ONONDAGA LAKE BASELINE MONITORING REPORT OF SEDIMENT RESUSPENSION ALONG THE WASTEBEDS 1-8 SHORELINE

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ACRONYMS

IPA	Individual particle analysis
mph	Mile(s) per hour
MSL	Mean sea level
NTU	Nephelometric turbidity unit
NYSDEC	New York State Department of Environmental Conservation
SMU	Sediment management unit
QA/QC	Quality assurance/quality control
QAPP	Quality Assurance Project Plan
SAX	Scanning electron microscopy interfaced with automated image and X-ray analyses
UFI	Upstate Freshwater Institute, Inc.
USEPA	United States Environmental Protection Agency

EXECUTIVE SUMMARY

Shoreline stabilization will be implemented along the Wastebeds 1-8 shoreline as part of the Onondaga Lake remedy. The purpose of the shoreline stabilization is to reduce wind-driven turbidity resulting from resuspension of sediment from the Wastebeds 1-8 shoreline. Baseline turbidity and other field parameter measurements were collected in Onondaga Lake from late August to late November 2012 in accordance with a NYSDEC-approved work plan. The data were collected to provide a baseline of data that will be used to document the decreases in turbidity anticipated to result from stabilizing the Wastebeds 1-8 shoreline.

This work resulted in a sufficient baseline data set to compare with anticipated reduced turbidity levels that will result from the shoreline stabilization. Measurements were collected using three different methods: 1) data sondes at three locations that provided measurements every 15 minutes; 2) a turbidity meter used weekly along five transects; and 3) turbidity meters deployed at 46 locations during a single-day wind event. Data from additional monitoring devices placed in the lake for other purposes served as controls to assist with assessing lake-wide variations in turbidity. In addition, particles in five lake water samples collected along the Wastebeds 1-8 shoreline during periods of visible near-shore resuspension were analyzed in a laboratory to confirm sources of elevated turbidity.

Baseline turbidity values along the Wastebeds 1-8 shoreline during low-wind intervals were routinely low and comparable to values measured at the South Deep sampling location in deep water. Baseline turbidity values as a whole were sensitive to both wind speed and wind direction. Large increases in baseline turbidity were observed in response to wind speeds over 12 miles per hour (mph) from directions likely to impact the shoreline. Wind-induced turbidity events were short-lived, and the resulting turbidity plumes were restricted to within approximately 50 ft of the shoreline, which is consistent with resuspension and rapid settling of large particles. There was no significant relationship between stream flow and turbidity at any of the three stations where sondes were used to collect data.

SECTION 1

INTRODUCTION

This summary report describes the objectives, sample locations, sample collection process, and data analyses performed for baseline monitoring of turbidity resulting from sediment resuspension along the Wastebeds 1-8 shoreline of Onondaga Lake. Descriptions of the field and analytical methods for this baseline monitoring are provided in the work plan approved by the New York State Department of Environmental Conservation (NYSDEC). Baseline monitoring data described in this report were collected from August 31 to November 28, 2012, in accordance with the approved work plan.

Shoreline stabilization was applied in accordance with the Record of Decision for the Onondaga Lake subsite (NYSDEC and United States Environmental Protection Agency [USEPA] 2005) along approximately 1.5 miles (2.4 kilometers) of the Sediment Management Unit (SMU) 3 shoreline. The stabilization area was extended to include a portion of the SMU 4 shoreline during design. The primary shoreline stabilization goal is to reduce wind-driven resuspension of shallow water material from the Wastebeds 1-8 shoreline. This will be accomplished by placing a layer of gravel over the existing substrate to stabilize near-shore sediments. The shoreline stabilization is specific to the shallow water portion of SMU 3 and SMU 4, extending up to the existing elevation of 365 mean seal level (MSL), which is close to the highest high water mark for Onondaga Lake. Stabilization of the Wastebeds 1-8 shoreline began in February 2014 in accordance with an approved design (Parsons and Anchor QEA, 2012).

The primary objectives of monitoring the Wastebeds 1-8 shoreline prior to stabilization were to:

- Provide sufficient data to support a post-remediation evaluation of the effectiveness of shoreline stabilization at decreasing wind driven near-shore turbidity.
- Characterize the temporal and spatial extent of wind-driven turbidity events along the Wastebeds 1-8 shoreline.
- Assess the ability to differentiate turbidity caused by wind driven shoreline resuspension from other sources of turbidity such as inflows from Ninemile Creek.
- Categorize turbidity events based on wind velocity and direction so that comparisons can be made to post-stabilization turbidity during similar events.

SECTION 2

WORK SCOPE

2.1 DATA COLLECTION

Three data sondes were deployed in Onondaga Lake adjacent to the shoreline of Wastebeds 1-8 to collect turbidity, specific conductance and temperature measurements every 15 minutes continuously from August 31 to November 28, 2012. Sondes were affixed to stakes and replaced approximately weekly to download data and to calibrate and maintain the sondes.

The data sondes were placed at three stations to assess turbidity impacts associated with resuspension of near shore materials (Table 1 and Figure 1). The three stations were located outside the dredging and/or capping areas (i.e., Remediation Areas A, B, or C). Each sonde was located where water depth was approximately 2.5 ft and with the probe approximately 1.2 ft above lake sediment. Locations of the three monitoring stations were selected based on the following factors:

- Waves generated by winds originating from the northwest to southeast direction impacting at least one of the stations
- Areas accessible by boat where shoreline stabilization is planned
- Observation of visible turbidity plumes made during a prior field reconnaissance

Data from additional monitoring devices served as controls to assist with assessing lake-wide variations in turbidity from external factors such as algae blooms and runoff events. These devices included the robotic monitoring buoy at the South Deep station, turbidity sondes elsewhere in the lake used to monitor the effectiveness of lake dredging, and sondes in Onondaga and Ninemile Creeks upstream of remediation work areas.

Turbidity measurements were also collected weekly from September 7 to November 28, 2012, by boat using a hand-held turbidity meter along five transects perpendicular from shore and extending from water depths of approximately 3 ft to 10 ft (1 to 3 meters). The five transects were approximately perpendicular to shore at Stations 1, 2, and 3, at a location between Stations 2 and 3, and at a location just south of Station 3 (Table 1). Turbidity values measured during these weekly efforts were low, generally less than 3 Nephelometric turbidity units (NTUs). More turbid water was observed on windy days close to the shoreline in water too shallow to operate the boat. Data from these transects did not reveal any organized spatial patterns of higher turbidity closer to shore or at particular sites (Appendix A and data plots).

Turbidity measurements were also collected by boat using a hand-held turbidity meter at 46 locations along the Wastebeds 1-8 shoreline during a high wind event on September 20, 2012. The 46 locations monitored on September 20, 2012, were distributed roughly uniformly from Station 1 to just south of Station 3. Thirty seven of the 46 locations were in less than 13 ft (4 meters) of water, and over 40 of the 46 locations were within approximately 100 ft of the shoreline. Winds were from the south to east on that day, with speeds that ranged from 3.0 to 19.6 miles per hour (mph) (average of 10.5 mph). This should have been sufficient to cause a

wind-driven sediment resuspension event at sonde Stations 2 and 3 (Station 1 is relatively sheltered from winds from that direction). Despite the relatively high winds, turbidities measured from the boat were only slightly elevated at Stations 2 and 3, with most measurements between 3 and 5 NTU (maximum of 6.7 NTU). However, the fixed data sondes at Stations 2 and 3 recorded much higher turbidities closer to shore on that day (over 100 NTU), strongly suggesting that the turbidity event was largely isolated to shallow water lake areas close to shore (Appendix A and data plots).

Inflow to Onondaga Lake from Ninemile Creek is in close proximity to the northern end of Wastebeds 1-8 (Figure 1), and turbidity from Ninemile Creek could be mistaken for turbidity caused by resuspension of nearshore sediment. Fortunately, the Ninemile Creek inflow has signatures that distinguish it from the ambient lake water. Turbidity associated with Ninemile Creek is caused mostly by clay particles, while calcium-rich particles dominate in the waste beds. These differences in particle type are readily differentiated through individual particle analysis (IPA) by scanning electron microscopy interfaced with automated image and X-ray analyses (SAX), which has been successfully applied to Onondaga Lake (Effler and Peng, 2012). The field team collected five lake water samples along the Wastebeds 1-8 shoreline for IPA/SAX analyses during periods of visible near-shore resuspension to confirm sources of elevated turbidity (Appendix B).

The primary focus of this baseline data collection work was to collect information at specified water depths rather than at particular distances from shore.

2.2 DATA ANALYSIS

Data collected in 2012 from sondes deployed near Wastebeds 1-8 were assessed to identify elevated turbidity levels from resuspension of near-shore wastebed sediments. Meteorological data from the robotic monitoring buoy at South Deep, from other remote meteorological stations located near the lake, and from the National Weather Service Station at nearby Syracuse Hancock International Airport were also assessed. Near-shore turbidity events off Wastebeds 1-8 were categorized based on wind velocity and direction so that data collected in the future during post-stabilization turbidity events can be directly compared to wind events of similar magnitude and direction. This comparison will be used to document the anticipated turbidity reduction anticipated as a result of shoreline stabilization (i.e., reductions in frequency, magnitude, duration, and/or spatial extent of turbidity impacts). These pre-stabilization data are presented in Plots 1 through 9.

Field data were collected and entered into a database that included turbidity, temperature, and specific conductance measurements.

2.3 QUALITY ASSURANCE/QUALITY CONTROL

Quality assurance/quality control (QA/QC) measures conducted as part of this work included consistent application of standard operating procedures for data collection and sonde maintenance. These standard operating procedures were included in the approved work plan. Relevant QA/QC procedures presented in the Quality Assurance Project Plan (QAPP) (Parsons, Anchor QEA, and Exponent, 2012) were also followed. For example, coordinates of the three stations were stored in hand-held global position system units and marked with poles and surface

floats to ensure that each sample was taken at the appropriate location, while the positions of the five transects were at locations perpendicular from shore and water depths verified by Upstate Freshwater Institute, Inc.'s (UFI) on board depth finders.

Each of the sondes deployed worked well throughout this baseline turbidity monitoring effort. The sondes were calibrated according to the manufacturer's recommendations immediately prior to each deployment. Sondes were calibrated for each location and deployed approximately weekly for one week deployment intervals. Upon recovery, the data from each sonde was offloaded, and the sonde was checked for drift. Sonde software had internal safeguards for probes to prevent operation outside standard tolerance intervals.

During the 2012 baseline turbidity monitoring effort, 46 water samples were analyzed for turbidity in UFI's laboratory. Considering the narrow turbidity range of paired values (1 to 7 NTUs), laboratory turbidity results compared well with turbidity measurements made in the field (R^2=0.75), where R^2 is the correlation coefficient ranging from 0 to 1 with 1 being a perfect correlation.

SECTION 3

DATA ASSESSMENT

A detailed assessment of the data was completed and discussed with NYSDEC on December 6, 2013. Presentation materials developed to facilitate the December 2013 discussion are included as Appendix A. Detailed data collected during this effort are presented in Appendix B. Representative photos are included as Appendix C. The data evaluation is summarized below.

Median baseline turbidity results from each of the three Wastebeds 1-8 stations are of the same magnitude as turbidities measured at the same water depth in the deep water portion of the lake at South Deep (Table 2). The overall median turbidity from all three Wastebeds 1-8 stations from September through November 2012 was 2.7 NTUs. Ninety percent of turbidity measurements collected in 2012 along the Wastebeds 1-8 shoreline had a magnitude less than 11 NTUs.

Wind speeds impacted baseline turbidity results at each of the three stations. Each station had a range of wind directions most likely to affect it based on land topography. Median turbidity at each station increased when wind speeds from impacting directions increased (Figure 2). Turbidity results corresponding to a large event (i.e., the highest turbidity readings) were assessed based on the highest 1 percent (99th percentile) of all turbidity measurements recorded during the 2012 baseline monitoring effort. Large events included minimum turbidity results of 83 NTUs, and large event turbidities were commonly above 100 NTUs. Large events also corresponded to wind speeds over 12 mph from impacting directions. Wind-induced turbidity events were short-lived, and the resulting turbidity plumes were restricted to within approximately 50 ft of the shoreline. This is consistent with resuspension and rapid settling of large particles. Large turbidity events were observed during each of the three months at each of the three monitoring stations with one exception (Figure 3). Station 1 (Figure 3) had no large turbidity event during September 2012 most likely due to a significant bed of aquatic vegetation present at that location at that time, which appeared to attenuate wave energies prior to reaching the shoreline.

Stream flows entering Onondaga Lake were not a significant contributor to large turbidity events adjacent to Wastebeds 1-8 during the 2012 monitoring period. Turbidity results adjacent to the Wastebeds 1-8 shoreline were compared to stream flows recorded by the United States Geological Survey near the mouths of Ninemile and Onondaga Creeks. Turbidity data compared with stream flows from the nearest tributary showed no significant relationship between in-lake turbidity and stream flow from September through November 2012.

A total of five samples collected along the Wastebeds 1-8 shoreline were analyzed using IPA/SAX to characterize particles in water. Four of the samples were collected by boat during the wind event on September 20, 2012, and one sample was collected closer to shore by wading in shallow water on October 17, 2012. Results from the IPA/SAX work are provided in Appendix B.

The samples collected on September 20 had low turbidity values (2.4 to 7.6 NTUs), suggesting only modest contributions from resuspended wastebed material. The particles were similar to those collected at South Deep in terms of both size (median diameter of 6 to 8 microns or 0.006 to 0.008 millimeter) and composition (mostly clay and calcium aggregates).

In contrast, the sample collected on October 17 was very turbid (225 NTUs) and contained larger particles (median diameter of 12 microns) comprised almost entirely of calcium and calcium aggregates. The size and distinctive chemical composition of these particles is consistent with wastebed material. These results suggest resuspension and rapid deposition of wastebed material took place in the near shore zone along Wastebeds 1-8.

Results from this baseline monitoring work suggest assessing the following parameters may help to evaluate post-stabilization effectiveness after shoreline stabilization is completed:

- Turbidity “peaks” during wind events
- Shifts in median turbidity values at specified intervals of wind speed
- Changes in slopes of wind/turbidity graphs

SECTION 4

CONCLUSION AND RECOMMENDATIONS

Data collected, analyzed, and presented in this report provide a sufficient baseline data set to compare with future measurements along the shoreline of Wastebeds 1-8 following stabilization of the shoreline. Other conclusions from this data collection and assessment include the following:

1. Baseline turbidity values along the Wastebeds 1-8 shoreline during low-wind intervals were routinely small and comparable to values at the 2-meter water depth at the deep water location (South Deep). The overall median baseline turbidity from all three stations was 2.7 NTUs. Ninety percent of the baseline turbidity measurements along the Wastebeds 1-8 shoreline had a magnitude less than 11 NTUs. Station 1 (the northernmost station) had the lowest median turbidity and lowest number of recorded turbidity events.
2. Baseline turbidity values were sensitive to both wind speed and wind direction. Large increases in baseline turbidity (typically over 100 NTUs) were observed in response to wind speeds over 12 mph from directions likely to impact the respective shoreline stations.
3. Wind-induced turbidity events were short-lived, and the resulting turbidity plumes were restricted to within approximately 50 ft of the shoreline, which is consistent with resuspension and rapid settling of large particles.
4. There was no significant relationship between stream flow and turbidity at any of the three stations where sondes collected data throughout the 2012 baseline monitoring period.
5. Because submerged macrophytes have the potential to limit near-shore resuspension and turbidity, specifically near Station 1 (W1), analysis of post-remediation data should be done in the context of whether or not macrophytes are present at the time of post-remediation monitoring. If macrophytes are not yet established following remediation or are not present seasonally, post-remediation turbidity values may be biased high relative to the baseline data set.

