Appendix D: Oakville Water Purification Plant Sixteen Mile Creek Plume Assessment

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The Regional Municipality of Halton

Oakville Water Purification Plant

Sixteen Mile Creek Plume Assessment

Our Project No. 8811884.450
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Table of contents

List of Tables

List of Figures

Appendices

1. Introduction

The Regional Municipality of Halton (Region) has identified the need for increased capacity at the Oakville Water Purification Plant (WPP) in the Sustainable Halton Water and Wastewater Master Plan, and is seeking to have the WPP officially re-rated from 109 ML/d to 130 ML/d. The Region has initiated a Schedule B Municipal Class Environmental Assessment (EA) for the re-rating of the Oakville Water Purification Plant. The Region is also considering extending the intake pipe further offshore to avoid high turbidity due to suspended sediment within the discharge from Sixteen Mile Creek.

GHD Inc. has been retained by the Region to conduct a geomorphic assessment of the sediment plume emanating from Sixteen Mile Creek. The study is required to inform the development of options to mitigate the high turbidity periodically found within the intake. While the formation of the Sixteen Mile Creek plume is largely natural process, it can cause problems when high suspended sediment concentrations reach the intake for the WPP located approximately 880 m offshore of Kerr Street at a depth of 9.6 m. Knowledge of the plume processes including suspended sediment concentrations and distribution is required to assess the potential options to mitigate concentrations at the intake, and these options include relocation of the intake pipe to deeper water further offshore.

The aim of the geomorphic assessment is to determine the sediment plume extent and concentration for typical events which cause high levels of turbidity within the WPP intake. The results were used to determine potential benefits of relocating the intake with respect to suspended sediment contamination. The study only focused on suspended sediment and did not consider other existing or emerging containments.

The first phase of the study consisted of a review of the background material and identification of data gaps. The results were provided in the *Oakville Water Purification Plant: Environmental and Geomorphological Baseline Summary Report* prepared for the Region in October 2014 by Exp Services Inc., LGL Limited and GHD Inc. The review of baseline data revealed that there was nominal data available on the extent and concentration of the Sixteen Mile Creek sediment plume within Lake Ontario. Further investigation through field sampling and numerical modelling was recommended to fill the data gap.

This report builds on the baseline assessment and consists of the following:

- Review of previous studies;
- Description of data sources and data compilation for use in the numerical modelling;
- Field sampling of suspended sediments concentrations within sediment plumes;
- Assessment of conditions during plant shutdowns;
- Numerical modelling of plume concentrations and extent for various creek flows and lake conditions; and
- Discussion of potential solutions.

2. Historical Review

2.1 Sediment Plumes

Sediment plumes within Lake Ontario at the mouths of creeks and rivers are naturally occurring processes which occur due to the transport of sediment from the watershed to the lake. Plumes are composed of fine silts and clays which have been transported in suspension within watercourses. Plumes increase in size during large rainfall events due to the increase in the supply of sediment through erosion in the watershed and the increased flow within the creeks and tributaries to carry the sediment.

Sixteen Mile Creek transports a range of sediment sizes ranging from gravel to clay. The coarser material is carried as bedload and is deposited as flow velocities decrease within Oakville Harbour. Silts and clays are transported in suspension and require a longer amount of time to settle to the harbour bed. Most of the sand and a portion of the silt and clay settle out of suspension in the harbour, although much of the fine silt and clay is transported through the harbour and out into the lake. It is this fine silt and clay which constitute the sediment plume. The distribution and concentration of sediment within the plume is mainly determined by: suspended sediment concentrations at the creek mouth; flow within the creek; the temperature difference between the creek and the lake; temperature stratification within the lake; and lake currents.

The concentration of suspended sediment at the mouth of the creek depends on: the amount, intensity, and distribution of rainfall within the watershed as well as seasonal effects such as vegetation, ice and snow cover, and snow melt. Vegetation, ice and snow act to hold sediment in place and decrease the amount of erosion and supply of sediment to the watercourse. Snow melt in the spring increases the volume of flow which in turn is able to entrain and transport more sediment. This is particularly effective during heavy rains in the spring when vegetation has not yet established to stabilize the sediment. Suspended sediment concentrations can also increase due to poor erosion and sediment control practices on construction sites.

2.2 Previous Studies

The following studies were reviewed as part of the baseline data assessment:

- GHD, 2014. Sediment management study: Oakville and Bronte Harbours. Report prepared for the Town of Oakville, June 2014;
- Bowen, G.S. and Booty, W., 2011. Watershed pollutant load assessments for the Canadian side of the western basin of Lake Ontario: A report prepared for the CTC source protection region. Prepared by TRCA and Environment Canada, June 2011; and,
- Baird, 2009. Assimilative Capacity Study for the Mid-Halton WWTP Phase IV and V Expansion. Report prepared for The Regional Municipality of Halton.

A brief summary of each study is provided below focusing on the information relevant to the plume.

GHD, 2014. Sediment Management Study: Oakville and Bronte Harbours. Report prepared for the Town of Oakville, June 2014

This report summarizes the results of a sediment management study for Oakville Harbour and Bronte Harbour. The study was conducted due to the sediment deposition at the harbours which creates navigational issues within the harbours that impact harbour operation and boater safety.

While not directly addressing the sediment plume outside of the harbour, the study contained relevant data and discussion with respect to understanding the dynamics of the plume. The report includes, with respect to Sixteen Mile Creek: an investigation into the sources of sediment for Sixteen Mile Creek; options to reduce sediment supply from the catchment; investigation into the processes of deposition at the harbours; and options to mitigate or manage sediment deposition and removal.

The following is a summary of the main findings and conclusions of the study that are of relevance to the investigation of the sediment plume exiting the harbour.

- The Sixteen Mile Creek watershed consists of 371 km^2 with 1,100 km of watercourse. Sixteen Mile Creek has three main branches (East, Middle and West) with a total length of 150 km. The watershed is divided by the Niagara Escarpment which consists of steep vertical cliffs of dolostone bedrock. Headwaters of the West and Middle branches originate above the Escarpment, and headwaters for the East branch originate in the northeast below the escarpment.
- The surficial geology mainly consists of fine-textured glaciolacustrine deposits interbedded flow till, rainout deposits and silt and clay and glaciolacustrine derived silty to clayey till.
- The majority of the Sixteen Mile Creek watershed consists of agricultural land with only 16% defined as urban within the Town of Milton and south of Dundas Street West within the Town of Oakville.
- Oakville Harbour acts as a sediment sink where sediment deposited at an average rate of 1,700 m^3/yr.
- Sediments deposited within Oakville Harbour were comprised of materials in the medium silt to fine sand class size. Fine silts and clay were transported through the harbour.
- Sediment deposition within the harbour was from the creek with very little sediment transported by waves to the mouth of the harbour.
- The shoreline between Burlington and Toronto has been classified as a ‘non-drift zone’ by MNR (1988) which is a section of shoreline where there is very limited availability of sediment for transport. The Oakville shoreline is composed of shale bedrock just below the lake level which is overlain by a thin layer of till and fine sand (MNR, 1988).
- Sediment is not supplied to the nearshore through shoreline erosion since the majority of the shoreline has also been armoured through urban development.
- Suspended sediment samples were collected at 18 locations within the watershed following a 26.4 mm watershed wide rain event on August 1st 2013. Total suspended solids (TSS) among the samples ranged from 4 to 215 mg/L.
- Flow and sediment transport monitoring data available for several hydrometric monitoring stations within the watershed from the Environment Canada HYDAT database was presented. The relevant data are provided below in **Section 3.3**.

The following recommendations were made with respect to reducing sediment generation and supply from the watersheds due to development and construction activities:

- The focus should be on compliance rather than new technologies or techniques.
- Monitoring requirements should be maintained at the current levels or increased.
- The implementation of existing technologies could be improved.

- There should be a focus on erosion control (keeping soil in place) in addition to sediment control (trapping soil prior to it being washed into a watercourse). Methods to reduce agricultural inputs should be explored (*e.g.* vegetated buffers, tillage methods and other farming practices).
- The volume of sediment that is transported through the harbour to form the offshore sediment plume was not estimated.
- Options for mitigation and management of sediment deposition within the harbours were investigated and included limiting sediment input, reducing sedimentation, reducing draft depth requirements, relocating the harbour, and a dredging program and alternative forms of dredging.
- A maintenance dredging program was proposed to remove the sediment deposited within the harbour every two years.

Bowen, G.S. and Booty, W., 2011. Watershed Pollutant Load Assessments for the Canadian Side of the Western Basin of Lake Ontario: A report prepared for the CTC source protection region. Prepared by TRCA and Environment Canada, June 2011

This study consisted of estimates of pollutant loads for seven watersheds discharging into Lake Ontario. The study was intended to aid in the understanding of the transport mechanisms of pollutants from local watersheds to Lake Ontario with a focus on potential impacts to drinking water supplies. Sixteen Mile Creek was one of the watersheds studied. Total Phosphorus (TP), Filtered Reactive Phosphorus (FRP), nitrogen oxides (NOx) and Total Suspended Solids (TSS) were estimated based on water samples specifically for this study and samples collected as part of the Provincial Water Quality Monitoring Network (PWQMN). Sixteen Mile Creek estimates were limited by the need to rely on monitoring stations from the upper reaches of the watershed.

The following information from the report is relevant for the study of the sediment plume. It should be noted that all TSS and total load values were rough estimates.

- Identified snow melt as a dominant factor for sediment loading into the Lake.
- Most suspended solids loads are delivered by a small number of events.
- Event Mean Concentrations for wet weather events in Sixteen Mile Creek were estimated at approximately 220 mg/L in 2008 and 155 mg/L in 2009.
- Average daily suspended sediment load for Sixteen Mile Creek was estimated as 69,000 kg.
- Total suspended solids carried by Sixteen Mile Creek were approximately 22,000 ton in 2008 and 21,000 ton in 2009.

Baird, 2009. Assimilative Capacity Study for the Mid-Halton WWTP Phase IV and V Expansion. Report prepared for The Regional Municipality of Halton.

This report summarizes the Assimilative Capacity Study that was prepared in support of the Municipal Class Environmental Assessment Study Project for the Mid-Halton Wastewater Treatment Plant (WWTP) Phase IV and V expansion by Baird & Associates.

The report contains a detailed review of water quality data within Lake Ontario adjacent to Oakville. Background concentrations for temperature, pH, ammonia and total phosphorus were quantified for each season. Historic records of currents, TSS, turbidity and dissolved oxygen were also analyzed.

The review was used to determine ambient conditions within Lake Ontario which were then used to establish numerical modelling scenarios for different seasons and current speed and directions.

Numerical modelling was used to assess the impacts of the effluent from the Mid-Halton and Oakville South West WWTP on the water quality within Lake Ontario, specifically at the shoreline and the Oakville and Burloak WTPs. The water quality model CORMIX was used to model the near-field mixing process dominated by the effluent jet. MIKE3 was used to model the far-field dispersion of the effluent plume where ambient currents determine the distribution of the plume. The MIKE3 modelling showed that Provincial Water Quality Objectives (PWQO) were met at the Oakville and Burloak WTP intakes.

The summary of ambient lake conditions and the development of modelling scenarios to determine the dispersion of the plume from the WWTPs can provide a basis for numerical modelling of the Sixteen Mile Creek plume.

3. Data Collection

3.1 Lake Bathymetry

The most recent bathymetric data for the mouth of Sixteen Mile Creek and the area surrounding the location of the Water Purification Plant (WPP) intake are summarized in **Table 1**. The NOAA (1999) data and GHD (2013) data were combined to produce bathymetry for use in the numerical model (**Appendix A**). The NOAA data were found to be inaccurate within approximately 100 m of the shoreline. However, spot measurements of depth further offshore showed good agreement with the NOAA data.

Table 1: Lake Bathymetry at the mouth of Sixteen Mile Creek and near the Oakville WPP intake

Data Source	Year	Resolution	Extent	Comment
NOAA	1999	67 m x 93 m	Lake wide	-
GHD	2013	DEM generated from dense sonar tracks	Oakville Harbour and in the vicinity of the harbour entrance	-
MNR	2002	10 m x 10 m	Greater Toronto Area	MNR has confirmed that the SHOALS data for the study area is not available

3.2 Bed Characteristics

Sediment samples from the bed of Oakville Harbour were collected using an Ekman grab sampler from a small vessel in the spring of 2013 (GHD, 2014). Location of the samples as well as their relative size is provided in **Appendix B Figure B1**. **Table 2** and **Table 3** present the grain size characteristics for Oakville Harbour (GHD, 2014). Grain sizes ranged from medium silt to medium sand. The grain size distribution was poorly sorted to very poorly sorted indicating a wide range of grain sizes within each sample. All samples contained a mix of sand, silt and clay with most samples dominated by silt. The coarsest sample was found at OAK01 and was composed of 90% sand. Sand was expected at the harbour mouth due to the onshore directed transport of sand by waves and the offshore movement of the finer material by river flows.

Table 2: Sediment composition (GHD, 2014)

Class Size / ID	% Gravel	% Sand	% Silt	% Clay
OAK1	0	90	5	5
OAK3	0	16	67	18
OAK4	0	1	71	28
OAK5	0	15	65	20
OAK6	0	34	48	18
OAK7	0	8	68	24
OAK8	3	17	48	33
OAK9	0	1	67	32

Table 3: Grain size characteristics (GHD, 2014)

ID	Method of Moments: Geometric			Folk and Ward: Descriptions		
	Mean (mm)	Standard Deviation (mm)	Skewness (mm)	Mean	Sorting	Skewness
OAK01	0.185	0.0029	-0.00227	Medium Sand	Poorly Sorted	Very Fine Skewed
OAK02	Fine sand, organics					
OAK03	0.023	0.0034	-0.00058	Coarse Silt	Very Poorly Sorted	Very Fine Skewed
OAK04	0.011	0.0032	0.00031	Medium Silt	Very Poorly Sorted	Fine Skewed
OAK05	0.021	0.0036	-0.00018	Coarse Silt	Very Poorly Sorted	Very Fine Skewed
OAK06	0.032	0.0049	0.00024	Very Coarse Silt	Very Poorly Sorted	Fine Skewed
OAK07	0.015	0.0036	0.00002	Medium Silt	Very Poorly Sorted	Very Fine Skewed
OAK08	0.015	0.0071	0.00131	Medium Silt	Very Poorly Sorted	Coarse Skewed
OAK09	0.012	0.0038	0.00016	Medium Silt	Very Poorly Sorted	Fine Skewed
OAK10	Brown clayey silt					

3.3 Sixteen Mile Creek Data

Historical Flows

Flow data from station 02HB004 -East Sixteen Mile Creek near Omagh (WSC, 2014a) and station 02HB005 -Sixteen Mile Creek at Milton (WSC, 2014b) were used to estimate the flow at the Sixteen Mile Creek mouth. The location of these stations is shown in **Appendix C Figure C1**. The B02HB004 station is situated about 11 km from the mouth with a drainage area of 193 km^2. **Figure C2** shows the historical flow data from 1956 to 2014 for this station. The 02HB005 station is situated about 6 km upstream of the confluence with the East Sixteen Mile Creek with a drainage area of 101 km^2. **Figure C3** shows the historical flow data from 1957 to 2014 for this station. The confluence is 8 km upstream of the mouth.

The flows at the mouth of the creek were estimated from the two flow monitoring stations within the watershed using the relationship for the transposition of flood discharges (MTO, 1997):

$Q2 = Q1 (A2/A1)^{0.75}$ **(Equation 1)**

Where:

Q1 = known peak discharge

Q2 = unknown peak discharge

A1 = known basin area

A2 = unknown basin area

Note that this technique only provides a rough estimate of flows at the mouth given that the monitoring stations are located far upstream. To account for additional flows downstream of the confluence, a factor of 1.5 was applied to the flow data. **Figure C4** shows the estimated flow at the mouth of the creek for the period 1957 to 2014.

The maximum flows in spring (March 1 to May 31) and summer (June 1 to August 31) for the period 1957 to 2014 are shown in **Figures C5** and **C6**, respectively. Percentiles for maximum flows were estimated at the mouth for the period 1957 to 2014. The spring and summer 25th-75th flows ranged from 41 m^3/s to 91 m^3/s and from 4 m^3/s to 16 m^3/s, respectively. The maximum flow in spring was 184.3 m^3/s. The maximum flow in summer was 69 m^3/s. **Table 4** shows the spring and summer percentiles for the period 1957 to 2014.

Table 4: Percentiles for Maximum Flows at the mouth (1957-2014)

Percentile	Spring Q (m^3/s)	Summer Q (m^3/s)
20th	29.7	3.8
25th	41.0	4.1
50th	69.8	8.0
75th	91.4	16.3
93rd	103.1	30.6
100th	184.3	69.0

Flood Events

The flood flows (2-yr, 5-yr, 10-yr, 25-yr, 50-yr, 100-yr and Regional) for the Sixteen Mile Creek are summarized in **Table 5**. The 0.5-yr and 1-yr events were extrapolated using a logarithmic curve. The discharges for these flow events are summarized in **Table 5**.

Table 5: Sixteen Mile Creek flood events (GHD, 2014)

Event	Discharge (m^3/s)
Regional	1198
100-yr	311
50-yr	279
25-yr	237
10-yr	190
5-yr	160
2-yr	100
1-yr	68*
0.5-yr	30*

* Estimated discharge using logarithmic curve fitting

Historical Suspended Sediments

Suspended sediment concentrations from station 02HB004 -East Sixteen Mile Creek near Omagh (WSC, 2014c), station 02HB005 -Sixteen Mile Creek at Milton (WSC, 2014d) and 06006300102 – Lakeshore Road (PWQM, 2014a) were used to determine the relationship between suspended sediment concentrations and flows at the mouth of the creek. **Figure C1** shows the location of these stations. Sporadic suspended sediment concentrations were collected in stations B02HB004 and B02HB005 as shown in **Figures C7** and **C8**, respectively. Suspended sediment concentrations from 2010 to 2013 at Lakeshore Road are provided in **Figure C9**.

The relationship between suspended sediment concentrations and flows at the mouth of the creek is shown in **Figure C10**. All sediment data from the three locations were included in the figure. The suspended sediment concentrations show large variability even for the same flow. A curve was fitted to predict the concentrations observed in station 02HB004. The curve was intended to be conservative which would generally result in over predicting suspended sediment concentrations.

Historical Temperature

Sporadic measurements of the temperature at station 06006300102 –Lakeshore Road (PWQM, 2014b) were available for the period 2000 to 2012. **Figure C11** shows the temperature data. The temperature in summer (June 1- August 31) was 23 ^{o}C (75th percentile).

3.4 Lake Ontario Data

Currents

Current speeds and directions were obtained from the data described in McCorquodale (2005 and 2007). The data were measured near Port Credit by the Ministry of Environment (MOE). Two Acoustic Doppler Current Profilers (ADCP) were placed offshore of Port Credit (in 41 m and 8.9 m water depth) and data were collected every half hour between April to November, 2014 at 1 m depth intervals (Baird, 2009). **Table 6** presents the current data used in this study.

Table 6: Current Data for Lake Ontario near Port Credit (from McCorquodale, 2005 and 2007)

Current Class	onshore	Offshore	Long NE	Long SW	Totals
0-4.5 cm/s	4.1%	7.7%	28.8%	7.0%	47.7%
4.5-7.5 cm/s	1.7%	5.6%	7.2%	5.5%	19.9%
7.5-12 cm/s	1.4%	4.9%	6.9%	4.9%	18.1%
12-20 cm/s	0.6%	3.5%	4.1%	1.8%	9.9%
>20 cm/s	0.1%	1.6%	1.6%	1.0%	4.3%
Totals	7.9%	23.3%	48.6%	20.2%	99.9%

Note: flow is toward the direction shown

Historical Water Levels

The yearly average water levels in Lake Ontario were obtained for the period 1918 to 2014 (NOAA, 2014). The long-term average water level for the period 1970-2014 was 74.8 m. **Figure C12** shows the water levels in Lake Ontario. The long-term average water level was used for all the modelling scenarios.

Temperature

Temperatures in Lake Ontario are fairly consistent with depth (or isothermal) in the spring, fall and winter months (Baird, 2009). During isothermal conditions, the density is the same throughout the water column, and as a result the water column is fully mixed. During the summer months, the upper layers of the water column become warmer than the lower layers, resulted in stratification and reduced mixing through the water column.

The spring and summer seasons were defined as follows: spring (March 1 – March 30) and (June 1 – August 31). The spring season is isothermal with temperature of approximately 5.1^{o}C. The summer season is stratified with surface temperature of approximately 20 ^{o}C and bottom temperature of approximately 12 ^{o}C.

4. Field Data

Suspended Sediments

Sigma portable pump samplers (HACH SD900) were used to collect water samples near the surface and near the bed for TSS analysis. Samples were collected at Oakville Harbour, the creek mouth, at various locations within the sediment plume, and outside the sediment plume.

Sampling of two plume events was conducted on July 28, 2014 and September 11, 2014. During each plume event samples were collected for TSS analysis at 2 depths at each of 24 locations.

- Sampling on July 28, 2014: this event was sampled followed a 60 mm rainfall event (Town of Oakville Station 6155750). Photographs of the plume are shown in **Figure 1** and **Figure 2**. Samples were collected at the surface and at approximately 3 m depth. The results are shown in **Appendix B Figure B2**. Concentrations ranged from 112 mg/L at the harbour entrance to 9 mg/L at the edge of the plume. Concentrations were generally greater at the surface and lower at depth. Ambient concentrations outside of the plume were between 4 and 15 mg/L.
- Sampling on September 11, 2014: this event was sampled followed a 20 mm rain event (Town of Oakville Station 6155750). Photographs of the plume are shown in **Figure 3** and **Figure 4**. Samples were collected at the surface and close to the bed. The results are shown in **Appendix B Figure B3**. Concentrations ranged from 50 mg/L at the harbour entrance to 6 mg/L at the edge of the plume. Concentrations were generally greater at the surface and much lower near the bed.

Suspended sediment samples from the harbour entrance collected on July 28, 2014 were sent to a laboratory for particle size analysis using a computerized digital image system. Particle sizes ranged from fine sand to clay (1 µm to 237 µm). Median particle size was 7 µm and the mean size was 37 µm (silt). The sizes were used to establish the plume characteristics for the numerical modelling.

Figure 1: Plume conditions at the entrance of Oakville Harbour on July 28, 2014

Figure 2: Plume extent offshore of Oakville Harbour on July 28, 2014

Figure 3: Plume conditions offshore of the mouth on September 11, 2014

Figure 4: Plume extent offshore of Oakville Harbour on September 11, 2014

Flow Measurement

The flow at Sixteen Mile Creek was measured upstream of Oakville Harbour as 6.5 m^3/s on July 28, 2014. The velocity measurements were conducted using a SonTek FlowTracker Handheld Acoustic Doppler Velocimeter.

Salinity

Salinity of 0.2 ppt was measured at Oakville Harbour and Lake Ontario on September 11, 2014.

5. WPP Intake Turbidity Assessment

5.1 WPP Intake Turbidity

Turbidity data was available from the Region for flows entering the plant through the intake pipe, and was measured where the flow entered the plant. The turbidity data was plotted along with flows at the mouth of Sixteen Mile Creek. **Appendix D** presents the turbidity data from 2010 to 2014.

The largest peaks in turbidity in the plant generally correspond to high flows in the spring. The high turbidity was likely due to entrainment of sediment by the freshet after most of the snow and ice has melted and before vegetation had established. Large flow events were not always accompanied by high turbidity at the intake. This was likely due to other factors such as lake currents and sediment supply. For example, lake currents from west to east could position the plume away from the intake location, and large rain events in the late summer would likely entrain less sediment due to vegetation cover. Similar effects would occur in throughout the winter months due to the stabilization of sediment by ice and snow cover.

The Region also provided turbidity data for the period 2008 to 2013 where turbidity peaks were greater than 20 NTU. Corresponding intake flow rates were also provided. The turbidity data peaked at a ceiling of 100 NTU, where a value reading equal or greater than 100 NTU was recorded as 100 NTU. The data received was reviewed to identify potential shutdowns at the intake due to high turbidity. Note that the data was not complete as all turbidity events could not be obtained by the Region; a large portion of the 2010 data was not available.

The peak events were plotted against the estimated discharge at the mouth of Sixteen Mile Creek **Figure 5**. In general, higher turbidity events were linked to higher discharge from Sixteen Mile Creek, however there was a high degree of scatter to the results: the 100 NTU ceiling for results likely distorts the relationship. Much of the scatter is related to other variables such as the direction and strength of the prevailing current within the lake, the relative density of the creek and the lake water, and direction of winds. The impacts associated with these factors were explored by modelling scenarios and discussed in **Section 6.8**.

Shutdowns that were likely due to high turbidity were identified in the available 2008 - 2013 peak turbidity data. An attempt was made to correlate the high turbidity shutdowns with the available environmental data including proceeding precipitation, hindcast wave parameters, creek discharge, and wind speed and direction (**Table 7**). Hindcast wave parameters and wind speed and direction were obtained from USACE (2013). Shutdowns occurred when the rainfall was generally greater than 16 mm, although they typically occurred for larger events of greater than 26 mm. Shutdowns were associated with lower rainfall amounts where snow melt also occurred. For example, Event 5 was associated with only 10 mm of rainfall, despite 20 cm of snow melt noted at Pearson Airport.

Similarly, only 1 mm of rainfall occurred during Event 9 which was accompanied by approximately 10 cm of snow melt in the proceeding 3 days. Rainfall and rapid snow melt result in high levels of discharge. The entrainment of fine sediment would also be exacerbated during snow melt events given the lack of stabilization by vegetation, and assuming the ground surface was not frozen.

Shutdowns at the intake occurred for events with turbidity as low as 26 NTU. The shutdowns at low turbidity could have been due to the anticipation of higher turbidity peaks which did not materialize. Nearly half of the shutdowns occurred for turbidity greater than 100 NTU.

It is unknown what resulted in the shutdown during the relatively low turbidity peak for Event 11. Creek discharge was very low and wind speed was not likely high enough to generate local suspension of sediment at the intake location. The shutdown was likely due to other reasons besides high turbidity.

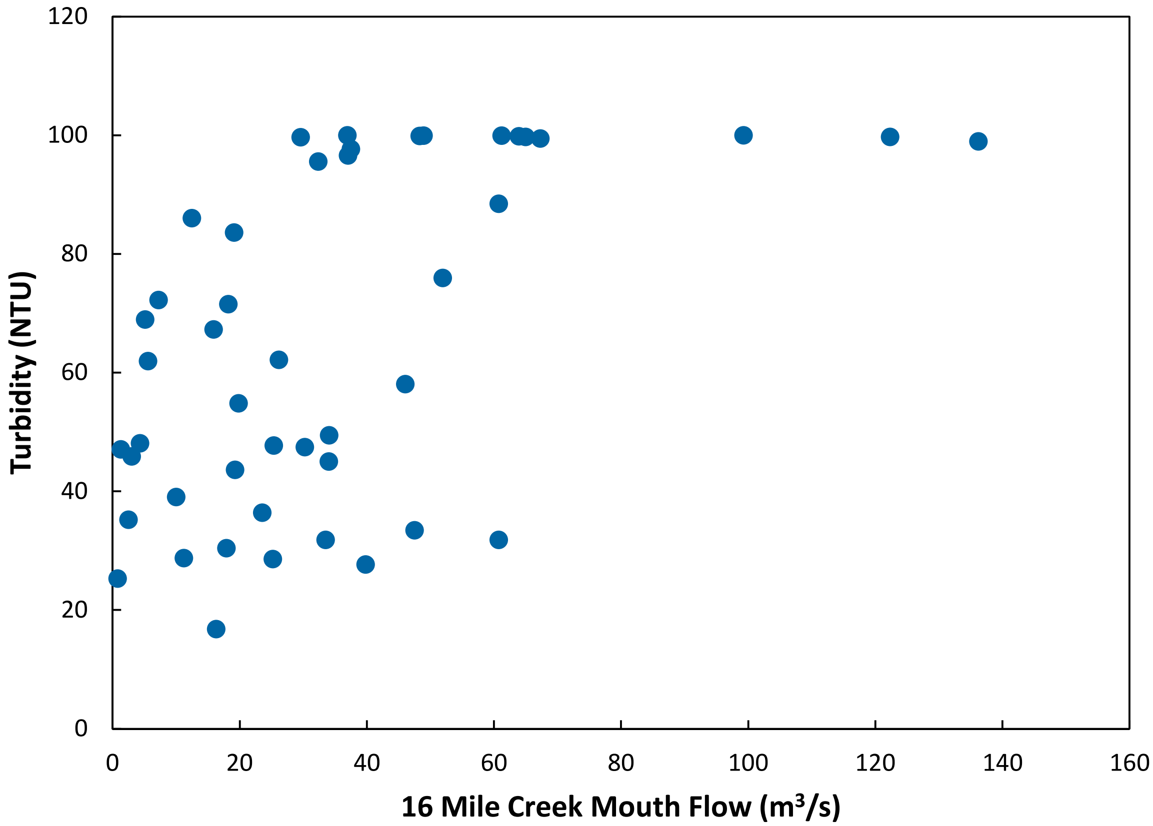

Figure 5: WPP intake turbidity and corresponding discharge at the mouth of Sixteen Mile Creek

Note that WPP intake turbidity readings were provided with an upper limit of 100 NTU. Values at 100 NTU may be higher than indicated.

Table 7: Turbidity shutdown events

Event	Date	Precipitation (mm)	Creek Discharge (m^3/s)	Significant Wave Height (m)	Wave Direction (degrees)	Wind Speed (m/s)	Wind Direction (degrees)	Max. Turbidity (NTU)	Shutdown Event			Plant Flow Rate (MLD)	
									Inlet #1	Inlet #2	Duration (hours)	Inlet #1	Inlet #2
1	3/5/2008	25	15	1.6	73	11	158	44	yes	partial	4	24.5	24.4
2	7/9/2008	16	2	0.3	227	7	248	26	yes	yes	3	31.7	31.2
3	7/23/2008	50*	34	0.4	53	6	24	52	yes	not in use	7	34.3	0
4	11/16/2008	26	25	0.8	224	13	298	28	yes	not in use	4	35.0	0
5	12/28/2008	10	99	2.1	203	19	222	>100	not in use	yes	8	0	38.1
6	3/8/2009	27	37	0.6	78	6	145	>100	partial	partial	22	38.7	0
7	4/3/2009	41	41	1.1	73	9	103	>100	yes	not in use	17	46.7	0
8	1/13/2013	37	61	NA	NA	NA	NA	>100	yes	not in use	92	32.3	0
9	3/11/2013	1*	49	NA	NA	NA	NA	>100	yes	not in use	29	37.4	0
10	4/10/2013	36	54	NA	NA	NA	NA	70	yes	not in use	67	30.5	0
11	9/17/2013	0	1	NA	NA	<9*	NA	35	yes	yes	7	48.2	0

* As recorded at Environment Canada Toronto Pearson International Airport weather station. All other precipitation data from Town of Oakville Station (6155750)

6. Numerical Modelling (MIKE3)

6.1 Introduction

An event based modelling approach was used since continuous data was not available. Events were chosen based on those most likely to result in high turbidity at the existing intake.

The discharge of the Sixteen Mile Creek sediment plume into the near shore region of Lake Ontario was modelled using MIKE3-FM. The model was selected due to its adaptability to the study area, the ability to simulate the dynamic interaction between the creek flow, lake currents and density differences, and its robustness, reliability and accuracy. The model was developed by the Danish Hydraulic Institute (DHI, 2014) and has been used in numerous environmental and ecological studies around the world.

MIKE3-FM is a general numerical modelling system based on a flexible mesh approach for simulation of flows in estuaries, bays and coastal areas. MIKE3-FM simulates unsteady three-dimensional flows taking into account density variations, bathymetry and external forcing such as meteorology, currents and other hydrographic conditions. The areas of application of the model involve problems where flow and transport phenomena are important with emphasis on coastal applications and in sediment transport studies for fine cohesive materials or sand/mud mixtures in estuaries and coastal areas in which degradation of water quality may occur.

MIKE3-FM consists of six main modules: 1- Hydrodynamic module, 2- Transport module, 3- Water Quality module, 4- Particle Tracking module, 5- Mud Transport module and 6- Sand Transport module. The Hydrodynamic and Mud Transport modules used in this study are outlined below.

The Hydrodynamic module, MIKE3-FM-HD, is based on the numerical solution of the three-dimensional incompressible Reynolds averaged Navier-Stokes equations invoking the assumption of Boussinesq for hydrostatic pressure. The hydrodynamic model consists of continuity, momentum, temperature, salinity and density equations. This module provides the hydrodynamic basis for the Mud Transport Module.

The Mud Transport module, MIKE3-FM-MT, describes the erosion, transport and deposition of mud or sand/mud mixtures under the action of currents and waves. This module is applicable for mud fractions alone and sand/mud mixtures. Features such as forcing by waves, salt-flocculation, detailed description of the settling process, layered description of the bed and morphological update of the bed can be included in the simulation.

6.2 Modelling Considerations

Basic assumptions were necessary for the hydrodynamic and mud transport modelling.

The assumptions for the hydrodynamic modelling were:

- Waves were not included in the model;
- Typical along shore, offshore and onshore currents were simulated; and
- Typical temperatures in the lake for the spring and summer seasons were used in the model.

The assumptions for the mud transport modelling were:

- One grain size was adopted to represent the suspended sediment; and
- Uniform bed composition was used for the creek and the near shore region.

6.3 Computational Domain

The computational grid consisted of 5840 elements and 3080 nodes. The vertical grid was divided into 9 layers to account for buoyancy effects during summer. The grid spanned 3 km alongshore and 2.5 km offshore. The computational grid was divided into four regions: i) Oakville Harbour, ii) the region outside the creek mouth, iii) the region in the vicinity of the WPP intake, and iv) the region beyond the intake. A grid of 10 m was used within Oakville Harbour from a location 200 m downstream of Lakeshore Road West to the creek mouth. A grid of 25 m was used for the region outside the creek mouth covering a distance from the mouth to the North-East shoreline of 240 m, from the mouth to the South-West shoreline of 300 m and from the mouth to the lake of 600 m. A grid of 50 m was used for the region near the WPP intake covering a distance from the mouth to the North-East shoreline of 600 m, from the mouth to the South-West shoreline of 800 m and from the mouth to the lake of 1,200 m. A grid of 75 m was used for the region beyond the intake covering a distance from the mouth to the North-East shoreline of 750 m, from the mouth to the South-West shoreline of 1,200 m and from the mouth to the lake of 1,800 m. The grid size outside these four regions was 100 m. **Figure E1** shows the computational grid and the location of the existing WPP intake.

6.4 Model Setup

Hydrodynamic Model

The hydrodynamics (three-dimensional flow velocities) were simulated by MIKE3-FM-HD. The model setup is described below.

- The vertical mesh was divided into nine layers to account for buoyancy effects.
- Temperature/density stratification was included in the model.
- Shore parallel lake currents were simulated by imposing an inflow in the open boundary (*e.g.* east boundary) and water levels in the opposite open boundary (*e.g*. west boundary).
- Offshore/onshore lake currents were simulated by imposing wind stress on the water surface and water levels in the open boundary (*e.g.* south boundary).
- The temperature in Lake Ontario was set to 5.1 ^{o}C to represent the isothermal condition in spring.
- The thermal stratification was modelled in summer by imposing temperatures ranging from 12 ^{o}C (near the bottom) to 20 ^{o}C (near the surface).

Mud Transport Model

The transport of cohesive sediments was simulated by MIKE3-FM-MT. The model setup is described below.

- The bed composition in the creek and the near shore lake region was characterized by two layers (a soft mud layer and hard mud layer).

- A single sediment size was used to characterize the suspended sediment with a settling velocity of 6×10^{-6} m/s.
- A sand mixture was not included in the model.
- Flocculation was not included in the model.
- Horizontal and vertical dispersion coefficients were calibrated to reproduce the observed suspended sediment concentrations during the field sampling.

6.5 Model Calibration

The Mud Transport model was calibrated to provide reasonable and more realistic predictions of the distribution and concentration of sediment within the plume. The model parameters (*e.g.* dispersion coefficients) were calibrated to reproduce the conditions of the sampling conducted on July 28, 2014. The sampling results are shown in **Appendix B**. The lake current direction during the sampling was Southwest (SW) as shown in **Figure 1**.

Several assumptions were made during the model calibration and include:

- The Sixteen Mile Creek flows were obtained from real time flows from station 02HB004 and station 02HB005;
- Suspended sediment concentrations were determined using the curve shown in **Figure C10**;
- The creek temperature was 23 ^{o}C (75th percentile);
- The lake current direction was SW with an assumed speed of 3 cm/s;
- The lake was stratified; and
- The lake water level was 74.8 m.

The boundary conditions in the creek were defined as follows:

- Flows at the mouth were estimated using **Equation 1** (increased by 1.5) for the period July 27-28, 2014. The maximum flow in the mouth was 10.1 m^3/s as shown in **Figure F1**.
- Suspended sediment concentrations were estimated at the mouth for the period July 27 – 28, 2014. The maximum suspended sediment concentration was 131 mg/L as shown in **Figure F2**. This concentration was slightly above the observed concentration of 112 mg/L.

Horizontal and vertical dispersion coefficients in the Mud Transport model were calibrated. The settling velocity, the creek temperature and the lake current speed were assessed through sensitivity analysis which showed no significant change in the distribution and concentration of sediments within the plume. The creek temperature impacted sediment concentrations within the plume due to changes in buoyancy at the mouth; creek temperatures below 23 ^{o}C correlated with observed changes due to the intrusion of the cold water into the lake. Calibrations results for the creek temperature of 23 ^{o}C are presented.

Figures F3 and **F4** show the comparison of predicted versus observed concentrations near the surface and at mid-depth, respectively. The model predictions near the surface and at mid-depth were found to be rational, as presented in the figures.

Figure F5 shows the observed (denoted by the orange line in the figure) and predicted extent of the sediment plume. The predicted extent of the sediment plume was well represented by the model.

6.6 Model Validation

The Mud Transport model was validated with a second set of plume sampling data completed on September 11, 2014. During the sampling event, an offshore wind from the northwest was observed which produced a southeast current. The current speed was not measured.

Several assumptions were made for the validation of the model. These include:

- Real time Sixteen Mile Creek flows were obtained from station 02HB004 and station 02HB005;
- Suspended sediment concentrations were determined using the curve as shown in **Figure C10**;
- The creek temperature was 23 ^{o}C (75th percentile);
- An offshore current with an assumed speed of 3 cm/s;
- The lake was stratified; and
- The lake water level was 74.8 m.

