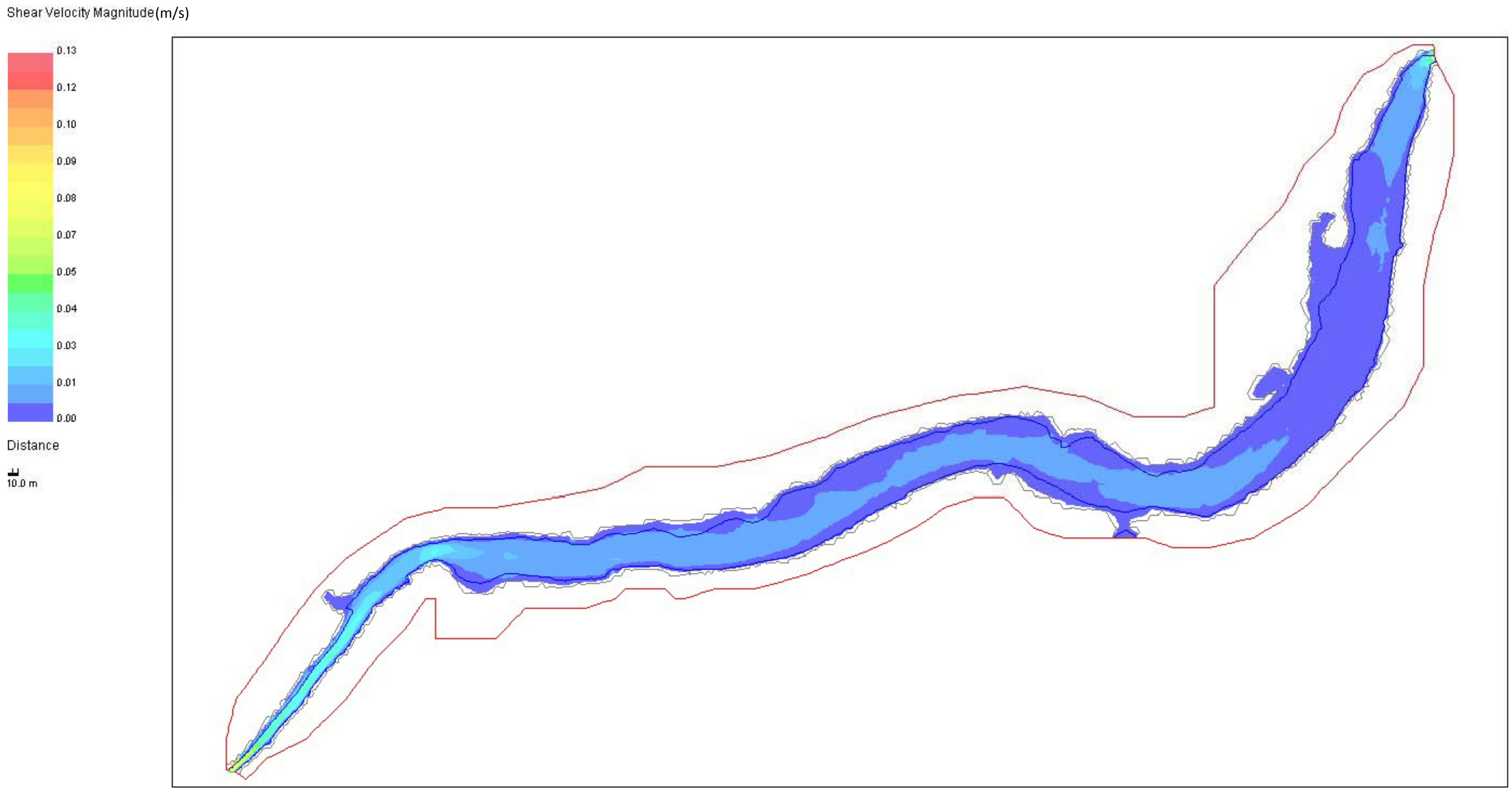
Contour Map of Shear Velocity Distribution - 25 Year Event

Figure 17



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DATE: November 2011

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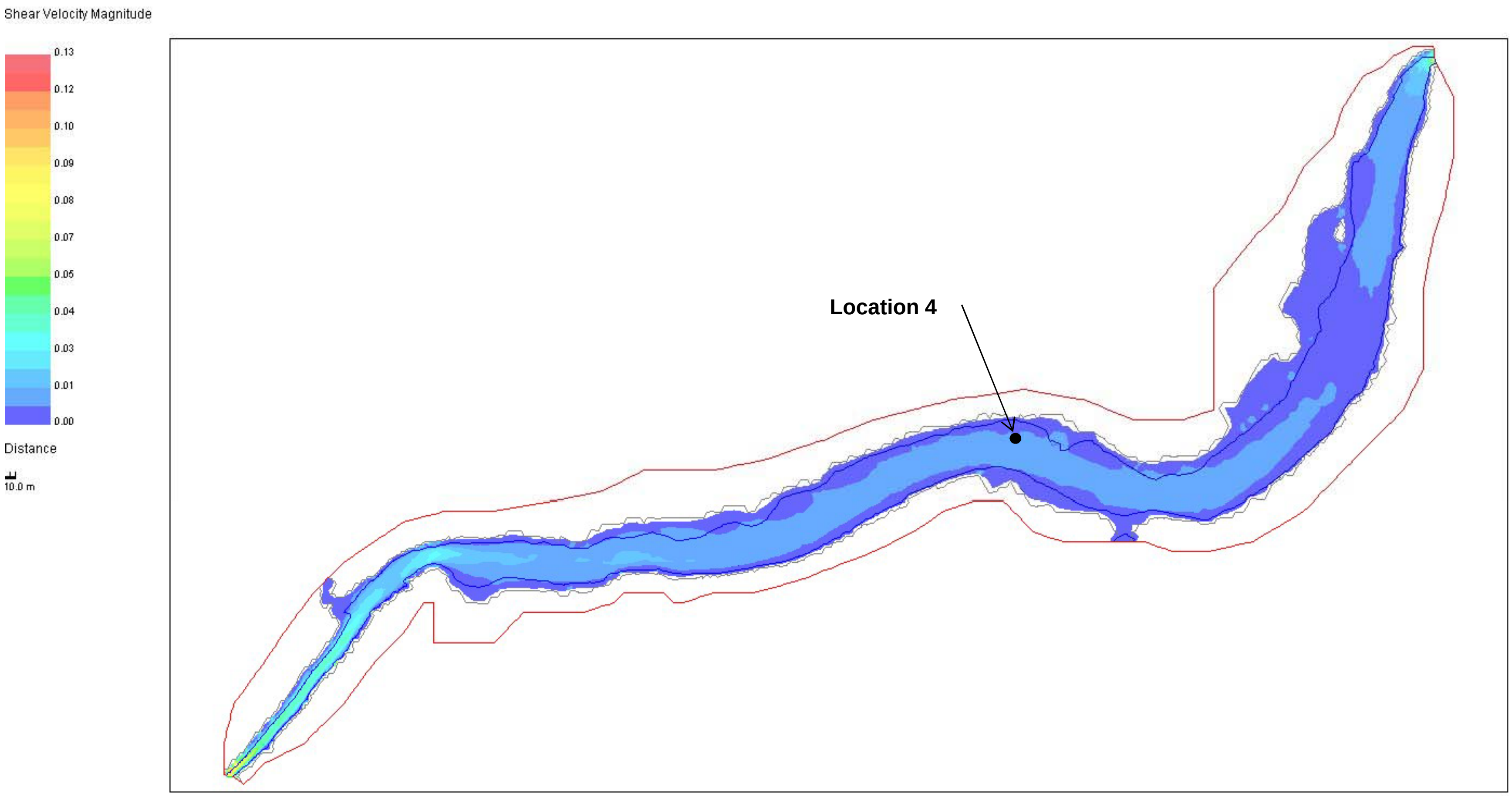
Contour Map of Shear Velocity Distribution - 50 Year Event	Figure 18



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DATE: November 2011

Golder Associates

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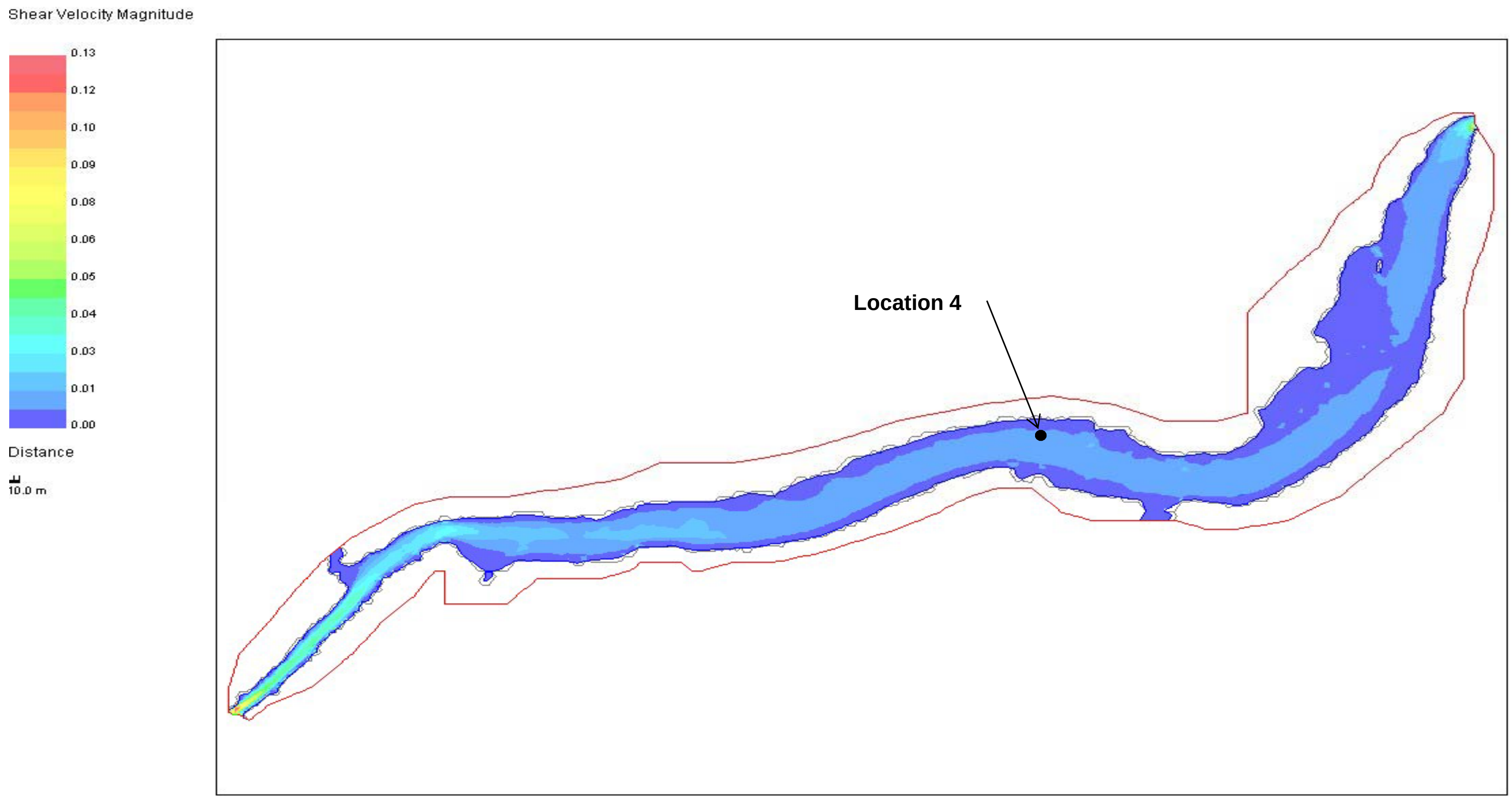
Contour Map of Shear Velocity Distribution - 100 Year Event	Figure 19



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DATE: November 2011

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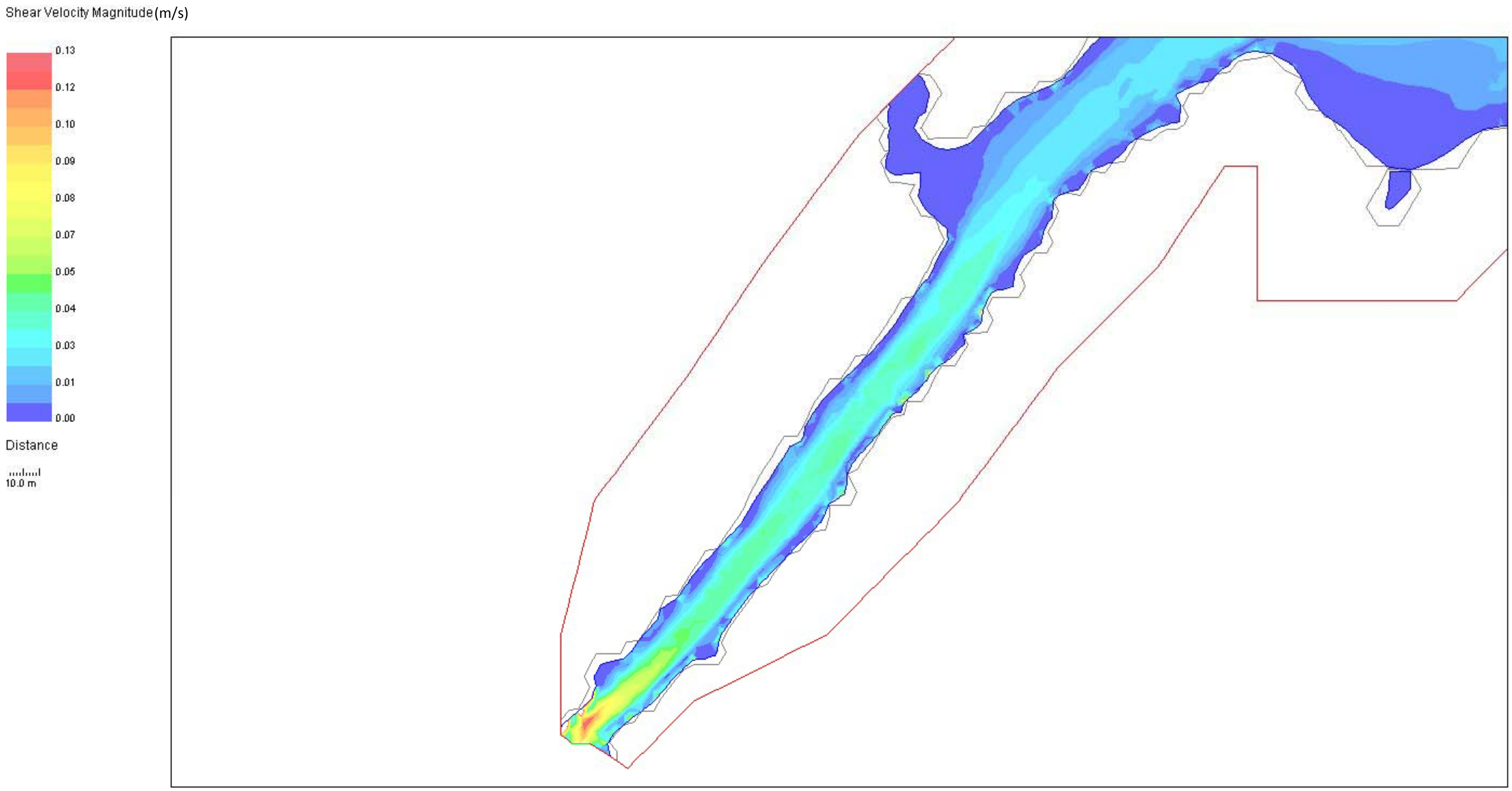
Shear Velocity Distribution at Inlet: 100 Year Storm	Figure 20