SECTION 5

REFERENCES

Effler, S.W. and F. Peng. 2012. *Light-Scattering Components and Secchi Depth Implications in Onondaga Lake, New York, USA*. Fundamental and Applied Limnology 179: 251-265.

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Parsons and Anchor QEA, 2012. *Onondaga Lake Capping, Dredging, Habitat and Profundal Zone (Sediment Management Unit 8) Final Design*. Prepared for Honeywell. Morristown, NJ. March 2012.

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TABLE 1

REPRESENTATIVE COORDINATES, ESTIMATED DISTANCES FROM SHORE, AND APPROXIMATE WATER DEPTHS FOR SONDE DEPLOYMENTS AND WEEKLY TRANSECTS

Location	Lat	Lon	Distance from Shore (m)	Distance from Shore (ft)	Approx. Water Depth (m)	Station
Onondaga Lake Sonde Locations	43.0906	76.2194	19	62	0.75	W1 sonde
	43.0898	76.2178	12	39	0.75	W2 sonde
	43.0807	76.2096	6	18	0.75	W3 sonde
Onondaga Lake Transect Locations	43.0914	76.2191	108	354	3	W1T
	43.0913	76.2193	79	259	2	W1T
	43.0912	76.2195	32	105	1	W1T
	43.0896	76.2168	84	276	3	W2T
	43.0898	76.2174	57	187	2	W2T
	43.0899	76.2178	28	92	1	W2T
	43.0862	76.2165	126	413	3	W2AT
	43.0859	76.2163	95	312	2	W2AT
	43.0856	76.2167	64	210	1	W2AT
	43.0806	76.2093	31	102	3	W3T
	43.0807	76.2094	13	43	2	W3T
	43.0806	76.2095	8	26	1	W3T
	43.0783	76.2077	87	285	3	W3AT
	43.0784	76.2079	64	210	2	W3AT
	43.0782	76.2081	31	102	1	W3AT

TABLE 2

MEDIAN TURBIDITY RESULTS BY STATION FOR EACH MONTH OF BASELINE MONITORING ALONG WASTEBEDS 1-8 SHORELINE

Station Number	Sept. 2012	Oct. 2012	Nov. 2012	Sept.-Nov. 2012
1	1.2	3.2	1.8	1.7
2	2.5	2.9	1.8	2.4
3	4.1	4.6	2.9	3.8
South Deep	2.6	3.1	3.0	2.8

Note: Results are presented in Nephelometric turbidity units (NTUs).

FIGURE 1

LOCATIONS OF MONITORING STATIONS ALONG WASTEBEDS 1-8 SHORELINE

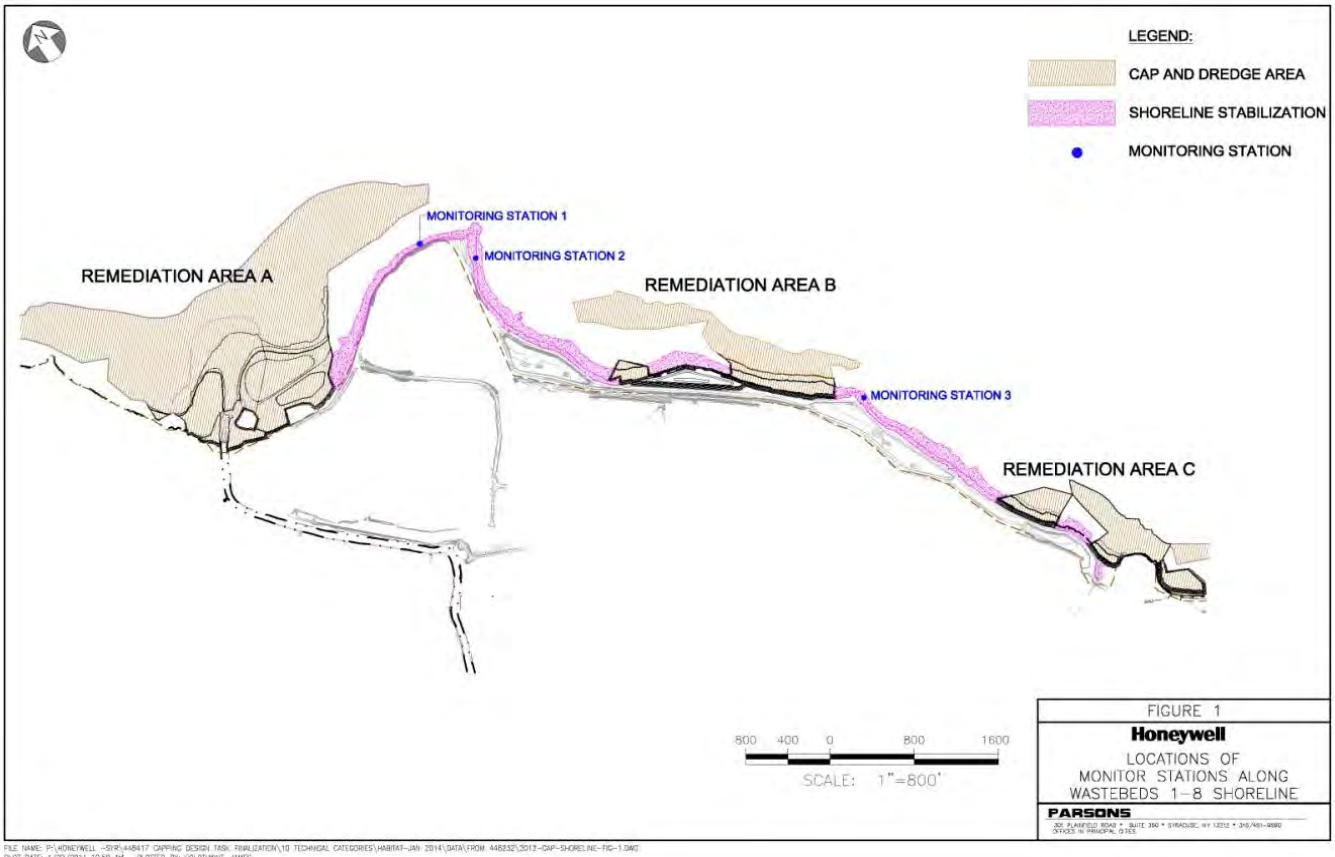


FIGURE 2

TURBIDITY AS A FUNCTION OF WIND SPEED FOR IMPACTING DIRECTIONS

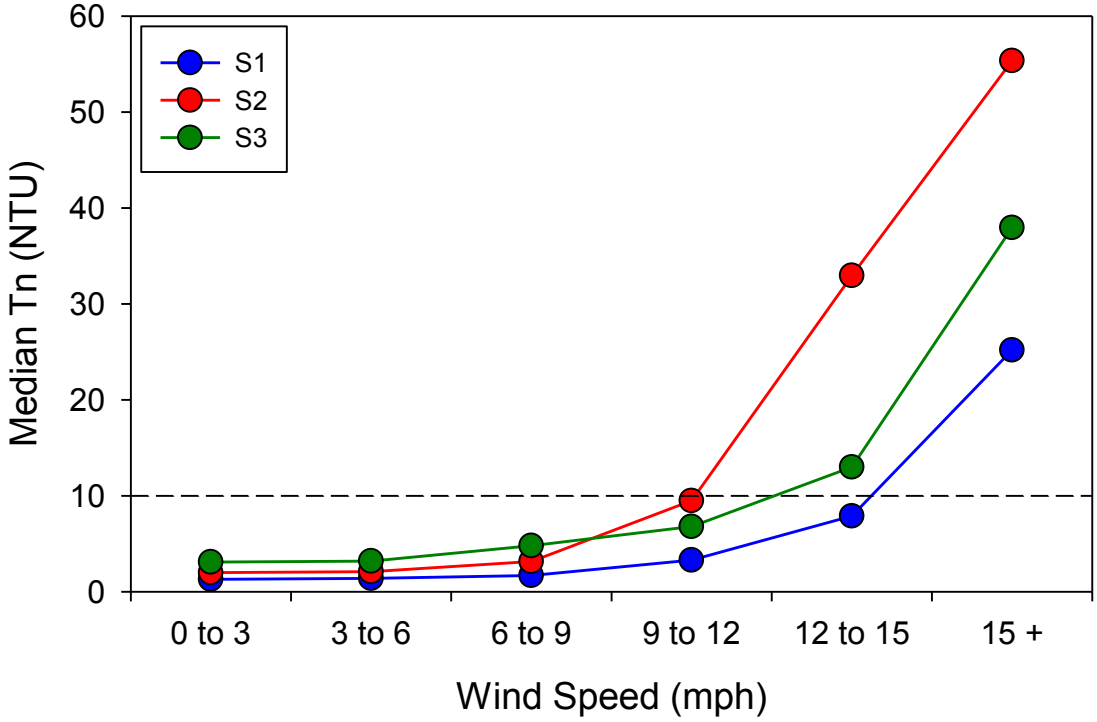
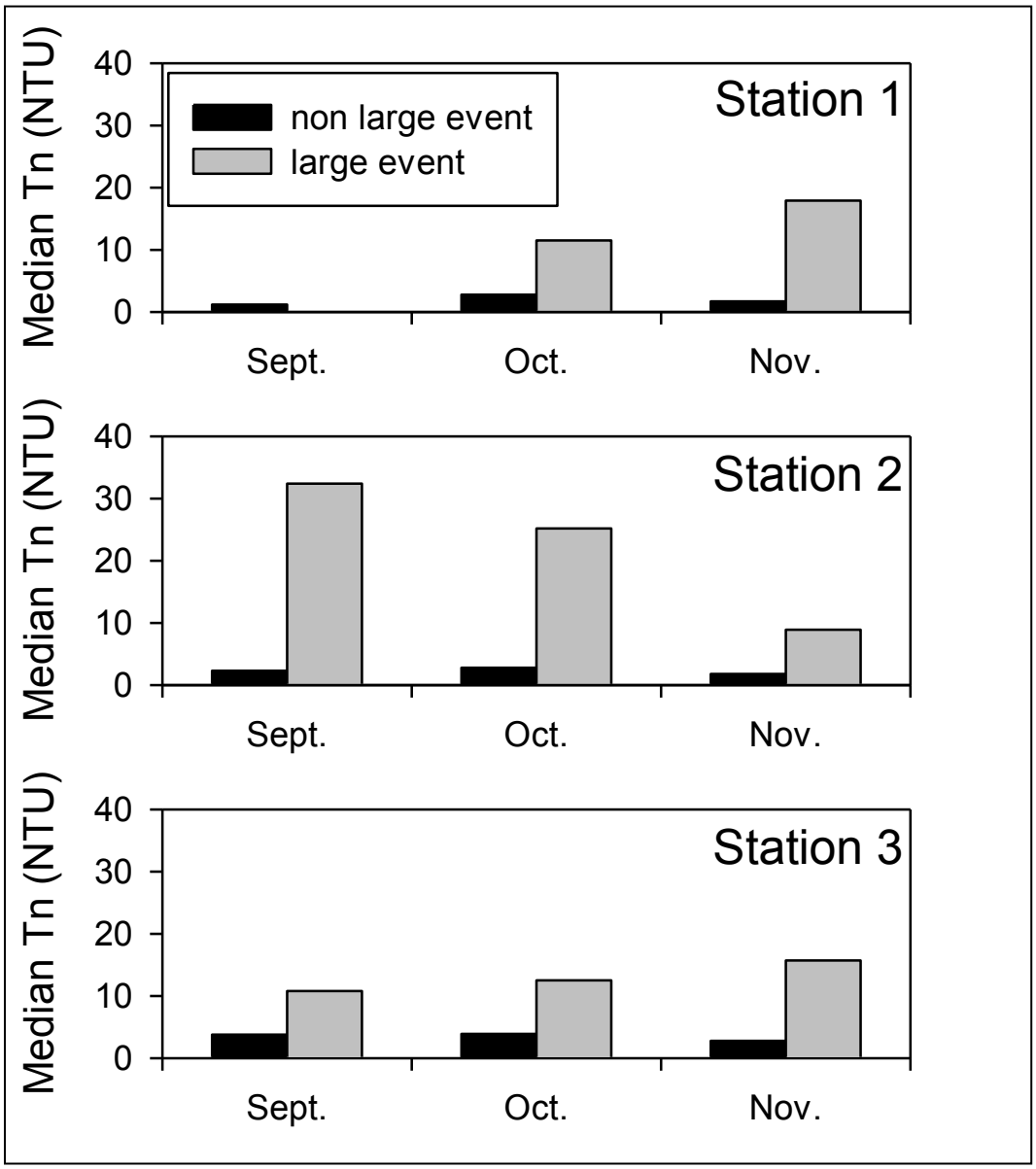
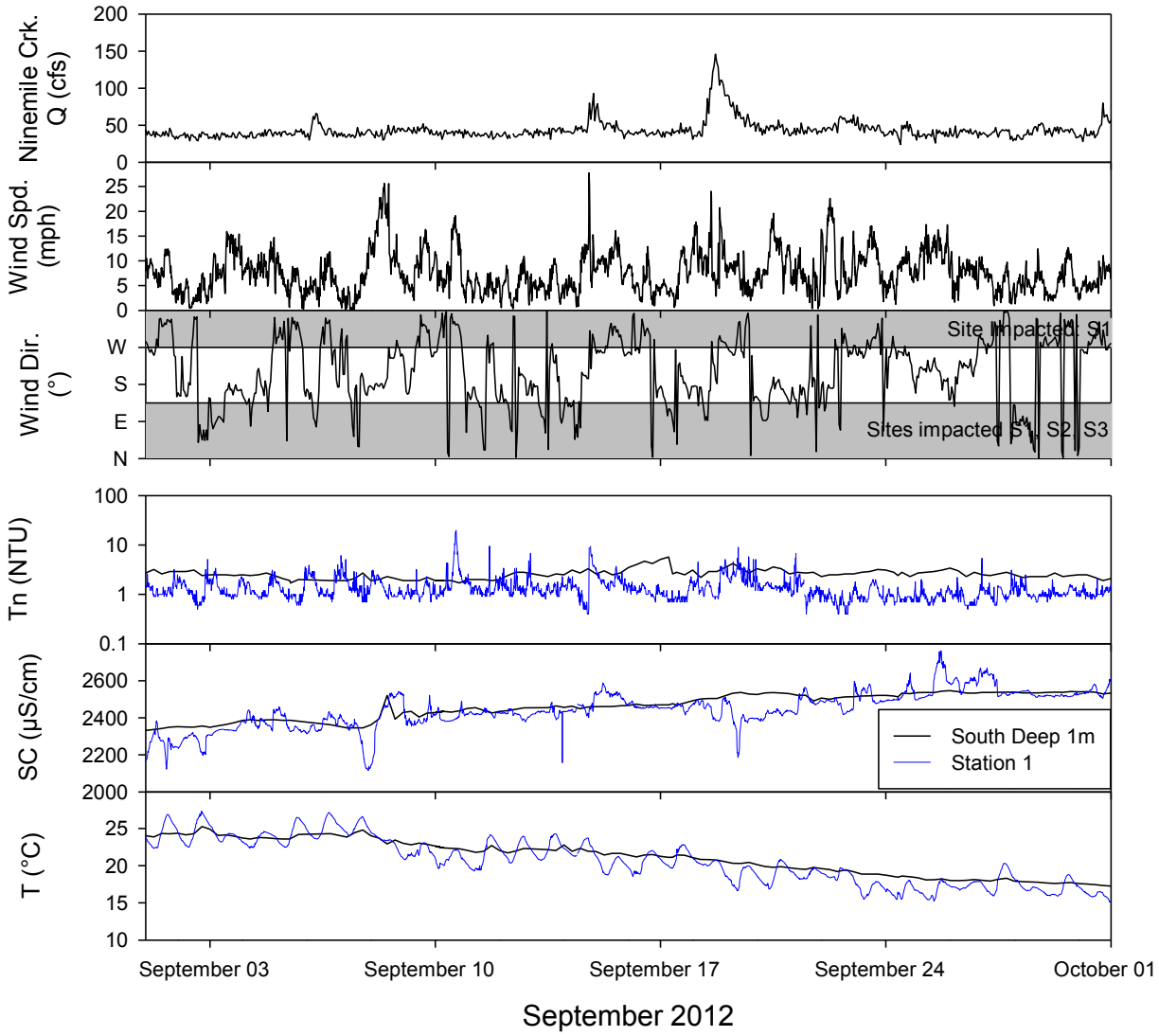