The boundary conditions in the creek were defined as follows:

- Flows at the mouth were estimated using **Equation 1** (increased by 1.5) for the period September 10 – 11, 2014. The maximum flow in the creek was 17.3 m^3/s as shown in **Figure G1**.
- Suspended sediment concentrations were estimated at the mouth for the period September 10 – 11, 2014. Using the discharge relation, as shown in **Figure C10**, the maximum suspended sediment concentration was 195 mg/L. This greatly overestimated the observed concentration of 39 mg/L. The suspended sediment boundary concentrations were therefore reduced to match the field observations at the mouth of the creek.

Figures G3 and **G4** show the comparison of predicted versus observed concentrations near the surface and near the bed, respectively. While there was considerable scatter in the prediction versus the observed concentrations, the predictions were reasonable given the poor relation between discharge and suspended sediment concentrations. **Figure G5** shows the observed (denoted by the orange line in the figure) and predicted extent of the sediment plume. The shape of the plume was reasonably predicted given the unknown lake currents at the time of sampling.

The model reasonably replicates the field sampling results with the correction made to the suspended sediment concentrations at the creek. This was expected given the poor relation between discharge and suspended sediment concentration for the data available (**Figure C10**). The curve fit to the data as displayed in **Figure C10** is intended to be conservative, which in most cases, will result in over prediction of suspended sediment concentrations.

6.7 Modelling Scenarios

Several modelling scenarios were selected to determine the distribution and concentrations of the plume near the bed immediately offshore of the Water Purification Plant. The scenarios consisted of different flow events in Sixteen Mile Creek for typical lake current directions, lake current velocities and lake temperatures for the spring and summer seasons. The typical lake current velocities and lake temperature scenarios were obtained from Baird (2009). The scenarios focused on conditions that would most likely to result in high turbidity at the existing intake location. All modelling scenarios are listed in **Table 8**.

The Sixteen Mile Creek flow scenarios for spring ranged from 30 m^3/s to 311 m^3/s. This corresponds to flow return periods of 0.5-yrs to 100-yrs. Due to limited temperature data, a temperature of 1.1 °C was used in spring based on the observed temperature in March 2010. The lake temperature was 5.1 °C (isothermal; Baird, 2009). Shore parallel, offshore and onshore lake currents with velocities ranging from 1 cm/s to 10 cm/s were simulated for each scenario (Baird, 2009).

The Sixteen Mile Creek flow scenarios for summer ranged from 30 m^3/s to 68 m^3/s. This corresponds to flow return periods of 0.5-yrs to 100-yrs. The temperature in the creek was 23°C which is the 75th percentile for the period 2010 to 2012. The lake was stratified with near surface temperatures of 20 °C, and 12 °C near the bed (Baird, 2009). Shore parallel, offshore and onshore lake currents with velocities ranging from 1 cm/s to 10 cm/s were simulated (Baird, 2009).

A lake current to the northeast was not included in the modelling scenarios as it would displace the sediment plume away from the WPP intake. Therefore, a current towards the southwest was used in the modelling scenarios. Scenarios with shore parallel currents were simulated for a period of 24 hours. Scenarios with offshore and onshore currents were simulated for a period of 12 hours.

Figures H1 to **H8** present the hydrographs and suspended sediment concentrations within Sixteen Mile Creek used in the simulations.

Table 8: Modelling scenarios

Scenario	Sixteen Mile Creek Discharge (m^3/s)	Sixteen Mile Creek Temperature (°C)	Current Direction	Current Speed (cm/s)	Lake Temperature (°C)	Season	Simulation Time
1	30	1.1	SW	1	5.1	Spring	24 hours
2	68	1.1	SW	1	5.1	Spring	24 hours
3	146	1.1	SW	1	5.1	Spring	24 hours
4	190	1.1	SW	1	5.1	Spring	24 hours
5	311	1.1	SW	1	5.1	Spring	24 hours
6	68	1.1	SW	3	5.1	Spring	24 hours
7	146	1.1	SW	3	5.1	Spring	24 hours
8	190	1.1	SW	3	5.1	Spring	24 hours
9	311	1.1	SW	3	5.1	Spring	24 hours
10	30	1.1	Offshore	3	5.1	Spring	12 hours
11	68	1.1	Offshore	3	5.1	Spring	12 hours
12	146	1.1	Offshore	3	5.1	Spring	12 hours
13	146	1.1	Offshore	10	5.1	Spring	12 hours
14	30	1.1	Onshore	10	5.1	Spring	12 hours
15	68	1.1	Onshore	3	5.1	Spring	12 hours
16	146	1.1	Onshore	1	5.1	Spring	12 hours
17	30	1.1	Onshore	1	5.1	Spring	12 hours
18	68	1.1	Onshore	10	5.1	Spring	12 hours
19	146	1.1	Onshore	3	5.1	Spring	12 hours
20	30	23	SW	1	20 (surface to mid-depth), 12 mid-depth to bottom)	Summer	24 hours
21	68	23	SW	1	20 (surface to mid-depth), 12 mid-depth to bottom)	Summer	24 hours
22	68	23	SW	3	20 (surface to mid-depth), 12 mid-depth to bottom)	Summer	24 hours
23	30	23	Offshore	3	20 (surface to mid-depth), 12 mid-depth to bottom)	Summer	12 hours

Scenario	Sixteen Mile Creek Discharge (m^3/s)	Sixteen Mile Creek Temperature (^oC)	Current Direction	Current Speed (cm/s)	Lake Temperature (^oC)	Season	Simulation Time
24	68	23	Offshore	3	20 (surface to mid-depth), 12 mid-depth to bottom)	Summer	12 hours
25	68	23	Offshore	10	20 (surface to mid-depth), 12 mid-depth to bottom)	Summer	12 hours
26	30	23	Onshore	3	20 (surface to mid-depth), 12 mid-depth to bottom)	Summer	12 hours
27	68	23	Onshore	3	20 (surface to mid-depth), 12 mid-depth to bottom)	Summer	12 hours
28	30	23	Onshore	10	20 (surface to mid-depth), 12 mid-depth to bottom)	Summer	12 hours
29	68	23	Onshore	10	20 (surface to mid-depth), 12 mid-depth to bottom)	Summer	12 hours

6.8 Modelling Results

Modelled results of the sediment plume for the 29 scenarios as listed in **Table 8** are provided in **Figures H9** to **H37**. Each figure shows the concentration and extent of suspended sediment concentration near the lake bed at the peak of the flow event. The subplot under each figure shows a time series of suspended sediment concentrations for each event predicted at the existing intake location.

Sediment Plume Extent

The offshore and alongshore extent of the plume varied greatly depending on the creek discharge and the prevailing lake currents. The predicted offshore limit for each scenario is listed in **Table 9** to **Table 12**. It must be note that onshore directed surface currents result in offshore directed currents at the bed and vice versa.

The greatest offshore plume extents at the bed were associated with weak shore parallel currents, high creek discharge and onshore directed surface currents, which resulted in offshore directed currents at the bed. Creek discharge as low as 68 m^3/s (1-yr return period) would generally extend the plume more than 1 km offshore, except for during summer conditions where vertical mixing is reduced, and during strong shore parallel currents which turn the plume sharply along the shoreline. Even the 0.5-yr return period flow (30 m^3/s) would extend out to the intake location under onshore or offshore currents in the spring.

Plumes with the least offshore extents were associated with: strong along-shore currents that turn the plume close to the shoreline; low creek discharge; and summer conditions where there is more limited vertical mixing.

The existing intake is located approximately 880 m offshore. The plume extended as far offshore as the intake for most of the scenarios that were modelled (18 of 29). However, small changes in the prevailing current could result in additional flow events impacting the intake. For example, the plume in scenarios 15 and 16 narrowly misses the intake location. A small current to the southwest would push the plume over the intake.

It is expected that even lower flows than those modelled could impact the intake under the right current conditions. For example, the 0.5-yr return period flow was found to extend up to 1900 m offshore, which was well beyond the existing intake.

Table 9: Sediment plume extent for spring scenarios (SW current)

Scenario	Flow (m^3/s)	Return Period (yr)	Current Speed (cm/s)	Plume Extent (m)
1	30	0.5	1 (SW)	800
2	68	1	1 (SW)	1,000
3	146	4	1 (SW)	1,400
4	190	10	1 (SW)	1,500
5	311	100	1 (SW)	>2,200
6	68	1	3 (SW)	670
7	146	4	3 (SW)	920
8	190	10	3 (SW)	1,050
9	311	100	3 (SW)	1,400

Table 10: Sediment plume extent for spring scenarios (offshore/onshore surface current)

Scenario	Flow (m^3/s)	Return Period (yr)	Current Speed (cm/s)	Plume Extent (m)
10	30	0.5	3 (Offshore)	890
11	68	1	3 (Offshore)	1,300
12	146	4	3 (Offshore)	1,500
13	146	4	10 (Offshore)	650
14	30	0.5	3 (Onshore)	1,500
15	68	1	3 (Onshore)	1,900
16	146	4	3 (Onshore)	> 2,200
17	30	0.5	10 (Onshore)	1,900
18	68	1	10 (Onshore)	2,000
19	146	4	10 (Onshore)	> 2,200

Table 11: Sediment plume extent for summer scenarios (SW current)

Scenario	Flow (m^3/s)	Return Period (yr)	Current Speed (cm/s)	Plume Extent (m)
20	30	0.5	1 (SW)	320
21	68	1	1 (SW)	480
22	68	1	3 (SW)	480

Table 12: Sediment plume extent for summer scenarios (offshore/onshore surface current)

Scenario	Flow (m^3/s)	Return Period (yr)	Current Speed (cm/s)	Plume Extent (m)
23	30	0.5	3 (Offshore)	700
24	68	1	3 (Offshore)	950
25	68	1	10 (Offshore)	650
26	30	0.5	3 (Onshore)	350
27	68	1	3 (Onshore)	780
28	30	0.5	10 (Onshore)	600
29	68	1	10 (Onshore)	1,050

Suspended Sediment Concentrations at the WWP Intake

Maximum suspended sediment concentrations at the existing intake are listed in **Table 13** to **Table 16**. The maximum predicted turbidity, as represented by TSS, at the existing intake among the modelling scenarios occurred for Scenario 9 where a 100-yr return period flow was deflected southwest by a 3 cm/s current towards the southwest. Suspended sediment concentration was greater than 100 mg/L at the intake for 12 of the 29 scenarios. However, there were many events where the plume was close to the intake and a small change in the current strength or direction could result in significant increases in turbidity.

High turbidity events at the existing intake occurred for weak southwest directed lake currents and high creek discharge. The maximum concentration at the intake for the lowest creek flow modelled (0.5-yr return period) was 75 mg/L. This concentration could increase with small variations in the lake currents as seen for scenario 10 (**Figure H18**), where concentrations adjacent to the intake were greater than 100 mg/L.

Maximum suspended sediment concentrations at the intake were plotted against the peak discharge for each modelled scenario (**Figure 6**). Concentrations at the intake generally increased with increasing discharge from Sixteen Mile Creek. There was considerable scatter in the relation depending on the current and season. For example, concentration for the 146 m^3/s flow varied from zero for a 10 cm/s offshore surface current to 673 mg/L for a 3 cm/s current from the southwest. Concentrations at the bed were higher for spring temperature conditions where the colder sediment laden creek flow sank in the unstratified lake water.

Table 13: Maximum suspended sediment concentration at WWP intake for spring scenarios (SW current)

Scenario	Flow (m^3/s)	Return Period (yr)	Current Speed (cm/s)	Suspended Sediment Concentration (mg/L)
1	30	0.5	1 (SW)	75
2	68	1	1 (SW)	285
3	146	4	1 (SW)	542
4	190	10	1 (SW)	665
5	311	100	1 (SW)	788
6	68	1	3 (SW)	0
7	146	4	3 (SW)	673
8	190	10	3 (SW)	1,025
9	311	100	3 (SW)	1,510

Table 14: Maximum suspended sediment concentration at WWP intake for spring scenarios (offshore/onshore current)

Scenario	Flow (m^3/s)	Return Period (yr)	Current Speed (cm/s)	Suspended Sediment Concentration (mg/L)
10	30	0.5	3 (Offshore)	56
11	68	1	3 (Offshore)	270
12	146	4	3 (Offshore)	546
13	146	4	10 (Offshore)	0
14	30	0.5	3 (Onshore)	7
15	68	1	3 (Onshore)	24
16	146	4	3 (Onshore)	81
17	30	0.5	10 (Onshore)	0
18	68	1	10 (Onshore)	60
19	146	4	10 (Onshore)	222

Table 15: Maximum suspended sediment concentration at WWP intake for summer scenarios (SW current)

Scenario	Flow (m^3/s)	Return Period (yr)	Current Speed (cm/s)	Suspended Sediment Concentration (mg/L)
20	30	0.5	1 (SW)	0
21	68	1	1 (SW)	0
22	68	1	3 (SW)	8

Table 16: Maximum suspended sediment concentration at WWP intake for summer scenarios (offshore/onshore current)

Scenario	Flow (m^3/s)	Return Period (yr)	Current Speed (cm/s)	Suspended Sediment Concentration (mg/L)
23	30	0.5	3 (Offshore)	20
24	68	1	3 (Offshore)	111
25	68	1	10 (Offshore)	12
26	30	0.5	3 (Onshore)	2
27	68	1	3 (Onshore)	3
28	30	0.5	10 (Onshore)	6
29	68	1	10 (Onshore)	103

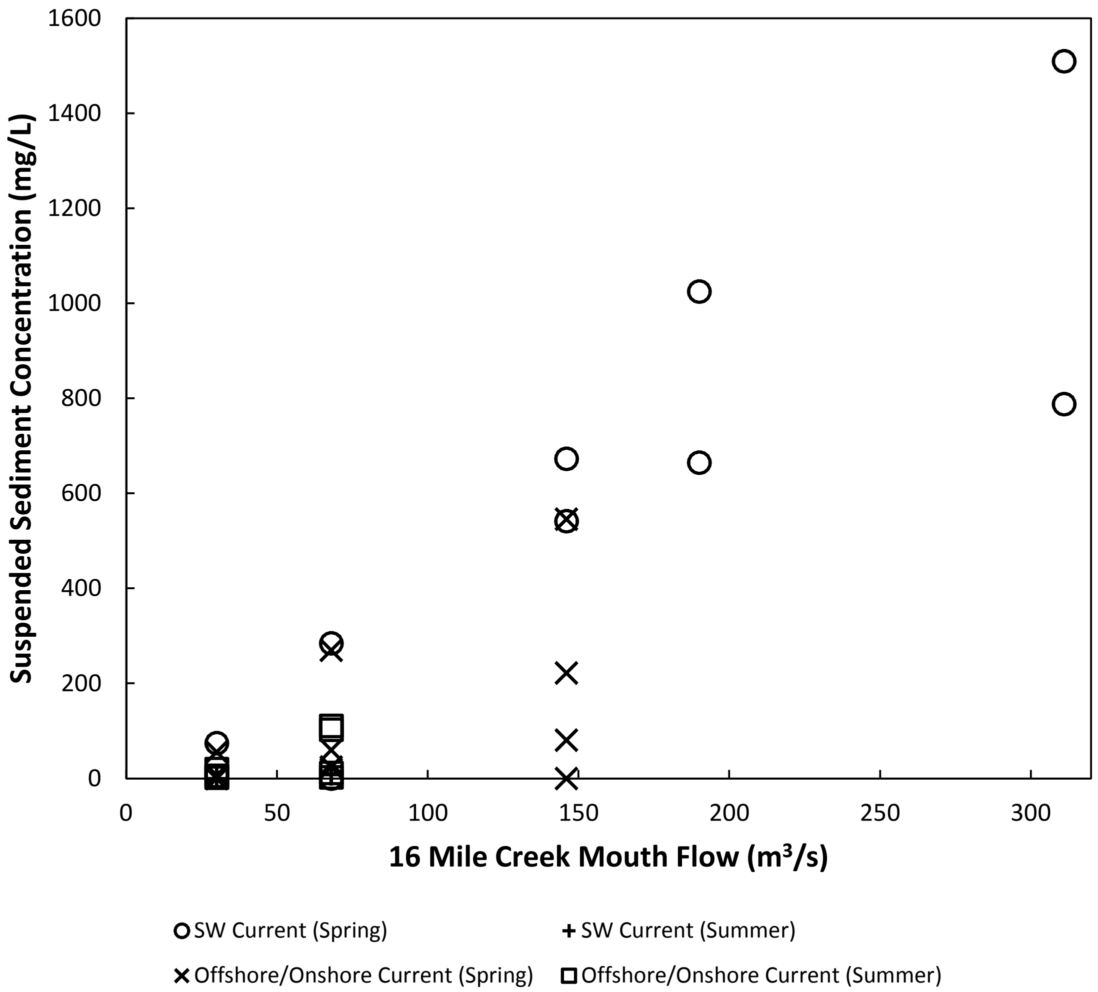

Figure 6: Modelled suspended sediment concentration and corresponding discharge at the mouth of Sixteen Mile Creek

Frequency of Occurrence

The potential frequency of occurrence of high turbidity (as represented by TSS) events at the intake location was difficult to determine due to the numerous variables involved. It is possible for TSS as high as 100 mg/L to occur for creek discharges as low as 30 m^3/s (0.5-yr return period) given the right lake current speed and direction. The frequency of occurrence of suitable lake currents could be estimated from the available current data (**Table 17**). High sediment concentrations at the intake would not occur when lake currents are directed towards the northeast east. In addition, they would not typically occur when shore parallel currents are greater than approximately 12 cm/s as these currents act to keep the plume close to shore. The highlighted values in **Table 17** denote the currents most likely to direct creek discharge towards the intake. These currents occur for a total of 43 % of the time. This indicates that for any given creek discharge with high turbidity, there is less than 43 % chance that the currents will be suitable to direct the turbidity towards the existing intake location.

Table 17: Current Data for Lake Ontario near Port Credit (from McCorquodale, 2005 and 2007)

Highlighted values denote current with the potential to direct creek discharge towards the intake.

Current Class	onshore	Offshore	Long NE	Long SW	Totals
0-4.5 cm/s	4.1%	7.7%	28.8%	7.0%	47.7%
4.5-7.5 cm/s	1.7%	5.6%	7.2%	5.5%	19.9%
7.5-12 cm/s	1.4%	4.9%	6.9%	4.9%	18.1%
12-20 cm/s	0.6%	3.5%	4.1%	1.8%	9.9%
>20 cm/s	0.1%	1.6%	1.6%	1.0%	4.3%
Totals	7.9%	23.3%	48.6%	20.2%	99.9%

Note: flow is toward the direction shown

Relocation of the Intake

Modelling results were used to estimate the potential benefits of relocating the intake a further 1 km offshore. A very rough approximation of the potential decrease in turbidity was completed using the scenarios that were modelled. Note that this evaluation is only approximate given that the scenarios are only a subset of the wide spectrum of potential conditions and are not an exhaustive list of potential events. **Table 18** shows the maximum TSS for each scenario at the existing intake location as well as the maximum TSS at a location 1 km offshore of the existing intake location. TSS was lower 1 km further offshore for 19 of the 29 scenarios modelled. TSS was higher at the offshore location for 5 of the 29 scenarios.

It is clear that plume impacts will decrease significantly 1 km further offshore for most scenarios with less than 68 m^3/s flows (1-yr return period). Flows of 68 m^3/s or greater could still result in higher concentrations at the offshore location. This was found to occur with onshore surface currents and weak shore parallel currents (Scenarios 15, 16, 18 and 19). Small variations in current direction and speed could easily result in high turbidity at the offshore location for flows greater than 146 m^3/s (4-yr return period). This can be seen in the distribution of the plume for Scenarios 3, 4, and 5 (**Figures H11**, **H12**, and **H13**).

Table 18: Comparison of turbidity at the existing intake and 1 km further offshore

Scenario	Sixteen Mile Creek Discharge (m^3/s)	Return Period (yr)	Current Direction	Current Speed (cm/s)	TSS at existing Intake (mg/L)	TSS 1 km offshore of existing intake (mg/L)
1	30	0.5	SW	1	75	0
2	68	1	SW	1	285	0
3	146	4	SW	1	542	0
4	190	10	SW	1	665	0
5	311	100	SW	1	788	0
6	68	1	SW	3	0	0
7	146	4	SW	3	673	0
8	190	10	SW	3	1,025	0
9	311	100	SW	3	1,510	0
10	30	0.5	Offshore	3	56	42
11	68	1	Offshore	3	270	46
12	146	4	Offshore	3	546	80
13	146	4	Offshore	10	0	0
14	30	0.5	Onshore	10	7	19

Scenario	Sixteen Mile Creek Discharge (m^3/s)	Return Period (yr)	Current Direction	Current Speed (cm/s)	TSS at existing Intake (mg/L)	TSS 1 km offshore of existing intake (mg/L)
15	68	1	Onshore	3	24	180
16	146	4	Onshore	1	81	230
17	30	0.5	Onshore	1	0	0
18	68	1	Onshore	10	60	160
19	146	4	Onshore	3	222	320
20	30	0.5	SW	1	0	0
21	68	1	SW	1	0	0
22	68	1	SW	3	8	0
23	30	0.5	Offshore	3	20	0
24	68	1	Offshore	3	111	0
25	68	1	Offshore	10	12	1
26	30	0.5	Onshore	3	2	0
27	68	1	Onshore	3	3	0
28	30	0.5	Onshore	10	6	0
29	68	1	Onshore	10	103	0

7. Climate Change and Lake Level Regulation

Potential climate change impacts that are relevant to the location of the intake with respect to the sediment plume from Sixteen Mile Creek include:

- Lake and creek temperatures;
- Water level fluctuations;
- Extreme storm events; and
- Other Potential Contaminants.

Each potential impact is discussed further below. Note that due to the lack of information on local climate change trends available at this time, only a qualitative discussion of potential impacts is provided.

Lake and creek temperature

Increasing air temperature due to climate change will likely result in increased lake and creek temperatures. The depth of the thermocline may become shallower and summer stratification may increase in duration and strength (DFO, 2013). However, there is limited data available for prediction in Lake Ontario (DFO, 2013). An increase in the duration and strength of the summer stratification would result in a more buoyant sediment plume and less mixing with the deeper water. This could result in the plume extending further offshore with concentrations decreasing as the plume spreads out over a larger area. Without further information, it would be reasonable to assume that the temperature impacts to the plume would be similar at the existing intake location and a potential new location further offshore.

Water level fluctuations

It is expected that climate change will have minimal impact on the water levels within Lake Ontario due to downstream structural controls. Water levels will change slightly in the future due to changes in the water level regulation regime. The International Joint Commission potential future water level Plan 2014 was developed to better replicate natural conditions. The water levels are shown in **Appendix I** and include:

- Water levels based on International Joint Commission (IJC) Plan 1958DD, which is a close approximate of the current regulation regime;
- Water levels based on Plan 2014, which is the current new water level plan being considered by the IJC; and,
- Water levels based on Plan E, which are the water levels which would occur if there was no control over the outflow from Lake Ontario.

Plan 2014 has slightly higher peaks and generally higher troughs, although there are occasions where the water levels are lower than the current plan. Overall, water levels would be higher for the proposed Plan 2014 than for the current plan in the future. This would have minor impacts on the suspended sediment plume and would not likely be of significance in evaluating a new potential intake location.

DFO (2013) also reports that water level impacts to Lake Ontario will likely be minor due to climate change because of structural controls, however they do note that lower levels are likely but higher levels could also be possible. A review by NOAA and The Nature Conservancy (2014) suggest using historic records of high and low water levels for climate change planning. Given the limited knowledge of future water levels, and the expectation that water levels will only be minorly impacted by climate change, additional modelling of potential water level impacts to the plume concentration and distribution would not be beneficial at this time.

Extreme storm events

Specific information on climate change trends and projection with respect to coastal and riverine processes are lacking (DFO, 2013). There is the potential for an overall increase in occurrence and intensity of extreme rainfall events and a decline in the total number of winter storm events as well as a decline in snow fall (NRCan, 2006; SENES Consultants Ltd., 2011). These changes have the potential to both increase and decrease the size and concentration of plume events.

The increase in extreme rainfall events would likely occur in the summer months. The events have the potential to create large suspended sediment plumes through the increased entrainment of sediment. However, since they will likely occur in the summer when vegetation stabilization would be greatest, the increased entrainment of sediment by overland flow will be limited. This will reduce the impact of the events on the concentration of the plume. Regardless of the concentration of sediment within the plumes, the larger events will transport the sediment further offshore which could reduce the benefit of moving the intake further offshore.

The predicted decline in snow fall would lead to a reduction in the discharge of the spring freshet. As noted in **Section 5.1**, highest turbidity at the intake was typically measured in the early spring during the freshet. This is due to both the high flows and limited vegetation cover in the early spring. Less snow fall and smaller freshets could result in a decrease in the concentration of the turbidity peaks in the spring.

Overall an increase in the frequency of extreme storm events will likely cause a rise in the turbidity at the intake.   This increase will likely be similar for both the existing intake location and a location 1 km further offshore. Quantification of the impacts is not possible at this time without better information on the potential increase in storm frequency and the impacts to suspended sediment concentration.

Other Potential Contaminants

Other contaminants may exist which were not evaluated as part of this study. These other contaminants could include impacts from other stormwater outfalls, wastewater treatment plant outfalls and potential for environmental impacts such as Algae Blooms on the raw water quality. It is understood that this report was prepared to complete the evaluation of the suitability of an extension of the existing raw water intake at the Oakville WTP. Should a raw water intake extension or new intake be selected as the preferred alternative it is recommended that additional water quality studies be completed to address other potential contaminants which could be present at the raw water intake and use this data to aid in determining the precise location of the raw water intake.

8. Summary and Recommendations

The extent and concentration of the Sixteen Mile Creek sediment plume was investigated through field sampling and numerical modelling. Suspended sediment sampling was conducted for two flow events. MIKE3-FM was used to model 29 plume scenarios. The scenarios span a wide range of creek discharge and lake current combinations. The scenarios were developed on the basis of their potential to result in high turbidity at the existing intake location, and to represent the range of typical conditions. The field data collected was used for calibrating and verifying the numerical model.

The following is a summary of the main findings of the study.

- The maximum field sampled suspended concentration was 112 mg/L. Ambient concentrations outside the plume were between 4 mg/L and 15 mg/L. Concentrations were generally higher at the surface than at the bed.
- The largest peaks in turbidity in the plant generally correspond to high flows in the spring. The high turbidity was likely due to entrainment of sediment by the freshet after most of the snow and ice has melted and before vegetation had established.
- Only 11 shutdowns due to high turbidity were evident in the 6 years of intake turbidity data provided by the Region. However, this was not a complete data set and additional shutdowns had likely occurred.
- 29 model scenarios were modelled including:
  - Creek flows from 30 m^3/s to 310 m^3/s;
  - Spring and summer temperature conditions; and
  - Onshore, offshore and south westerly lake currents.
- The greatest offshore plume extents at the bed were associated with: weak shore parallel currents; high creek discharge; and onshore directed surface currents, which resulted in offshore directed currents at the bed.

- Plumes with the least offshore extent were associated with: strong shore parallel currents which turn the plume close to the shoreline; low creek discharge; and summer conditions where there is more limited vertical mixing.
- The highest suspended sediment concentrations at the existing intake occurred for weak southwest directed lake currents and high creek discharge. Concentrations were higher at the bed during the spring due to greater vertical mixing than in the summer.
- Lake currents were favourable for directing the plume towards the existing intake less than 43 % of the time.
- Knowledge of potential climate change and their impact on the sediment plume processes is limited. Given the limited information available at this time, it would not be possible to quantify the difference in climate change impacts on the intake turbidity at the existing intake location and a potential new location 1 km further offshore.
- Relocating the intake 1 km further offshore would reduce the impacts of the more frequent flows below the 1-yr return period. Larger less frequent flows could still result in high suspended sediment concentrations at the relocated intake depending on the prevailing current.

The question of whether high turbidity has a significant impact on the operation of the WPP was beyond the scope of this assessment. The study focused on the extent and concentration of the sediment plume to assess whether or not relocating the intake will provide improvements to the water turbidity. Turbidity will likely improve by relocating the intake further offshore for the more frequent, smaller flows less than the 1-yr return period, however, larger and less frequent flows could still impact an intake located 2 km offshore.

Rather than relocating the intake, an alternative solution could be to obtain prior warning when high turbidity events may occur. This could be accomplished by installing an optical turbidity sensor upstream in Sixteen Mile Creek attached to a modem to utilize wireless cellular technology which would transmit real time warnings when a predefined turbidity level is exceeded. This would be similar to the systems already used as part of the *Silt Smart Protocol* (Version 1.2, March 2012) developed by CVC and the MNRF through consultation with DFO and MOECC for monitoring for high turbidity events from development sites. This would provide short term warning of a high turbidity event travelling downstream within the creek.

Creek monitoring could be further augmented by real time measurement of currents and turbidity offshore of Oakville Harbour. If the lake current is moving from the southwest to the northeast it would be unlikely that high turbidity from the creek would reach the intake. This would be a more expensive system than creek monitoring, given that the system would require a buoy and current meter in addition to the optical turbidity sensor and telemetry capabilities. Maintenance would also be more costly given the offshore location.

Should you at any point require further clarification, or if we can be of additional assistance please contact the undersigned.

Respectfully submitted,

GHD Limited

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Camilo Pinilla, Ph.D., P.Eng.
Water Resource Engineer

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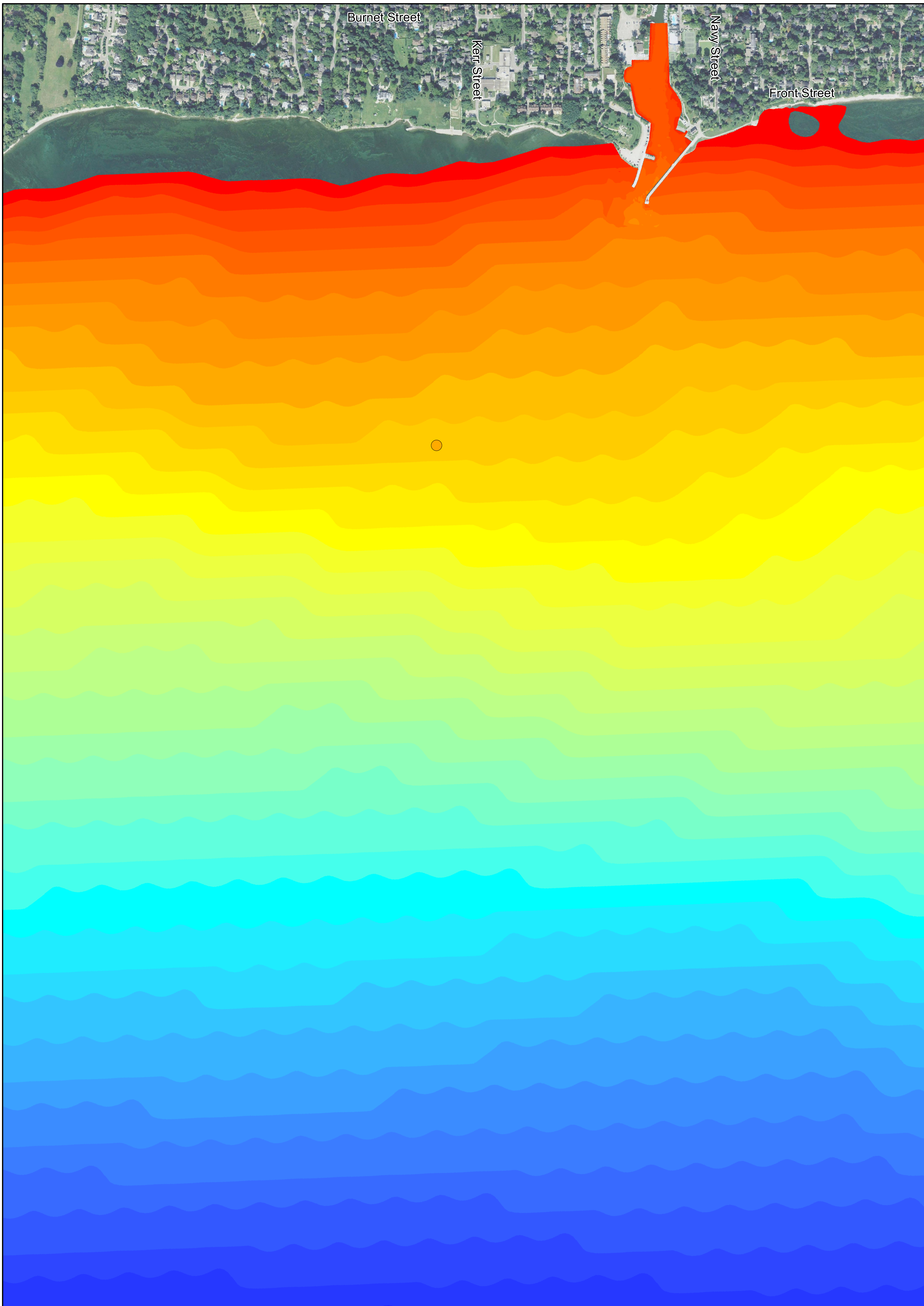
Water Survey of Canada (WSC) 2014b. Historical Flow Data – Sixteen Mile Creek at Milton (Station 02HB005).

Water Survey of Canada (WSC) 2014c. Sediment Data – East Sixteen Mile Creek near Omagh (Station 02HB004).

Water Survey of Canada (WSC) 2014d. Sediment Data – Sixteen Mile Creek at Milton (Station 02HB005).

Appendix A
Bathymetry



Legend

Water Depth (m) *

-1.00 - 0.00	20.00 - 25.00
0.00 - 5.00	25.00 - 30.00
5.00 - 1.00	30.00 - 35.00
10.00 - 15.00	35.00 - 40.00
15.00 - 20.00	

Oakville WPP Intake

* Depths are relative to Chart Datum for Lake Ontario (74.2 metres above I.G.L.D. 1985)

Oakville WPP Intake: GHD, 2014; Water Depth: NOAA, 1999, and GHD, 2013-2014; Imagery: Google Earth Pro, 2009

Sixteen Mile Creek

Lake Ontario Bathymetry

N

0 100 200

Metres

APPENDIX A

DATE: SEPT. 2014

PROJECT: 8811884.100

DRAWN BY: J.D., L.P.

Appendix B
Bed Sediments Characteristics and Field Sampling Results

Legend

Sediment Size

d_{50} (mm)

- N/A
- < 0.004 (Clay)
- 0.004 - 0.062 (Silt)
- 0.062 - 0.125 (Very Fine Sand)
- 0.125 - 0.25 (Fine Sand)
- 0.25 - 0.50 (Medium Sand)

0 40 80

Metres

N

Sediment Sorting: GHD, 2013; Orthoimagery: Town of Oakville, 2010.

Bronte Harbour Sediment Sorting

DRAWN BY: J.D., L.W.	DATE: JAN. 2014
PROJECT: 13017.450	FIGURE B1

Legend

- Oakville WPP Intake
- Sampling Location
- Approximate Edge of Plume
- Surface Layer TSS (mg/L)
- Subsurface Layer (~3 m depth) TSS (mg/L)

Oakville WPP Intake, Approximate Edge of Plume, Sampling Location, Surface Layer and Subsurface Layer TSS: GHD, 2014; Imagery: Google Earth Pro, 2009

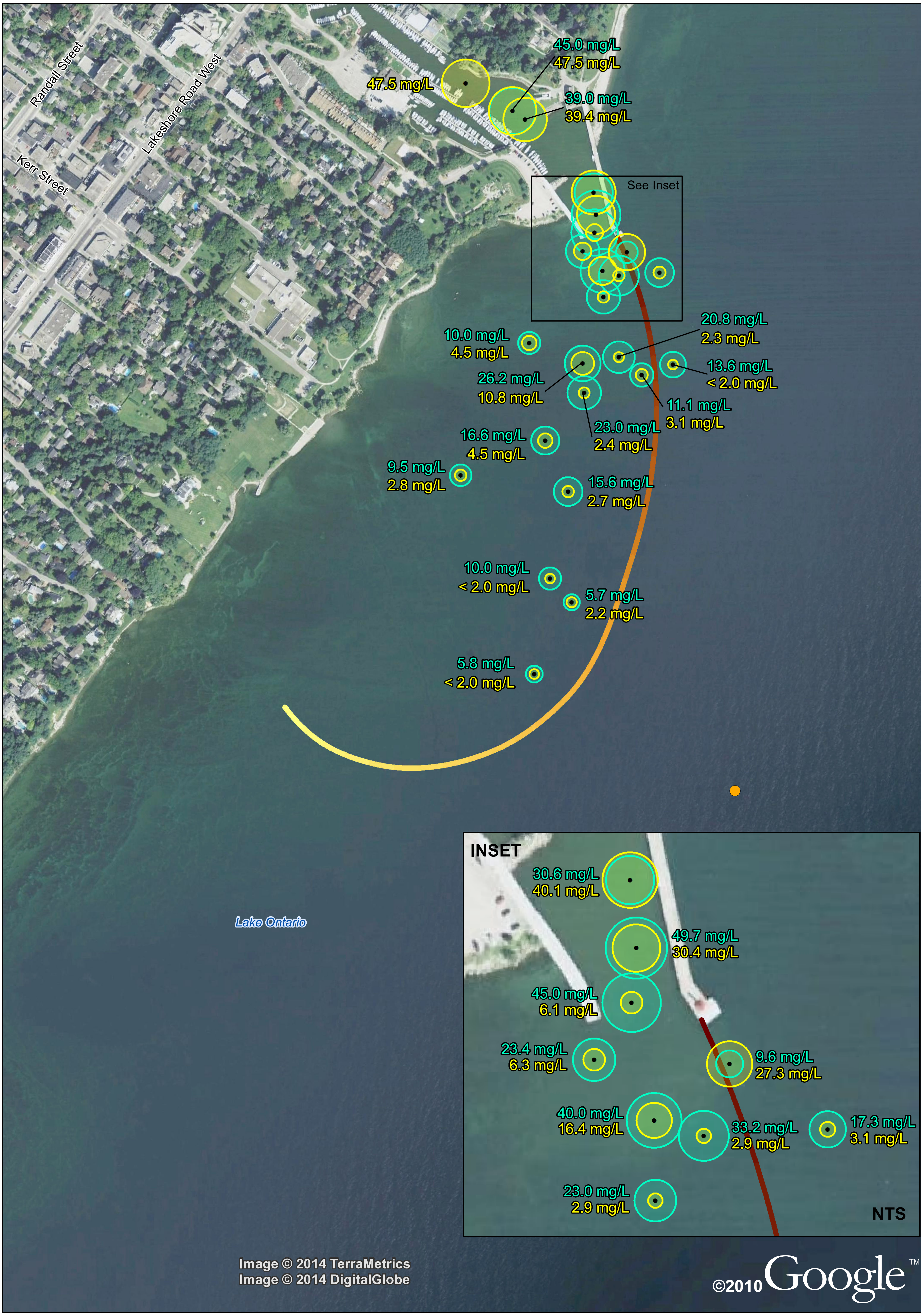
Sixteen Mile Creek

Total Suspended Solids
July 28, 2014

N
0 50 100
Metres

APPENDIX B2
DATE: SEPT. 2014
PROJECT: 8811884.100
DRAWN BY: J.D., R.G.

