Lake St. Martin Outlet Channel Post-Project Shoreline Morphology Assessment

Prepared for:

The KGS Group

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Location of Proposed Outlet Channel in Sturgeon Bay, June 2019
(image courtesy L. Wazney, KGS Group)

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1.0 INTRODUCTION

The location of the proposed Lake St. Martin outlet channel is mapped on Figure 1.1 and was designed to enhance water supply management between Lake Manitoba, Lake St. Martin and Lake Winnipeg. The Baseline Shoreline Assessment report (Zuzek Inc., 2020a) summarized our shoreline observations from two field trips, the bathymetric and sonar data collection to characterize the lake bottom, the long-term shoreline change analysis, and preliminary sediment transport modelling. The overall findings were summarized in a sediment budget for the existing conditions.

This post-project shoreline morphology assessment is the second report prepared by Zuzek Inc. under contract to the KGS Group to investigate the potential impacts of the channel inlet on the Lake St. Martin shoreline and the outlet on the Sturgeon Bay shoreline.

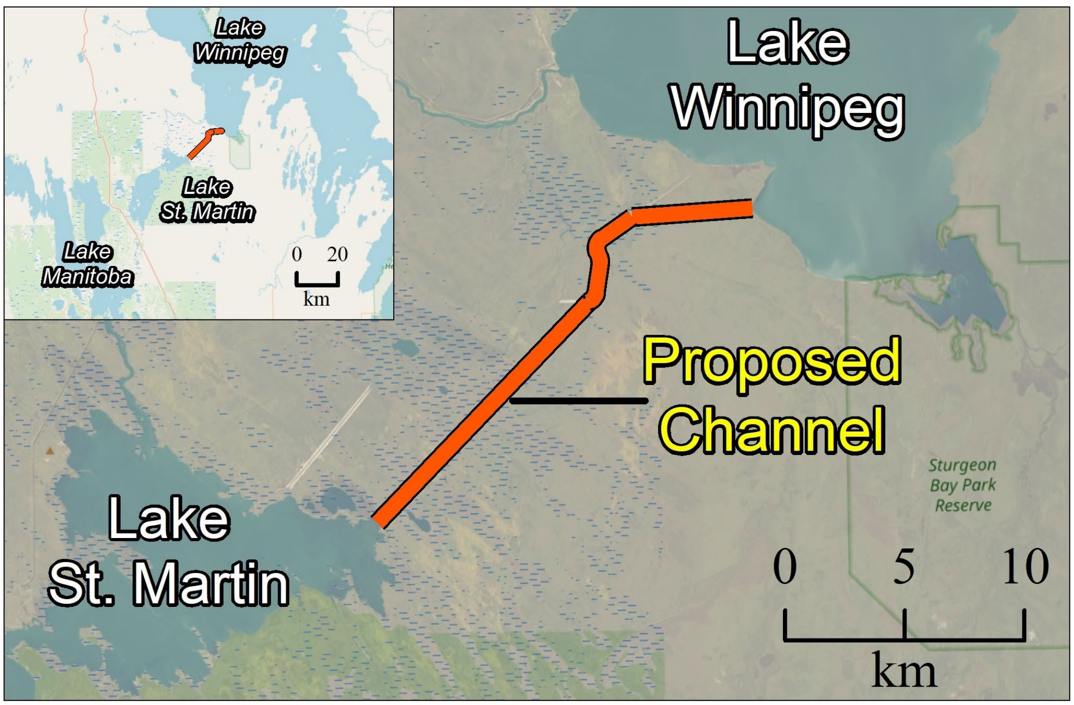


Figure 1.1 Proposed Lake St. Martin Outlet Channel

1.1 Key Findings from Baseline Shoreline Assessment

The key observations and technical findings from the baseline shoreline assessment are summarized for the inlet on Lake St. Martin and the outlet on Sturgeon Bay in Lake Winnipeg.

Lake St. Martin Inlet

- The shoreline in the north basin of Lake St. Martin is dominated by boulder headlands and shallow embayments. The comparison of historical aerial photographs to modern imagery suggests the shoreline is stable and erosion is not a major process near the inlet.

- Due to the small wave climate and irregular shoreline, longshore sediment transport is not a dominant physical process that influences shoreline morphology or rates of change.

- The waterline position migrates upslope and downslope in response to fluctuating lake levels. Submerged and emergent plant communities, where present, also migrate upslope and downslope in response to lake level cycles.

Sturgeon Bay Outlet

- Based on the preliminary sediment modelling, the shoreline from the Dauphin Rivermouth to Willow Point was identified as a littoral sub-cell. The shoreline from the east side of Willow Point to the Sturgeon Bay Park Reserve was also identified as a littoral sub-cell.

- Most of the shoreline from the Dauphin Rivermouth to the Sturgeon Bay Park Reserve is eroding. Even sediment sink areas feature erosion rates, as sand is being driven into the marshes during wave overtopping events and by aeolian processes.

- Submergence of the shoreline due to differential isostatic rebound rates along the north-south axis of Lake Winnipeg may be contributing to the long-term recession of the shoreline, especially at the Sturgeon Bay Park Reserve.

- Sediment is transported in a southward direction along the backside of Willow Point towards the proposed outlet during storms from the north and north-east. The potential for sedimentation once the channel is operational required further investigation.

1.2 Scope of Post-project Assessment

The post-project shoreline morphology assessment builds off the baseline report (Zuzek Inc, 2020a) and includes:

- Additional numerical modelling of storm events to simulate nearshore waves and currents for the existing shoreline morphology and post-project condition.

- Evaluation of sediment transport potential for large storms at different lake levels for the existing conditions (pre-project) and post-project scenario.

- Consideration of shoreline/channel stabilization structures for the inlet and outlet.

- Assessment of the potential impact of the channel once operational on the inlet and outlet shoreline morphology.

2.0 UPDATED SEDIMENT MODELLING FOR EXISTING CONDITIONS

The KGS Group developed a two-dimensional wave and hydrodynamic model for Lake Winnipeg to assess waves, currents, and water levels for the existing conditions and post-project scenario. These models also supported the preliminary sediment transport modelling completed for the baseline shoreline assessment of the proposed Lake St. Martin outlet channel, as outlined in Zuzek Inc. (2020a). Section 2.0 of this report summarizes the findings from updated sediment transport modelling in Sturgeon Bay and presents a refined regional sediment budget.

2.1 Updated Model Bathymetry for Sturgeon Bay

As outlined in Zuzek Inc. (2020a), differences in the resolution of the SOLIX bathymetry and the original MIKE21 model Digital Elevation Model (DEM) were identified. Consequently, the MIKE21 model DEM was updated with the SOLIX data and the storm simulations were re-run by the KGS Group. The updated time-series wave data was exported for the sediment transport investigation described in the following sections.

2.2 Regional Sediment Transport Results

The winds from the Environment and Climate Change Canada Station on George Island were selected to screen windstorms from the historical data, which covers March 2004 to present. The storm listing is provided in Table 2.1 for the top 46 events based on wind speed at the peak of the storm. Two representative storms (10 and 32) were selected for the sediment transport modelling with the CERC formula (CEM, 2002).

2.2.1 Storm 10 NNW

Events from the north-northwest to the southeast have the potential to generate waves that will propagate into Sturgeon Bay. Storm 10 was selected as a representative severe event from the north, which generate waves that propagate down the long axis of the north basin of Lake Winnipeg into Sturgeon Bay. It featured a peak wind speed of 21.4 m/s from the north (time series data presented in Figure 2.1). The results of the modelling are summarized:

- **Wave Heights**: the predicted wave heights at the peak of the storm from the MIKE21 spectral wave model are presented in Figure 2.2. The colours symbolize the wave height, while the vectors indicate the wave direction. Northeast of Willow Point, peak wave heights range from 2.2. to 2.6 m. As waves propagate onshore, refraction, diffraction, bottom friction, and breaking reduce wave heights closer to shore, which range from 1.2 to 1.6 m.

- **Hydrodynamics**: The wave induced currents and general circulation during the peak for Storm 10 are summarized in Figure 2.3. Key patterns emerged from the model output:

    - **North of the Dauphin River**: waves approach the shoreline at an oblique angle and generate strong southward currents that have the potential to transport sand and gravel towards the Dauphin River mouth.

- **Dauphin River to Willow Point**: the incident wave attack in Figure 2.2 is normal to the shoreline orientation, which reduces the speed of longshore currents and sediment transport potential to the east. The reduced gradient in the longshore current on the north side of Willow Point leads to the deposition of sand in this region.

- **Outlet Shoreline**: On the east side of Willow Point, longshore currents accelerate again towards the Sturgeon Bay Park Reserve.

- **Shoreline North of Sturgeon Bay Park Reserve**: the shoreline orientation results in oblique wave attack and the generation of strong longshore currents capable of transporting sand and gravel to the south.

- **Sturgeon Bay Park Reserve**: Given the east-west shoreline orientation and incident wave attack from Storm 10 (wave approach is normal to the shoreline orientation), longshore currents are weak along the Sturgeon Bay Park Reserve shoreline. Longshore currents from the northeast and northwest that transport sand and gravel to the Park Reserve converge and result in the deposition of sediment in this region.

- **Potential Sediment Transport**: Figure 2.4 summarizes the potential net sediment transport predictions for Storm 10 at the ten modelling profiles described in Zuzek Inc. (2020a). Key findings include:

  - Profile 1 to 3: the net direction for sediment transport is to the east and responsible for the transport of sand to this region of the shoreline during wave attack from the north.

  - Profile 4: net transport is to the west, which counters the longshore transport from Profiles 2 and 3, and results in sediment deposition along the shoreline.

  - Profile 5: wave breaking at Willow Point for Storm 10 generates currents capable of bypassing sediment to the southeast, however, the substrate data collected indicates this region of the shoreline is a large cobble-lag deposit. Therefore, the potential for sand and gravel to bypass Willow Point is presumed to be low since the supply is also low.

  - Profile 6 to 9: the net longshore transport direction is to the east, leading to the transport of sand towards the Sturgeon Bay Park Reserve.

  - Profile 10: the net transport direction at Profile 10 is to the west, which is opposite of the Profile 9 prediction, resulting in the convergence of sediment transport along the Park Reserve shoreline. This convergence is responsible for the sediment sink along the nearshore and shoreline of the Park.

Table 2.1 Windstorm Listing for George Island, March 2004 to January 2019

Rank	Max Time	Max WSPD (m/s)	WDIR @ Max	Start	End	Duration
1	2010-10-27 10:00	24.7	360	2010-10-26 16:00	2010-10-28 0:00	33
2	2006-10-12 20:00	24.2	290	2006-10-11 19:00	2006-10-13 19:00	49
3	2017-03-08 7:00	24.2	330	2017-03-07 13:00	2017-03-08 14:00	26
4	2004-10-01 19:00	22.8	-999	2004-10-01 3:00	2004-10-02 0:00	22
5	2007-09-10 21:00	22.8	-999	2007-09-10 18:00	2007-09-11 3:00	10
6	2012-09-08 4:00	22.8	350	2012-09-08 0:00	2012-09-08 9:00	10
7	2015-10-12 2:00	21.9	10	2015-10-12 1:00	2015-10-12 11:00	11
8	2006-09-17 12:00	21.7	-999	2006-09-15 14:00	2006-09-17 16:00	51
9	2014-11-07 17:00	21.4	340	2014-11-07 13:00	2014-11-09 4:00	40
10	**2015-08-23 16:00**	**21.4**	**360**	**2015-08-23 0:00**	**2015-08-23 20:00**	**21**
11	2018-09-16 11:00	21.4	60	2018-09-16 10:00	2018-09-16 19:00	10
12	2006-10-08 9:00	20.6	280	2006-10-08 7:00	2006-10-08 12:00	6
13	2008-07-12 19:00	20.6	290	2008-07-12 12:00	2008-07-12 23:00	12
14	2010-08-24 15:00	20.6	310	2010-08-24 13:00	2010-08-24 21:00	9
15	2013-10-12 15:00	20.6	320	2013-10-12 8:00	2013-10-12 19:00	12
16	2014-07-01 3:00	20.3	360	2014-06-30 22:00	2014-07-01 7:00	10
17	2005-10-07 21:00	20.0	110	2005-10-07 15:00	2005-10-08 1:00	11
18	2017-10-18 6:00	20.0	230	2017-10-18 5:00	2017-10-18 21:00	17
19	2018-10-19 19:00	19.7	340	2018-10-19 11:00	2018-10-20 1:00	15
20	2005-01-13 13:00	19.4	260	2005-01-13 10:00	2005-01-13 15:00	6
21	2010-08-15 14:00	19.4	330	2010-08-14 19:00	2010-08-16 15:00	45
22	2012-08-16 1:00	19.4	10	2012-08-15 15:00	2012-08-16 2:00	12
23	2004-12-17 15:00	19.2	270	2004-12-17 13:00	2004-12-17 18:00	6
24	2011-12-06 4:00	19.2	180	2011-12-06 0:00	2011-12-06 18:00	19
25	2016-12-07 0:00	18.9	10	2016-12-06 15:00	2016-12-07 6:00	16
26	2004-09-06 16:00	18.6	-999	2004-09-06 15:00	2004-09-06 22:00	8
27	2004-10-03 9:00	18.6	-999	2004-10-03 4:00	2004-10-03 14:00	11
28	2007-06-18 23:00	18.6	290	2007-06-18 21:00	2007-06-19 2:00	6
29	2008-02-09 21:00	18.6	260	2008-02-09 8:00	2008-02-09 23:00	16
30	2008-08-22 22:00	18.6	290	2008-08-22 16:00	2008-08-23 6:00	15
31	2012-09-19 7:00	18.6	330	2012-09-19 7:00	2012-09-19 16:00	10
32	**2014-08-24 12:00**	**18.6**	**60**	**2014-08-24 6:00**	**2014-08-24 14:00**	**9**
33	2015-07-29 13:00	18.6	330	2015-07-29 10:00	2015-07-29 16:00	7
34	2015-11-19 3:00	18.6	350	2015-11-19 0:00	2015-11-19 20:00	21
35	2016-09-25 21:00	18.3	330	2016-09-25 12:00	2016-09-26 19:00	32
36	2017-11-10 12:00	18.3	180	2017-11-10 9:00	2017-11-10 20:00	12
37	2011-04-30 12:00	18.1	40	2011-04-30 0:00	2011-04-30 22:00	23
38	2012-01-01 3:00	18.1	320	2012-01-01 1:00	2012-01-01 7:00	7
39	2014-11-19 8:00	18.1	340	2014-11-19 1:00	2014-11-19 8:00	8
40	2014-11-16 11:00	17.8	20	2014-11-16 8:00	2014-11-16 20:00	13
41	2017-10-29 19:00	17.8	30	2017-10-29 17:00	2017-10-30 4:00	12
42	2011-11-29 10:00	17.5	200	2011-11-29 10:00	2011-11-29 16:00	7
43	2014-10-05 19:00	17.5	330	2014-10-05 19:00	2014-10-06 0:00	6
44	2017-09-04 15:00	17.5	340	2017-09-04 15:00	2017-09-04 21:00	7
45	2007-11-14 3:00	16.9	-999	2007-11-13 15:00	2007-11-14 9:00	19
46	2014-10-16 15:00	16.9	30	2014-10-16 15:00	2014-10-16 21:00	7