FIGURE 3

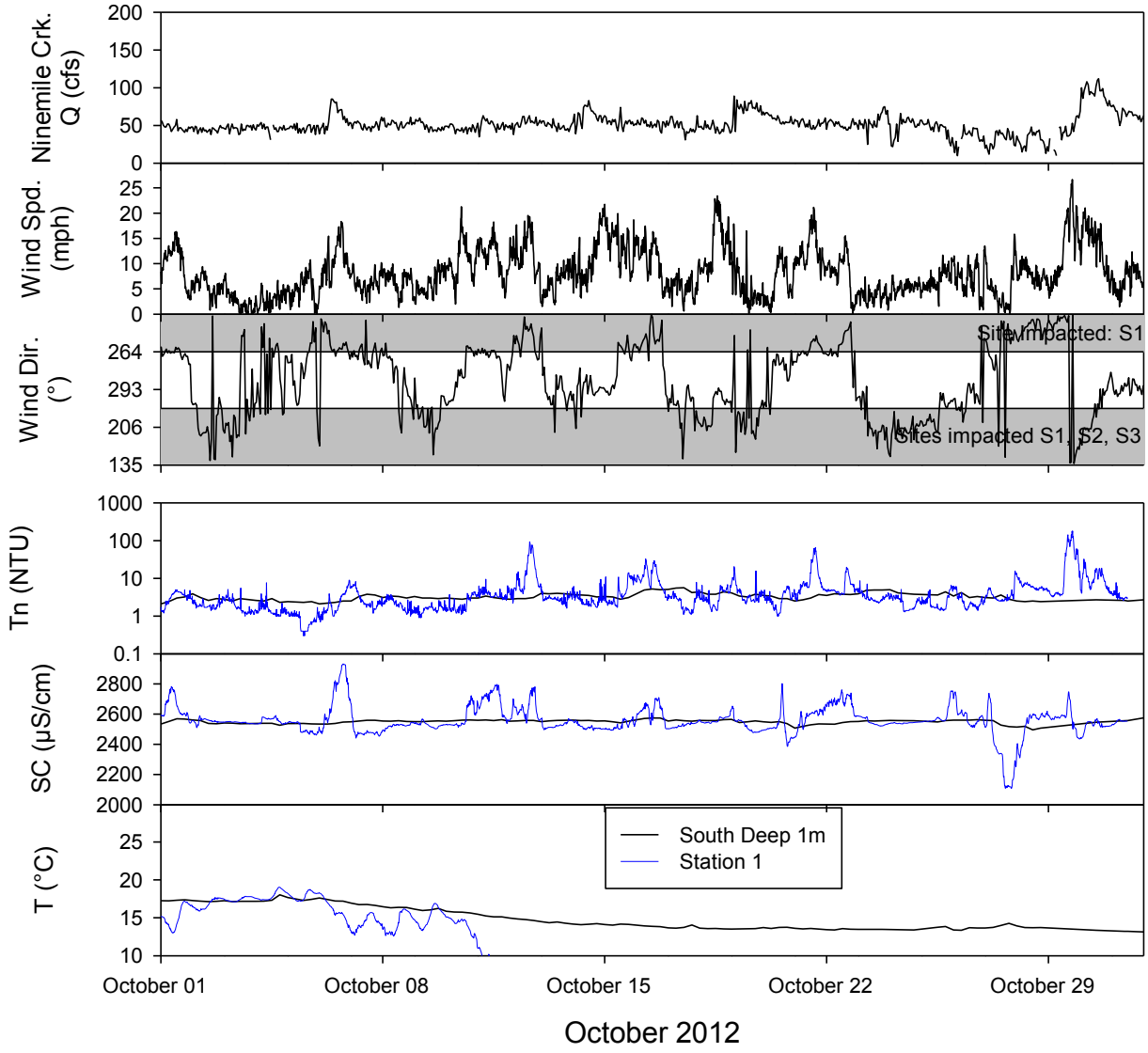
TURBIDITIES FOR LARGE AND NON-LARGE EVENTS BY STATION FOR EACH MONTH OF MONITORING



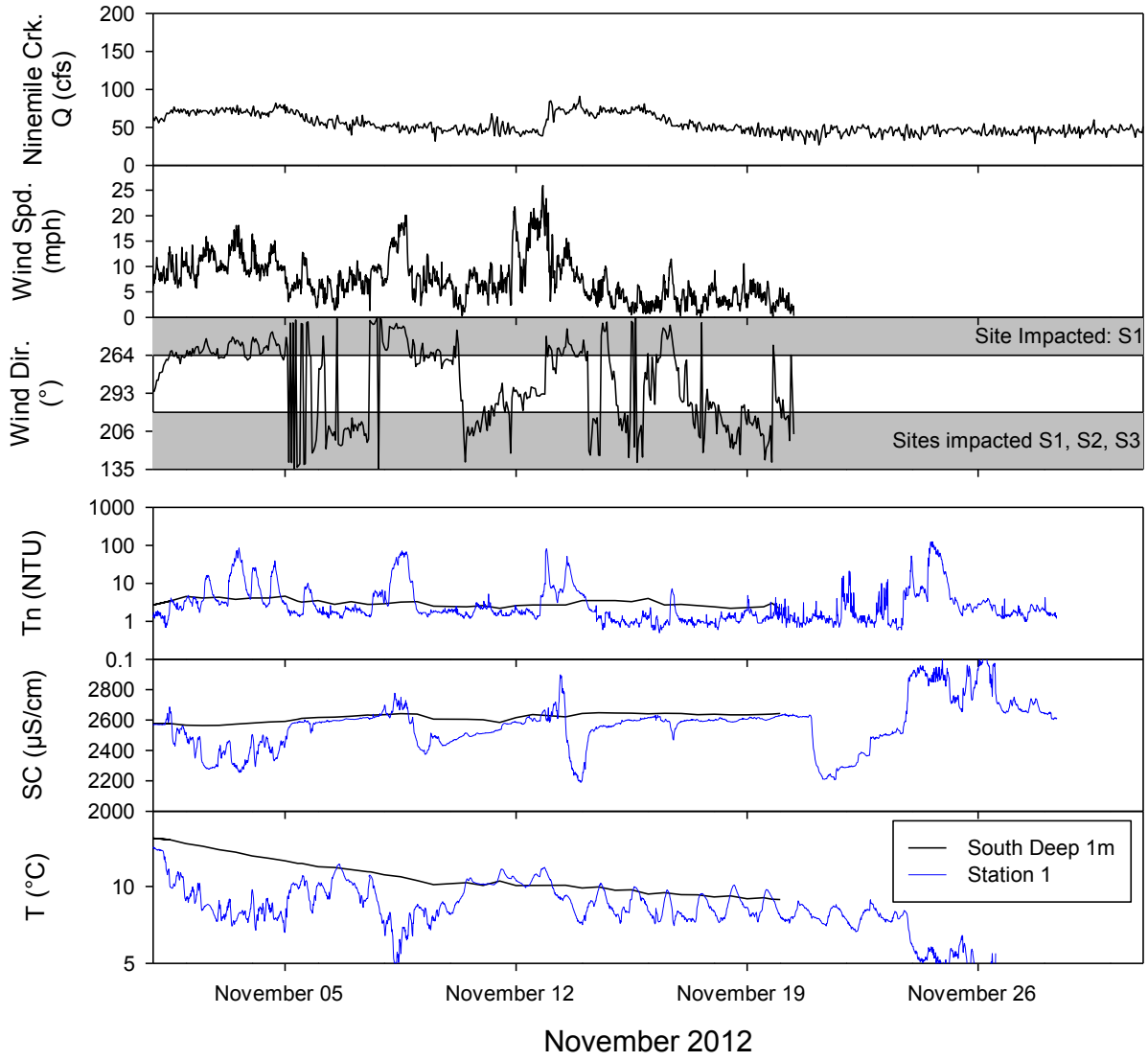
DATA PLOTS



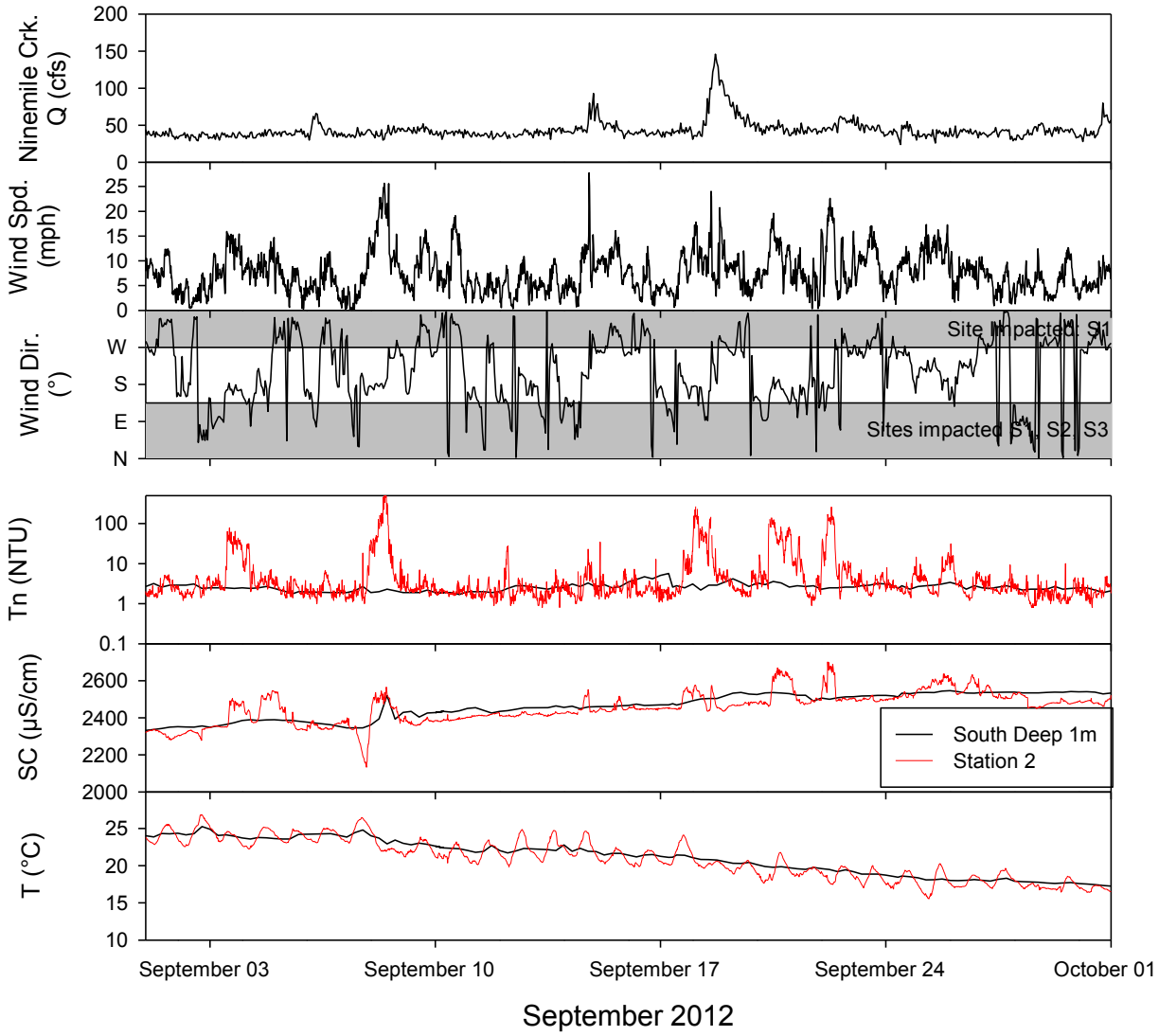
PLOT 1 STATION 1 TIMES SERIES WITH DRIVERS AND SOUTH DEEP 1M REFERENCE (SEPTEMBER 1 - SEPTEMBER 30, 2012)