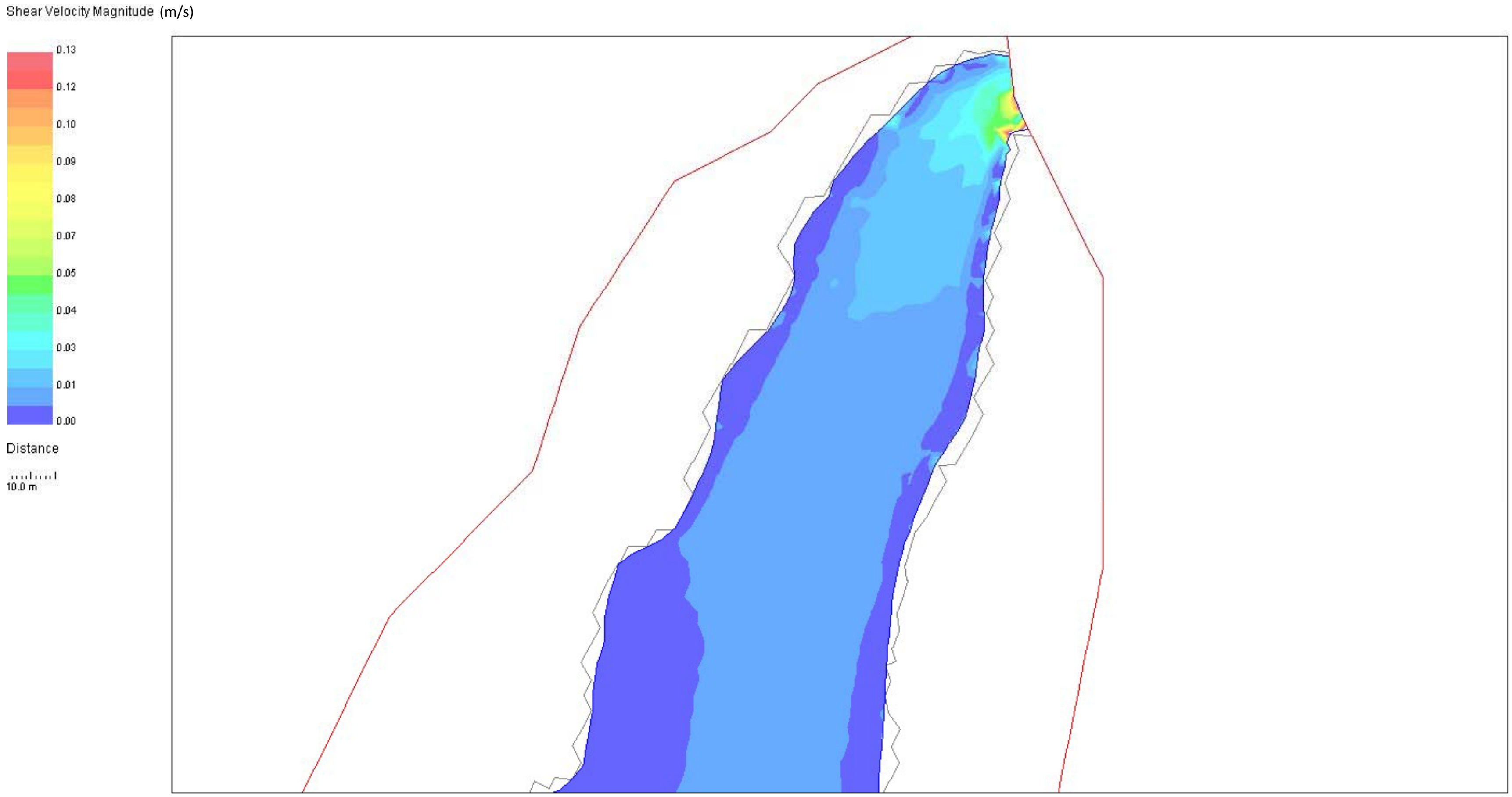


PROJECT: 03-1112-059
DATE: November 2011

Golder Associates

DRAWN: CD
CHECK: KM

Shear Velocity Distribution at Outlet: 100 Year Storm | **Figure 21**



PROJECT: 03-1112-059

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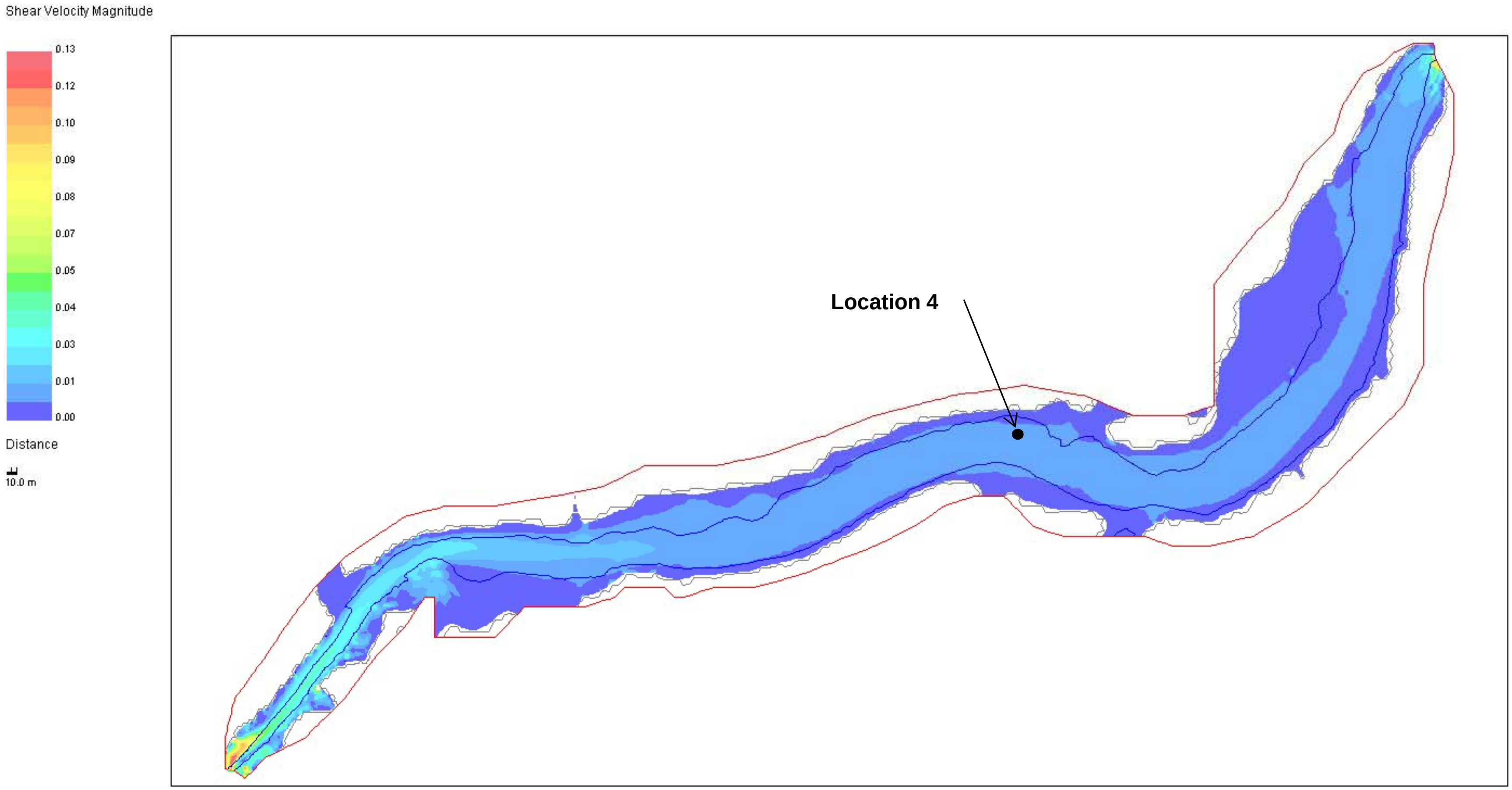
Contour Map of Shear Velocity Distribution - Hurricane Hazel

Figure 22



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DATE: November 2011

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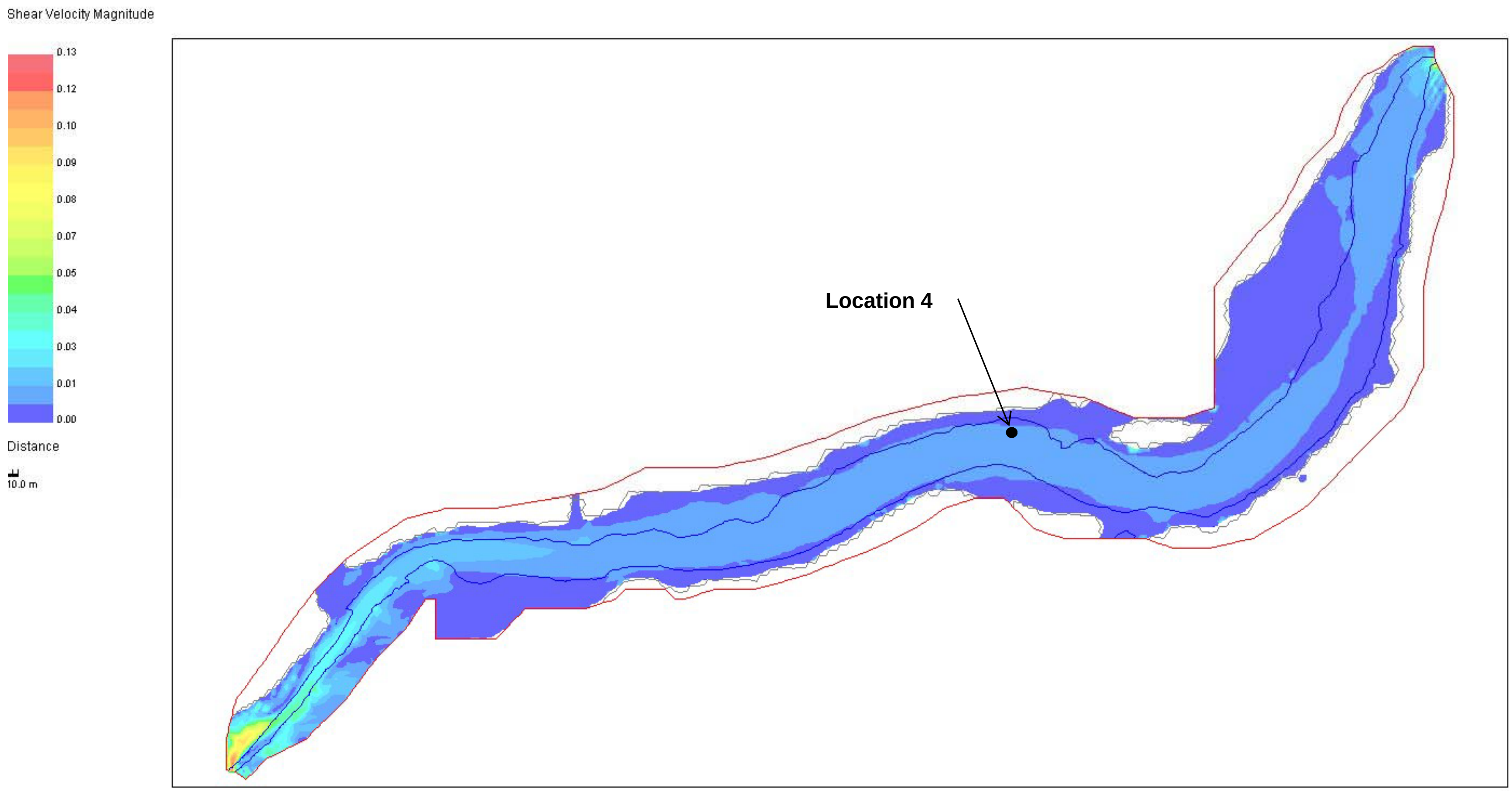
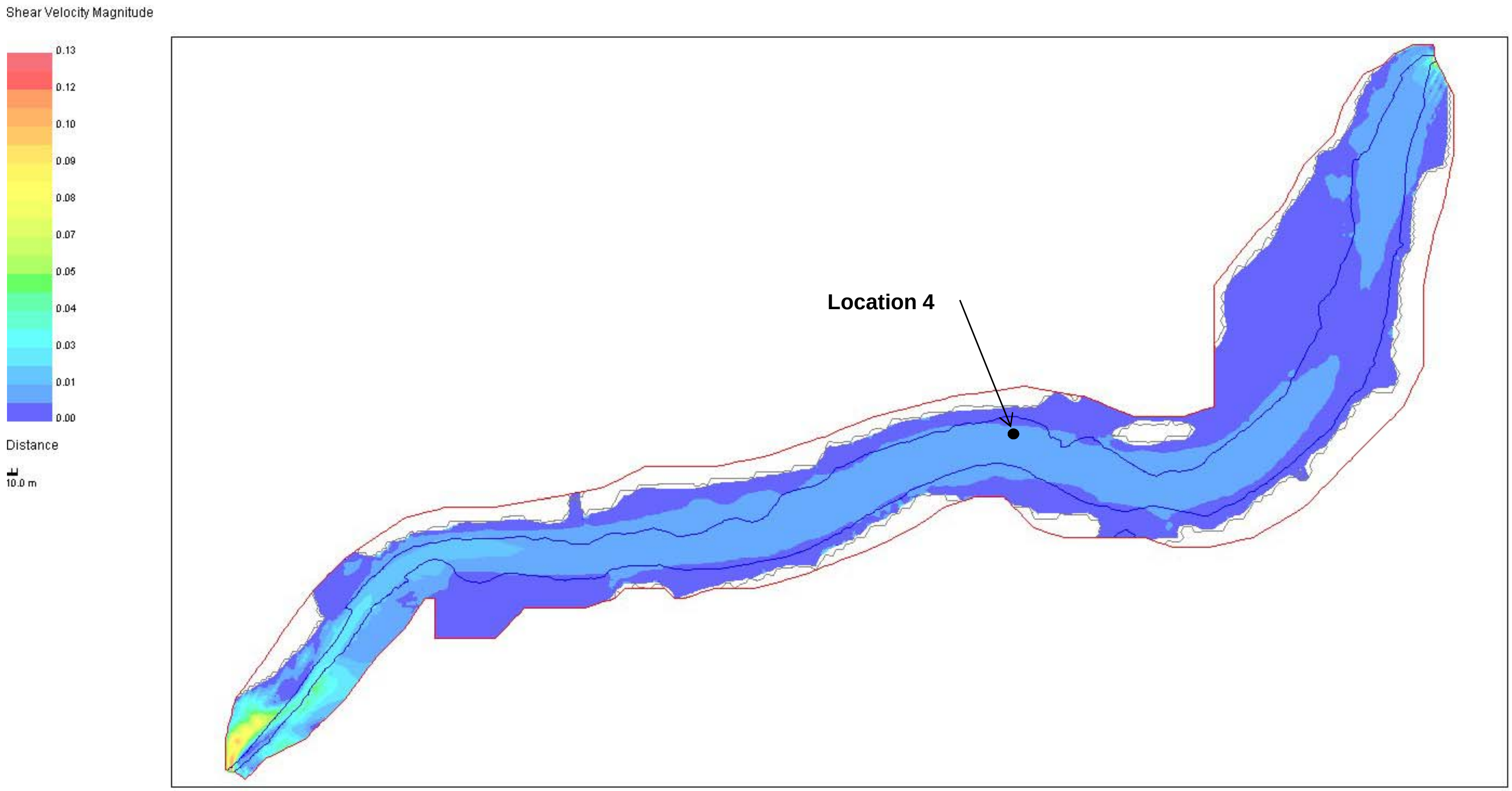
CHECK: KM

Contour Map of Shear Velocity Distribution - Tropical Storm PMP	Figure 23



PROJECT: 03-1112-059	Golder Associates	**DRAWN:** CD	
DATE: November 2011		**CHECK:** KM	

