2015

Long Reach Lane at Long Marsh, Harpswell, 2015 Post-Project Monitoring Report, Year 1 of 5

Matthew Craig
Casco Bay Estuary Partnership

2015 Post-Construction Monitoring Report: Long Reach Lane at Long Marsh, Harpswell

Year 1 of 5

Compensation for the Martin's Point Bridge Project, Falmouth-Portland (PIN 16731.00)

March 2015

Prepared For:

MAINE DEPARTMENT OF TRANSPORTATION
Division of Field Services and Mitigation
16 State House Station
Augusta, Maine 04333

Prepared By:

CASCO BAY ESTUARY PARTNERSHIP
University of Southern Maine
PO Box 9300, 34 Bedford Street
Portland, Maine 04104-9300

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. OVERVIEW

In 2012, the Maine Department of Transportation (MaineDOT) proposed a mitigation project at Long Reach Lane in Harpswell (Figure 1) to compensate for the functional impacts to marine wetlands associated with the construction of the Martin's Point Bridge between Falmouth and Portland. The mitigation project took place in January and February 2014, and resulted in the successful replacement of a 36" (7.1 ft^2 flow area) round concrete pipe beneath Long Reach Lane with a larger 6' x 12' concrete box culvert (72 ft^2 flow area) in February 2014 (photo MaineDOT, below).

This report presents the results of pre-construction monitoring, which occurred during the 2013 growing season, and Year 1 of post-construction monitoring, which occurred during the 2014 growing season, at the Long Marsh mitigation site.

1.1 Project Monitoring

The Casco Bay Estuary Partnership (CBEP), which is hosted by the University of Southern Maine, was contracted by MaineDOT to conduct monitoring within the Project Area for one year pre-construction, and five years post-construction. CBEP, one of 28 National Estuary Programs nationwide, has focused on assessment, restoration, and monitoring at tidal marshes in Casco Bay since 2009.

The *Martin's Point Bridge Wetland Mitigation Plan* (*Plan;* MaineDOT 2012) describes the mitigation site Project Area as the marsh area upstream (south) of Long Reach Lane, and north of a bedrock feature locally known as "the narrows" (Figure 1). The *Plan* also states:

> In "*…the Marsh area south of the narrows … there are three large established patches of Phragmites that makes up approximately 7% of this portion of the marsh surface area. This area is outside of the project area."* (MaineDOT, Section J)

To monitor ecosystem change in response to the mitigation project, CBEP established 10 monitoring Stations at Long Marsh, spaced so that they were evenly distributed. Station 1 was located outside the Project Area, immediately to the north of Long Reach Lane, and Stations 2-10 were located within the Project Area, south of Long Reach Lane and north of the narrows (Figure 2).

The *Plan* specifies parameters for one year pre-construction, and five years post-construction monitoring:

- Hydrology signal – using continuous water level recorders deployed upstream and downstream of Long Reach Lane.
- Pore water and surface water salinity.
- Vegetation – abundance (percent cover) of halophytic, brackish, freshwater, and invasive plant species.
- Channel morphology – cross sectional area.
- Erosion – post-project visual surveys within the construction area.
- Photo stations.

1.2 Summary of Mitigation Goals and Performance Standards

The stated objective of the mitigation project was to eliminate the tidal restriction created by Long Reach Lane in Harpswell (MaineDOT 2012). The following performance standards were established for this objective:

1) *Tide curve data upstream of the crossing will be 80% or greater than that of the downstream area after crossing construction…The intention is that 80% (as opposed to 100%) removal will give us a comfortable operating margin, accounting for potential uncertainty in the model. If this standard is not met, the opening size will be enlarged to meet this standard. There may be a phase delay associated with this site after construction which will not be remediated.*
2) *All the constructed features such as slopes, soils, substrates within the mitigation site will be stabilized and free from erosion.* (MaineDOT 2012, Section I)

In addition, the *Plan* laid out a set of mitigation goals:

1) *Vegetation in the upstream marsh will transition from a salt marsh – brackish – freshwater system to predominately salt tolerant species. After the culvert replacement it is expected that a salinity gradient will limit freshwater species establishment. These species will be confined to the marsh edge fringe where overtopping does not occur and will include at a minimum the southernmost 30 acres of the marsh.*
2) *Invasive species, namely Phragmites australis (Common Reed) and Lythrum salicaria (Purple Loosestrife) will be monitored and controlled using integrated pest management techniques. The goal will be to eliminate the establishment of Common Reed and Loosestrife in the marsh*

restoration area. The project enhancement and restoration area does not support any Common Reed or Purple Loosestrife. (MaineDOT 2012, Section J)

Review of the 2013 and 2014 monitoring data indicates that site conditions within the Project Area are changing in response to the new culvert, consistent with the mitigation project objective, performance standards, and goals. Table 1 summarizes the status of tidal hydrology, erosion, and other monitored parameters in the first growing season post-construction (2014), based on a comparison with pre-construction monitoring data collected in 2013, and describes whether the status is consistent with pre-defined standards and goals for the mitigation site.

The performance standards – hydrology signal and erosion control – were met in 2014. Comparison of tidal hydrology data in 2013 and 2014 demonstrates that the primary performance standard for the mitigation site, that the upstream tide curve exceeds 80% that of the downstream tide curve, has been achieved as a result of the increased flow volume provided by the new culvert. A detailed analysis of tidal hydrology is provided in Section 3.1. The second performance standard – erosion control – met the standard in 2014, with the slopes, soils, and substrates within the mitigation site stable.

For the remaining monitoring parameters, response to the modified hydrology beneath Long Reach Lane is presumed to be ongoing, with Year 1 post-construction data indicating that changes in site conditions are 'on-track' in that they are consistent with the objective and goals for the mitigation site over the 5-year post-construction monitoring period.

Table 1. Summary of Performance Standards and Monitoring Parameters

Performance Standard/ Monitoring Parameters	2014 Findings (Year 1 post-construction)	Meet Standard?*
Hydrology signal	*Upstream tide curve exceeds 80% that of downstream tide curve*	Yes
Erosion control	*Slopes, soils, substrates within the mitigation site are stable*	On-track
Pore water salinity	*Pore water salinity levels increased throughout the Project Area*	On-track
Vegetation community	*Salt marsh vegetation abundance increased in the Project Area; brackish and freshwater vegetation abundance decreased, with extensive dead cat tail stands*	On-track
Channel morphology	*Channel cross sectional area increased throughout Project Area*	On-track
Invasive species	*Purple loosestrife nearly eliminated from Project Area*	On-track

* *Hydrology signal and erosion control are the only two performance standards. Assessment of other monitoring parameters provided for context.*

1.3 Remedial actions

CBEP is not aware of any remedial actions that were recommended or undertaken by MaineDOT at the mitigation site.

Generally it is not CBEP's role to undertake remedial actions at the site. CBEP observed Purple Loosestrife at several locations within the Project Area during 2013 pre-construction monitoring. These observations were georeferenced and photographed and a careful survey for Purple Loosestrife was undertaken in 2014. Year 1 post-construction invasive plant monitoring indicates that the increase in tidal inundation has greatly reduced the abundance of Purple Loosestrife in the Project Area. CBEP field staff hand-pulled a few individual Purple Loosestrife plants clustered near the upland edge at Station 4 in 2014. Plants were destroyed to prevent propagation. Based on the sharp decline in invasive plant observations in 2014, which is presumed to be a response to the increase tidal inundation and soil salinity, we anticipate that Purple Loosestrife could be completely absent from the site within the 5-year monitoring period. CBEP will continue to intensively survey the Project Area for invasive plants, and any observations will be documented, georeferenced, photographed, and flagged. CBEP will consult with MaineDOT on management strategies for Purple Loosestrife and any other invasive plant species as needed. Additional information on species of concern is provided in Section 3.6.

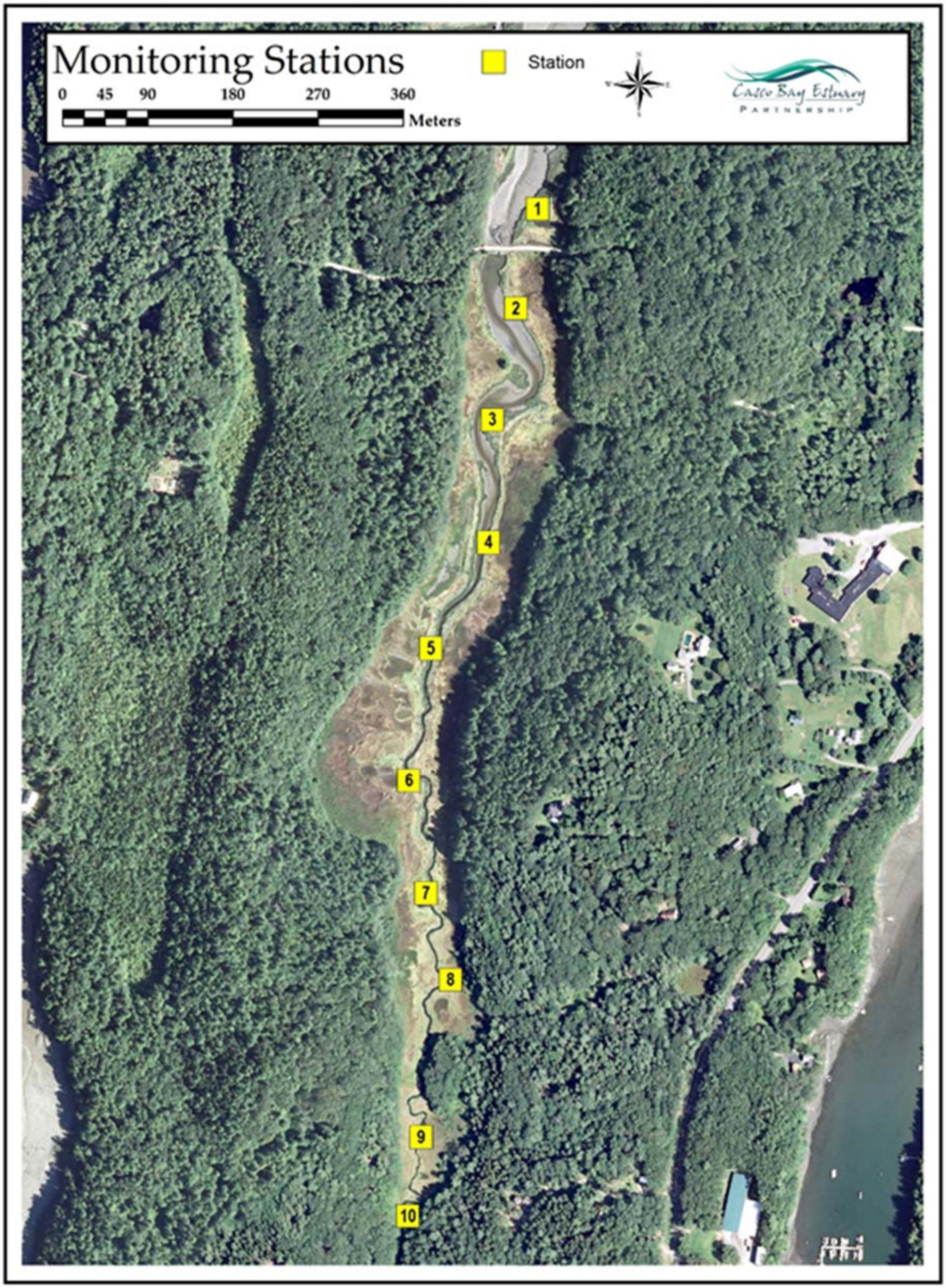
CBEP also removed a few large pots discovered in dead cattail stands near Station 4, and other litter, as needed, that washed onto the high marsh in 2013 and 2014.

1.4 Erosion

The mitigation site is stable. As expected, the creek channel is widening and deepening within the Project Area in response to the changed hydrology resulting from the new culvert beneath Long Reach Lane. Other than this morphological response of the creek channel to the increased tidal exchange, and the associated sediment movement within and out of the system, the slopes, soils, and substrates adjacent within the construction area at Long Reach Lane were stable and no remedial actions were deemed to be necessary. CBEP will continue to closely monitor the stability of soil conditions at the Long Reach Lane construction site in years 2-5.

Figure 1. Project Area map.

Figure 2. Monitoring Station location map. Long Reach Lane is visible between Station 1 and Station 2. Stations 2-10 fall within the Project Area.



2. METHODS

Construction was originally anticipated for winter 2012/13 and so 2013 was expected to constitute the post-construction period. However, construction took place in winter 2013/14 so 2013 constitutes pre-construction, and 2014 constitutes Year 1 post-construction. Monitoring methods are based on protocols and methods laid out in Sections K and L of the *Mitigation Plan*, and which generally align with protocols set forth in the *Regional Standards to Identify and Evaluate Tidal Wetland Restoration in the Gulf of Maine* (Neckles & Dionne 1999) for the selected parameters. Parameters were monitored in association with designated Stations unless otherwise noted (Table 2).

Table 2. Monitoring parameters by Station.

Station	Hydrology Signal	Pore Water Salinity	Surface Water Salinity**	Vegetation	Channel Morphology	Plant Species of Concern
1	X	X		X	X	X
2	X	X	X	X	X	X
3				X	X	X
4		X		X	X	X
5				X	X	X
6		X*		X	X	X
7				X	X	X
8		X	X	X	X	X
9			X	X	X	X
10		X	X	X	X	X

* At Station 6, two pore water wells were monitored.
** Surface water salinity data was collected at multiple Stations in 2013 & 2014, but some data were not included in this report due to equipment malfunction.

2.1 Hydrology signal

MaineDOT used Solinst Levelogger Gold unvented loggers to monitor pre- and post- construction surface water hydrology. A separate Solinst Barologger was deployed so that a barometric correction could be applied and logger data converted to water depth on logger. The depths were converted to elevation by relating surveyed elevations at known times to corresponding data logger water depths.

The *Plan* provided the following guidance for

monitoring hydrology signal:

> *Two tide data loggers will be installed upstream and downstream of the Long Reach Lane culvert and measurements conducted 2 months prior and post construction. The downstream logger will be located in the downstream transect and the upstream logger in the mid marsh area transect.* (MaineDOT 2012, Section L)

2.2 Pore water salinity

CBEP constructed wells from 2" PVC consistent with established protocols for monitoring pore water salinity (Neckles and Dionne 1999). Pore water wells were installed at Stations 1, 2, 4, 6, 8, and 10 approximately 10 meters from the tidal creek channel edge. An additional pore water well (6a) was installed approximately 10 m from the upland edge at Station 6 (Figure 3). Surface water samples are taken from the tidal creek where vegetation transects intersect with the marsh channel. Water samples are collected using a syringe with a tube for extension into wells and the tidal creek, and sampled within two hours of predicted low tide. Salinity readings are read from a handheld refractometer that is calibrated with de-ionized water. Observations are recorded on a site-specific data sheet.

Figure 3. Pore water well location map.

2.3 Surface Water Salinity

Two methods are used to monitor surface water salinity: (1) grab sample collection during rounds of pore water salinity sampling within +/- 2 hours of low tide; and (2) deployment of automated sondes to collect samples every 15 minutes.

Grab samples are collected using a syringe with a tube for extension into wells and the tidal creek, and sampled within two hours of low tide. Salinity readings are read from a handheld

refractometer that is calibrated with de-ionized water. Observations are recorded on a site-specific data sheet.

CBEP used In-Situ *Aquatroll 200* vented data loggers to collect continuous salinity readings for extended periods, typically 2-3 weeks per deployment. These instruments collect multiple parameters including water surface level, temperature, conductivity, and salinity. Instruments are programmed to collect 3 averaged readings, which are recorded every 15 minutes.

CBEP loggers are deployed in PVC pipes secured to 5' tall (typ.) metal fence posts that were previously hammered into the creek channel bottom. Vented cables are run from the instrument onto the marsh surface and then suspended several feet above the surface using metal fence posts and PVC housing, to ensure that the cable tip, which enables mid-deployment downloads, remains dry for the duration of the deployment period. Between deployment periods, loggers are calibrated in the lab according to manufacturer specifications for conductivity/salinity measurements. Loggers are sent to the manufacturer on an annual basis to calibrate the pressure transducer, maintain O-rings, and assess overall instrument function.

Typical deployment of Aquatroll 200 surface water salinity monitoring instruments.

2.4 Vegetation

CBEP established vegetation transects at each Station. Transects were set to allow for representative sampling of established marsh areas and adequate sampling intensity. Vegetation data are collected in meter-square plots located every 10-15 meters along the length of each transect. The number of plots collected along each transect varies from 10 to

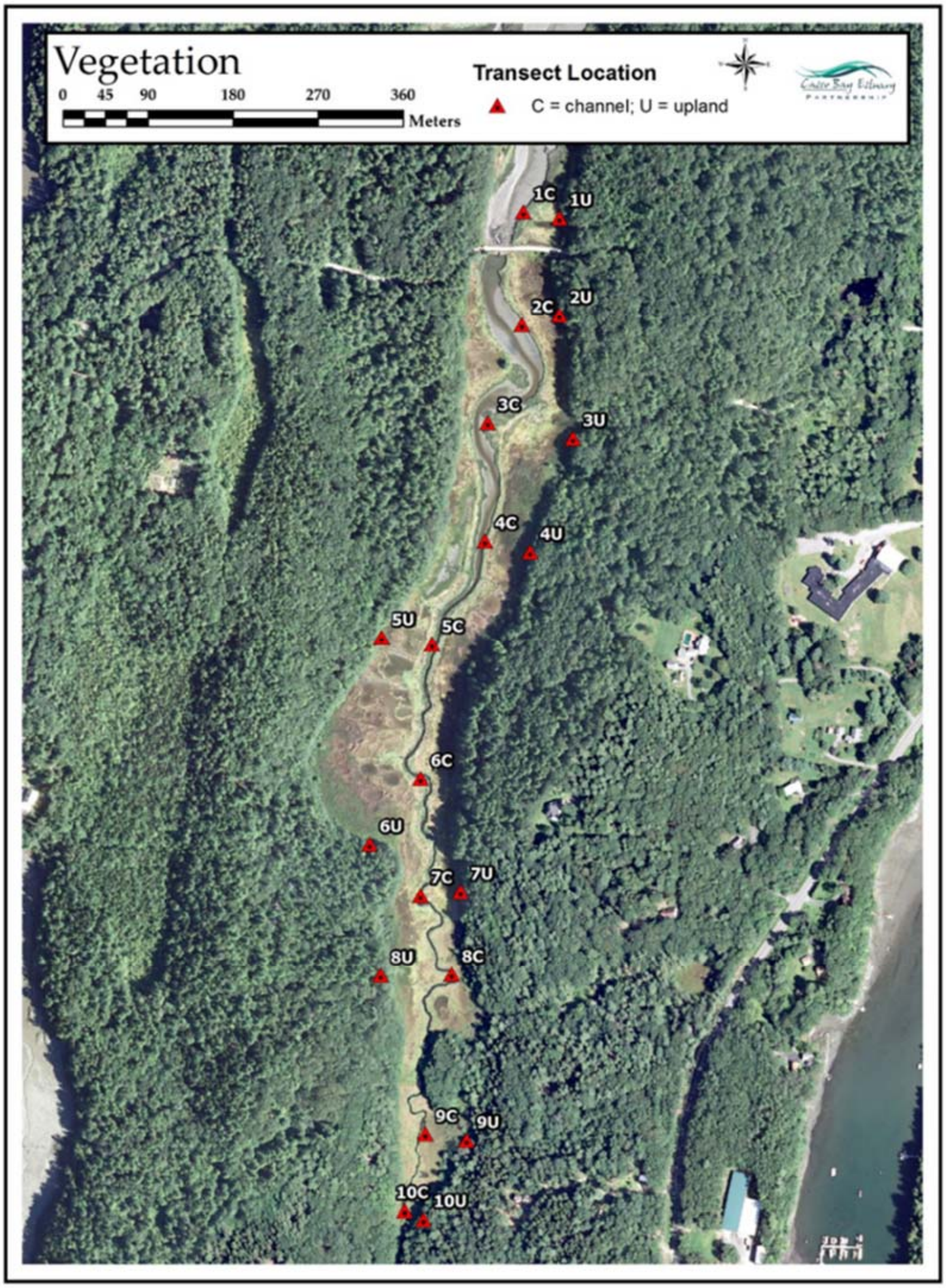


Figure 4. Vegetation transect location map.

12, with most transects having 11 plots. Observers replicate transect locations year over year by extending a tape measure from a PVC stake marking the channel edge (e.g., 1C) to another PVC stake located at the upland edge (e.g., 1U) (Figure 4). Transects run perpendicular to the tidal creek toward the upland edge, with 0' (zero) starting at the channel. Data collected in each plot includes: (1) a list of the well represented (>10% coverage) species in the plot; (2) percent coverage by those species; (3) overall percent coverage for the plot; and, (4) general hydrologic conditions. Data for each plot was recorded on a separate data sheet. All project vegetation data are entered into a Microsoft Access database.