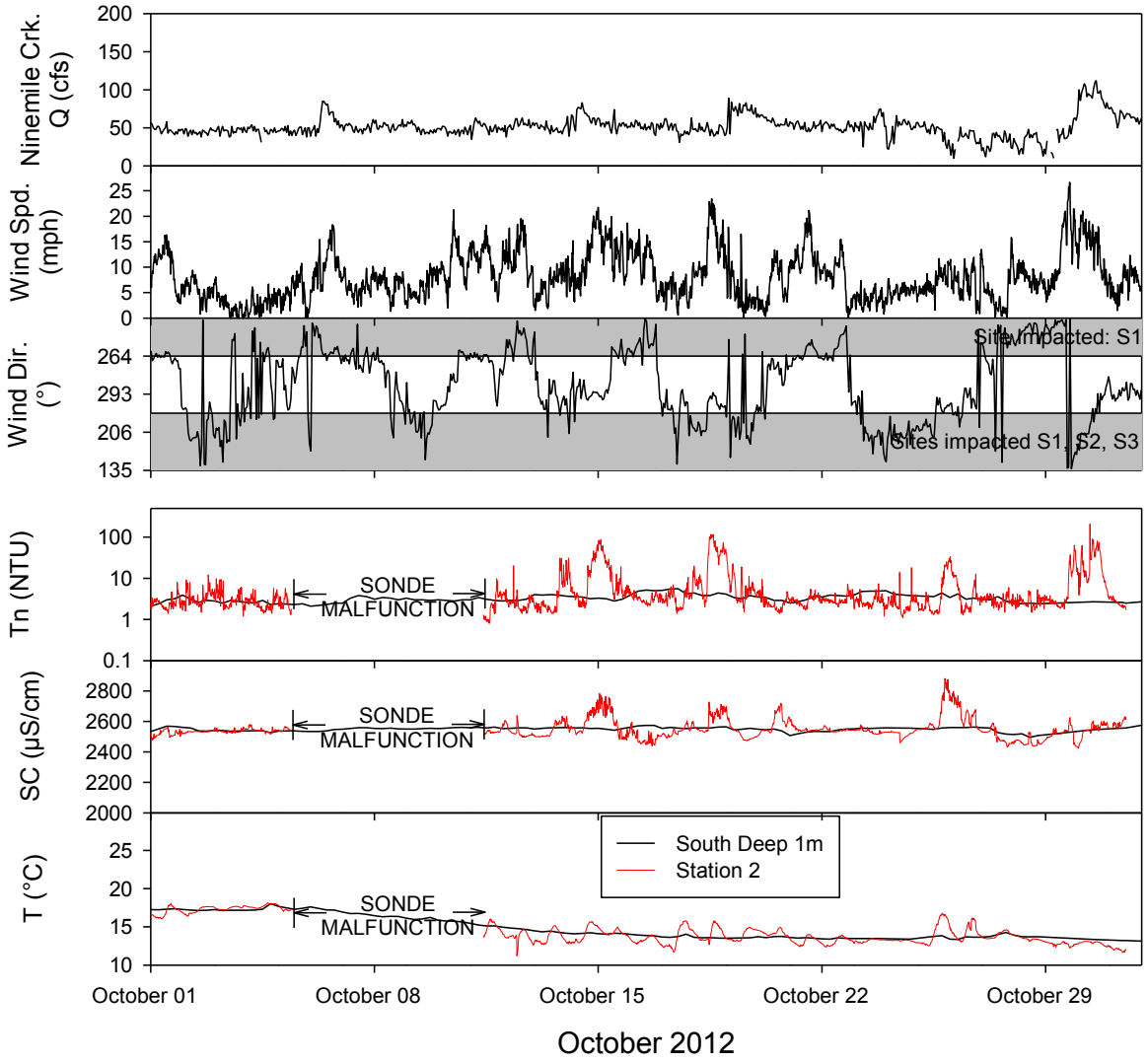
PLOT 2 STATION 1 TIMES SERIES WITH DRIVERS AND SOUTH DEEP 1M REFERENCE (OCTOBER 1 - OCTOBER 31, 2012)



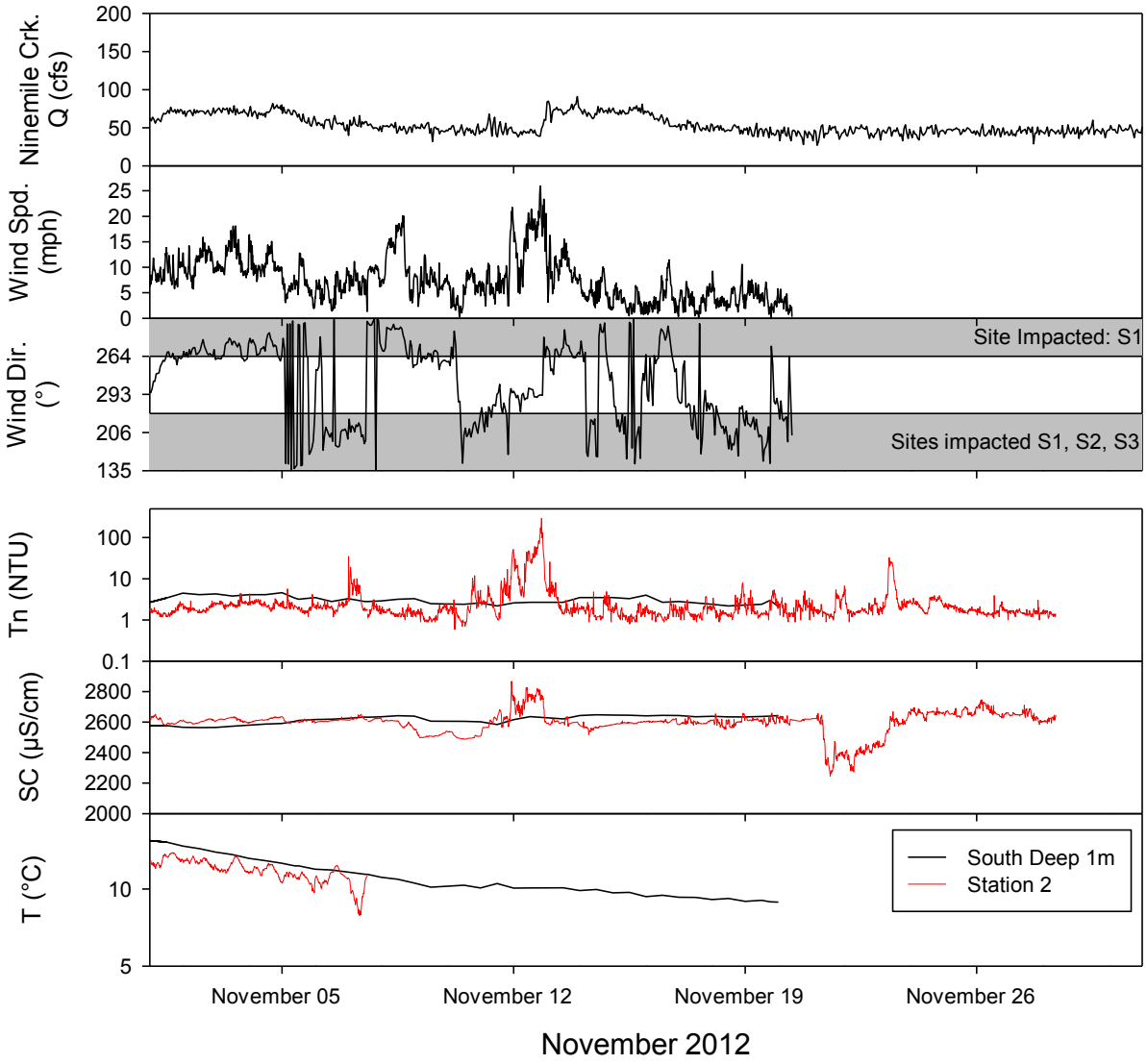
PLOT 3 STATION 1 TIMES SERIES WITH DRIVERS AND SOUTH DEEP 1M REFERENCE (NOVEMBER 1 - NOVEMBER 28, 2012)



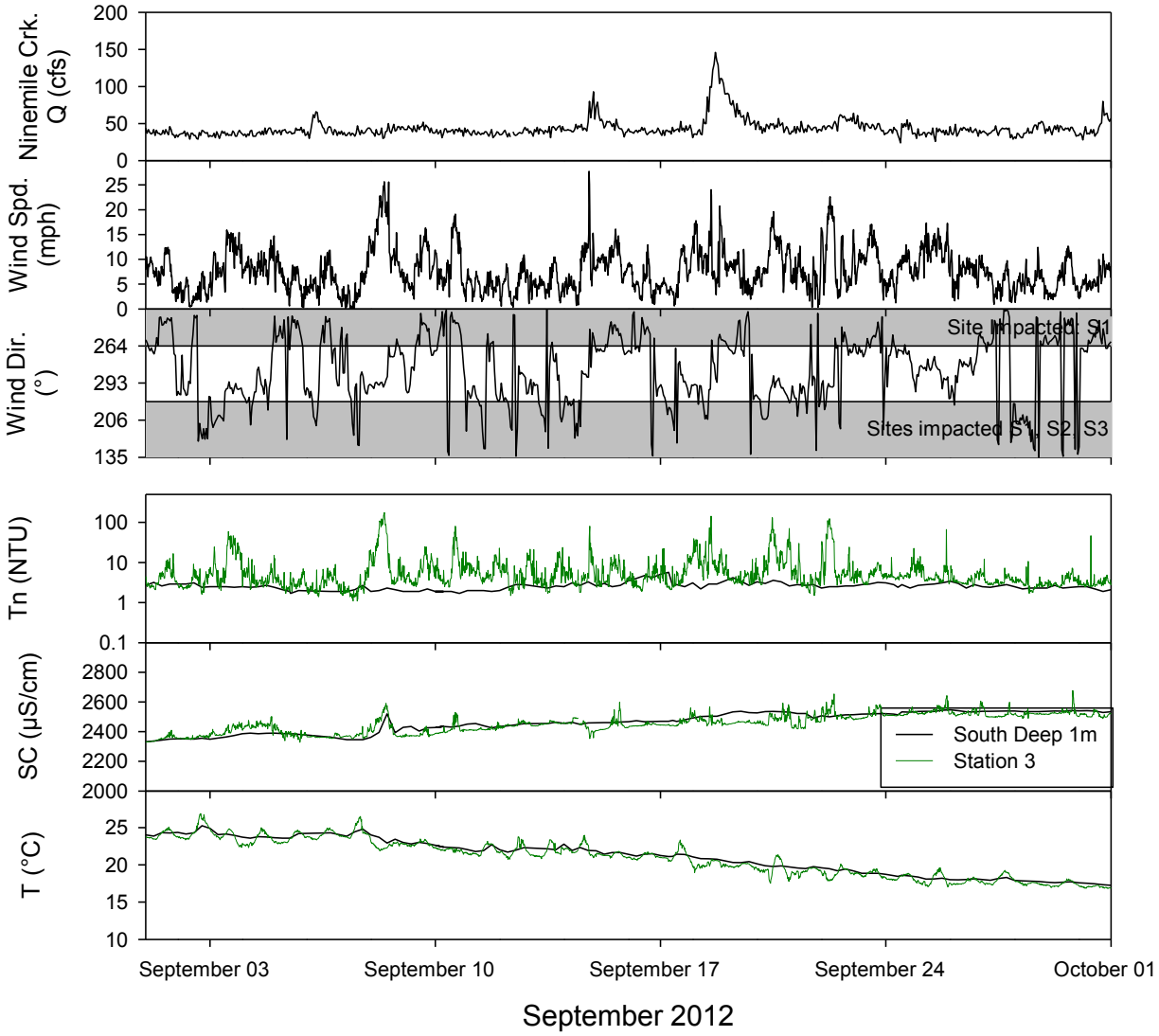
PLOT 4 STATION 2 TIMES SERIES WITH DRIVERS AND SOUTH DEEP 1M REFERENCE (SEPTEMBER 1 - SEPTEMBER 30, 2012)



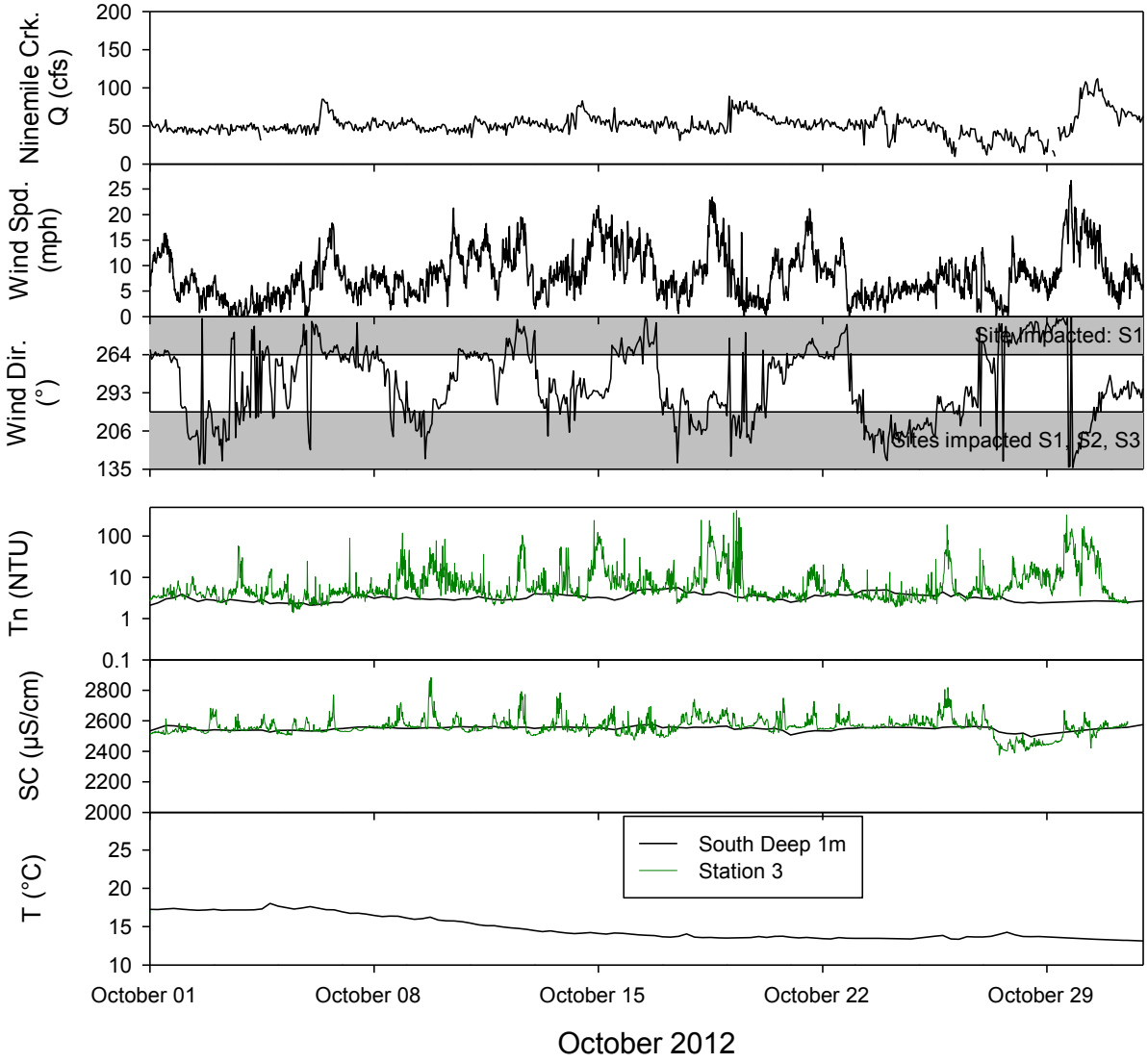
PLOT 5 STATION 2 TIMES SERIES WITH DRIVERS AND SOUTH DEEP 1M REFERENCE (OCTOBER 1 - OCTOBER 31, 2012)