Contour Map of Shear Velocity Distribution - Thunderstorm PMP	Figure 24

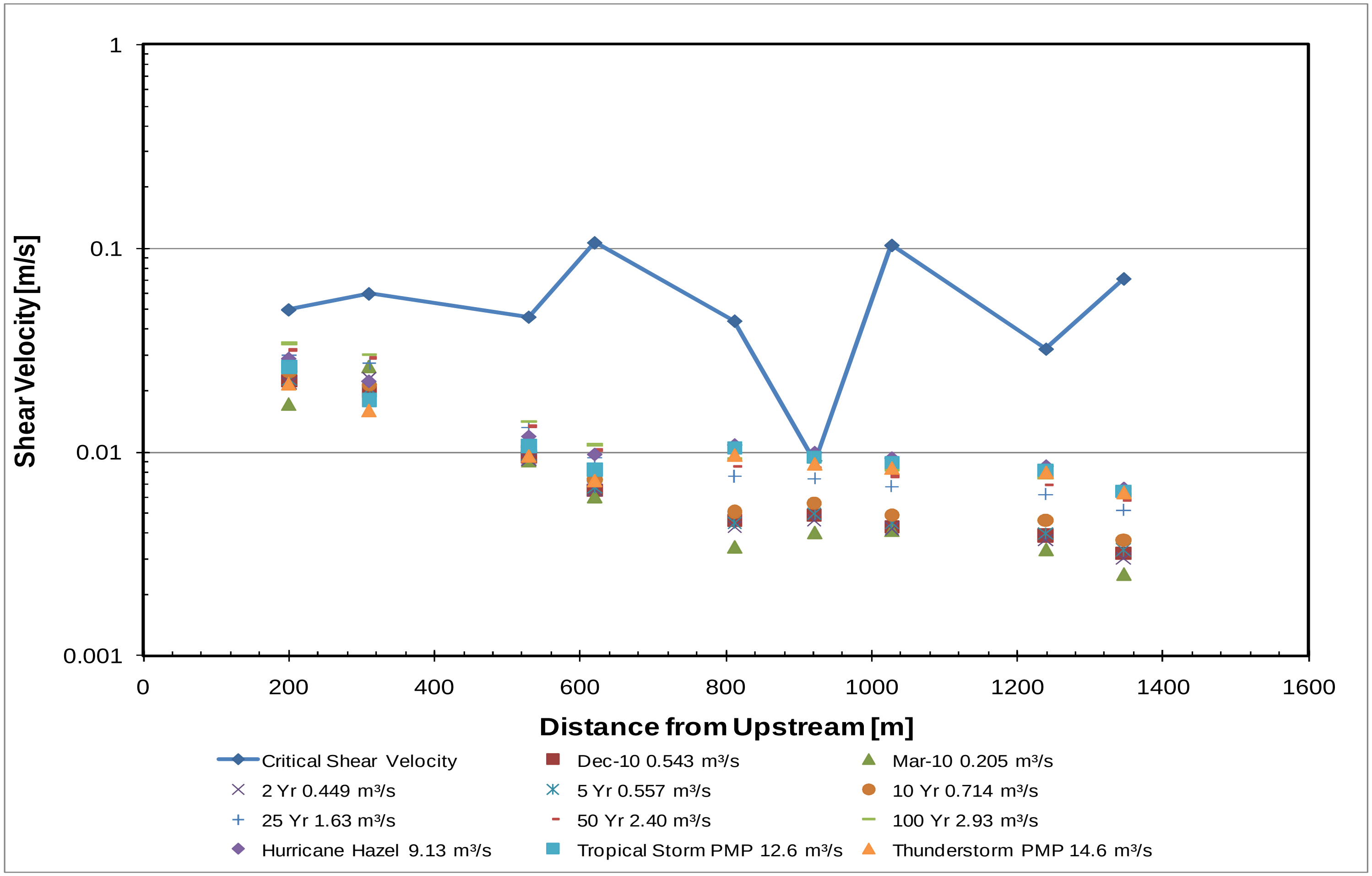


PROJECT: 03-1112-059
DATE: November 2011

Golder Associates

DRAWN: CD
CHECK: KM

Comparison of Measured and Predicted Shear Velocities	Figure 25



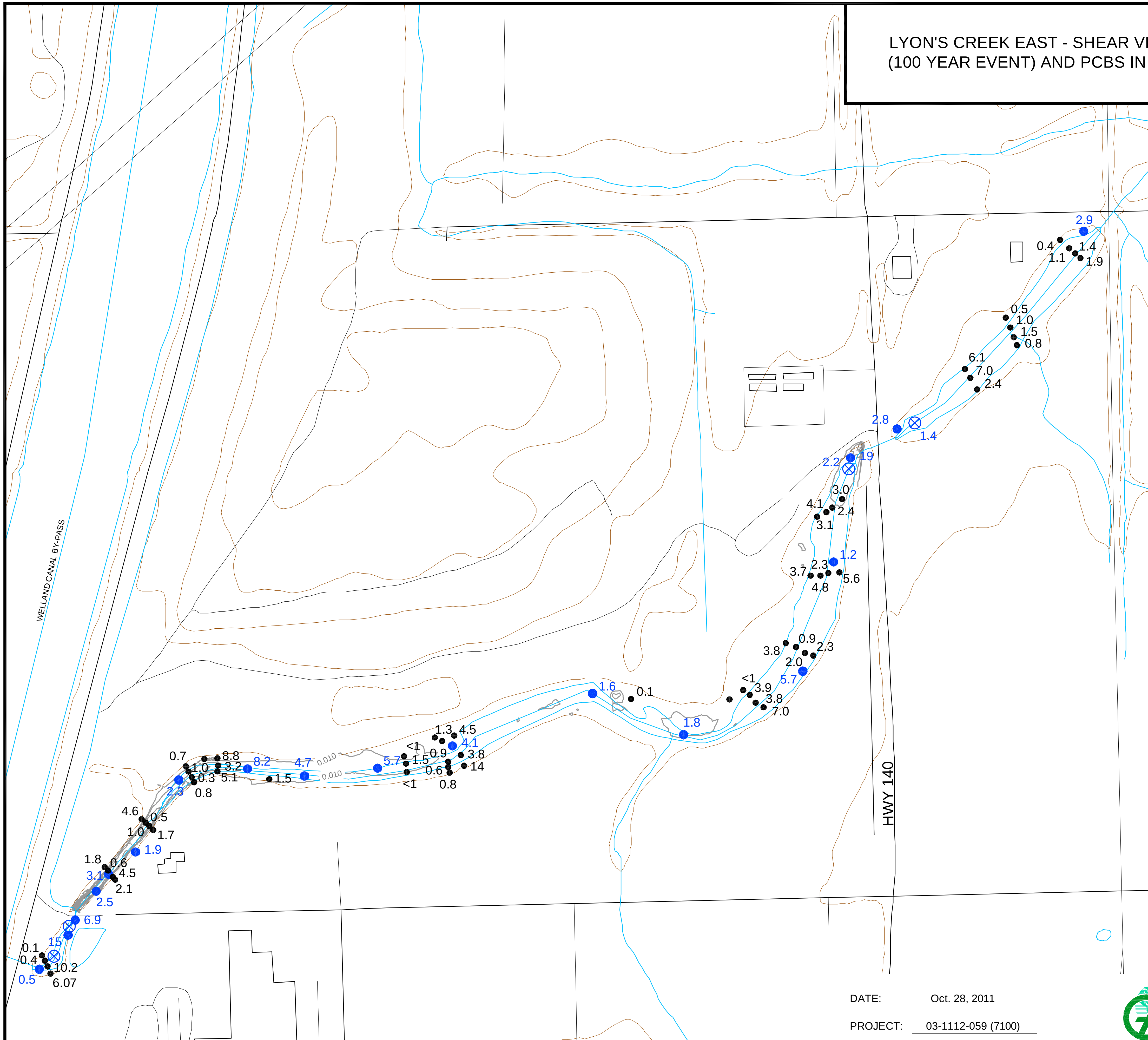
PROJECT: 03-1112-059
DATE: November 2011

Golder Associates

DRAWN: CD
CHECK: KM

LYON'S CREEK EAST - SHEAR VELOCITY DISTRIBUTION (100 YEAR EVENT) AND PCBS IN SURFICIAL SEDIMENTS

FIGURE 26



LEGEND

- ⊗ MOE 2002-3 (CORES)
- ● MOE 2002-3 (GRABS)
- • GOLDER - DILLON 2005 SAMPLING POINTS

NOTE

PCB CONCENTRATIONS IN µg/g

VELOCITIES IN m/s

120 0 120 240

SCALE 1:6000 METRES

DATE: Oct. 28, 2011

PROJECT: 03-1112-059 (7100)

Golder Associates

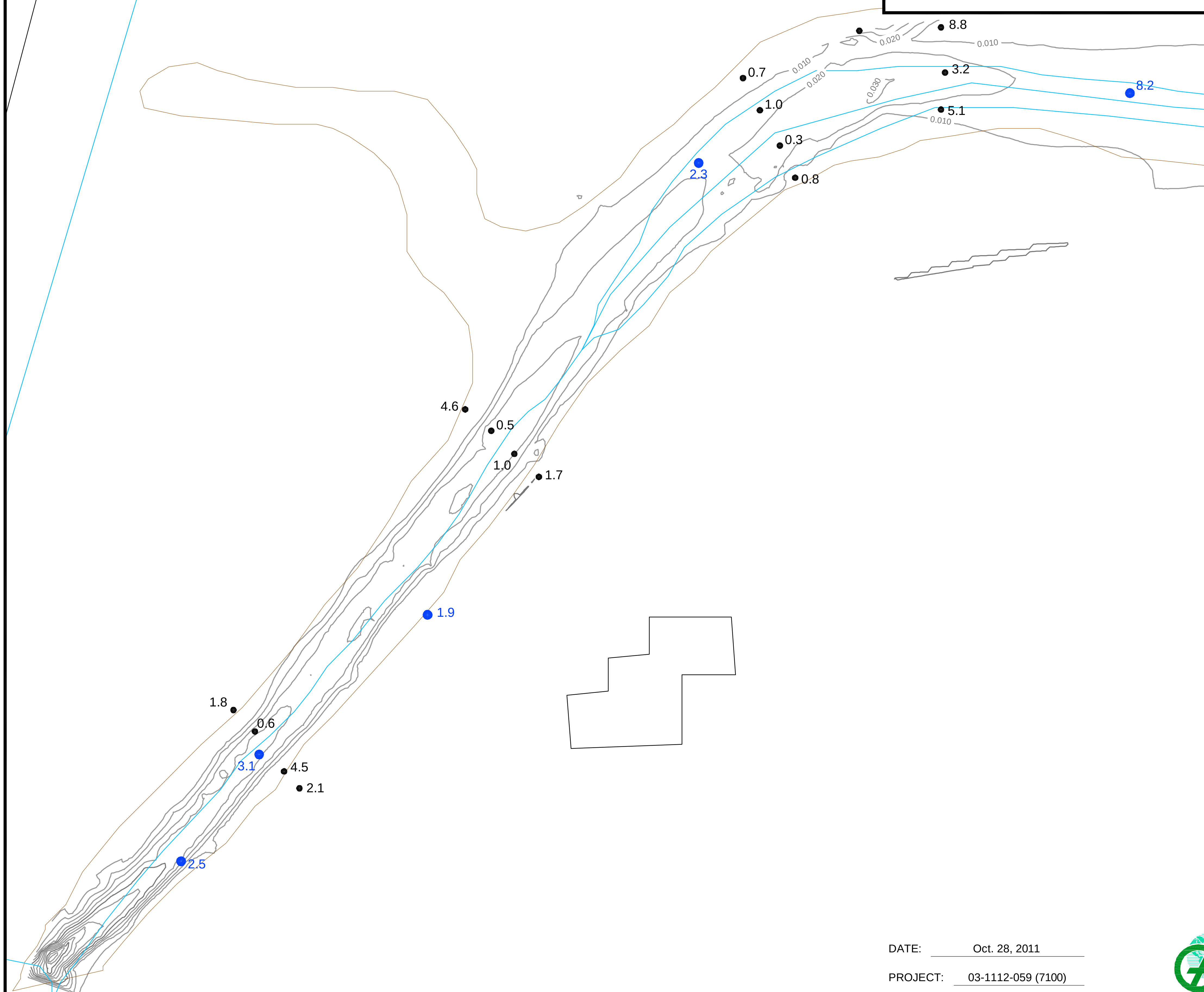
CAD: KD/DD

CHK: RJ

PLOT DATE: October 28, 2011
FILENAME: T:\Projects\2003\03-1112-059 (NPCA, Niagara)\~FB~ (7100)\031112059FB026.dwg

LYON'S CREEK EAST - SHEAR VELOCITY DISTRIBUTION (100 YEAR EVENT) AND PCBS IN SURFICIAL SEDIMENTS

FIGURE 27



LEGEND

- MOE 2002-3 (CORES)
- MOE 2002-3 (GRABS)
- GOLDER - DILLON 2005 SAMPLING POINTS

NOTE

PCB CONCENTRATIONS IN µg/g

VELOCITIES IN m/s

20 0 20 40

SCALE 1:1000 METRES

DATE: Oct. 28, 2011

PROJECT: 03-1112-059 (7100)

Golder Associates

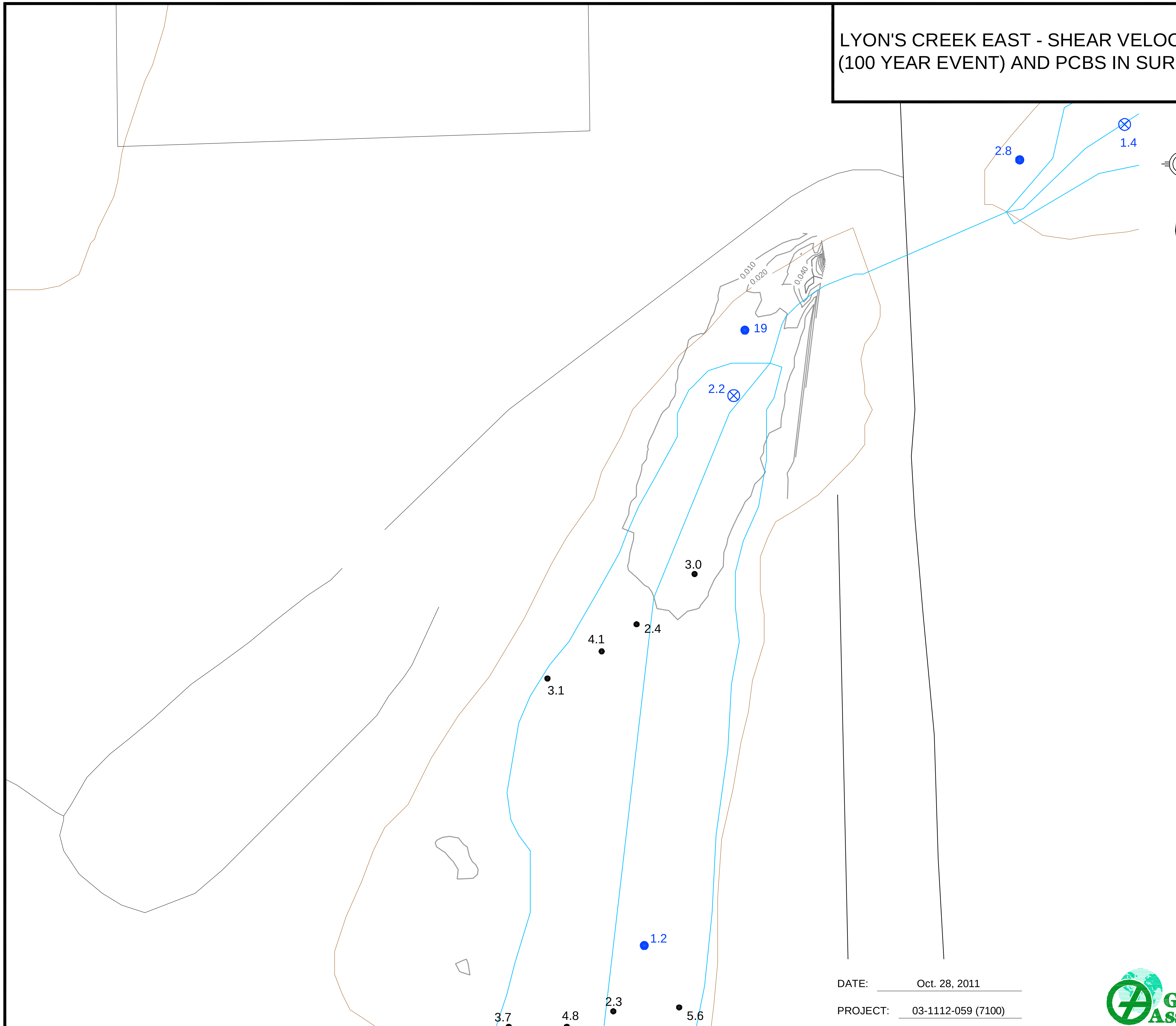
CAD: KD/DD

CHK: RJ

PLOT DATE: October 28, 2011
FILENAME: T:\Projects\2003\03-1112-059 (NPCA, Niagara)\-FB- (7100)\031112059FB027.dwg

LYON'S CREEK EAST - SHEAR VELOCITY DISTRIBUTION (100 YEAR EVENT) AND PCBS IN SURFICIAL SEDIMENTS

FIGURE 28



LEGEND

- MOE 2002-3 (CORES)
- MOE 2002-3 (GRABS)
- GOLDER - DILLON 2005 SAMPLING POINTS

NOTE

PCB CONCENTRATIONS IN µg/g

VELOCITIES IN m/s

20 0 20 40

SCALE 1:1000 METRES

DATE: Oct. 28, 2011

PROJECT: 03-1112-059 (7100)