Note: Duration based on exceedance of 16 m/s wind speed threshold

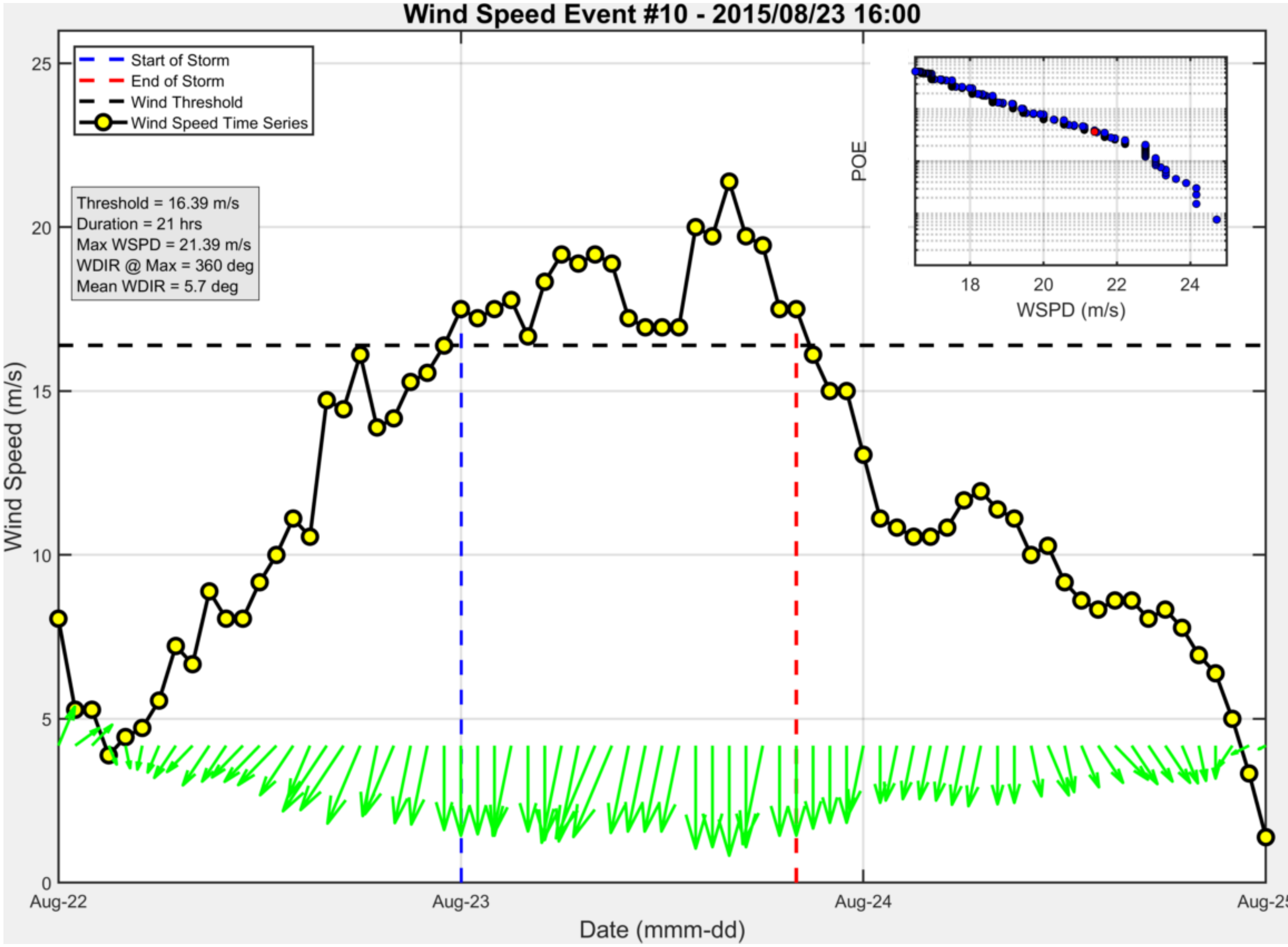


Figure 2.1 Time Series Wave Height and Direction for Storm 10, George Island

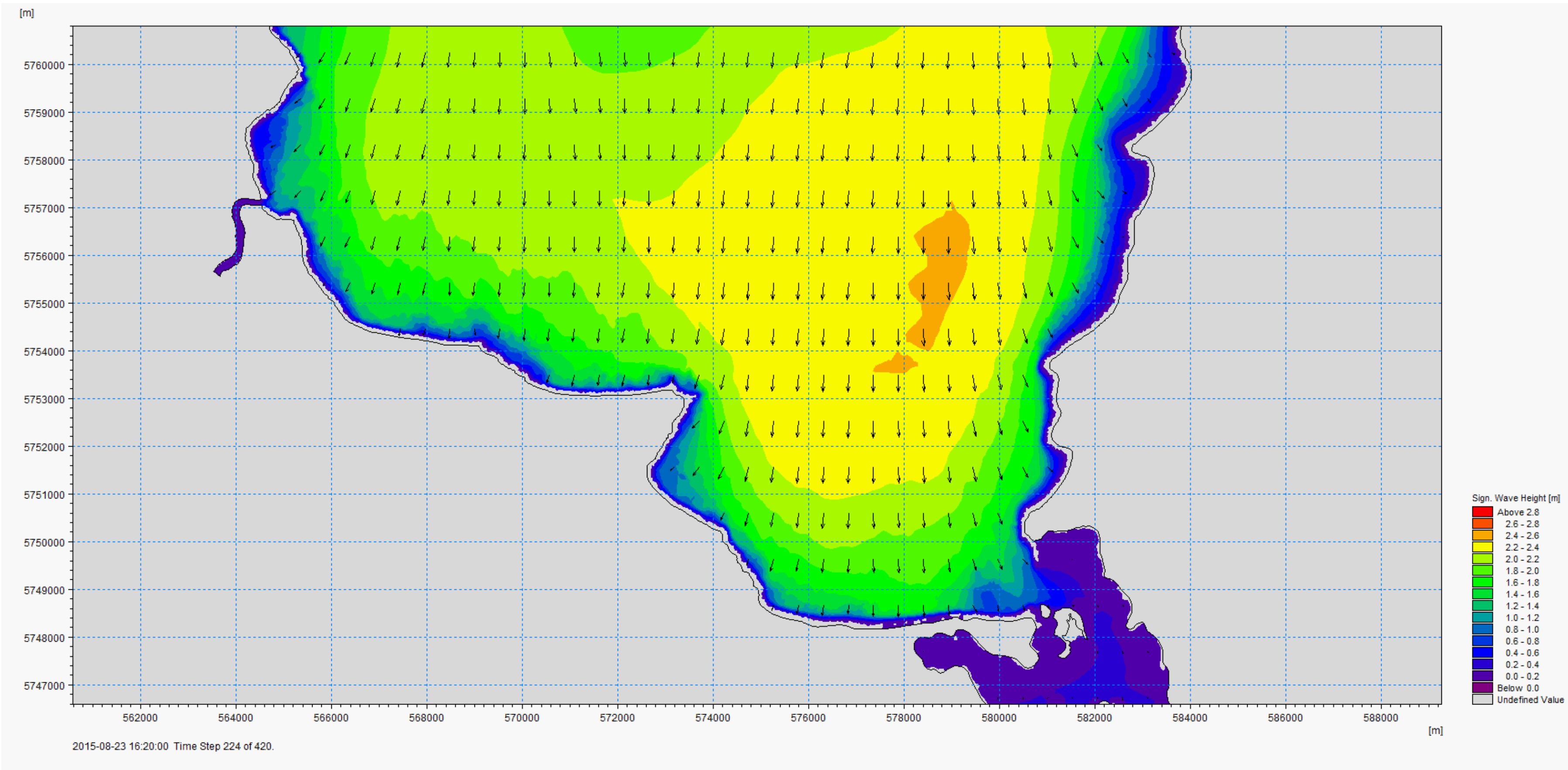


Figure 2.2 MIKE21 Wave Height Predictions at the Peak of Storm 10 (2015.08.23)

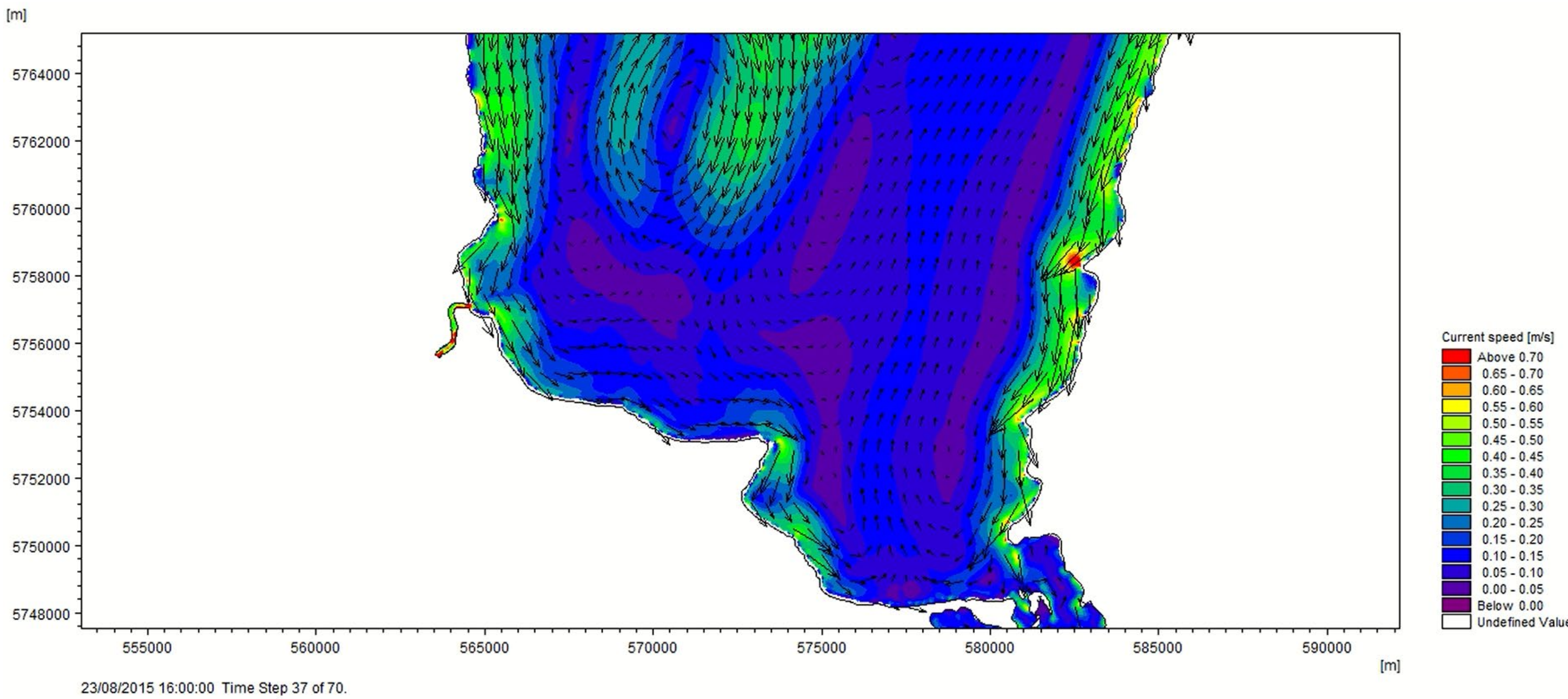


Figure 2.3 Hydrodynamics from MIKE21 Model at Peak of Storm 10

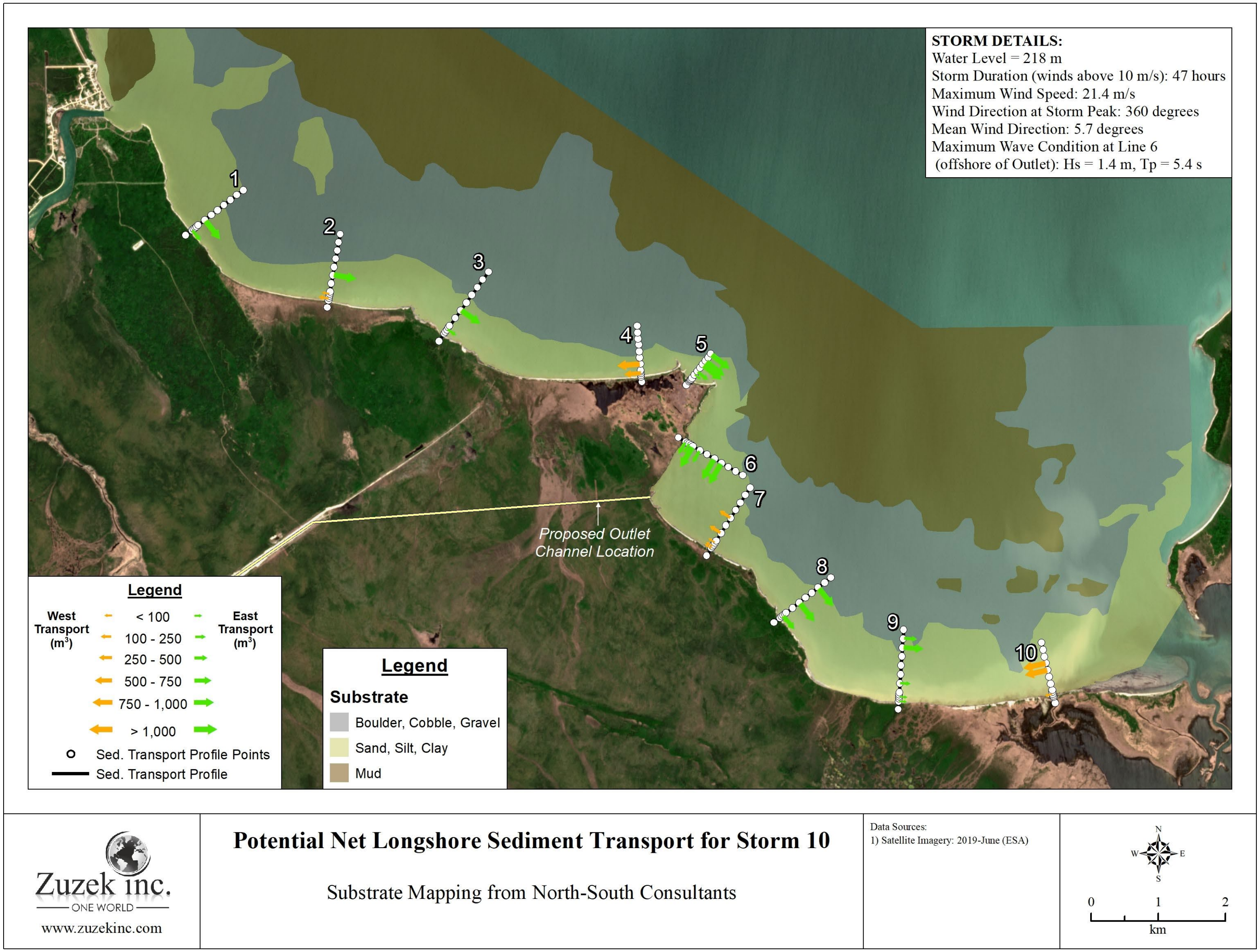


Figure 2.4 CERC Formula Potential Sediment Transport Estimates for Storm 10 (lake level 218 m)

2.2.2 Storm 32 NE

A second event, Storm 32, was selected to simulate storms from the north-east quadrant. Refer to Figure 2.5 for a summary of the time series wind data. The peak wind speed was 18.6 m/s from the east north-east, which was slightly lower than the peak wind speed for Storm 10. However, the event featured wind speeds over 10 m/s for almost three days, which is roughly twice the duration of Storm 10. Key findings from the modelling for Storm 32 are summarized:

- **Wave Heights**: Storm 32 generated a strong east to west gradient in wave height, as seen in Figure 2.6. Along the east shore of Sturgeon Bay, the wave heights were close to zero due to offshore winds, increasing to 1.8 m between Willow Point and the Dauphin River.