2.5 Channel Morphology

CBEP established channel cross section transects at each Station. In addition, CBEP surveyed a longitudinal profile of the channel bottom from Station 1 to Station 3 (approximate). Cross sectional areas are surveyed in identical locations from stakes on the east and west side of the channel (e.g., XS1E, and XS1W; Figure 5) proximate to where vegetation transects originate at the marsh channel. Elevations are surveyed at regular increments or where elevation grade changes are evident, using an auto level on a tripod and a stadia rod, and tied to local benchmarks with known elevations relative to NAVD 88. Cross section and longitudinal profile data are recorded onto project-specific data sheets and entered into the *Reference Reach Spreadsheet* (Mecklenburg 2006) to standardize and quantify survey data. The spreadsheet is used broadly in among natural resource managers as a tool for quantifying channel morphology (Alex Abbott, personal communication).

Figure 5. Cross section transect location map.

2.6 Plant species of concern

Once per field season, an intensive meander survey for invasive plant species is conducted throughout the Project Area. Incidental observations of invasive plants during other monitoring activities are also documented. During the meander survey, invasive plant species are identified, photographed, described in field notebooks, geo-referenced, and flagged if possible. Any indication that invasive plant species of concern are establishing or expanding within the Project Area would be immediately communicated to DOT, with recommendations for control measures, if needed.

2.7 Erosion

CBEP conducts regular visual surveys within the construction area to check for signs of erosion along the road bank, or structural failure within or adjacent to the culvert. Observations of erosion would be recorded and findings would be photographed, georeferenced, flagged, and immediately reported to DOT if needed.

2.8 Photographic documentation

CBEP established a series of photo stations associated with the construction area, channel cross sections, and vegetation transects in order to provide a visual record of changes at and adjacent to the mitigation site and the Project Area during the monitoring period. Photos are taken annually at a minimum at each photo station.

2.9 Wildlife use

CBEP collects data on general wildlife use or signs observed throughout the mitigation site and Project Area during each visit.

2.10 Additional data

Additional data sets have been collected at Long Marsh by CBEP and other researchers during the monitoring period.

- Additional field observational data, such as dead vegetation, etc., was periodically collected during the course of field sampling activities, recorded in field notebooks, and photographed, by CBEP staff.
- As part of broader CBEP monitoring of tidal marshes in Casco Bay, two additional Stations were established outside of the Project Area, to the south of “the narrows,” and as time allowed, CBEP collected data on the core parameters at these Stations. Parameters monitored included vegetation transects, pore water and surface water

salinity, surface water hydrology, and channel cross sections. These data were collected at no cost to DOT, but are available separately from this report upon request.

- University of Southern Maine Department of Biology graduate student Andrea (Shri) Verrill, working with guidance and assistance from CBEP staff, collected additional vegetation, marsh elevation, groundwater elevation, and pore water salinity data in 2013 and 2014 as part of her master's thesis research. These data were not included in this report.
- Dr. Beverly Johnson from Bates College collected groundwater hydrology data at multiple locations in the marsh in 2013 and 2014. These data were not included in this report.
- Project SHARP (Saltmarsh Habitat & Avian Research Program), of which the University of Maine's School of Biology and Ecology is a collaborator, has a long-term bird monitoring station on Long Marsh, located within the Project Area.

3. RESULTS & DISCUSSION

This section presents results from 2013 (pre-construction) and 2014 (Year 1 post-construction) monitoring of surface water hydrology, pore water and surface water salinity, vegetation, channel morphology, plant species of concern, wildlife use, erosion, and photo documentation.

The new culvert increased ice movement within the Project Area (CBEP, March 2014).

Replacement of the culvert at Long Reach Lane took place over several weeks during the winter of 2013-2014 and concluded in February. A thick layer of ice covered much of the flats, tidal creek, and adjacent marsh surface over the winter. As ice thawed, the new increase in tidal exchange resulted in large blocks of ice moving between the creek and high marsh surface, depositing wrack, sediments, and chunks of peat on the high marsh. At a small scale, vegetation communities, marsh surface elevation, and channel morphology appear to have been altered by ice scour and resulting sediment deposition, following decades of impoundment. Ice movement affected the location of markers and wells at some Stations, but only one marker, denoting the vegetation transect at Station 1, was lost.

Peat and sediment on the high marsh surface resulting from ice scour, at Station 1 (top), and Station 6 (bottom; CBEP,

Hydrology signal, pore water salinity, vegetation, channel morphology, and plant species of concern were monitored in 2013 and 2014. Photo stations, and other observations such as wildlife use, were also recorded. The results of pre-construction monitoring in 2013, and Year 1 post-construction monitoring in 2014, are provided below.

3.1 Hydrology Signal

Note: The content for this section was provided by Charles Hebson, P.E., Chief Hydrologist with MaineDOT. The figures referenced in the text have been grouped at the end of this section.

There are two performance objectives for the compensatory Long Reach Lane (LRL) culvert replacement in the *Martin's Point Bridge Wetlands Mitigation Plan*. The first objective pertains to hydraulic performance of the replacement box culvert:

> *Tide curve data upstream of the crossing will be 80% or greater than that of the downstream area after crossing construction (see Reference Elevations for Mean High Water). The intention is that 80% (as opposed to 100%) removal will give the sponsor a comfortable operating margin, accounting for potential uncertainty in the model. If this standard is not met, the opening size will be enlarged to meet this standard. There may be a phase delay associated with this site after construction which will not be remediated.* (MaineDOT 2012, Section I)

Based on our evaluation of pre- and post-construction water level data, we conclude that this performance objective has been met.

Data Collection

MaineDOT collected water level data in the years 2012, 2013 and 2014. Construction was originally anticipated for winter 2012/13 and so 2013 was expected to constitute the post-construction period. However, construction took place in winter 2013/14 so 2014 constitutes post-construction.

Solinst Levelogger Gold unvented loggers were used; a separate Solinst Barologger was deployed so that a barometric correction could be applied and logger data converted to water depth on logger. The depths were converted to elevation by relating surveyed elevations at known times to corresponding data logger water depths.

The periods of data collection were:

2012: 11 June – 4 December
2013: 30 April – 10 December
2014: 23 April – 19 November

2012: Loggers were deployed at 3 locations: downstream (DS), i.e., the open water north of Long Reach Lane that forces the tidal response in Long Reach Marsh; lower marsh (LM), just south of Long Reach Lane; mid marsh (MM), in the channel south of the lower marsh logger. These locations are proximate to monitoring Stations 1, 2, and 4/5, established in 2013. A subset of the 2012 data (6/11 – 8/07) was presented in the *Mitigation Plan*.

2013: In addition to the 2012 locations, 2 additional locations (for a total of 5) were included, upper marsh (UM) and above narrows (AN). Altogether, these locations are proximate to monitoring Stations 1, 2, 4, 8 and 10.

2014: The same general locations were used as in 2013. The UM logger was located above the rock ford in the upper marsh (approximately at Station 9).

Data Evaluation

For consistency with the *Mitigation Plan* document, data for 6/11-8/07/2012 were used as the baseline pre-construction data set for comparison to the 2014 post-construction data; the 2013 data are not presented here. The stage drop across Long Reach Lane is the difference in stage at the DS and US locations and is the basis for evaluating the effectiveness of the new box culvert. The upper marsh (more southerly) loggers provide useful information on the propagation of the tidal signal into the upper marsh. However, since they do not figure directly in the evaluation of the mitigation performance objective they are not discussed here.

The original culvert at LRL, prior to replacement, was 36" diameter and thus constituted a serious restriction to tidal exchange with Long Reach Marsh south of LRL. The restriction manifested as a "head (stage) drop" from one end of the culvert to the other on both incoming and outgoing tides. On incoming tides, the restriction reduces the tidal flow that would otherwise pass under LRL. On outgoing tides, the restriction inhibits drainage of the marsh. The head drop is greatest at high tides, limiting inflow. Comparing downstream (open water) high tides to upstream (or lower marsh) high tides, the head ranged from 0.5' to over 2' at spring tides. The objective of the compensatory culvert replacement was to significantly reduce and effectively eliminate this restriction.

These high tides are critical to establishment of salt marsh vegetation on the high marsh surface. The marsh surface was rarely inundated. With outgoing tides, the restriction prevented adequate drainage, thereby inhibiting development of intertidal vegetated and mudflat habitat.

The performance objective is posed as a percentage reduction in the head drop across the culvert. Head is defined between corresponding high tides downstream (open water; north of LRL) and upstream (lower marsh; south of LRL):

$$\Delta = {}_{ht}Z_{ds} - {}_{ht}Z_{us}$$

Hereafter, the subscript "ht" will be dropped, with the understanding that we are referring to high tides. The percent reduction from pre-construction to post-construction, as compared to pre-construction head drops, is:

% Reduction = 100 x $\{(\Delta_{post} - \Delta_{pre})/ \Delta_{pre}\}$

For the purposes of this evaluation we will be using tidal data sets from 2012 (pre) and 2014 (post). We also collected data pre-construction data in 2013, but are using the 2012 data set for consistency with the *Mitigation Plan*. Then our % reduction is calculated as:

% Reduction = $\{(\Delta_{2014} - \Delta_{2012})/ \Delta_{2012}\}$

We present most of our results as a side-by-side comparisons of data from 2012 and 2014. Figure 6 shows Portland high tides vs. downstream high tides. As expected, the results are the same for both years. Open water (downstream) high tide elevations are essentially identical to Portland. Similarly, high tide times of occurrence are also nearly identical, as shown in Figure 7. The scale obscures the actual differences in time of occurrence, which can be as large as 10 minutes or so.

Figure 8 shows a typical high tide window, taken in July. (Note that the date of highest tide has shifted from 2012 to 2014.) Figure 8 shows the impact of replacing the 36"D pipe with the 6'R x 12'S box culvert. Note how the 2012 maximum drop of 2' (7/8/12) has been reduced to less than 6". The upstream low tide has also been reduced, reflecting improved drainage due to the lower invert of the new culvert. However, drainage is now controlled by the channel elevation upstream of the head cut, not by the culvert invert. This figure, while illustrative, is not particularly useful for further analysis.

Figure 9 shows the extracted high and low tides for upstream (US), downstream (DS) and Portland (Port). This shows how the drop in 2012 ranges from 3"- 6" at the lowest high tides to slightly more than 2' at the highest high tides. In 2014, the drop across the culvert has been eliminated, at least by visual examination at this scale. Again, the upstream low tide has not changed much, because it is controlled by channel elevation and not culvert invert.

Figure 10 shows the head drop for the same data window in the previous figures. The maximum head drop, occurring at the maximum high tides, has been reduced from 2' to 0.33', a percent reduction of 100 x {(2 – 0.33)/2} = 83.5%, exceeding the performance standard. The graphs in Figure 10 have essentially the same shape, and might suggest that there has been no change if one does not pay careful attention to the vertical scale. Therefore, the time series have plotted to the same scale in Figure 11. The reduction in head drop is immediately evident.

The graphs presented thus far are useful in showing the improvement that has been achieved, how it evolves over the tidal cycles, and how it relates to higher and lower high tides. However, such time series graphs are not ideal for systematically evaluating the entire data sets, with particular attention to high tides. Therefore, the remainder of the discussion will focus in the high tides that have been extracted from the complete data series.

Figure 12 compared downstream to upstream high tides. The red line is the line of perfect match; flow restriction and consequent head drop are indicated when the data pairs fall below the match line. The drops are always smaller with the lower high tides and larger with the higher high tides. The improvement from 2012 to 2014 is obvious. Figure 13 shows the data for 2012 and 2014 plotted together, as well as showing the "best fit" quadratic curves fitted to the data. These curves will be used later to numerically evaluate the head drop reduction that has been achieved.

The head drop data are shown explicitly in Figure 14, with the drops plotted against the downstream stage. The vertical horizontal "zero line" indicates the hypothetical case of no drop and perfect match between downstream and upstream. Again, careful attention should be paid to the vertical scale. The data show the same shape, and superficially are similar except that there is much more scatter in the 2014. However, the magnitudes of the 2014 data are much smaller than the 2012 data (2014 vertical scale maximum = 0.5 vs. 2012 vertical scale maximum = 2.0). The scatter in the 2014 data is explained by the fact that the magnitude of the drops, particularly at the lower high tides, is of the same magnitude as the noise in the data. The 2012 drops are significantly larger the noise, and so the scatter is not as pronounced.

The same data are depicted in Figure 15, with linear and log vertical scales, as well as with "best fit" exponential curves. The noise in the 2014 data is much easier to see in the log-linear graph. The noise also manifests itself in the lower R^2 statistic for the 2014 data. In fitting the 2014 data, data points for $Z_{DS} < 5'$ (yellow-ish "+" symbols) were not used, because there is essentially no meaningful head drop and the calculated differences are almost entirely noise.

A final depiction of the change in the tidal regime at Long Marsh is shown in Figure 16, a stage duration curve. Pre-construction, the upper limit on US high tide precludes nearly any inundation of the high marsh surface. Post-construction, US stages are greater than the maximum pre-construction value 7% of the time. Furthermore, the US duration curve is virtually indistinguishable from the DS open water curve for stage values above the US channel invert.

We have presented strong evidence for greatly improved tidal exchange under Long Reach Lane, based on visual inspection of data plots and evaluation of isolated individual data points. We conclude this discussion by evaluating the entire data sets utilizing the "best fit" curves for $\Delta = f(Z_{DS})$ and $Z_{US} = g(Z_{DS})$.

The functions for $\Delta = f(Z_{DS})$ are:

2012: $\Delta = 0.0338 \times \exp(0.6094 Z_{DS})$

2014: $\Delta = 0.0009 \times \exp(0.8804 Z_{DS})$

The functions for $Z_{US} = g(Z_{DS})$ are:

2012: $Z_{US} = -0.0128Z^2_{DS} + 1.7762Z_{DS} - 1.4137$

2014: $Z_{US} = -0.0381Z^2_{DS} + 1.3007Z_{DS} - 0.6134$

The equation for calculating percent reduction in head drop was given above. The results are shown in Figure 17.

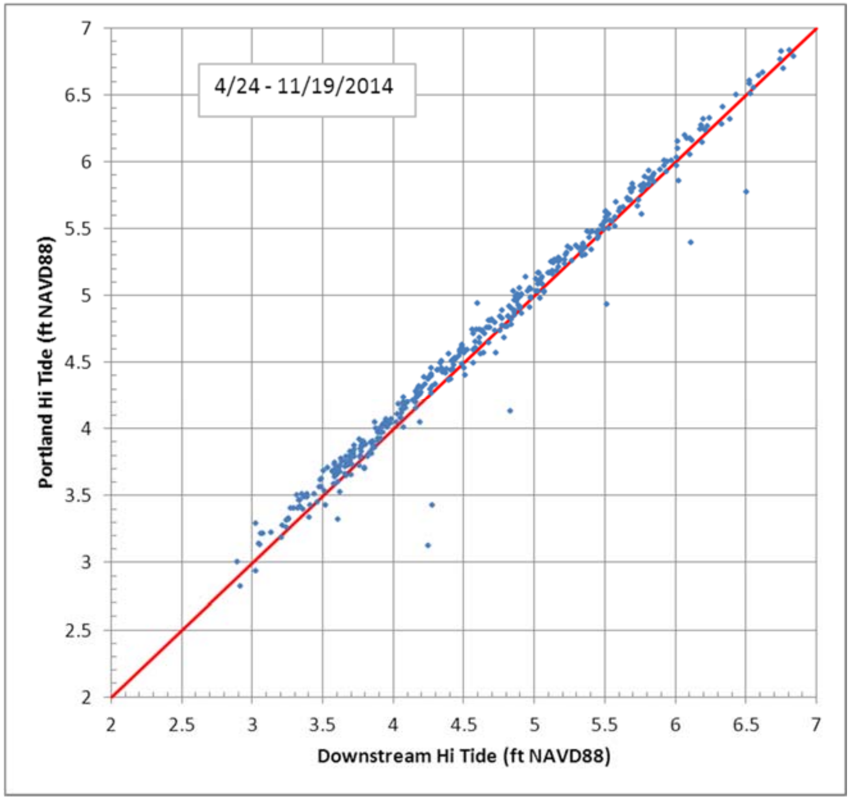
When calculated using the direct equations for Δ, the result is a simple monotonically decreasing function. This makes sense, as we expect the head drop in the new box culvert to be larger at the higher high tides (larger Z_{DS}). Percent reduction of over 90% has been achieved for Mean High Water (MHW, approximately 4.5'), and it is still greater than 80% for the Portland Highest Astronomical High Tide (HAT, approximately 6.7').

When calculated using the functions $Z_{US} = g(Z_{DS})$, the results for tides greater than Mean High Water are nearly identical to using the best-fit Δ equations: percent reductions range from 91% - 94% at MHW, to 83% - 84% at HAT. However, this curve shows the odd behavior of decreasing improvement with high tides. This is an artifact of the curve fitting, data noise, and the fact that the magnitude of head drop at these lower high tides is exceedingly small (3" or less).

An independent calculation of percentage improvement was made by considering the change in Mean Higher High Water (MHHW). Based on the 2012 data subset, the MHHW were 5.06' (DS) and 4.23' (US); the corresponding 2014 values were 5.03' (DS) and 4.96' (US). The percentage improvement in MHHW drop across the culvert is 100 x (0.83 – 0.07)/0.83 = 92%. By this measure, the stage drop has been effectively eliminated.

Based on this analysis, we conclude that the performance objective of reducing the head drop across Long Reach Lane by at least 80% has been achieved.

Figure 6. Portland High Tide vs Long Reach Downstream High Tide.



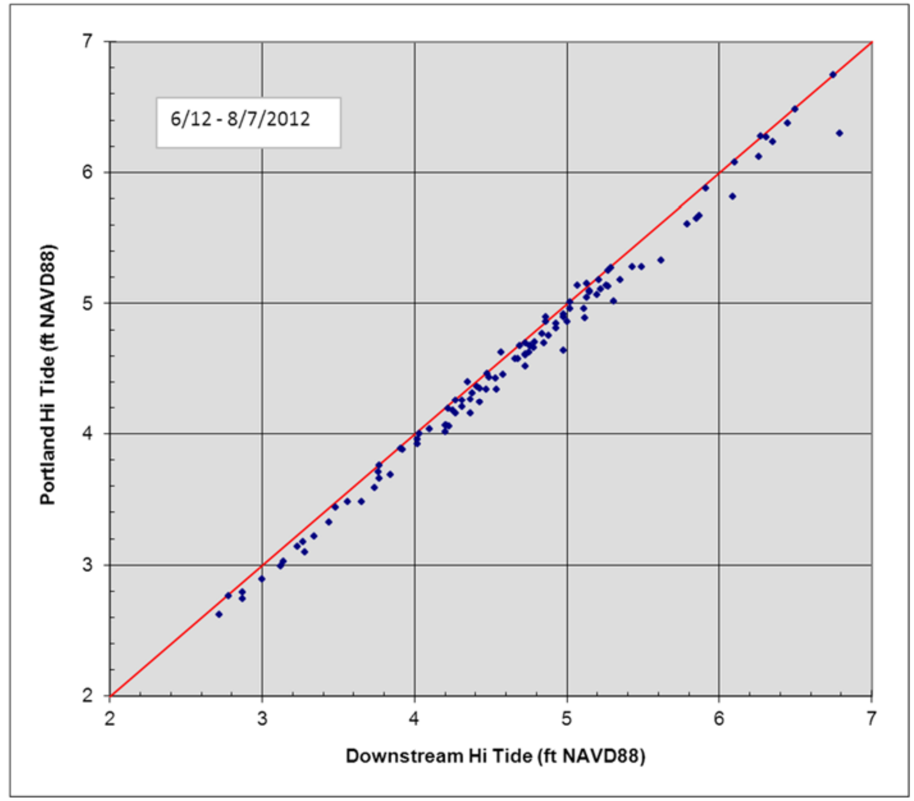
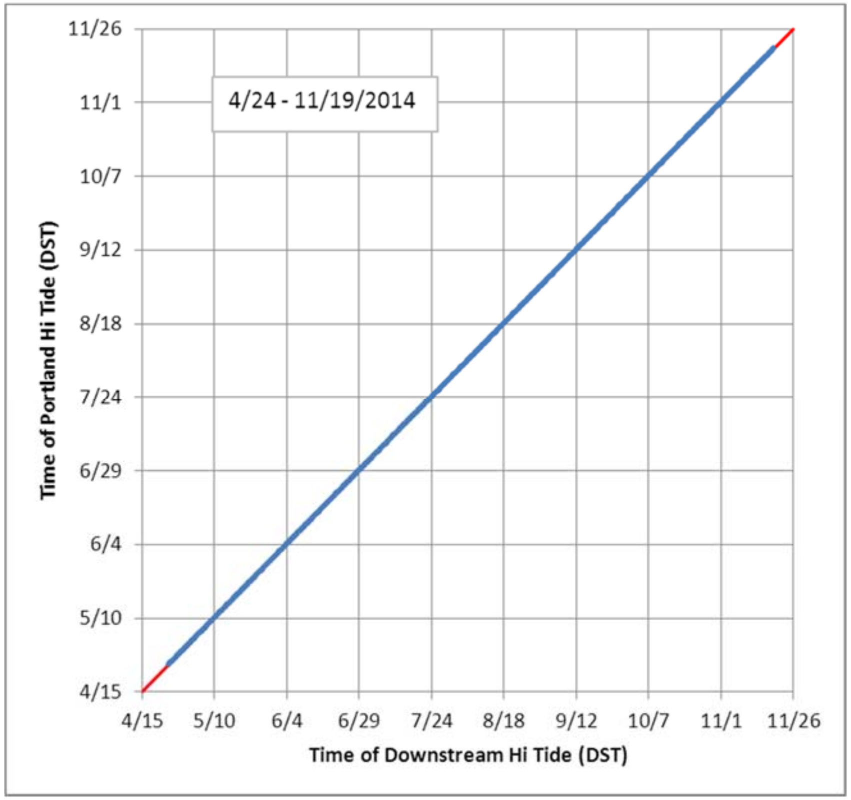


Figure 7. Time of High Tides in Portland and Long Reach Downstream.