Golder Associates

CAD: KD/DD

CHK: RJ

APPENDIX A

Photographs

Photograph 1: Lyon's Creek study reach outlet culvert

Photograph 2: Concrete pump housing at canal

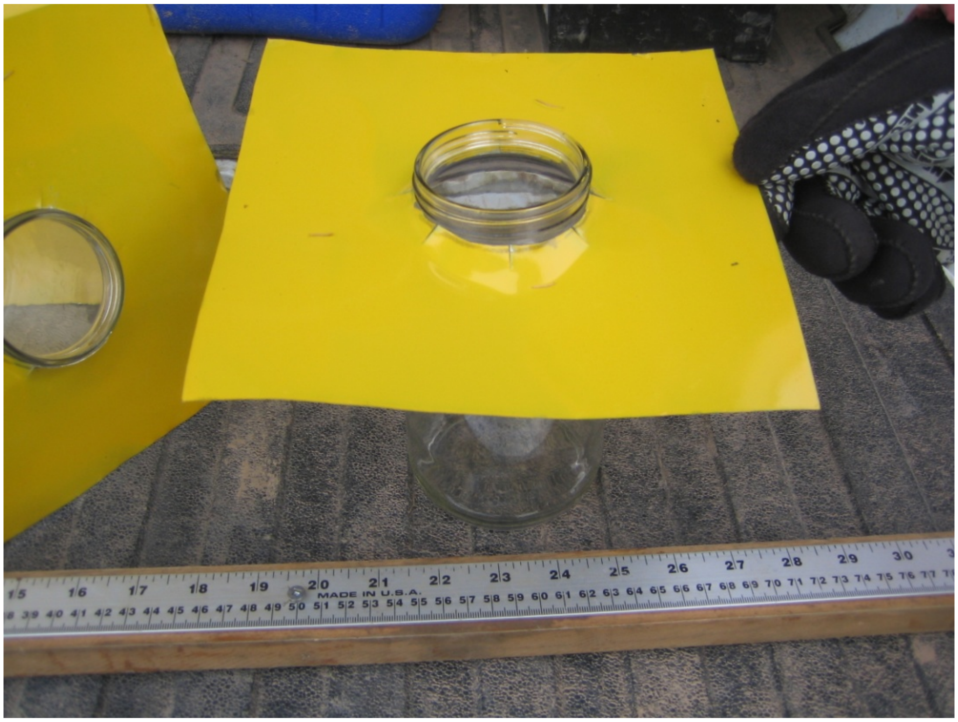
Photograph 3: SW3, discharge from pond on north shore

Photograph 4: SW4, downstream end of culvert at Ridge Road crossing

Photograph 5: SW5, downstream end of culvert at Ridge Road crossing

Photograph 4: Flume deployed in stream

Photograph 5: Flume on shore



Photograph 6: Sediment trap

Photograph 7: Sediment traps being set

Photograph 8: Ship passing in canal

Photograph 9: YSI on a float in canal

n:\active\2003\1112\03-1112-059 - niagara pen-sed assessment-niagara river\phase iv\sediment transport 2009\final_report\031112059 - appendix a (23sept2011).docx

APPENDIX B

Input Stream Water Quality Results

STATION		DATE	PARAMETER	VALUE	UNIT	MDL
SW1		2009-12-10	<100 >60 um	<2	mg/L	2
SW1		2009-12-10	>100 um	5	mg/L	2
SW1		2009-12-10	Total Suspended Solids	296	mg/L	2
SW1		2009-12-10	<11 >1 um	268	mg/L	2
SW1		2009-12-10	<30 >11 um	2	mg/L	2
SW1		2009-12-10	<60 >30 um	6	mg/L	2
SW2		2009-12-10	<11 >1 um	51	mg/L	2
SW2		2009-12-10	<30 >11 um	3	mg/L	2
SW2		2009-12-10	<60 >30 um	3	mg/L	2
SW2		2009-12-10	<100 >60 um	<2	mg/L	2
SW2		2009-12-10	>100 um	2	mg/L	2
SW2		2009-12-10	Total Suspended Solids	60	mg/L	2
SW3		2009-12-10	<11 >1 um	44	mg/L	2
SW3		2009-12-10	<30 >11 um	2	mg/L	2
SW3		2009-12-10	<60 >30 um	2	mg/L	2
SW3		2009-12-10	<100 >60 um	<2	mg/L	2
SW3		2009-12-10	>100 um	2	mg/L	2
SW3		2009-12-10	Total Suspended Solids	55	mg/L	2
SW4		2009-12-10	<11 >1 um	22	mg/L	2
SW4		2009-12-10	<30 >11 um	<2	mg/L	2
SW4		2009-12-10	<60 >30 um	<2	mg/L	2
SW4		2009-12-10	<100 >60 um	<2	mg/L	2
SW4		2009-12-10	>100 um	2	mg/L	2
SW4		2009-12-10	Total Suspended Solids	26	mg/L	2
SW5		2009-12-10	<11 >1 um	91	mg/L	2
SW5		2009-12-10	<30 >11 um	2	mg/L	2
SW5		2009-12-10	<60 >30 um	2	mg/L	2
SW5		2009-12-10	<100 >60 um	<2	mg/L	2
SW5		2009-12-10	>100 um	<2	mg/L	2
SW5		2009-12-10	Total Suspended Solids	95	mg/L	2

STATION		DATE	PARAMETER	VALUE	UNIT	MDL
SC		2010-03-30	<11 >1 um	9	mg/L	2
SC		2010-03-30	<30 >11 um	<2	mg/L	2
SC		2010-03-30	<60 >30 um	<2	mg/L	2
SC		2010-03-30	<100 >60 um	<2	mg/L	2
SC		2010-03-30	>100 um	<2	mg/L	2
SC		2010-03-30	Total Suspended Solids	8	mg/L	2
SW2		2010-03-30	<11 >1 um	20	mg/L	2
SW2		2010-03-30	<30 >11 um	<2	mg/L	2
SW2		2010-03-30	<60 >30 um	<2	mg/L	2
SW2		2010-03-30	<100 >60 um	<2	mg/L	2
SW2		2010-03-30	>100 um	<2	mg/L	2
SW2		2010-03-30	Total Suspended Solids	25	mg/L	2
SW3		2010-03-30	<11 >1 um	5	mg/L	2
SW3		2010-03-30	<30 >11 um	<2	mg/L	2
SW3		2010-03-30	<60 >30 um	<2	mg/L	2
SW3		2010-03-30	<100 >60 um	<2	mg/L	2
SW3		2010-03-30	>100 um	<2	mg/L	2
SW3		2010-03-30	Total Suspended Solids	6	mg/L	2

Your C.O.C. #: 17567101, 175671-0

Attention: Craig De Vito
Golder Associates Ltd
Mississauga - Standing Offer
2390 Argentia Rd
Mississauga, ON
L5N 5Z7

Report Date: 2009/12/17

CERTIFICATE OF ANALYSIS

MAXXAM JOB #: A9G9434
Received: 2009/12/15, 16:55

Sample Matrix: Water
Samples Received: 2

Analyses	Quantity	Date Extracted	Date Analyzed	Laboratory Method	Method Reference
Total Suspended Solids	2	N/A	2009/12/16	CAM SOP-00428	SM 2540D

* RPDs calculated using raw data. The rounding of final results may result in the apparent difference.
* Results relate only to the items tested.

Encryption Key

Please direct all questions regarding this Certificate of Analysis to your Project Manager.

CHRISTINE MCLEAN, Project Manager
Email: christine.mclean@maxxamanalytics.com
Phone# (905) 817-5700

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For Service Group specific validation please refer to the Validation Signature Page

Total cover pages: 1

Golder Associates Ltd

Maxxam Job #: A9G9434
Report Date: 2009/12/17

RESULTS OF ANALYSES OF WATER

Maxxam ID		EQ8521	EQ8522		
Sampling Date		2009/12/10	2009/12/10		
	Units	**IN**	**OUT**	**RDL**	**QC Batch**
Inorganics					
Total Suspended Solids	mg/L	<10	24	10	2038046

RDL = Reportable Detection Limit
QC Batch = Quality Control Batch

Maxxam Analytics International Corporation o/a Maxxam Analytics 6740 Campobello Road, Mississauga, Ontario, L5N 2L8 Tel: (905) 817-5700 Toll-Free: 800-563-6266 Fax: (905) 817-5777 www.maxxam.ca

Package 1	2.0°C

Each temperature is the average of up to three cooler temperatures taken at receipt

GENERAL COMMENTS

Maxxam Analytics International Corporation o/a Maxxam Analytics 6740 Campobello Road, Mississauga, Ontario, L5N 2L8 Tel: (905) 817-5700 Toll-Free: 800-563-6266 Fax: (905) 817-5777 www.maxxam.ca

Golder Associates Ltd

Maxxam Job #: A9G9434
Report Date: 2009/12/17

QUALITY ASSURANCE REPORT

			Method Blank		RPD		QC Standard	
QC Batch	Parameter	Date	Value	Units	Value (%)	QC Limits	% Recovery	QC Limits
2038046	Total Suspended Solids	2009/12/16	<10	mg/L	1.1	25	102	85 - 115

N/A = Not Applicable
RPD = Relative Percent Difference
Duplicate: Paired analysis of a separate portion of the same sample. Used to evaluate the variance in the measurement.
QC Standard: A blank matrix to which a known amount of the analyte has been added. Used to evaluate analyte recovery.
Method Blank: A blank matrix containing all reagents used in the analytical procedure. Used to identify laboratory contamination.

Maxxam Analytics International Corporation o/a Maxxam Analytics 6740 Campobello Road, Mississauga, Ontario, L5N 2L8 Tel: (905) 817-5700 Toll-Free: 800-563-6266 Fax: (905) 817-5777 www.maxxam.ca

Validation Signature Page

Maxxam Job #: A9G9434

The analytical data and all QC contained in this report were reviewed and validated by the following individual(s).

TROY CARRIERE, B.Sc., C.Chem, Scientific Specialist

===

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Your Project #: 03-1112-059
Your C.O.C. #: OO601157

Attention: Craig De Vito
Golder Associates Ltd
Mississauga - Standing Offer
2390 Argentia Rd
Mississauga, ON
L5N 5Z7

Report Date: 2010/04/06

CERTIFICATE OF ANALYSIS

MAXXAM JOB #: B039062
Received: 2010/04/01, 13:25

Sample Matrix: Water
Samples Received: 4

Analyses	Quantity	Date Extracted	Date Analyzed	Laboratory Method	Method Reference
Total Suspended Solids	4	N/A	2010/04/05	CAM SOP-00428	SM 2540D

* RPDs calculated using raw data. The rounding of final results may result in the apparent difference.
* Results relate only to the items tested.

Encryption Key

Please direct all questions regarding this Certificate of Analysis to your Project Manager.

CHRISTINE MCLEAN, Project Manager
Email: christine.mclean@maxxamanalytics.com
Phone# (905) 817-5700

==
Maxxam has procedures in place to guard against improper use of the electronic signature and have the required "signatories", as per section 5.10.2 of ISO/IEC 17025:2005(E), signing the reports. For Service Group specific validation please refer to the Validation Signature Page.

Total cover pages: 1

Maxxam Job #: B039062
Report Date: 2010/04/06

Golder Associates Ltd
Client Project #: 03-1112-059

RESULTS OF ANALYSES OF WATER

Maxxam ID		FM1727	FM1728	FM1729	FM1730		
Sampling Date		2010/03/31	2010/03/31	2010/03/31	2010/03/31		
	Units	**IN**	**OUT**	**SW4**	**SW5**	**RDL**	**QC Batch**
Inorganics							
Total Suspended Solids	mg/L	<10	10	<10	15	10	2115895

RDL = Reportable Detection Limit
QC Batch = Quality Control Batch

Maxxam Analytics International Corporation o/a Maxxam Analytics 6740 Campobello Road, Mississauga, Ontario, L5N 2L8 Tel: (905) 817-5700 Toll-Free: 800-563-6266 Fax: (905) 817-5777 www.maxxam.ca

Maxxam Job #: B039062
Report Date: 2010/04/06

Golder Associates Ltd
Client Project #: 03-1112-059

Package 1	3.3°C

Each temperature is the average of up to three cooler temperatures taken at receipt

GENERAL COMMENTS

Maxxam Analytics International Corporation o/a Maxxam Analytics 6740 Campobello Road, Mississauga, Ontario, L5N 2L8 Tel: (905) 817-5700 Toll-Free: 800-563-6266 Fax: (905) 817-5777 www.maxxam.ca

Maxxam Job #: B039062
Report Date: 2010/04/06

Golder Associates Ltd
Client Project #: 03-1112-059

QUALITY ASSURANCE REPORT

			Method Blank		RPD		QC Standard	
QC Batch	Parameter	Date	Value	Units	Value (%)	QC Limits	% Recovery	QC Limits
2115895	Total Suspended Solids	2010/04/05	<10	mg/L	NC	25	101	85 - 115

N/A = Not Applicable
RPD = Relative Percent Difference
QC Standard: A blank matrix to which a known amount of the analyte has been added. Used to evaluate analyte recovery.
Method Blank: A blank matrix containing all reagents used in the analytical procedure. Used to identify laboratory contamination.
NC (RPD): The RPD was not calculated. The level of analyte detected in the parent sample and its duplicate was not sufficiently significant to permit a reliable calculation.

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Validation Signature Page

Maxxam Job #: B039062

The analytical data and all QC contained in this report were reviewed and validated by the following individual(s).

Cristina Carriere

CRISTINA CARRIERE, Scientific Services

==

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Your P.O. #: 03-1112-059
Your Project #: 03-1112-059
Your C.O.C. #: OO590639

Attention: Craig De Vito
Golder Associates Ltd
Mississauga - Standing Offer
2390 Argentia Rd
Mississauga, ON
L5N 5Z7

Report Date: 2010/07/13

CERTIFICATE OF ANALYSIS

MAXXAM JOB #: B090366
Received: 2010/07/09, 15:40

Sample Matrix: Water
Samples Received: 2

Analyses	Quantity	Date Extracted	Date Analyzed	Laboratory Method	Method Reference
Total Suspended Solids	2	N/A	2010/07/12	CAM SOP-00428	SM 2540D

* RPDs calculated using raw data. The rounding of final results may result in the apparent difference.
* Results relate only to the items tested.

Encryption Key

Please direct all questions regarding this Certificate of Analysis to your Project Manager.

CHRISTINE MCLEAN, Project Manager
Email: christine.mclean@maxxamanalytics.com
Phone# (905) 817-5700

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Total cover pages: 1

Maxxam Job #: B090366
Report Date: 2010/07/13

Golder Associates Ltd
Client Project #: 03-1112-059

Your P.O. #: 03-1112-059

RESULTS OF ANALYSES OF WATER

Maxxam ID		GL2700	GL2701		
Sampling Date		2010/07/09	2010/07/09		
	Units	**IN**	**OUT**	**RDL**	**QC Batch**
Inorganics					
Total Suspended Solids	mg/L	<10	<10	10	2202964

RDL = Reportable Detection Limit
QC Batch = Quality Control Batch

Maxxam Analytics International Corporation o/a Maxxam Analytics 6740 Campobello Road, Mississauga, Ontario, L5N 2L8 Tel: (905) 817-5700 Toll-Free: 800-563-6266 Fax: (905) 817-5777 www.maxxam.ca

Maxxam Job #: B090366
Report Date: 2010/07/13

Golder Associates Ltd
Client Project #: 03-1112-059

Your P.O. #: 03-1112-059

QUALITY ASSURANCE REPORT

			Method Blank		RPD		QC Standard	
QC Batch	Parameter	Date	Value	Units	Value (%)	QC Limits	% Recovery	QC Limits
2202964	Total Suspended Solids	2010/07/12	<10	mg/L	NC	25	99	85 - 115

N/A = Not Applicable
RPD = Relative Percent Difference
QC Standard: A blank matrix to which a known amount of the analyte has been added. Used to evaluate analyte recovery.
Method Blank: A blank matrix containing all reagents used in the analytical procedure. Used to identify laboratory contamination.
NC (RPD): The RPD was not calculated. The level of analyte detected in the parent sample and its duplicate was not sufficiently significant to permit a reliable calculation.

Validation Signature Page

Maxxam Job #: B090366

The analytical data and all QC contained in this report were reviewed and validated by the following individual(s).

CRISTINA CARRIERE, Scientific Services

==

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APPENDIX C

Canal Water Quality Results

STATION		DATE	PARAMETER	VALUE	UNIT	MDL
SW1		2009-11-05	<11 >1 um	4	mg/L	2
SW1		2009-11-05	<30 >11 um	<2	mg/L	2
SW1		2009-11-05	<60 >30 um	<2	mg/L	2
SW1		2009-11-05	<100 >60 um	<2	mg/L	2
SW1		2009-11-05	>100 um	<2	mg/L	2
SW1		2009-11-05	Total Suspended Solids	5	mg/L	2
SW10		2009-11-05	<11 >1 um	5	mg/L	2
SW10		2009-11-05	<30 >11 um	<2	mg/L	2
SW10		2009-11-05	<60 >30 um	<2	mg/L	2
SW10		2009-11-05	<100 >60 um	<2	mg/L	2
SW10		2009-11-05	>100 um	<2	mg/L	2
SW10		2009-11-05	Total Suspended Solids	9	mg/L	2
SW11		2009-11-05	<11 >1 um	5	mg/L	2
SW11		2009-11-05	<30 >11 um	4	mg/L	2
SW11		2009-11-05	<60 >30 um	2	mg/L	2
SW11		2009-11-05	<100 >60 um	<2	mg/L	2
SW11		2009-11-05	>100 um	<2	mg/L	2
SW11		2009-11-05	Total Suspended Solids	7	mg/L	2
SW12		2009-11-05	Total Suspended Solids	16	mg/L	2
SW13		2009-11-05	Total Suspended Solids	4	mg/L	2
SW14		2009-11-05	Total Suspended Solids	5	mg/L	2
SW2		2009-10-28	<11 >1 um	<2	mg/L	2
SW2		2009-10-28	<30 >11 um	<2	mg/L	2
SW2		2009-10-28	<60 >30 um	<2	mg/L	2
SW2		2009-10-28	<100 >60 um	<2	mg/L	2
SW2		2009-10-28	>100 um	<2	mg/L	2
SW2		2009-10-28	Total Suspended Solids	<2	mg/L	2
SW3		2009-11-05	Total Suspended Solids	<2	mg/L	2
SW4		2009-11-05	Total Suspended Solids	2	mg/L	2
SW5		2009-11-05	Total Suspended Solids	2	mg/L	2
SW6		2009-11-05	Total Suspended Solids	6	mg/L	2
SW7		2009-11-05	Total Suspended Solids	10	mg/L	2
SW8		2009-11-05	Total Suspended Solids	41	mg/L	2
SW9		2009-11-05	Total Suspended Solids	28	mg/L	2

Your Project #: 03-1112-059 (7000)
Your C.O.C. #: 19560601, 195606-0

Attention: Craig De Vito
Golder Associates Ltd
Mississauga - Standing Offer
2390 Argentia Rd
Mississauga, ON
L5N 5Z7

Report Date: 2010/07/27

CERTIFICATE OF ANALYSIS

MAXXAM JOB #: B098696
Received: 2010/07/23, 16:45

Sample Matrix: Water
Samples Received: 7

Analyses	Quantity	Date Extracted	Date Analyzed	Laboratory Method	Method Reference
Total Suspended Solids	7	N/A	2010/07/27	CAM SOP-00428	SM 2540D

* RPDs calculated using raw data. The rounding of final results may result in the apparent difference.
* Results relate only to the items tested.