GHD



Legend

- Oakville WPP Intake
- Sampling Location
- Approximate Edge of Plume
- Surface Layer TSS (mg/L)
- Subsurface Layer (~2.3 to 6.3 m depth) TSS (mg/L)

Oakville WPP Intake, Approximate Edge of Plume, Sampling Location, Surface Layer and Subsurface Layer TSS: GHD, 2014; Imagery: Google Earth Pro, 2009

Sixteen Mile Creek

Total Suspended Solids
September 11, 2014

N

0 50 100

Metres

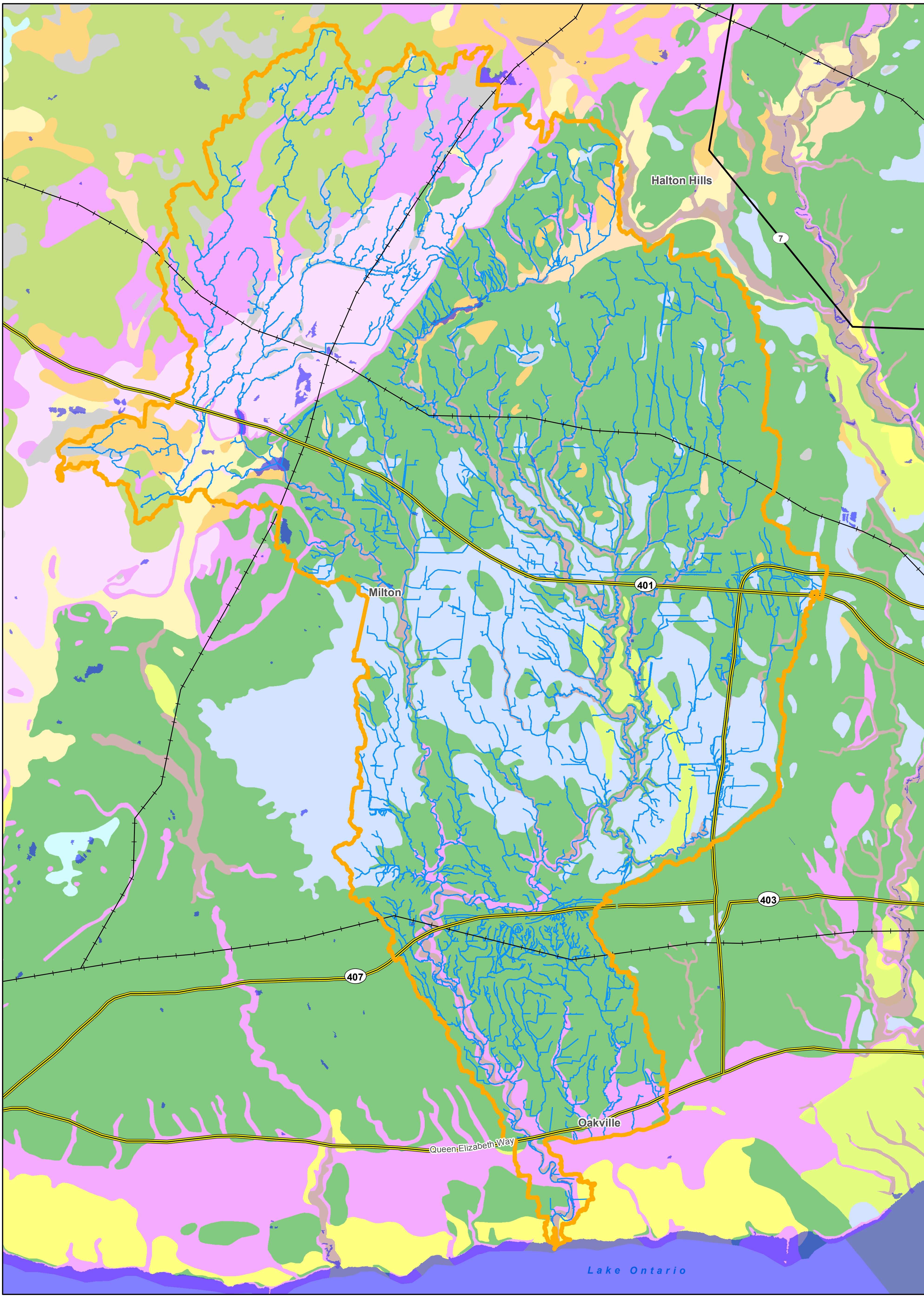
APPENDIX B3

DATE: APRIL 2015

PROJECT: 8811884.100

DRAWN BY: J.D., R.G.

Appendix C
Sixteen Mile Creek and Lake Ontario Data



Legend

- Highway
- Primary Road
- Railroad
- Watercourse
- Watershed

Surficial Geology

- 3: Paleozoic bedrock
- 4a: Mainly till veneer
- 5b: Stone-poor, carbonate-derived silty to sandy till
- 5d: Glaciolacustrine-derived silty to clayey till
- 6: Ice-contact stratified deposits
- 7a: Sandy deposits
- 7b: Gravelly deposits
- 8a: Massive-well laminated
- 8b: Interbedded flow till, rainout deposits and silt and clay
- 9: Coarse-textured glaciolacustrine deposits
- 9b: Littoral-foreshore deposits
- 12: Older alluvial deposits
- 14b: Littoral-foreshore deposits
- 19: Modern alluvial deposits
- 20: Organic deposits

Watercourse, and Watershed: Conservation Halton, 2013; Highway, Primary Road, and Railroad: ESRI, 2006;
Ontario Geological Survey 2003. Surficial Geology of Southern Ontario; Ontario Geological Survey, Miscellaneous Release--Data 128.

Bronte Creek Watershed

Surficial Geology

0 2 4
Kilometres

APPENDIX C1

DATE: FEB. 2014

PROJECT: 13017.450

DRAWN BY: J.D., R.G.

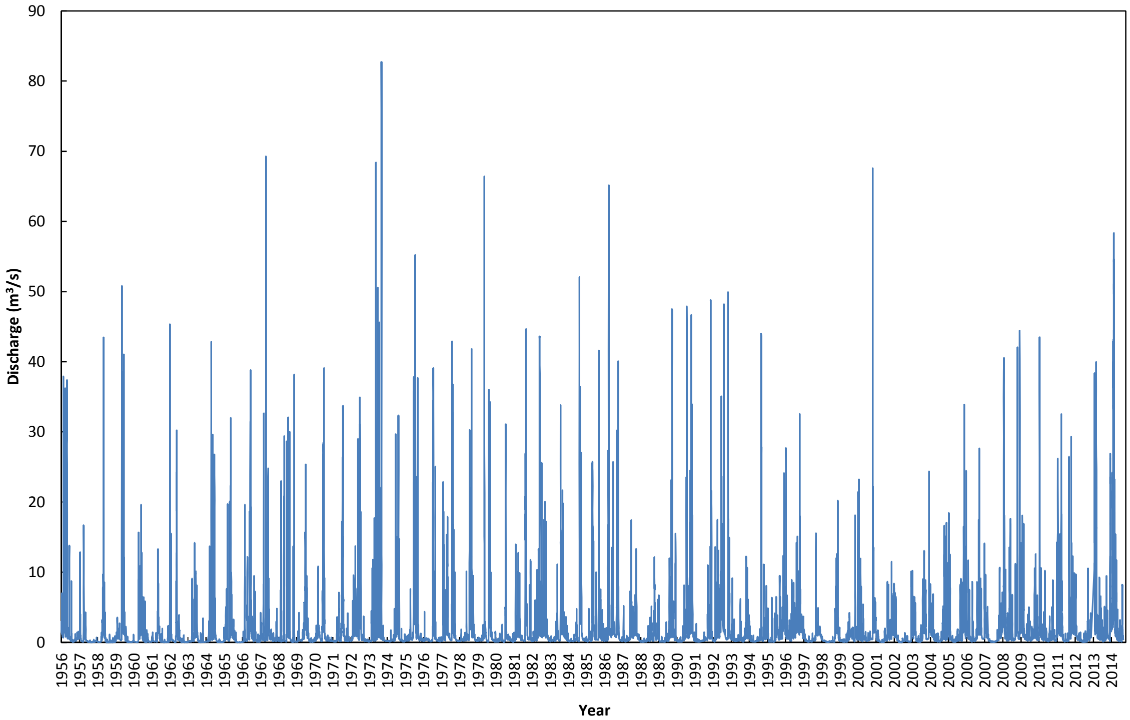


Figure C2: Historical flows for Station 02HB004 from 1956 to 2014

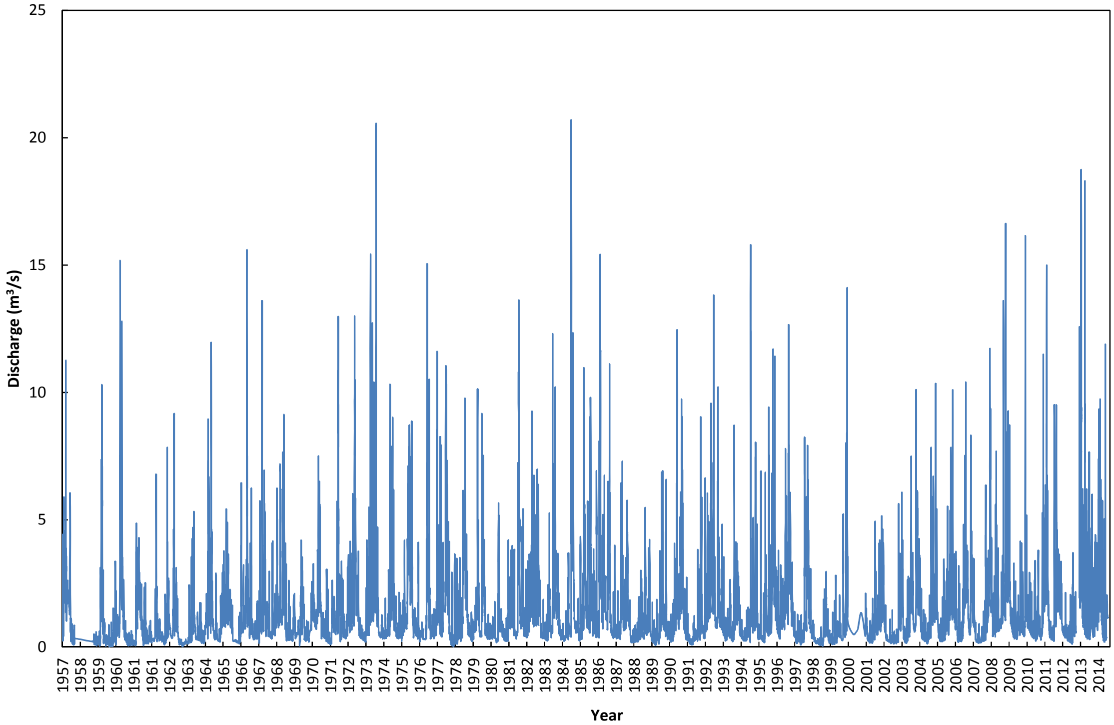


Figure C3: Historical flows for Station 02HB005 from 1957 to 2014

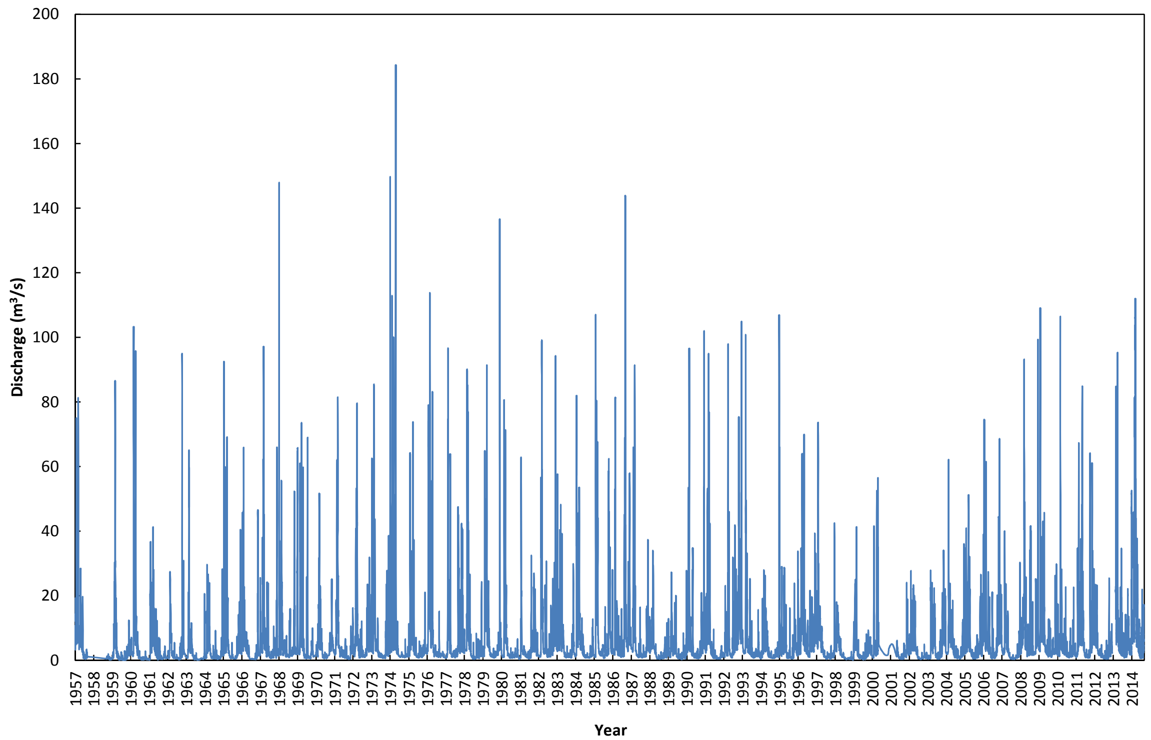


Figure C4: Estimated flows at the mouth from 1957 to 2014

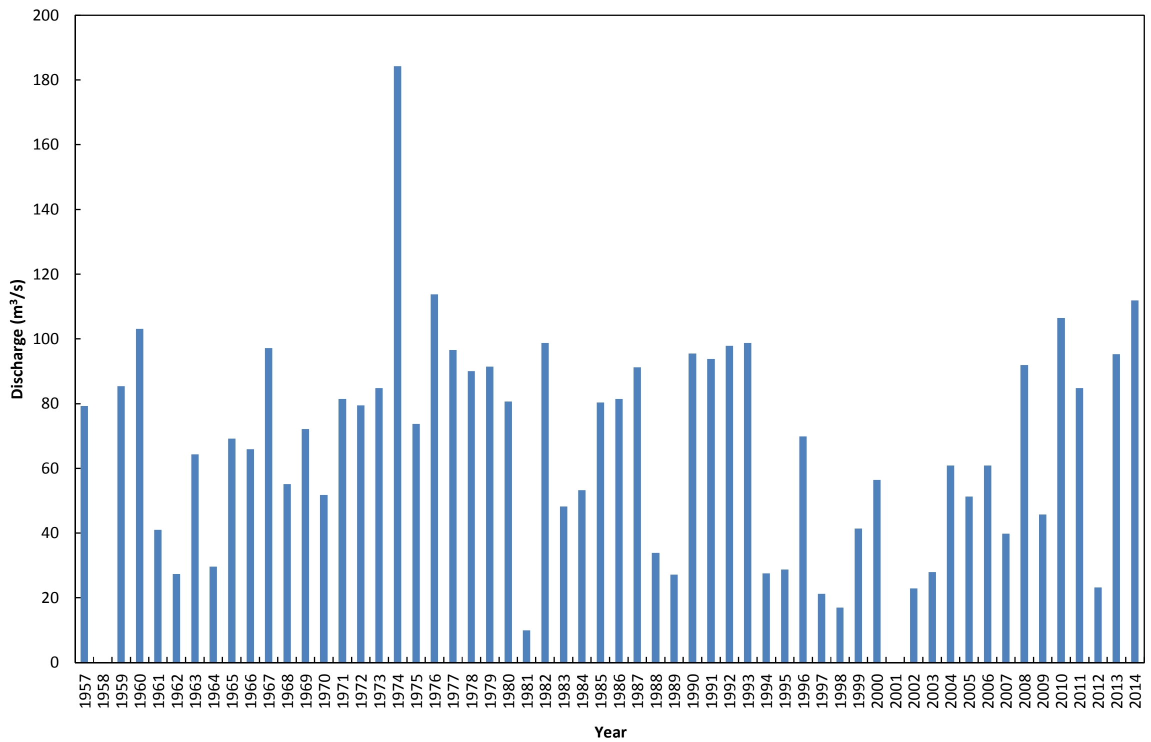


Figure C5: Maximum flows at the mouth in spring from 1957 to 2014

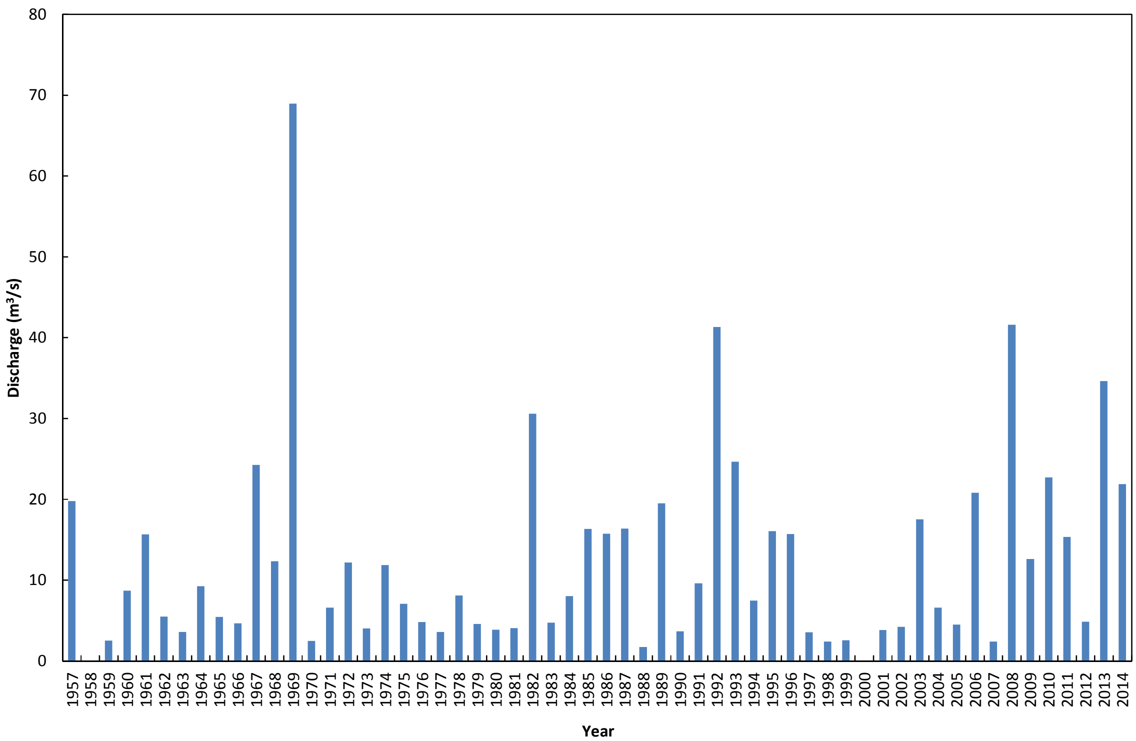


Figure C6: Maximum flows at the mouth in summer from 1957 to 2014

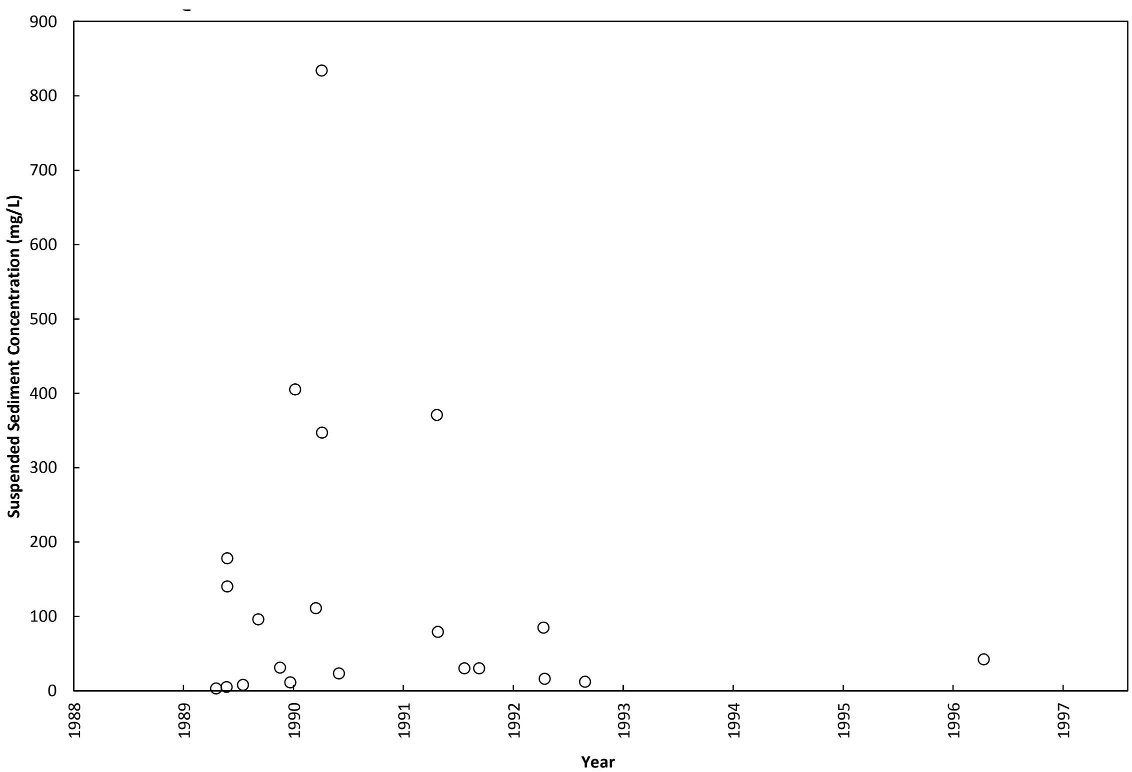


Figure C7: Suspended sediment concentrations for Station 02HB004

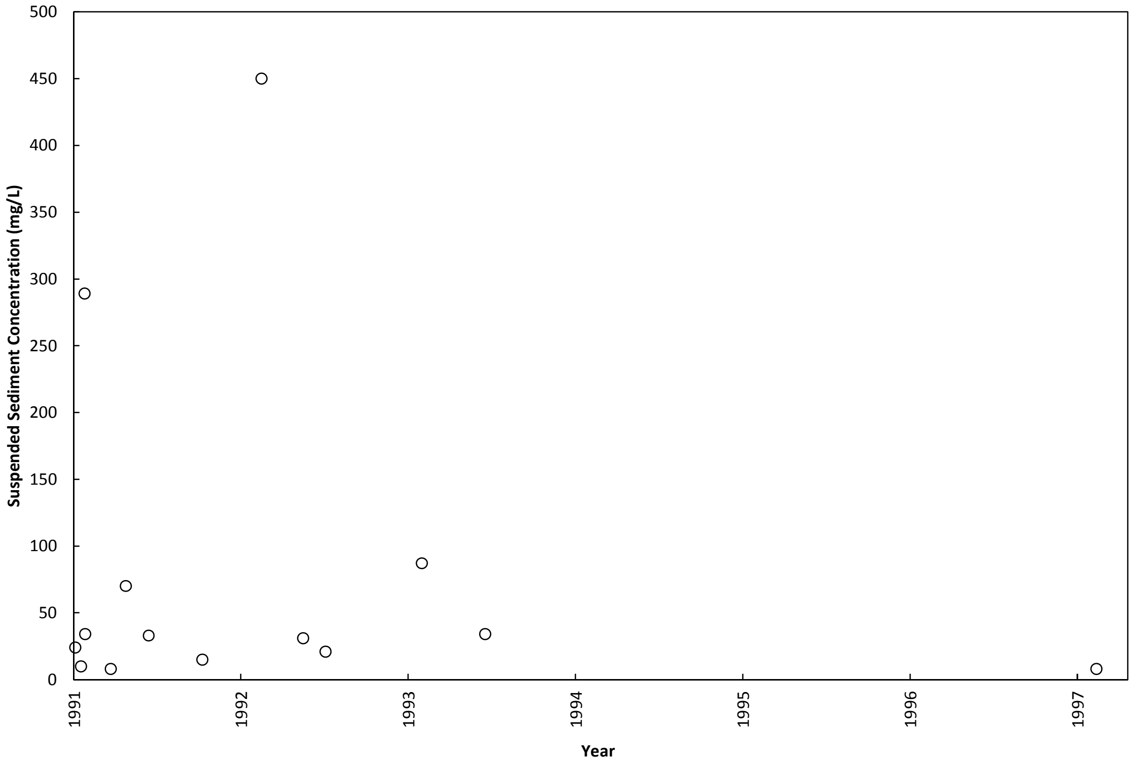


Figure C8: Suspended sediment concentrations for Station 02HB005

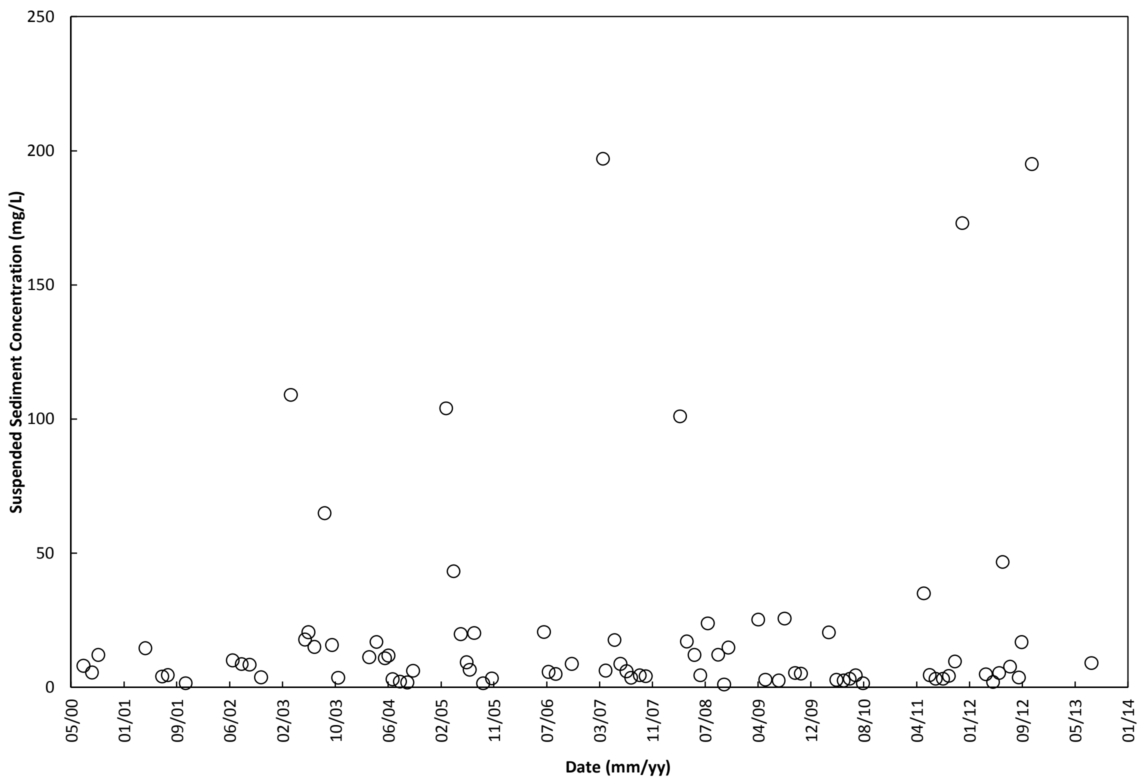


Figure C9: Suspended sediment concentrations for Station 06006300102

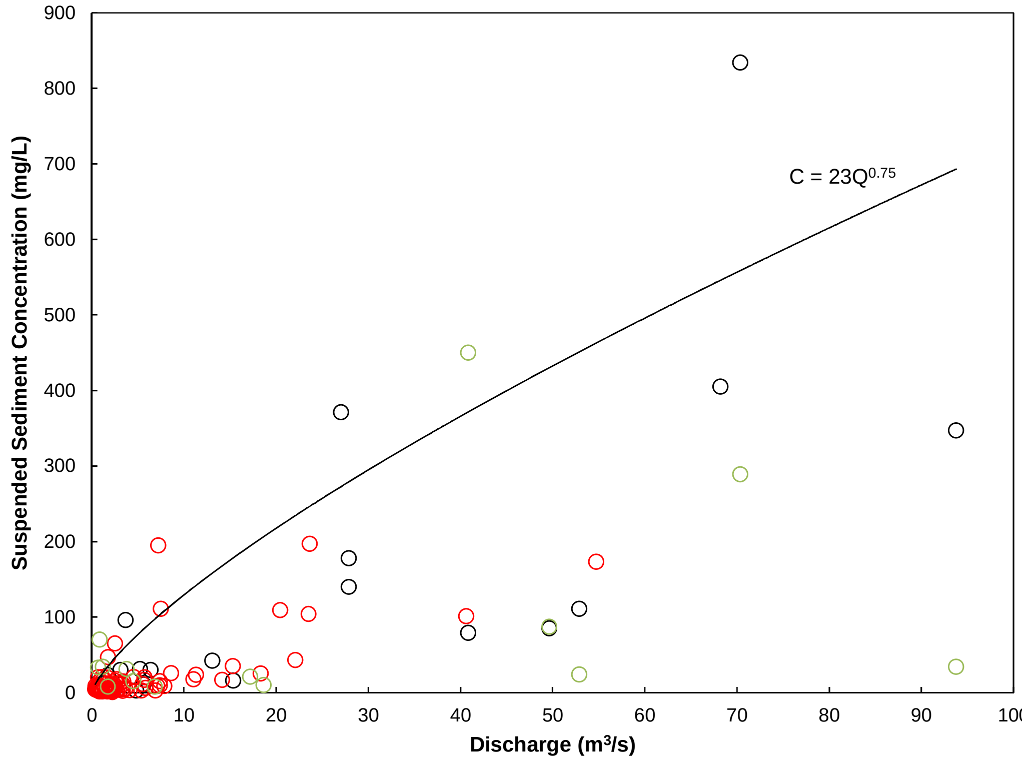


Figure C10: Suspended sediment concentrations versus discharge at the mouth of the creek. Red symbol (Station 06006300102). Black symbol (Station 02HB004). Green symbol (Station 02HB005)