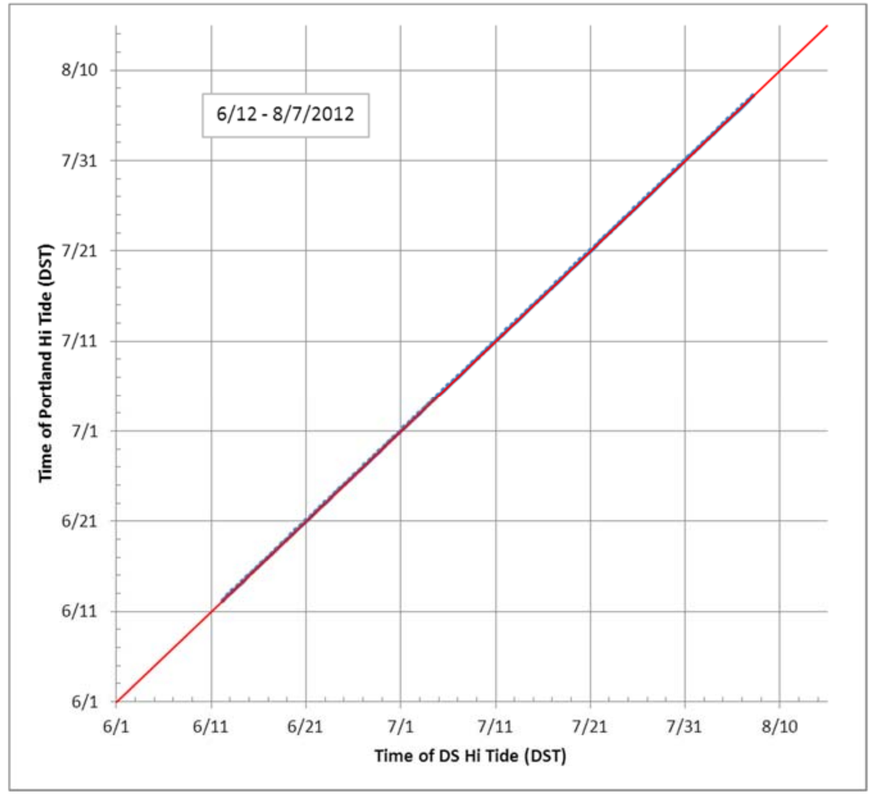
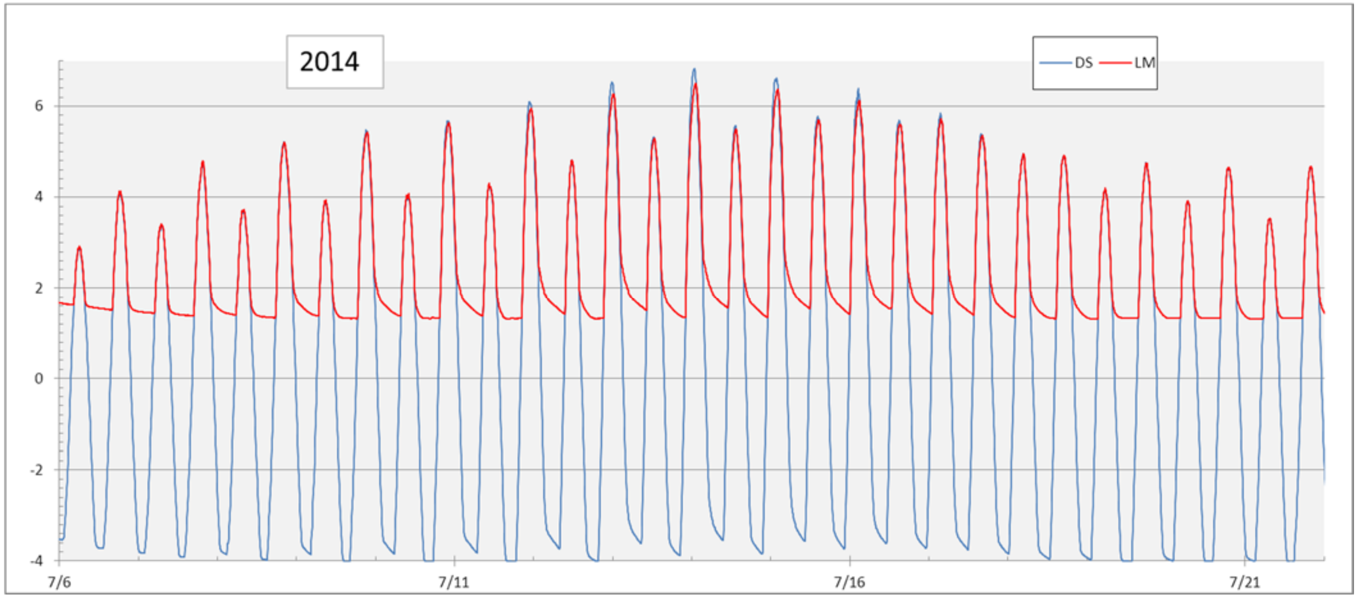


Figure 8. Typical High Tide Data Windows.



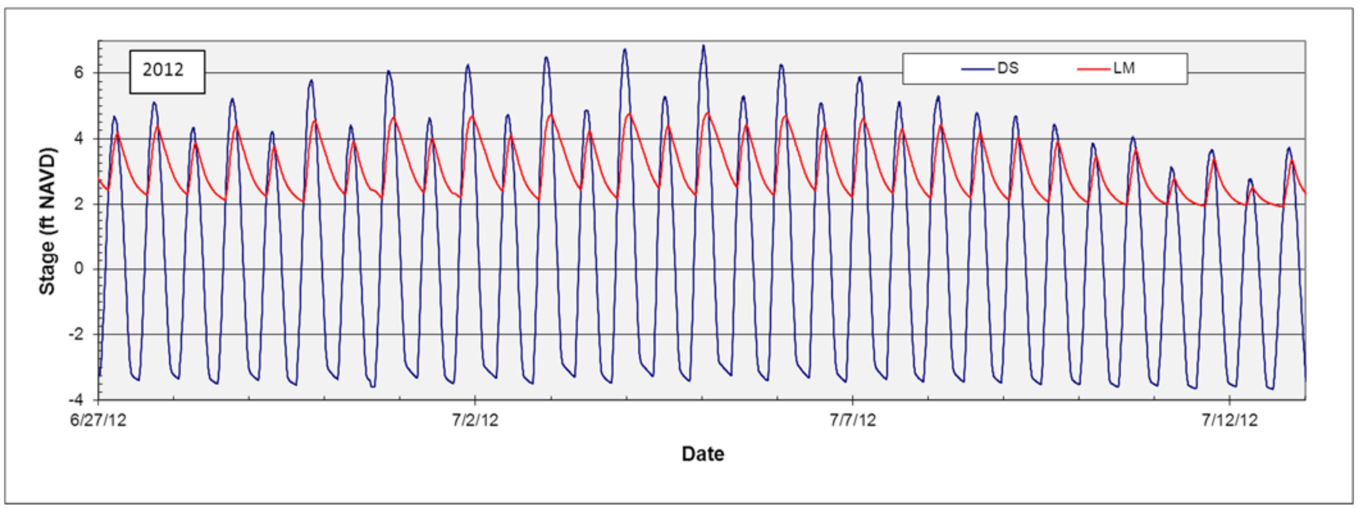
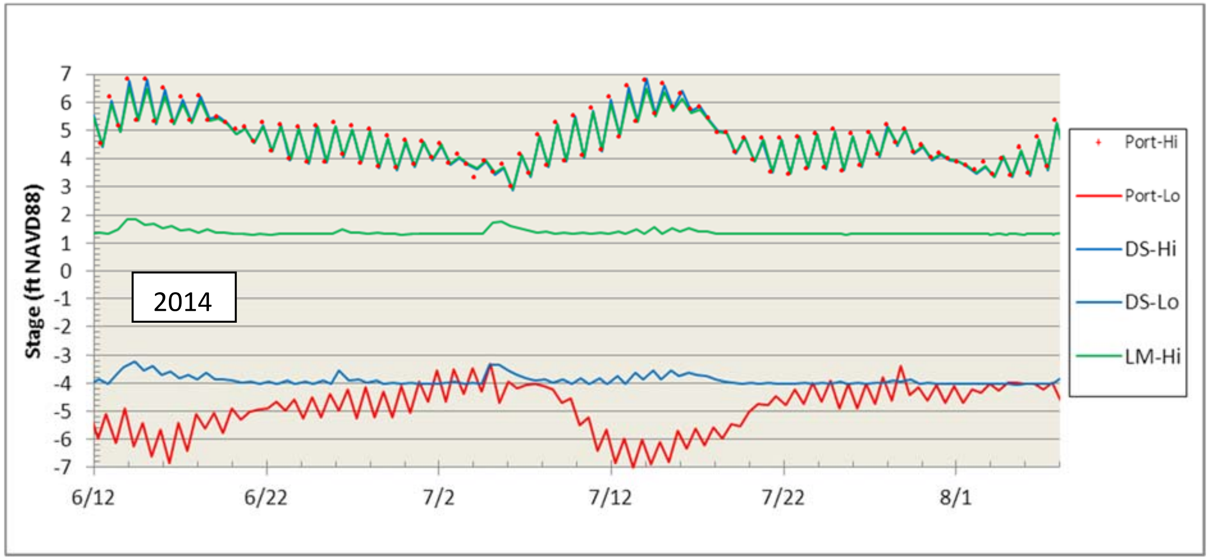


Figure 9. Time Series of High and Low Tides During Summer Period.



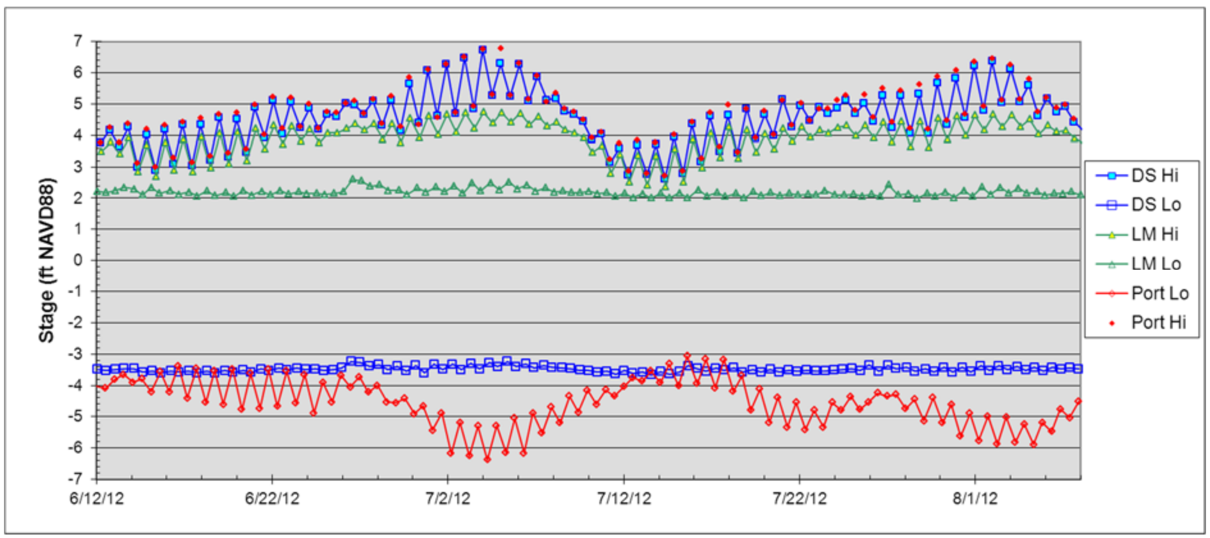
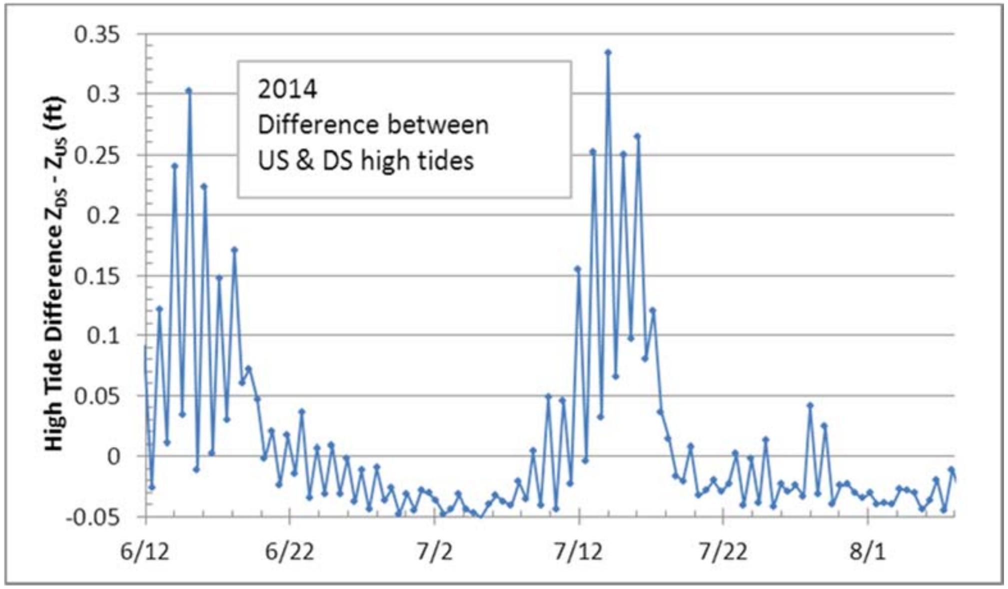


Figure 10. Time Series of Differences in High Tides Across Culvert, 2012 and 2014.



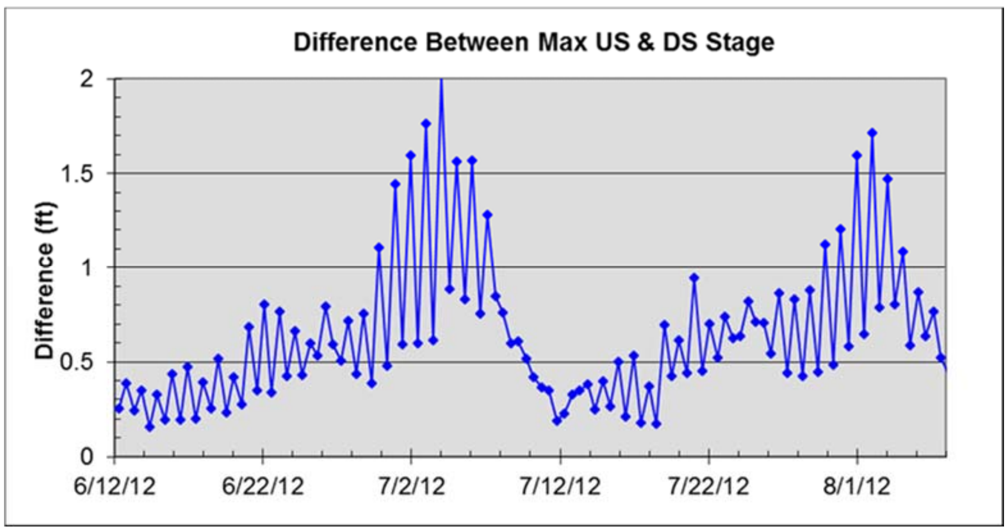


Figure 11. Time Series of Differences in High Tides Across Culvert, 2012 and 2014 (to same scale).

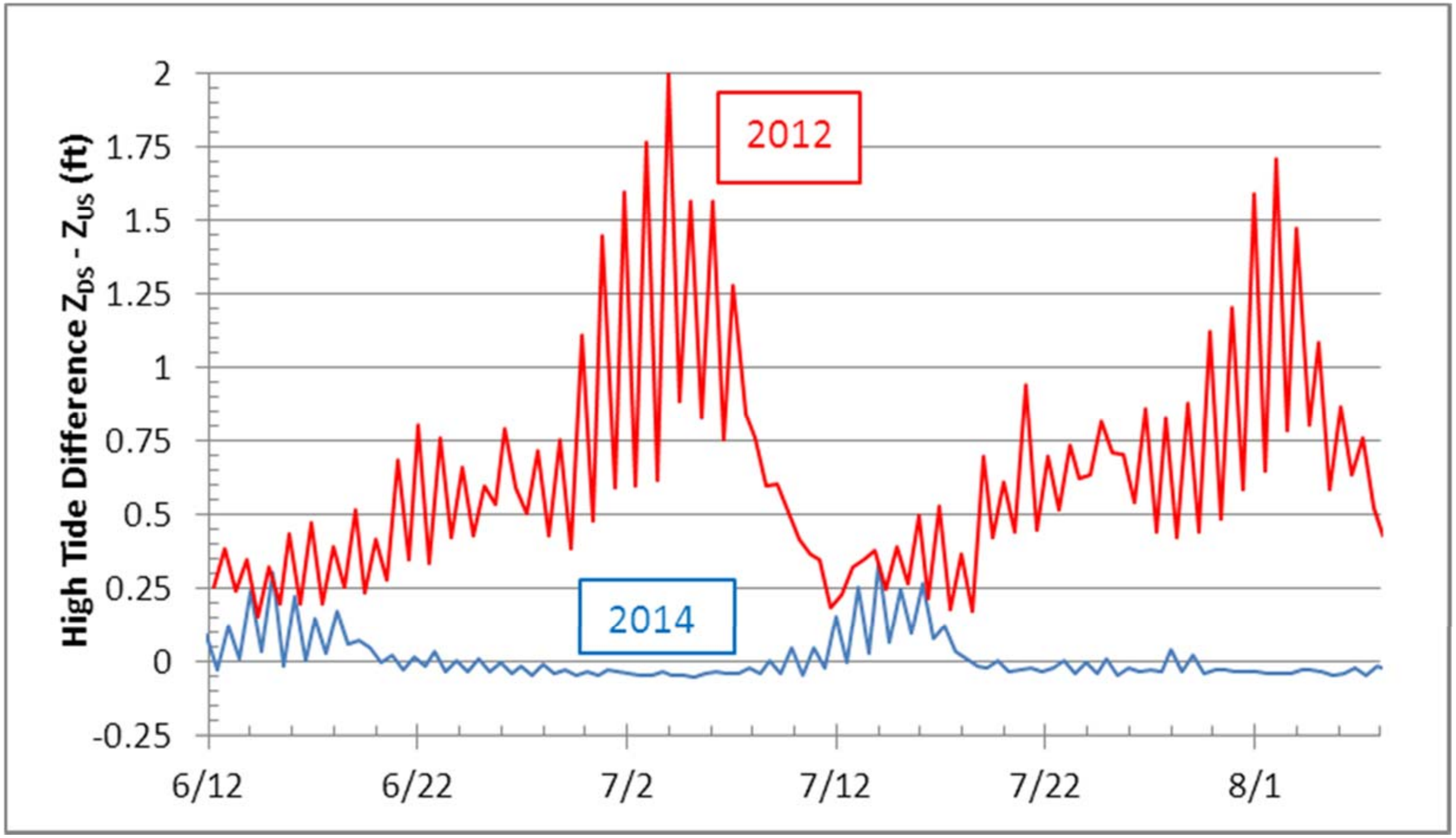


Figure 12. Upstream vs. Downstream High Tides, 2014 and 2012.