- **Hydrodynamics**: The wave induced currents and general circulation during the peak of Storm 10 are summarized in Figure 2.7. Key patterns emerged from the model output:

    - **North of the Dauphin River**: similar nearshore circulation to Storm 10, with currents moving southward along the shore towards the Dauphin River mouth due to oblique wave attack, although current speed was roughly half of Storm 10.

    - **Dauphin River to Willow Point**: with the incident wind and waves from the northeast, wave breaking results in the generation of longshore currents moving to the west, towards the Dauphin River.

    - **Outlet Shoreline**: On the back side of Willow Point, currents move south, as they did with Storm 10. This explains the absence of significant beach deposits in this region (i.e., north and northeast storms result in currents moving to the south and there is very little supply of new sand and gravel to this region).

    - **Shoreline North of Sturgeon Bay Park Reserve**: nearshore currents move to the south for Storm 32, towards the Sturgeon Bay Park Reserve.

    - **Sturgeon Bay Park Reserve**: At the peak of the storm, as seen in Figure 2.7, a strong clockwise eddy forms at the bottom of Sturgeon Bay.

- **Potential Sediment Transport**: Figure 2.8 summarizes the potential sediment transport predictions with the CERC formula for Storm 32 at the 10 modelling profiles described in Zuzek Inc. (2020a) for a lake level of 218.0 m CGVD. Key findings include:

    - Profile 1 to 4: the net direction for sediment transport is to the west.

    - Profile 5: very low potential for sediment to bypass Willow Point, to the southwest.

    - Profile 6: strong net transport potential to the south on the backside of Willow Point, however, there is no significant sediment supply to this region.

    - Profile 7 to 10: the waves are very small in this region of Sturgeon Bay and thus potential sediment transport is also very low. At Profile 8 the transport potential is to the east, while Profiles 9 and 10 have potential transport to the west.

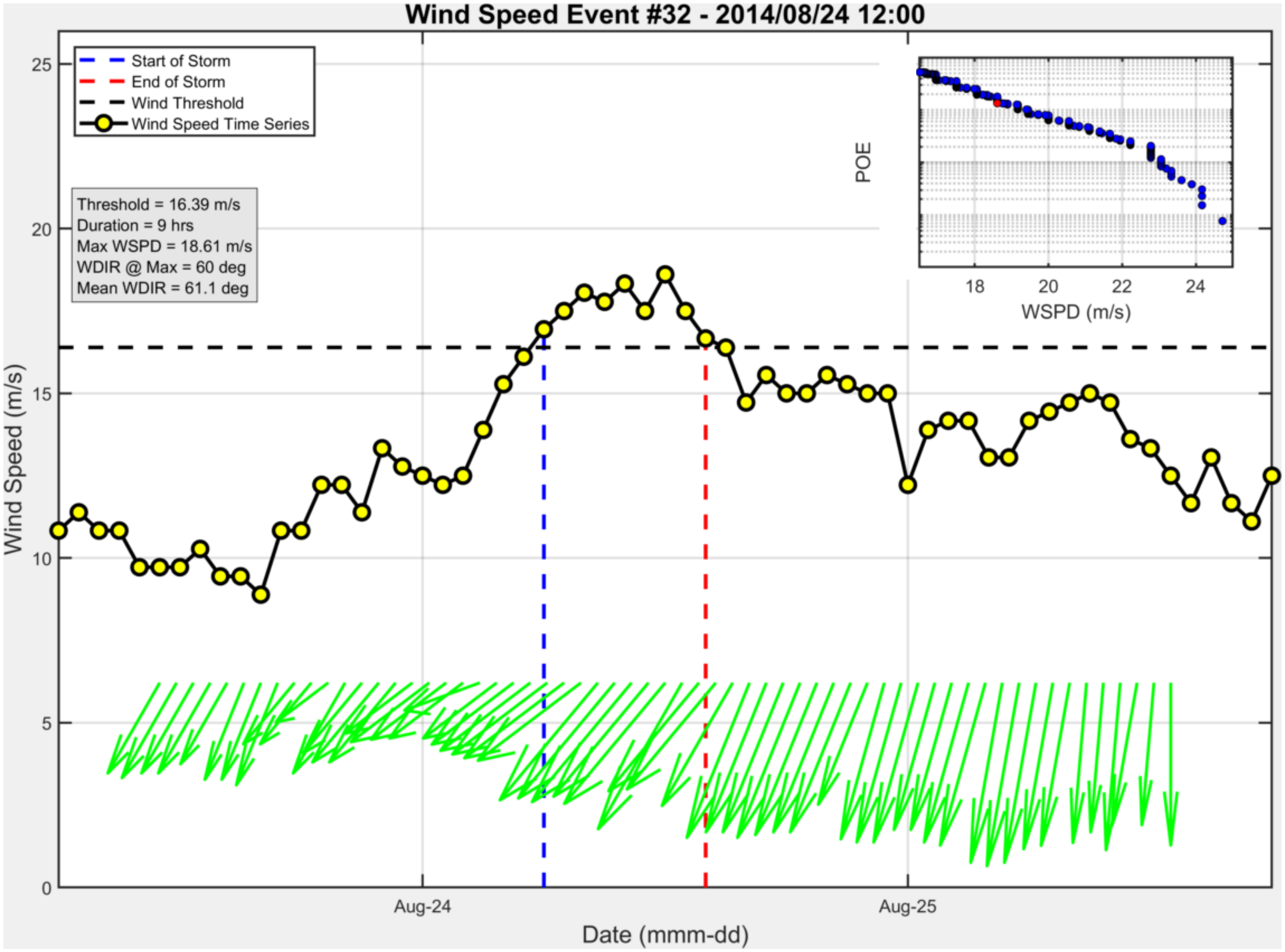


Figure 2.5 Time Series Wave Height and Direction for Storm 32, George Island

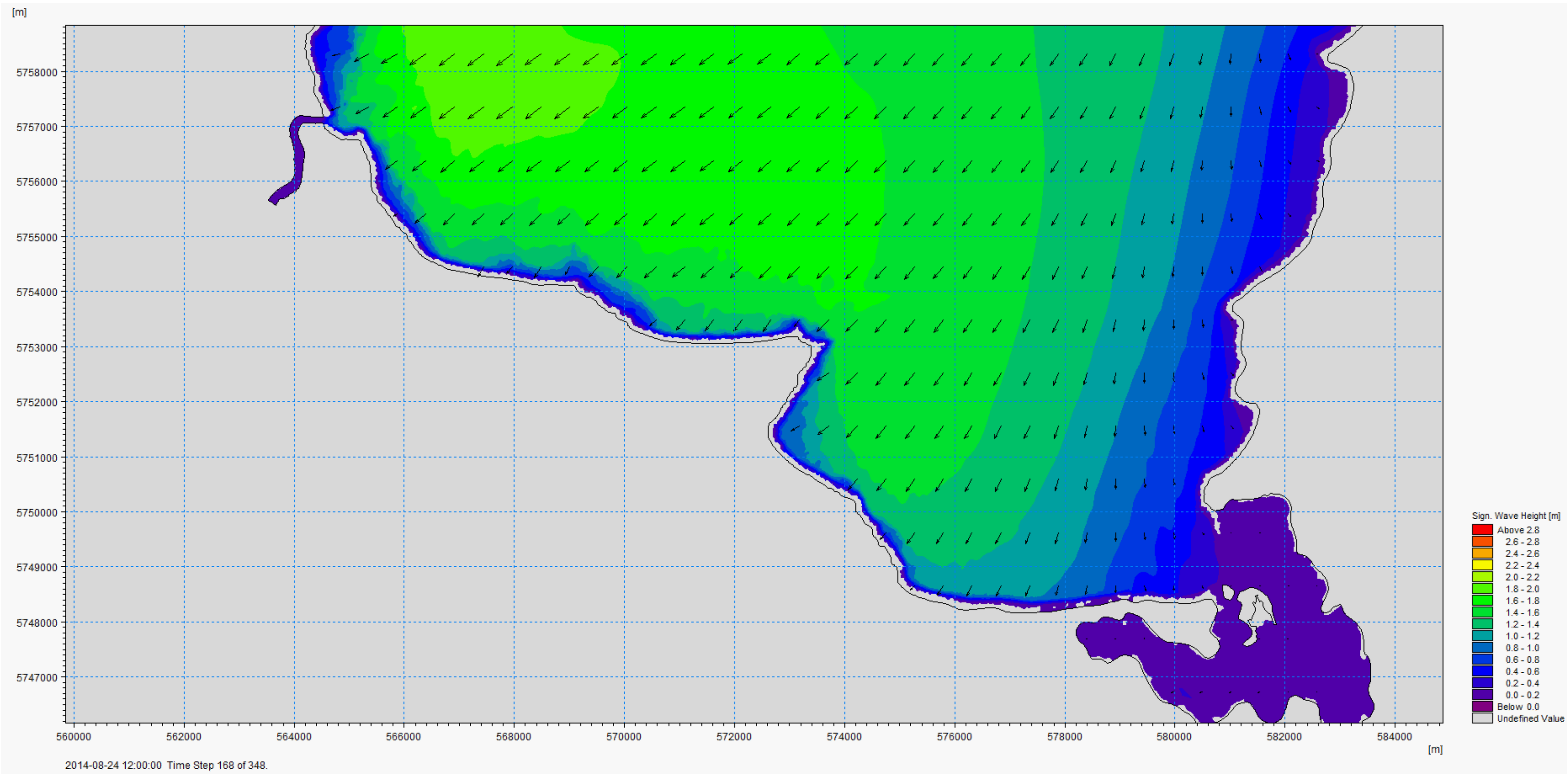


Figure 2.6 MIKE21 Wave Height Prediction at the Peak of Storm 32 (2014.08.24)