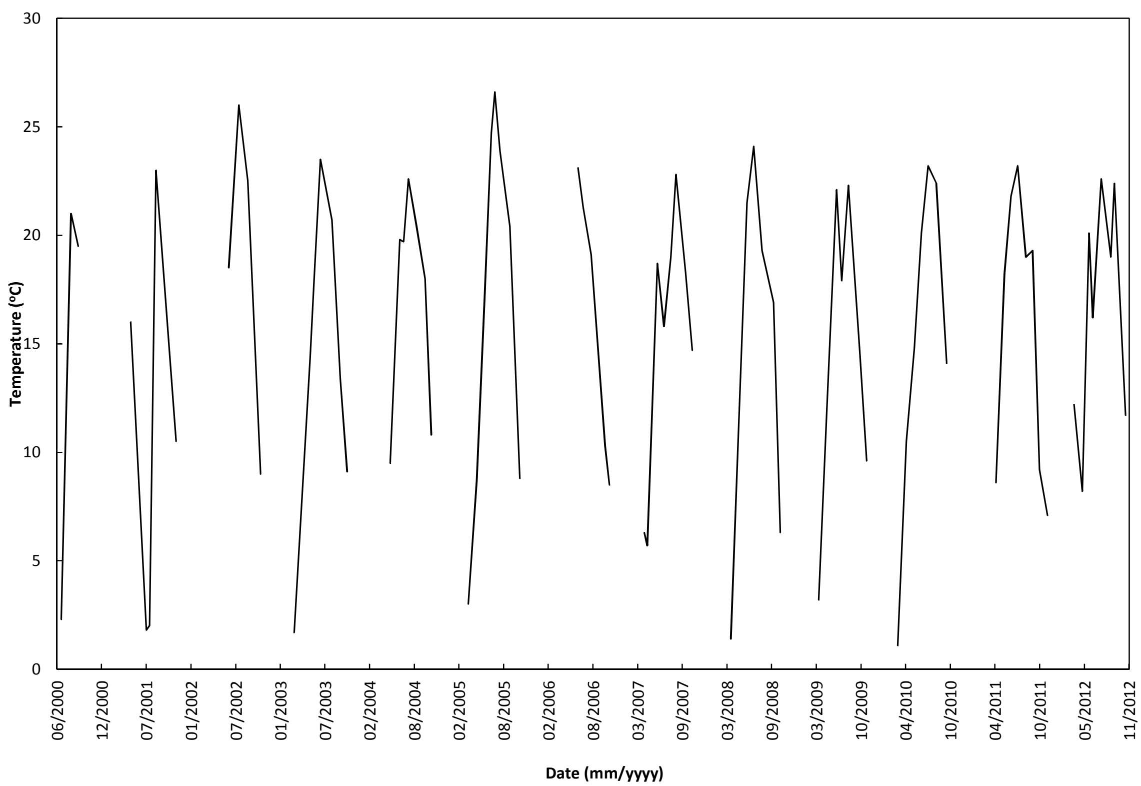


Figure C11: Temperature for Station 06006300102 from 2000 to 2012

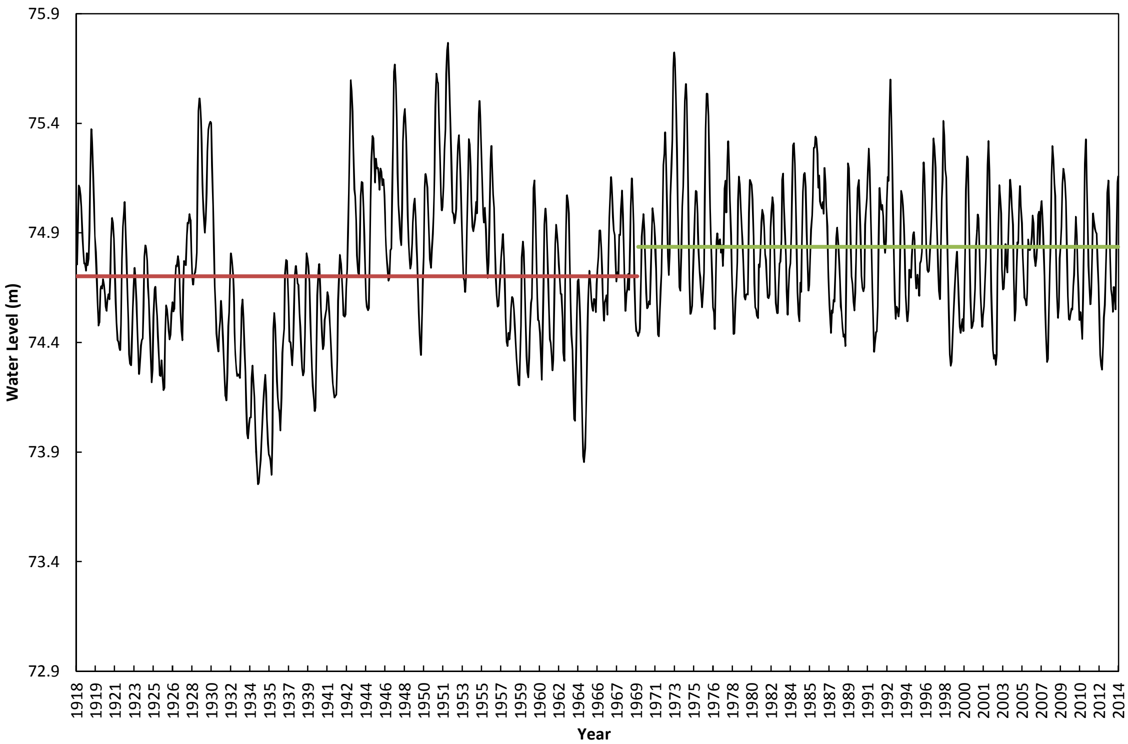


Figure C12: Historical Lake Ontario water levels from 1918 to 2014

Appendix D
Water Purification Plant Intake Turbidity

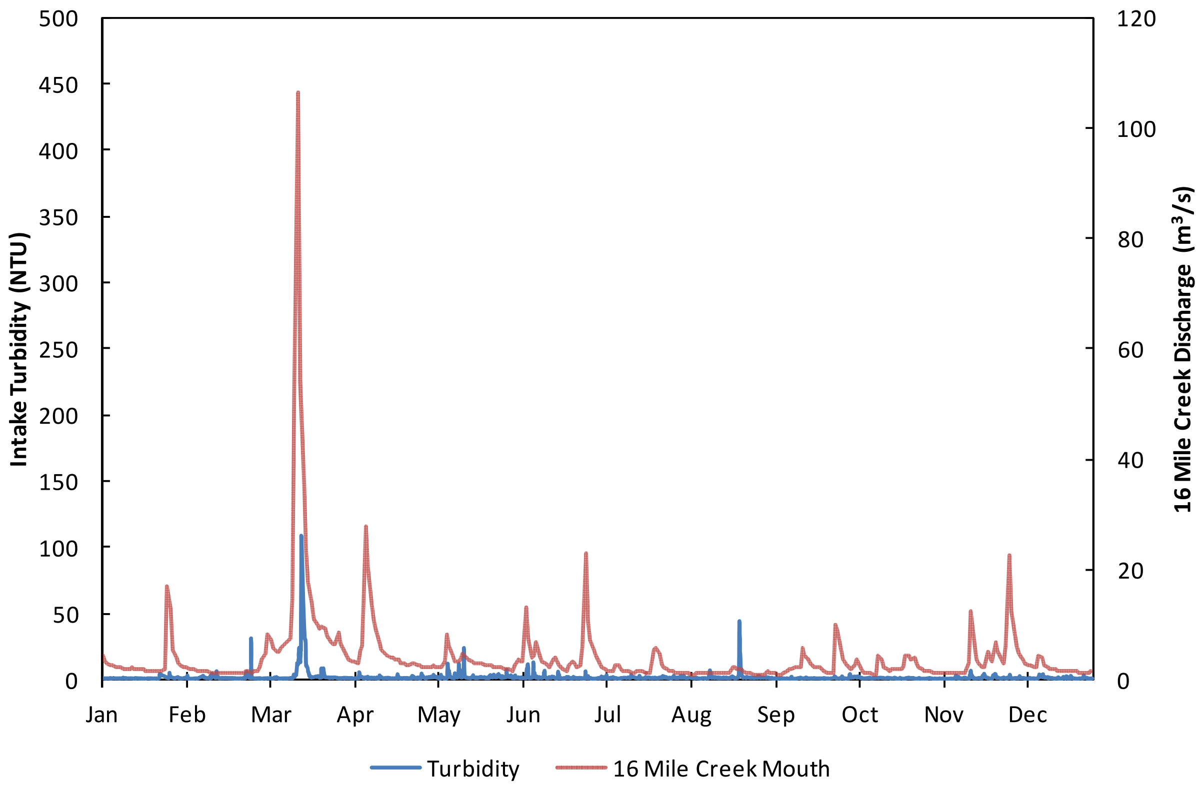


Figure D1: Turbidity at existing intake vs. flow at the mouth in 2010

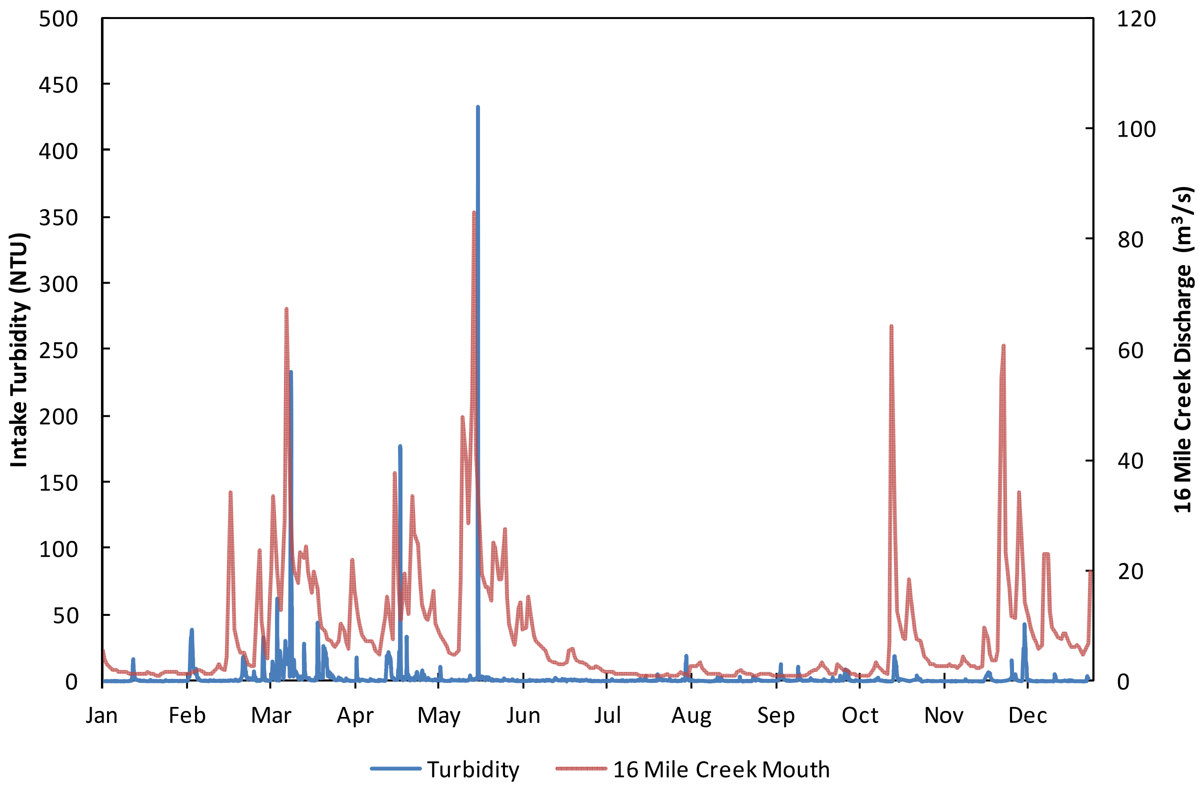


Figure D2: Turbidity at existing intake vs. flow at the mouth in 2011

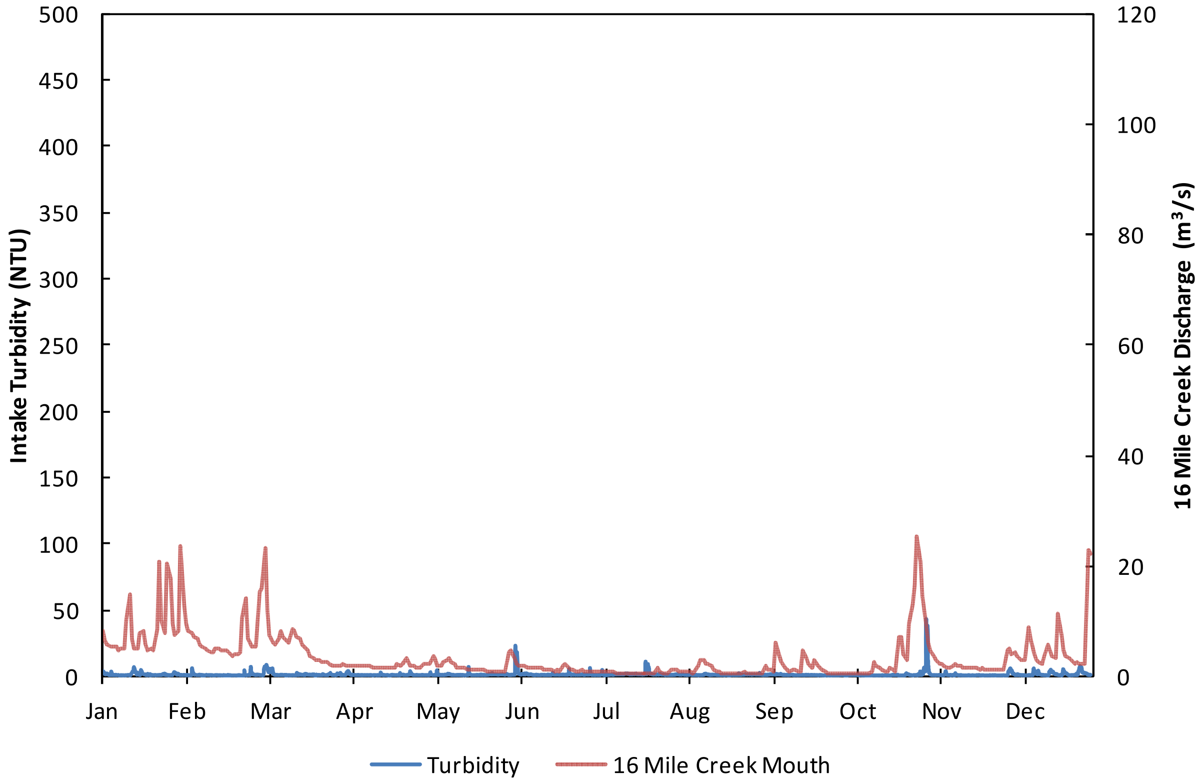


Figure D3: Turbidity at existing intake vs. flow at the mouth in 2012

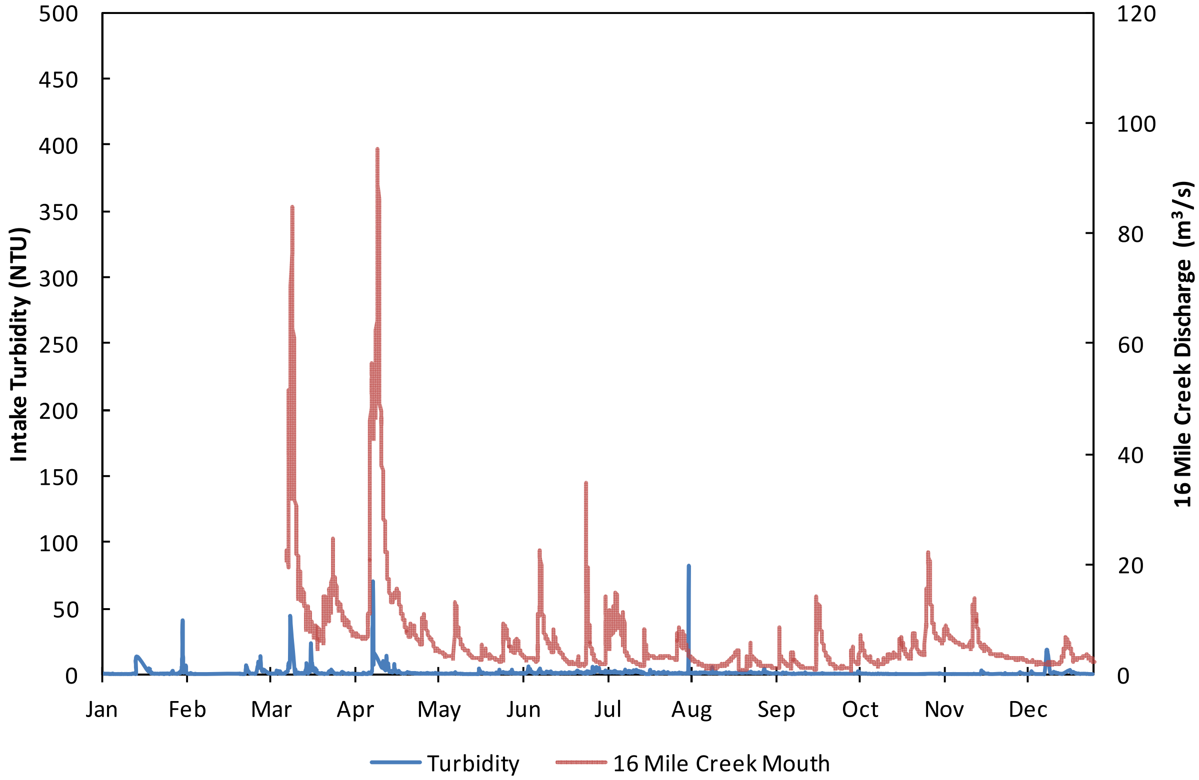


Figure D4: Turbidity at existing intake vs. flow at the mouth in 2013

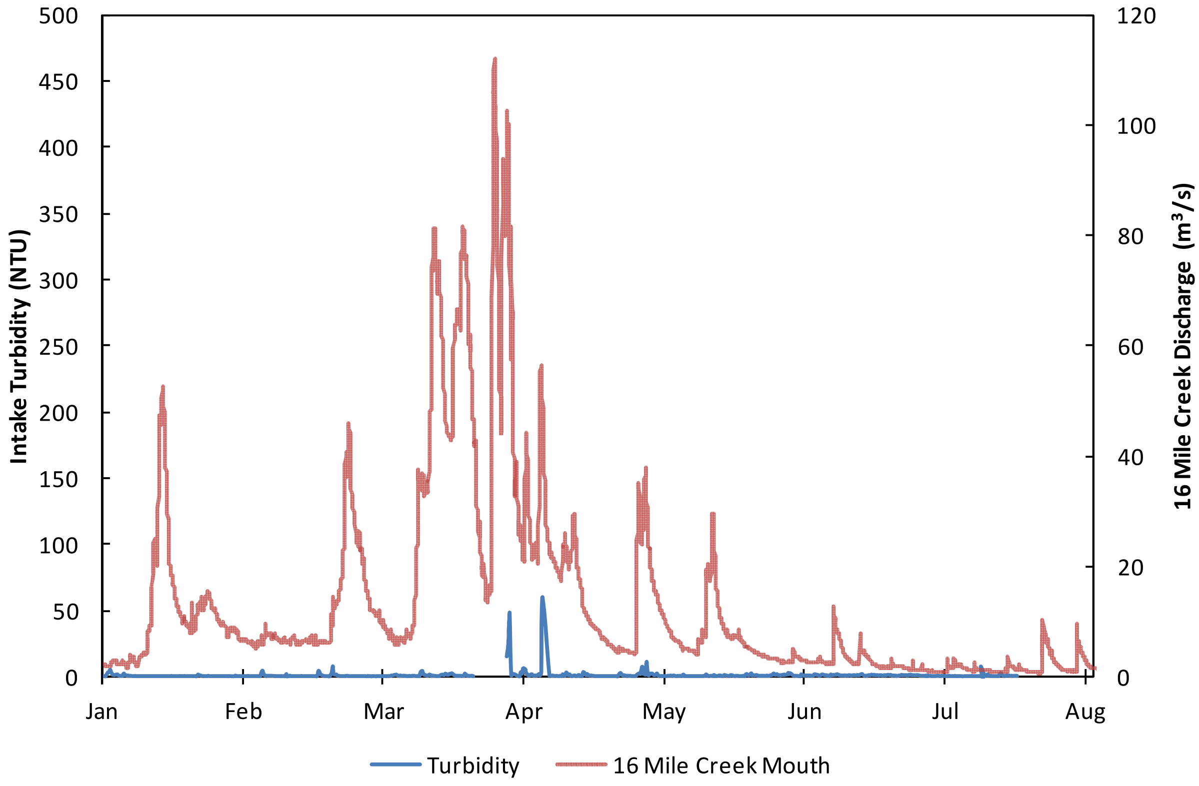


Figure D5: Turbidity at existing intake vs. flow at the mouth in 2014

Appendix E
Computational Domain

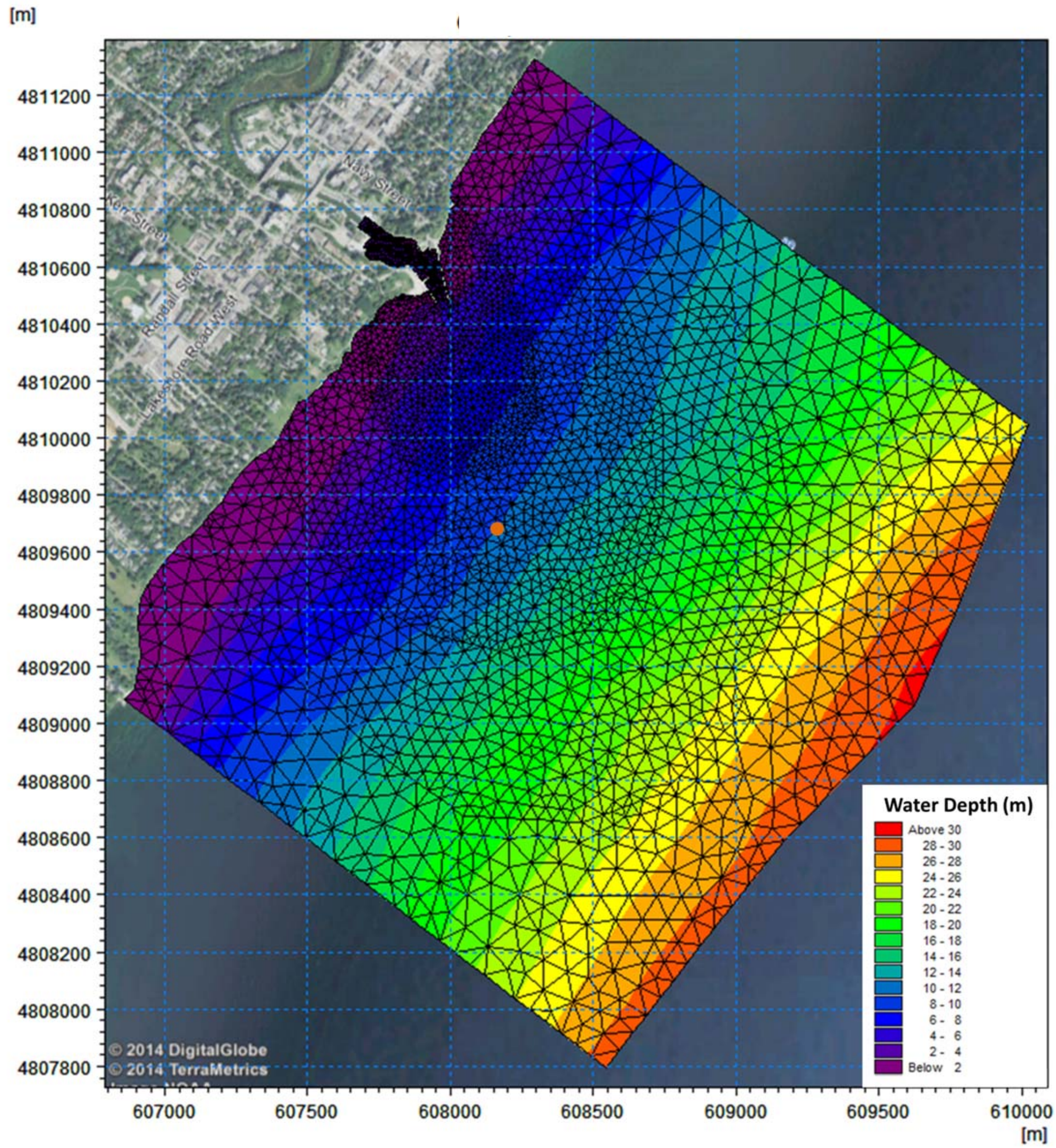


Figure E1: Computational domain. The orange symbol denotes the location of the existing Water Purification Plant intake

Appendix F
Model Calibration

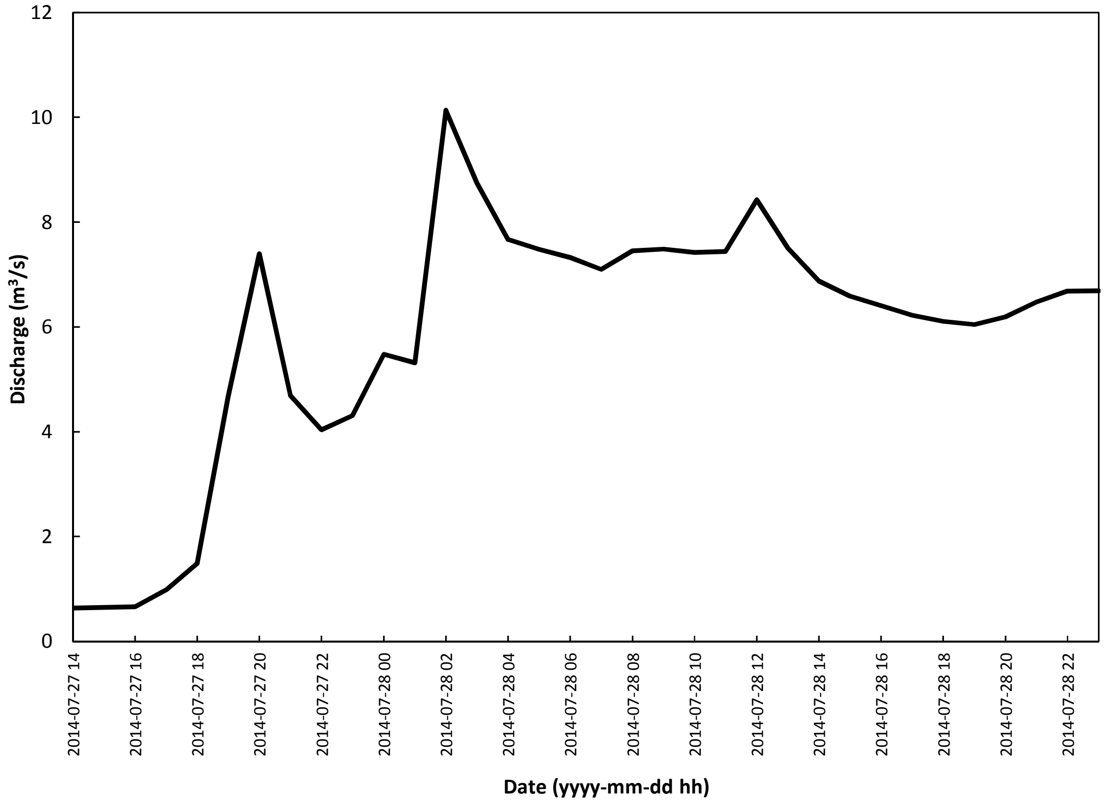


Figure F1: Hydrograph on July 27-28 at Sixteen Mile Creek

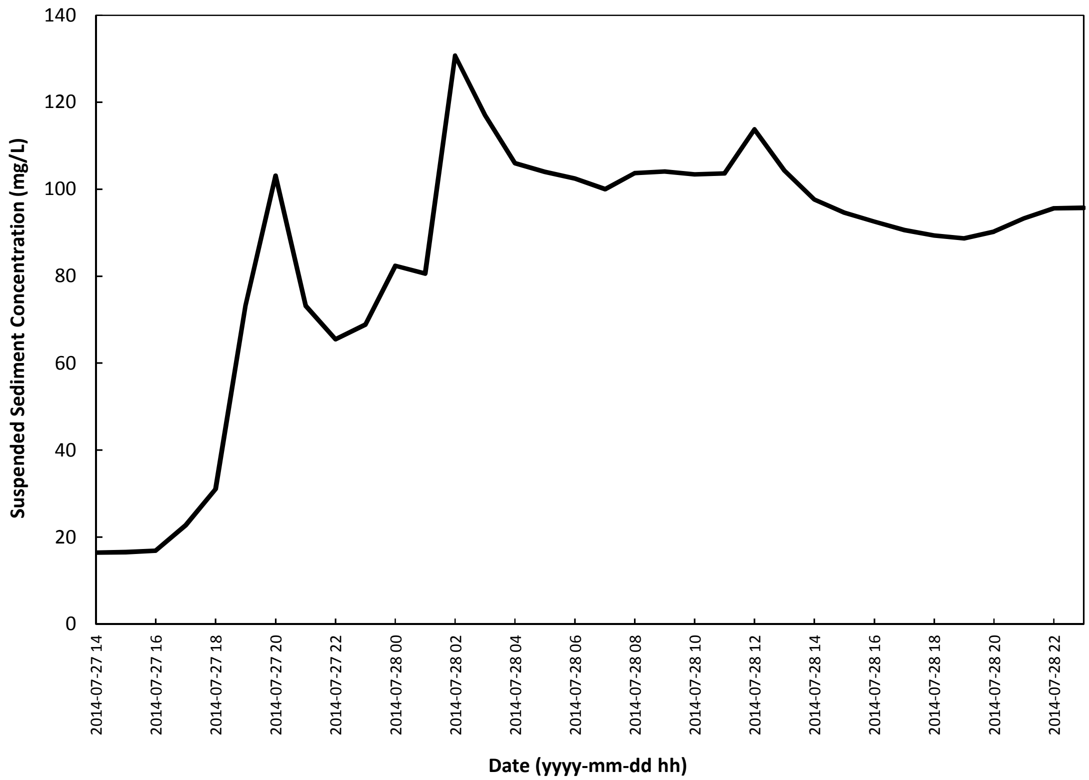


Figure F2: Susp. sediment concentration on July 27-28 at Sixteen Mile Creek

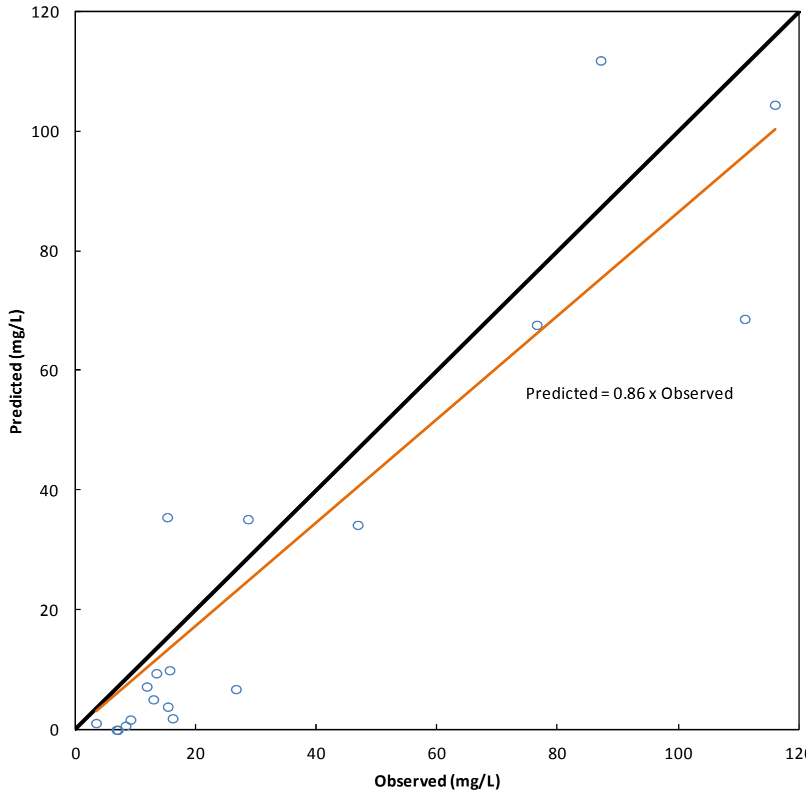


Figure F3: Predicted vs. observed concentrations near the surface

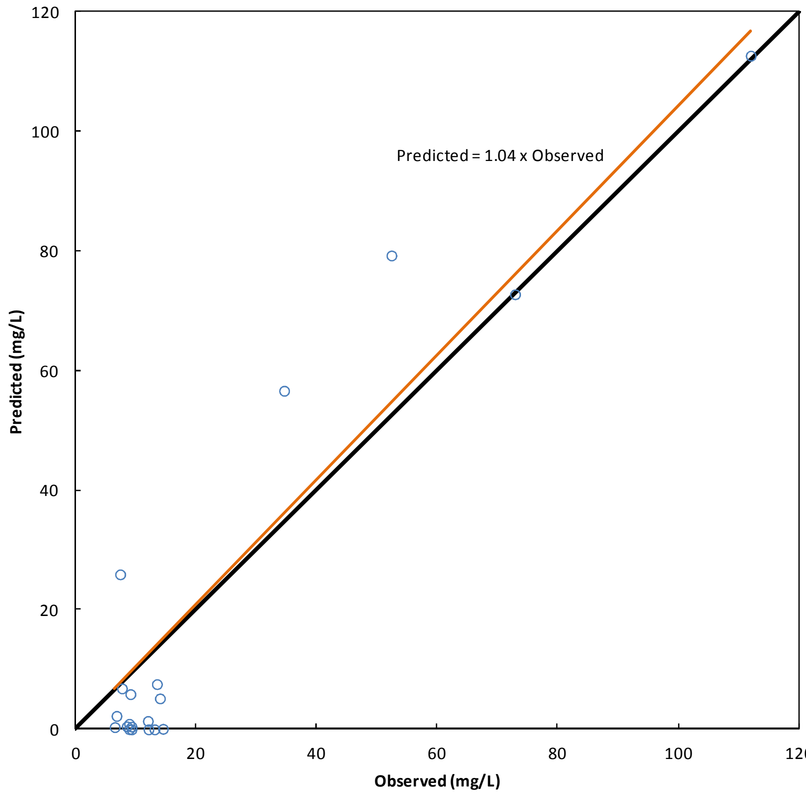


Figure F4: Predicted vs. observed concentrations at mid-depth

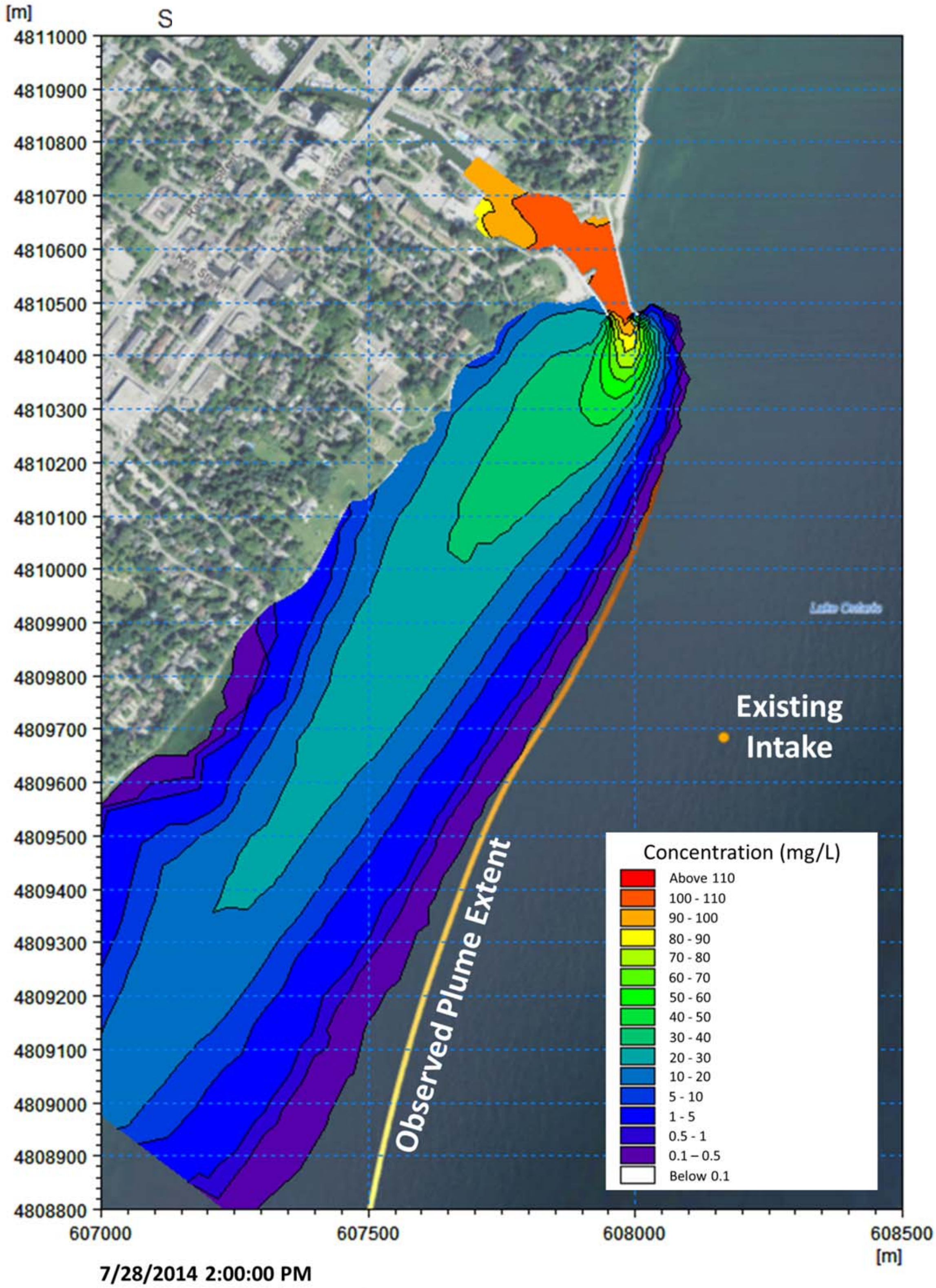


Figure F5: Predicted vs. observed concentrations near the surface. The orange symbol denotes the location of the existing WPP intake. The orange line denotes the sediment plume extent on July 28,-2014