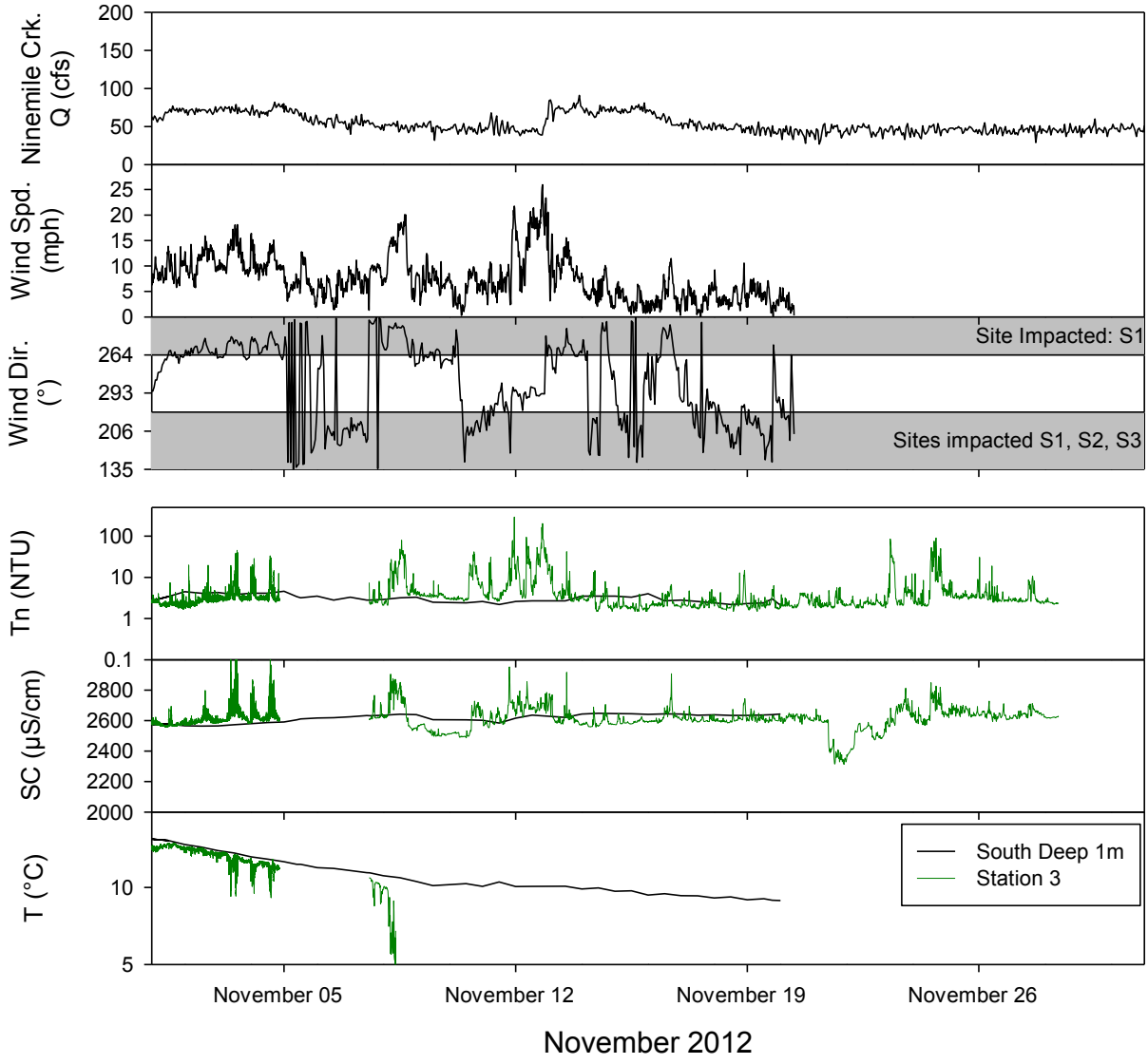
PLOT 6 STATION 2 TIMES SERIES WITH DRIVERS AND SOUTH DEEP 1M REFERENCE (NOVEMBER 1 - NOVEMBER 28, 2012)



PLOT 7 STATION 3 TIMES SERIES WITH DRIVERS AND SOUTH DEEP 1M REFERENCE (SEPTEMBER 1 - SEPTEMBER 30, 2012)



PLOT 8 STATION 3 TIMES SERIES WITH DRIVERS AND SOUTH DEEP 1M REFERENCE (OCTOBER 1 - OCTOBER 31, 2012)



PLOT 9 STATION 3 TIMES SERIES WITH DRIVERS AND SOUTH DEEP 1M REFERENCE (NOVEMBER 1 - NOVEMBER 28, 2012)

APPENDIX A

DECEMBER 2013 PRESENTATION SLIDES

Fall 2012 WB 1-8 Shoreline BaselineTurbidity Monitoring Results

Presented to NYSDEC

December 6, 2013

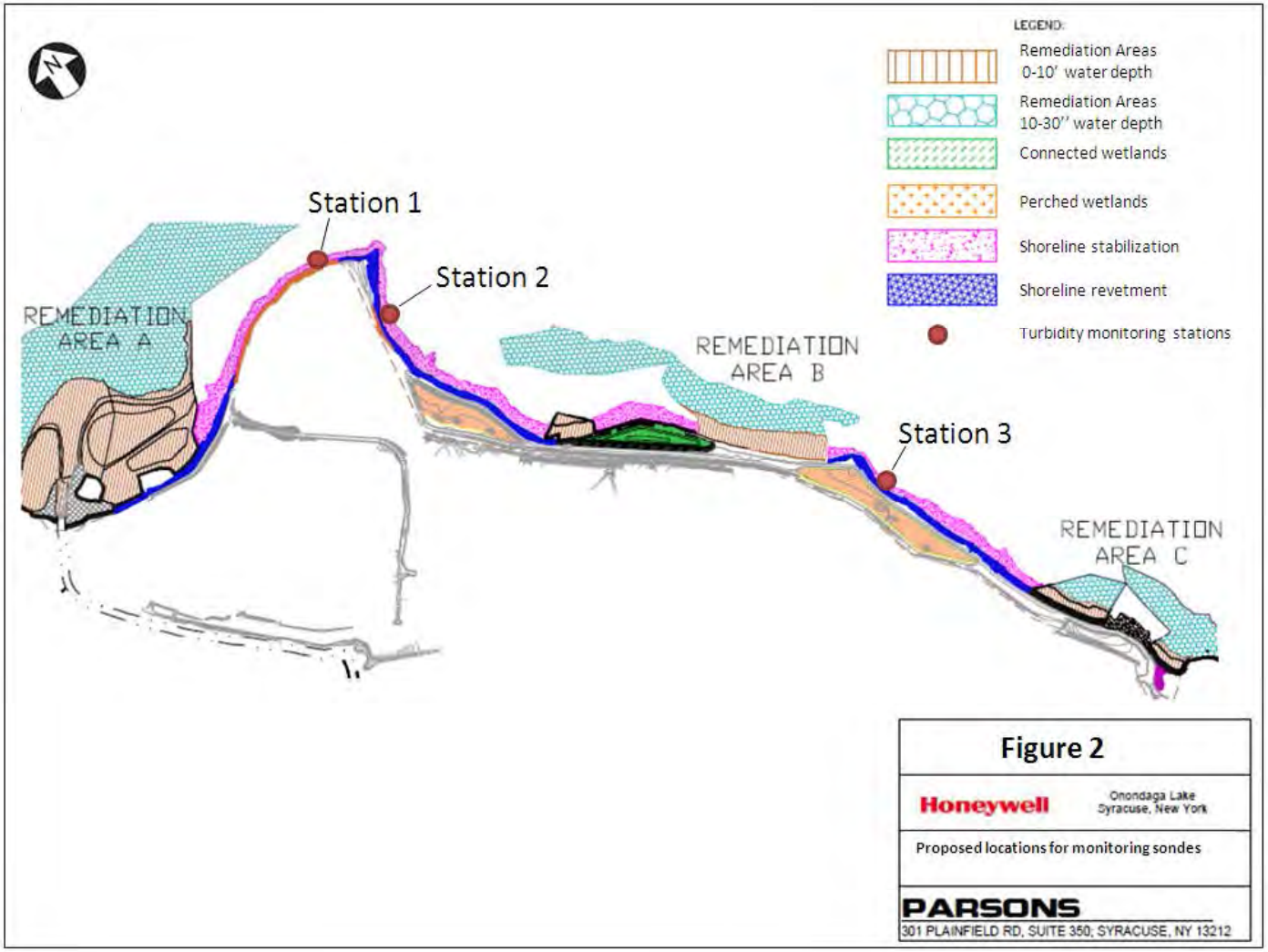
Objectives

- The objectives of monitoring the WB 1-8 shoreline are to:

1. Provide sufficient data to support post-remediation conclusions regarding the effectiveness of shoreline stabilization at decreasing wind driven nearshore turbidity.
2. Characterize the temporal and spatial extent of wind driven turbidity events along the WB 1-8 shoreline.
3. Assess the ability to differentiate turbidity caused by wind driven calcite resuspension from other sources of turbidity such as inflows from Nine Mile Creek.
4. Categorize turbidity events based on wind velocity and direction so that comparisons can be made to post-stabilization turbidity during similar events.

from: 2012 WORK PLAN FOR MONITORING OF SEDIMENT RESUSPENSION ALONG THE WASTEBED 1-8 SHORELINE OF ONONDAGA LAKE

Study System Map



Data Collection

- September 1 through November 28, 2012
- Three types of data collected
  1. In-situ data sondes
     - Temperature (T), specific conductance (SC), and turbidity (Tn) at 15 min intervals at Stations 1-3.
  2. Surface measurements
     - ~ weekly with YSI hand held data logger at 5 transects (15 locations) for T, SC, Tn
     - event gridding on Sept. 20
  3. Surface water samples
     - Tn, IPA

In-situ Sonde at Station 1

Data Overview

- All data

All In-Situ Data

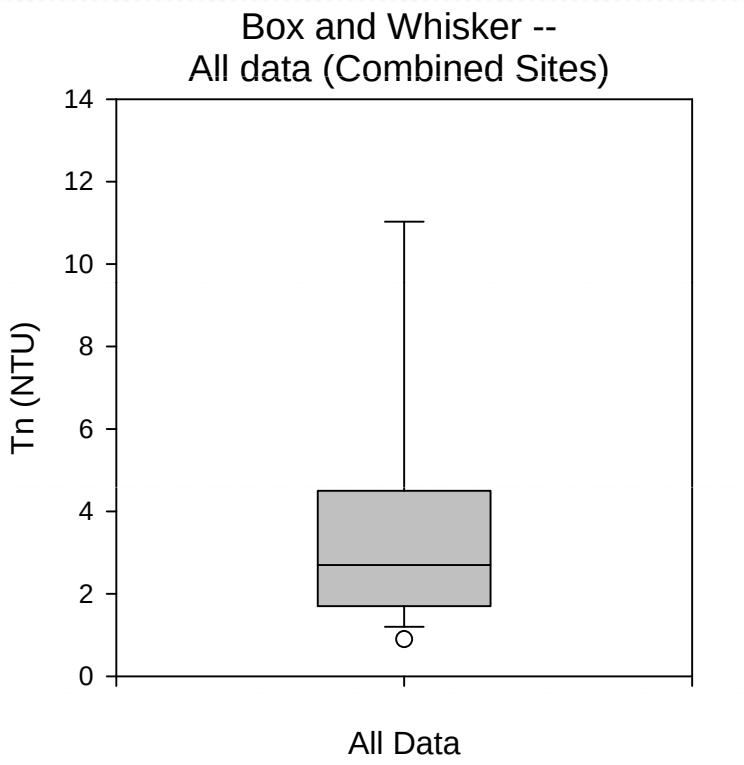
Median Tn (NTU) for each location by month and overall

Station	Sept.	Oct.	Nov.	All
1	1.2	3.2	1.8	1.7
2	2.5	2.9	1.8	2.4
3	4.1	4.6	2.9	3.8
S. Deep	2.6	3.1	3.0	2.8

- Station 3 tended to have the highest median Tn
- Median turbidity generally comparable to South Deep

North of Station 3 on Sept. 14, 2012

Description of Nearshore Turbidity Conditions to Determine Event Criteria

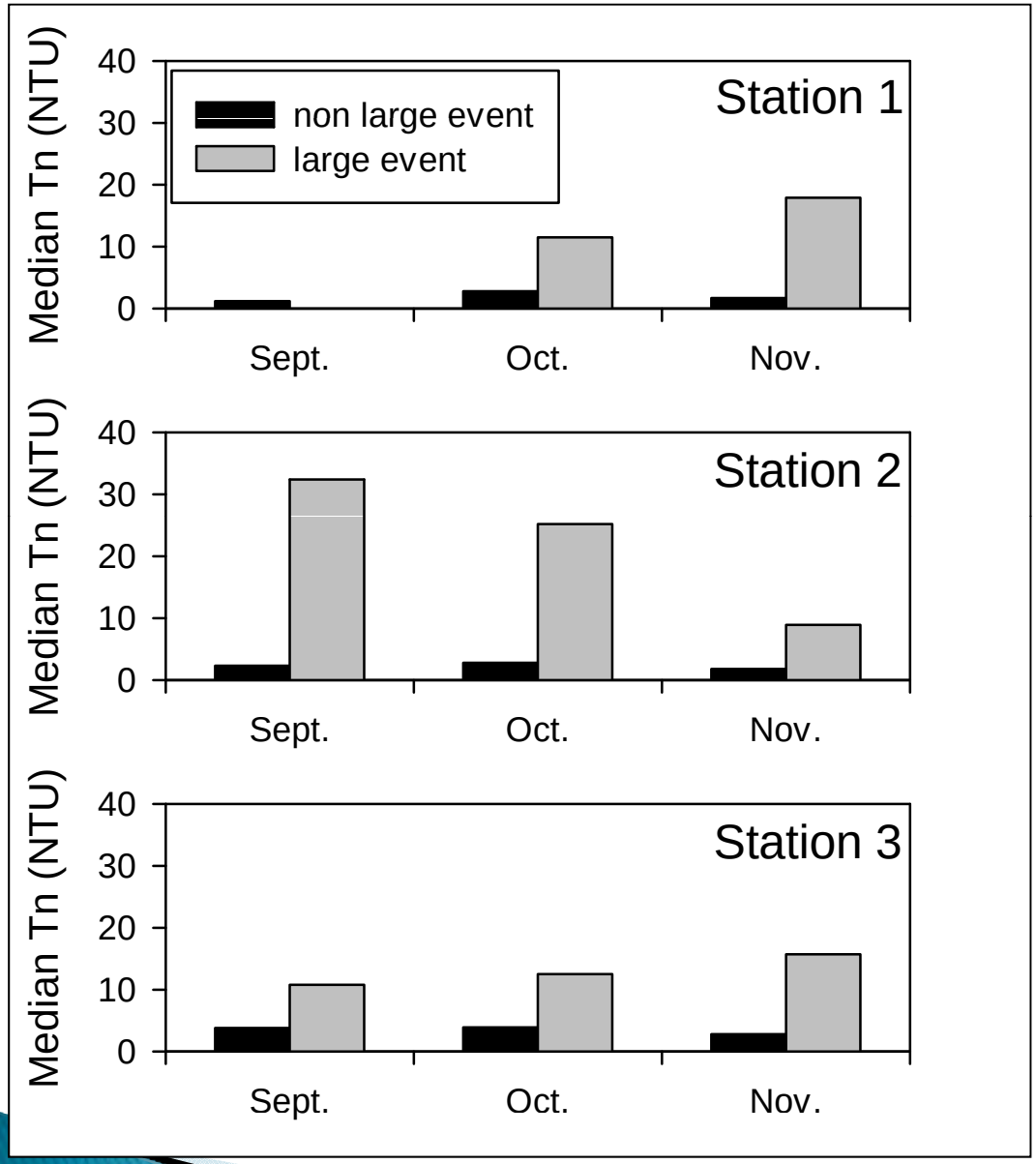


Percentile (%)	Turbidity (NTU)
1%	0.7
5%	0.9
10%	1.2
25%	1.7
50% (median)	2.7
75%	4.5
90%	11
95%	26
99%	83