Encryption Key

Please direct all questions regarding this Certificate of Analysis to your Project Manager.

CHRISTINE MCLEAN, Project Manager
Email: christine.mclean@maxxamanalytics.com
Phone# (905) 817-5700

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Total cover pages: 1

Maxxam Job #: B098696
Report Date: 2010/07/27

Golder Associates Ltd
Client Project #: 03-1112-059 (7000)

RESULTS OF ANALYSES OF WATER

Maxxam ID		GP3836		GP3837	GP3838	GP3839	GP3840	GP3841		GP3842		
Sampling Date		2010/07/22		2010/07/22	2010/07/22	2010/07/22	2010/07/22	2010/07/22		2010/07/22		
	Units	**SW1**	**QC Batch**	**SW2**	**SW3**	**SW4**	**SW5**	**SW6**	**QC Batch**	**SW7**	**RDL**	**QC Batch**
Inorganics												
Total Suspended Solids	mg/L	22	2217640	21	12	<10	<10	13	2217639	<10	10	2217640

RDL = Reportable Detection Limit
QC Batch = Quality Control Batch

Maxxam Job #: B098696
Report Date: 2010/07/27

Golder Associates Ltd
Client Project #: 03-1112-059 (7000)

QUALITY ASSURANCE REPORT

			Method Blank		RPD		QC Standard	
QC Batch	Parameter	Date	Value	Units	Value (%)	QC Limits	% Recovery	QC Limits
2217639	Total Suspended Solids	2010/07/27	<10	mg/L	NC	25	96	85 - 115
2217640	Total Suspended Solids	2010/07/27	<10	mg/L	NC	25	98	85 - 115

N/A = Not Applicable
RPD = Relative Percent Difference
QC Standard: A blank matrix to which a known amount of the analyte has been added. Used to evaluate analyte recovery.
Method Blank: A blank matrix containing all reagents used in the analytical procedure. Used to identify laboratory contamination.
NC (RPD): The RPD was not calculated. The level of analyte detected in the parent sample and its duplicate was not sufficiently significant to permit a reliable calculation.

Maxxam Analytics International Corporation o/a Maxxam Analytics 6740 Campobello Road, Mississauga, Ontario, L5N 2L8 Tel: (905) 817-5700 Toll-Free: 800-563-6266 Fax: (905) 817-5777 www.maxxam.ca

Validation Signature Page

Maxxam Job #: B098696

The analytical data and all QC contained in this report were reviewed and validated by the following individual(s).

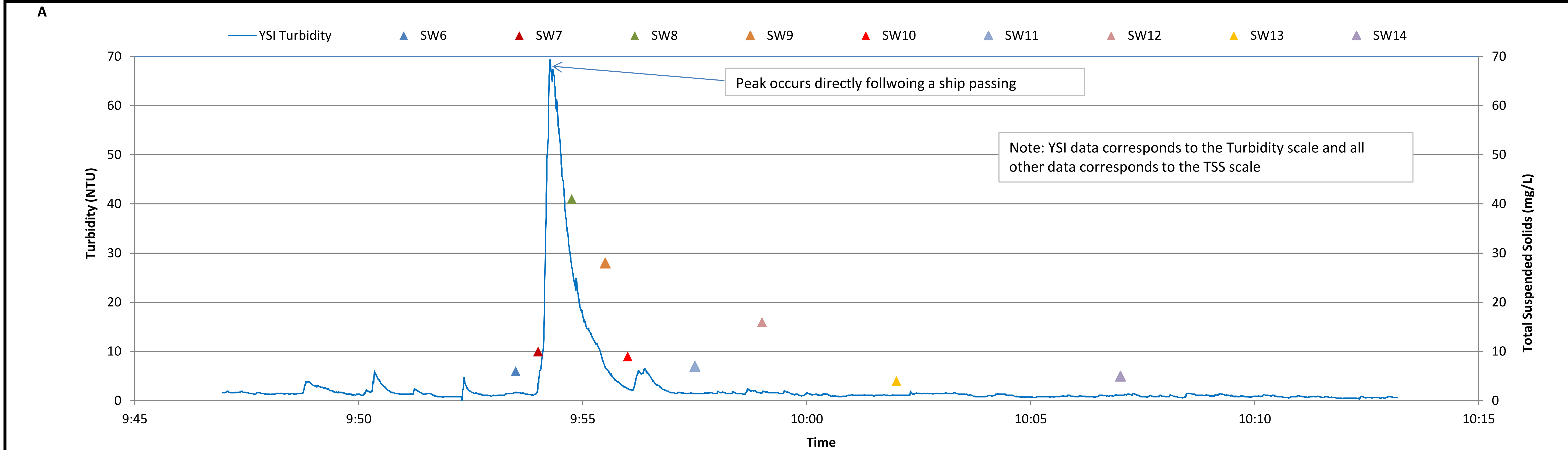
CRISTINA CARRIERE, Scientific Services

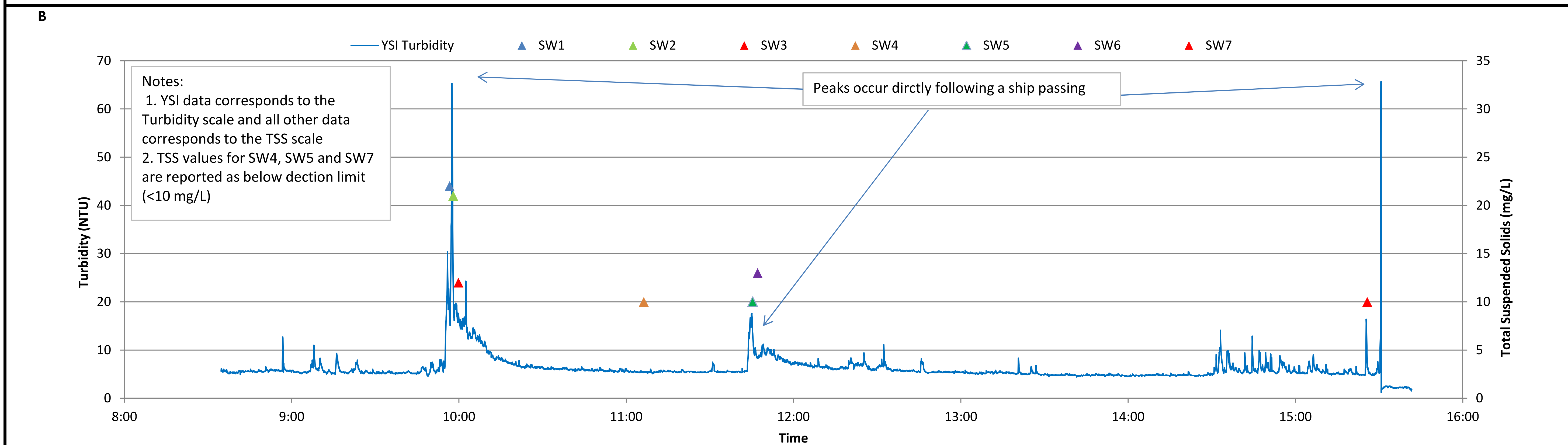
==

Maxxam has procedures in place to guard against improper use of the electronic signature and have the required "signatories", as per section 5.10.2 of ISO/IEC 17025:2005(E), signing the reports. For Service Group specific validation please refer to the Validation Signature Page.

Maxxam Analytics International Corporation o/a Maxxam Analytics 6740 Campobello Road, Mississauga, Ontario, L5N 2L8 Tel: (905) 817-5700 Toll-Free: 800-563-6266 Fax: (905) 817-5777 www.maxxam.ca