Appendix G
Model Validation

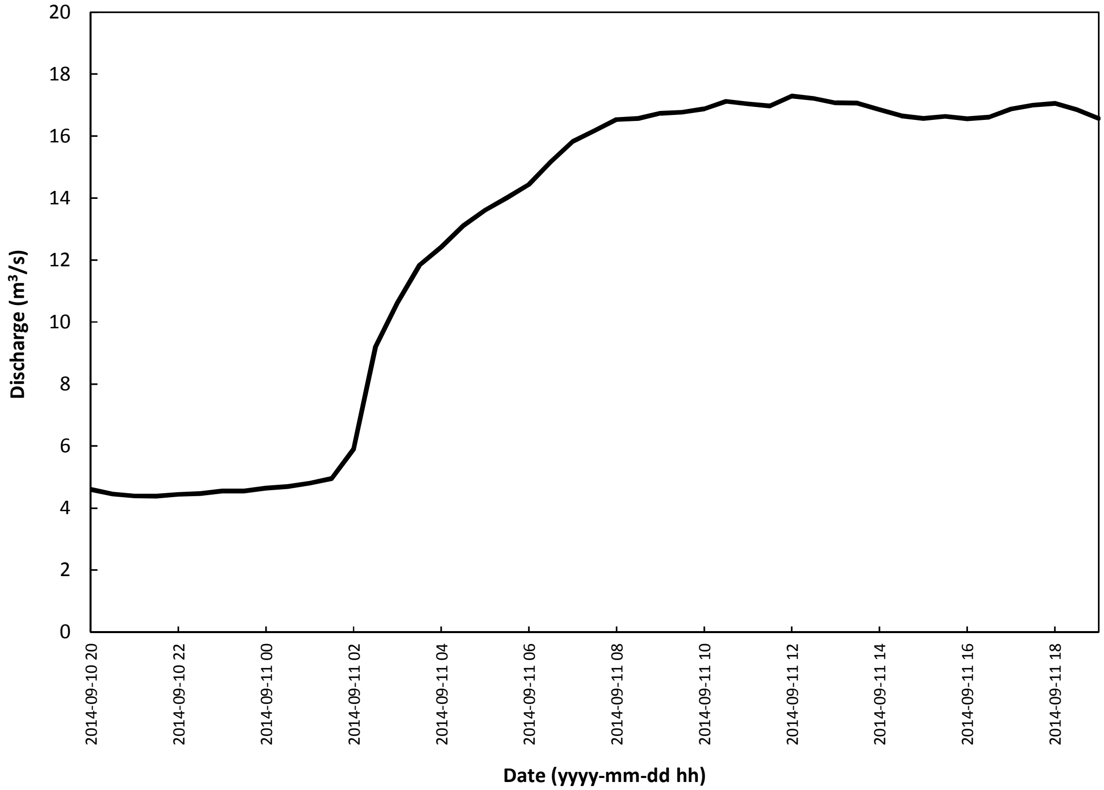


Figure G1: Hydrograph on Sep. 10-11 at Sixteen Mile Creek

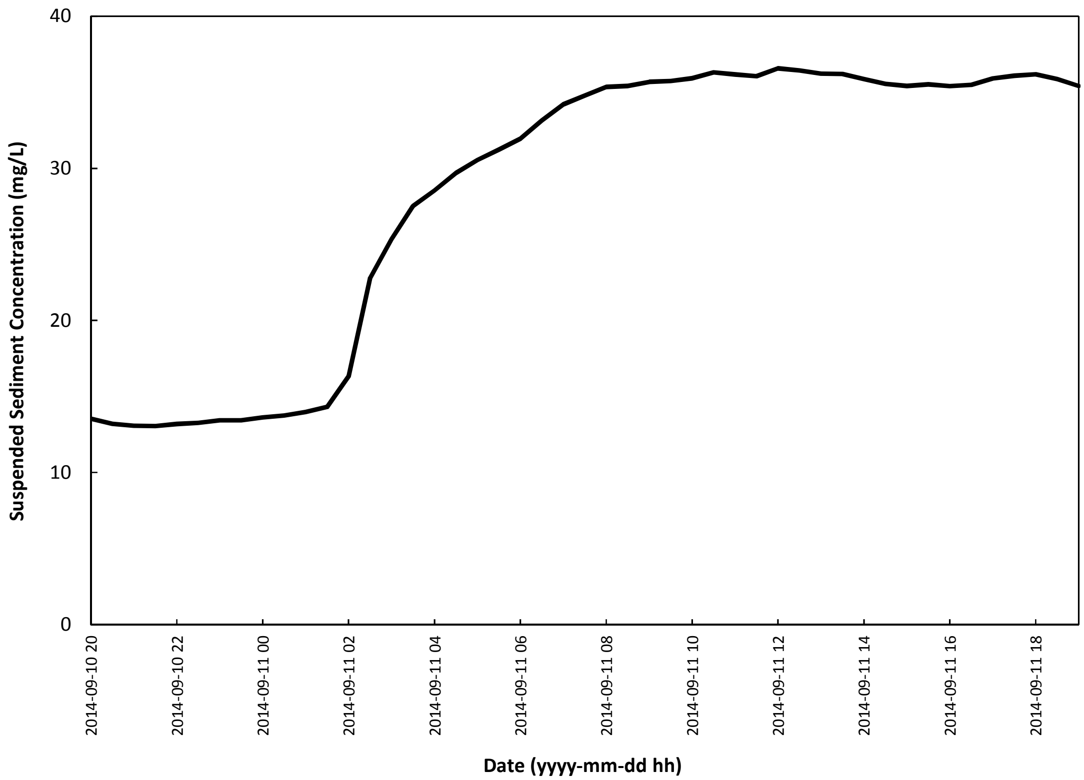


Figure G2: Susp. sediment concentration on Sep. 10-11 at Sixteen Mile Creek

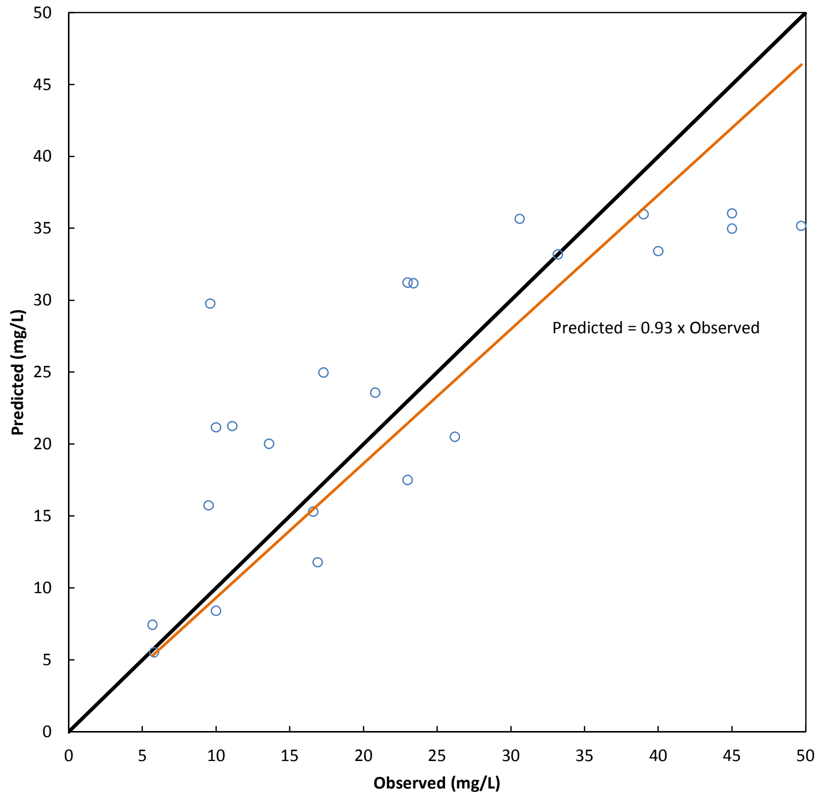


Figure G3: Predicted vs. observed concentrations near the surface

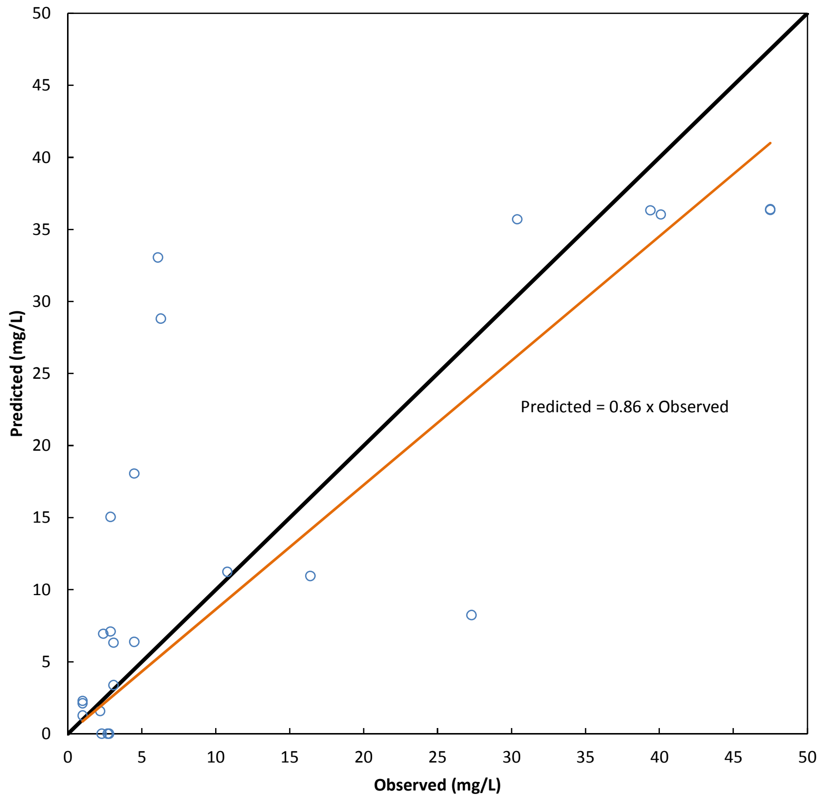


Figure G4: Predicted vs. observed concentrations near the bottom

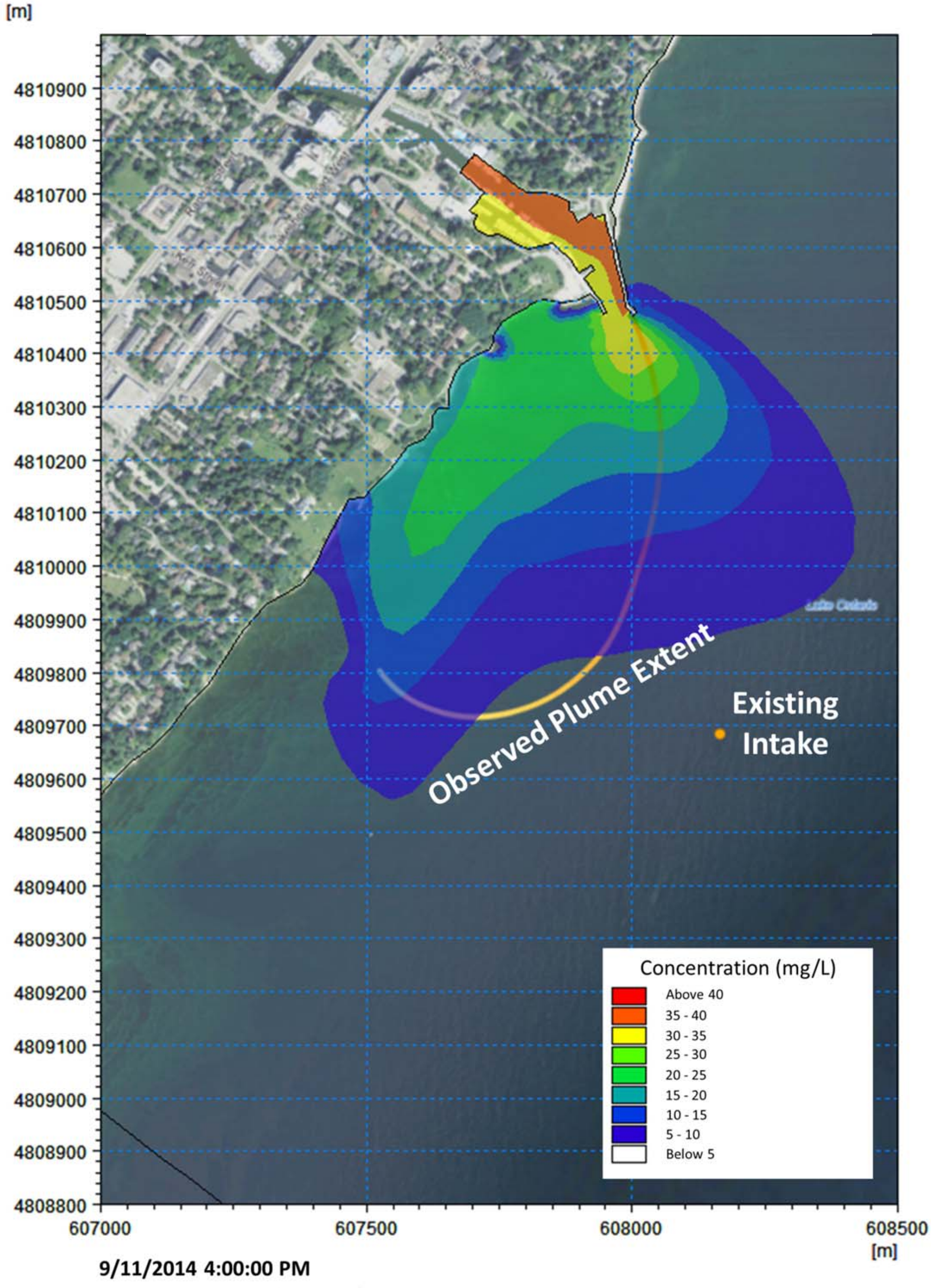


Figure G5: Predicted vs. observed concentrations near the surface. The orange symbol denotes the location of the existing WPP intake. The orange line denotes the sediment plume extent on September 1,-2014

Appendix H
Sediment Plume Assessment

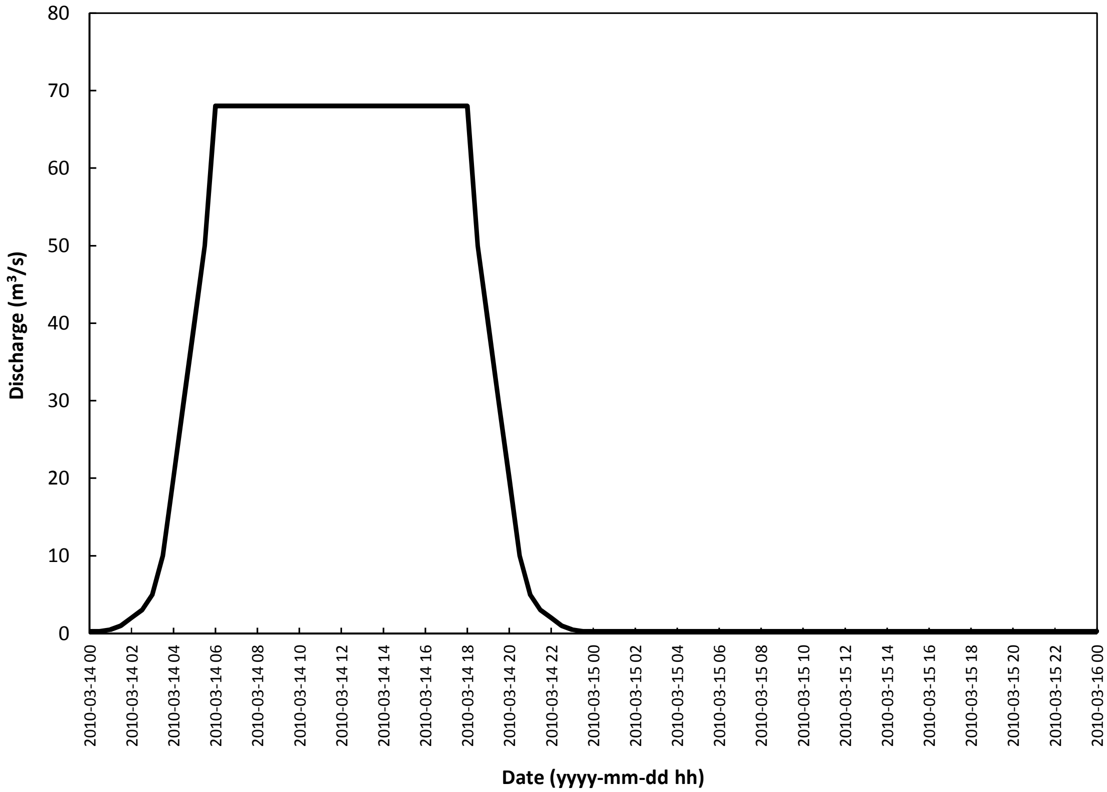


Figure H1: Hydrograph for spring scenarios (12 hours)

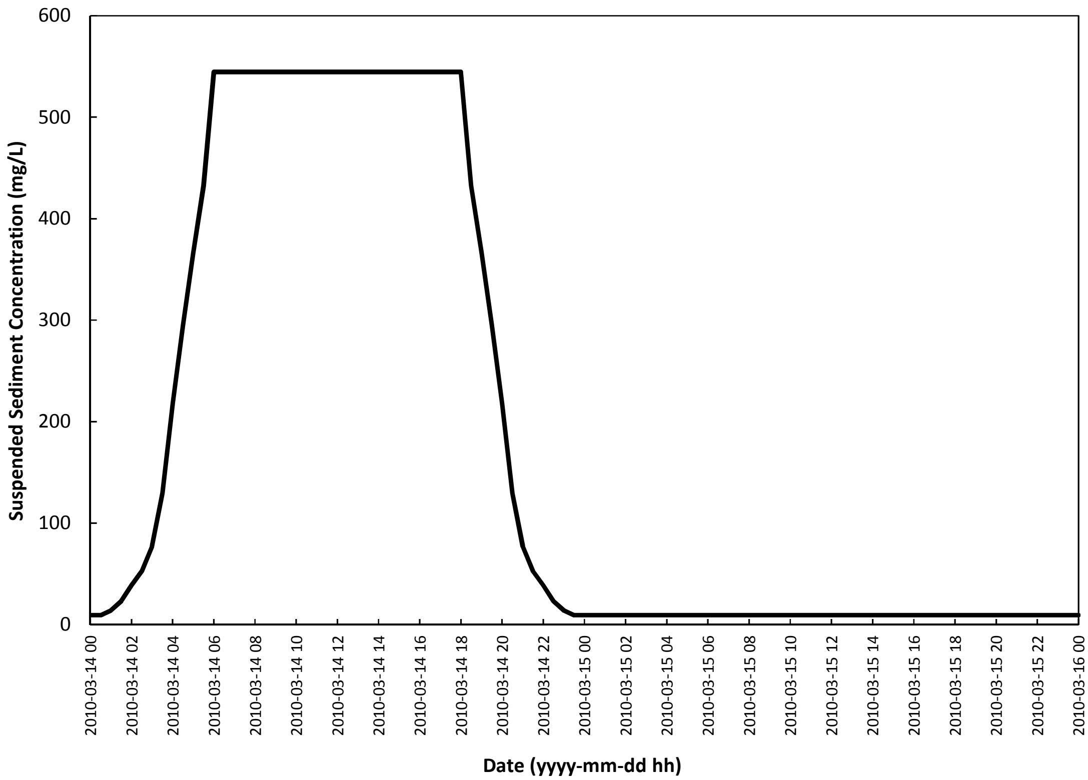


Figure H2: Susp. sediment concentrations for spring scenarios (12 hours)

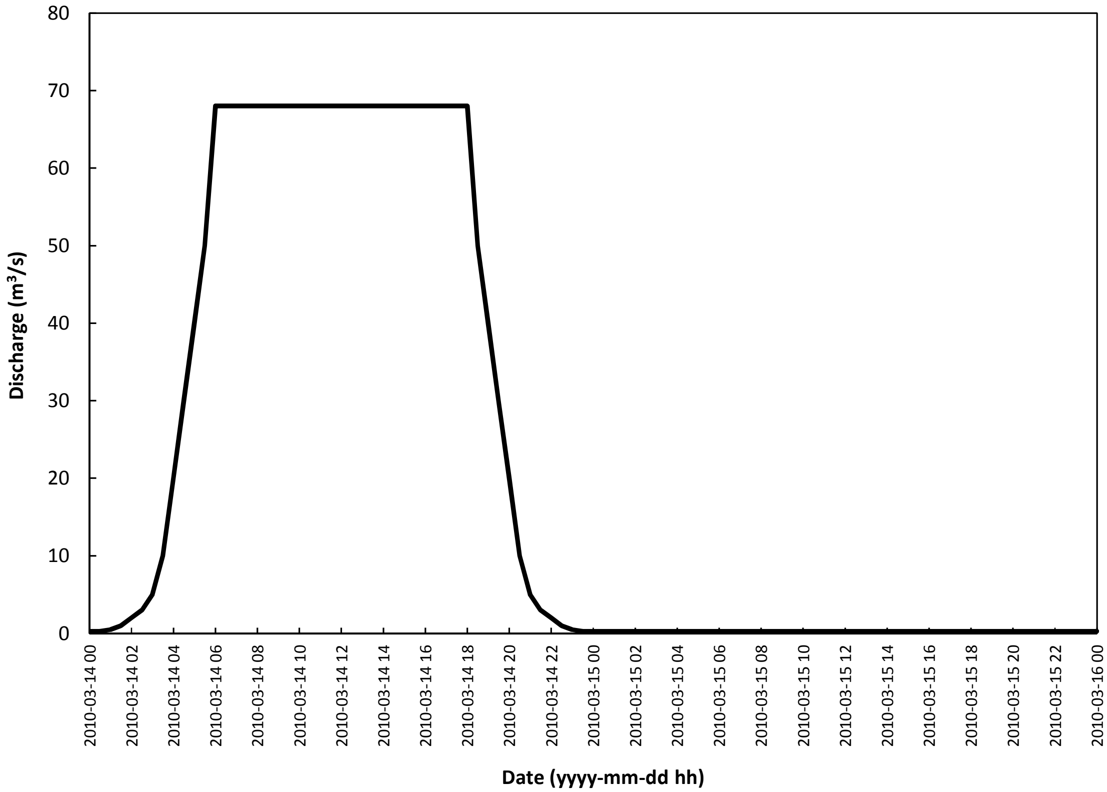


Figure H3: Hydrograph for spring scenarios (24 hours)

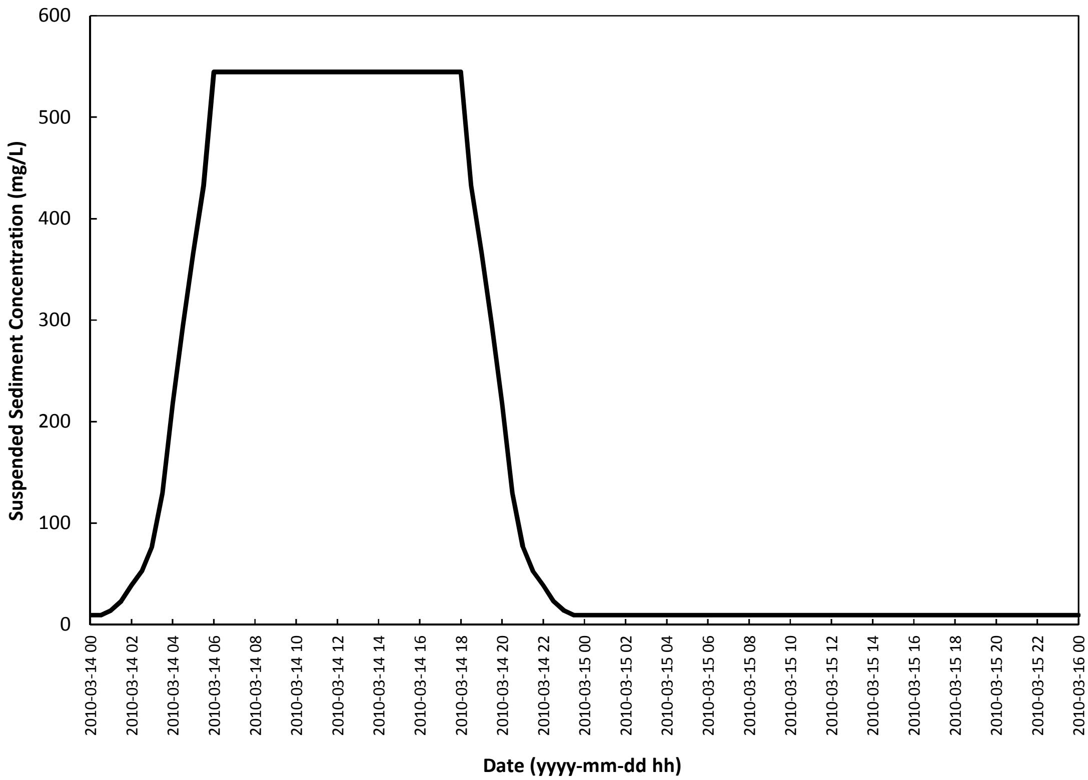


Figure H4: Susp. sediment concentrations for spring scenarios (24 hours)

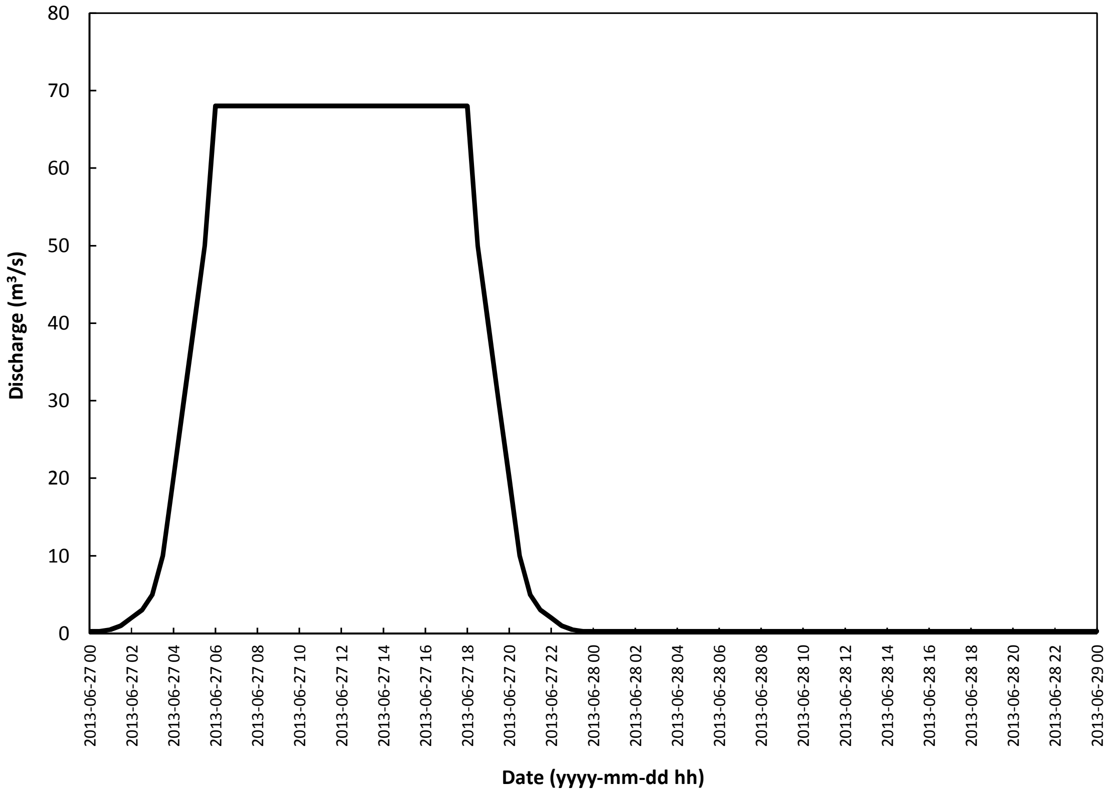


Figure H5: Hydrograph for summer scenarios (12 hours)

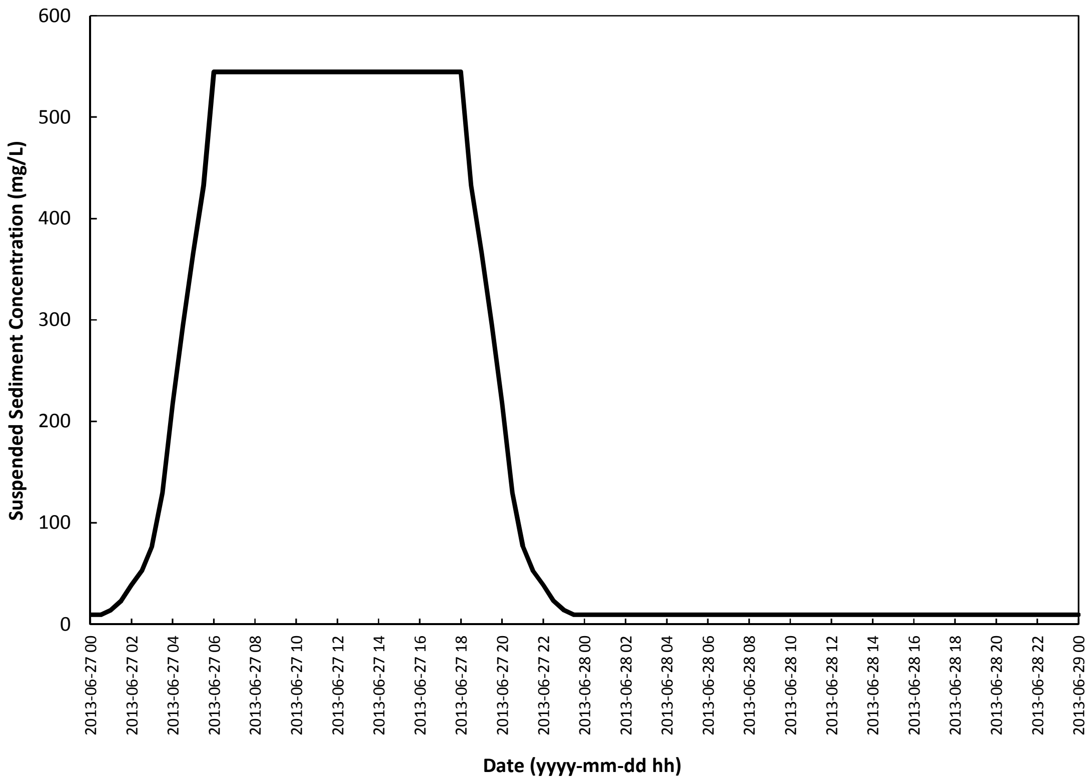


Figure H6: Susp. sediment concentrations for summer scenarios (12 hours)

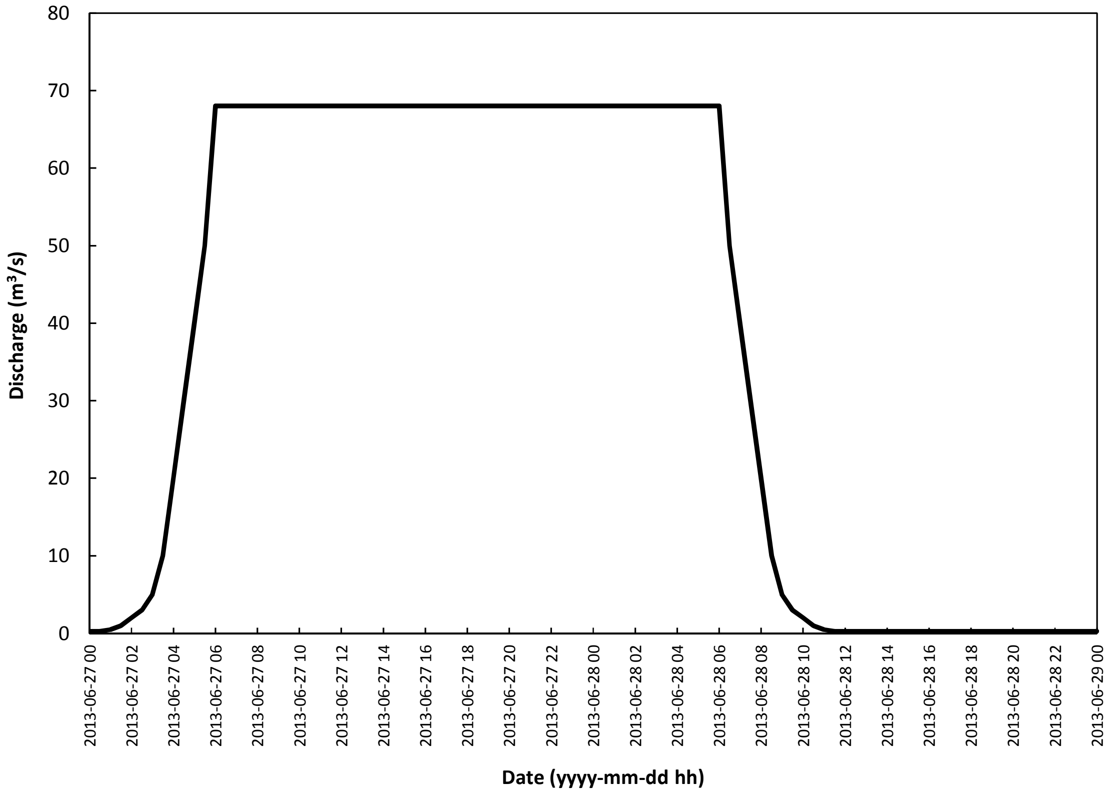


Figure H7: Hydrograph for summer scenarios (24 hours)

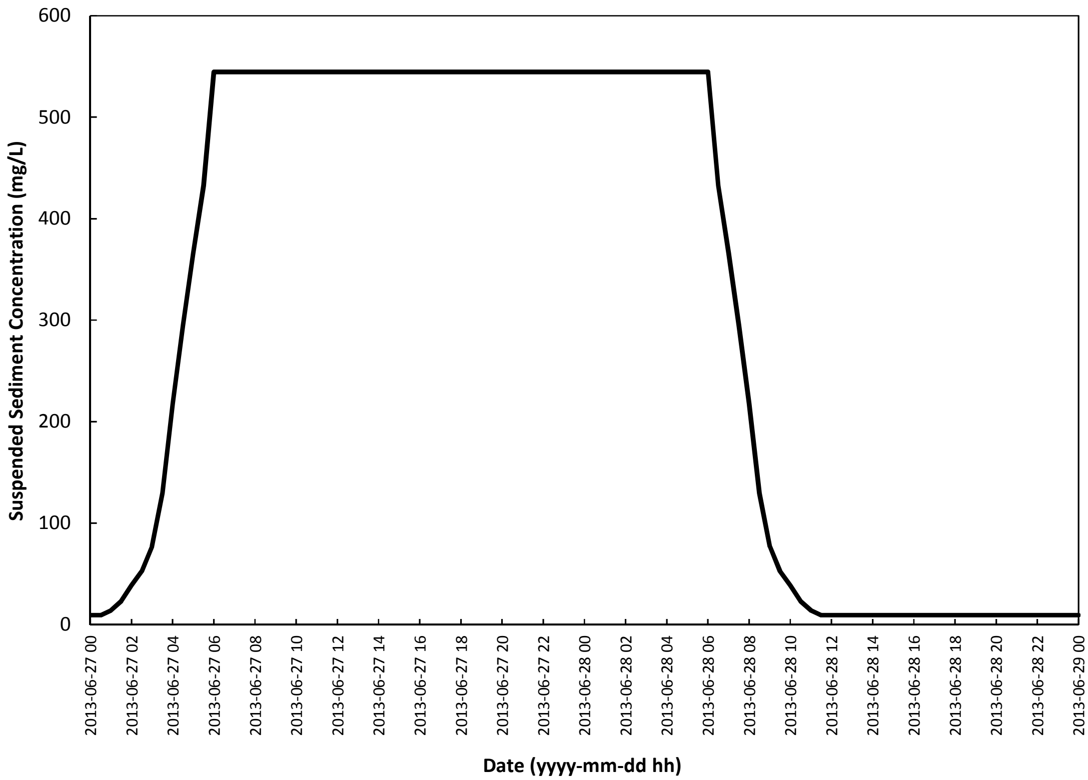
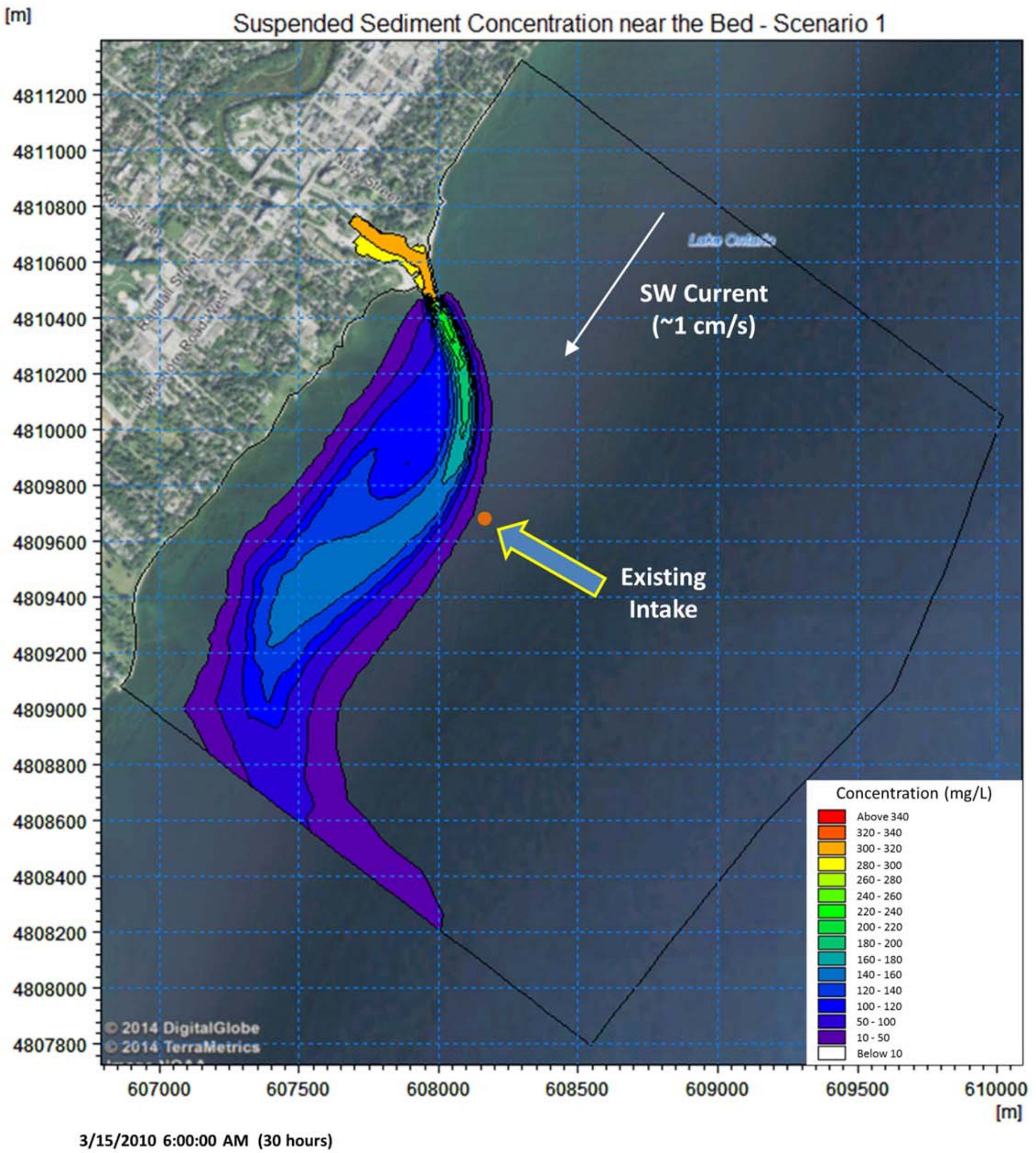


Figure H8: Susp. sediment concentrations for summer scenarios (24 hours)



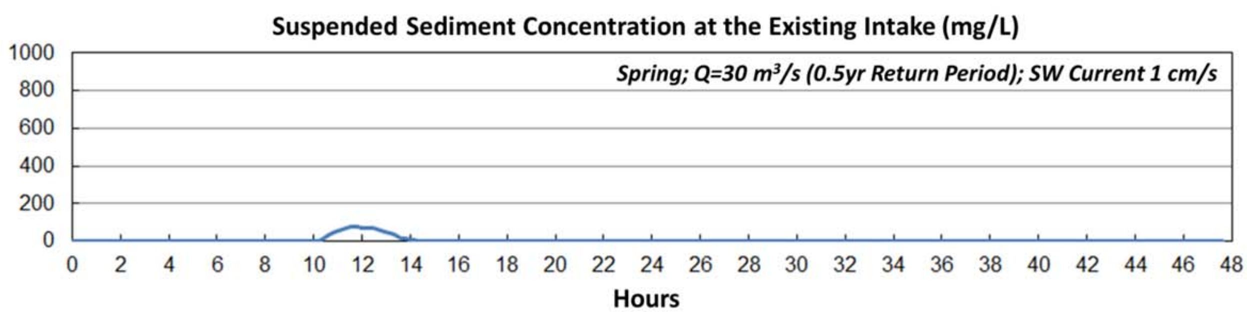


Figure H9: Sediment plume extent near the bed for Scenario 1

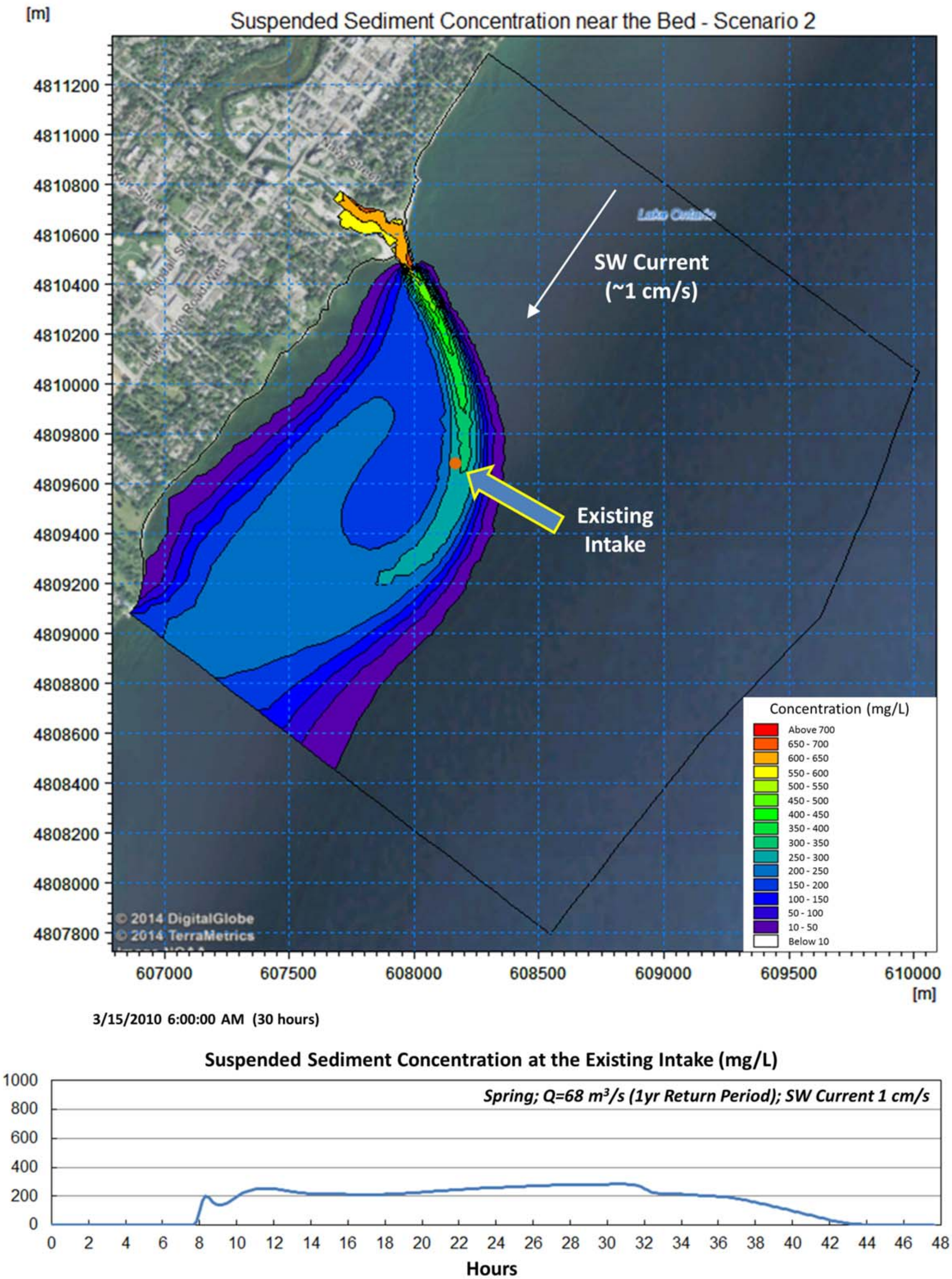
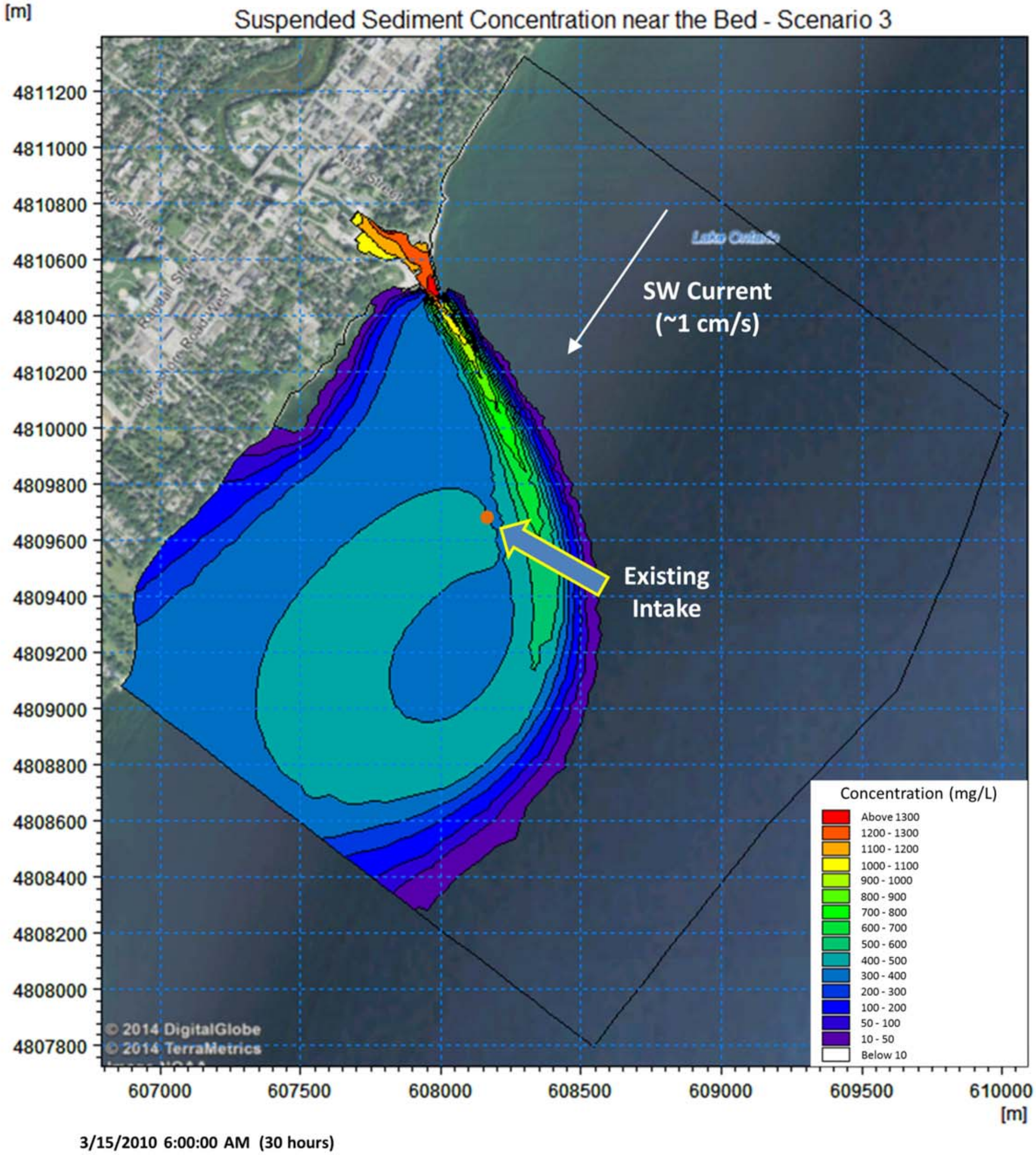