Large Events –Tn peaks greater than 83 NTU

Non-Large Events – all other data*

* simplified version of analyses



Comparison: Large Events vs. Non-Large Events

- Large increases in Tn during events
- Event median Tn 3.5-11 times larger than non-large event
- Event maximum Tn > 100 NTU were common

Large Event Data

- Events with peak turbidity greater than 83 NTU

Station 1 Event Summary Table

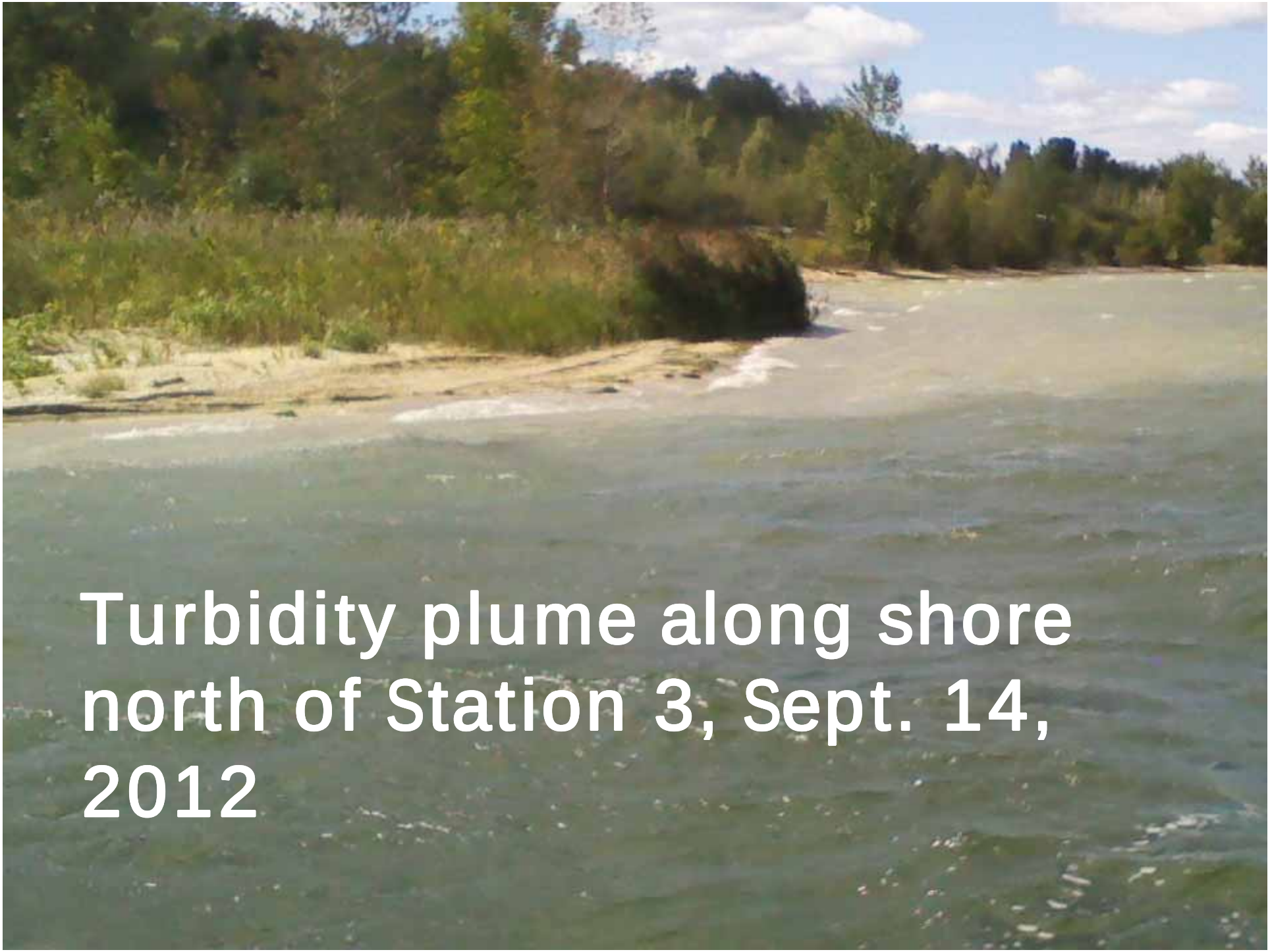
Event	Date	Duration (d)	Avg. Wind Spd. (mph)	Max. Wind Spd. (mph)	Dir.	Avg. Tn (NTU)	Max. Tn (NTU)
1	10/12/12	0.93	11.4	19.6	NW	19.33	93.3
2	10/29/12	1.52	15.2	26.7	NE, variable	30.39	178.8
3	11/03/12	1.67	11.6	18.1	NW	18.32	84.8
4	11/24/12	0.70	15.3	20.0	NW	51.56	123.9

Station 2 Event Summary Table

Event	Date	Duration (d)	Avg. Wind Spd. (mph)	Max. Wind Spd. (mph)	Dir.	Avg. Tn (NTU)	Max. Tn (NTU)
1	09/07/12	0.99	15.1	25.6	S	98.0	824.5
2	09/17/12	1.10	10.6	24.0	SE	47.0	268.1
3	09/20/12	1.16	10.5	19.6	SE	41.3	141.1
4	09/21/12	0.58	12.8	22.6	S	61.7	258.1
5	10/14/12	0.86	15.7	21.7	S	31.5	87.4
6	10/18/12	0.96	13.4	23.4	SE	41.5	116.8
7	10/29/12	1.30	14.8	26.7	E, variable	27.1	209.7
8	11/11/12	1.79	13.2	25.9	S	25.6	292.9

Station 3 Event Summary Table

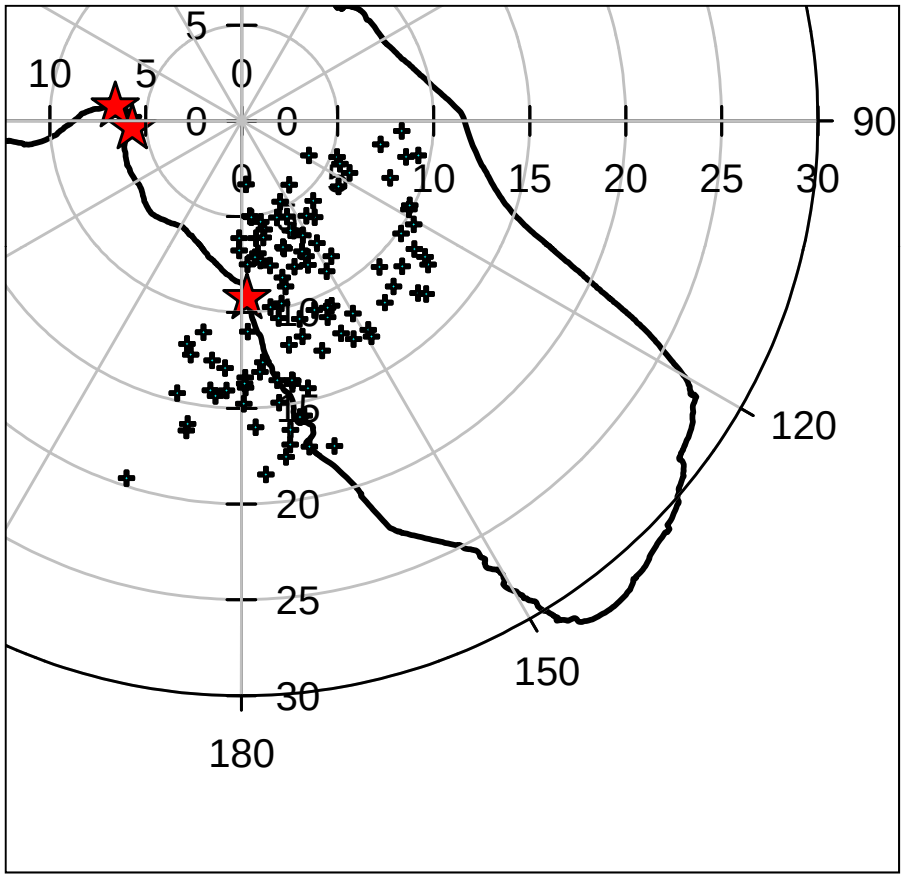
Event	Date	Duration (d)	Avg. Wind Spd. (mph)	Max. Wind Spd. (mph)	Dir.	Avg. Tn (NTU)	Max. Tn (NTU)
1	09/07/12	0.82	16.0	25.6	S	41.2	176.3
2	09/17/12	1.45	10.5	24.0	SE	15.0	143.0
3	09/20/12	1.21	10.4	19.6	SE	19.3	132.0
4	09/21/12	0.52	14.1	22.6	S	36.1	124.0
5	10/09/12	1.23	9.2	21.3	SE	14.1	83.6
6	10/12/12	0.35	15.3	19.6	NE	32.2	104.7
7	10/14/12	2.09	13.8	21.7	variable	17.7	241.8
8	10/17/12	1.78	10.4	23.4	SE	35.2	239
9	10/25/12	0.54	8.7	11.7	SE	21	186.7
10	10/29/12	1.52	15.3	26.7	E, variable	46	327.4
11	11/11/12	1.43	14.4	25.9	S	26	290.2
12	11/23/12	0.29	9.7	13.7	S	19	85.5
13	11/24/12	0.42	17.0	20.0	N	26	90.7


Turbidity plume along shore north of Station 3, Sept. 14, 2012

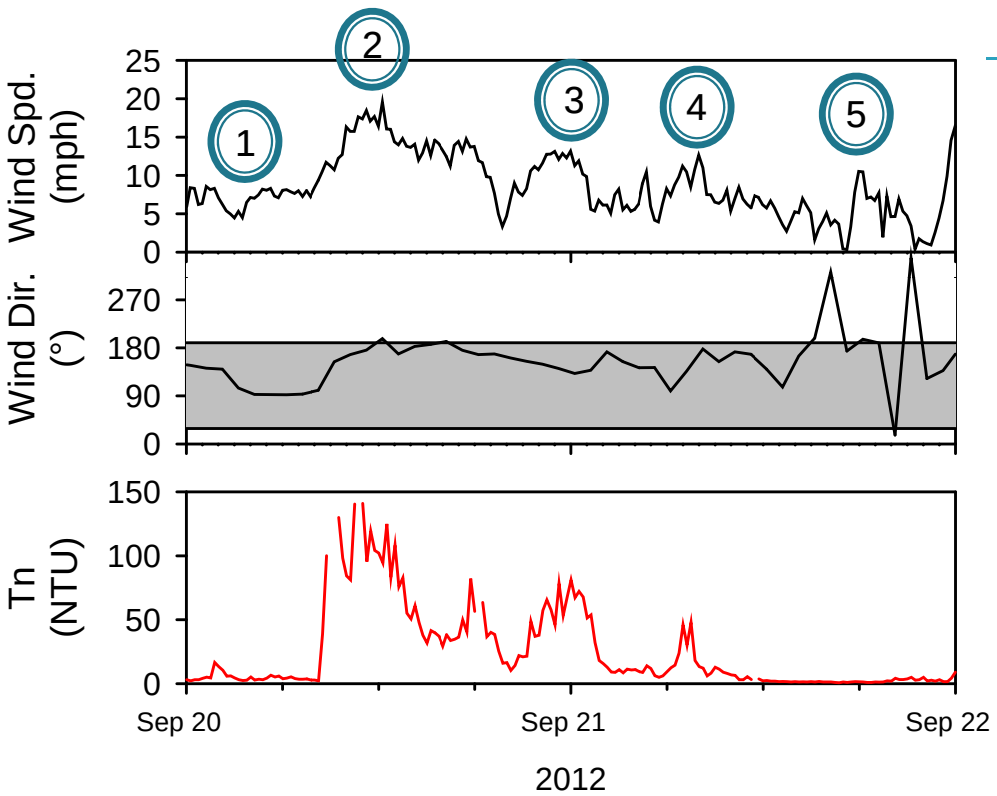
Example Event: September 20, 2012

- Wind event with Tn response Stations 2 and 3, Sept. 20, 2012
  - 9/20 8AM to 9/21 12PM
- Wind speed, 3.0 – 19.6 mph
  - 10.5 mph
- Primarily E to S direction
  - 90 to 180°
- UFI was able to collect 46 Tn observations along west shore
  - 9/20 10AM to 9/20 12 PM
- 3 In-situ sondes functional at 15 min data collection interval
- From primary wind direction, Station 3 and Station 2 should be impacted