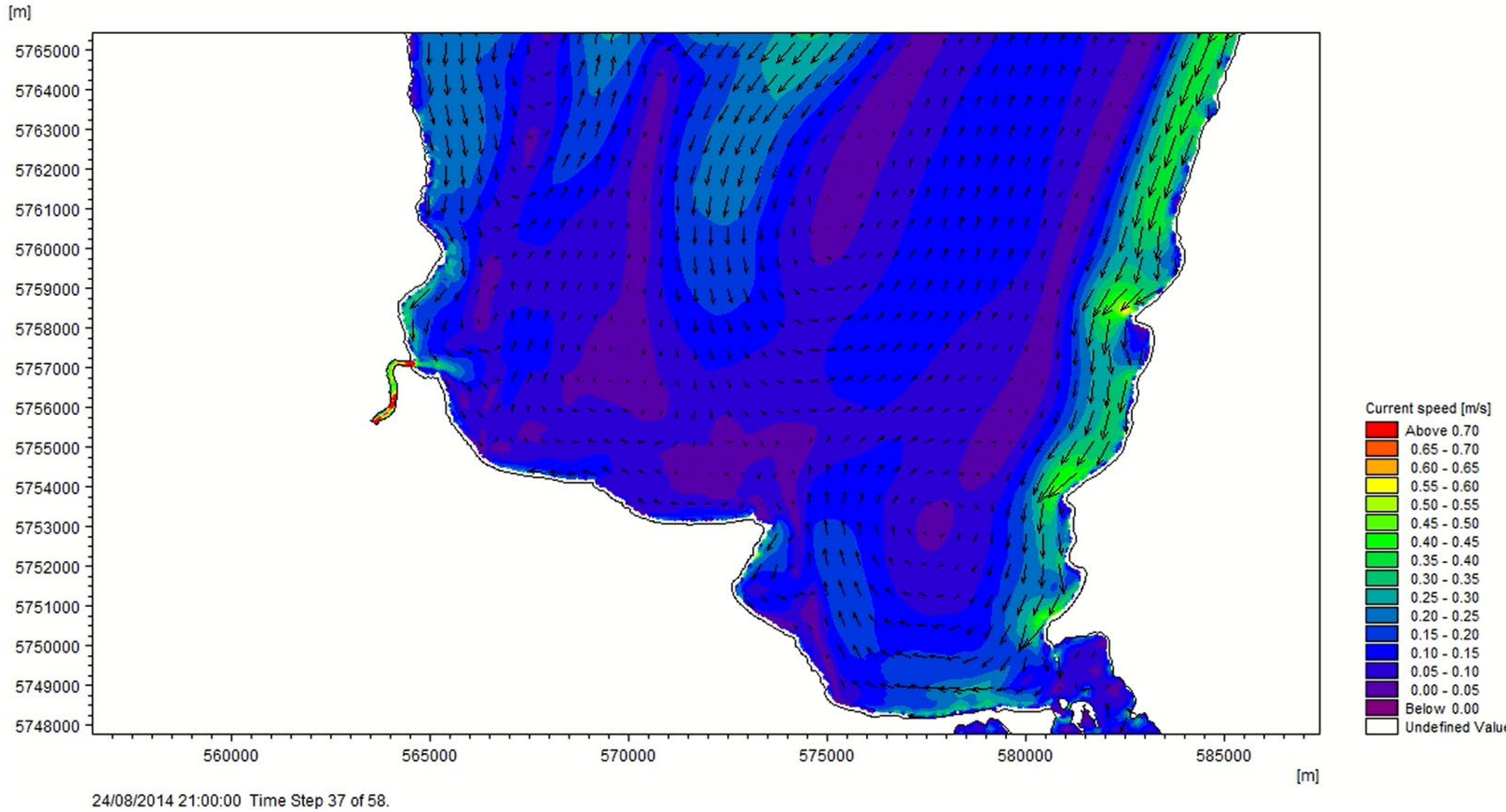
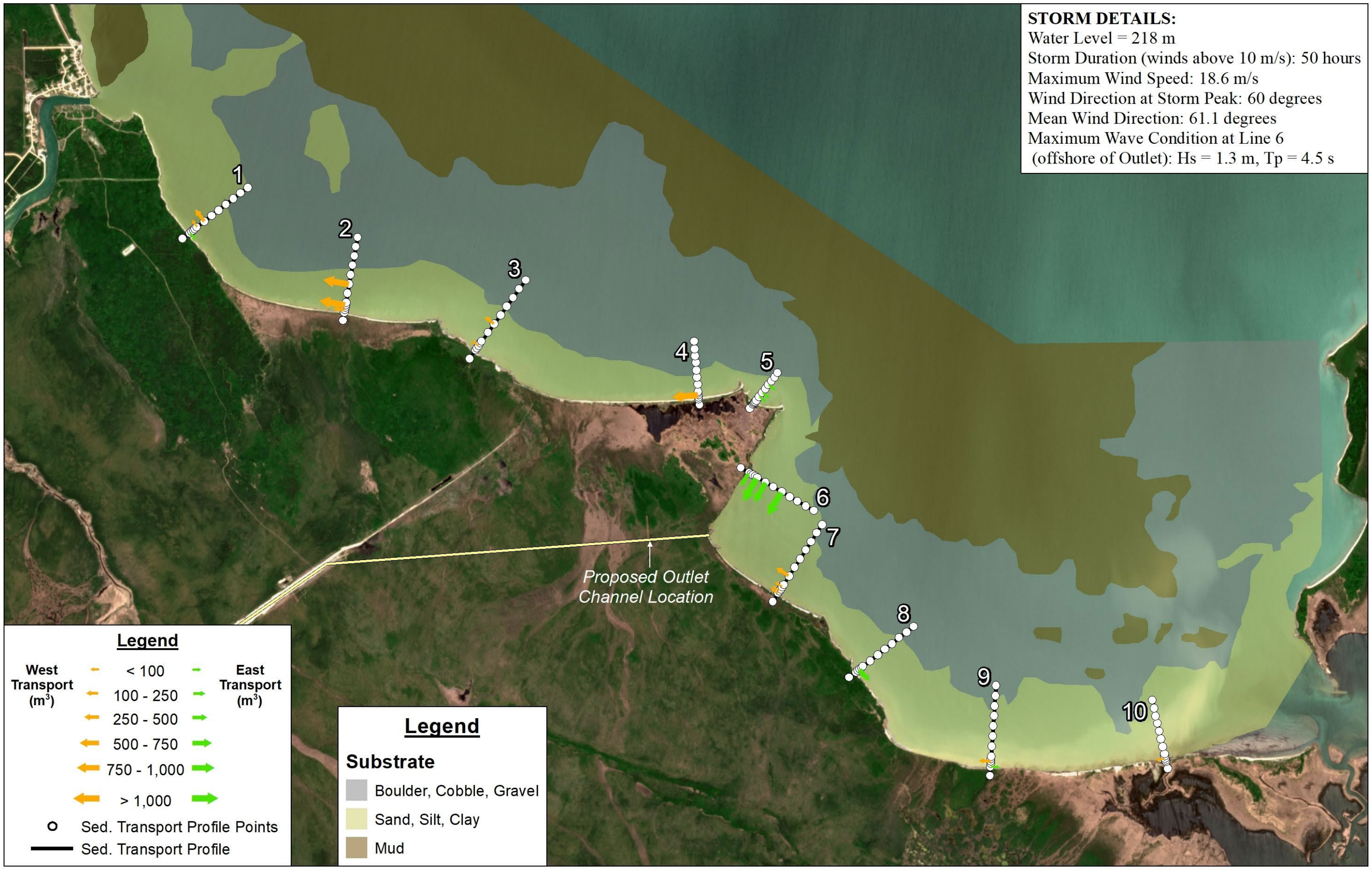


Figure 2.7 Hydrodynamics from MIKE21 at Peak of Storm 32



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Potential Net Longshore Sediment Transport for Storm 32

Substrate Mapping from North-South Consultants

Data Sources:
1) Satellite Imagery: 2019-June (ESA)

N W E S
0 1 2
km

Figure 2.8 CERC Formula Potential Sediment Transport Estimates for Storm 32 (lake level 218 m)

2.3 Influence of Lake Levels on Sediment Transport Pathways

The sediment transport estimates for Storm 10 and 32 described in Section 2.2 were completed at a high lake level of 218 m CGVD. To investigate the influence of different lake levels and lake bottom substrate on sediment transport potential, additional analysis was completed.

For Storm 10 which featured large waves from the north, the sediment transport predictions at Profile 6 and 7 are plotted in Figure 2.9 for a lake level of 217.0 m, 217.5 m and 218.0 m CGVD. For all three water levels, the transport predictions (green arrows) occur inshore of the 215 m contour, where the lake bottom was mapped as either sand or sand-silt-clay by North-South Consultants (2017). If these areas are sand, the predicted transport volumes may be close to the actual transport volume. However, given the complexities associated with predicted sediment transport volumes during storms, the most valuable component of the analysis are the gradients in transport and spatial differences, not the absolute values.

With the low water level of 217 m, the majority of the transport potential occurs around the 215 m contour for Profile 6, which is roughly 1 km offshore from the proposed outlet channel. With the high lake level scenario (218 m), larger waves break closer to the shore and consequently more transport is predicted at the 216 m contour. While a profile was not completed at the proposed outlet (between Profile 6 and 7), the 216 m contour is roughly 600 m offshore from the proposed outlet (see blue arrow). Therefore, even with a high lake level, the majority of potential longshore sediment transport appears to occur in a region offshore of the proposed outlet.

It should be noted that Profile 7 predict a very small volume of sediment transport towards the outlet (orange arrows in Figure 2.9). It should be noted that the CERC equation is a one-dimensional model and thus two-dimensional circulation, such as the current patterns predicted with the MIKE21 model are difficult to simulate. Therefore, the potential for east to west transport at Profile 7 is likely low.

The spatial analysis of potential sediment transport was repeated for Storm 32 at the same lake levels and the results are summarized in Figure 2.10. The results are similar to Storm 10. With a lake level of 217 m, the majority of the transport occurs around the 215 m contour, well offshore of the proposed outlet. With a high lake level of 218 m, the zone of transport potential moves closer to shore, but the majority is located at or offshore of the 216 m contour (blue arrow).

In summary, the location of the proposed outlet is a very shallow and sheltered region of Sturgeon Bay and wave breaking that generates longshore currents that transport sand and gravel occurs further offshore. The CERC equation suggest sand is moving approximately 500 m to 1 km offshore of the proposed outlet for the storms simulated in this investigation.

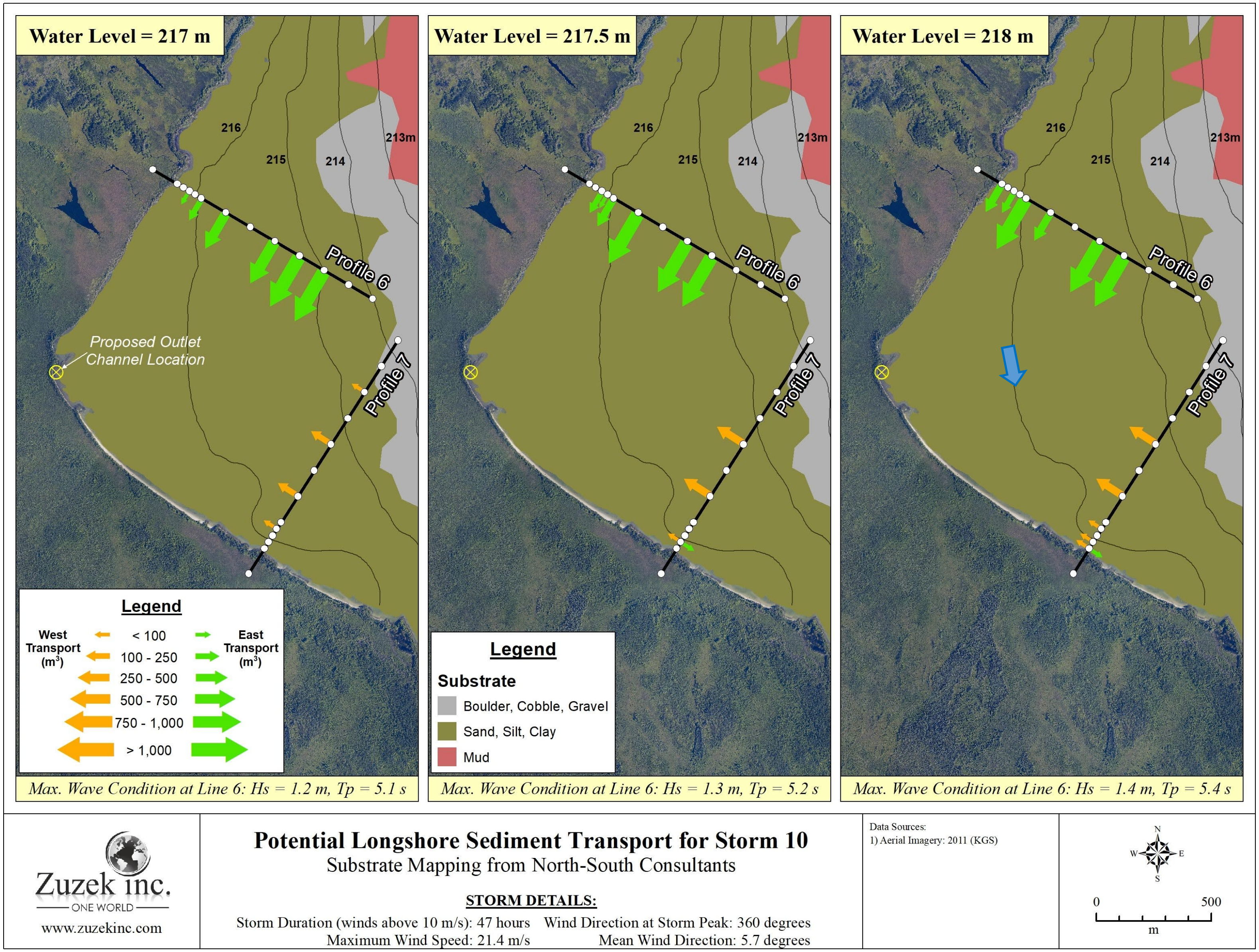


Figure 2.9 Influence of Lake Level on the Zone of Sediment Transport for Storm 10

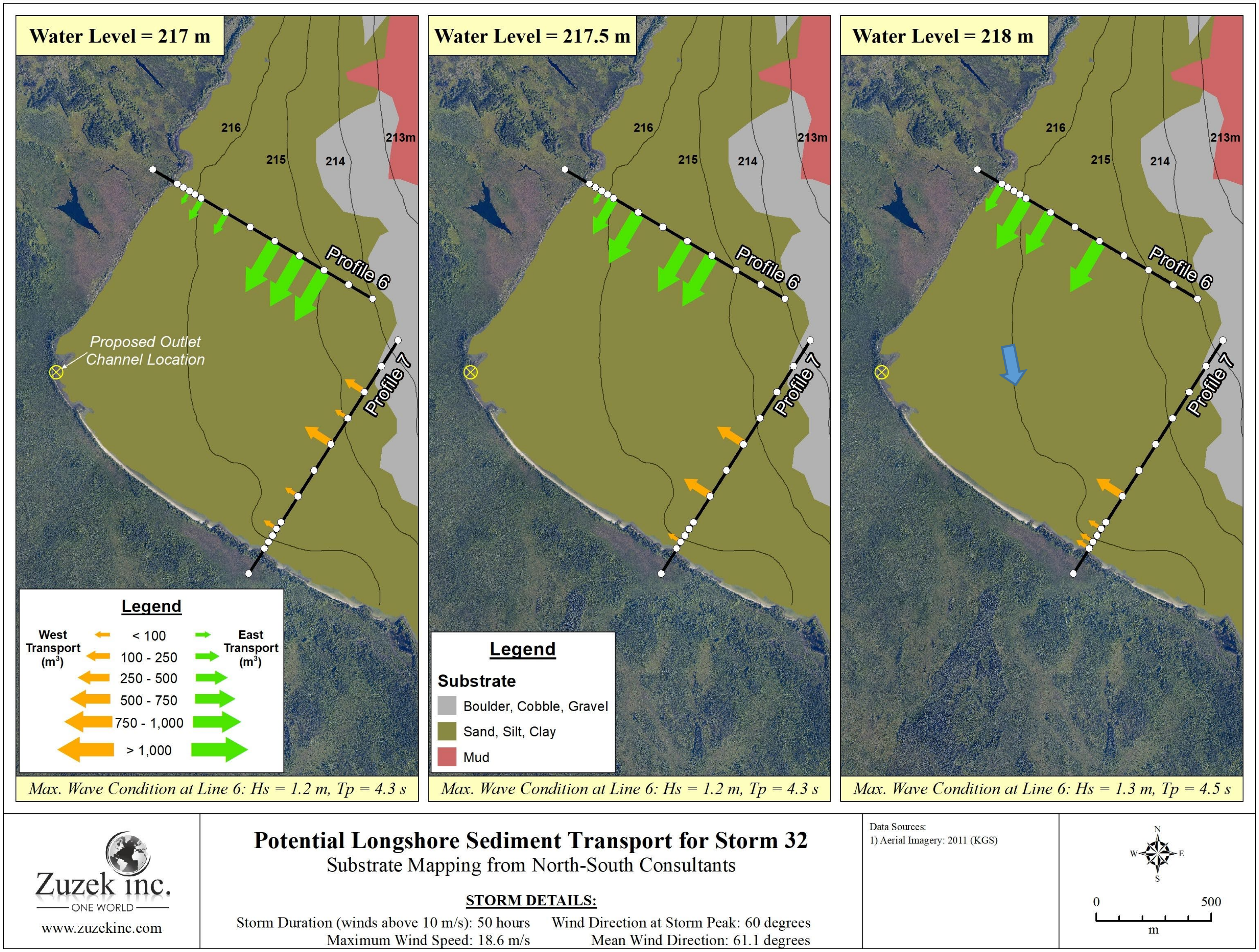


Figure 2.10 Influence of Lake Level on the Zone of Sediment Transport for Storm 32