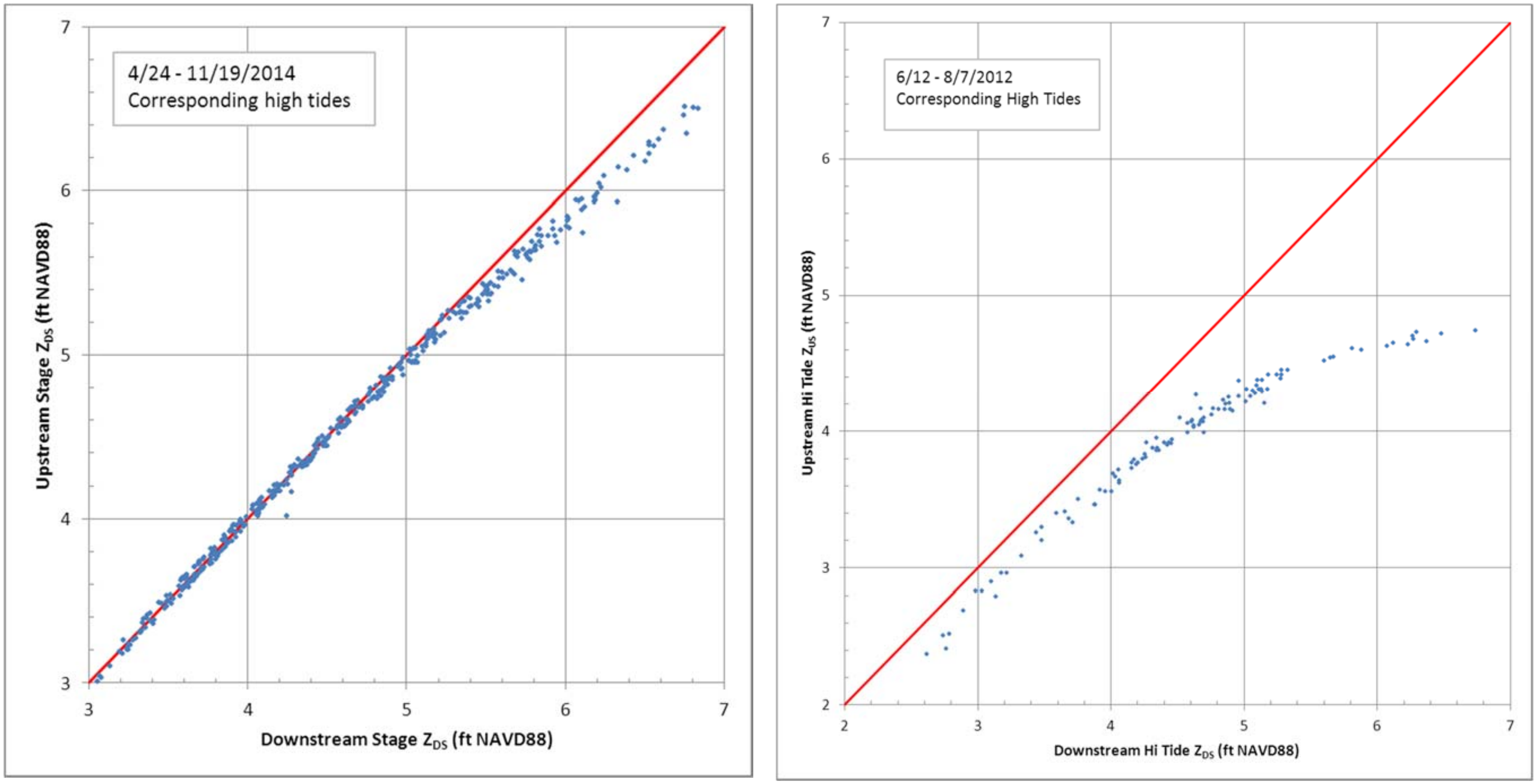


Figure 13. Upstream vs Downstream High Tides, 2014 and 2012 (plotted together with best-fit lines).

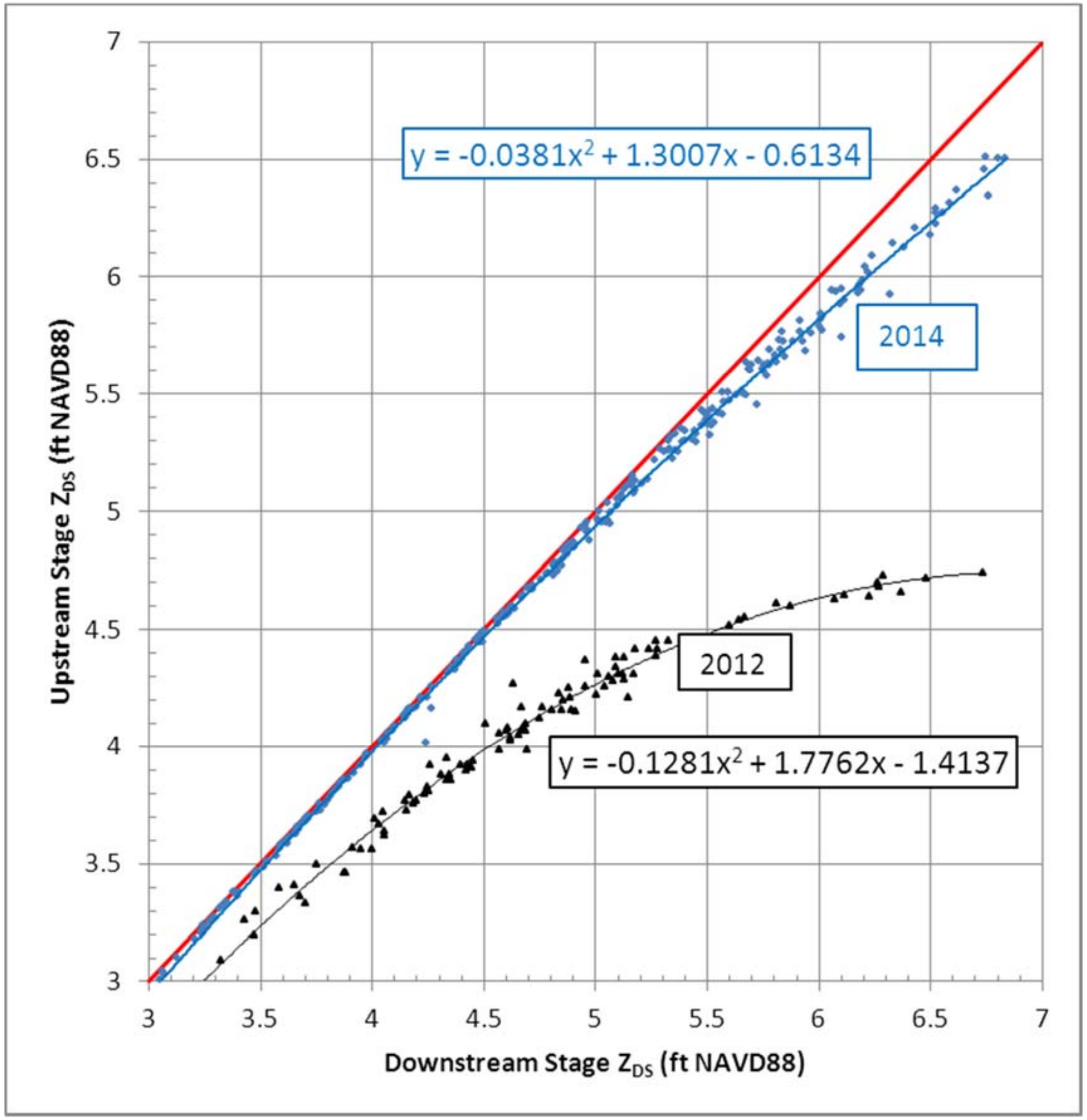


Figure 14. Difference in High Tides Across Culvert, 2014 and 2012.

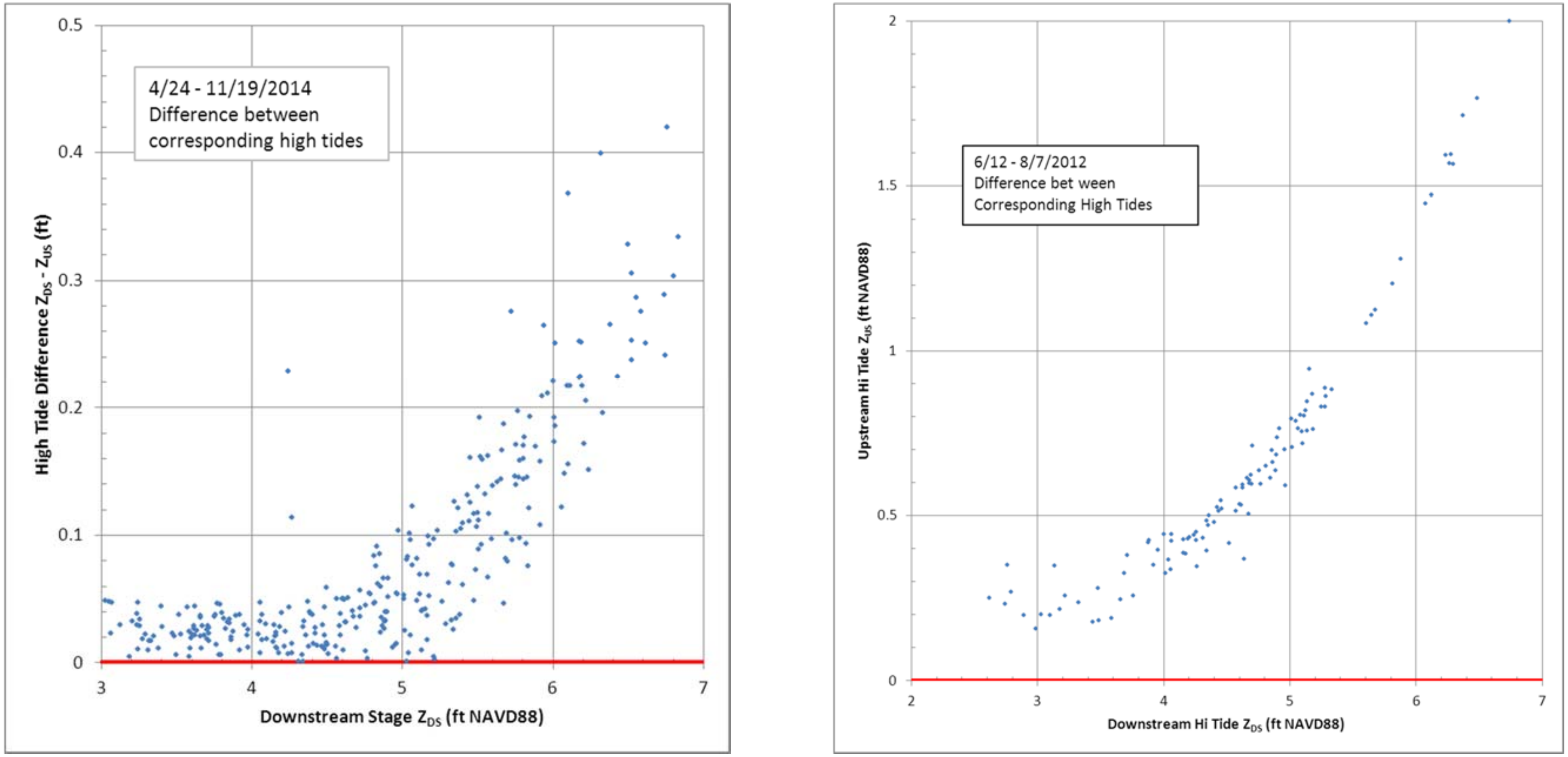


Figure 15. Difference in High Tides Across Culvert, 2014 and 2012 (plotted together with best-fit lines, linear & log-linear scales).

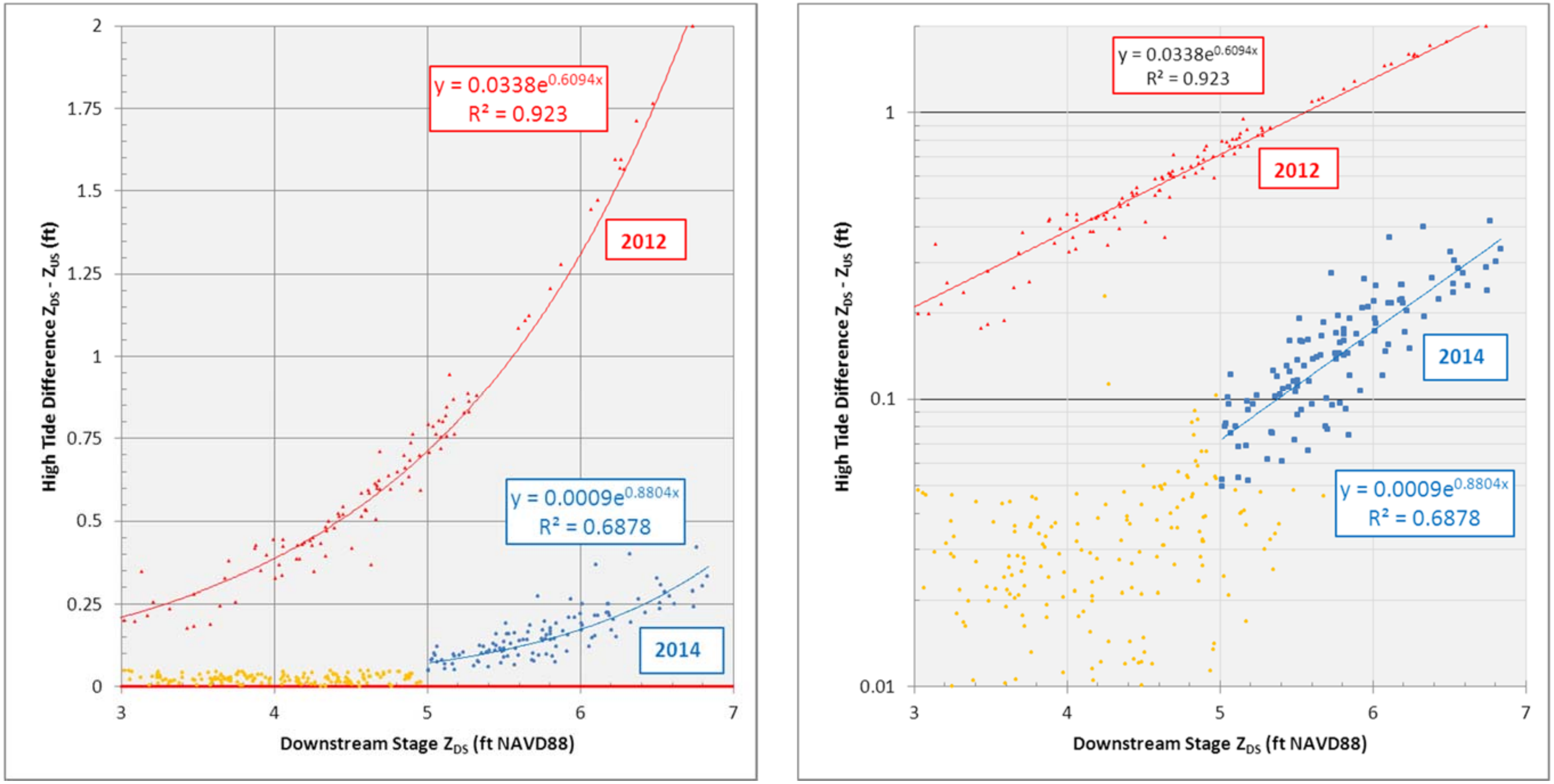


Figure 16. Stage Duration Curve.

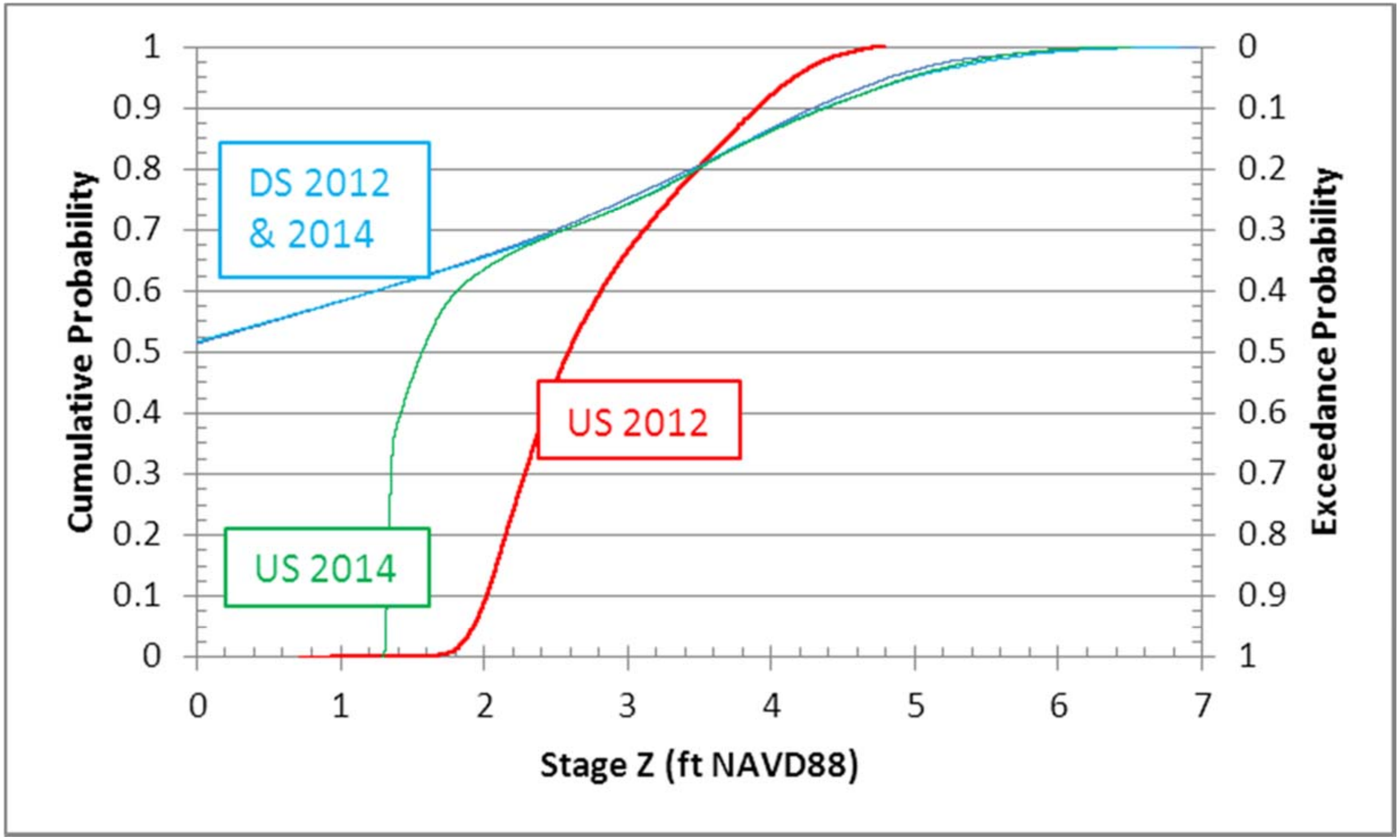
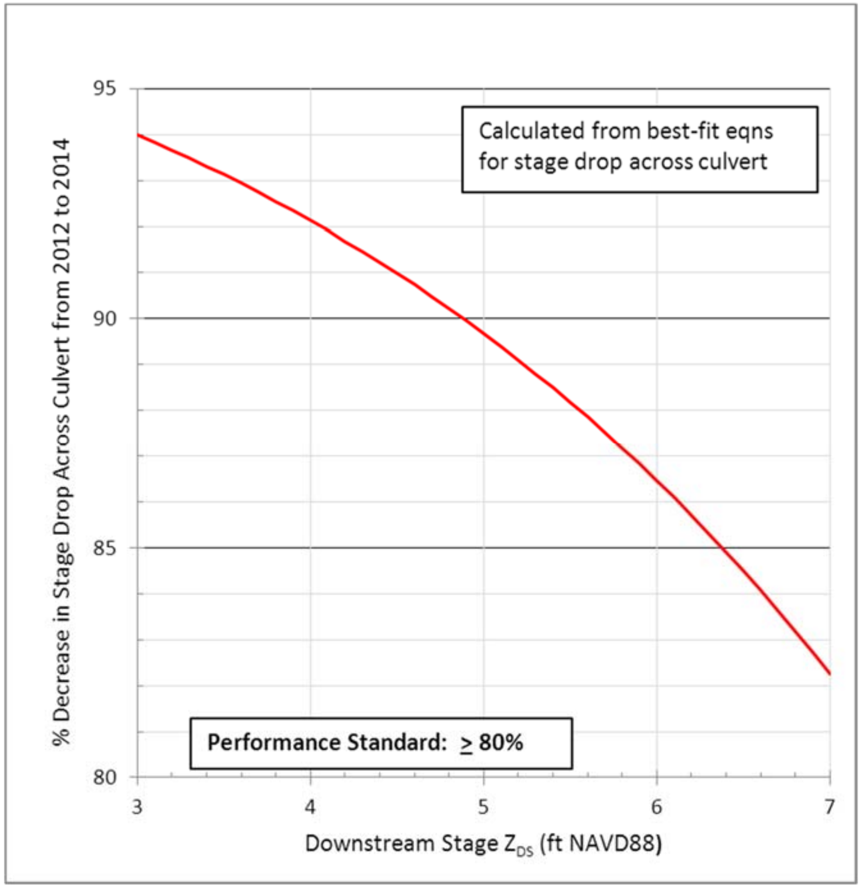
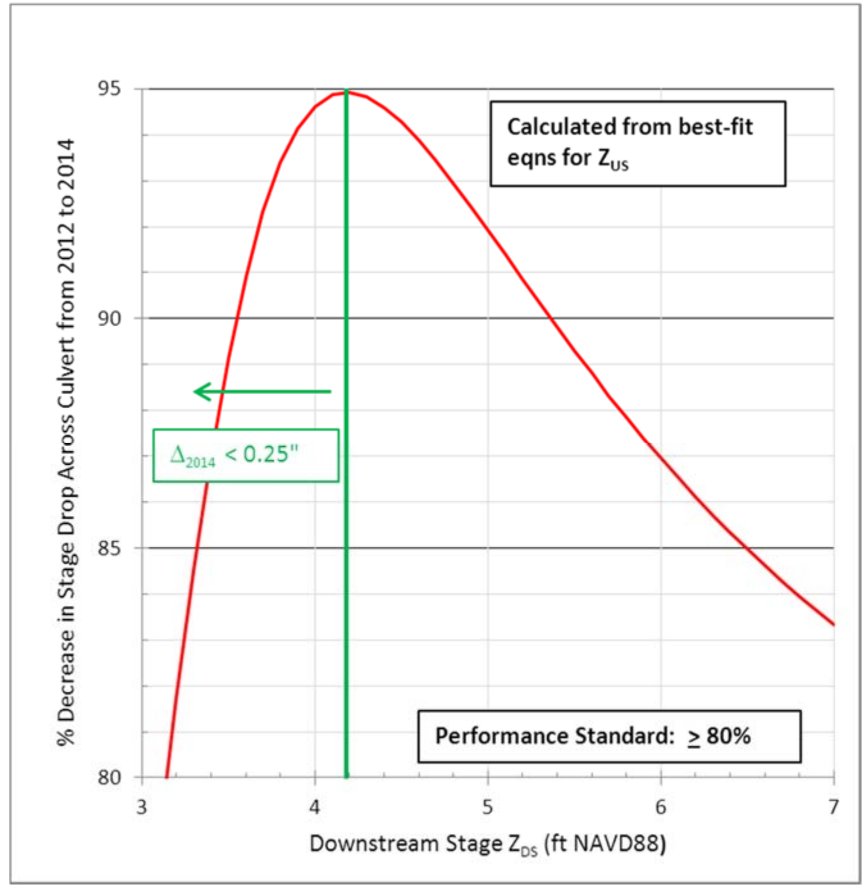


Figure 17. Percent Decrease in Stage Drop Across Culvert (by two different sets of best-fit equations).