Figure H10: Sediment plume extent near the bed for Scenario 2



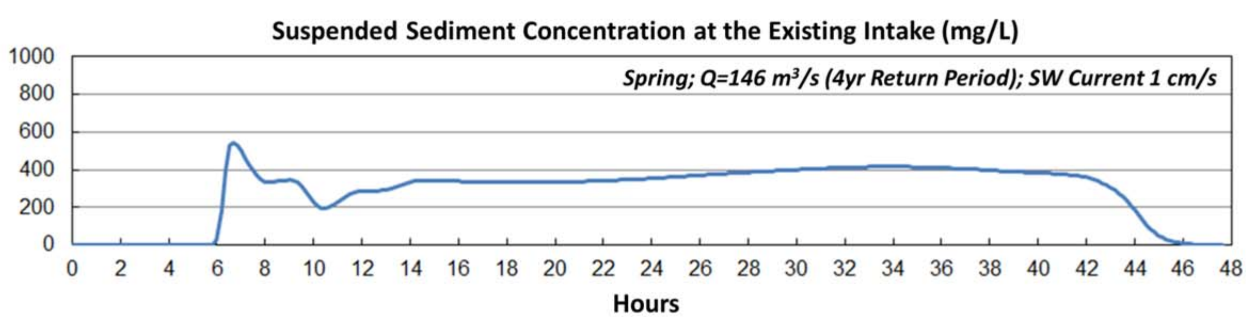


Figure H11: Sediment plume extent near the bed for Scenario 3

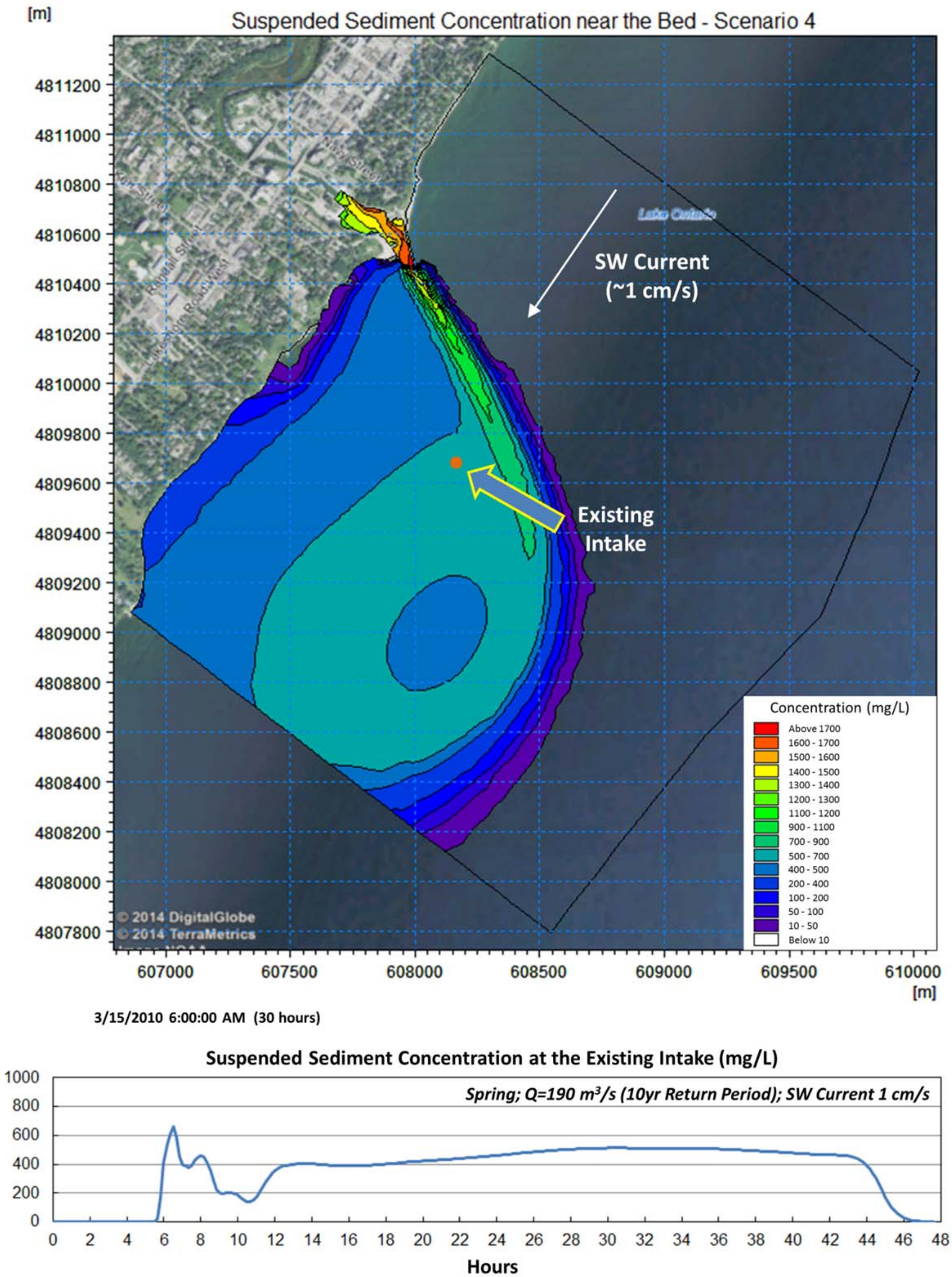


Figure H12: Sediment plume extent near the bed for Scenario 4

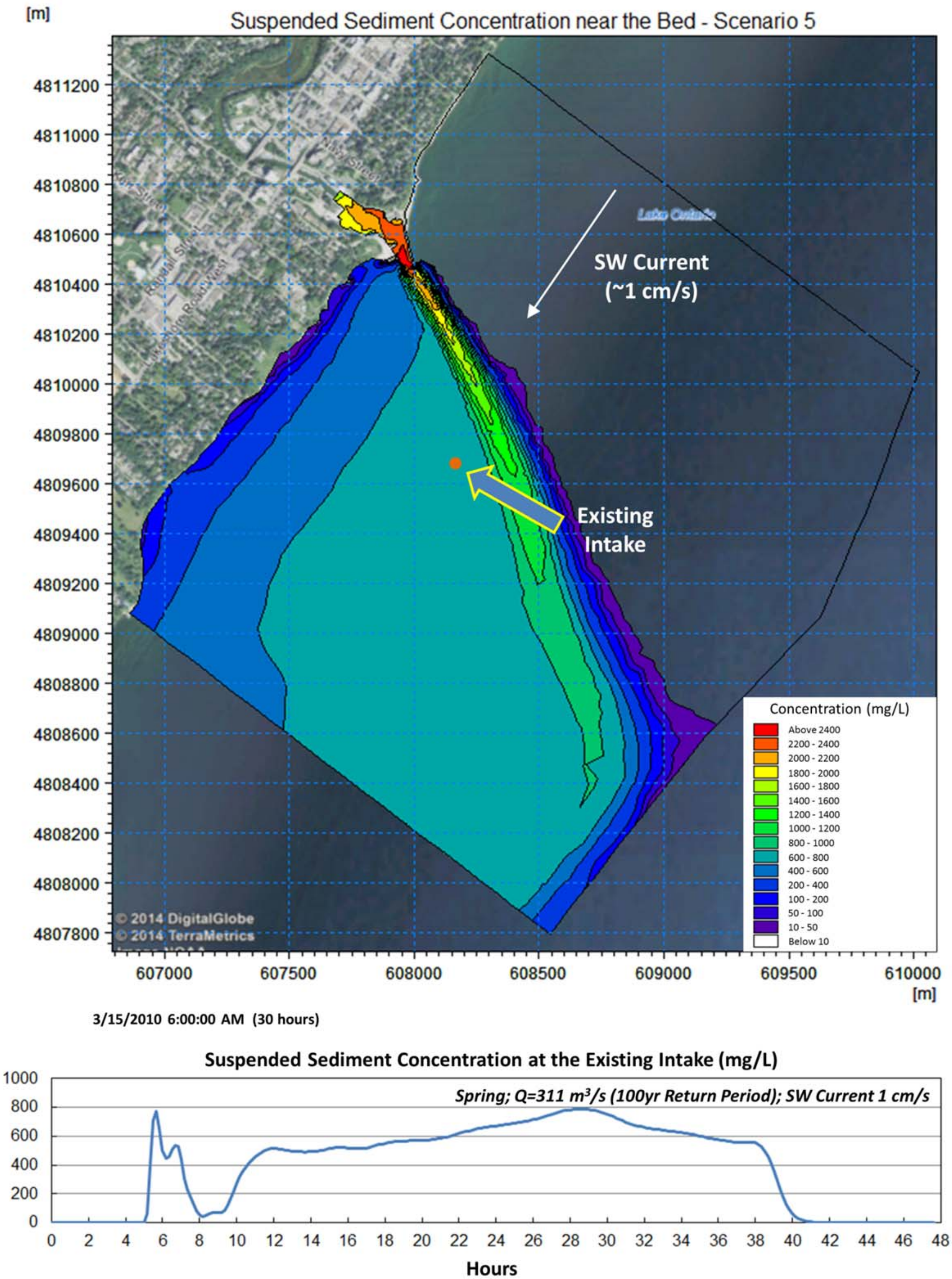


Figure H13: Sediment plume extent near the bed for Scenario 5

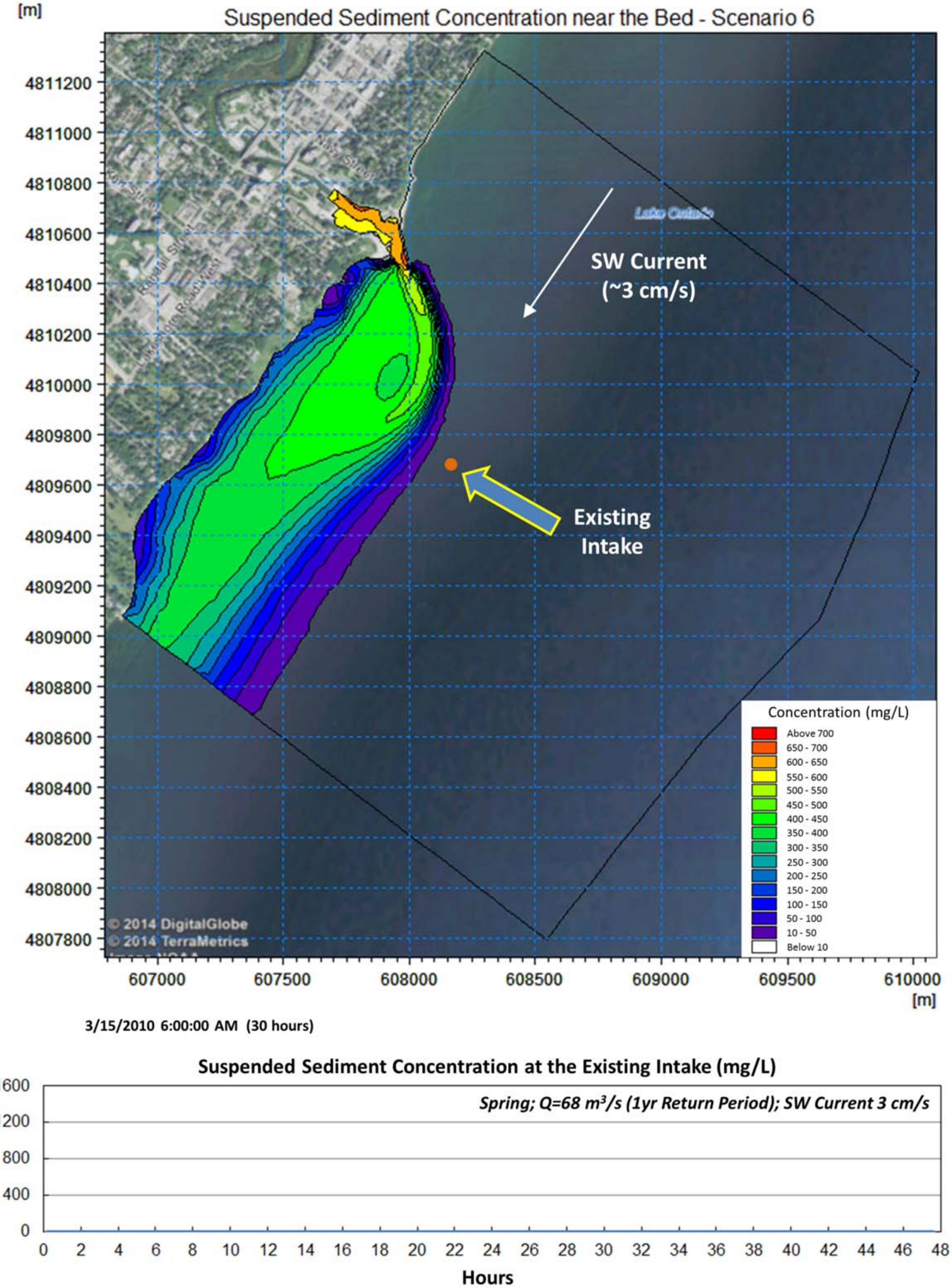


Figure H14: Sediment plume extent near the bed for Scenario 6

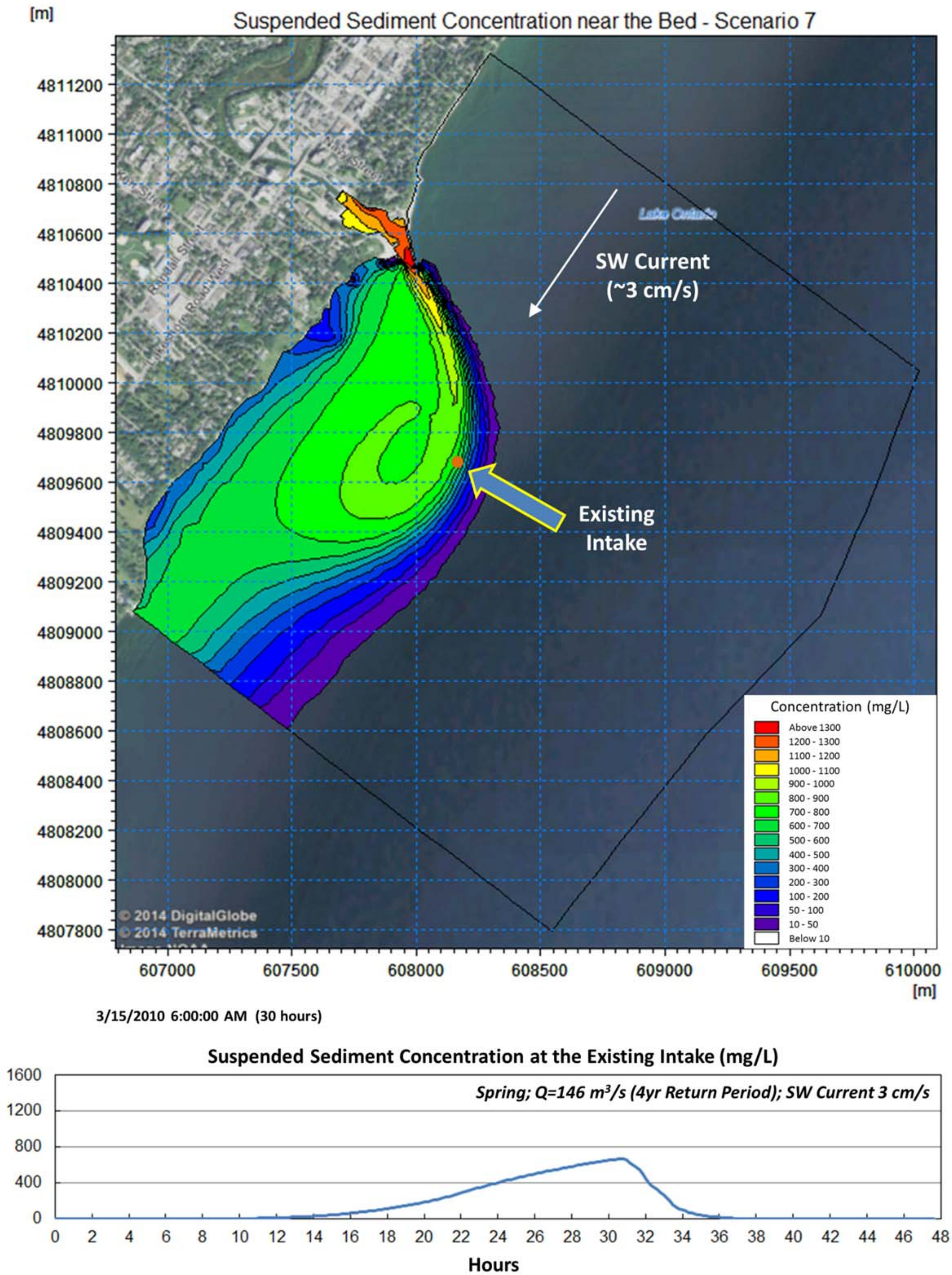


Figure H15: Sediment plume extent near the bed for Scenario 7

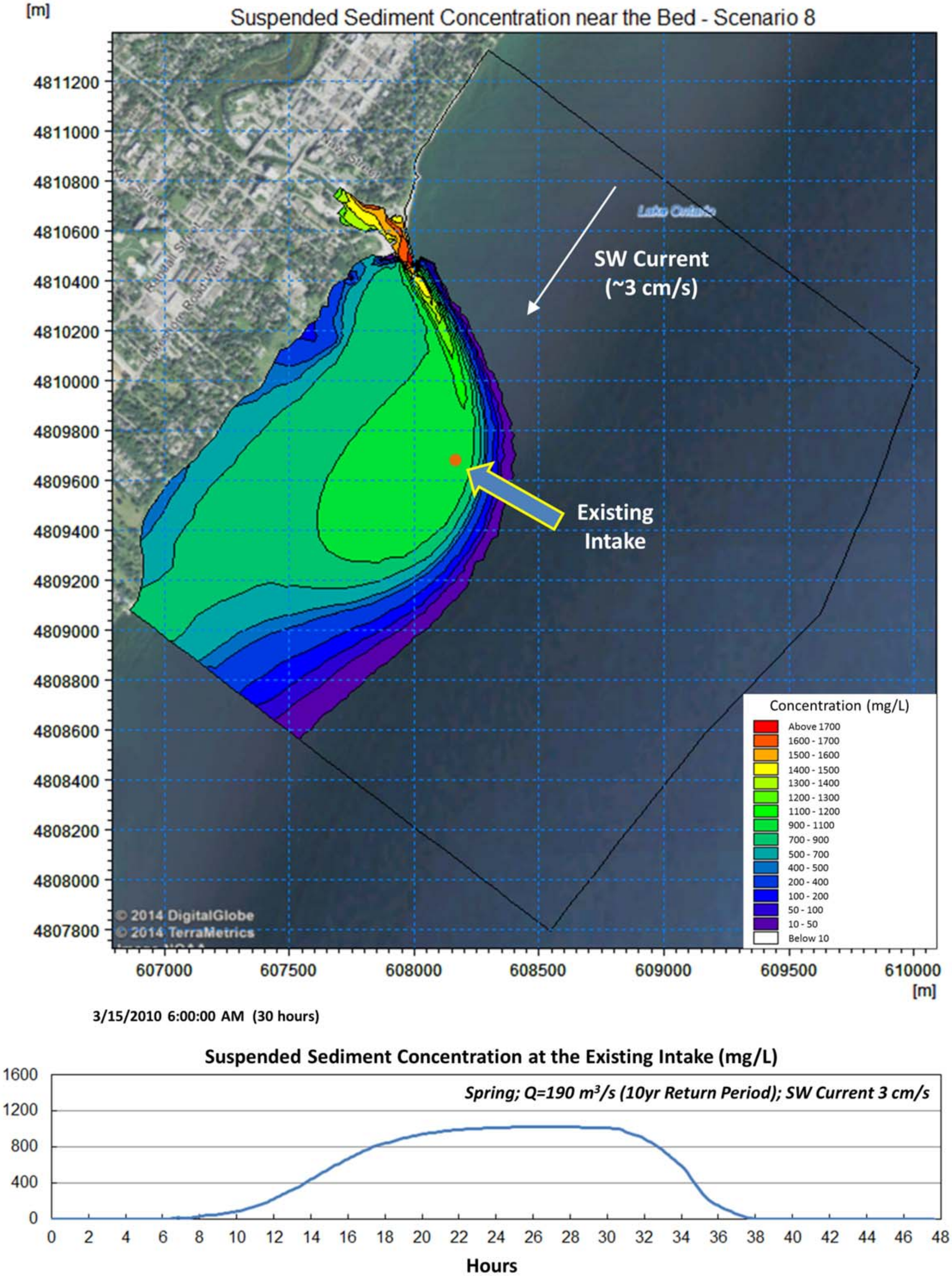


Figure H16: Sediment plume extent near the bed for Scenario 8

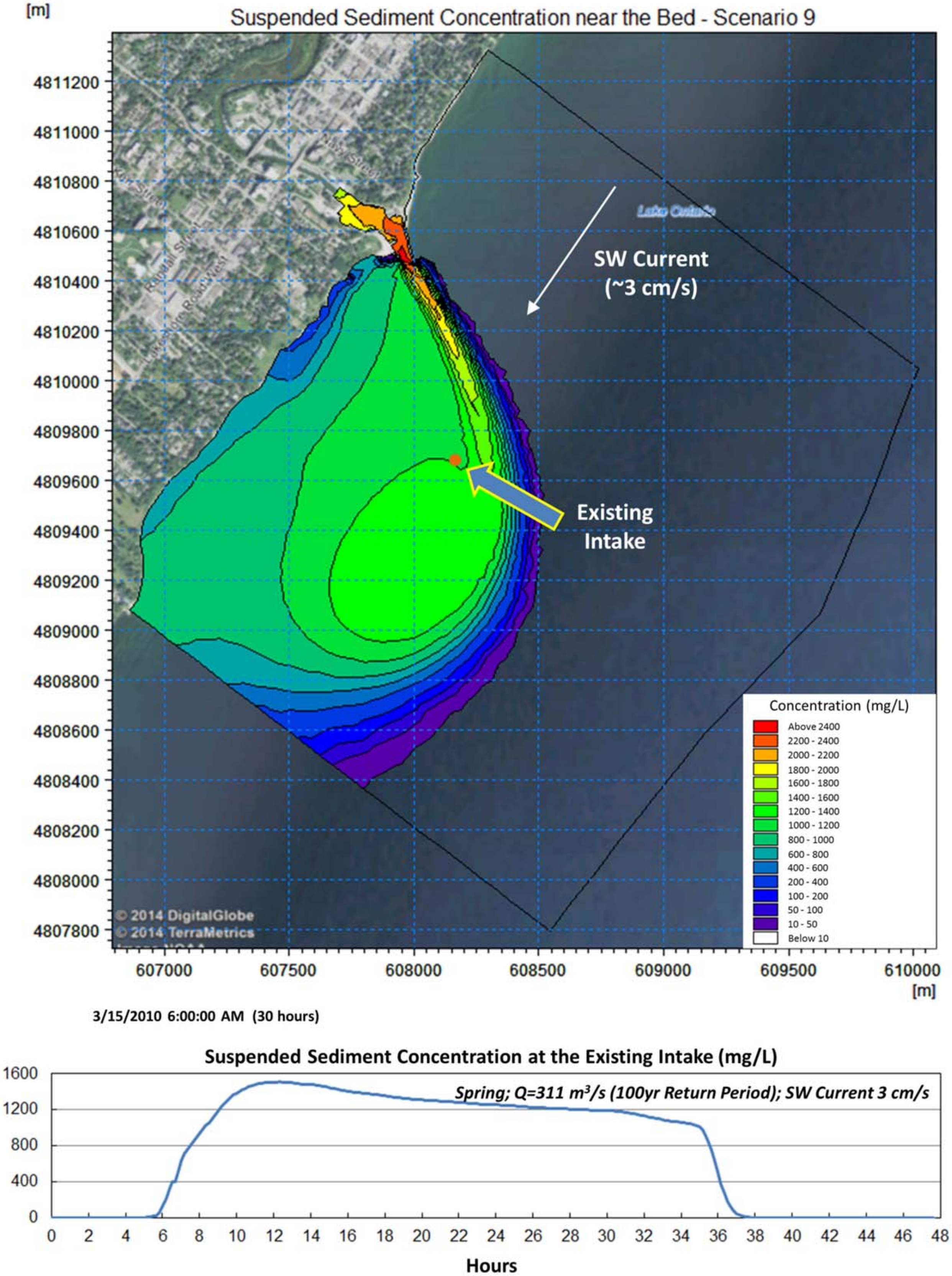


Figure H17: Sediment plume extent near the bed for Scenario 9

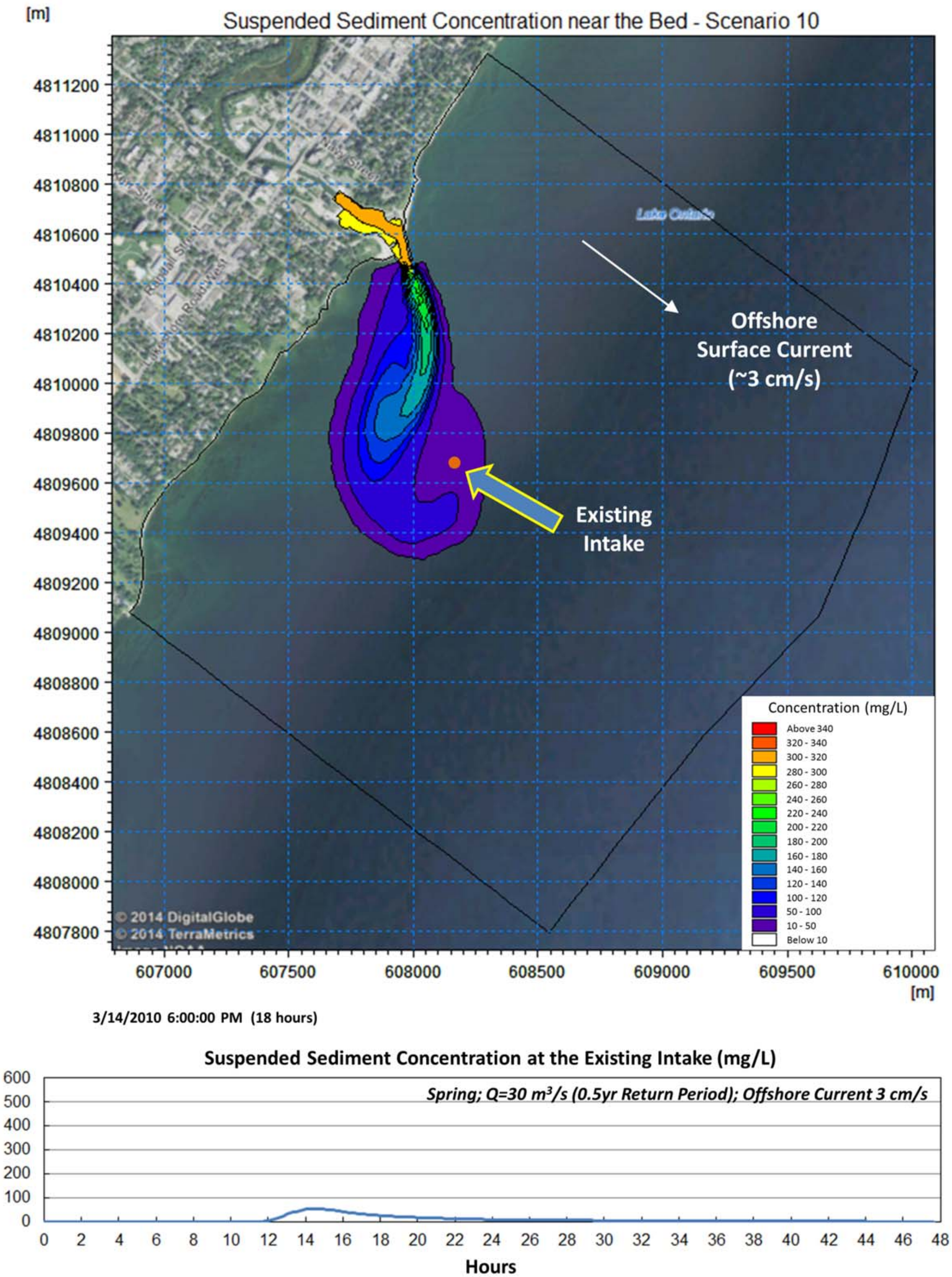


Figure H18: Sediment plume extent near the bed for Scenario 10

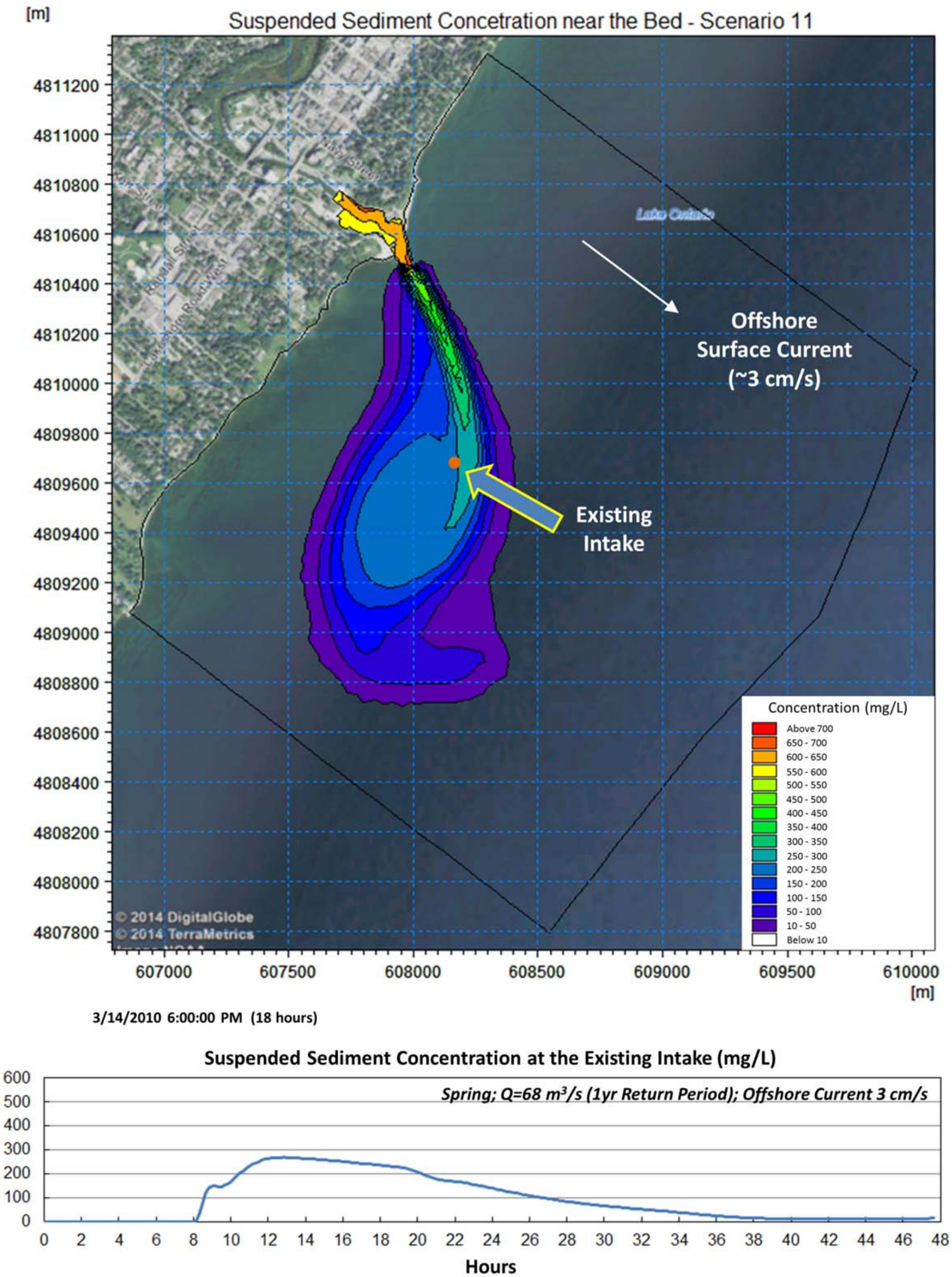


Figure H19: Sediment plume extent near the bed for Scenario 11