2.4 Updated Regional Sediment Budget for Sturgeon Bay

A sediment budget was presented in the Baseline Shoreline Assessment for Sturgeon Bay (Zuzek Inc., 2020a) for the existing conditions based on the information available at the time. With the additional numerical modelling of waves and currents, plus further sediment transport estimates with the CERC equation, the sediment budget for the existing site conditions has been updated in Figure 2.11 as follows:

- **Sediment Sources** – for the Sturgeon Bay sediment budget, we are focused on sand and pebbles/gravel, not fine sediment. While silts and clays are eroded from the glacial till and transported in tributaries, they are not stable on the beach and are eventually transported to deep water and deposited in the mud zone offshore. Predicted sources of sand and gravel include:
  - East and West Shorelines of Sturgeon Bay: The regional wave and hydrodynamic modelling presented in Section 2.2 suggests the west shoreline of the bay north of the Dauphin River mouth and the east shoreline north of the Sturgeon Bay Park Reserve may be sources of sand and gravel for the study area. It should be noted these areas were not visited during the field work to verify and are beyond the initial area of focus for the study (i.e., Dauphin River mouth to Sturgeon Bay Park Reserve).
  - Dauphin River: Large cobble and pebble shoals and bars were observed in the river (Zuzek Inc., 2020a) and similar material was collected with a ponar grab sample at the mouth. Therefore, the Dauphin River may be a small source of pebbles for the shoreline sediment budget.
  - The shoreline between the Dauphin River Mouth and Willow Point features a long-term erosion rate. The retreat of the shoreline and downcutting on the lake bottom will generate new sand and gravel for the shoreline sediment budget.
  - Southeast of Willow Point, shoreline erosion from the location of the proposed outlet to the Sturgeon Bay Park Reserve also produces some new material for the sediment budget.
- **Transport Pathways** – the updated sediment transport analysis identified two littoral sub-cells in the detailed study. The first extends from the Dauphin River mouth to Willow Point. The second sub-cell includes the east shore of Willow Point to the Sturgeon Bay Park Reserve. The extent that these cells extend up the west and east sides of Sturgeon Bay was not analyzed and is not critical to the analysis for this study. Based on the field observations and modelling, the amount of sediment exchange between these sub-cells is thought to be minimal. Key findings on sediment transport pathways, which are also summarized in Figure 2.11, include:
  - North Storms: Storm 10 is typical of large storms that generate waves in the northern basin of Lake Winnipeg. The sediment transport predictions indicate sand and gravel is transported eastward from the Dauphin River to Willow Point. There is a convergence of transport at Lines 3 and 4, leading to deposition. This is consistent with the field observations that suggest sand is accumulating in this

region (i.e., a sink area). Therefore, the amount of sediment available to bypass Willow Point is likely small and the substrate conditions observed in the field (primarily pebbles, cobbles, boulders) support this observation. Therefore, the tip of Willow Point has been identified as a littoral sub-cell boundary.

From Willow Point to the Sturgeon Bay Park Reserve, the dominant sediment transport direction is also towards the east, past the proposed outlet location. Although no sediment transport predictions were completed or observations collected in the field, the numerical modelling output suggests there is the potential for sediment to move southward along the east side of Sturgeon Bay, also contributing sand and gravel to the littoral sub-cell.

- Northeast Storms: While the fetch for these storms (e.g., Storm 32) is much smaller than events from the north, the localized shallow water wave heights for Storm 32 and 10 are similar. For the Dauphin River to Willow Point sub-cell, sediment moves to the west for Storm 32. However, in the sediment budget we have assumed the net transport direction is to the east, since the storm listing in Table 2.1 suggests large storms from the north are far more frequent than events from the northeast.

  For the Willow Point to Sturgeon Bay Park Reserve sub-cell, the CERC formula suggests sediment can move southward at Profile 6. However, there does not appear to be a significant source of sand and gravel to this region, thus the potential sediment transport predictions may be much higher than the actual or realized transport volumes. The longshore transport rates at lines 7 to 10 are small due to the small wave heights in this region and normal approach angles for the waves.

- **Sediment Sinks** – in a conventional sediment budget, sediment sinks, or depositional areas are either stable or migrating lakeward. The Sturgeon Bay sediment budget is an anomaly in that the two sediment sinks identified in this study are eroding:

  - West Side of Willow Point: the west side of Willow Point is a sediment sink, with the presence of a high coastal ridge and large depositional lobes of sand migrating into the marsh. However, the shoreline also features a long-term erosion rate, so the overall volume of sediment entering this sink is thought to be small.

  - Sturgeon Bay Park Reserve: The barrier beach that shelters the Reserve from Lake Winnipeg waves is migrating landward at 4 m to 7 m per year (Zuzek Inc., 2020a). While it migrates, sediment is trapped in the depositional sand lobes in the marsh. Field observations and sediment samples retrieved from the shallow nearshore zone at the entrance to the embayment suggest the lake bottom is also a sediment sink.

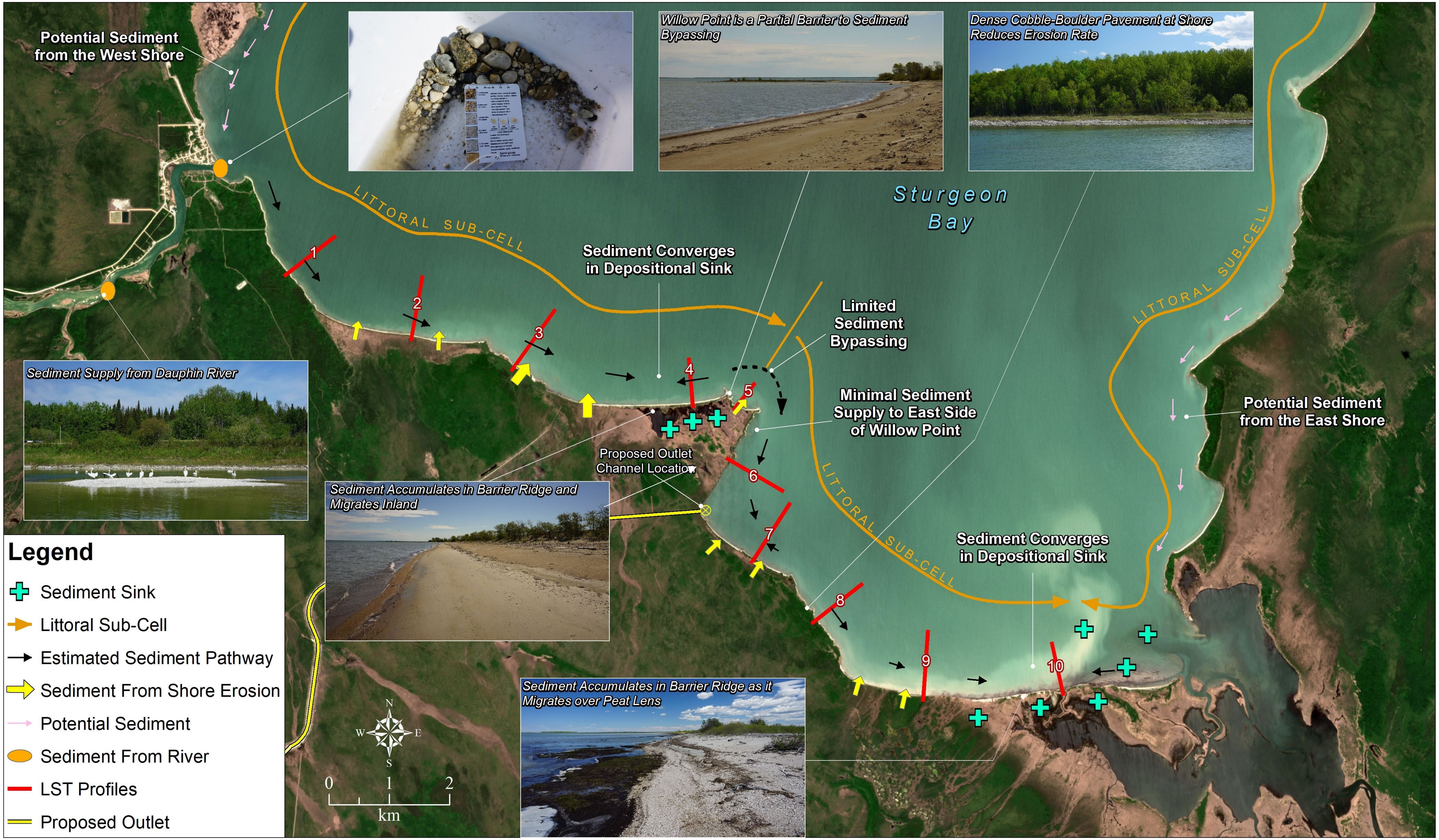


Figure 2.11 Regional Sediment Budget for Sturgeon Bay

3.0 POST-PROJECT EVALUATION

Section 3.0 summarizes the post-project evaluation for the inlet and outlet shoreline based on field observations, the past evolution of the emergency relief channel, and numerical modelling.

3.1 Lake St. Martin Inlet

The northern shoreline of Lake St. Martin features a series of shallow embayments, sheltered marshes, and cobble-boulder headlands. The proposed inlet is in the northeast corner, approximately 11.5 km southeast of the natural outlet at the Dauphin River. A plan view map of the preliminary design for the inlet prepared by the KGS Group (2019) is provided in Figure 3.1. Approximately 1 km of the lake bottom will be excavated to create an approach channel for the inlet from 0+000 to 1+000, shown in red below. The nearshore slope will be extremely flat (slope of 0.14%) to reduce bed shear stress and minimize lake bottom erosion potential.

The channel excavation on the beach and mainland starts at approximately 1+000, with the excavated material placed in spoil piles on the sides of the channel.

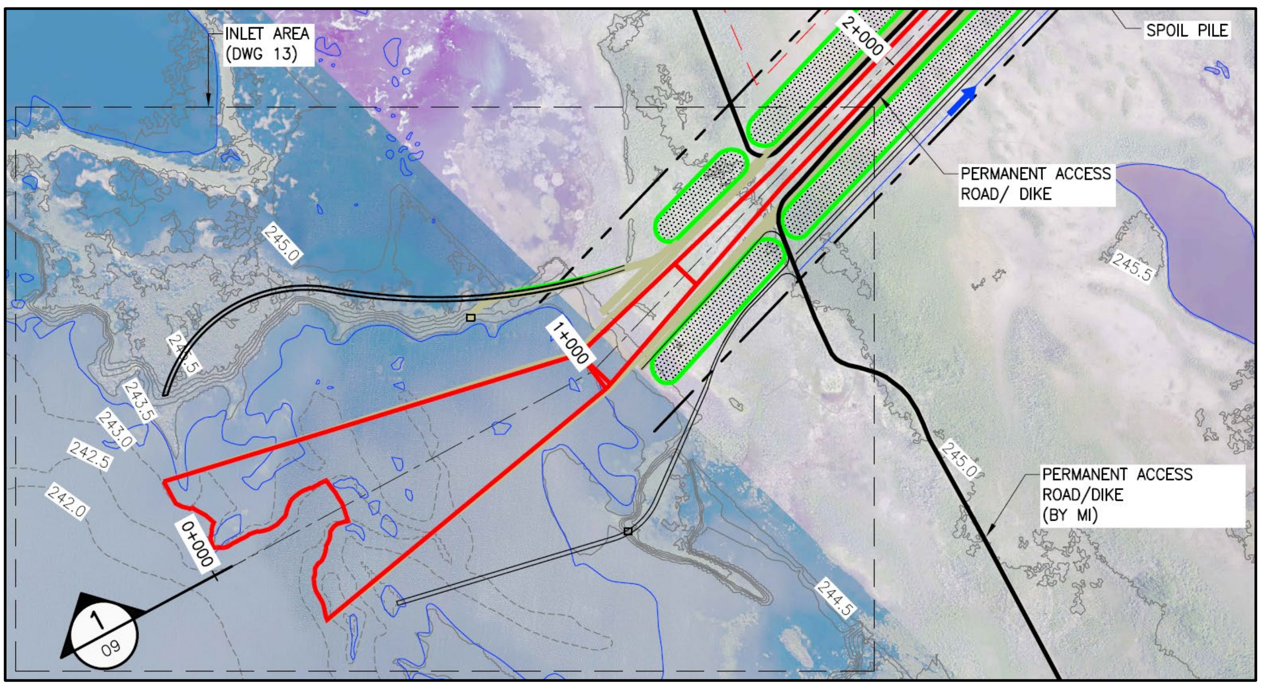


Figure 3.1 Inlet and Lake Bottom Excavation (KGS Preliminary Design 2019, Sheet 04)

As noted in the Baseline Shoreline Assessment (Zuzek Inc., 2020a), the embayment has been stable for the duration of the aerial photograph record, which dates back to 1948. Based on the measured stability of the shoreline and the low flow velocities in the approach channel, no significant shoreline alterations are anticipated once the inlet channel becomes operational.

These findings are consistent with the shoreline adjacent to the Reach 1 emergency relief channel, which was observed in June 2019. Following the construction and operation of the relief channel in 2011 (*confirm with KGS*), there were no visible signs of shoreline erosion and only minor shoreline alterations with the accumulation of some sand along the shoreline east of the former inlet.

3.2 Sturgeon Bay Outlet

The proposed outlet into Sturgeon Bay is located on the sheltered south side of Willow Point approximately 10 km southeast of the Dauphin River mouth. The channel daylights at the shoreline with an invert elevation of 215 m CGVD and will slope upward approximately 200 m to the existing elevation of the lake bottom based on the preliminary design by the KGS Group (2019). The sides of the outlet will be stabilized with jetties that are approximately 100 m in length. Refer to the preliminary engineering drawing in Figure 3.2. The location of the outlet in plan view was noted on Figure 2.11.