3.2 Pore Water Salinity

CBEP installed pore water wells in May 2013 to monitor salinity of water within the root zone. Following installation, six sets of pore water and surface water samples were collected during the 2013 field season. During the 2014 field season, nine sets of samples were collected (Table 3). Prior to the 2014 field season, pore water wells were re-located and their condition assessed following a winter with heavy ice buildup and ice movement on the marsh surface. All wells were located and confirmed set for use in 2014.

Table 3. Pore water salinity sampling dates.

Year	April	May	June	July	August	September	October
2013		5/21		7/1, 7/25	8/29	9/25	10/21
2014	4/23, 4/25	5/21	6/6, 6/24	7/8	8/28	9/17	10/28

Pore water salinity levels in the marsh are influenced by a number of factors, including tide height, precipitation, local soil conditions and runoff from adjacent uplands. Although more salt is being delivered to the Project Area following replacement of the Long Reach Lane culvert, it is useful to put the data into the context of seasonal precipitation. The West Bath Town Hall hosts a weather station that collects and records precipitation totals for the Maine Department of Marine Resources use in determining rainfall closures for local shellfish beds.

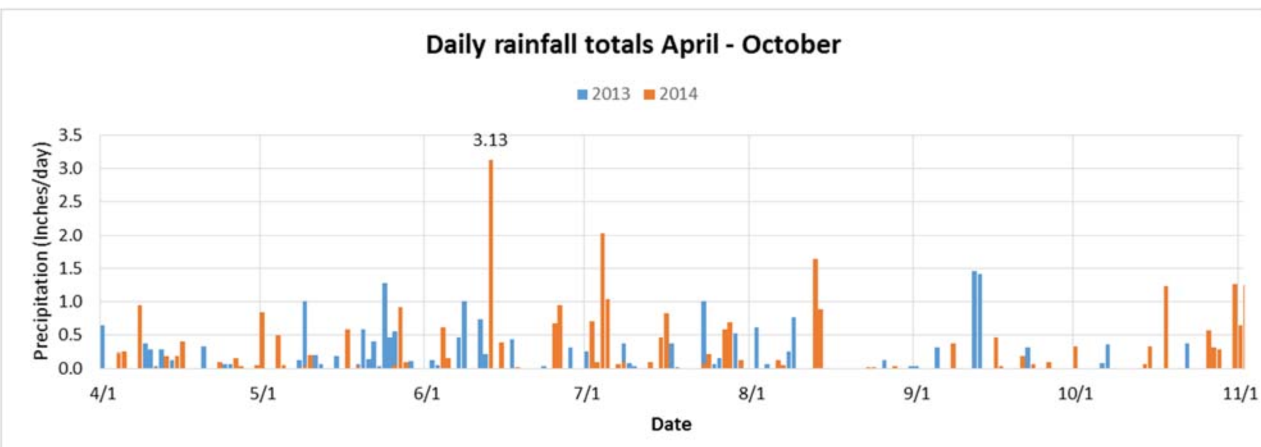


Figure 18. Daily rainfall totals (inches) at West Bath Town Hall.

These data are posted online at The Weather Underground and can be downloaded. A comparison of daily precipitation data during the 2013 and 2014 monitoring season shows that Long Marsh received more rainfall during the 2014 field season than it did in 2013. This difference can be attributed in large part to significant rain events (3.13” on 6/13/14; 3.89” 7/2-7/5/14; Figure 18), and in general, monthly rainfall totals were lower during the 2013 sampling season than 2014, with the exception of May and September (Table 4).

Table 4. Comparison of monthly precipitation with historic levels. Shown are monthly rainfall totals (inches) at West Bath Town Hall weather station and historic 'normal' monthly rainfall (Portland Jetport, 1961-1990).

Year	March	April	May	June	July	August	September	October	Cumulative
2013	1.9	2.4	5.3	3.6	3.3	2.0	3.7	1.5	23.7
2014	4.2	2.7	3.4	6.0	7.2	2.9	1.3	4.5	32.1
Normal	3.67	4.08	3.62	3.44	3.09	2.87	3.09	3.90	27.76

Table 5. Mean, minimum and maximum pore water salinity (PSU) pre- and post- construction.

Station	Mean		Min		Max	
	2013	**2014**	**2013**	**2014**	**2013**	**2014**
1	22.67	14.54	9.00	4.00	29.00	25.00
2	23.00	30.59	13.00	25.00	30.00	35.00
4	19.80	25.70	5.00	16.00	30.00	30.00
6	21.60	29.19	10.00	25.00	33.00	33.00
6a	8.60	24.74	2.00	10.00	15.00	29.00
8	27.20	28.44	20.00	23.00	33.00	32.00
10	25.40	26.96	17.00	24.00	30.00	32.00

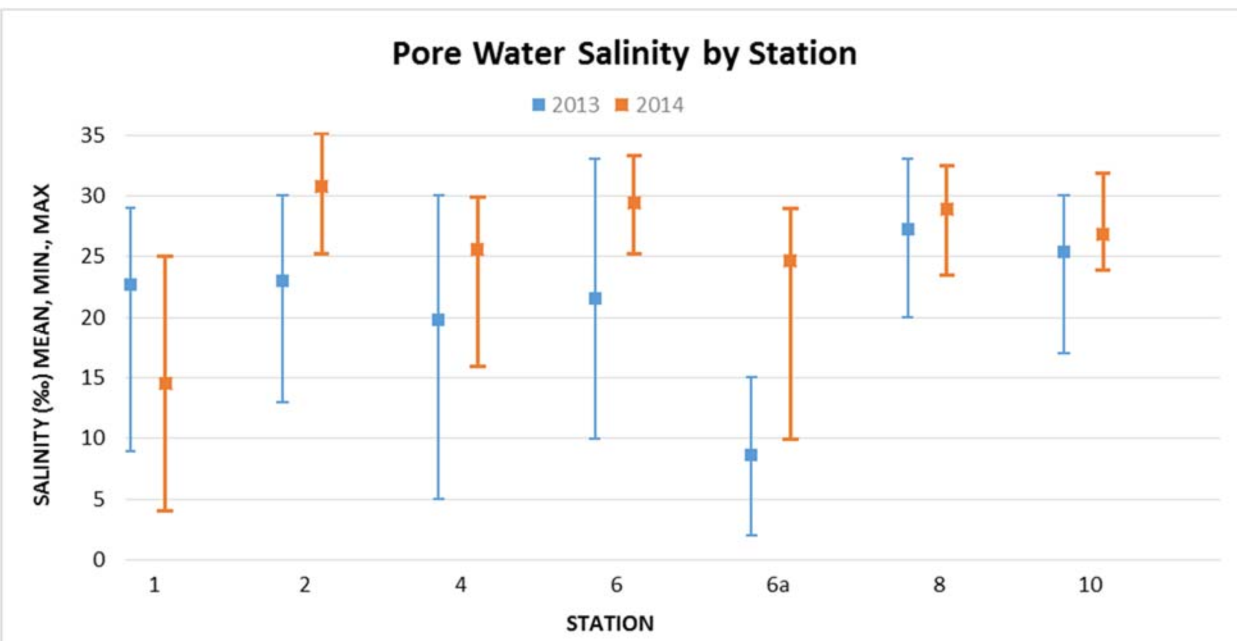


Figure 19. Mean, minimum, and maximum pore water salinity (PSU) pre- and post- construction.

Although recent studies incorporating more recent data than the "normal" rainfall totals shown in Table 4 suggest that precipitation totals may be increasing in spring, summer, and fall seasons (Wake *et. al*., 2009, p. 10), the Portland Jetport data still provides a useful baseline to show that 2014 rainfall totals were higher than normal, particularly in June and July. Therefore,

looking only at freshwater inputs during the monitoring season (and excluding precipitation from the preceding winters), we can conclude that the 2014 monitoring season was generally a wetter one at Long Marsh, particularly during the typically hottest and driest summer months, than the 2013 monitoring season.

Despite higher than normal rainfall, pore water salinity levels were generally higher throughout the Project Area in 2014 than in 2013, consistent with what we would expect to find resulting from the change in tidal hydrology within the Project Area resulting from the new culvert beneath Long Reach Lane. Although mean salinity (PSU) dropped at Station 1, which can be attributed in part to the significant rain events in June and July 2014, at all other Stations mean pore water salinity increased from 2013 – 2014 (Table 5; Figures 19-20). The largest increase was observed at Station 6a, located approximately 10m from the upland edge. In 2014, pore water salinity levels for each Station show a clear decrease between late June and July sampling dates, consistent with the timing of the ~3" rain events during that time period (Figure 20), but with the exception of Station 1, pore water salinity levels had rebounded by the date of the subsequent sampling round.

Even with higher than normal precipitation in 2014, mean pore water salinity, including all observations within the Project Area (excluding Station 1), were higher in 2014 (mean = 27.4 PSU) than in 2013 (mean = 20.3 PSU). In 2013, pore water salinity at Stations 2-10 trended upward over the course of the summer into fall, whereas in 2014, pore water salinity at Stations 2-10 was consistent, other than the July samples, across the season (Figure 21).

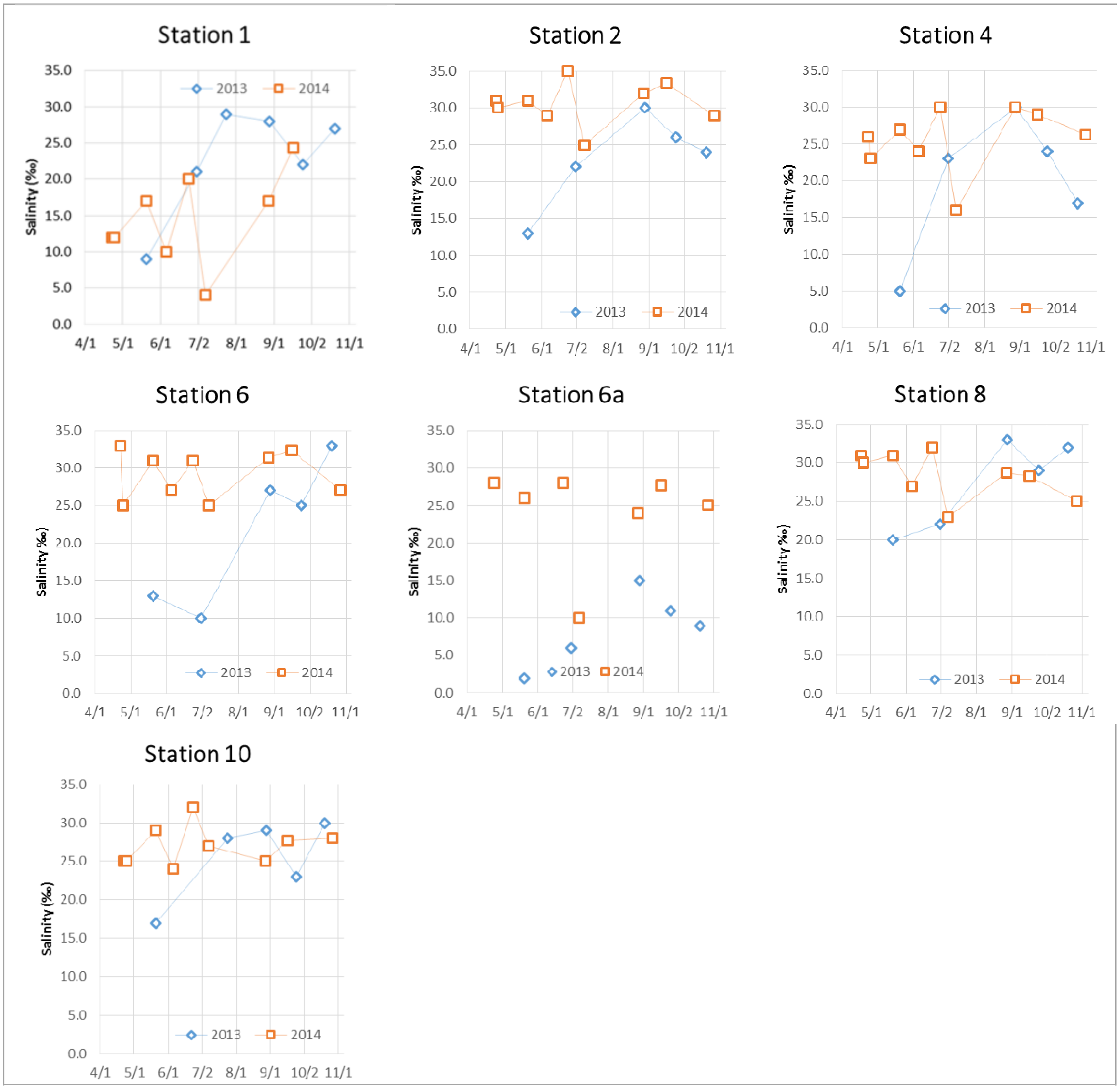


Figure 20. Plotted pore water salinity Stations 1, 2, 4, 6, 6a, 8, and 10.

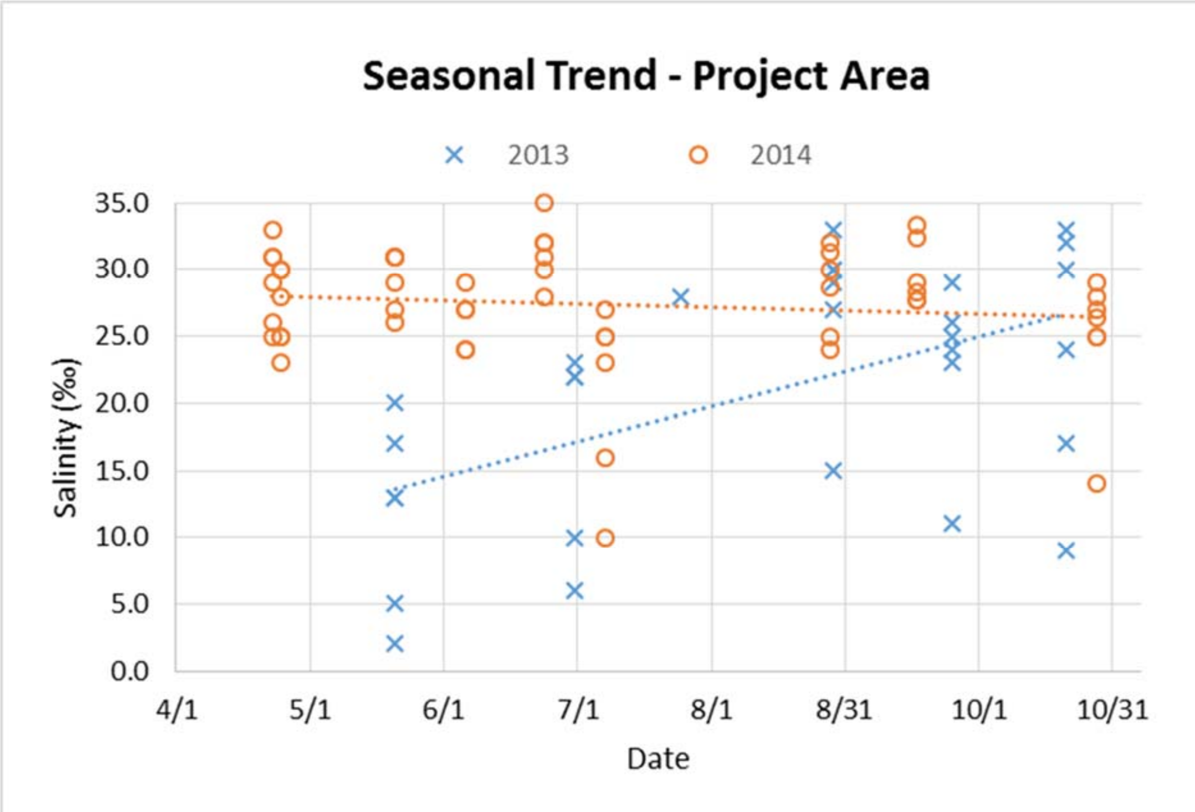


Figure 21. Year over year plot with trend lines of pore water salinity levels in the Project Area (excluding Station 1).

Overall, pore water salinity was observed to be higher within the Project Area in year 1 post-construction. Pore water salinity was also observed to be higher earlier in the growing season in 2014 than in 2013, consistent with expectations that the marsh is draining more quickly through the new culvert. This is illustrated by the dip and recovery of pore water salinity levels following heavy rain events in late June and early July 2014.

These data indicate that the change in tidal hydrology is delivering more salt water onto the high marsh, and that freshwater drains from pore water more quickly, resulting in higher salt content in the root zone, which influences the vegetation community. Pore water salinity levels appeared to be higher throughout the spring and summer in 2014 than they were in 2013, which, over time, we expect to influence the vegetation community. These data suggest that the vegetation community in the Project Area is likely to shift toward more salt tolerant plant communities and salt marsh, from brackish and freshwater communities, in the years to come.

3.3 Surface Water Salinity

Table 2 lists the dates of surface water salinity grab samples, which occurred during pore water salinity monitoring. Because surface water grab samples may vary widely associated with tide direction and stratification, these data are less useful for monitoring changes to the Project

Area pre- and post-construction. Therefore, this section summarizes the results of continuous salinity monitoring using automated In-Situ *Aquatroll 200* data loggers. Figures 22 (2013) and 23 (2014) plot pre- and post- construction salinity of the tidal creek in the Project Area. Figure 22 illustrates that in 2013, surface water salinity decreased moving south into the marsh, away from open water, with salinity at Station 2 rising to above 30 PSU at high tide, and dipping with outgoing tides. Salinity ranged lower at Station 8, and at Station 9/10 (at the "narrows"), salinity remained nearly fresh during a the neap tide phase (10/25 – 11/1/2013). Figure 24 illustrates that post-construction (April-May 2014), surface water salinity showed increased variation over 2013, ranging between the ~28 PSU at high tides, and dropping as low as single digits PSU at low tides. Similarly, in the upper marsh, Figure 23 illustrates that post-construction, surface water salinity at Stations 8 and 9/10, which were located less than 100 feet apart, become more similar. Notable differences in surface water salinity between Stations 8 and 9/10 were observed in 2014, however, due to a combination of freshwater inputs from the southern extent of the marsh (beyond the Project Area), and the presence of the "old road bed" or "ford" located in the channel between Station 8 and Station 9 (see Section 4). A plot of surface water salinity at Station 8 (downstream of the ford) vs. salinity at Station 9 (upstream of the ford, Figure 25) illustrates the effect of the ford on upstream salinity levels. The ford is impounding lower salinity water upstream. The instantaneous difference in salinity levels is particularly apparent during the neap tide phase, when tide water does not appear to pass beyond the ford's rock pile in the channel (Figure 26).