Welland CanalShip Monitoring	APPENDIX C





A. Monitoring Conducted on November 5, 2009 **B.** Monitoring Conducted on July 24, 2010

PROJECT: 03-1112-059
DATE: November 2011

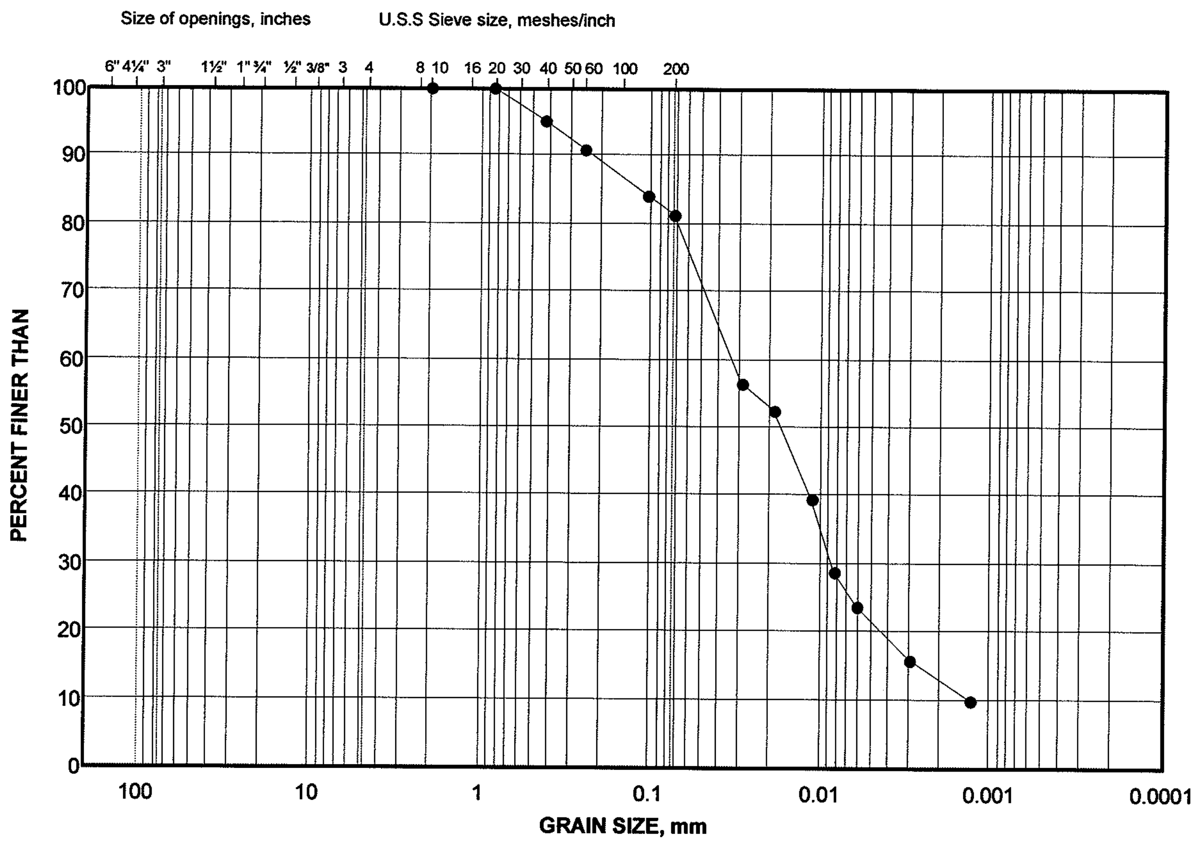
DRAWN: CMD
CHECK: KMM

Golder Associates

APPENDIX D

Sediment Trap Results

GRAIN SIZE DISTRIBUTION	FIGURE



COBBLE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT AND CLAY SIZES
SIZE	GRAVEL SIZE		SAND SIZE			FINE GRAINED

LEGEND

SYMBOL	BOREHOLE	SAMPLE	DEPTH(m)
●		XS7RB	

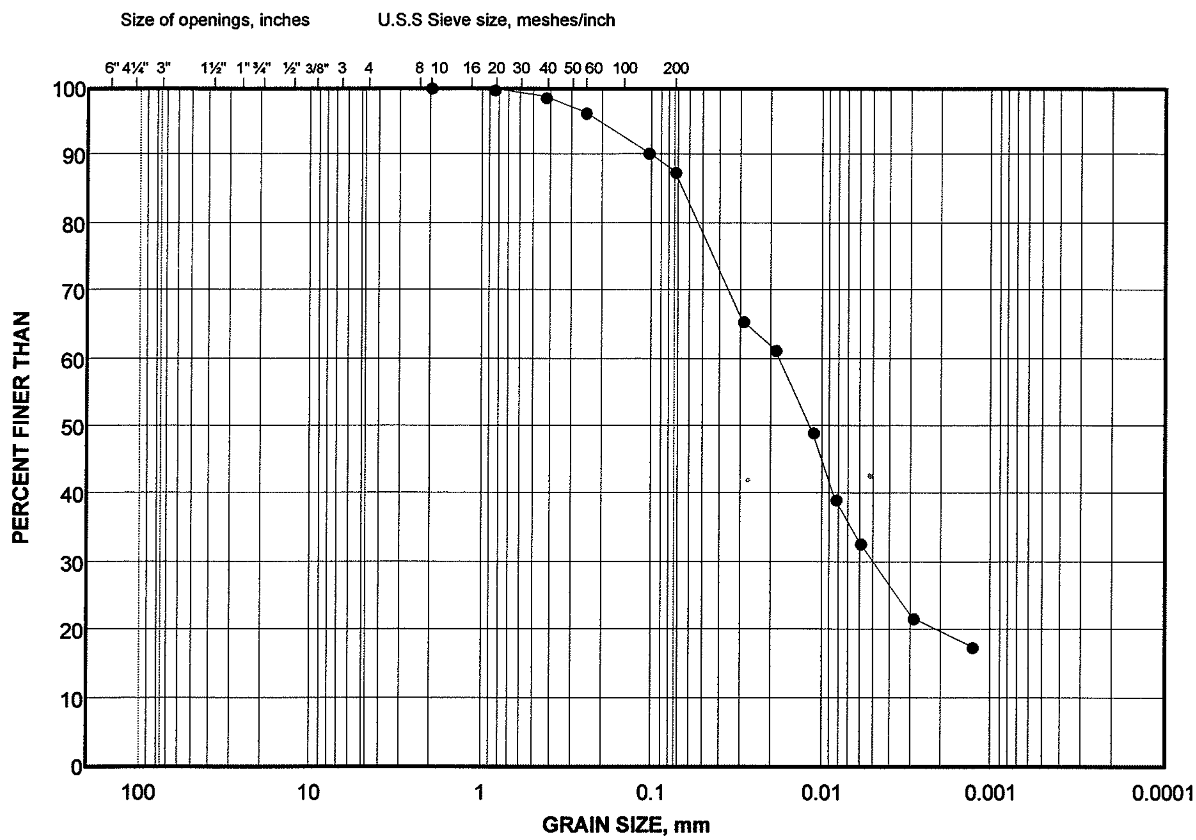
Project Number: 03-1112-059

Checked By: ____________

Golder Associates

Date: 19-Apr-10

GRAIN SIZE DISTRIBUTION	FIGURE



COBBLE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT AND CLAY SIZES
SIZE	GRAVEL SIZE		SAND SIZE			FINE GRAINED

LEGEND

SYMBOL	BOREHOLE	SAMPLE	DEPTH(m)
●		XS17RB	

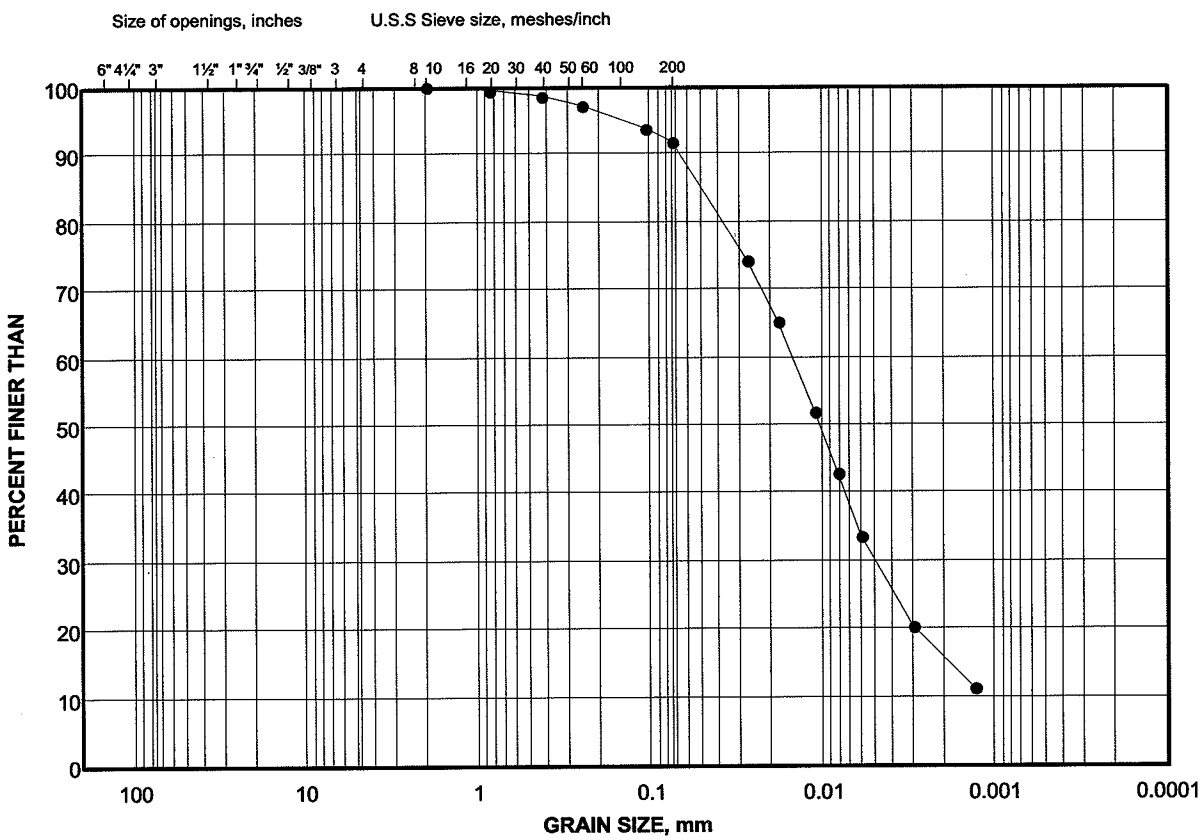
Project Number: 03-1112-059

Checked By: ____________

Golder Associates

Date: 19-Apr-10

GRAIN SIZE DISTRIBUTION	FIGURE



COBBLE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT AND CLAY SIZES
SIZE	GRAVEL SIZE		SAND SIZE			FINE GRAINED

LEGEND

SYMBOL	BOREHOLE	SAMPLE	DEPTH(m)
●		7LB	

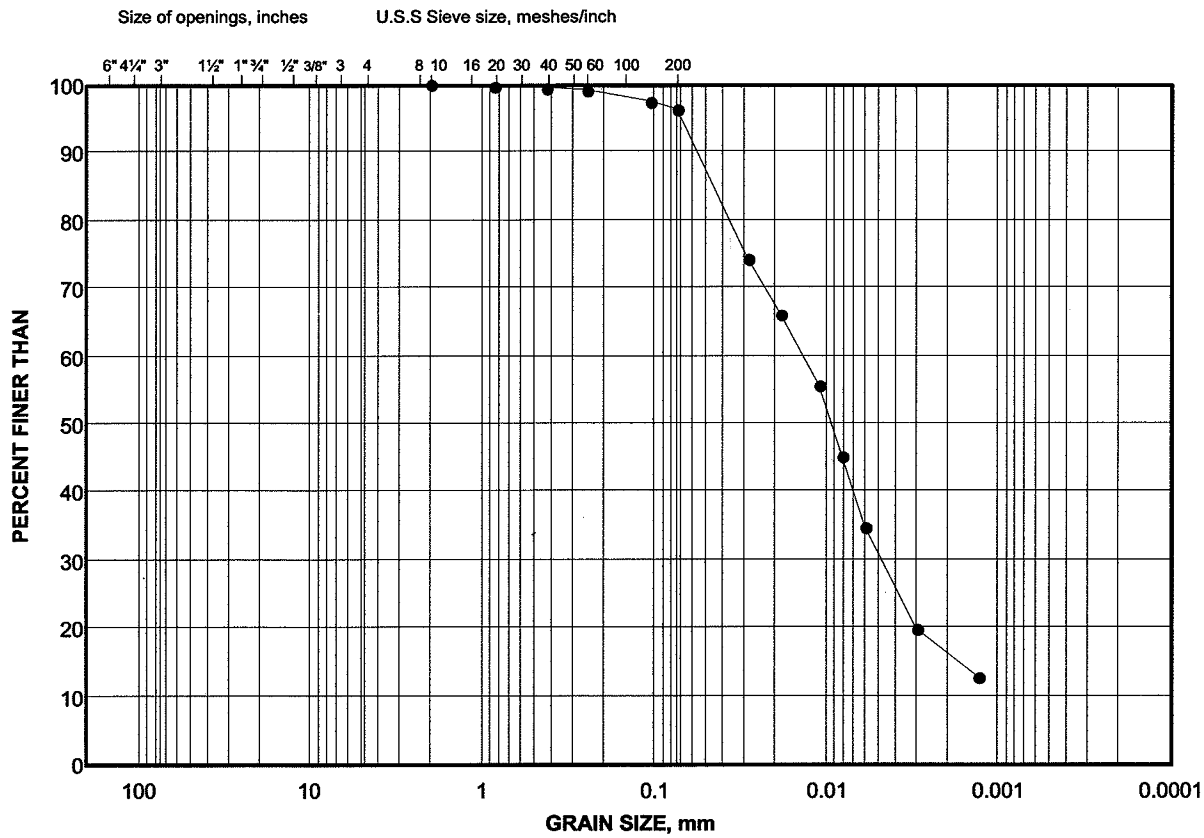
Project Number: 03-1112-059

Checked By: ____________

Golder Associates

Date: 01-Sep-10

GRAIN SIZE DISTRIBUTION	FIGURE



COBBLE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT AND CLAY SIZES
SIZE	GRAVEL SIZE		SAND SIZE			FINE GRAINED

LEGEND

SYMBOL	BOREHOLE	SAMPLE	DEPTH(m)
●		RB7	

Project Number: 03-1112-059

Checked By: ____________

Golder Associates

Date: 01-Sep-10

SUMMARY OF WATER CONTENT DETERMINATIONS

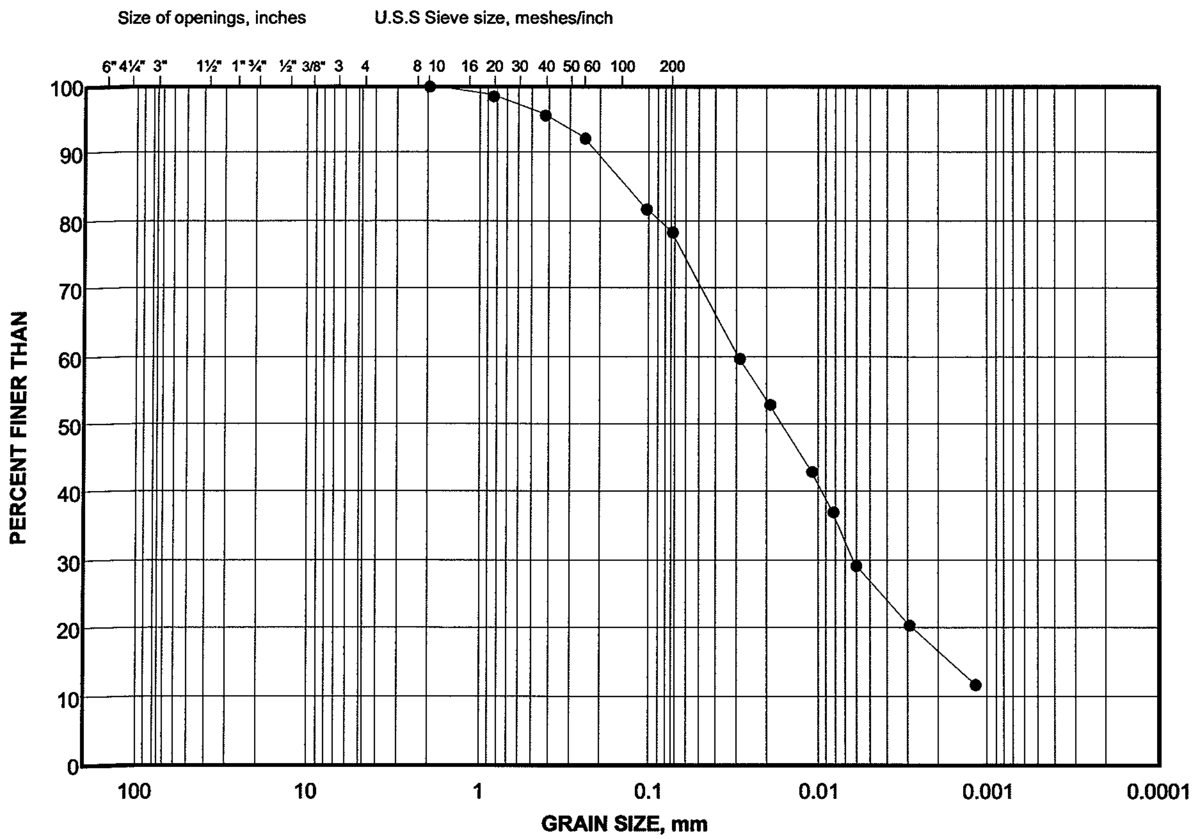
PROJECT NUMBER	03-1112-059
PROJECT NAME	Niagara Peninsula / Sed. Assessment / Niagara River
DATE TESTED	December, 2010

Sample No.	Water Content (%)	Atterberg Limits LL, PL, PI
7R	1986.3%	
9R	665.6%	
12R	2753.0%	
14R	599.5%	
16L	617.2%	
17R	627.2%	
OUT RB	548.2%	

Checked By: [signature]

Golder Associates

GRAIN SIZE DISTRIBUTION	FIGURE



COBBLE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT AND CLAY SIZES
SIZE	GRAVEL SIZE		SAND SIZE			FINE GRAINED

LEGEND

SYMBOL	BOREHOLE	SAMPLE	DEPTH(m)
●		OUT RB	

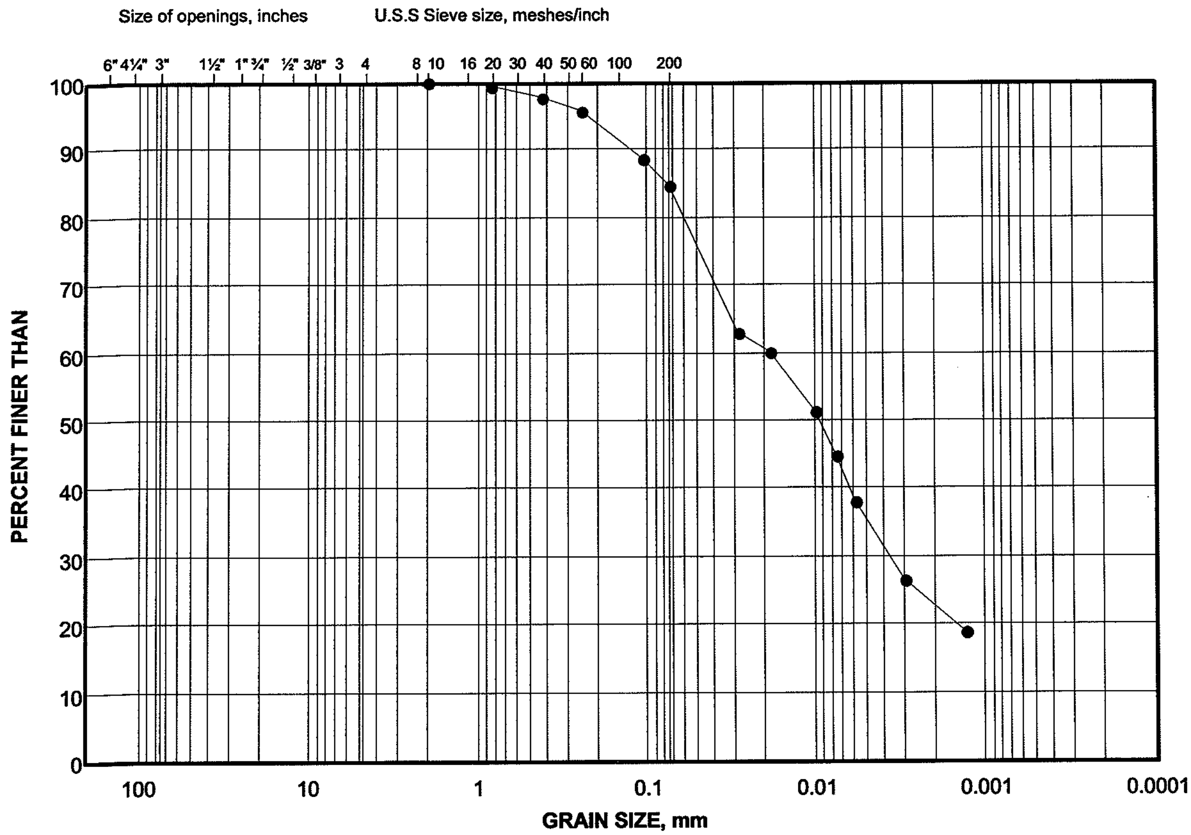
Project Number: 03-1112-059

Checked By: [signature]

Golder Associates

Date: 15-Dec-10

GRAIN SIZE DISTRIBUTION	FIGURE



COBBLE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT AND CLAY SIZES
SIZE	GRAVEL SIZE		SAND SIZE			FINE GRAINED

LEGEND

SYMBOL	BOREHOLE	SAMPLE	DEPTH(m)
●		14R	

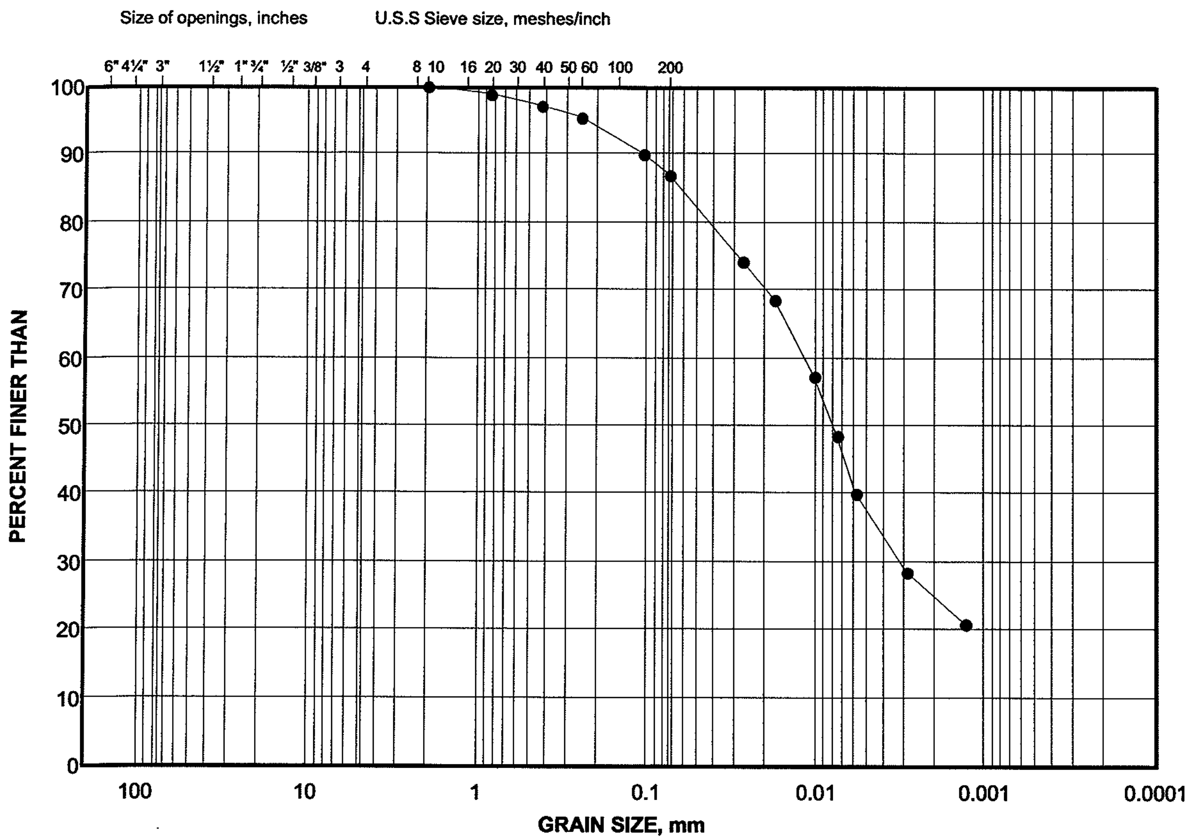
Project Number: 03-1112-059

Checked By: ____________

Golder Associates

Date: 14-Dec-10

GRAIN SIZE DISTRIBUTION	FIGURE



COBBLE	COARSE	FINE	COARSE	MEDIUM	FINE	SILT AND CLAY SIZES
SIZE	GRAVEL SIZE		SAND SIZE			FINE GRAINED

LEGEND

SYMBOL	BOREHOLE	SAMPLE	DEPTH(m)
●		9R	

Project Number: 03-1112-059

Checked By: ____________

Golder Associates

Date: 14-Dec-10

Maxxam

Success Through Science®

Your Project #: 03-1112-059
Site: LYON'S CREEK
Your C.O.C. #: 17182

Attention: Craig De Vito
Golder Associates Ltd
Mississauga - Standing Offer
2390 Argentia Rd
Mississauga, ON
L5N 5Z7

Report Date: 2010/12/07

CERTIFICATE OF ANALYSIS

MAXXAM JOB #: B0H3427
Received: 2010/12/01, 15:17

Sample Matrix: Soil
Samples Received: 3

Analyses	Quantity	Date Extracted	Date Analyzed	Laboratory Method	Method Reference
Volatile Organic Compounds in Soil	2	2010/12/03	2010/12/07	CAM SOP-00226	EPA 8260 modified
Volatile Organic Compounds in Soil	1	2010/12/04	2010/12/07	CAM SOP-00226	EPA 8260 modified

* RPDs calculated using raw data. The rounding of final results may result in the apparent difference.
* Results relate only to the items tested.