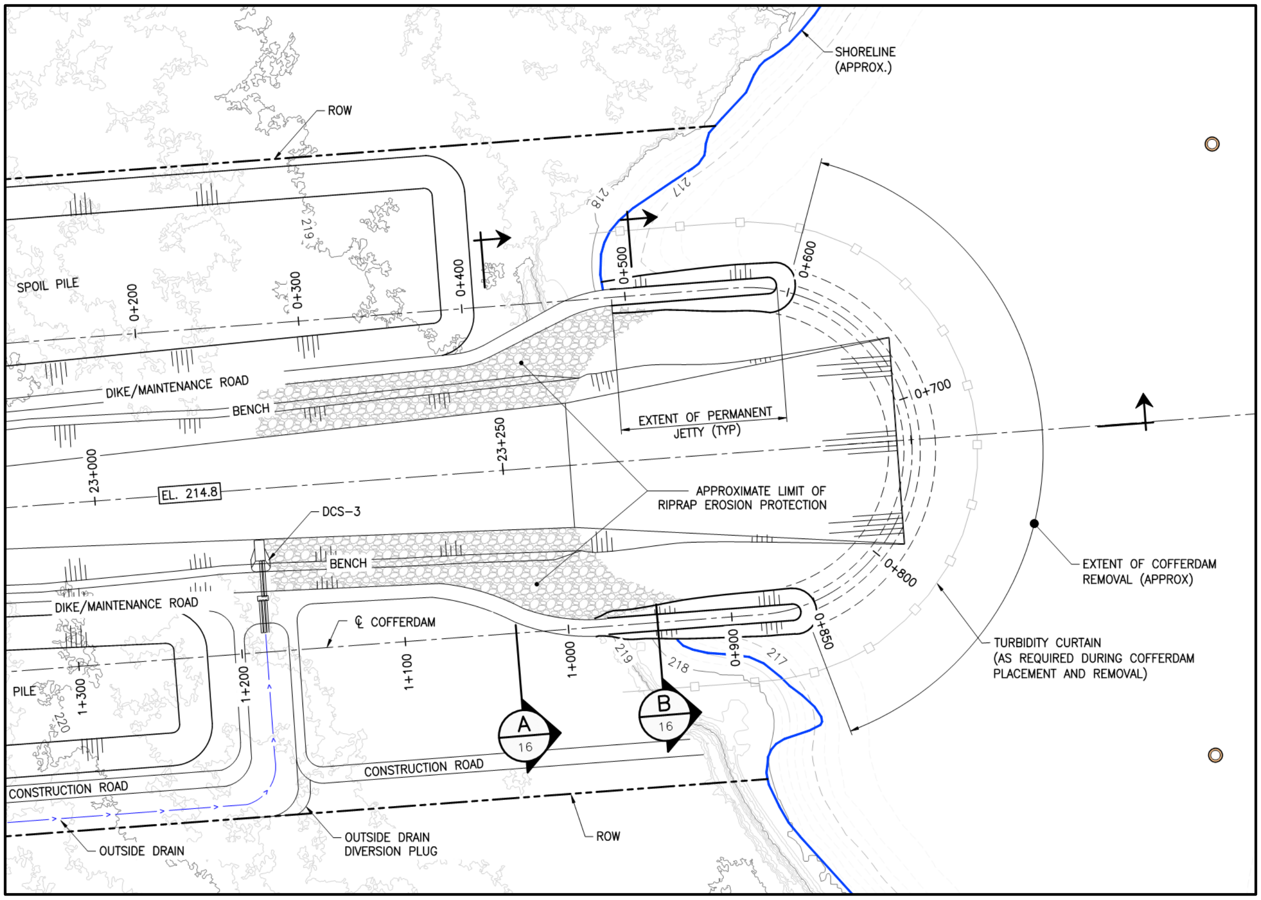


Figure 3.2 Preliminary Outlet Design at Shoreline (KGS Preliminary Design, Sheet 15)

The numerical tools used in Section 2.0 of the report were utilized to investigate the potential impacts of the channel on the nearshore wave climate, hydrodynamics, and ultimately shoreline evolution. The results are summarized in the following sections.

3.2.1 Wave Height Analysis

As described in Section 2.2, the MIKE21 spectral wave module was used to estimate nearshore wave heights for Storms 10 and 32. At the profiles used for the sediment transport predictions, time series wave height, period, and direction data was extracted from the model at 13 locations from deep water at the tip of the profile (Point 13, typically an elevation of 213 m CGVD) to the shoreline (Point 1, typical elevation of 217 to 2018 m CGVD). The save points for Profiles 6 and 7 adjacent to the proposed outlet were mapped on Figure 2.9 for reference.

The wave model was re-run for Storm 10 and 32 with the inlet in operation for the high lake level conditions (218.0 m CGVD). The time series wave data was extracted for the same 13 save points per profile for the storm with the outlet channel design discharge of 326 m^3/s. The comparison of the wave heights for the existing conditions and operation of the channel at Profiles 4, 6, and 8 are summarized in Figure 3.3 to Figure 3.6 for Storms 10 and 32. The results are summarized:

- Profile 4 for Storm 10 (west of Willow Point): The wave heights are the same for the pre- and post-channel simulation, except for minor changes at the peak of the storm (slight increase in the post-project wave height). The wave period is identical throughout the storm for the pre- and post-project simulations.

- Profile 6 for Storm 10 (north of the outlet channel): The wave height and period outputs from the model are the same throughout the storm, except for very minor increases in wave height for the post-project simulation at the peak of the storm (i.e., the average wave height increase was approximately 1.4% or less than 2 cm). The small increase in wave height may be attributed to higher localized water levels due to the channel inputs to Sturgeon Bay.

- Profile 8 for Storm 10 (east of outlet channel): The wave height and period predictions for the pre- and post-project condition are identical throughout the simulation at Profile 8 (Point 11).

- Profile 6 for Storm 32 (north of the outlet channel). With the northeast waves from Storm 32, similar trends emerged, with slightly larger waves at the peak of the storm, possibly attributed to higher localized water levels due to the channel operation. However, the average wave height increase at the peak of the storm was only 3.7 cm or 4.4% versus the pre-project simulation.

Based on the wave height comparisons for the pre-project condition and post-project channel, measurable changes in wave heights are not anticipated, and by extension nor are changes to wave dominated physical processes such as erosion, sediment transport, and deposition.

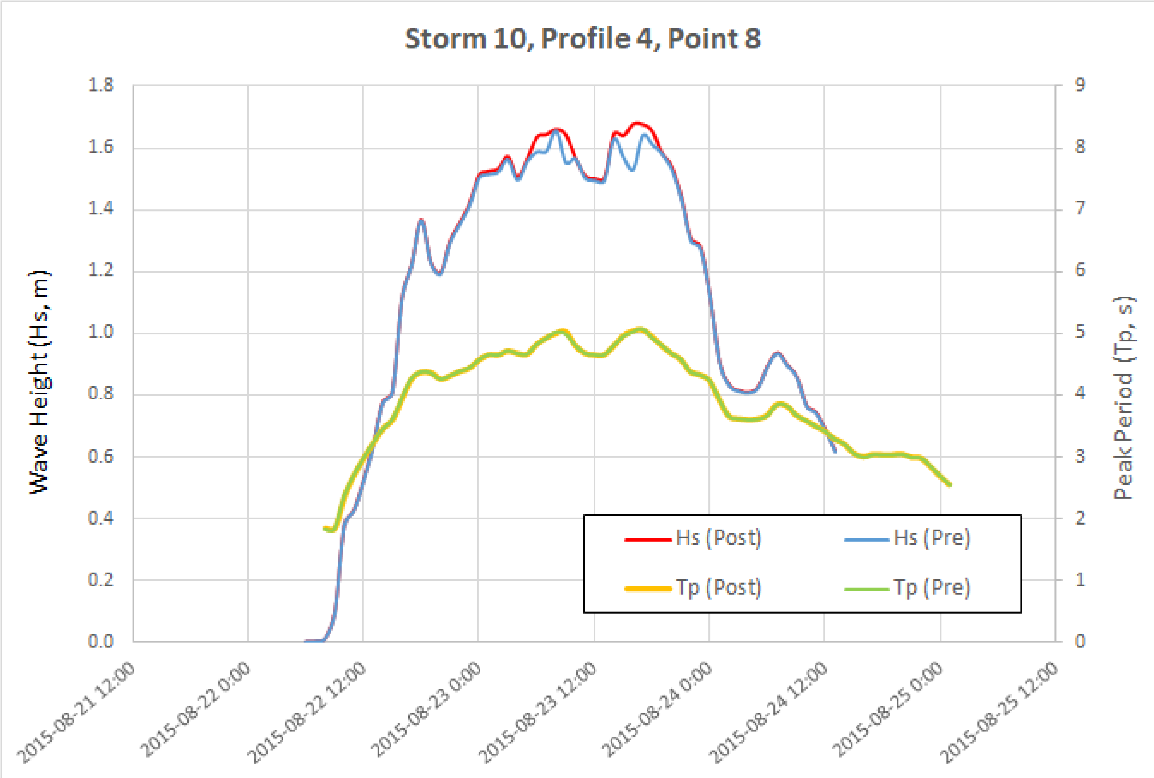


Figure 3.3 Storm 10 Pre- and Post-Project Wave Heights at Profile 4 (Point 8)

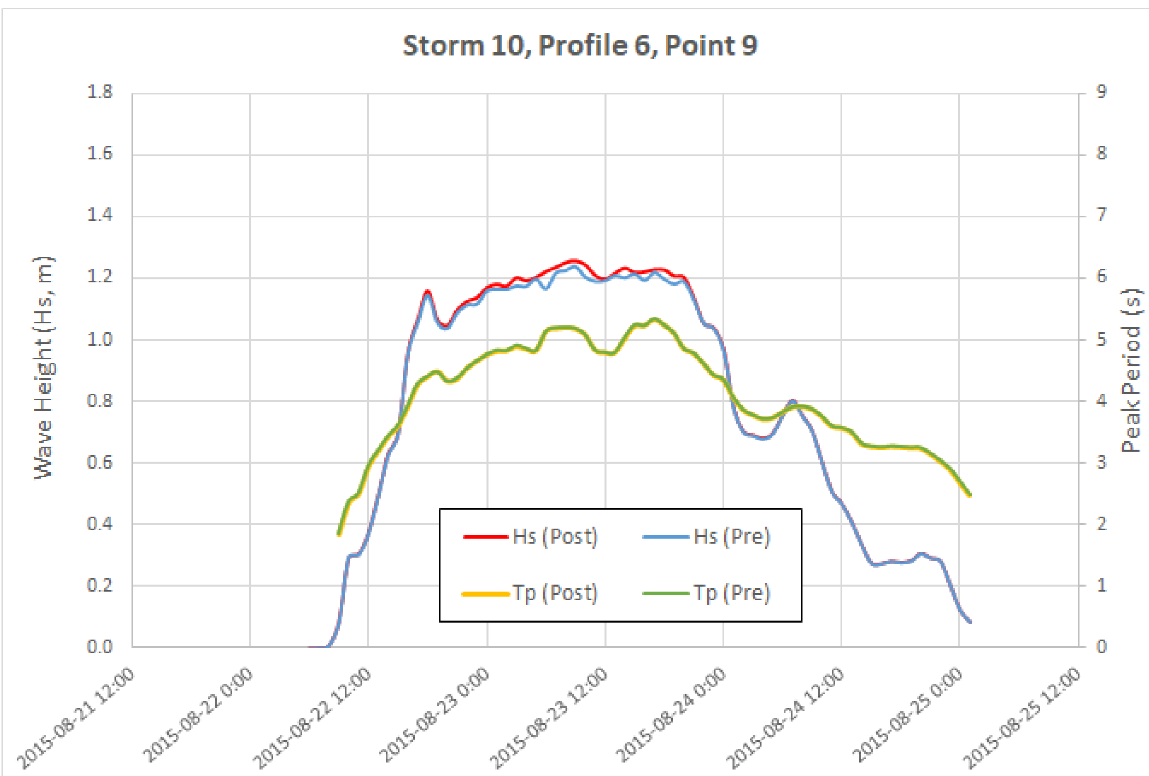


Figure 3.4 Storm 10 Pre- and Post-Project Wave Heights at Profile 6 (Point 9)

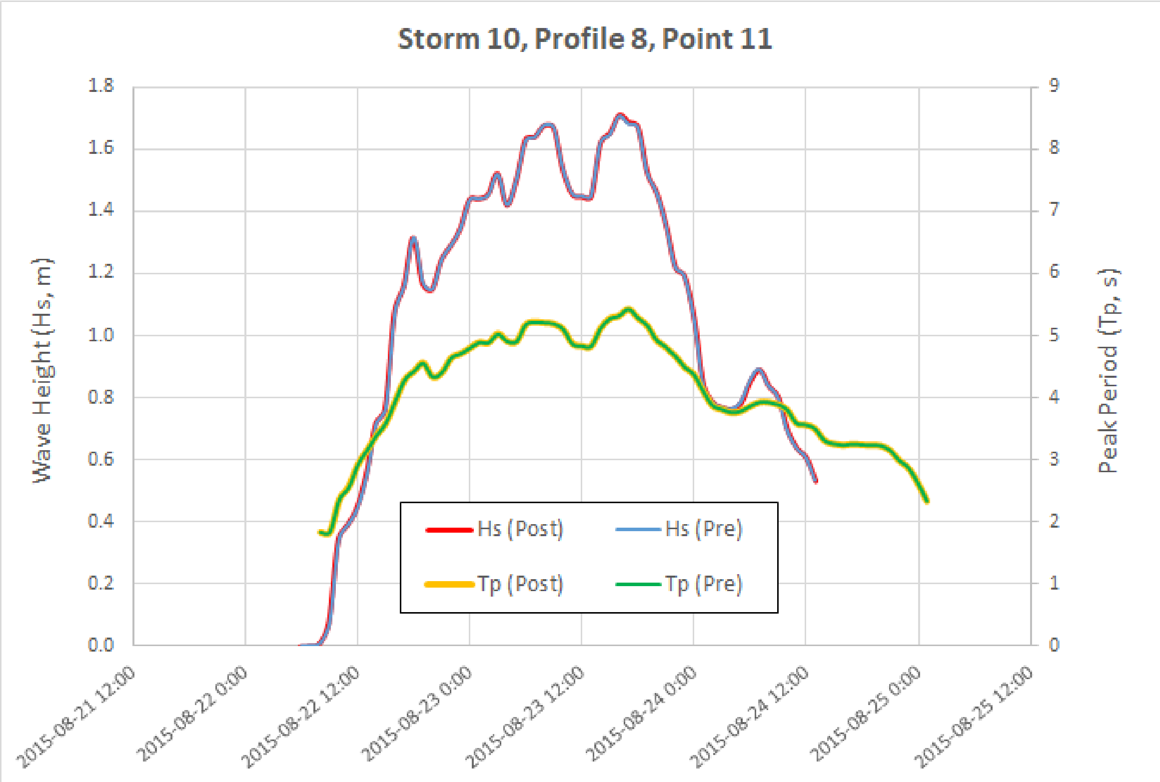


Figure 3.5 Storm 10 Pre- and Post-Project Wave Heights at Profile 8 (Point 11)