Wind compass with lake overlay



Example Time Series: Station 2 In-Situ Sonde Turbidity

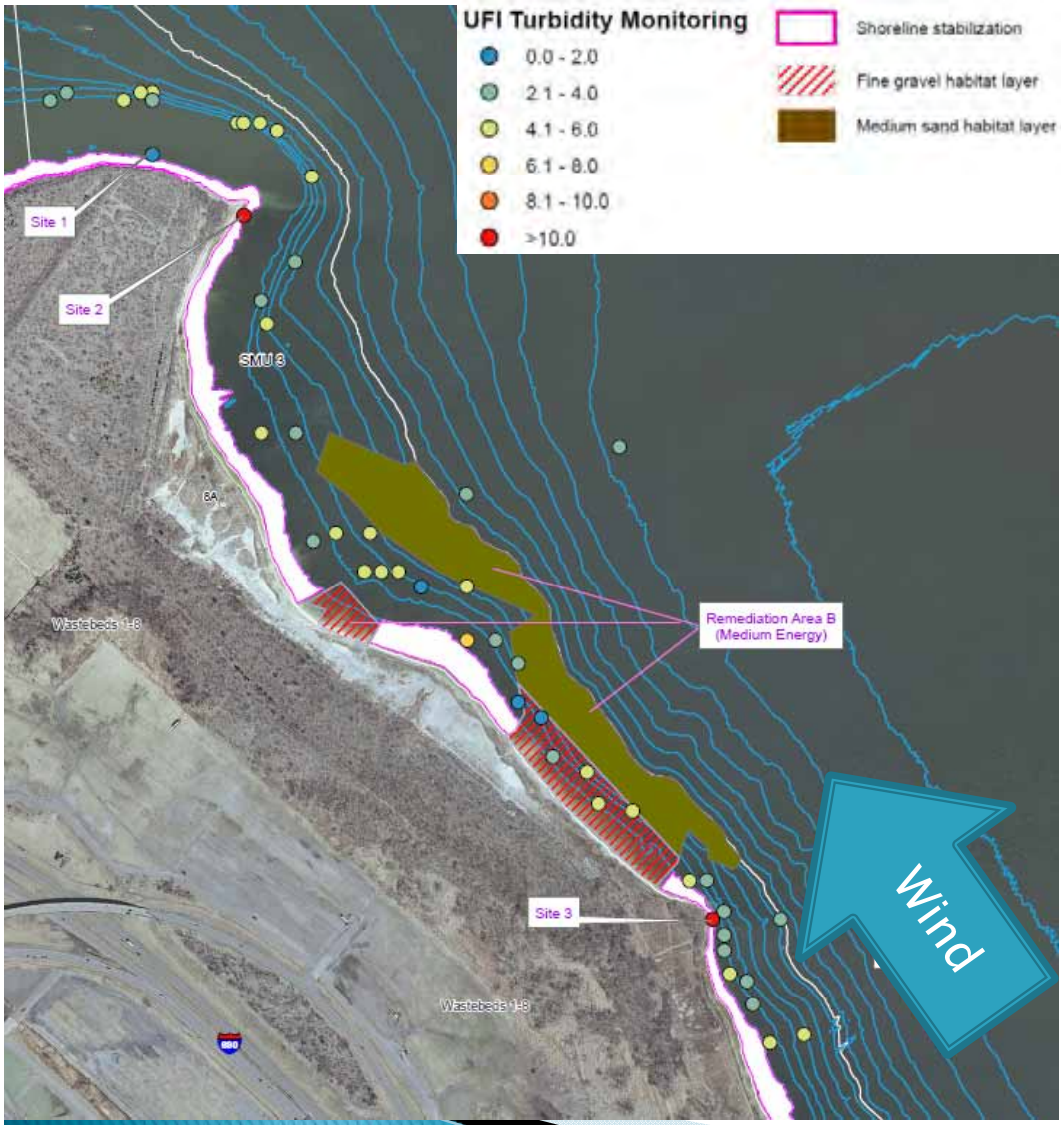


Segment	Wind Spd. (mph)	Wind Dir. (°)	Avg. Tn (NTU)
1	7.0	ESE	5.4
2	13.1	SE	61.4
3	9.7	SE	38.2
4	7.8	SE	12.3
5	4.9	variable	2.1

- **Tn depends on wind speed and direction**

Nearshore Turbidity Patterns

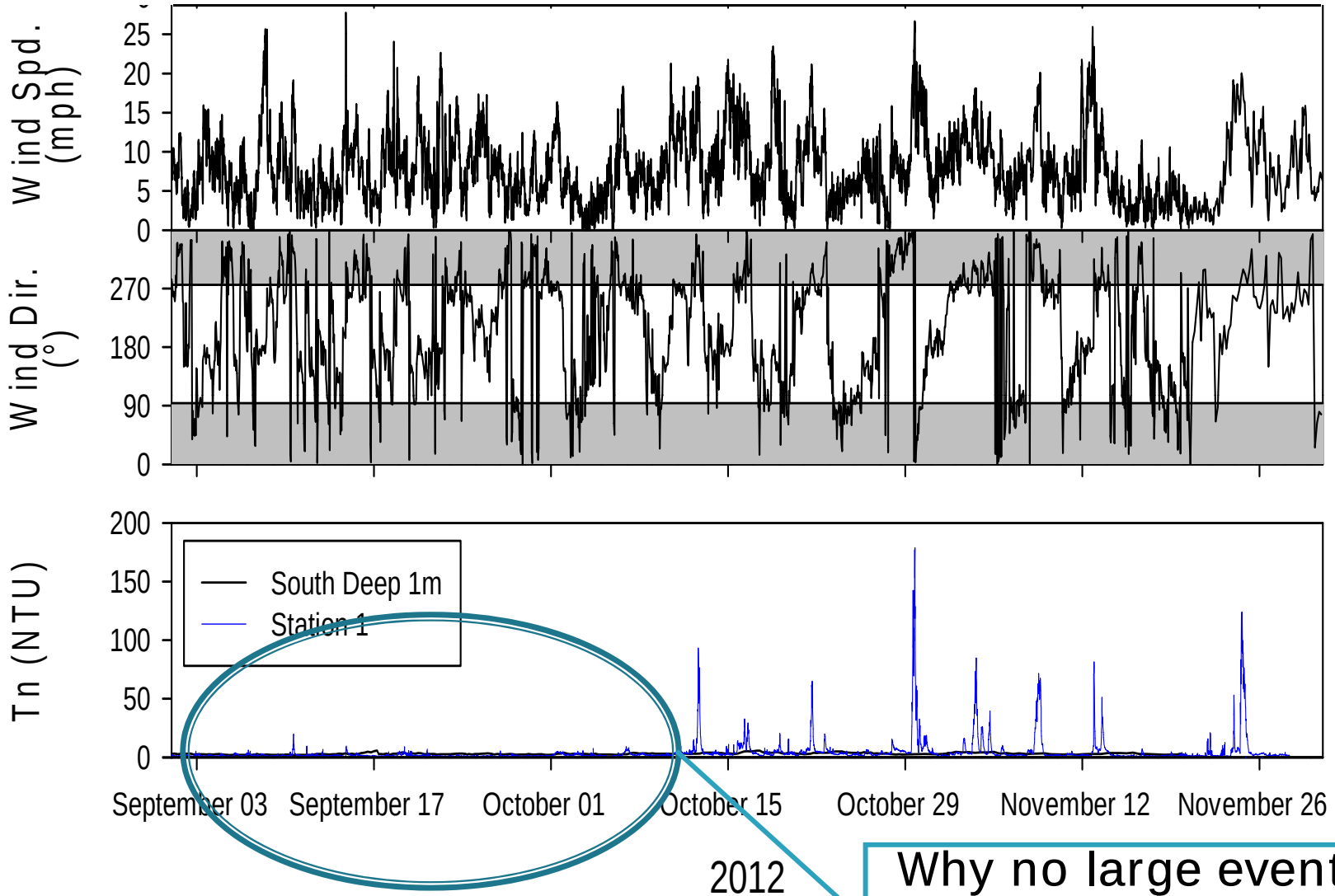
Gridding results



Summary:

- Most Tn observations from the gridding effort were low, ranging from 0.5 to 6 NTU
- Highest Tn was observed to within 20–50 ft of shore
- Highest measured Tn observations were near Station 2 (5– 7 NTU)
- Event average Tn from Station 2 and Station 3 sonde data was 109 and 71 NTU, respectively
- Average Station 1 sonde data was 1.3 NTU
- Average South Deep sonde data was 3.3 NTU

Station 1 Time Series

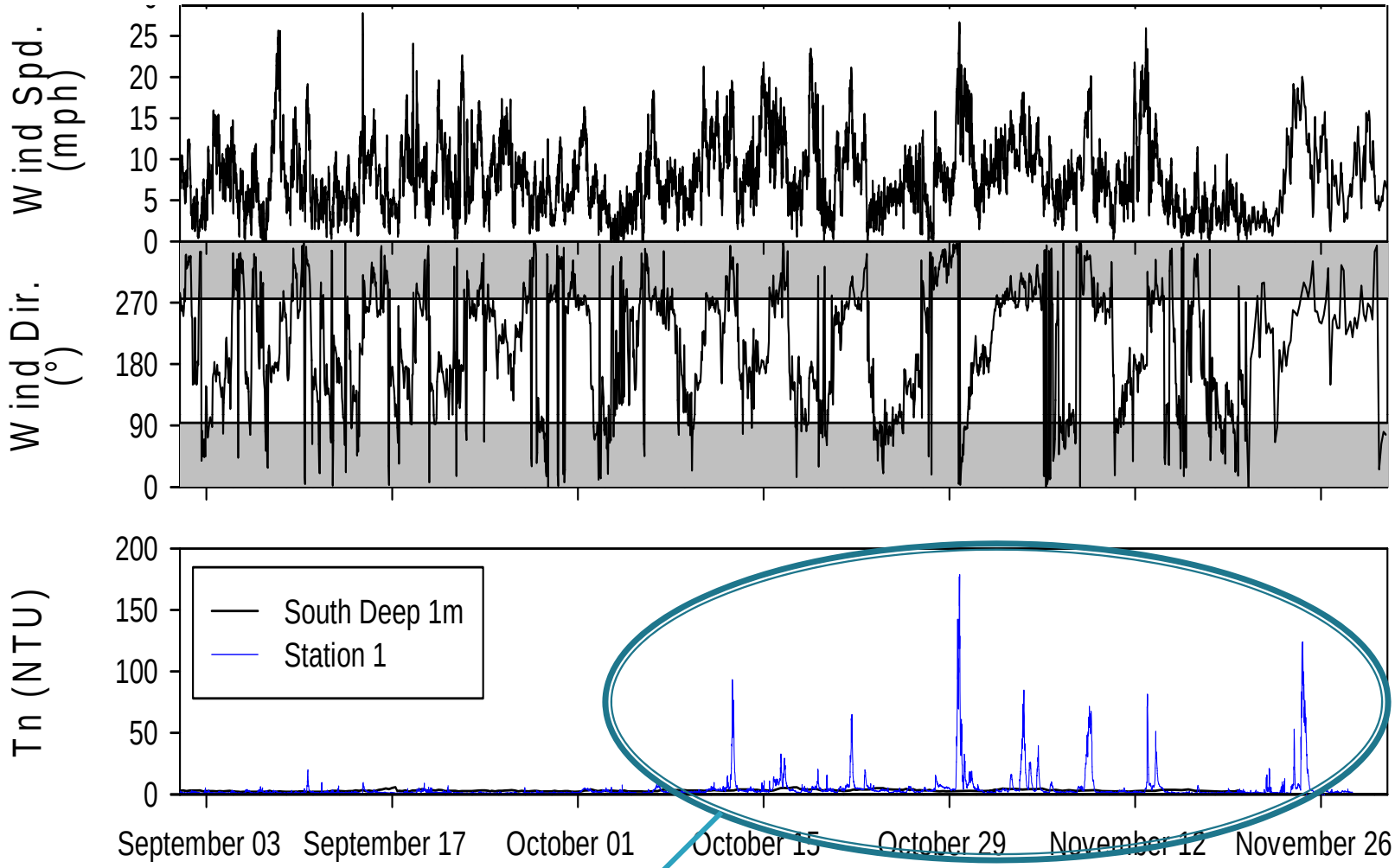


Why no large events at Station 1 in September?

Station 1 in September

- There were wind speed/direction opportunities in September to trigger turbidity events, however no large events were observed.
- Anecdotal evidence indicated large macrophyte beds in/around Station 1 that were present until early-mid October
- Suggests that macrophytes buffered wind/waves from resuspending littoral zone near Station 1

Station 1 Time Series



2012

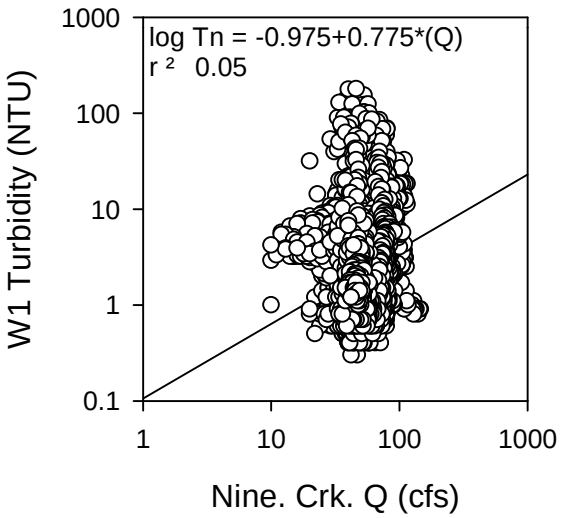
Large events observed after macrophyte senescence

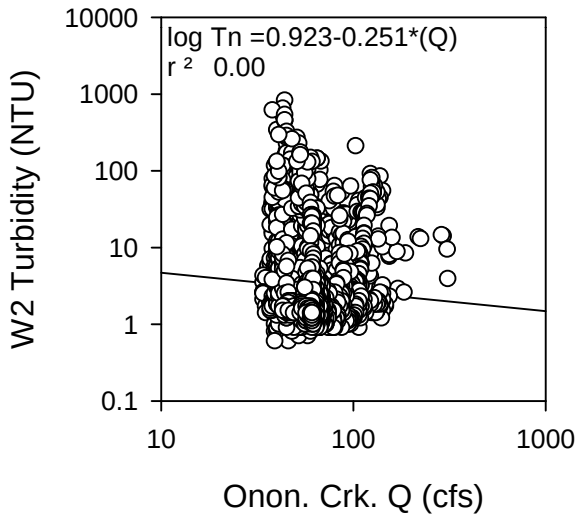
Turbidity Drivers

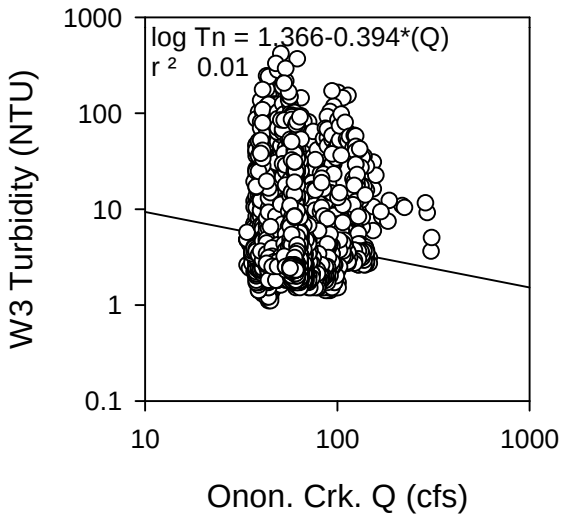
- Stream flow and wind considered

Relationships Between Turbidity and Stream Flow

- Regressed 15 min. Tn data with 15 min stream flow data (nearest major tributary)