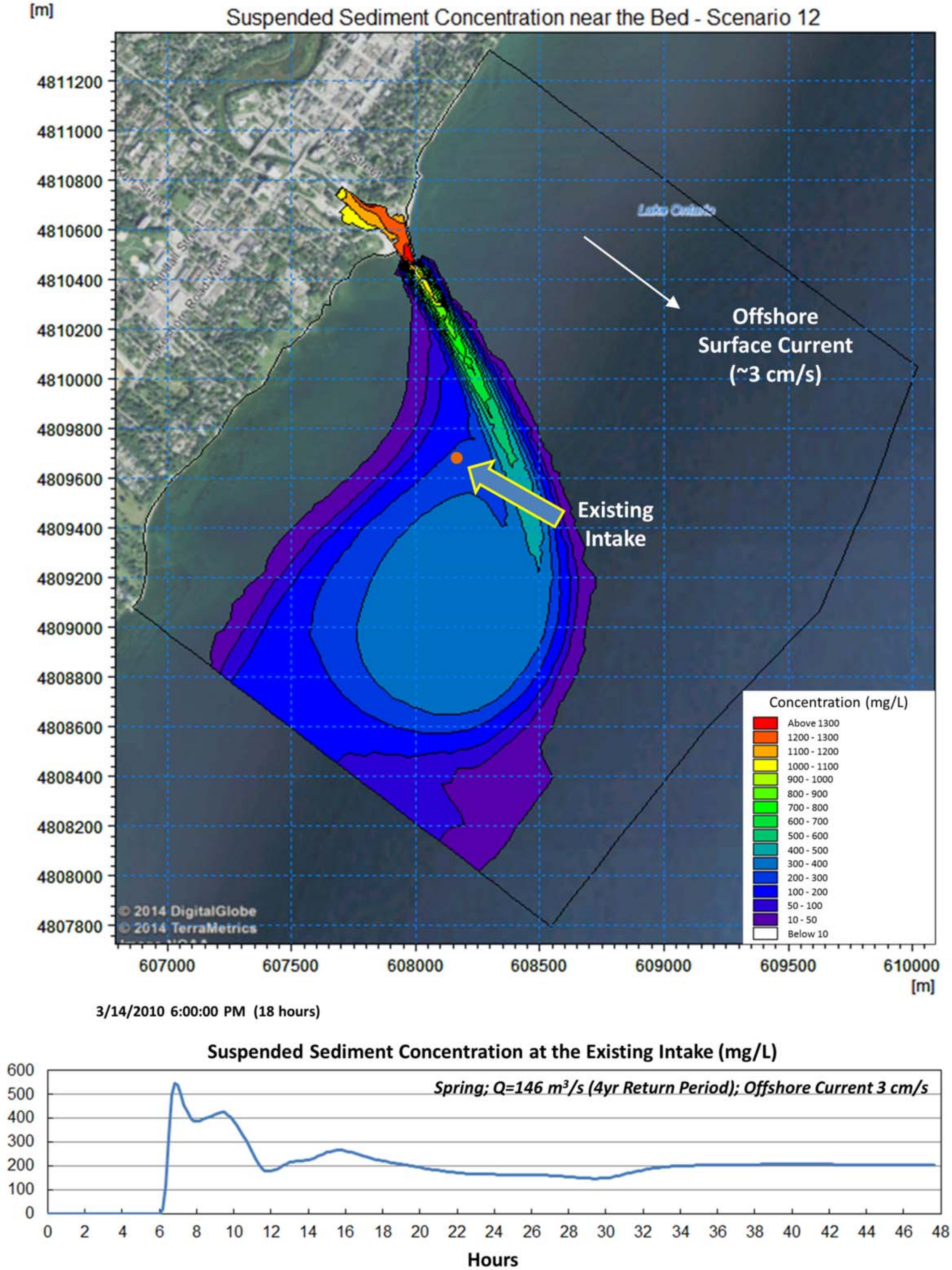


Figure H20: Sediment plume extent near the bed for Scenario 12

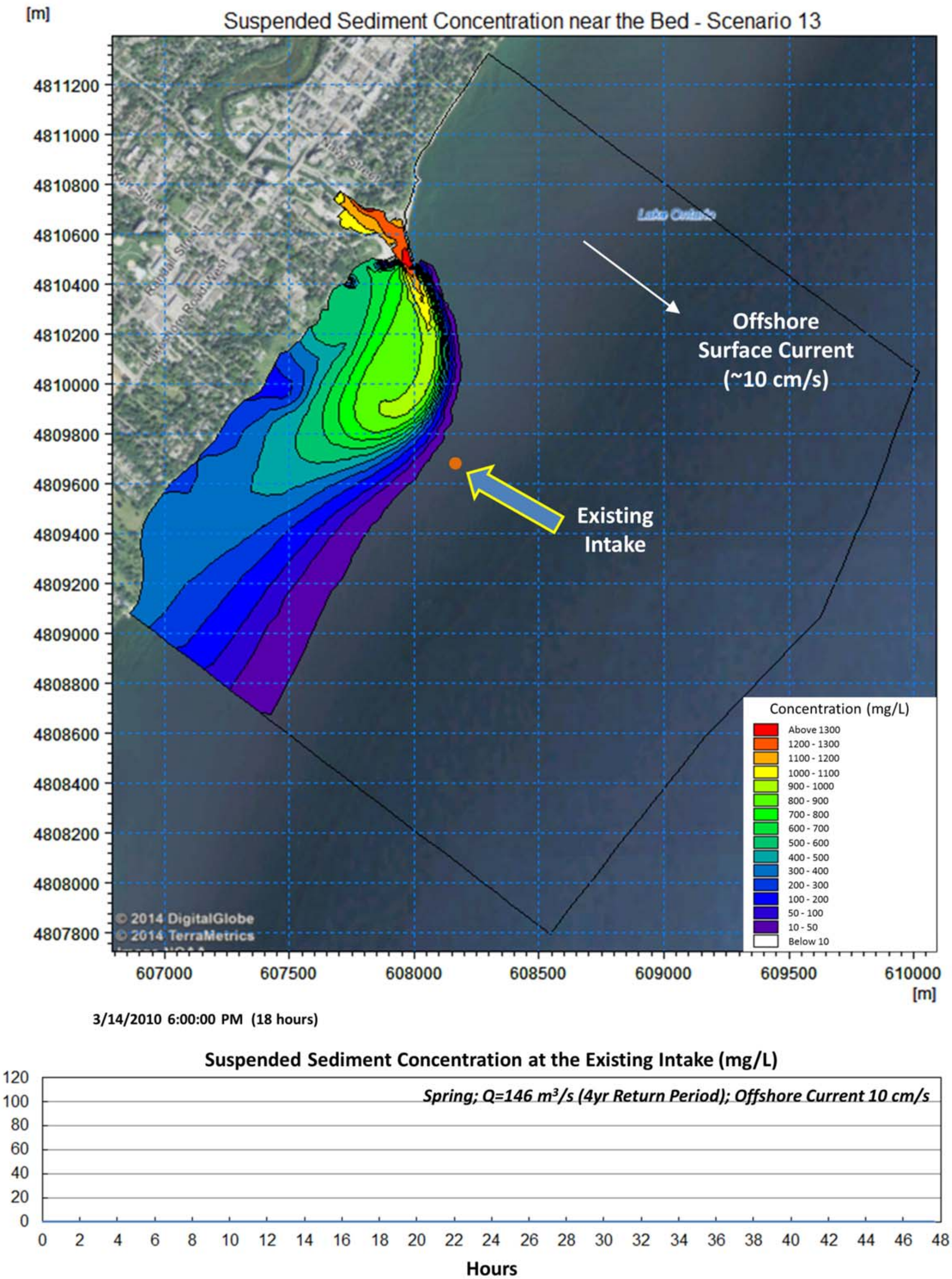


Figure H21: Sediment plume extent near the bed for Scenario 13

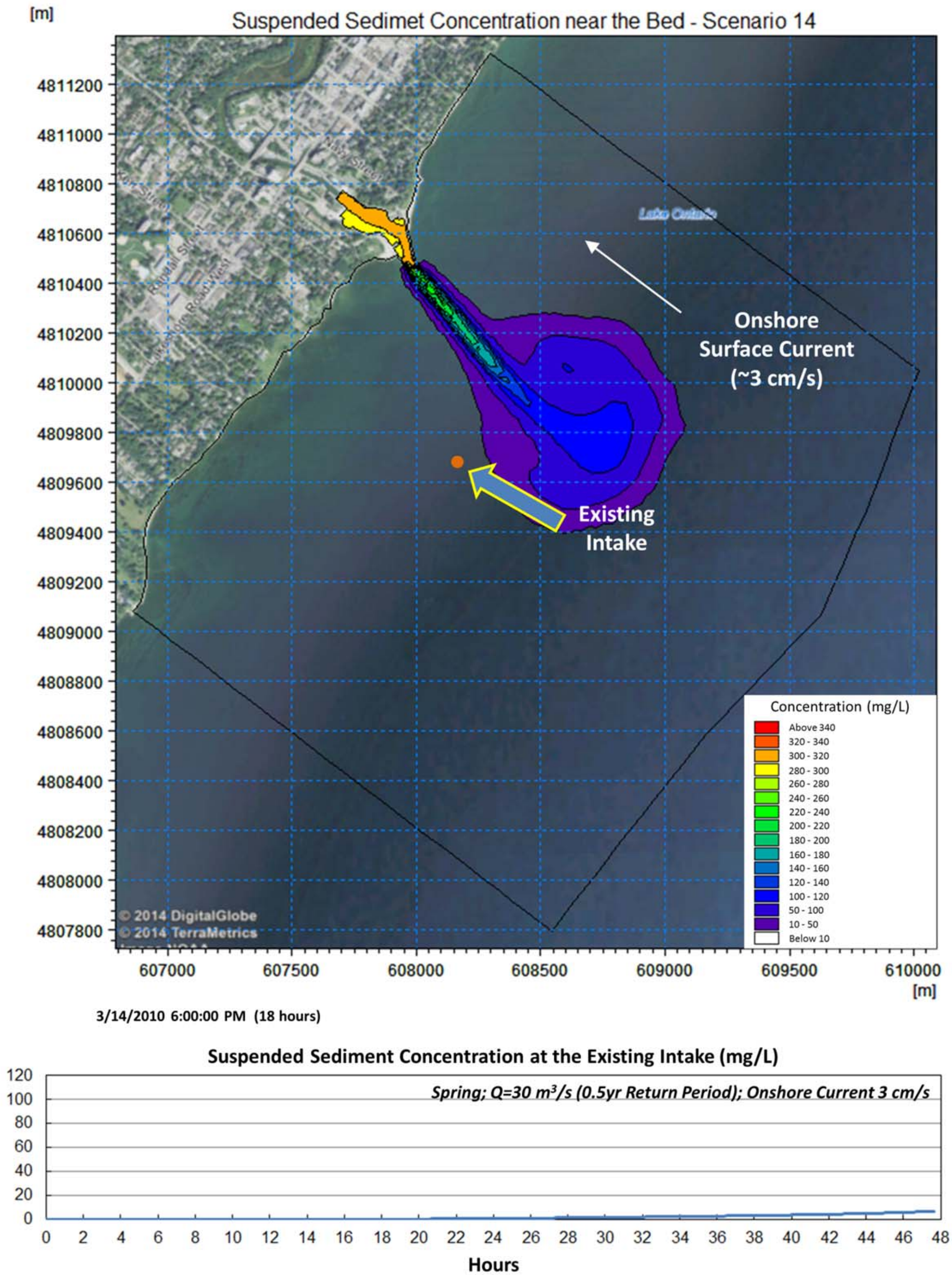


Figure H22: Sediment plume extent near the bed for Scenario 14

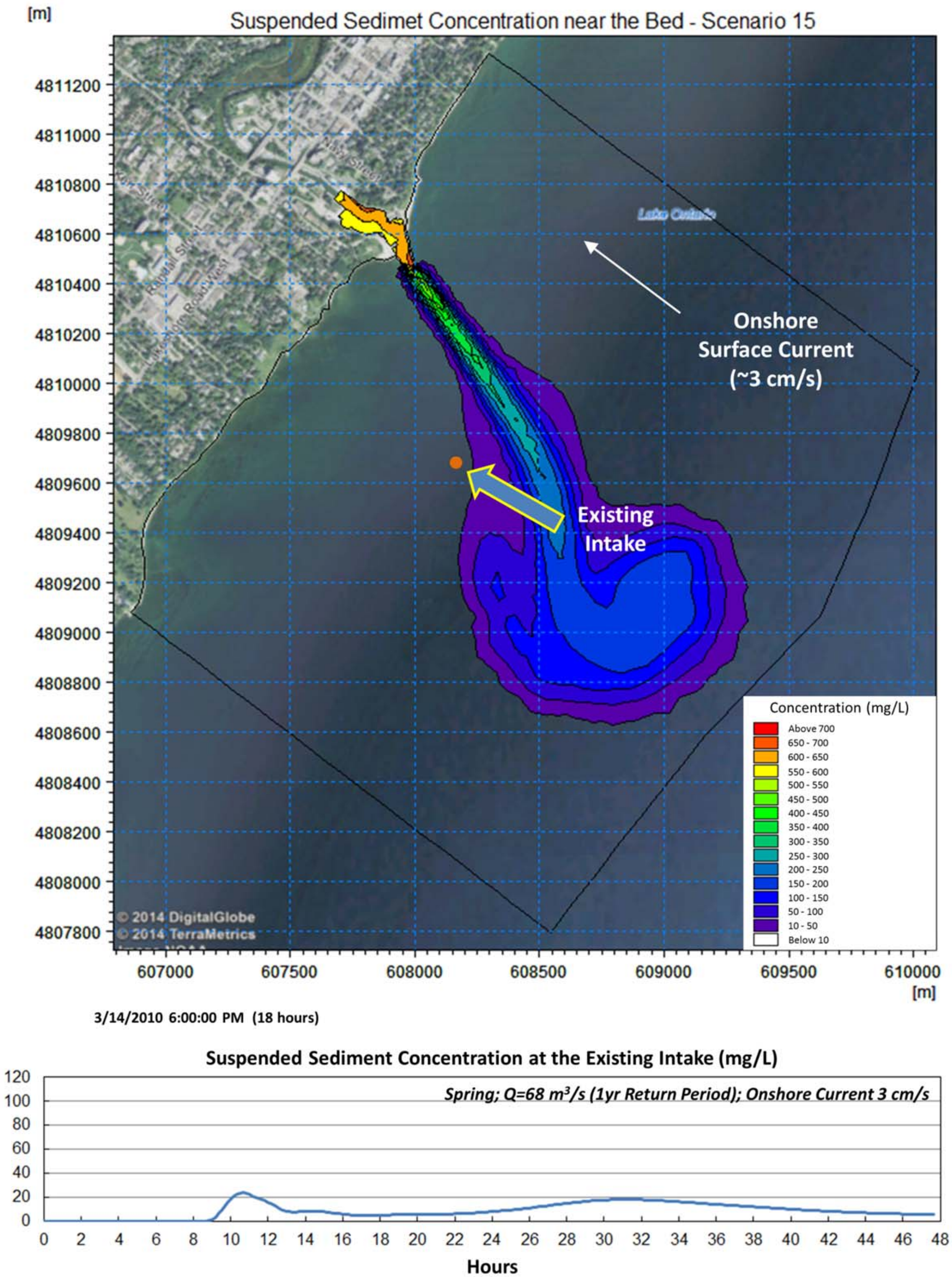


Figure H23: Sediment plume extent near the bed for Scenario 15

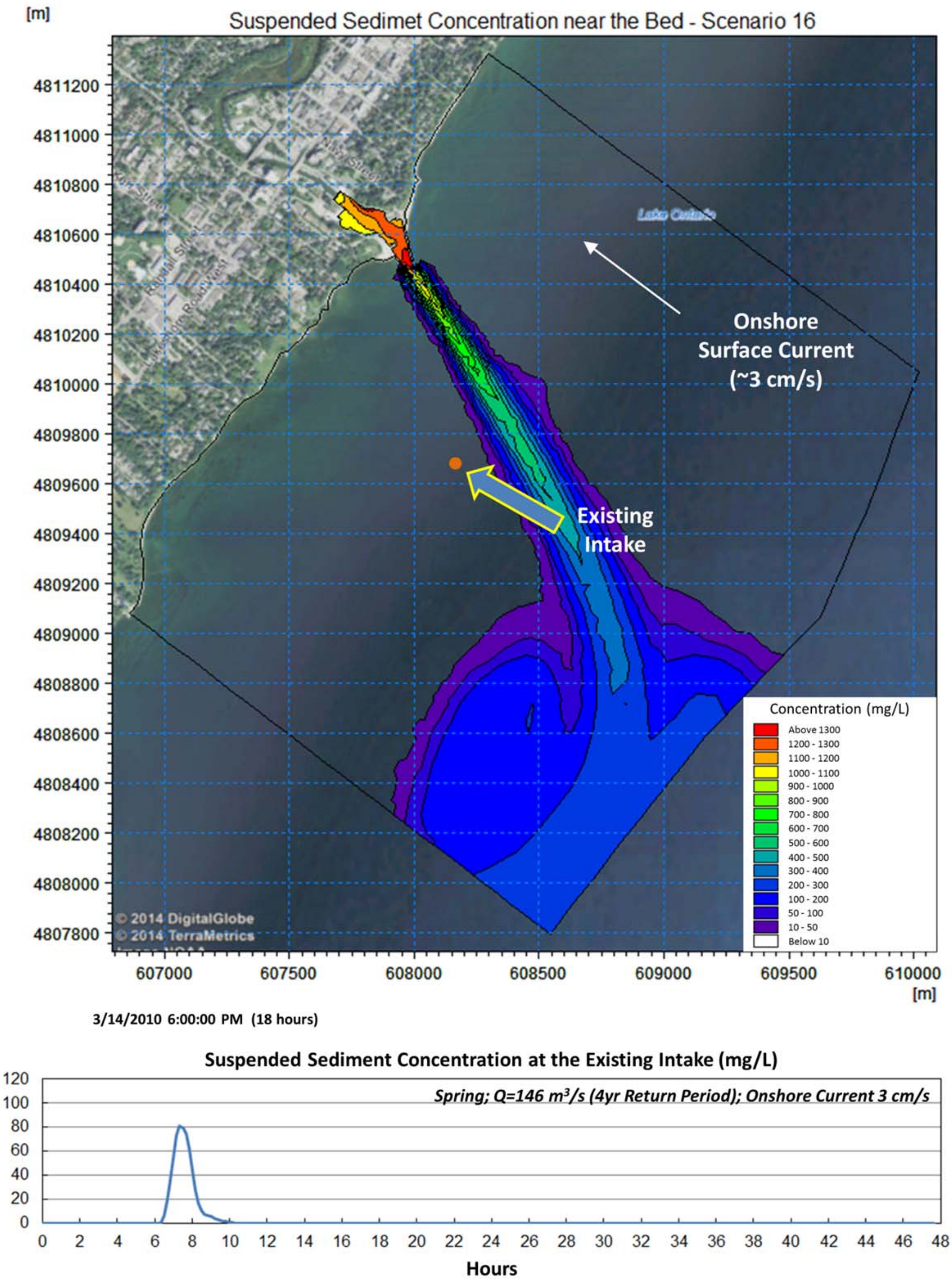
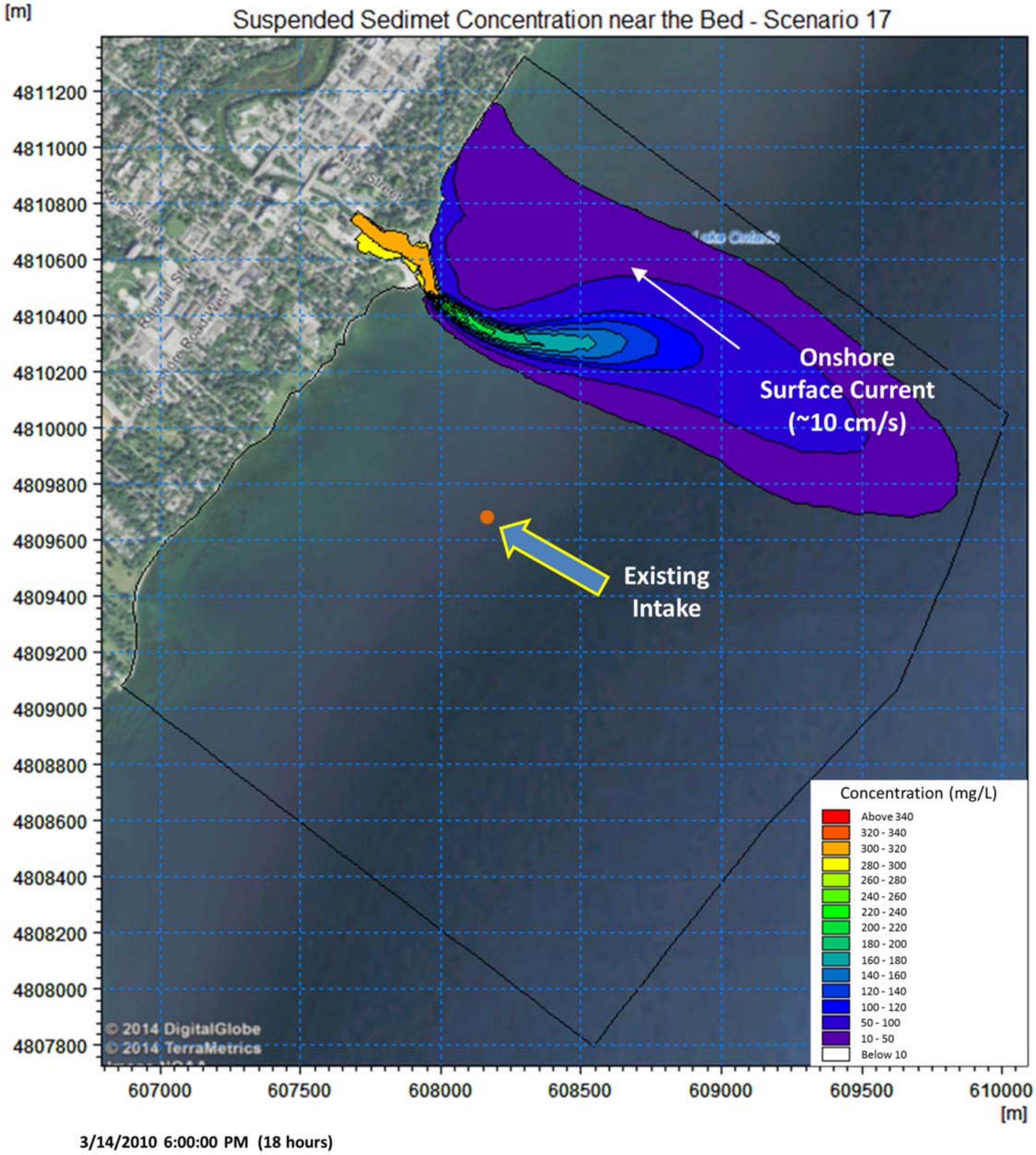


Figure H24: Sediment plume extent near the bed for Scenario 16



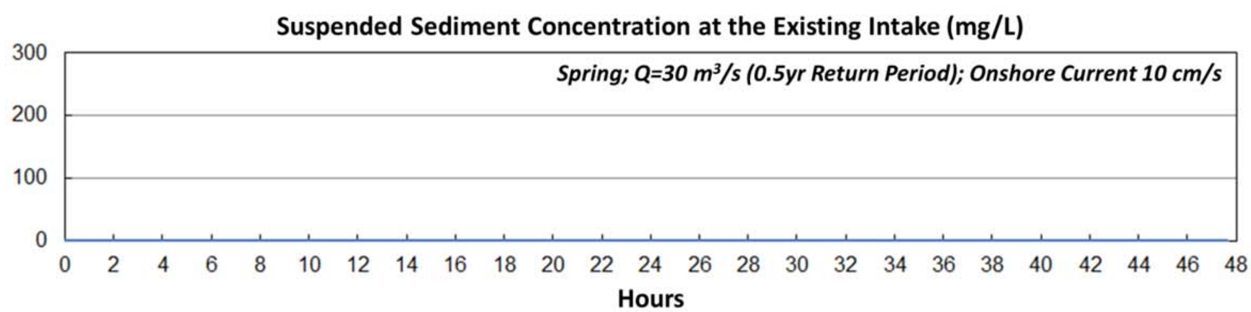


Figure H25: Sediment plume extent near the bed for Scenario 17

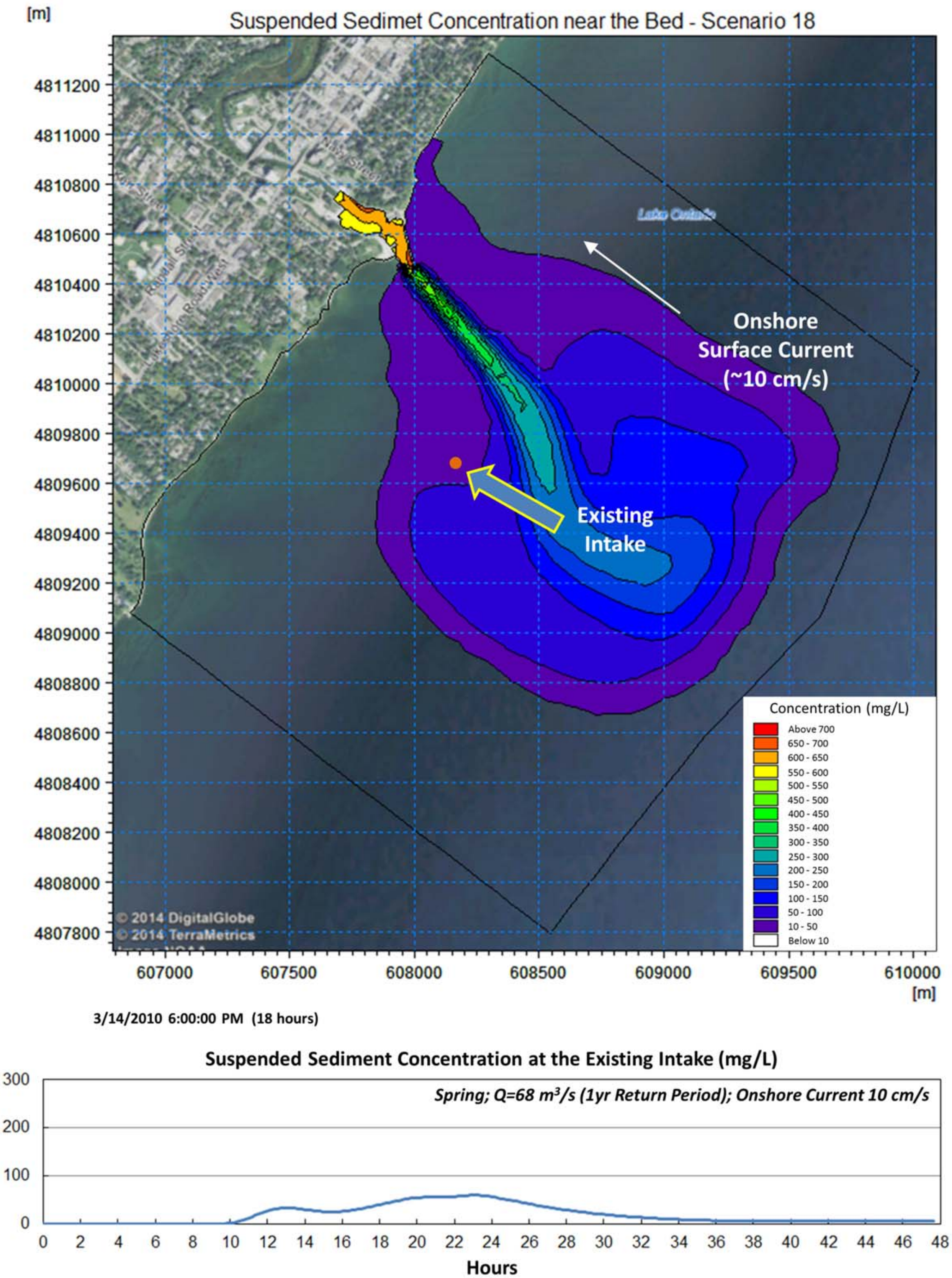


Figure H26: Sediment plume extent near the bed for Scenario 18

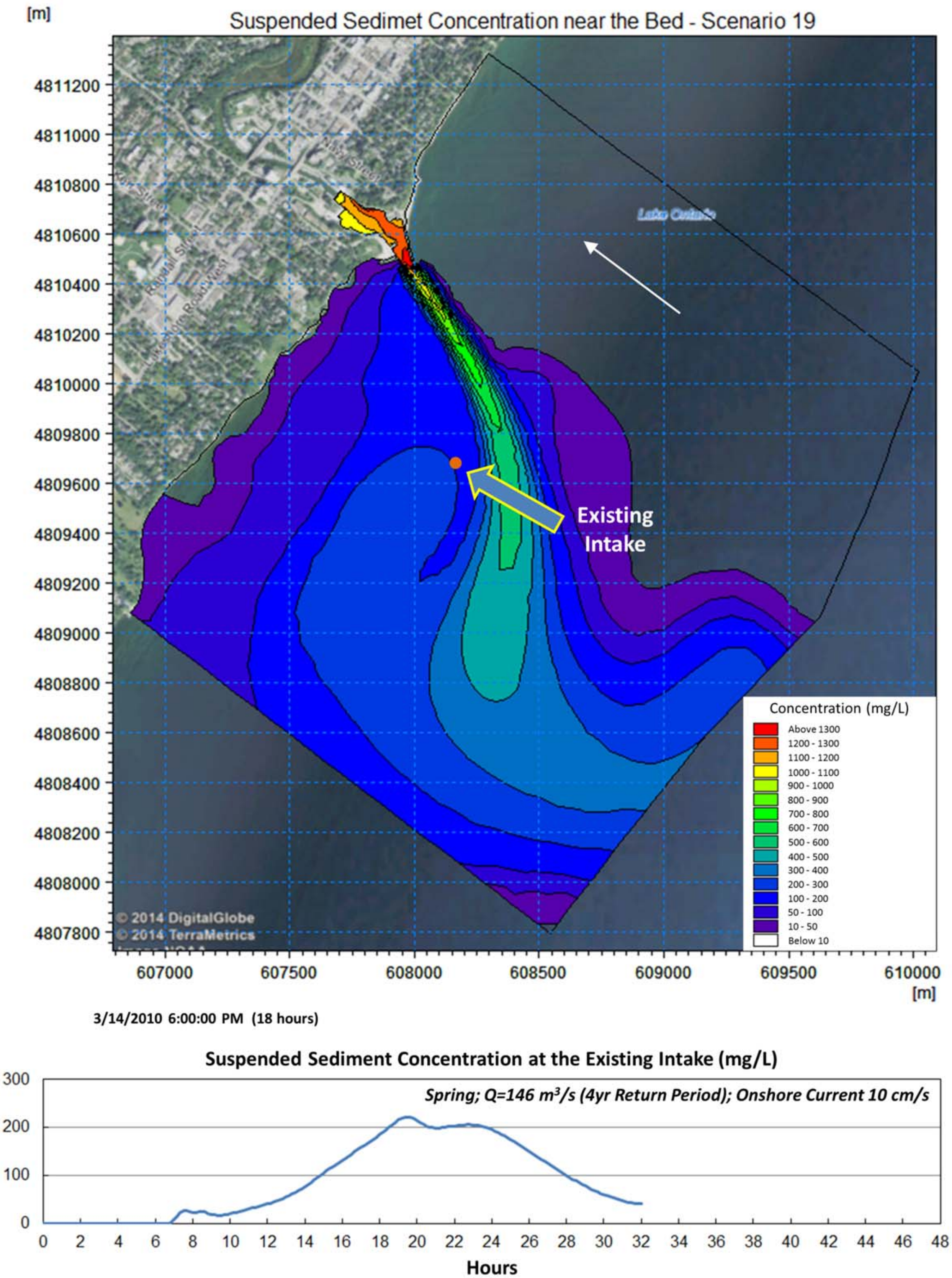


Figure H27: Sediment plume extent near the bed for Scenario 19

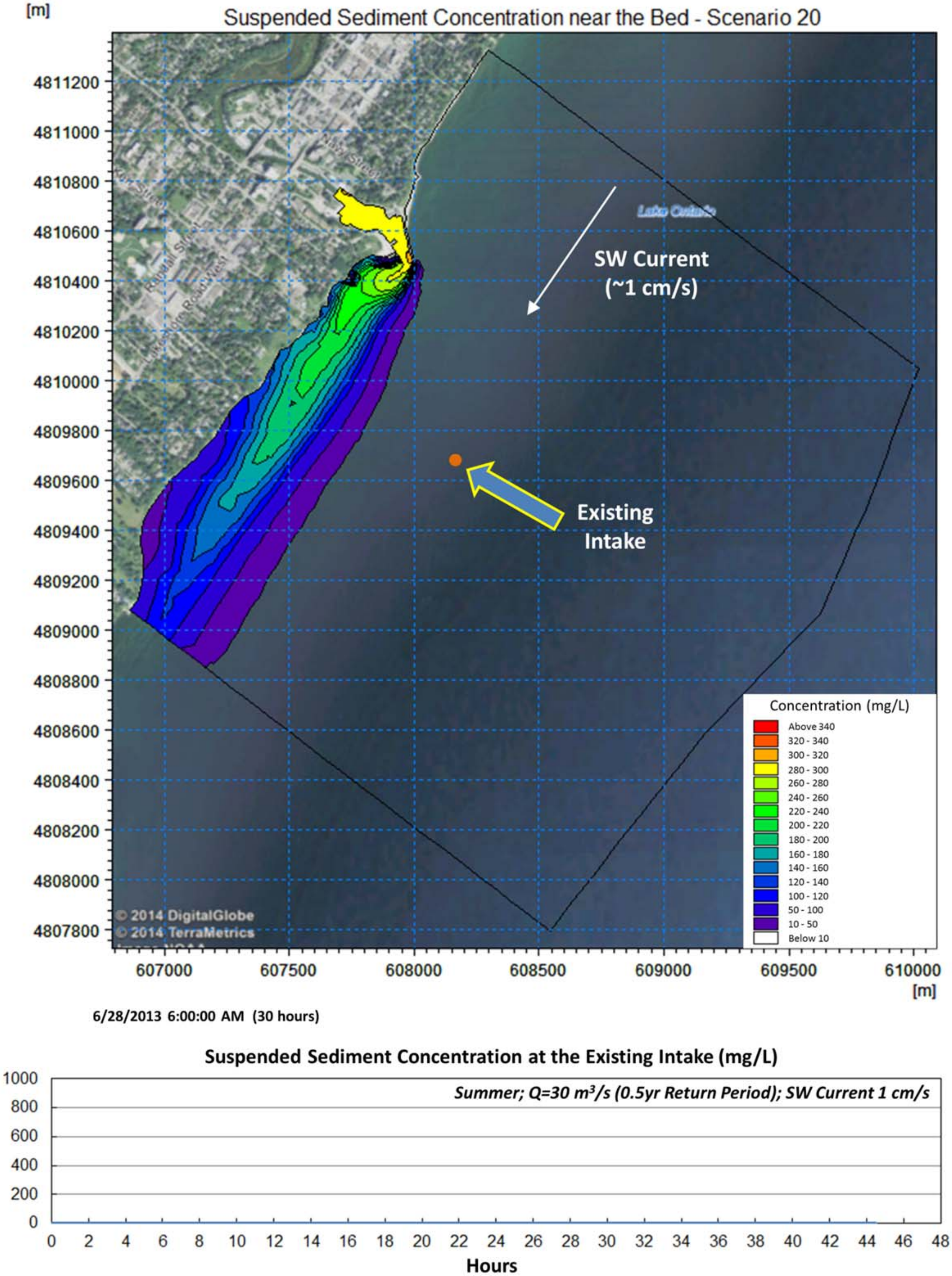
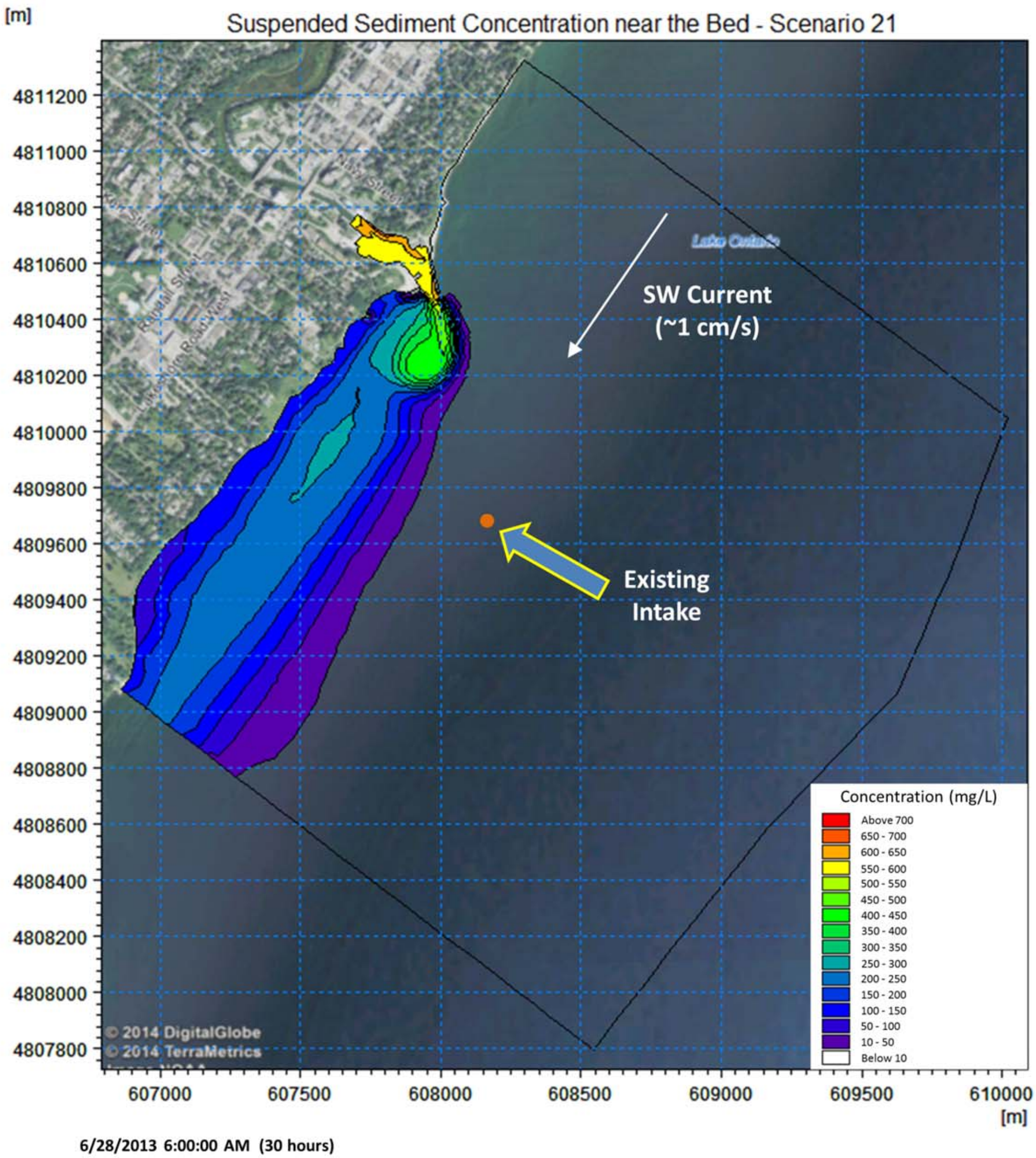