Encryption Key

Please direct all questions regarding this Certificate of Analysis to your Project Manager.

MATHURA THIRUKKUMARAN, CS Rep
Email: MThirukkumaran@maxxam.ca
Phone# (905) 817-5700

==
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Total cover pages: 1

Maxxam Job #: B0H3427
Report Date: 2010/12/07

Golder Associates Ltd
Client Project #: 03-1112-059
Project name: LYON'S CREEK
Sampler Initials: CD

VOLATILE ORGANICS BY GC/MS (SOIL)

Maxxam ID		IA4309	IA4310	IA4311		
Sampling Date		2010/11/26	2010/11/26	2010/11/26		
	Units	**9L**	**17L**	**7L**	**RDL**	**QC Batch**
Volatile Organics						
Acetone (2-Propanone)	ug/g	<5	<5	<5	5	2350152
Benzene	ug/g	<0.1	<0.1	<0.1	0.1	2350152
Bromodichloromethane	ug/g	<0.1	<0.1	<0.1	0.1	2350152
Bromoform	ug/g	<0.1	<0.1	<0.1	0.1	2350152
Bromomethane	ug/g	<0.2	<0.2	<0.2	0.2	2350152
Carbon Tetrachloride	ug/g	<0.1	<0.1	<0.1	0.1	2350152
Chlorobenzene	ug/g	<0.1	<0.1	<0.1	0.1	2350152
Chloroform	ug/g	<0.1	<0.1	<0.1	0.1	2350152
Dibromochloromethane	ug/g	<0.1	<0.1	<0.1	0.1	2350152
1,2-Dichlorobenzene	ug/g	<0.1	<0.1	<0.1	0.1	2350152
1,3-Dichlorobenzene	ug/g	<0.1	<0.1	<0.1	0.1	2350152
1,4-Dichlorobenzene	ug/g	<0.1	<0.1	<0.1	0.1	2350152
Dichlorodifluoromethane (FREON 12)	ug/g	<0.3	<0.3	<0.3	0.3	2350152
1,1-Dichloroethane	ug/g	<0.1	<0.1	<0.1	0.1	2350152
1,2-Dichloroethane	ug/g	<0.1	<0.1	<0.1	0.1	2350152
1,1-Dichloroethylene	ug/g	<0.1	<0.1	<0.1	0.1	2350152
cis-1,2-Dichloroethylene	ug/g	<0.1	<0.1	<0.1	0.1	2350152
trans-1,2-Dichloroethylene	ug/g	<0.1	<0.1	<0.1	0.1	2350152
1,2-Dichloropropane	ug/g	<0.1	<0.1	<0.1	0.1	2350152
cis-1,3-Dichloropropene	ug/g	<0.1	<0.1	<0.1	0.1	2350152
trans-1,3-Dichloropropene	ug/g	<0.1	<0.1	<0.1	0.1	2350152
Ethylbenzene	ug/g	<0.1	<0.1	<0.1	0.1	2350152
Ethylene Dibromide	ug/g	<0.1	<0.1	<0.1	0.1	2350152
Hexane	ug/g	<0.3	<0.3	<0.3	0.3	2350152
Methylene Chloride(Dichloromethane)	ug/g	<0.2	<0.2	<0.2	0.2	2350152
Methyl Isobutyl Ketone	ug/g	<1	<1	<1	1	2350152
Methyl Ethyl Ketone (2-Butanone)	ug/g	<1	<1	<1	1	2350152
Methyl t-butyl ether (MTBE)	ug/g	<0.1	<0.1	<0.1	0.1	2350152
Styrene	ug/g	<0.1	<0.1	<0.1	0.1	2350152
1,1,1,2-Tetrachloroethane	ug/g	<0.1	<0.1	<0.1	0.1	2350152
1,1,2,2-Tetrachloroethane	ug/g	<0.1	<0.1	<0.1	0.1	2350152
Tetrachloroethylene	ug/g	<0.1	<0.1	<0.1	0.1	2350152
Toluene	ug/g	0.5	<0.1	<0.1	0.1	2350152
1,1,1-Trichloroethane	ug/g	<0.1	<0.1	<0.1	0.1	2350152
1,1,2-Trichloroethane	ug/g	<0.1	<0.1	<0.1	0.1	2350152

RDL = Reportable Detection Limit
QC Batch = Quality Control Batch

Maxxam Job #: B0H3427
Report Date: 2010/12/07

Golder Associates Ltd
Client Project #: 03-1112-059
Project name: LYON'S CREEK
Sampler Initials: CD

VOLATILE ORGANICS BY GC/MS (SOIL)

Maxxam ID		IA4309	IA4310	IA4311		
Sampling Date		2010/11/26	2010/11/26	2010/11/26		
	Units	**9L**	**17L**	**7L**	**RDL**	**QC Batch**
Trichloroethylene	ug/g	<0.1	<0.1	<0.1	0.1	2350152
Vinyl Chloride	ug/g	<0.1	<0.1	<0.1	0.1	2350152
p+m-Xylene	ug/g	<0.1	<0.1	<0.1	0.1	2350152
o-Xylene	ug/g	<0.1	<0.1	<0.1	0.1	2350152
Xylene (Total)	ug/g	<0.1	<0.1	<0.1	0.1	2350152
Trichlorofluoromethane (FREON 11)	ug/g	<0.1	<0.1	<0.1	0.1	2350152
Surrogate Recovery (%)						
4-Bromofluorobenzene	%	92	95	91		2350152
D4-1,2-Dichloroethane	%	109	110	106		2350152
D8-Toluene	%	95	95	97		2350152

RDL = Reportable Detection Limit
QC Batch = Quality Control Batch

GENERAL COMMENTS

VOC Analysis: The samples were added to methanol and the extracts analysed by high level purge & trap (US EPA Method 5035) gas chromatography/mass spectrometry using US EPA Method 8260C (modified). The DLs were adjusted accordingly. No moisture correction was applied.

Maxxam Job #: B0H3427
Report Date: 2010/12/07

Golder Associates Ltd
Client Project #: 03-1112-059
Project name: LYON'S CREEK
Sampler Initials: CD

QUALITY ASSURANCE REPORT

			Matrix Spike		Spiked Blank		Method Blank		RPD	
QC Batch	Parameter	Date	% Recovery	QC Limits	% Recovery	QC Limits	Value	Units	Value (%)	QC Limits
2350152	4-Bromofluorobenzene	2010/12/06	78	60 - 140	100	60 - 140	95	%		
2350152	D4-1,2-Dichloroethane	2010/12/06	93	60 - 140	100	60 - 140	100	%		
2350152	D8-Toluene	2010/12/06	118	60 - 140	98	60 - 140	101	%		
2350152	Acetone (2-Propanone)	2010/12/06	73	24 - 171	96	60 - 140	<0.1	ug/g		
2350152	Benzene	2010/12/06	96	39 - 137	104	60 - 140	<0.002	ug/g	NC	50
2350152	Bromodichloromethane	2010/12/06	83	45 - 131	101	60 - 140	<0.002	ug/g		
2350152	Bromoform	2010/12/06	75	44 - 131	103	60 - 140	<0.002	ug/g		
2350152	Bromomethane	2010/12/06	105	20 - 146	94	60 - 140	<0.003	ug/g		
2350152	Carbon Tetrachloride	2010/12/06	103	40 - 139	112	60 - 140	<0.002	ug/g		
2350152	Chlorobenzene	2010/12/06	83	45 - 140	101	60 - 140	<0.002	ug/g		
2350152	Chloroform	2010/12/06	92	48 - 128	100	60 - 140	<0.002	ug/g		
2350152	Dibromochloromethane	2010/12/06	94	52 - 135	101	60 - 140	<0.002	ug/g		
2350152	1,2-Dichlorobenzene	2010/12/06	84	39 - 145	102	60 - 140	<0.002	ug/g		
2350152	1,3-Dichlorobenzene	2010/12/06	86	38 - 158	108	60 - 140	<0.002	ug/g		
2350152	1,4-Dichlorobenzene	2010/12/06	80	35 - 159	111	60 - 140	<0.002	ug/g		
2350152	Dichlorodifluoromethane (FREON 12)	2010/12/06	93	60 - 140	92	60 - 140	<0.005	ug/g	NC	50
2350152	1,1-Dichloroethane	2010/12/06	99	48 - 131	102	60 - 140	<0.002	ug/g		
2350152	1,2-Dichloroethane	2010/12/06	85	43 - 123	99	60 - 140	<0.002	ug/g		
2350152	1,1-Dichloroethylene	2010/12/06	93	50 - 134	98	60 - 140	<0.002	ug/g		
2350152	cis-1,2-Dichloroethylene	2010/12/06	96	45 - 136	100	60 - 140	<0.002	ug/g		
2350152	trans-1,2-Dichloroethylene	2010/12/06	99	45 - 138	101	60 - 140	<0.002	ug/g		
2350152	1,2-Dichloropropane	2010/12/06	91	51 - 130	101	60 - 140	<0.002	ug/g		
2350152	cis-1,3-Dichloropropene	2010/12/06	86	39 - 143	113	60 - 140	<0.002	ug/g		
2350152	trans-1,3-Dichloropropene	2010/12/06	91	33 - 135	104	60 - 140	<0.002	ug/g		
2350152	Ethylbenzene	2010/12/06	91	46 - 150	105	60 - 140	<0.002	ug/g	NC	50
2350152	Ethylene Dibromide	2010/12/06	84	48 - 136	100	60 - 140	<0.002	ug/g		
2350152	Hexane	2010/12/06	62	60 - 140	100	60 - 140	<0.005	ug/g	NC	50
2350152	Methylene Chloride(Dichloromethane)	2010/12/06	98	47 - 124	99	60 - 140	<0.003	ug/g		
2350152	Methyl Isobutyl Ketone	2010/12/06	80	48 - 133	107	60 - 140	<0.03	ug/g		
2350152	Methyl Ethyl Ketone (2-Butanone)	2010/12/06	78	39 - 160	103	60 - 140	<0.03	ug/g		
2350152	Methyl t-butyl ether (MTBE)	2010/12/06	117	37 - 150	123	60 - 140	<0.002	ug/g		
2350152	Styrene	2010/12/06	72	27 - 148	101	60 - 140	<0.002	ug/g		
2350152	1,1,1,2-Tetrachloroethane	2010/12/06	114	51 - 140	101	60 - 140	<0.002	ug/g		
2350152	1,1,2,2-Tetrachloroethane	2010/12/06	85	46 - 128	96	60 - 140	<0.002	ug/g		
2350152	Tetrachloroethylene	2010/12/06	88	45 - 154	99	60 - 140	<0.002	ug/g		
2350152	Toluene	2010/12/06	101	30 - 158	99	60 - 140	<0.002	ug/g	13.6	50
2350152	1,1,1-Trichloroethane	2010/12/06	102	44 - 136	106	60 - 140	<0.002	ug/g		
2350152	1,1,2-Trichloroethane	2010/12/06	96	56 - 135	94	60 - 140	<0.002	ug/g		
2350152	Trichloroethylene	2010/12/06	82	39 - 146	103	60 - 140	<0.002	ug/g		
2350152	Vinyl Chloride	2010/12/06	101	34 - 136	98	60 - 140	<0.002	ug/g		

Success Through Science®

Maxxam Job #: B0H3427
Report Date: 2010/12/07

Golder Associates Ltd
Client Project #: 03-1112-059
Project name: LYON'S CREEK
Sampler Initials: CD

QUALITY ASSURANCE REPORT

			Matrix Spike		Spiked Blank		Method Blank		RPD	
QC Batch	Parameter	Date	% Recovery	QC Limits	% Recovery	QC Limits	Value	Units	Value (%)	QC Limits
2350152	p+m-Xylene	2010/12/06	95	29 - 161	107	60 - 140	<0.002	ug/g	NC	50
2350152	o-Xylene	2010/12/06	103	45 - 150	108	60 - 140	<0.002	ug/g	NC	50
2350152	Trichlorofluoromethane (FREON 11)	2010/12/06	95	45 - 140	99	60 - 140	<0.002	ug/g		
2350152	Xylene (Total)	2010/12/06					<0.002	ug/g	12.7	50

N/A = Not Applicable

RPD = Relative Percent Difference

Duplicate: Paired analysis of a separate portion of the same sample. Used to evaluate the variance in the measurement.

Matrix Spike: A sample to which a known amount of the analyte of interest has been added. Used to evaluate sample matrix interference.

Spiked Blank: A blank matrix to which a known amount of the analyte has been added. Used to evaluate analyte recovery.

Method Blank: A blank matrix containing all reagents used in the analytical procedure. Used to identify laboratory contamination.

Surrogate: A pure or isotopically labeled compound whose behavior mirrors the analytes of interest. Used to evaluate extraction efficiency.

NC (RPD): The RPD was not calculated. The level of analyte detected in the parent sample and its duplicate was not sufficiently significant to permit a reliable calculation.

Maxxam

Success Through Science®

Validation Signature Page

Maxxam Job #: B0H3427

The analytical data and all QC contained in this report were reviewed and validated by the following individual(s).

Eva Pranjic (signature; stamp: CHARTERED CHEMIST, Eva Pranjic)

EWA PRANJIC, M.Sc., C.Chem, Scientific Specialist

==

Maxxam has procedures in place to guard against improper use of the electronic signature and have the required "signatories", as per section 5.10.2 of ISO/IEC 17025:2005(E), signing the reports. For Service Group specific validation please refer to the Validation Signature Page.

1-Dec-10 15:17

B0H3427

ENV-126 MHO

Maxxam 6740 Campobello Road, Mississauga, ON L5N 2L8
Phone: 905-817-5700 Fax: 905-817-5778 Toll Free: (8

CHAIN OF CUSTODY RECORD

17182

Page 1 of 1

INVOICE INFORMATION		REPORT INFORMATION		PROJECT INFORMATION	
Company Name:	Golder Associates	Company Name:		...on #:	
Contact Name:	Craig DeVito	Contact Name:		P.O. #:	03-1112-659
Address:	2390 Argentia Rd Mississauga	Address:		Project #:	
				Project Name:	Lyon's Creek
Phone:	905 567 4444 Fax:	Phone:	Fax:	Location:	
Email:	cdevito@golder.com	Email:		Sampled By:	

MAXXAM JOB NUMBER:

CHAIN OF CUSTODY #: 00

REGULATORY CRITERIA

Note: For regulated drinking water samples - please use the Drinking Water Chain of Custody Form.

- ☐ MISA
- ☐ PWQO
- ☐ Reg. 558
- Reg. 153: ☐ Table 1 ☐ Table 2 ☐ Table 3 ☐ Table 6; ☐ Residential / Parkland ☐ Industrial / Commercial ☐ Medium / Fine ☐ Coarse
- Reg. 153: ☐ 2004 ☐ 2011
- Sewer Use: ☐ Sanitary ☐ Storm
- Municipality:
- Other (specify):
- ...port Criteria on C of A? ☐

SAMPLES MUST BE KEPT COOL (<10°C) FROM TIME OF SAMPLING UNTIL DELIVERY TO MAXXAM.