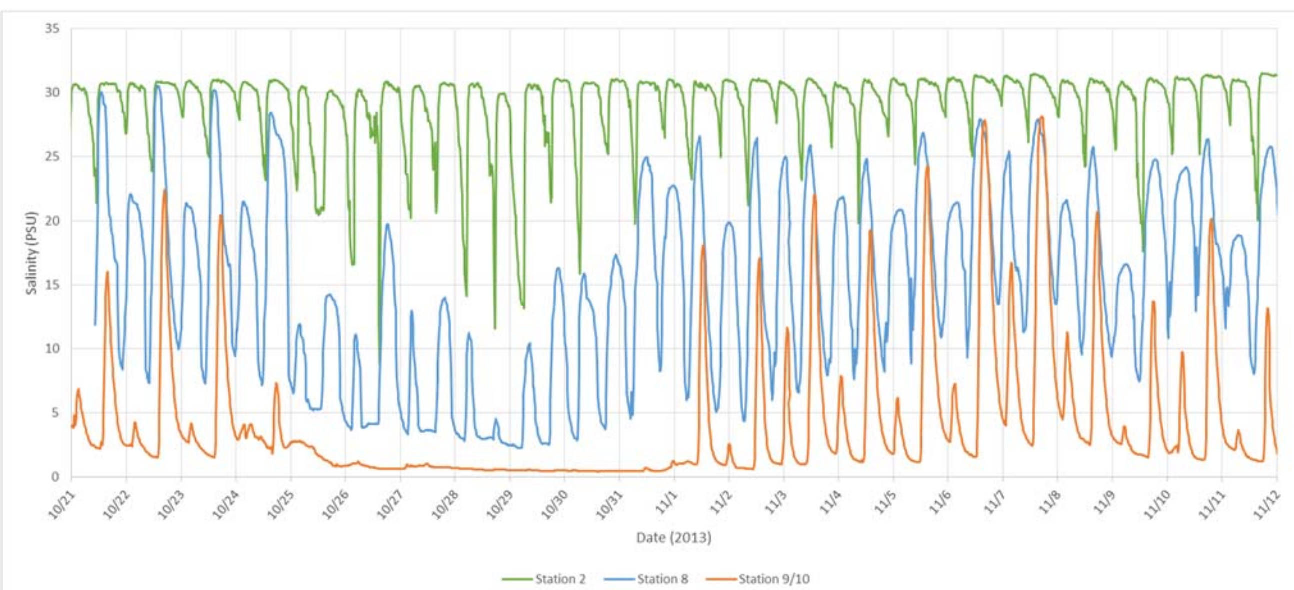


Figure 22. Surface water salinity readings in the Project Area, 2013.

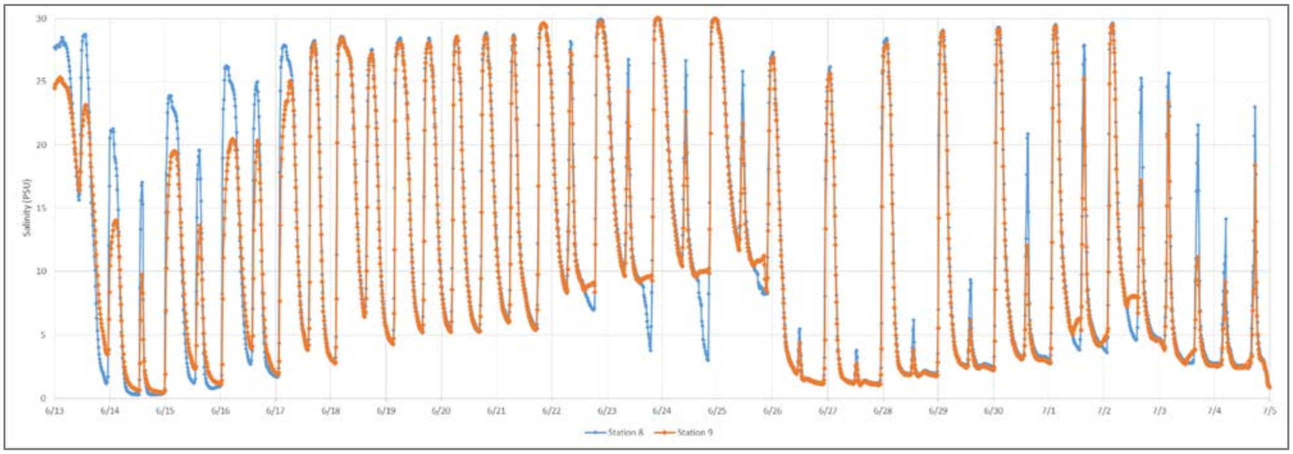


Figure 23. Surface water salinity readings at Stations 8 and 9/10, June 2014.

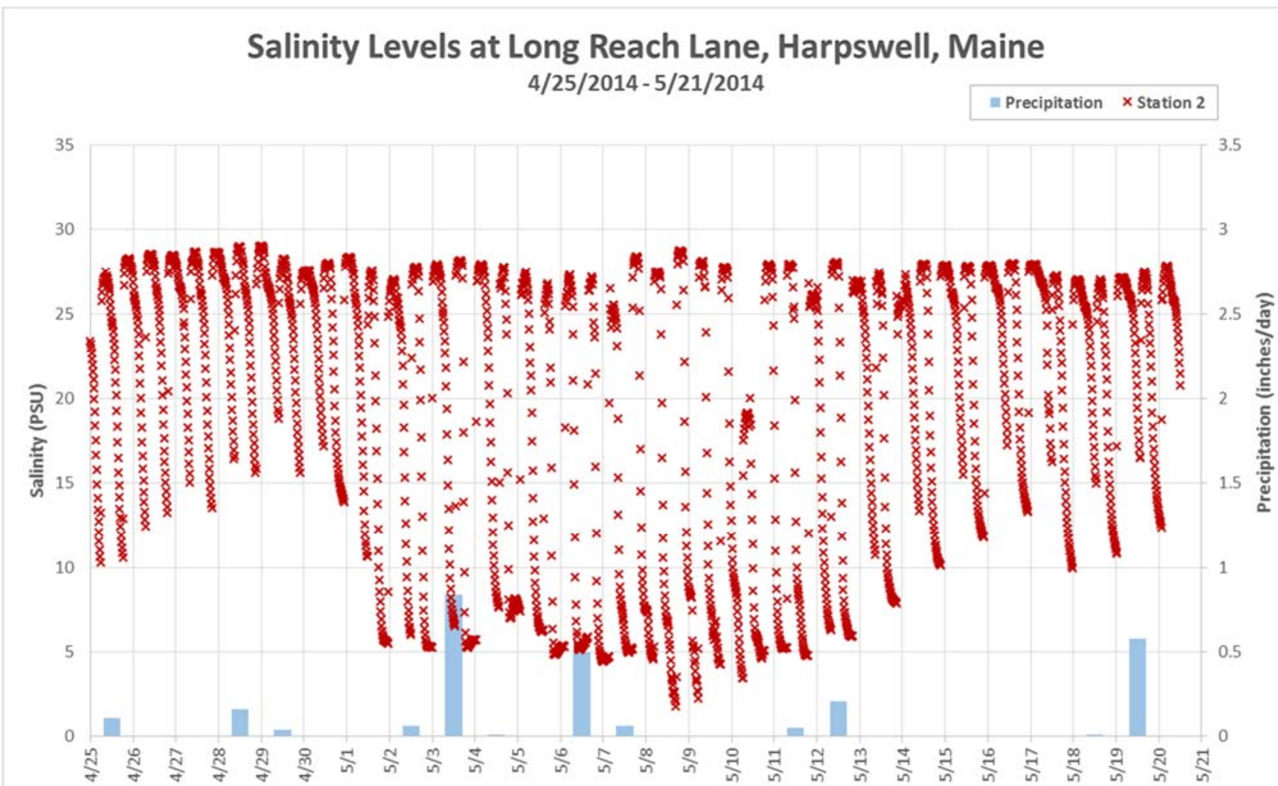


Figure 24. Surface water salinity plotted with precipitation, April-May 2014.

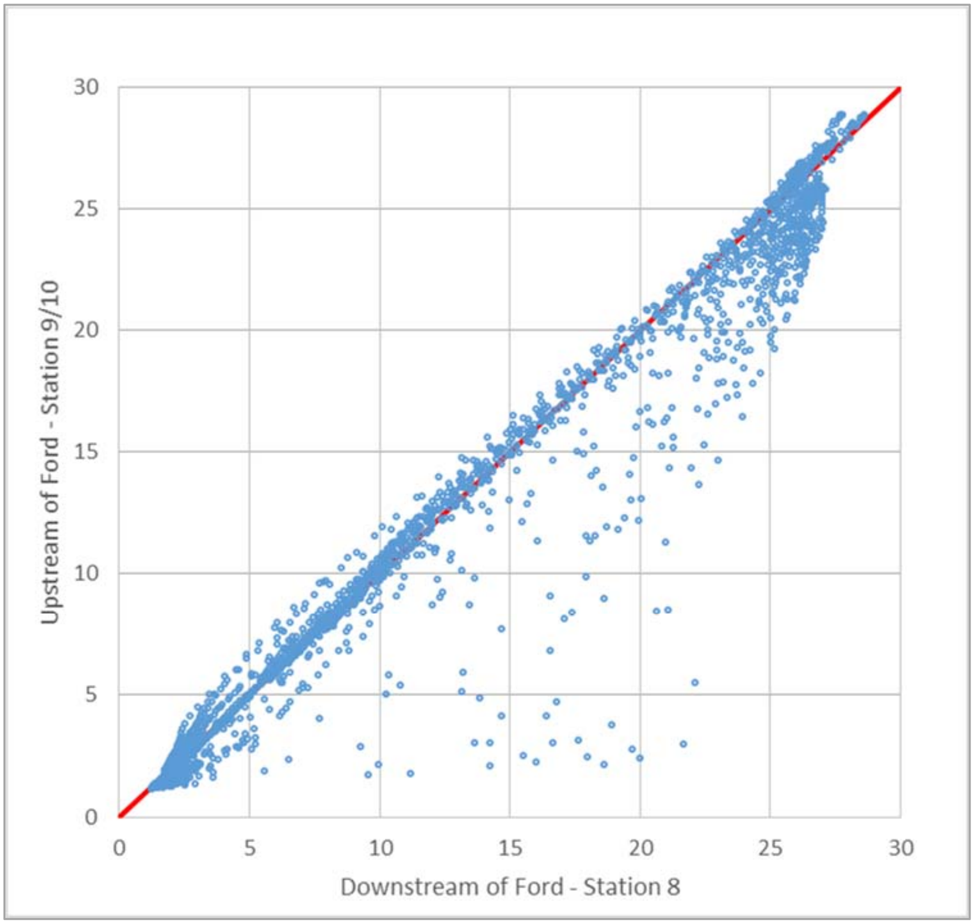


Figure 25. Downstream vs. upstream surface water salinity levels (PSU) at the "ford", spring 2014.

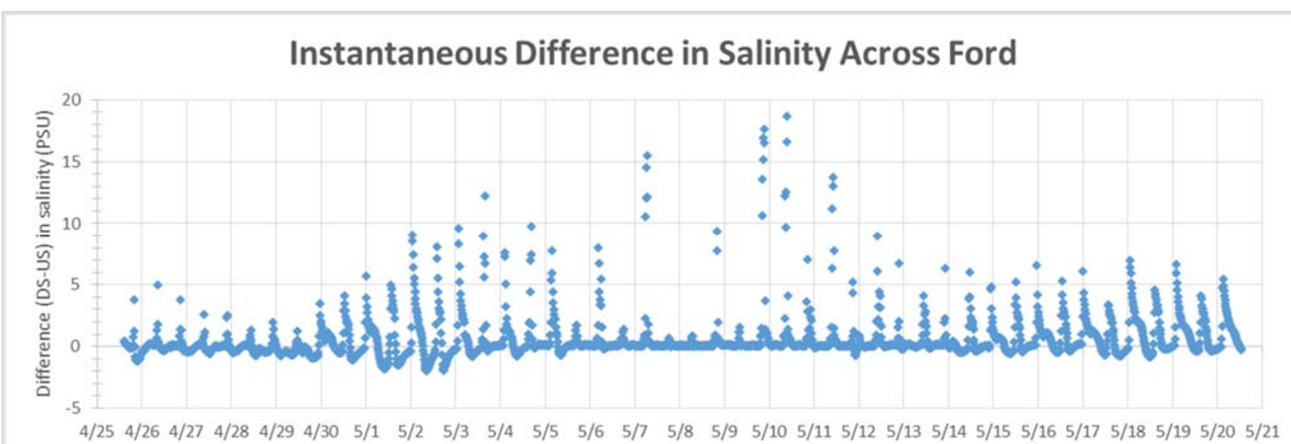


Figure 26. Instantaneous difference in surface water salinity across ford, spring 2014.

3.4 Vegetation

Vegetation transects were established and surveyed on July 15-16, 2013, and re-set and surveyed on July 8-9, 2014. A total of 110 plots were sampled in 2013 (12 plots along Station 1, and 98 plots along transects at Stations 2-10). A total of 113 plots were collected in 2014 (14 at Station 1, and 99 at Stations 2-10). Plot locations in 2013 and 2014 were at identical distances along each transect for most stations. The transect at Station 1 was longer in 2014 than in 2013, attributed to the fact that the transect was in a slightly different location due to the loss of stakes over the winter, presumably due to ice accumulation and/or movement.

A total of 72 plant species were identified across all Stations over the two monitoring events. Of those, 67 were observed during the 2013 vegetation surveys, and 49 were observed during the 2014 surveys. Of the 23 species that were observed in 2013 but not in 2014, 19 are grouped as freshwater community species, and 4 are brackish community species. The 3 species that were observed in 2014 but not in 2013 were freshwater community species (see Table 6).

Table 7 shows mean percent cover for each cover/community type against actual distance from the creek channel, by Station, in 2013 and 2014. Proximity to the creek channel appears to be associated with community type as shown by the prevalence of salt marsh community assemblages within 5 feet of the creek channel, even near the "narrows" at Station 10, in both 2013 and 2014. However, the 2013 vegetation data show that community type shifted markedly moving toward the upland edge, so that brackish and freshwater assemblages were increasingly abundant at distances of 100 feet or more from the creek edge, particularly at the southern Stations. In 2014, a change in this pattern is evident, with salt tolerant plants increasing in abundance in plots further away from the creek channel, and brackish and freshwater-grouped plants showing a marked decrease in area covered. This decrease is often associated with an increase in litter, which includes standing dead vegetation. The percent of plots covered by litter is particularly high at transects 4 and 6, which pass through large cattail stands. This illustrates a trend in evidence around the perimeter of much of the Project Area, where cattail stands died off in response to the higher tidal inundation, with mostly dead stands remaining (Table 12, vegetation transect photo stations). We anticipate that this trend is likely to continue as the energy stores of individual plants are depleted. Over the next few years, as light availability increases in former cattail stands, salt tolerant plant community cover is anticipated to increase.

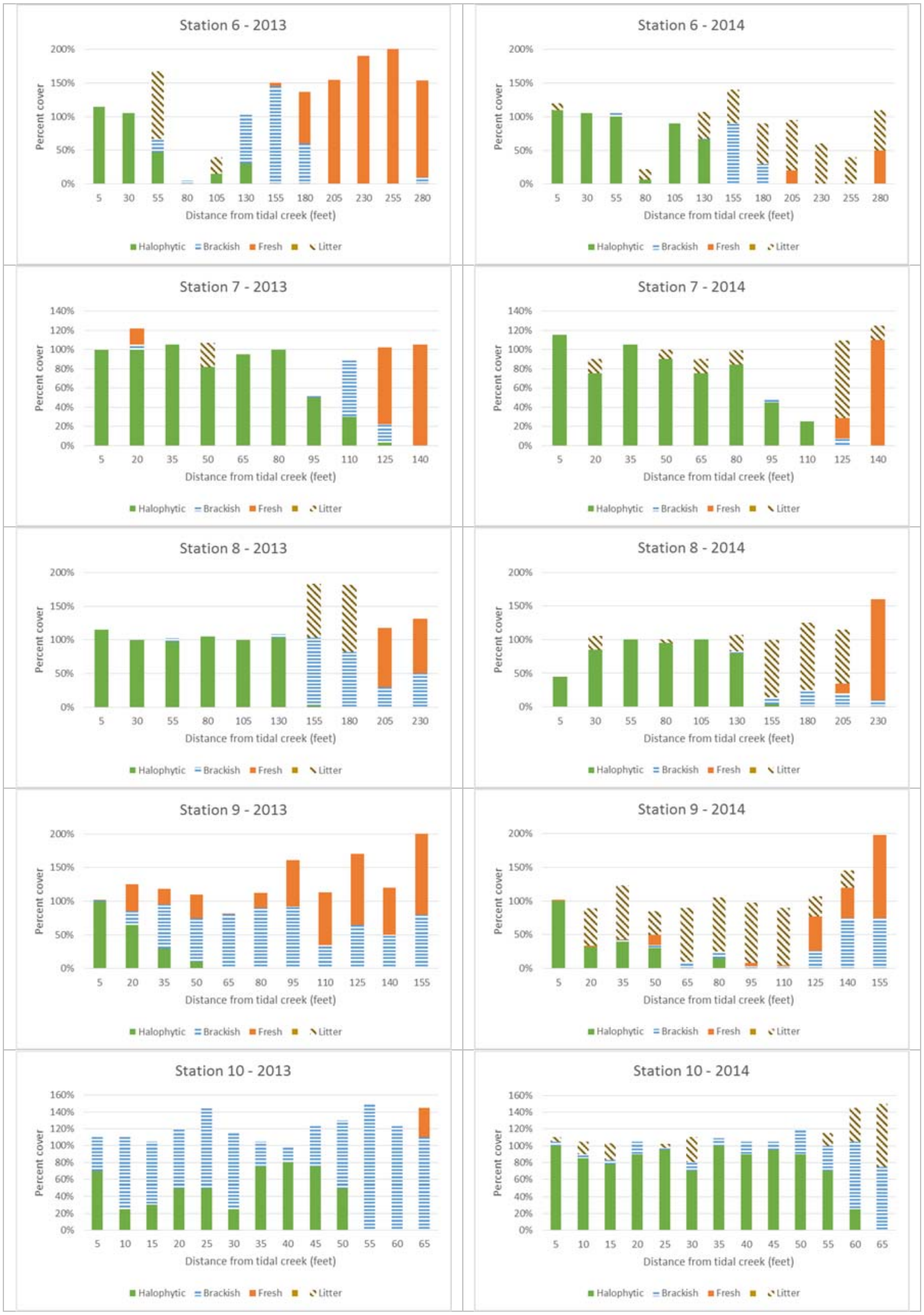
The effect of increased tidal inundation and salt delivery into soils was quickly evident where low lying vegetation was visibly stressed or dead by mid- to late spring 2014 (top right, junipers along a berm at Station 3; top left, white pine on a berm at Station 2; below, Typha and Spirea mortality near Station 4).

Table 6. List of observed plant species and associated community types. Groupings based on classifications in Tiner 2009 and Konisky et al *2006.*

Latin Name	Common Name	Community Group	2013	2014
Abies balsamea	Balsam Fir	Fresh	X	
Acer rubrum	Red Maple	Fresh		X
Agrostis stolonifera	Creeping Bent Grass	Brackish	X	X
Alnus incana	Speckled Alder	Fresh	X	X
Atriplex prostrata	Orach	Brackish	X	X
Bolboschoenus maritimus	Alkali Bulrush	Brackish	X	X
Calamagrostis Canadensis	Bluejoint Grass	Fresh	X	X
Calystegia sepium	Hedge Bindweed	Brackish	X	
Carex crinata	Fringed Sedge	Fresh	X	
Carex hystericina	Bottlebrush Sedge	Fresh	X	X
Carex lacustris	Lake Sedge	Fresh	X	X
Carex lurida	Shallow Sedge	Fresh	X	
Carex paleacea	Chaffy Sedge	Fresh	X	
Carex scoparia	Broom Sedge	Fresh	X	X
Carex stipata	Stalk-Grain Sedge	Fresh	X	
Carex utriculata	Common Beaked Sedge	Fresh		X
Cladium mariscoides	Smooth Sawgrass	Fresh	X	X
Distichlis spicata	Salt Grass	Halophyte		X
Dryopteris cristata	Crested Wood Fern	Fresh	X	
Dulichium arundinaceum	Three Way Sedge	Fresh	X	
Eleocharis sp.	Sedge	Brackish	X	
Elymus pycnanthus	Tick Quackgrass	Fresh	X	
Elymus repens	Creeping Wild Rye	Fresh	X	X
Equistem pratense	Horsetail	Fresh	X	X
Euthamia graminifolia	Flat-Top Goldentop	Fresh	X	
Festuca rubra	Red Fescue	Brackish	X	X
Galium asprellum	Rough Bedstraw	Fresh		X
Galium trifidum	Threepetal Bedstraw	Fresh	X	X
Glaux maritima	Milkwort	Brackish		X
Glyceria canadensis	Rattlesnake Mannagrass	Fresh	X	
Hordeum jubatum	Foxtail Barley	Brackish	X	X
Hypericum mutilum	St. John's Wort	Fresh	X	X
Ilex verticillata	Winterberry	Fresh	X	X
Impatens capensis	Jewelweed	Fresh	X	X
Juncus arcticus	Arctic Rush	Brackish	X	X
Juncus gerardii	Black Grass	Halophyte	X	X
Lycopus americanus	Cut-Leaf Water Horehound	Fresh	X	
Lycopus uniflorus	Northern Bugleweed	Fresh	X	X
Lysimachia terrestris	Swamp Candle	Fresh	X	X
Lythrum salicaria	Purple Loosestrife	Brackish	X	X
Onoclea sensibilius	Sensitive Fern	Fresh	X	X
Osmunda regalis	Royal Fern	Fresh	X	
Panicum dichotomiflorum	Panic Grass	Fresh	X	

Latin Name	**Common Name**	**Community Group**	**2013**	**2014**
Persicaria sagittata	Tearthumb	Fresh	X	
Proserpinaca palustris	Marsh Mermaidweed	Fresh	X	X
Puccinellia tenella	Alkali Grass	Brackish	X	
Quercus rubra	Northern Red Oak	Fresh	X	X
Ribes sp.	Currant	Fresh	X	
Rosa palustris	Swamp Rose	Fresh	X	
Rubus sp.	Blackberry	Fresh	X	X
Ruppia maritima	Widgeon Grass	Halophyte	X	X
Salicornia depressa	Common Glaswort	Halophyte	X	X
Schoenoplectus acutus	Hardstem Bulrush	Fresh	X	X
Schoenoplectus pungens	Three-Square Bulrush	Fresh	X	X
Scirpus sp.	Sedge	Brackish	X	
Scutellaria galericulata	Hooded Skullcap	Fresh	X	X
Solidago altissima	Tall Goldenrod	Fresh	X	X
Solidago sempervirens	Seaside Goldenrod	Halophyte	X	X
Spartina alterniflora	Smooth Cordgrass	Halophyte	X	X
Spartina patens	Salt Hay	Halophyte	X	X
Spartina pectinata	Freshwater Cordgrass	Brackish	X	X
Spirea alba	White Meadowsweet	Fresh	X	X
Spirea tomentosa	Steeplebush	Fresh	X	
Symphyotricum novi-belgii	Aster	Brackish	X	
Thelypteris palustris	Eastern Marsh fern	Brackish	X	X
Toxicodendron radicans	Poison Ivy	Brackish	X	X
Triglochin maritimum	Seaside Arrowgrass	Halophyte	X	X
Typha angustifolia	Narrow-Leaf Cattail	Brackish	X	X
Typha latifolia	Broad-Leaf Cattail	Fresh	X	X
Typha x glauca	hybrid cattail	Brackish	X	X
Vaccinium macrocarpon	Large Cranberry	Brackish	X	X
Viola sp.	violet	Fresh	X	

Table 7. Community type (mean % cover) for each Station, by transect distance, 2013 and 2014.