Figure H28: Sediment plume extent near the bed for Scenario 20



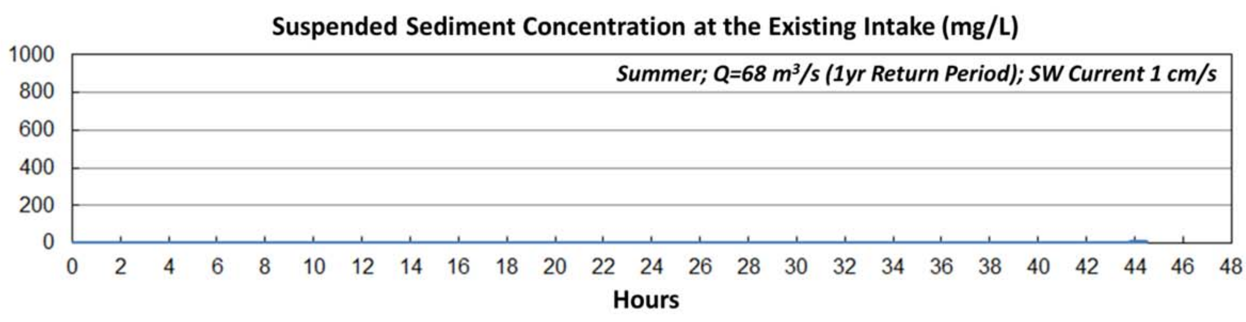
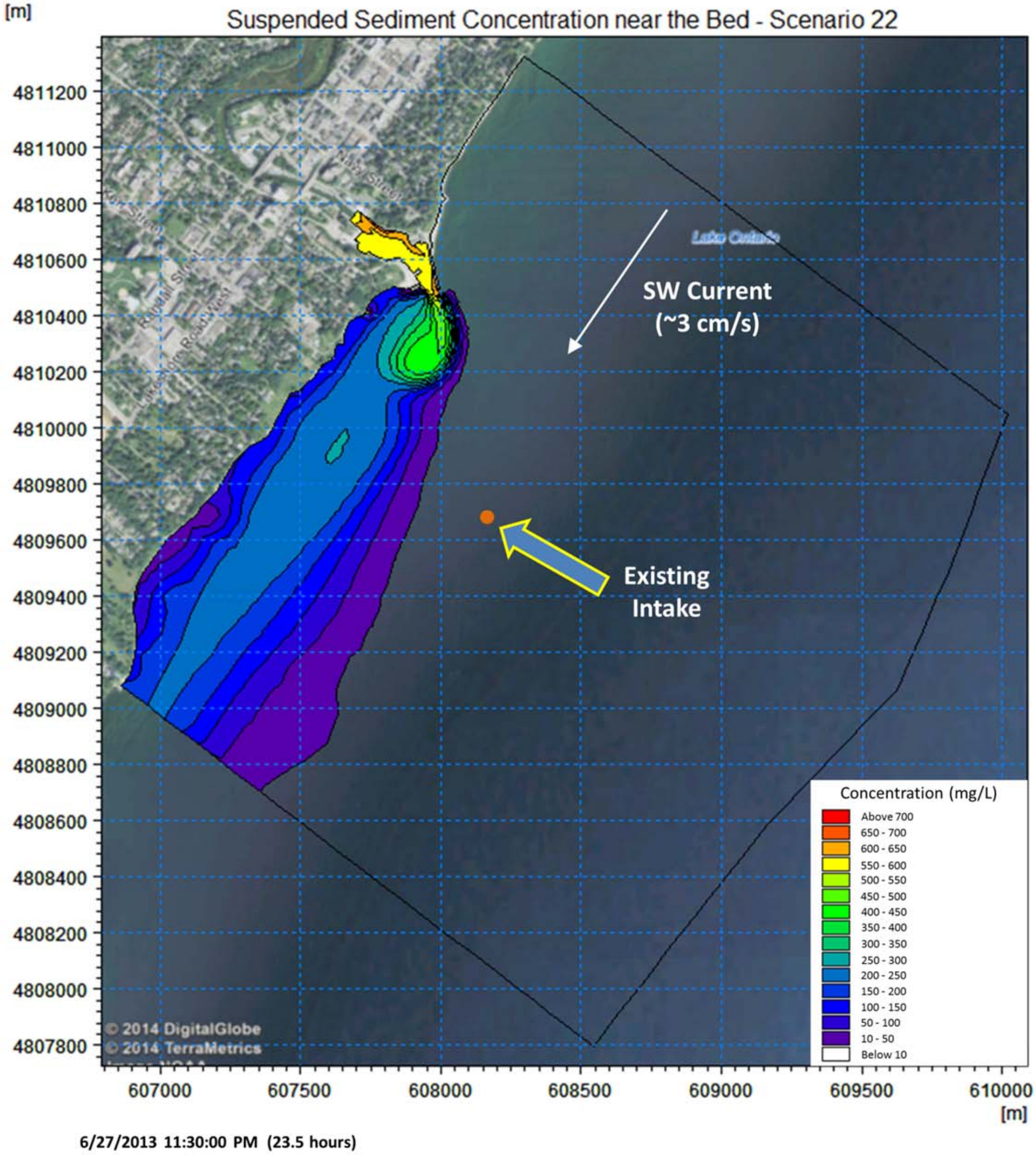


Figure H29: Sediment plume extent near the bed for Scenario 21



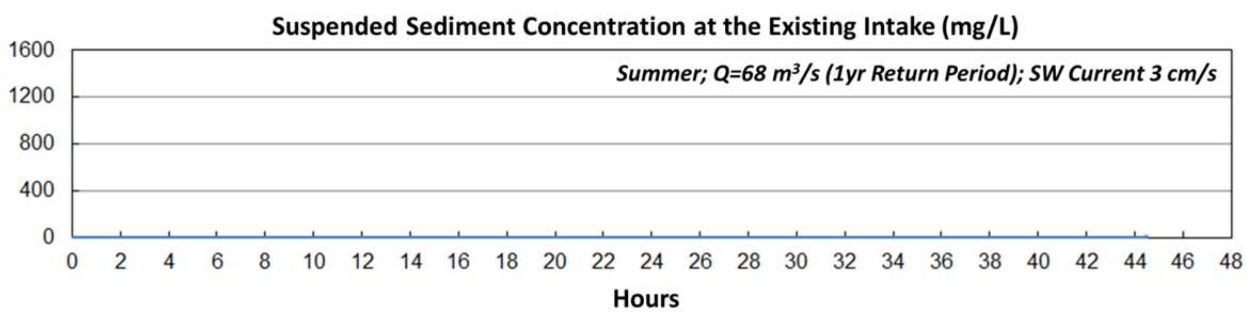


Figure H30: Sediment plume extent near the bed for Scenario 22

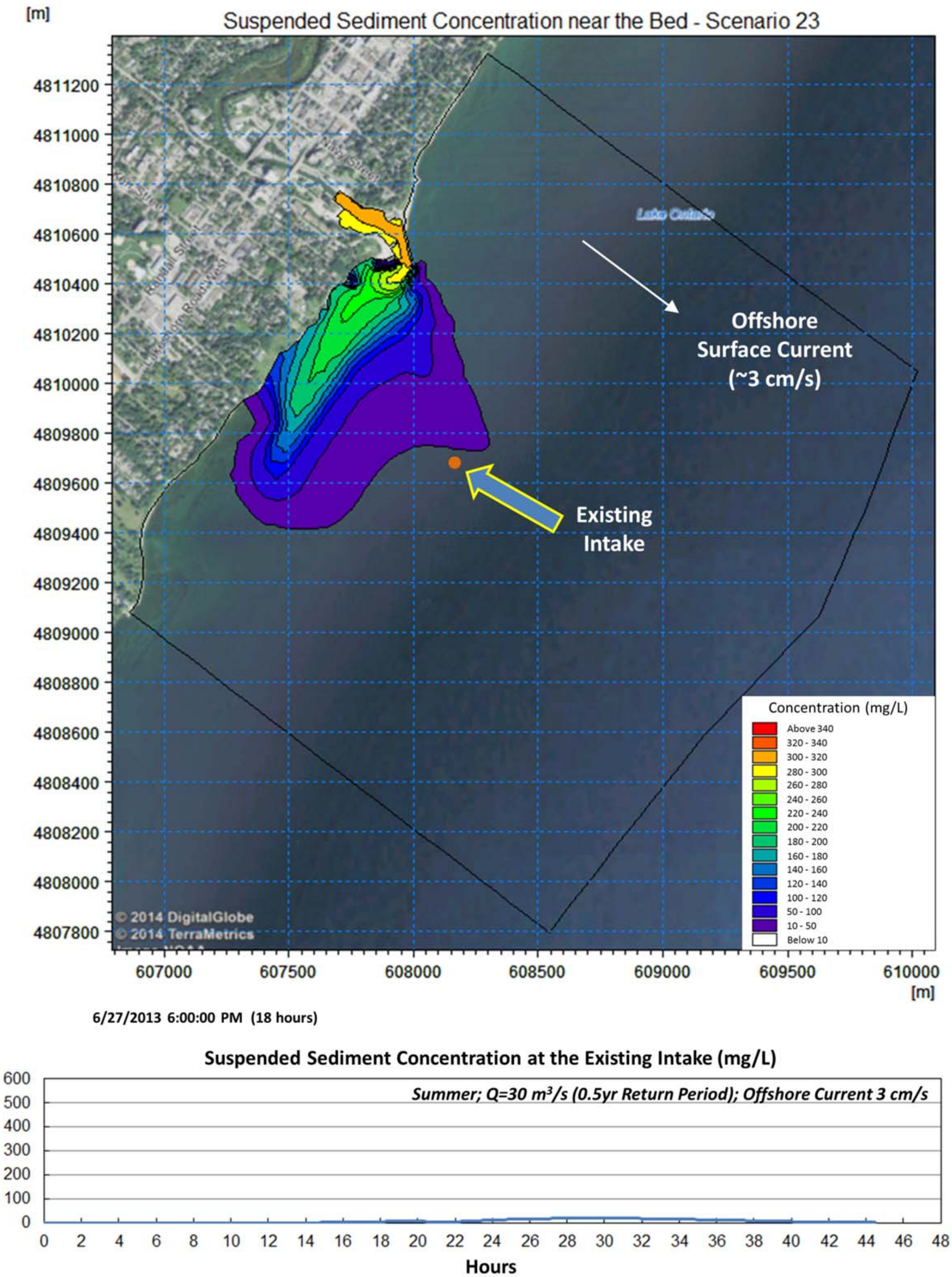


Figure H31: Sediment plume extent near the bed for Scenario 23

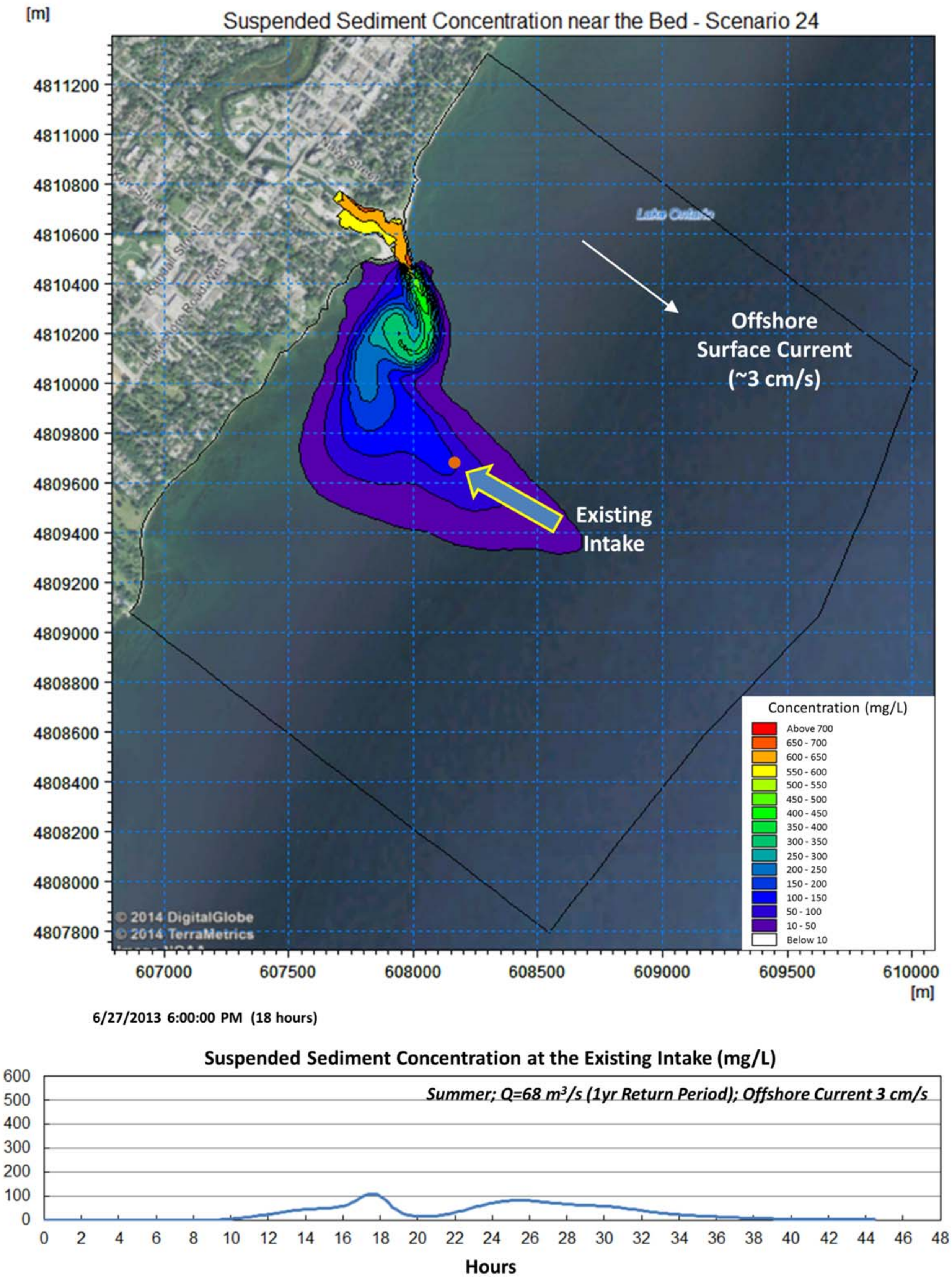


Figure H32: Sediment plume extent near the bed for Scenario 24

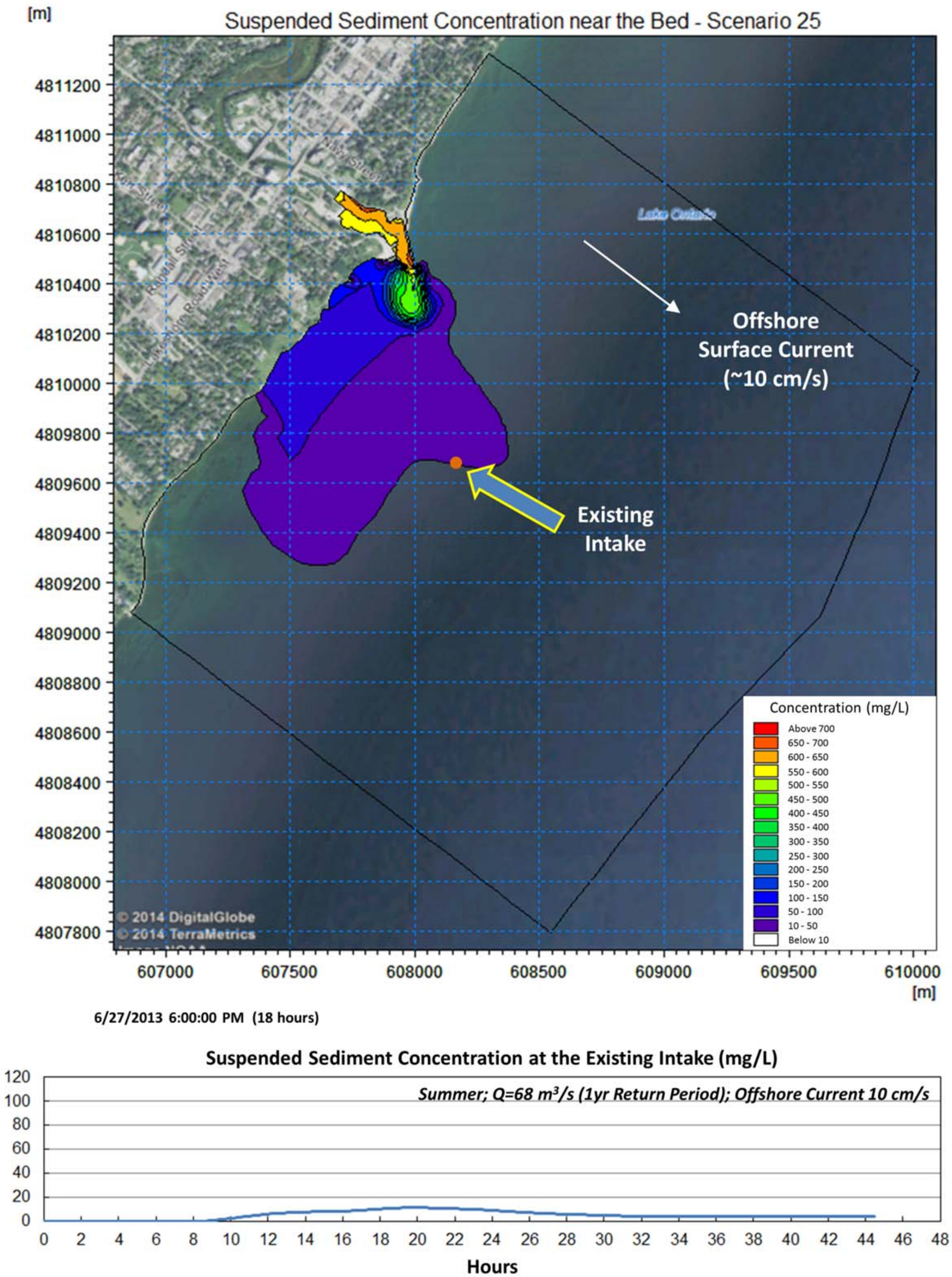
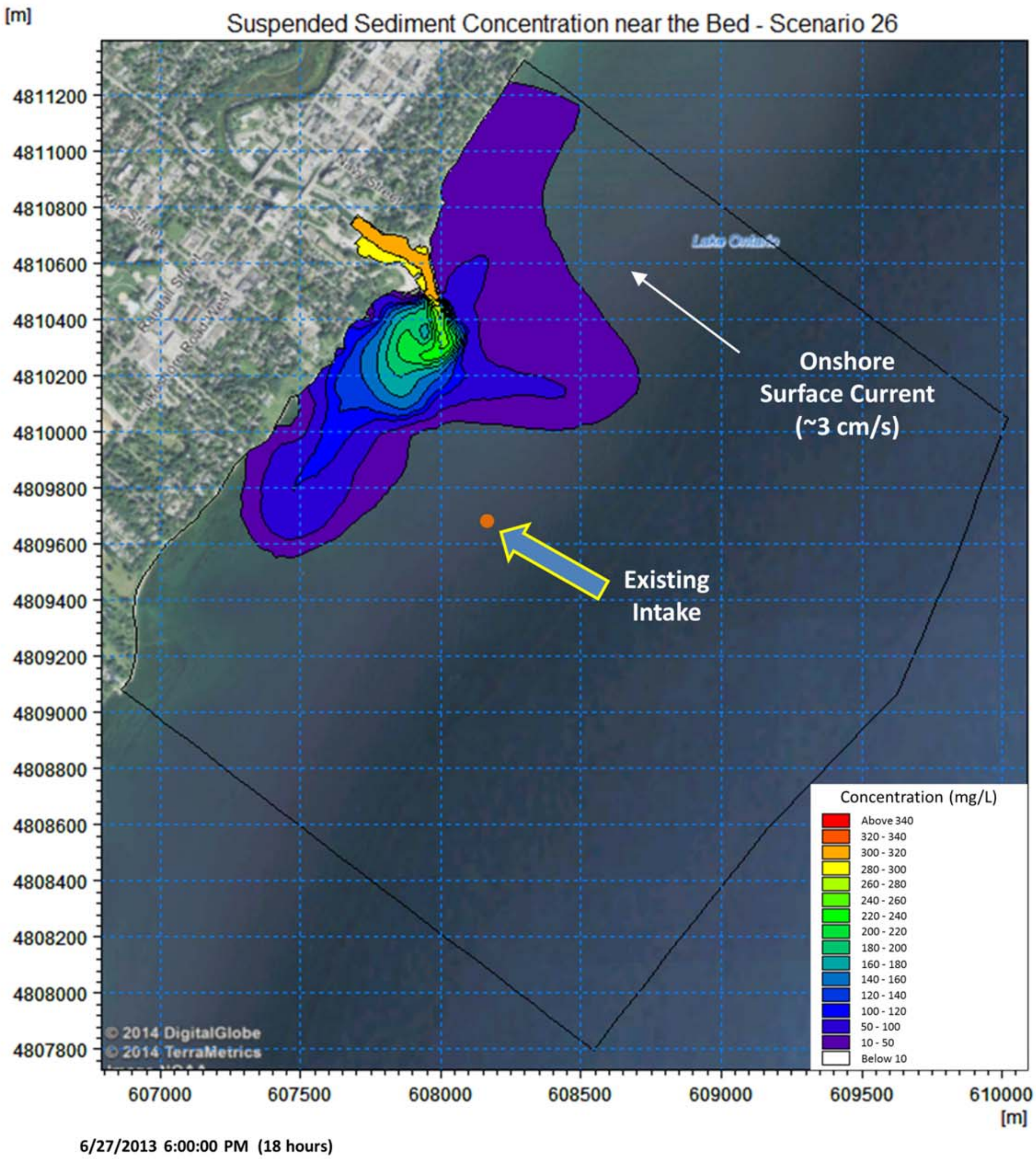


Figure H33: Sediment plume extent near the bed for Scenario 25



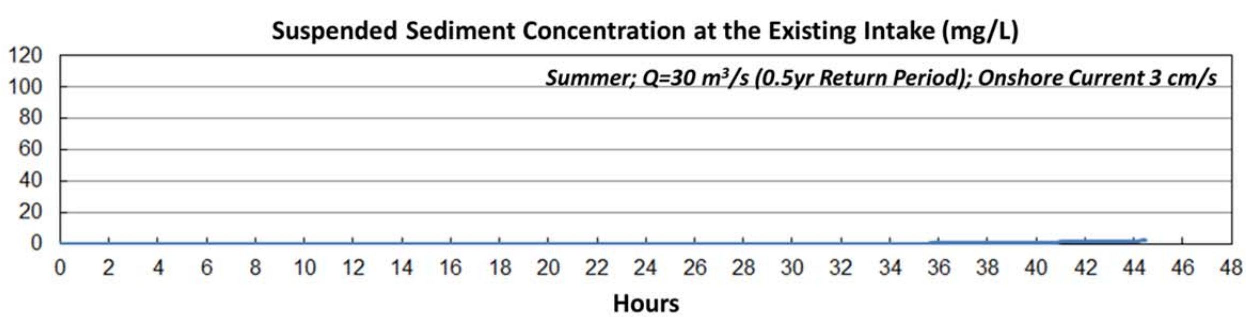


Figure H34: Sediment plume extent near the bed for Scenario 26

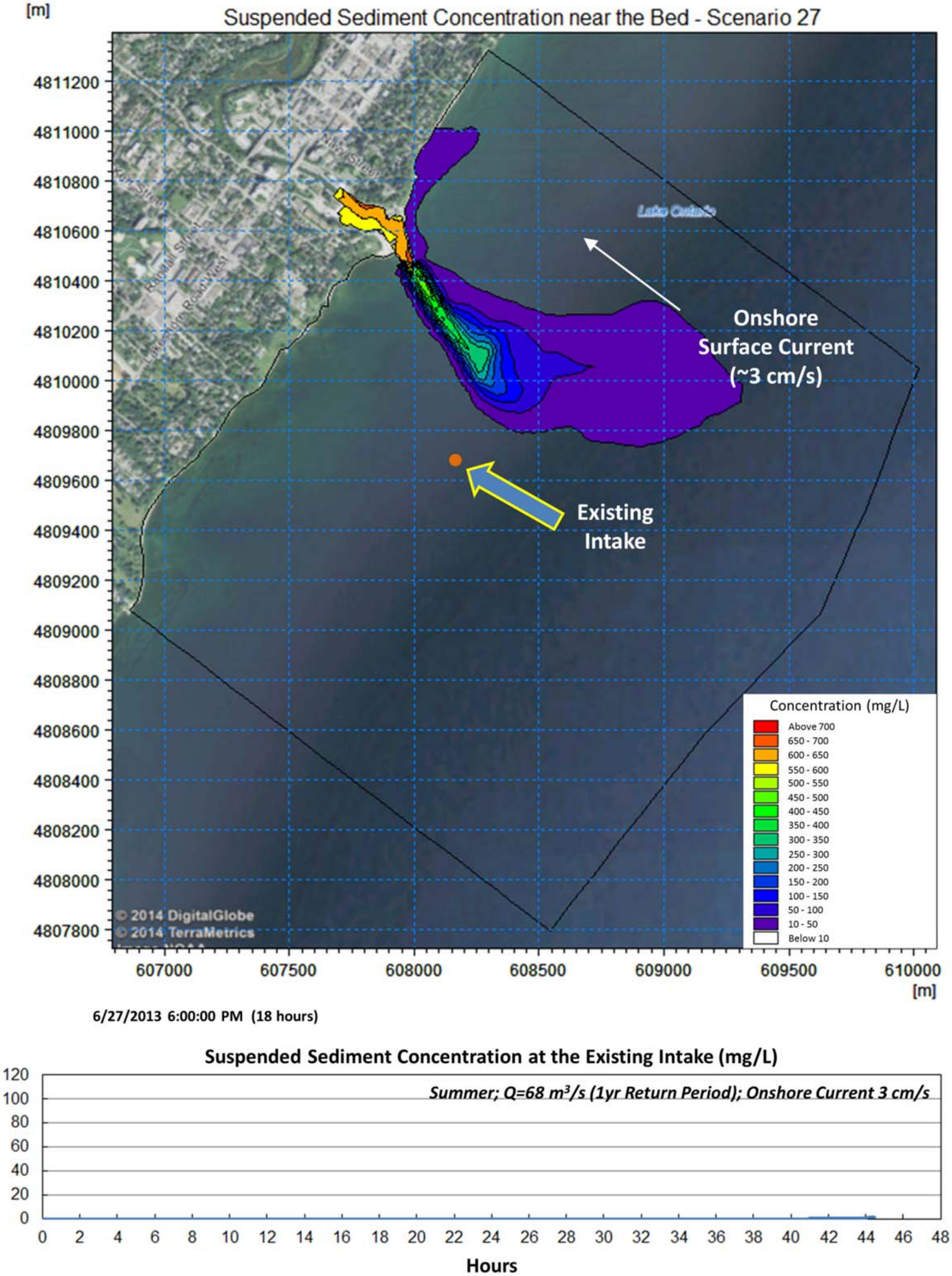
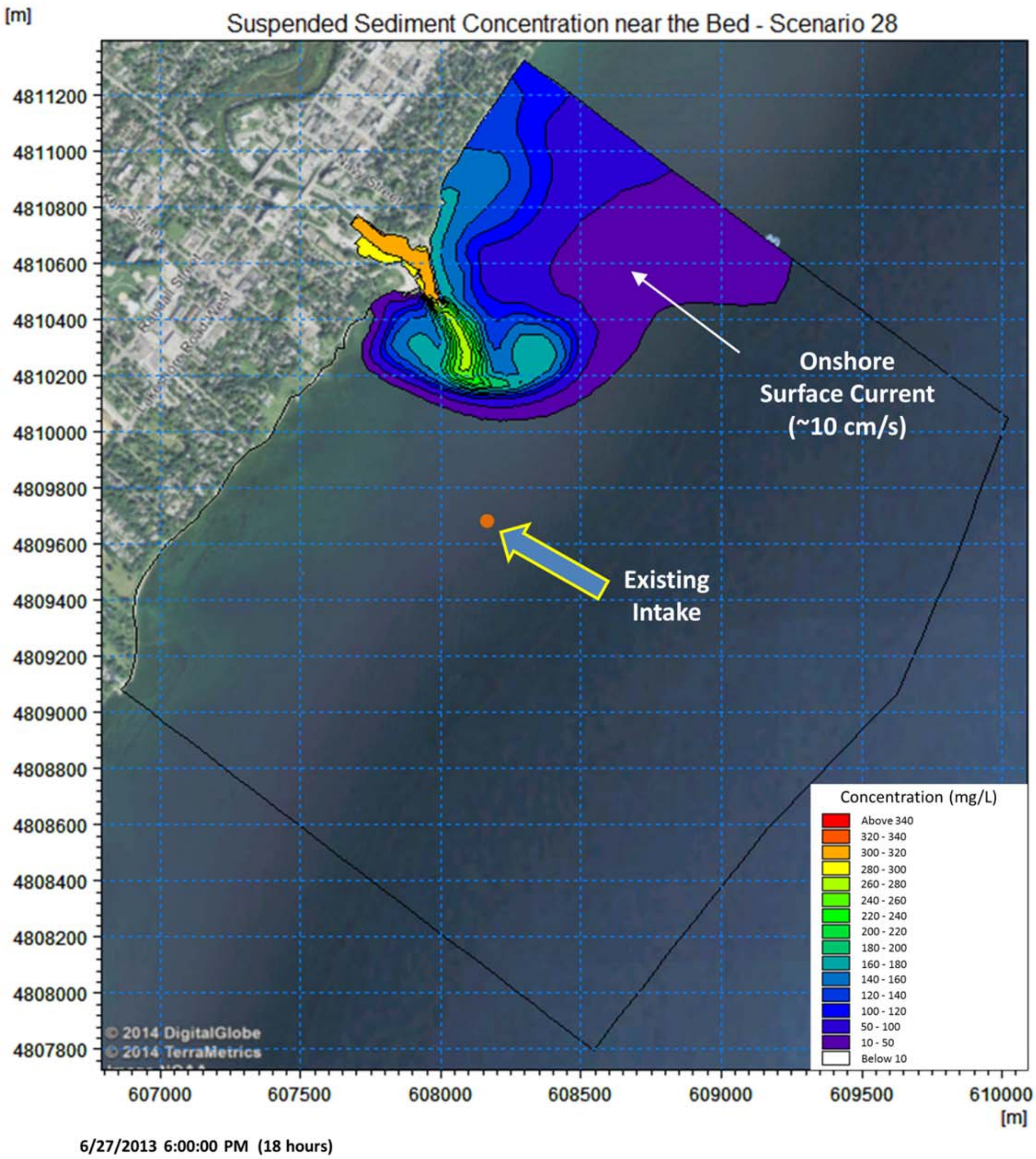


Figure H35: Sediment plume extent near the bed for Scenario 27



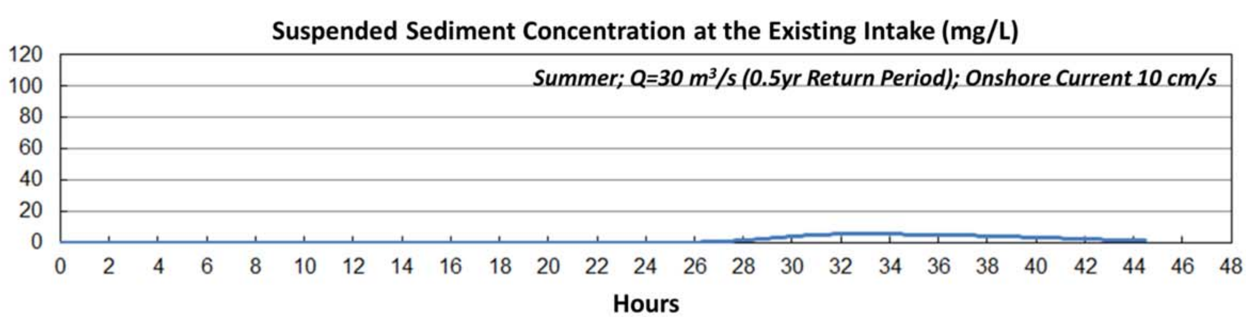
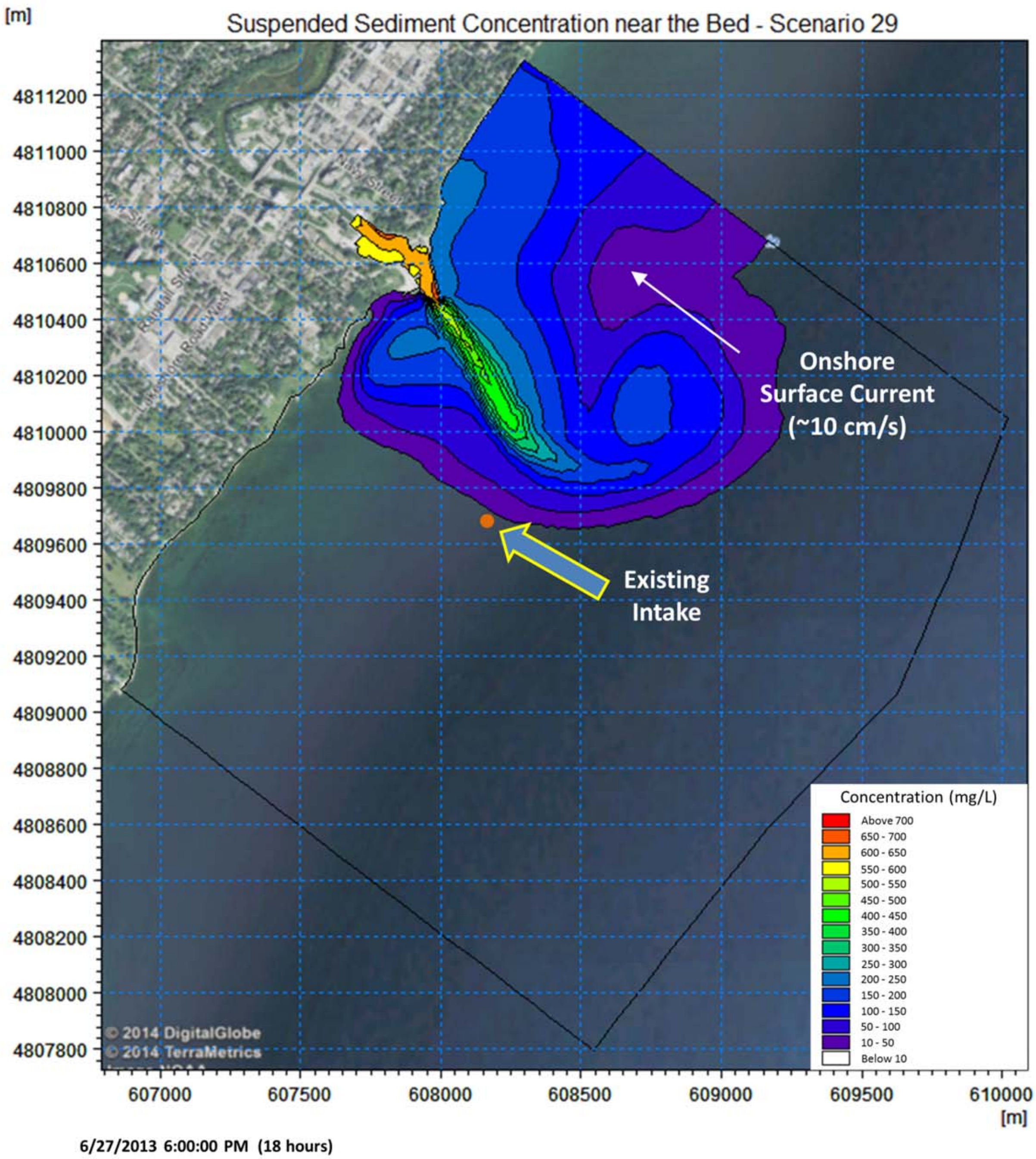


Figure H36: Sediment plume extent near the bed for Scenario 28



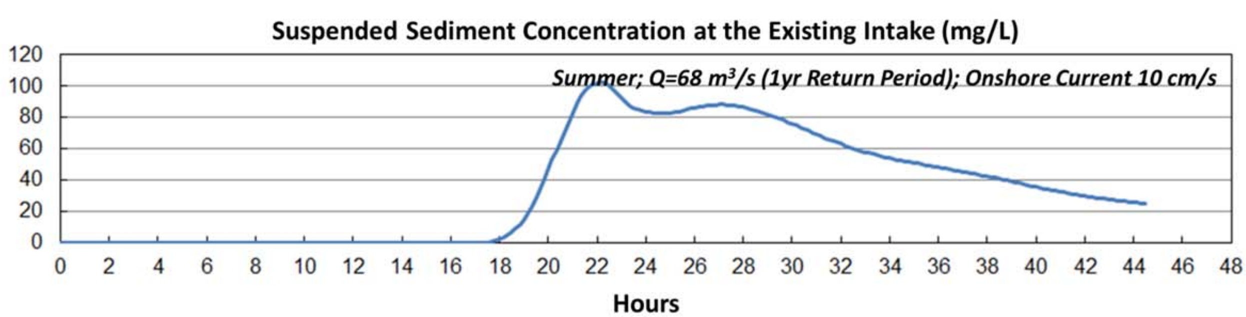
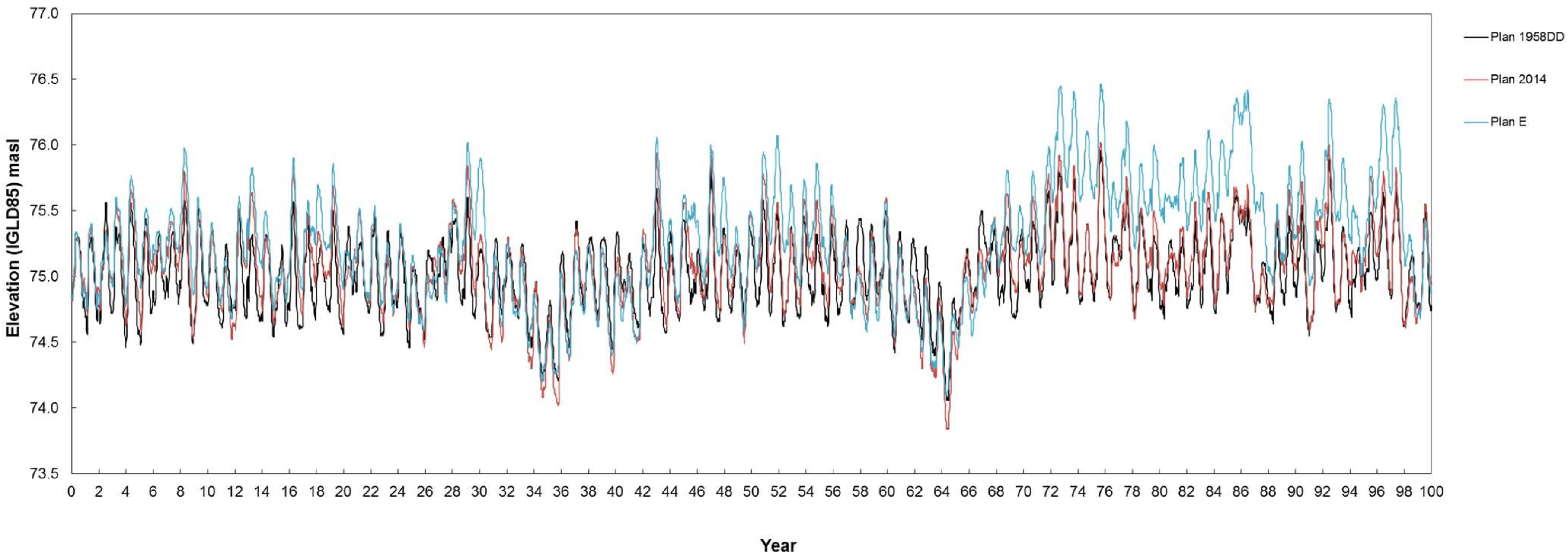


Figure H37: Sediment plume extent near the bed for Scenario 29

Appendix I
Water Levels (IGLD85)

Lake Ontario Water Levels for Different Regulation Regimes



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