ANALYSIS REQUESTED (Please be specific)

TURNAROUND TIME (TAT) REQUIRED

PLEASE PROVIDE ADVANCE NOTICE FOR RUSH PROJECTS.

Regular (Standard) TAT: ☐ 5 to 7 Working Days

Rush TAT: Rush Confirmation #: (call Lab for #)

☐ 1 day ☐ 2 days ☐ 3 days

DATE Required:

TIME Required:

Please note that TAT for certain tests such as BOD and Dioxins/Furans are > 5 days - contact your Project Manager for details.

	Sample Identification	Date Sampled	Time Sampled	Matrix (GW, SW, Soil, etc.)	Regulated Drinking Water? (Y / N)	Metals Field Filtered? (Y / N)	VOC	# of Cont.	COMMENTS / TAT COMMENTS
1	9L	26 Nov 10		Sediment			X	1	"VOC's in sediment"
2	17L	"		↓			X	1	
3	7L	"		↓			X	1	
4									
5									
6									
7									
8									
9									
10									
11									
12									

RELINQUISHED BY (Signature/Print)	RECEIVED BY (Signature/Print)	Date	Time	# JARS USED AND NOT SUBMITTED	Laboratory Use Only — Temperature (°C) on Receipt
[signature] / Craig DeVito	[signature] Daisy Tsang	2010/12/01	15:17		19/19/19°C

*MANDATORY SECTIONS IN GREY MUST BE FILLED OUT. AN INCOMPLETE CHAIN OF CUSTODY MAY RESULT IN ANALYTICAL TAT DELAYS.

COC-1004 (03/10) - ENV. ENG.

Maxxam Analytics International Corporation o/a Maxxam Analytics

White: Maxxam Yellow: Mail Pink: Client

APPENDIX E

Flume Methodology, Design and Results

1.0 FLUME METHODOLOGY AND DESIGN

The flume apparatus designed for this study consisted of a partially open bottomed rectangular channel. The walls of the flume extend from the stream bed to the water surface. The entrance to the flume is seamlessly flared open to reduce flow disturbance. The flume apparatus uses an electric trolling motor with thirty pounds of thrust that is operated over a range of current velocities through a rheostatic control (power stages). The motor was mounted near the downstream end of the flume and drew flow through the rectangular section. The bottom of the flume is partially open. It has two sections the first from the entrance of the flume to two thirds (2/3) of the way to the end has an open bottom is open to expose the sediment to the area of testing and the second section is covered beneath the area of the propeller of the trolling motor. The propeller of the trolling motor creates turbulence and a jet of water in the area of the propeller; therefore the covered bottom under the motor is designed to stop erosion directly under the propeller, ensuring shear can only occur in the study area upstream, where a more stable flow profile exists. A diagram of the flume apparatus is shown in Figure 1.

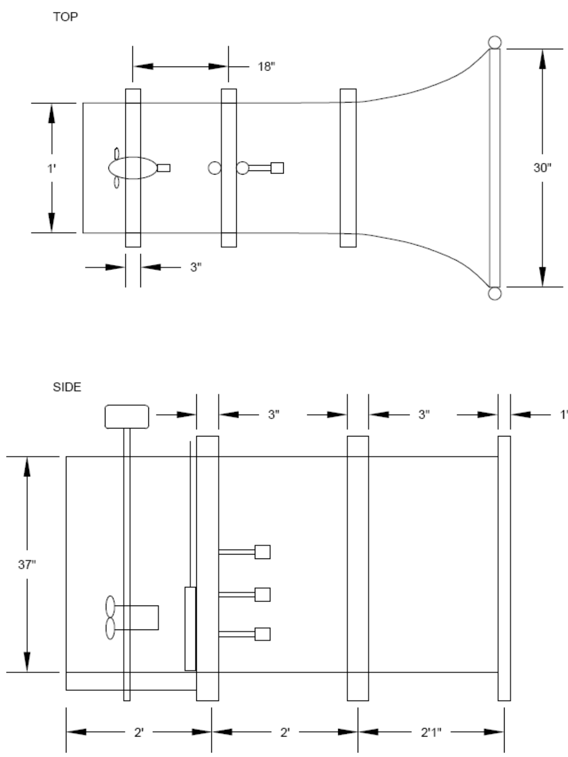

Figure 1: Flume Apparatus Diagram

The monitoring equipment on the flume included three electromagnetic velocity flow meters, a continuous turbidity probe and a peristaltic pump (for water quality sampling). The velocity flow meters were installed evenly through the depth profile, with probes orientated forward into the study area allowing a corresponding velocity profile to be estimated. A YSI sonde equipped with an optical turbidity probe was situated directly downstream of the velocity meters approximately 2 cm from the bottom of the flume apparatus. The YSI was programmed to record continuously throughout the study. Periodically, manual readings were taken from the YSI display to synchronize experiment times with recordings. The peristaltic pump was stored in an adjacent canoe and pulled samples through a rubber hose installed at the same location as the turbidity probe (approximately 2 cm from the bottom, directly downstream of the velocity meters). Collected water quality samples were subsequently analyzed for total suspended solids and grain size. A photograph of the flume setup without the monitoring equipment is shown below.

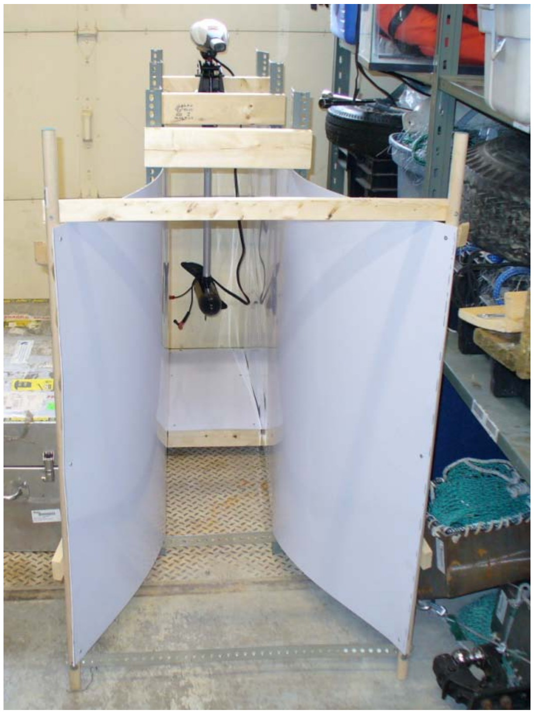

Photo 1: Flume with electric motor

The photograph above was taken facing the upstream side of the flume. The monitoring equipment was installed at the leading edge of the downstream covered bottom section. The photograph below (Photo 2) is a view from above the flume. From this Photograph the array of velocity meters can be seen facing upstream and the YSI and sampling hose located directly behind the meters.

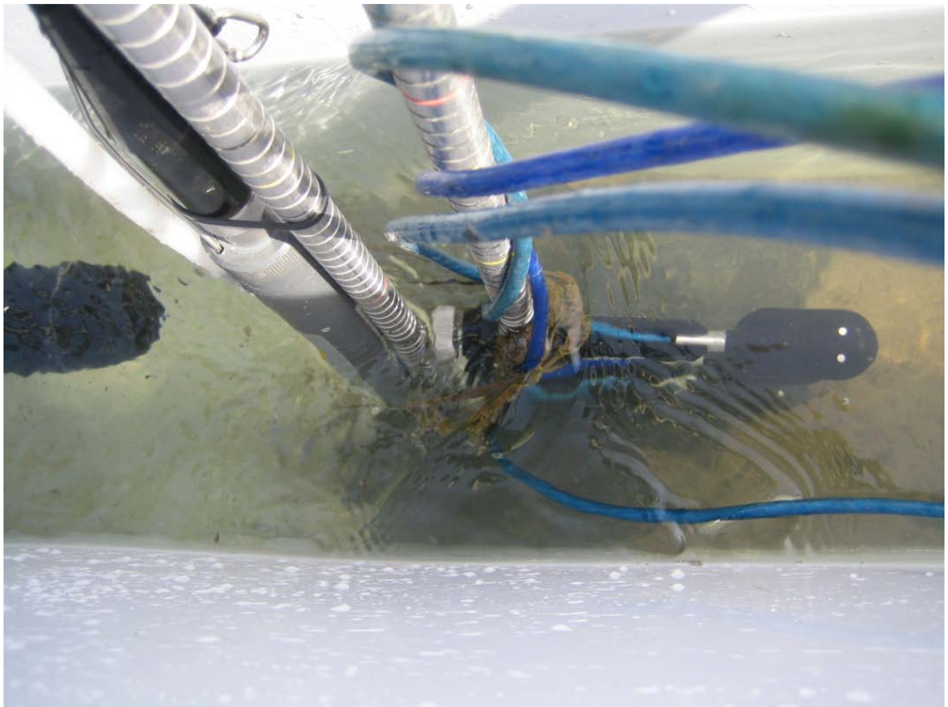

Photo 2: Monitoring equipment operating in flume

The experiment was conducted at eleven different locations along the stream reach in order to generate an appropriate representation of the channel sediment and its properties. The experiments were conducted in the early spring before the aquatic vegetation began its growing season. Poor weather days were avoided to minimize complications with flume deployment and operation caused by wind and wave action. At each location the flume apparatus was orientated in the stream to face upstream by gently lowering the flume on to the sediment. Once the flume was in place the unit was allowed to stabilize with motor remaining off. This allowed the stream flow moving through the flume apparatus to stabilize and the velocity meters to collect an initial average velocity profile measurement, the turbidity probe to record initial readings and an initial water quality sample to be taken. After initial readings and samples had been taken, the velocity enhancer was adjusted to the lowest of the power settings (stage one). This process was repeated, adjusting for all of the five motor stages. Visual observations were recorded throughout the study to identify the point of incipient sediment motion. Sediment suspension generally occurred soon after motor stage adjustment and therefore the data collection at this point were important. The turbidity probe sampled continuously and did not require adjustment. However water quality needed to be sampled immediately following each stage adjustment. The pump sampled for approximately twenty or thirty seconds before the sample bottle was filled, by this time any transient sediment suspension was completed or declined to a steady rate.

2.0 CRITICAL SCOUR VELOCITY CALCULATIONS

The turbulent region of a velocity profile is indicated by the associated Reynolds's number in the region. In turbulent flow the Reynolds's number is greater than approximately 12 000. Reynolds's numbers for all locations was found to be within the turbulent range. It is indicated in the Prandtl-von-Karman equation that velocity in the turbulent region is a logarithmic function of the distance from the channel bed (Chow, 1959). The equation can be written,

$$\frac{\overline{U}}{u_*} = \frac{1}{k} ln\left(\frac{y}{y_0}\right)$$

where k is von Karman's constant (constant of proportionality) which has been determined experimentally to equal 0.4, $\overline{U}$ is the velocity at a distance y from the channel bed. u_* is the friction velocity or shear velocity. y_0 is the constant of integration and for rough surfaces y_0 varies with surface roughness and can be expressed as the product of the roughness height k_s and m,

$$y_0 = mk_s$$

where m is equal to approximately $\frac{1}{30}$ (Chow, 1959). Substituting y_0 in the Prandtl-von-Karman equation gives the following,

$$\frac{\overline{U}}{u_*} = \frac{1}{k} ln\left(\frac{y}{mk_s}\right)$$

and

$$\overline{U} = \frac{u_*}{k} ln(y) + \frac{u_*}{k} \ln\left(\frac{1}{k_s m}\right)$$

When the measured velocities are plotted with respect to the logarithmic scale of the distance from the channel bed the remaining variables in the above equation can be determined through a line of best fit.

$$\frac{u_*}{k} = Coefficient1$$

$$\frac{u_*}{k} ln\left(\frac{1}{k_s m}\right) = Coefficient2$$

The plots of $\overline{U}$ versus $ln(y)$ are presented in **Error! Reference source not found.**7 of the Main Report.

Critical shear stress was determined from the following equation.

$$\tau_c = \rho\, (u_*)^2$$

STATION		DATE	PARAMETER	VALUE	UNIT	MDL
L7-5		2010-04-13	<11 >1 um	174	mg/L	4
L7-5		2010-04-13	<30 >11 um	241	mg/L	4
L7-5		2010-04-13	<60 >30 um	137	mg/L	4
L7-5		2010-04-13	<100 >60 um	17	mg/L	4
L7-5		2010-04-13	>100 um	75	mg/L	4
L7-5		2010-04-13	Total Suspended Solids	799	mg/L	2
L8-5		2010-04-13	<11 >1 um	82	mg/L	4
L8-5		2010-04-13	<30 >11 um	116	mg/L	4
L8-5		2010-04-13	<60 >30 um	67	mg/L	2
L8-5		2010-04-13	<100 >60 um	4	mg/L	4
L8-5		2010-04-13	>100 um	23	mg/L	4
L8-5		2010-04-13	Total Suspended Solids	320	mg/L	2

Your Project #: 03-1112-059
Your C.O.C. #: 18702404, 187024-0

Attention: Craig De Vito
Golder Associates Ltd
Mississauga - Standing Offer
2390 Argentia Rd
Mississauga, ON
L5N 5Z7

Report Date: 2010/04/23

CERTIFICATE OF ANALYSIS

MAXXAM JOB #: B047964
Received: 2010/04/21, 13:38

Sample Matrix: Water
Samples Received: 8

Analyses	Quantity	Date Extracted	Date Analyzed	Laboratory Method	Method Reference
Total Suspended Solids	8	N/A	2010/04/23	CAM SOP-00428	SM 2540D

* RPDs calculated using raw data. The rounding of final results may result in the apparent difference.
* Results relate only to the items tested.

Encryption Key

Please direct all questions regarding this Certificate of Analysis to your Project Manager.

CHRISTINE MCLEAN, Project Manager
Email: christine.mclean@maxxamanalytics.com
Phone# (905) 817-5700

==
Maxxam has procedures in place to guard against improper use of the electronic signature and have the required "signatories", as per section 5.10.2 of ISO/IEC 17025:2005(E), signing the reports. For Service Group specific validation please refer to the Validation Signature Page.

Total cover pages: 1

Maxxam Job #: B047964
Report Date: 2010/04/23

Golder Associates Ltd
Client Project #: 03-1112-059

RESULTS OF ANALYSES OF WATER

Maxxam ID		FQ4608	FQ4609	FQ4610		FQ4611		FQ4612	FQ4613	FQ4614		FQ4615		
Sampling Date		2010/04/13 12:00	2010/04/13 12:00	2010/04/13 12:00		2010/04/13 12:00		2010/04/13 12:00	2010/04/13 12:00	2010/04/13 12:00		2010/04/13 12:00		
	Units	**L1-5**	**L2-5**	**L4-5**	**RDL**	**L5-5**	**RDL**	**L6-5**	**L10-5**	**L11-5**	**RDL**	**L11-1**	**RDL**	**QC Batch**
Inorganics														
Total Suspended Solids	mg/L	120	260	590	10	2800	50	1100	1500	740	20	21	10	2131882

RDL = Reportable Detection Limit
QC Batch = Quality Control Batch

Package 1	1.0°C

Each temperature is the average of up to three cooler temperatures taken at receipt

GENERAL COMMENTS

All samples were received and analyzed after the recommended hold time had expired. Please view results with discretion.

Golder Associates Ltd
Client Project #: 03-1112-059

Maxxam Job #: B047964
Report Date: 2010/04/23

QUALITY ASSURANCE REPORT

			Method Blank		RPD		QC Standard	
QC Batch	Parameter	Date	Value	Units	Value (%)	QC Limits	% Recovery	QC Limits
2131882	Total Suspended Solids	2010/04/23	<10	mg/L	NC	25	95	85 - 115

N/A = Not Applicable

RPD = Relative Percent Difference

QC Standard: A blank matrix to which a known amount of the analyte has been added. Used to evaluate analyte recovery.

Method Blank: A blank matrix containing all reagents used in the analytical procedure. Used to identify laboratory contamination.

NC (RPD): The RPD was not calculated. The level of analyte detected in the parent sample and its duplicate was not sufficiently significant to permit a reliable calculation.

Validation Signature Page

Maxxam Job #: B047964

The analytical data and all QC contained in this report were reviewed and validated by the following individual(s).

BRAD NEWMAN, Scientific Specialist

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At Golder Associates we strive to be the most respected global company providing consulting, design, and construction services in earth, environment, and related areas of energy. Employee owned since our formation in 1960, our focus, unique culture and operating environment offer opportunities and the freedom to excel, which attracts the leading specialists in our fields. Golder professionals take the time to build an understanding of client needs and of the specific environments in which they operate. We continue to expand our technical capabilities and have experienced steady growth with employees who operate from offices located throughout Africa, Asia, Australasia, Europe, North America, and South America.

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