Station 6 - 2013
200%
150%
100%
50%
0%
Percent cover
5 30 55 80 105 130 155 180 205 230 255 280
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter
Station 6 - 2014
200%
150%
100%
50%
0%
Percent cover
5 30 55 80 105 130 155 180 205 230 255 280
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter
Station 7 - 2013
140%
120%
100%
80%
60%
40%
20%
0%
Percent cover
5 20 35 50 65 80 95 110 125 140
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter
Station 7 - 2014
140%
120%
100%
80%
60%
40%
20%
0%
Percent cover
5 20 35 50 65 80 95 110 125 140
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter
Station 8 - 2013
200%
150%
100%
50%
0%
Percent cover
5 30 55 80 105 130 155 180 205 230
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter
Station 8 - 2014
200%
150%
100%
50%
0%
Percent cover
5 30 55 80 105 130 155 180 205 230
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter
Station 9 - 2013
200%
150%
100%
50%
0%
Percent cover
5 20 35 50 65 80 95 110 125 140 155
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter
Station 9 - 2014
200%
150%
100%
50%
0%
Percent cover
5 20 35 50 65 80 95 110 125 140 155
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter
Station 10 - 2013
160%
140%
120%
100%
80%
60%
40%
20%
0%
Percent cover
5 10 15 20 25 30 35 40 45 50 55 60 65
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter
Station 10 - 2014
160%
140%
120%
100%
80%
60%
40%
20%
0%
Percent cover
5 10 15 20 25 30 35 40 45 50 55 60 65
Distance from tidal creek (feet)
Halophytic Brackish Fresh Litter

Station 1 lies outside the Project Area enabling comparison with a relatively less disturbed ('reference') area that was not affected by the culvert replacement. Figure 27 breaks out Station 1 from the Project Area. The location of vegetation transect 1 differed in 2013 and 2014. In 2013, plots averaged 85.9% halophytic plant coverage, compared with 39.4% within the Project Area. Brackish plants covered an average of 10.4% of plot area at Station 1, and 25.4% in the Project Area, and freshwater plants covered an average of 1.2% of plot area at Station 1, but over 23% in the Project Area. A clear shift is evident in 2014. The proportion of halophytic (salt tolerant) to brackish to fresh plant coverage became more similar upstream and downstream of Long Reach Lane, with 56.9% halophytic at Station 1 and 48.2% halophytic throughout the Project Area; 18.1% brackish at Station 1 and 8.8% within the Project Area, and 12.2% fresh at Station 1, and 12.3% fresh within the Project Area. The increase of litter at Station 1 in 2014 is attributable to a substantial wrack deposit leftover from the winter of 2013-201 4, and the increase of litter in the Project Area is attributed to standing dead freshwater and brackish vegetation. Figure 28 displays 2013 and 2014 abundance just within the Project Area.

Figure 27. Comparison of plot coverage between Station 1 and the Project Area, pre- and post- construction.

A similar pattern is evident summarizing the data by transect (Figure 29). The transect at Station 4 runs through what was a cattail stand in 2013. Although the halophytic cover was nearly identical in both 2013 and 2014, the coverage of brackish (28.6% to 5.0%) and freshwater (31.8% to 11.9%) plants dropped, with a corresponding increase in litter coverage. This shift from fresh and brackish communities to halophytes is evident at each Station

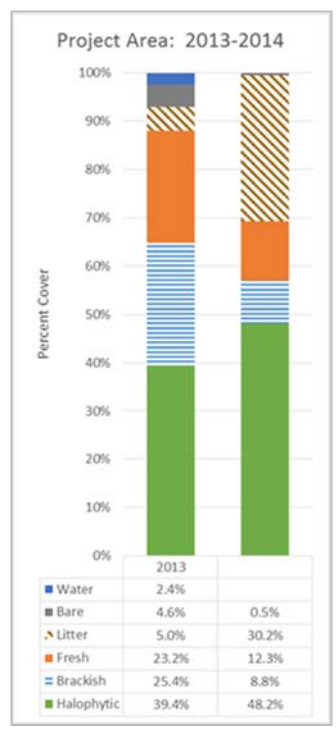


Figure 28. Average percent cover within the Project Area, 2013-2014.

within the Project Area, particularly at Stations 6, 8, 9, and 10, which are among the furthest from Long Reach Lane.

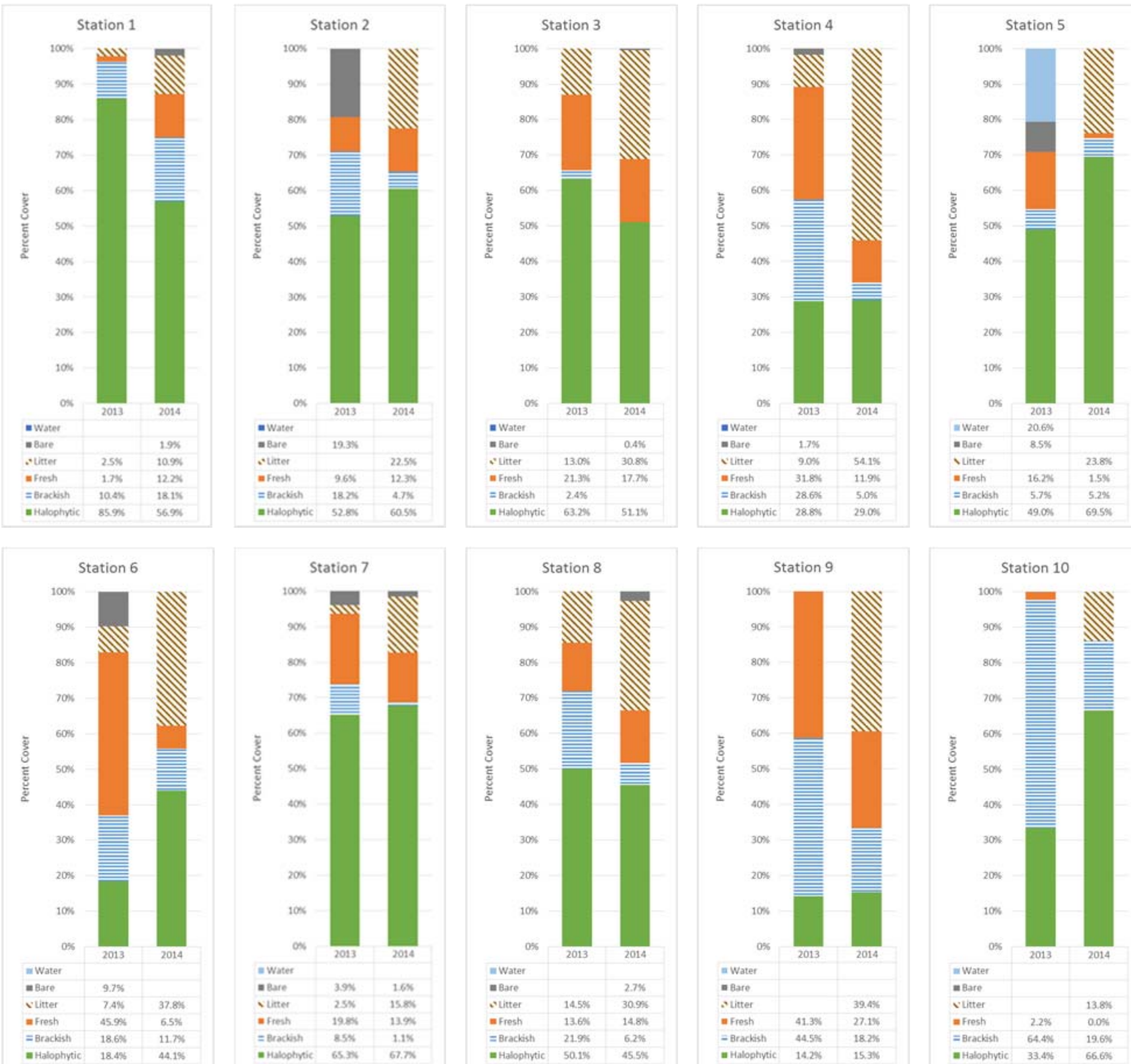


Figure 29. Pre- and Post- Vegetation Community Abundance by Transect

A graph of 2013 vegetation cover by plot for the entire Project Area (Figure 30), pulling other cover classes (bare, water, litter), illustrates that plots proximate to the creek (1-4) have a higher proportion of halophytic plants, with the mid-transect plots (6, 7, 8) having proportionally more brackish coverage, and the plots closest to the upland edge (9, 10, 11) having more freshwater vegetation. The same graph for 2014 (Figure 31) illustrates again that vegetation type has shifted, with halophytic vegetation proportionally higher than other vegetation types until the plots reach the upland edge (plots 10 and 11). At each plot within the Project Area, there was an increase of halophytic plant cover, while brackish cover declined at every plot (Figure 32). Freshwater vegetation cover declined except at Station 11, at the upland edge.

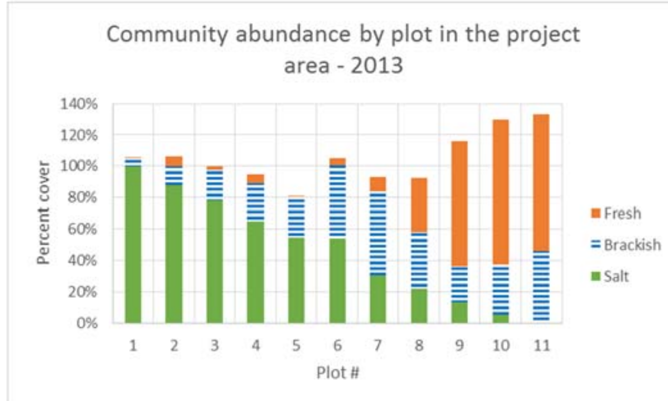


Figure 30. 2013 community abundance by plot in the Project Area.

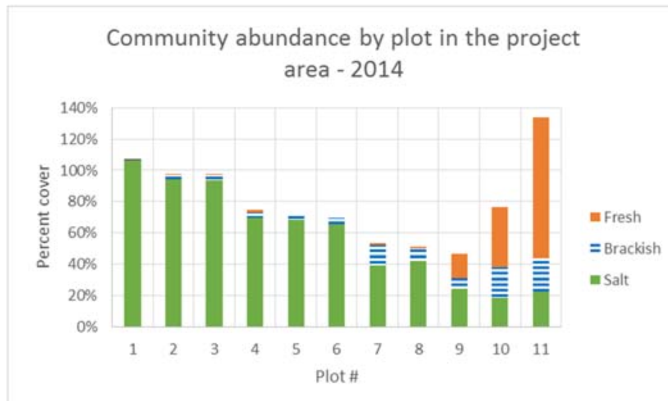


Figure 31. 2014 community abundance by plot in the Project Area.

As with pore water salinity, Long Marsh's vegetative community year-1 post-construction shows a marked change consistent with what we would expect in response to the new culvert, which increased tidal exchange. Together, the salinity and vegetation data indicate that the vegetation community within the Project Area is shifting in response to the new tidal hydrology. Effects of increased tidal elevation and duration of inundation are evident in the plant community shifts at Stations furthest from the construction site, in plant community shifts mid-way through the transects and at approaching the upland edge, and widespread increase in litter as a result of dead freshwater loving and brackish plants. Viewed at the scale of the Project Area, the shift in community type is particularly evident in looking at living cattail plants (Figure 33).

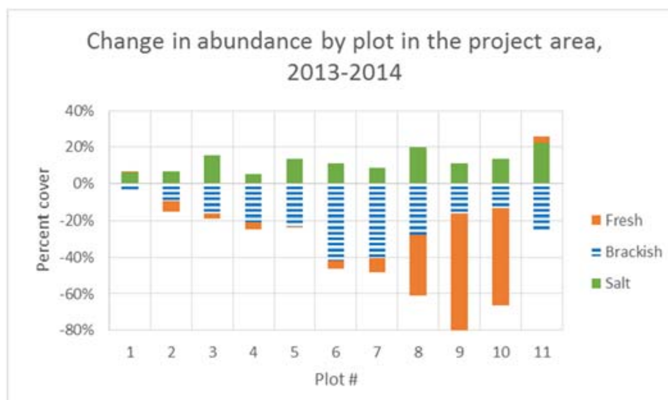


Figure 32. Change mean percent cover by plot in the Project Area, 2013-2014.

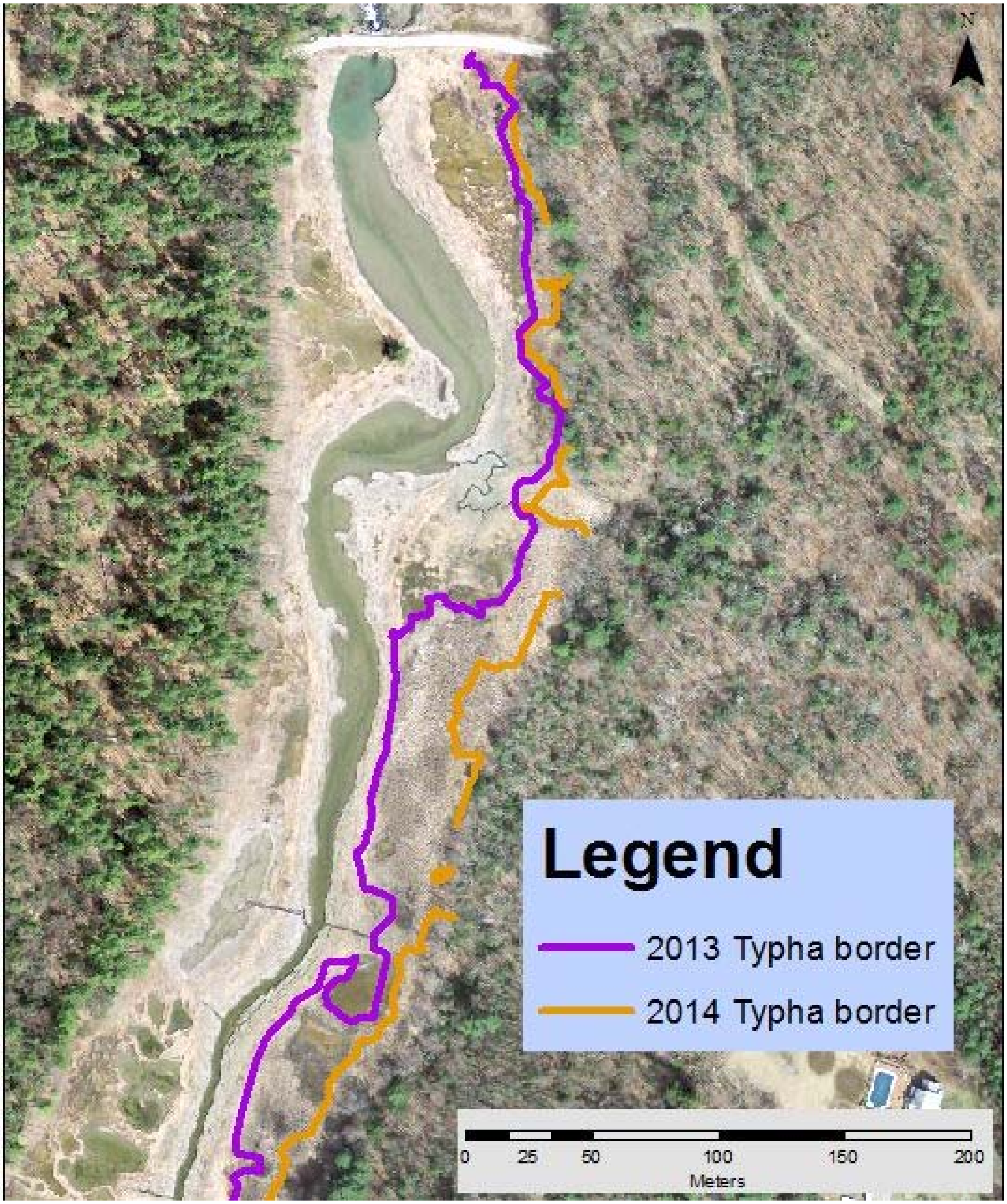


Figure 33. Living Typha *spp. boundaries on the east side of the Project Area, pre-construction (2013), and Year 1 post-construction (2014). Illustration by S. Verrill.*

3.5 Channel Morphology

CBEP surveyed channel cross sections at each Station, as well as a longitudinal profile through the mitigation site, in 2013 and 2014. Cross section surveys, and the August longitudinal profile surveys, were conducted by CBEP. The December 2013 longitudinal profile was performed by a team of DOT on the auto level, and CBEP holding the stadia rod.

Table 8. Channel morphology survey dates.

Location	2013	2014
Station 1	7/25	6/17
Station 2	7/31	6/17
Station 3	8/5	6/18
Station 4	8/5	6/18
Station 5	8/5	6/18
Station 6	8/5	6/18
Station 7	8/5	6/18
Station 8	8/5	6/18
Station 9	7/25	7/8
Station 10	7/25	7/8
Longitudinal Profile	8/30; 12/10	8/5

Longtidinal profiles are plotted in Figures 34-35, with elevations in feet relative to NAVD 88. Mean high water (MHW, 4.12’) at the Portland Tide Station is shown for context. It was not feasible to start and end the longitudinal profiles at fixed locations due to unconsolidated sediment conditions on the channel bottom. The longitudinal profile was surveyed in sections due to difficulty accessing the channel thalweg prior to construction, due to deep fine sediments in the channel. On 8/30/13, the section of the creek channel upstream of Long Reach Lane was surveyed by kayak during high tide, due to safety concerns associated with walking the channel thalweg. This allowed for collecting data points far up the creek channel, reflected by the longer transect length (Figure 34). In December 2013, the presence of early season ice on a portion of the upstream channel surface provided enough stability to collect additional data points along the creek channel bottom. These two data sets were combined into a single longitudinal profile by tying elevations into local benchmarks, and by using coordinate data to calculate distance along the channel bottom. For the 2014 longitudinal profile survey, it was possible to walk along the thalweg upstream of Long Reach Lane (Figure 35), but not as far upstream as the 2013 survey by kayak. Although transect lengths differed, the location of channel cross sections at Stations 1 and 2 are shown for context, allowing for comparison year to year.

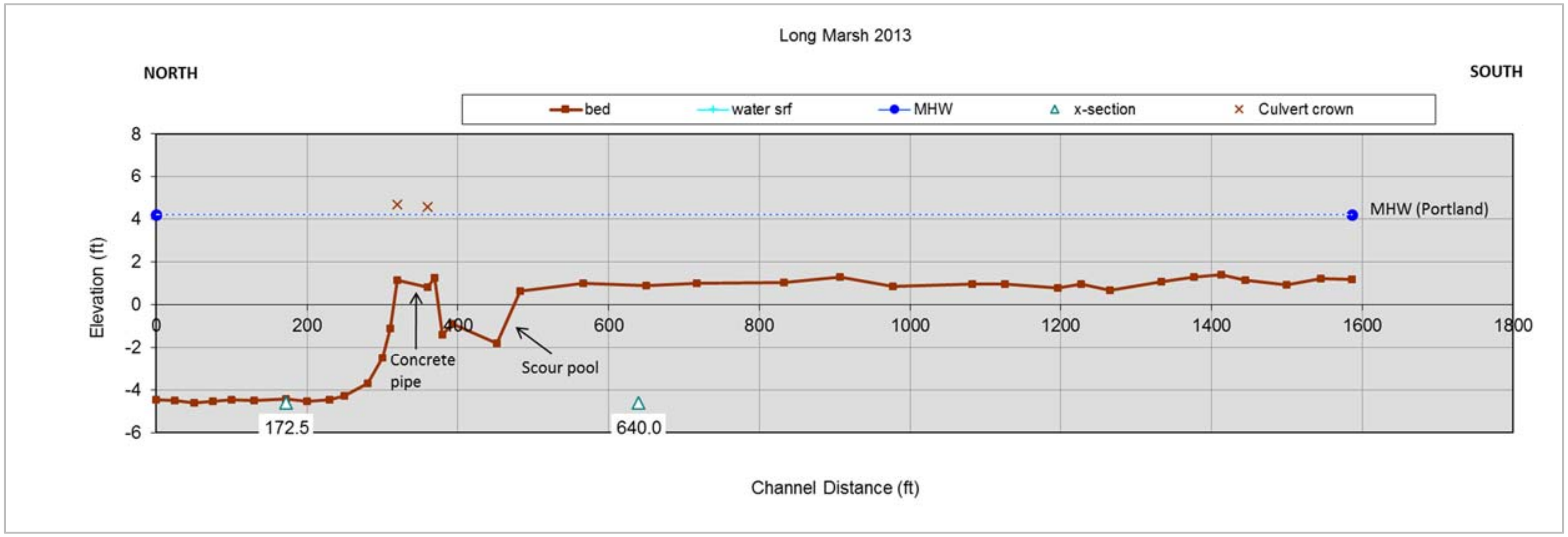


Figure 34. Longitudinal channel profile, 2013. Elevations shown in NAVD 88. (Mecklenburg 2006).