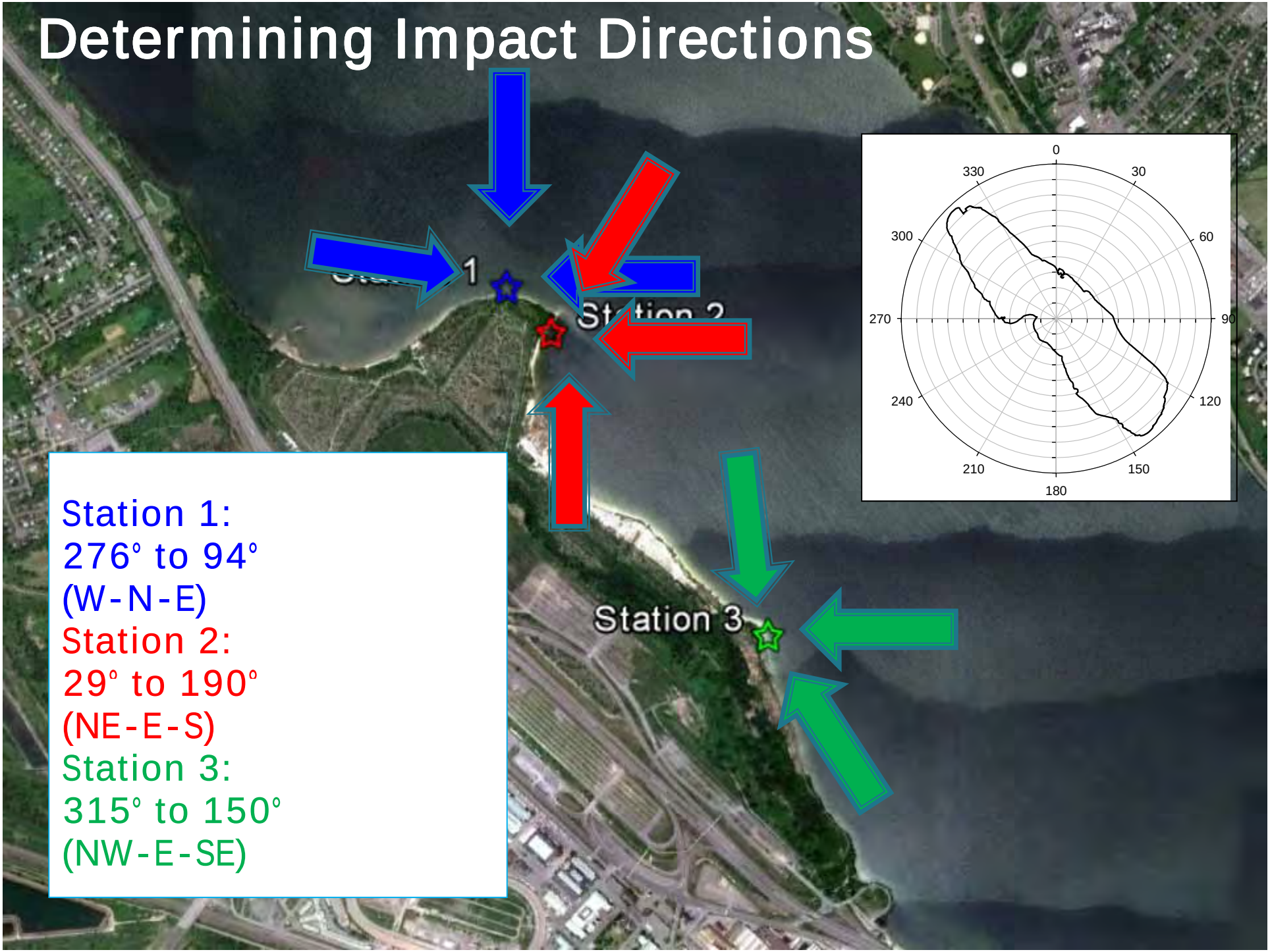






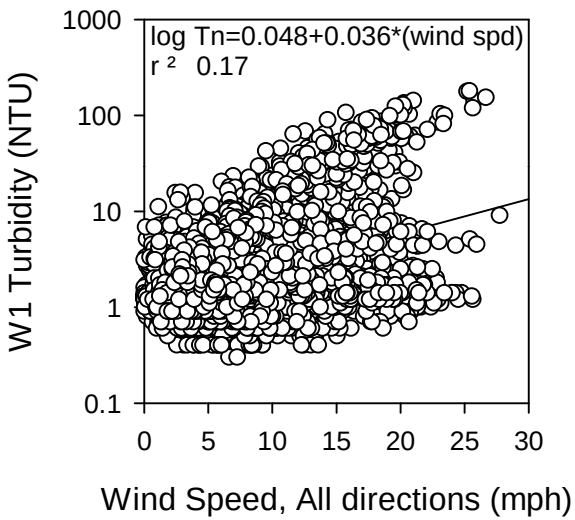
- no significant relationship between stream flow and site Tn during study interval
  - not much variation on flow in fall 2012

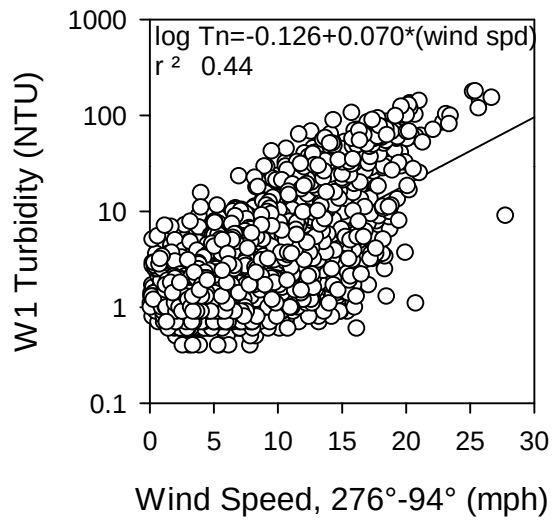
Determining Impact Directions



Station 1:
276° to 94°
(W-N-E)
Station 2:
29° to 190°
(NE-E-S)
Station 3:
315° to 150°
(NW-E-SE)

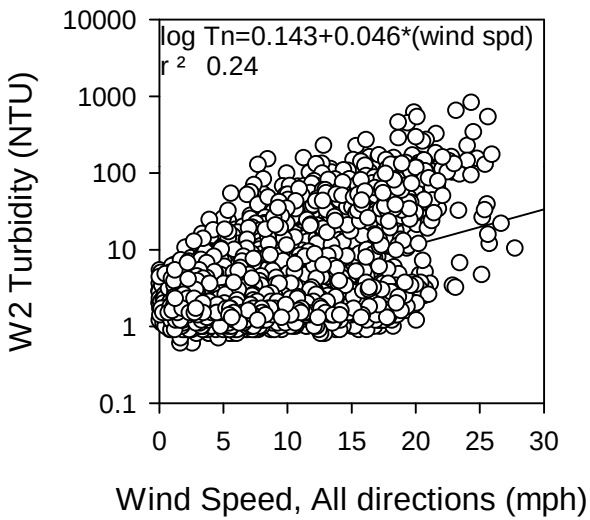
Relationships Between Turbidity and Wind Speed: Station 1

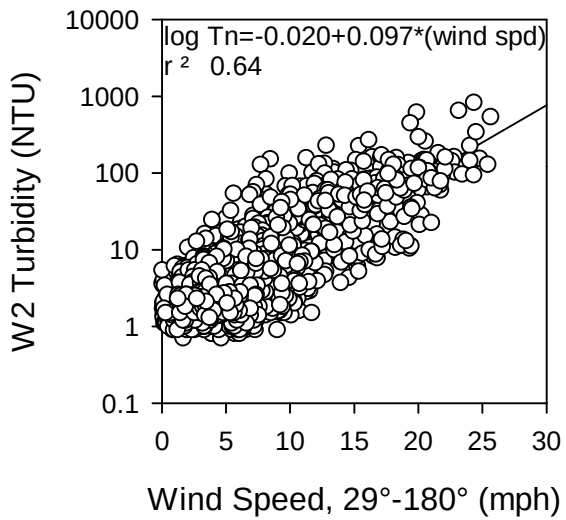




Stronger relationship when only wind directions likely to impact Station 1 are considered

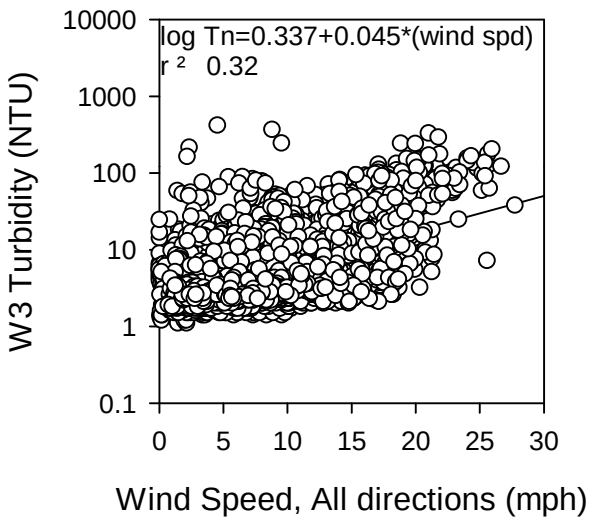
Relationships Between Turbidity and Wind Speed: Station 2

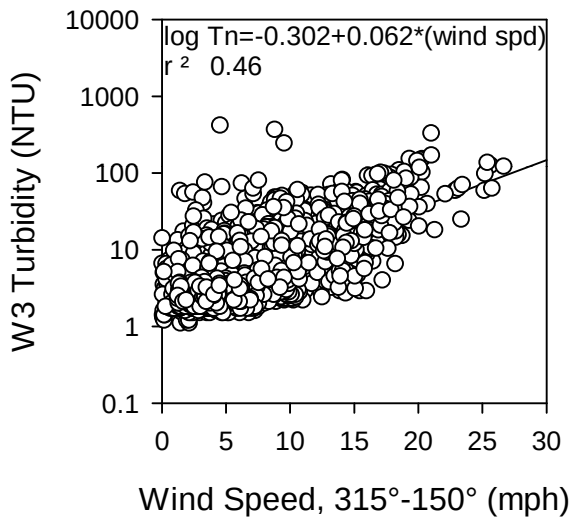




Stronger relationship when only wind directions likely to impact Station 2 are considered

Relationships Between Turbidity and Wind Speed: Station 3

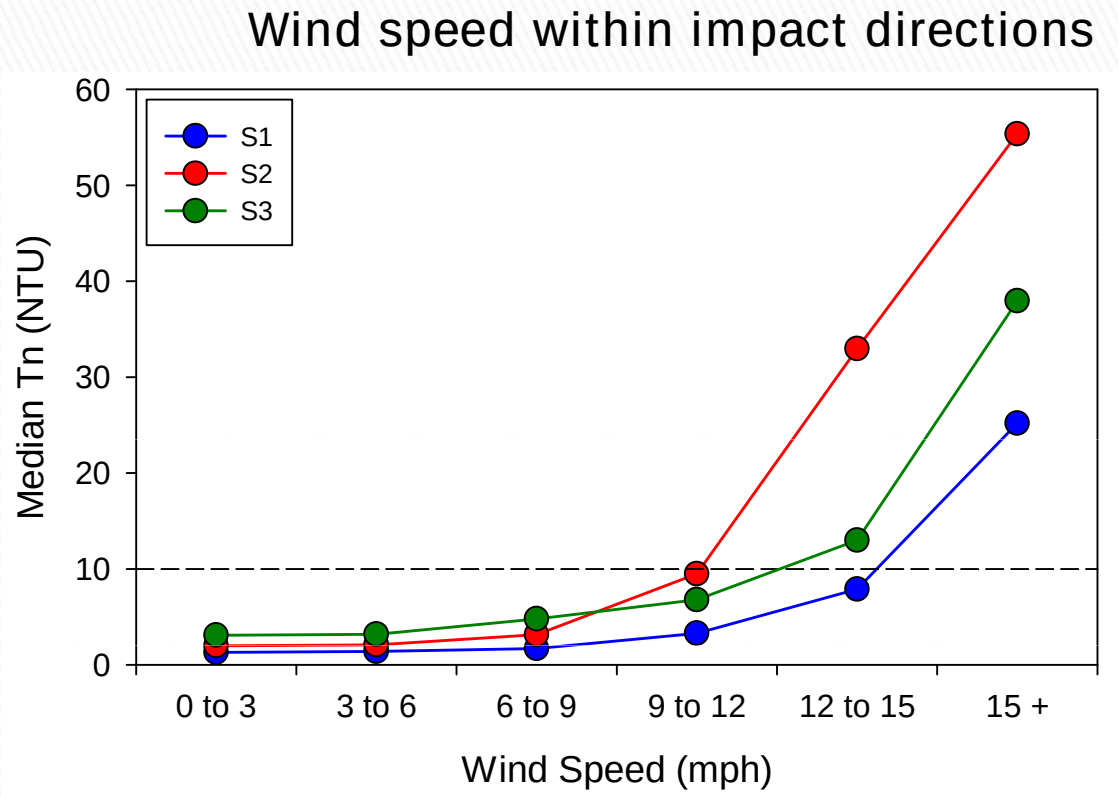




Stronger relationship when only wind directions likely to impact Station 3 are considered

Median Turbidity as a Function of Wind Speed

- All stations demonstrated increases in median Tn as wind speed increased
- Station 1 had the lowest overall Tn at each wind speed interval
- Station 3 had the highest Tn levels at lower wind speeds (0-9 mph)
- Station 2 had higher Tn at the highest wind speeds (9+mph)



Metrics That Can be Used to Evaluate Post-Stabilization Conditions

- Changes in peak Tn during events
  - smaller peaks and/or shorter durations would indicate improvements
- Shifts in median Tn at specified wind intervals
  - lower median Tn at wind intervals would indicate improvements
- Changes in slopes of wind speed vs. Tn regressions
  - lower slopes would indicate improvements

Summary

- Most Tn observations were low - 90 % of observations were less than 11 NTU.
- Large increases in Tn (> 100 NTU) common during periods of elevated wind speed from directions with long fetch
- Good correlation between wind speed (from impact directions) vs. Tn at each site (r^2 ranged from 0.44 to 0.64)
- The most conspicuous Tn plumes were observed close to shore (~ 50 ft., from anecdotal evidence and photographs)
  - wind pushing towards shore?
  - plumes composed of large particles that settle rapidly?
- Evidence that submerged macrophytes limit resuspension of sediment near Station 1

Conclusions

- Sonde deployments are the preferred method for collection of data to identify and quantify wind induced Tn events
- The robust dataset collected in 2012 is sufficient to serve as a baseline for post-stabilization comparison
- Multiple techniques identified to evaluate post-stabilization effectiveness
  - Decrease in Tn "peaks" during wind events
  - Shifts in median Tn at specified intervals of wind speed
  - Changes in wind/Tn slopes
- Path Forward
  - Work plan approval
  - Complete shoreline stabilization starting January 2014
  - Submit data summary report
  - Post-stabilization monitoring; 2015(?)
    - same general scope as 2012 with additional analysis