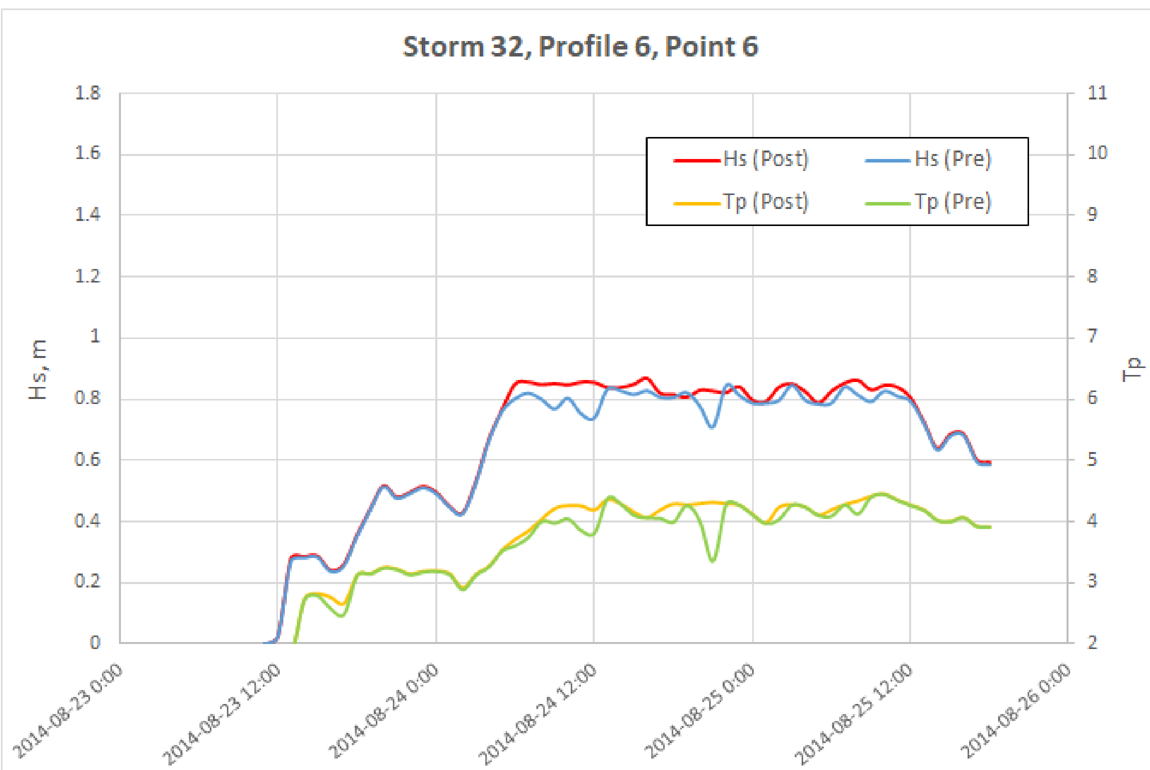


Figure 3.6 Storm 32 Pre- and Post-Project Wave Conditions at Profile 6 (Point 6)

3.2.2 Hydrodynamics

The MIKE21 hydrodynamic module was used to simulate the currents and general circulation in Lake Winnipeg. Storm 10 and 32 were evaluated with the existing shoreline conditions (pre-project) and with a functioning outlet channel in Sturgeon Bay (post-project).

3.2.2.1 Storm 10 for Pre- and Post-project Conditions

The results for Storm 10 are provided in Figure 3.7 for Willow Point and the proposed outlet location for the pre-project and post-project scenario. Key findings include:

Storm 10, 20 Hours:

- Longshore currents are moving west to east around Willow Point based on the transport vectors (black arrows). Comparing the colour contours of current speed (m/s), there are no significant changes in the circulation patterns for the pre- and post-project simulation at Willow Point.
- At the proposed outlet location, there is a dead zone where current speeds decrease significantly at hour 20. For the post-project simulation velocities in the channel discharge exceed 0.50 m/s, however the general circulation patterns along shore remains unchanged, with west to east currents.
- Offshore the current is moving north, with slightly higher velocities for the post-project scenario possibly due to the discharge volumes from the channel.

Storm 10, 37 Hours (storm peak):

- The current pattern and velocities around Willow Point are similar for the pre- and post-project simulation.
- The current velocities decrease along the back side of Willow Point (east facing shore) from greater than 0.5 m/s to less than 0.2 m/s at the location of the proposed outlet. If there was sediment moving around Willow Point, the decreasing gradient in the longshore current would create a deposition zone in this region of Sturgeon Bay. However, the absence of a beach deposit in this region confirms the earlier assumption that the volume of sediment bypassing at Willow Point is small.
- The discharge from the channel features current speeds greater than 0.5 m/s, which follow the longshore current to the southeast. These currents exceed the background condition in the pre-project simulation and may result in local scour of the lake bottom.
- Offshore, currents are moving to the north for the pre- and post-project simulation.

Storm 10, 50 Hours (end of storm):

- The general circulation pattern of west to east currents is the same in the pre- and post-project simulation, except for the additional channel discharge which flows to the east.

Based on the comparison for Storm 10, the general circulation patterns and current speeds are similar for the pre- and post-project simulations, with the obvious exception being the outlet channel plume in the post-project run. However, with the strong west to east longshore currents, the plume moves along the shoreline to the southeast. Fine sediment, such as silts and clays, will be mixed with existing sediment in suspension and transported alongshore towards the Sturgeon Bay Park Reserve.

3.2.2.2 Storm 32 for Pre- and Post-project Conditions

The results for Storm 32 are presented in Figure 3.8 for Willow Point and the proposed outlet location for the pre-project and post-project scenario. A map with the full simulation for Sturgeon Bay was presented in Figure 2.7 for reference. Key findings include:

Storm 32, 12 Hours:

- Longshore currents are moving east to west from Willow Point to the Dauphin.
- At the proposed outlet location, a weak counter clockwise eddy forms for the existing conditions. With weak longshore current the channel plume flows roughly 4 km eastward into Sturgeon Bay, rather than alongshore as it did with Storm 10.
- For all the Storm 32 timesteps (12, 30, and 54 hours) the discharge velocities in the channel plume exceed the local conditions for the pre-storm simulation, which could lead to localized scour of the lake bottom.
- The strong west to east currents in the channel plume interact with the northward currents offshore of the outlet, which could lead to the deposition of fine sediment carried in suspension in the plume. This region of the lake was mapped as a mud bottom by North-South Consultants (refer to Figure 2.8), so deposition of additional clay and silt would not alter the existing substrate conditions.

Storm 32, 30 Hours (storm peak):

- The currents west of Willow Point are similar for the pre- and post-project simulation, moving to the west.
- The offshore current east of the channel outlet strengthens and converges with the discharge plume, which will further disperse fine sediments carried in suspension (e.g., silt and clay sediment).

Storm 32, 54 Hours (end of storm):

- Near the end of the storm, the wind direction shifts from northeast at the peak to the north, as seen in Figure 2.5. Consequently, the local longshore current direction switches from west to east around Willow Point and past the outlet. The discharge plume also swings to the southeast and follows the longshore currents towards the Sturgeon Bay Park Reserve.

The hydrodynamic modelling for the pre- and post-project simulations for Storm 32 indicate the outlet channel plume will not alter the general circulation patterns or current speeds. With weaker longshore currents, the plume travels further offshore for Storm 32, potentially dispersing any suspended sediment further offshore and in the region previously mapped as a mud bottom by North South Consultants (2017). The discharge velocities at the mouth of the outlet exceed the background wave induced currents for Storm 32, which could lead to localized scour of the lake bottom. The magnitude of the scour potential has not been investigated, nor has the future frequency of channel discharge of this magnitude.

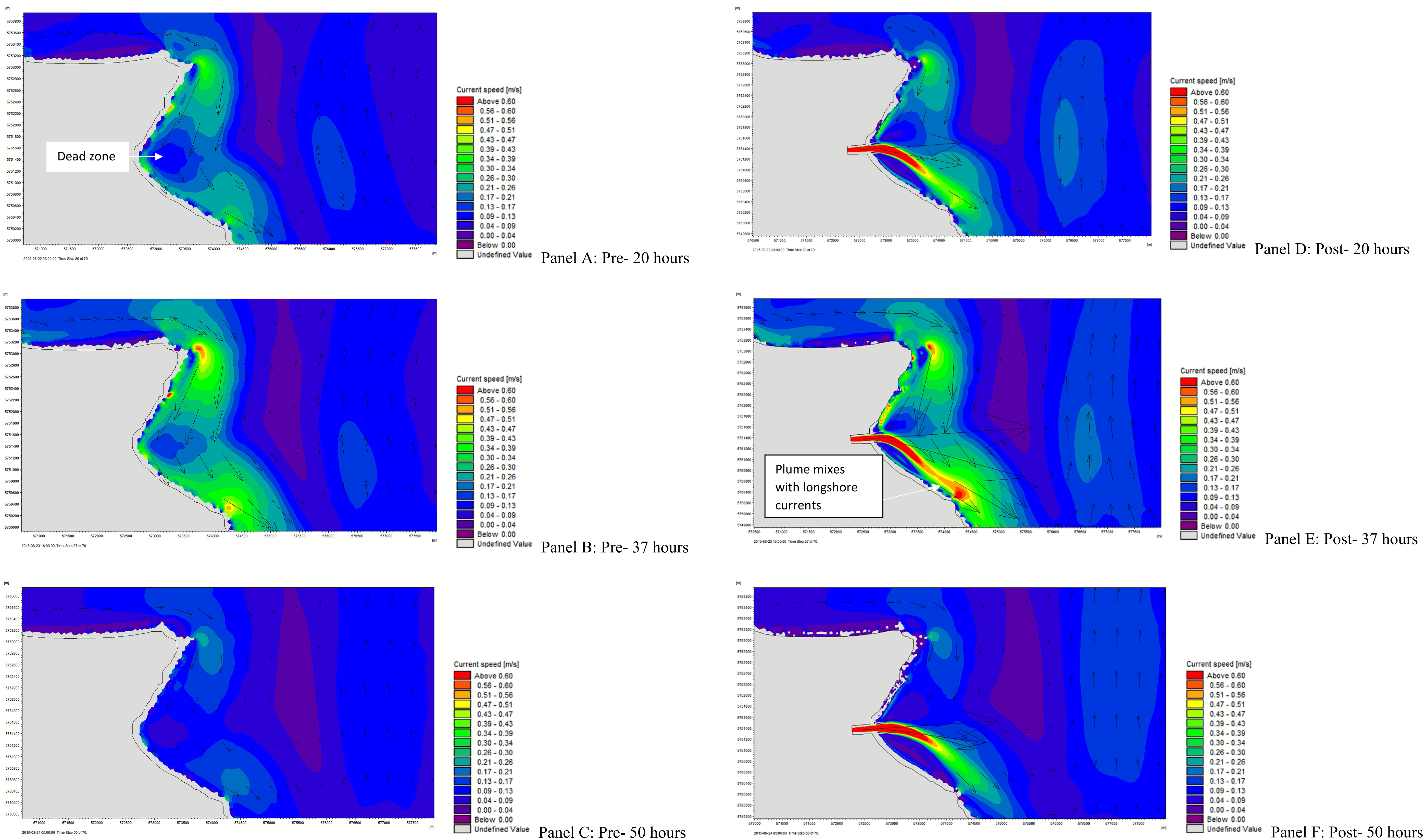


Figure 3.7 Storm 10 Pre-project Conditions (Panel A to C) and Post-project with Channel in Operation (Panel D to F)

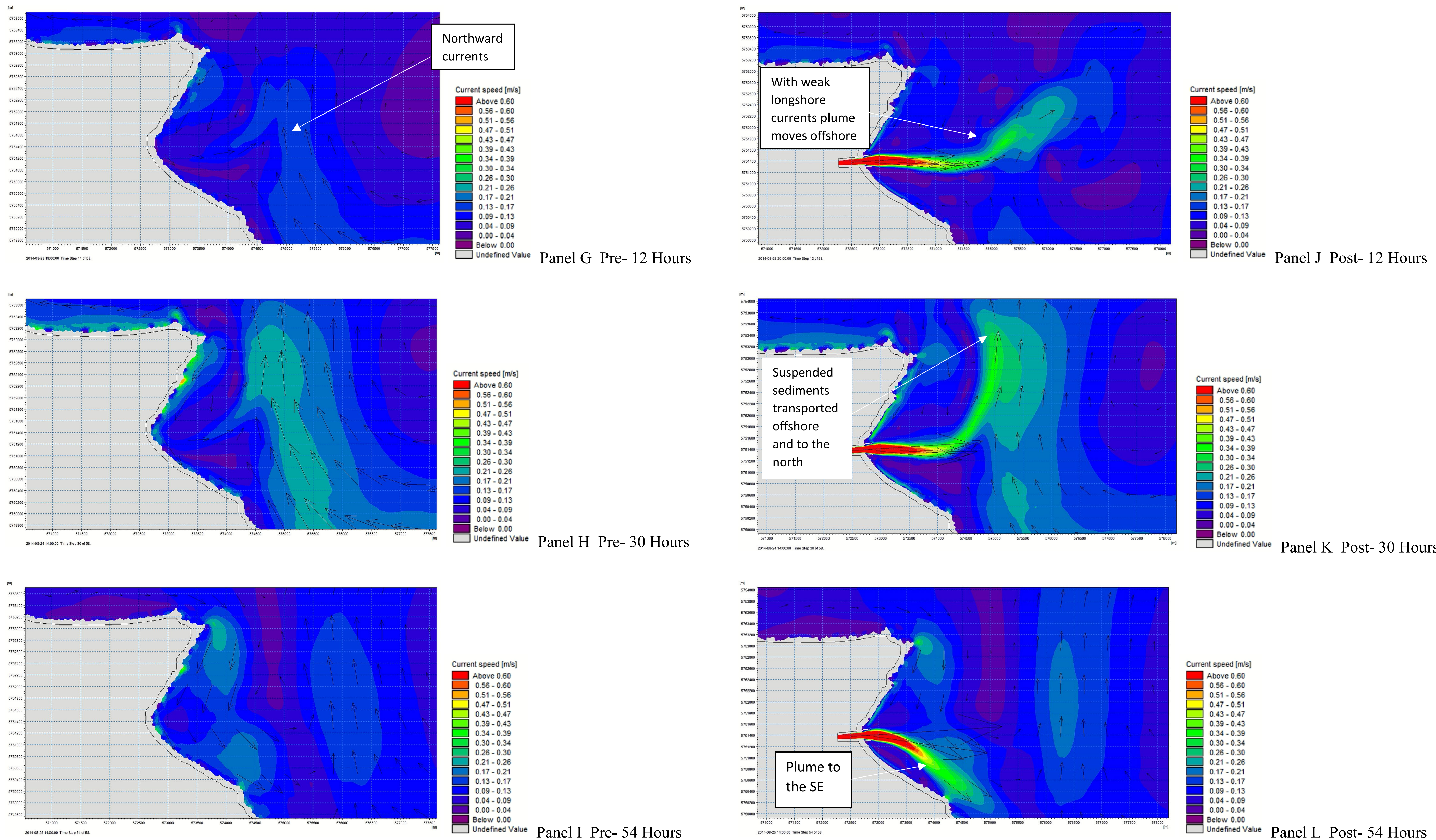


Figure 3.8 Storm 32 Existing Conditions (Panel G to I) and Post-project with Channel in Operation (Panel J to L)

3.3 Potential Impacts the Channel Operation on the Shoreline and Nearshore

The numerical simulations of nearshore waves and hydrodynamics for the pre- and post-project conditions were investigated for Storms 10 and 32 at the outlet, which are representative of the two dominant storm directions that impact Sturgeon Bay. The key findings from the model runs and implications for future shoreline evolution once the channel is operational are summarized for the outlet. The results from the Baseline Shoreline Assessment (Zuzek Inc., 2020a) were used to comment on the inlet in Lake St. Martin.

3.3.1 Lake St. Martin Inlet

The potential impacts of the inlet on the Lake St. Martin shoreline are minimal and summarized as follows:

- The local shoreline at the inlet has been stable for more than 70 years (Zuzek Inc., 2020a) and no significant modifications to physical processes that influence shoreline morphology are anticipated with the proposed design presented in Figure 3.1. Therefore, no changes in the local shoreline are expected post-project.

- When the channel is operational, small amounts of sand and gravel may accumulate immediately adjacent to the inlet. This risk could be mitigated with small headlands constructed at the edge of the inlet with native boulders excavated from the approach channel. Refer to Figure 3.9. These structures could be designed to enhance and diversify local habitat.

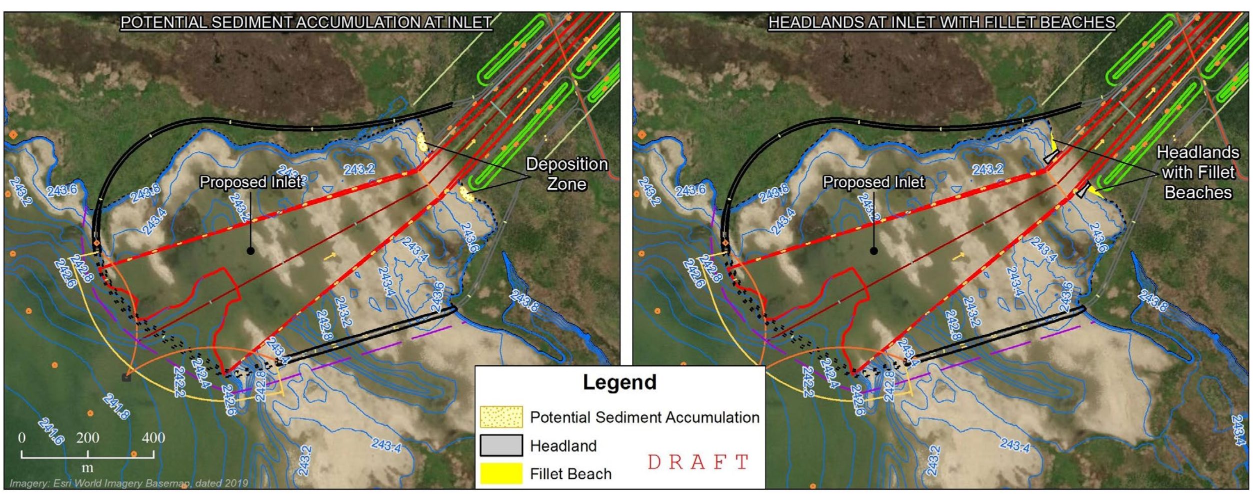


Figure 3.9 Potential Sediment Areas and Proposed Headlands

3.3.2 Sturgeon Bay Outlet

The potential impacts of the outlet on the Sturgeon Bay shoreline and nearshore are summarized:

- The Storm 10 and 32 simulations for the pre- and post-project conditions west of Willow Point suggest there will be no significant changes to the wave climate or the currents during major storm events. Thus, the key physical processes that control the evolution and rate of change for this shoreline, namely erosion, sediment transport, and deposition are not expected to change once the channel is in operation. It is important to note a long-term shoreline recession rate was documented in the baseline assessment for this region (Zuzek Inc., 2020a).

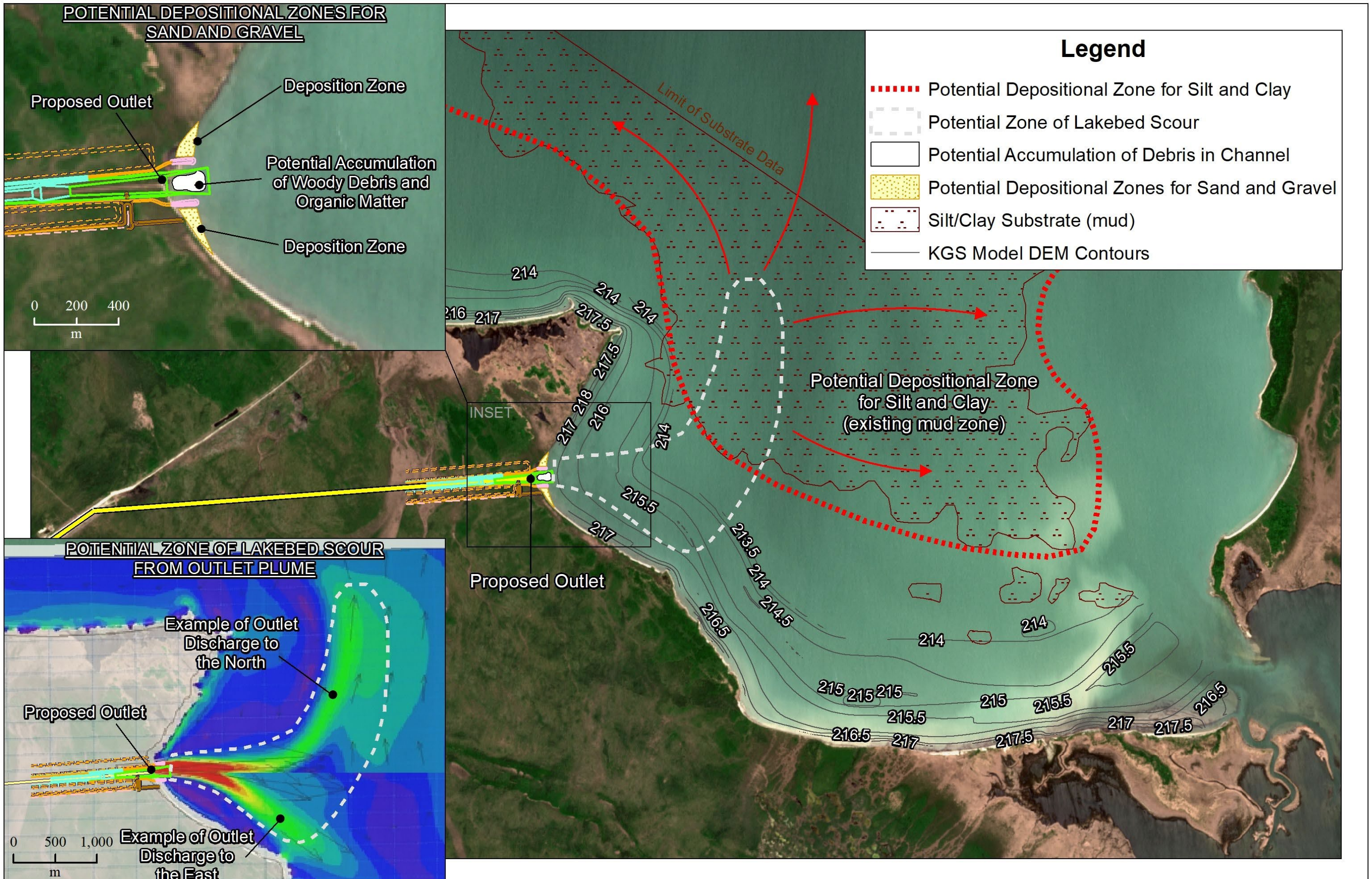
- Between Willow Point and Sturgeon Bay Park Reserve, there were no significant changes in the wave heights or general circulation patterns along the shoreline for the pre- and post-project simulations. However, velocities in the channel plume do exceed natural background conditions for Storm 10 and 32, which may result in localized scour of the lake bottom. Based on the technical analysis in this report, the zone of potential scour is noted on Figure 3.10.

- Based on the storms simulated, the advection of the channel plume in Sturgeon Bay will be moderated by storm direction and the intensity of the currents along the shoreline. For Storm 10, which featured strong longshore currents from west to east, the plume mixed with the longshore current and was transported to the southeast. However, for Storm 32 the plume first traveled east, then north, following by southeast at the end of the event. For this simulation, any fine particles carried in suspension in the plume would be widely distributed throughout Sturgeon Bay where they would settle to the lake bottom post-storm. In the absence of detailed modelling to simulate advection and dispersion of the channel plume, we have assumed the depositional zone would align with the current mud bottom substrate region. Refer to Figure 3.10 for additional details.

- A decreasing gradient in longshore currents from the tip of Willow Point to the proposed outlet were observed in the Storm 10 simulation. While the supply of new sand and gravel to this region of the shoreline is limited, a decreasing gradient combined with the discharge from the channel could lead to sedimentation of sand and gravel adjacent to the proposed north jetty. Similarly, with Storm 32 there is a weak longshore current that moves towards the outlet from Profile 7. When the channel is in operation, this current will be blocked, and sediment accumulation may occur against the proposed south jetty. The location of these potential depositional zones adjacent to the outlet are estimated on Figure 3.10.

- The accumulation of fine sediments in the channel mouth may occur when the channel is not operational under storm or non-storm conditions. If sediment does accumulate in the outlet, the current speeds associated with the design discharge (i.e., greater than 0.6 m/s for the Storm 10 and 32 simulations) should be sufficient to self flush the channel mouth.

- Woody debris and organic material may also accumulate in the outlet mouth when the channel only features base flow. A contingency plan should be developed to remove debris if negative impacts to the shoreline or nearshore of Sturgeon Bay are anticipated.



Zuzek inc. ONE WORLD www.zuzekinc.com	**Potential Zones of Lakebed Scour and Deposition for the Operation of the Outlet Channel** ***Sturgeon Bay (Lake Winnipeg)***	Image: ESA Sentinel 2A Satellite dated June 18, 2019 Contours in metres. DRAFT	N W E S 0 500 1,000 m

Figure 3.10 Risk Map of Potential Erosion and Accretion Areas

4.0 CONCLUSIONS

The overall conclusions for the post-project shoreline morphology assessment are summarized below:

- The inlet is located along the northeast shoreline of Lake St. Martin in a shallow semi-sheltered embayment. While the waterline migrates upslope and downslope with fluctuating water levels, the physical shoreline position has been stable for 70 years. No significant changes to the shoreline morphology are anticipated for this region of Lake St. Martin once the channel is operational.

- Small boulder headlands are recommended on the sides of the inlet to stabilize the shoreline and trap any sediment (sand and gravel) that moves towards the inlet. Recommendations for the layout will be provided during the final design phase of the project.

- With exposure to large storm events originating in the north basin of Lake Winnipeg, the associated waves and currents in Sturgeon Bay control the physical processes that affect shoreline evolution, including erosion, sediment transport, and deposition. These processes were investigated in this study and the Baseline Shoreline Assessment (Zuzek Inc., 2020a). Key findings include:

    - No significant changes to the wave climate or currents that transport sediment alongshore is anticipated for the shoreline from the mouth of the Dauphin River to Willow Point. As documented in the Baseline Shoreline Assessment (Zuzek Inc., 2020a), this shoreline already features a small long-term recession rate, and the continuation of this erosion trend is anticipated for the post-project scenario.

    - Except for the advection of the outlet channel plume into the bay, the numerical modelling did not identify any significant changes in the general circulation patterns from Willow Point to the Sturgeon Bay Park Reserve for the Storm 10 and 32 simulations for the existing conditions and post-project scenario.

    - When the channel is operational, the discharge plume will block storm generated longshore currents and may result in sediment accumulation in the fillet beaches adjacent to the proposed jetties. Over time the growth of these beach deposits will diversify the local shoreline habitat and may result in positive ecological benefits.

    - The current velocities in the channel plume exceed local conditions during the pre-project simulations for Storm 10 and 32. These currents may result in localized scour of the lake bottom.

    - During storm conditions, the advection of the channel plume into Sturgeon Bay will be dynamic and dependent on the hydrodynamic conditions (e.g., storm and non-storm conditions, the strength of longshore currents, and general circulation patterns in the bay). A dynamic plume will disperse fine silt and clay particles in suspension from the channel broadly throughout the bay, which already features a muddy substrate in deep water. In the absence of any numerical modeling on the plume dispersion, we assume the future depositional zone for fine sediment to align with the current mud zone.

  - When the channel is not operational and only features a small base flow, sediment, woody debris and organic material (e.g., peat, aquatic plants, and algae) may accumulate at the inlet mouth between the jetties. A maintenance contingency plan should be developed if negative impacts are anticipated with flushing this debris into the nearshore upon channel start-up.

  - The operation of the channel during non-storm conditions was not investigated since storm events drive changes in the shoreline morphology and nearshore zone. Non-storm conditions during channel operation will be investigated in the future to support the environmental regulatory review.

- Jetties are recommended for the outlet in Sturgeon Bay to stabilize the shoreline, channel the discharge plume into Sturgeon Bay, and trap sand and gravel that moves along the shore towards the outlet. Additional recommendations for the jetties, including length and orientation, will be provided during the final design phase of this project.

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