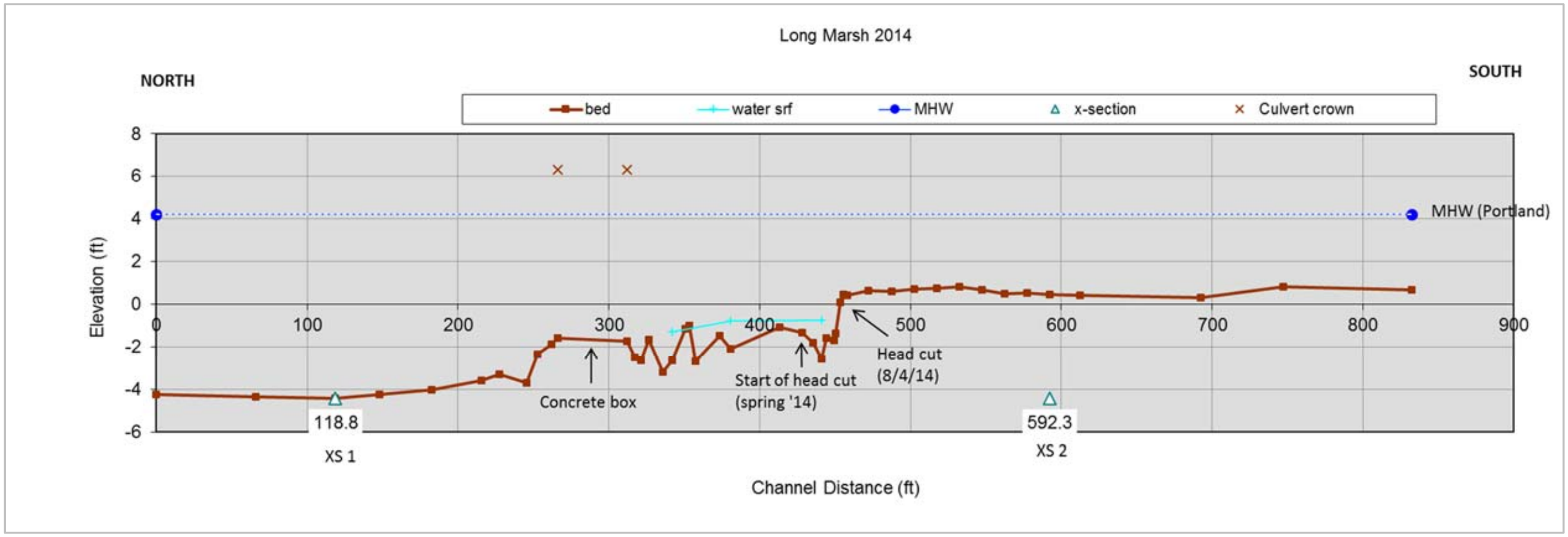


Figure 35. Longitudinal channel profile, 2014. Elevations shown in NAVD 88. (Mecklenburg 2006).

The 2013 profile (Figure 34) illustrates mudflat downstream of the road, rip-rap at the base of the outlet, the invert of the original round pipe, a deep scour pool hidden beneath water impounded upstream, and acculated sediment upstream of the scour pool. Upstream of the scour pool, sediment elevations level off consistent with the invert of the culvert.

Although the scale is not identical, the 2014 profile (Figure 35) shows mudflat downstream of the road, with elevations slightly higher, possibly from sediment moving out of the upstream channel. Rip-rap at the base of the outlet remains, but the new culvert invert is lower, near the depth of the scour pool. A series of sediment deposits are evident upstream of the culvert inlet, resulting in a series of shallow ripples and pools in the former scour pool. A head cut is migrating up the channel, which is being tracked using stakes at the channel edge. Upstream of the head cut, the channel bottom levels off, but at a lower elevation.

Channel cross section transects were surveyed at each Station in 2013 and 2014. Figure 36 plots Stations 1-5 for each year, and Figure 37 plots Stations 6-10 for each year, with MHW (4.12') at the Portland Tide Station for context. MHW was used in the Reference Reach Spreadsheet (Mecklenburg 2006) to calculate channel dimensions and cross sectional area, allowing for a standardized comparison of change in channel characteristics from one year to the next, which is particularly useful for looking at channel evolution in relation to increased inundation of the marsh surface. At each Station, the west side of the marsh is shown on the left side (0') of the transect. Elevations are in feet relative to NAVD 88. At most Stations, transects begin and end at fixed points that are higher than MHW, with the exception of Station 7. The location of cross section transects was identical each year, but slight differences in transect length were unavoidable at a couple locations because of conditions in the field. This was due to a breeze pulling the tape, which hangs above the channel, so that it is not as taut, and therefore a bit longer.

Headcut in the creek channel upstream of Long Reach Lane (CBEP, 4/24/14).

Rills along the west channel edge downstream of Long Reach Lane in 2014 (view to south, top), and 2012 (view to north, bottom), which were picked up in channel cross section surveys (photos CBEP).

Channel cross section transect comparisons between 2013 and 2014:

- At Station 1, surveys show slumping banks which are evident in 2014 on each channel bank downstream of Long Reach Lane, at approximately 50 feet and 175 feet along the transect. This is consistent with anecdotal observations of local residents, who have commented that it appeared the downstream channel was widening. Photos of the area from 2012 and 2014 (p. 54) show that this erosion began prior to construction.
- At Station 2, the channel features became more angular in 2014, particularly at the base of the channel banks, and at the thalweg, suggesting active scour. Unconsolidated sediment appears to have moved out of the channel outside the thalweg as well.
- At Station 3, the thalweg is both deeper and wider in 2014.
- At Station 4, the same angular channel shape is evident, indicative of active scour as the channel evolves to the new hydrological regime in 2014.
- Station 5 shows a new, steep angular incision of over 1.5 feet at the thalweg in 2014.
- In 2014, the channel is incising at the base of the western bank at Station 6 (note that the vertical scales are slightly different).
- At Station 7, the channel shows a more rounded shape, but is still incising in 2014.
- At Station 8, the thalweg is incising in 2014, and erosion is visible along the eastern bank.
- At Station 9, the channel is incising in 2014, and a secondary channel-like feature is incising along the eastern side, suggesting that the channel is rapidly widening.
- At Station 10, which is located close to “the narrows,” less channel evolution is evident, although the base of the channel bank appears more angular.

Selected photographs from the cross section surveys are included in Section 3.7 of this report. At most Stations, photographs were taken looking upstream, downstream, and from each channel bank, providing a visual record of change. At some Stations, additional photos were taken showing views to the upland edge.

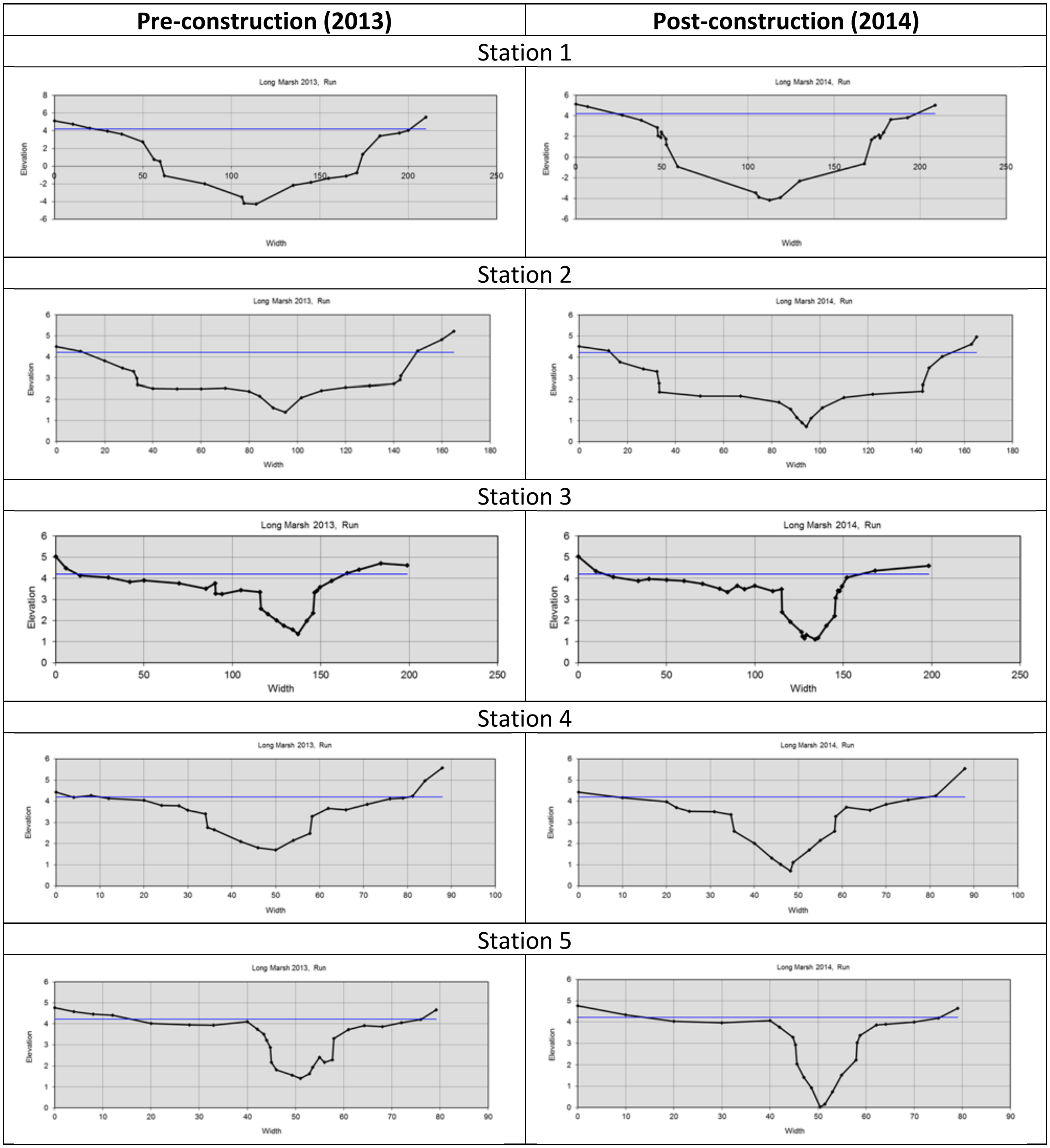
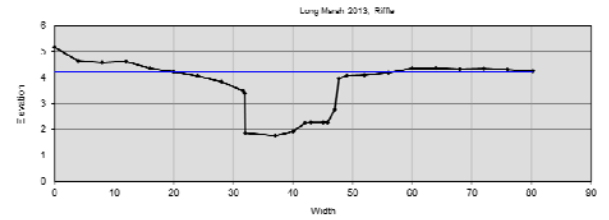
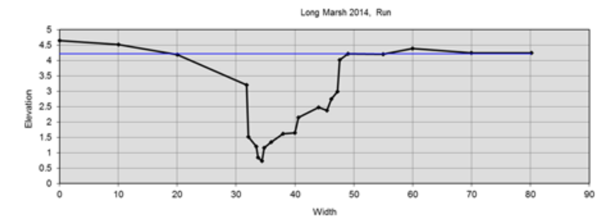


Figure 36. Plotted channel cross sections (Stations 1-5).

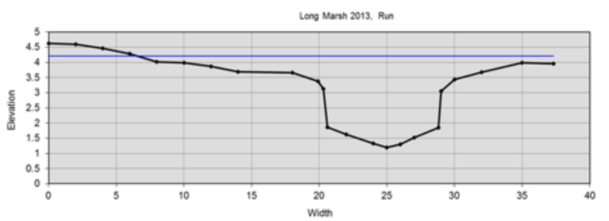
Pre-construction (2013)	Post-construction (2014)

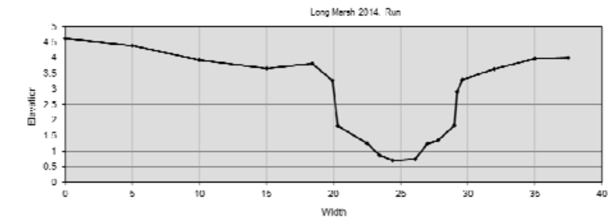
Station 6



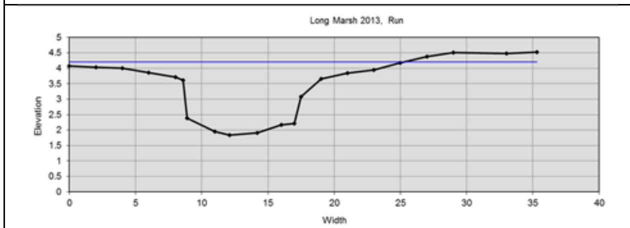


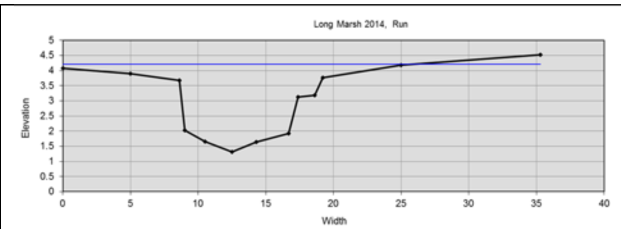
Station 7



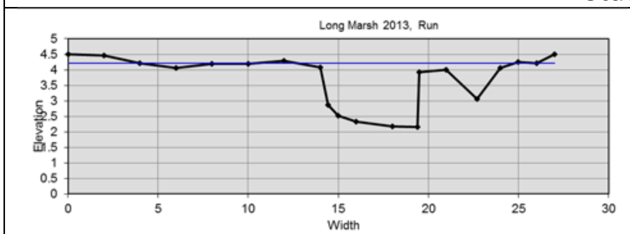


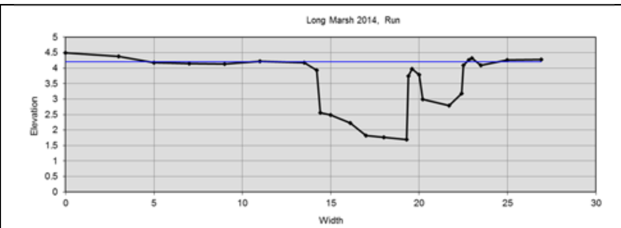
Station 8



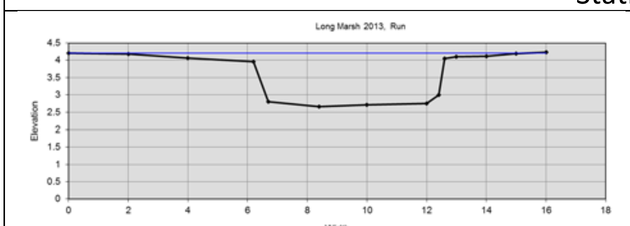


Station 9





Station 10



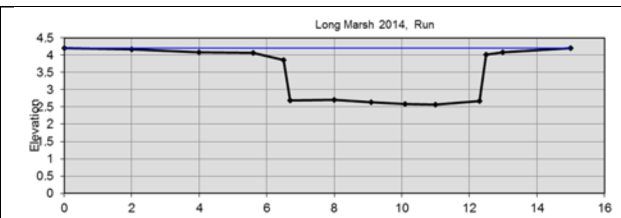


Figure 37. Plotted channel cross sections (Stations 6-10).

These visual indicators the channel is actively evolving are reflected in the quantitative metrics of the cross section transects as well (Table 9, Figures 38-39). Cross section area increased at every Station within the Project Area from 2013 to 2014. Cross section area increased by more than 10% at all but two Stations in the Project Area, and was highest (16.7%) at Station 2, the first Station upstream of Long Reach Lane. At Station 10, the furthest transect from Long Reach Lane, cross section area increased by the lowest of all Stations in the Project Area (1.0%). This may be due to the presence of the historic ford across the creek channel upstream of Station 8 (see photo, Section 4), which is likely acting as a grade control for the upstream channel (reflected in the profiles of Stations 9 and 10).

While mean channel depth increased slightly at most Stations in the Project Area, the maximum channel depth increased at every Station in the Project Area, with six Stations showing that the thalweg is at least .5’ lower following construction. The biggest changes in maximum depth were seen at Station 5 (1.4’ lower), and at Station 6 (1.0’ lower). Figure 40 plots mean and maximum channel depth at each Station in 2013 and 2014, and suggests that the “short-term” channel response to the new culvert was still underway at the time that the transects were surveyed, between 6 and 7 months following construction. The difference in channel response moving in the southernmost Stations may also be a function of varying ice out progress in different areas of the marsh during the spring of 2014. However, the presence of a historic ford between Station 8 and Station 9 is likely also affecting the rate and extent of channel evolution at Stations 9 and 10 (see Section 4).

Table 9. Channel cross section metrics (derived from Mecklenburg 2006).

	Cross Section Area (sq. ft.)		Width (ft.)		Mean Depth (ft.)		Max. Depth (ft.)	
Station	**2013**	**2014**	**2013**	**2014**	**2013**	**2014**	**2013**	**2014**
1	800.0	796.4	178.4	174.2	4.5	4.6	8.5	8.4
2	214.9	257.9	138.2	141.7	1.6	1.8	2.8	3.5
3	124.3	128.1	151.6	145.7	0.8	0.9	2.8	3.1
4	66.3	76.6	71.8	71.4	0.9	1.1	2.5	3.5
5	44.7	52.2	60.1	61.3	0.7	0.9	2.8	4.2
6	37.9	42.7	36.2	36.1	1.0	1.2	2.5	3.5
7	32.9	36.6	30.8	30.5	1.1	1.2	3.0	3.5
8	24.4	27.2	25.4	25.9	1.0	1.0	2.4	2.9
9	12.7	14.8	18.5	18.9	0.7	0.8	2.1	2.5
10	9.9	10.0	15.3	15.0	0.6	0.7	1.6	1.6

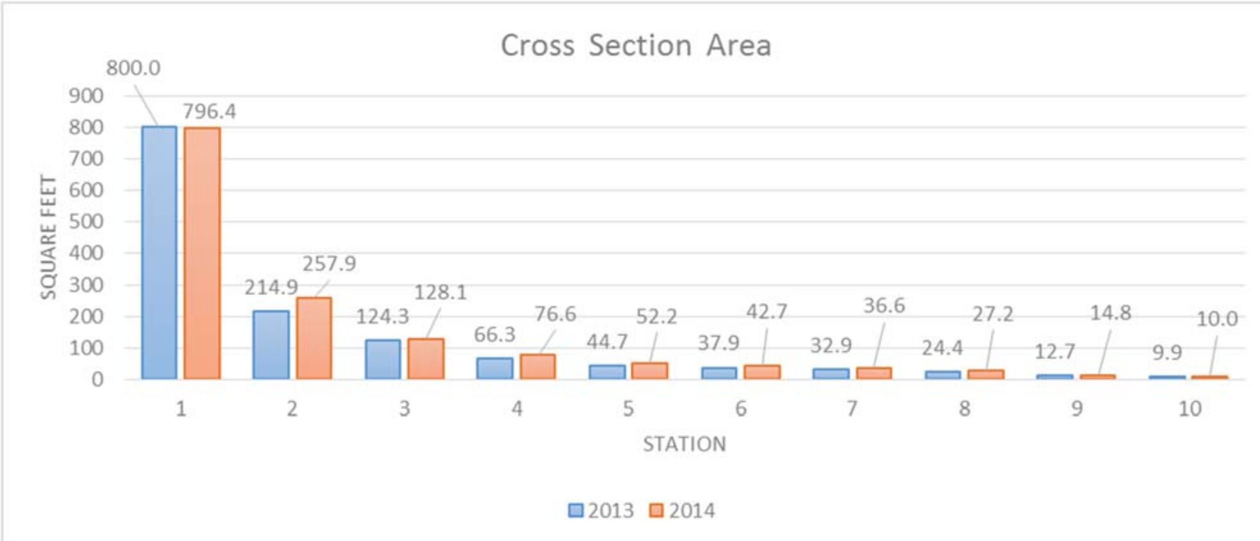


Figure 38. Graphed cross sectional area by Station, 2013 and 2014. (Derived from Mecklenburg 2006).

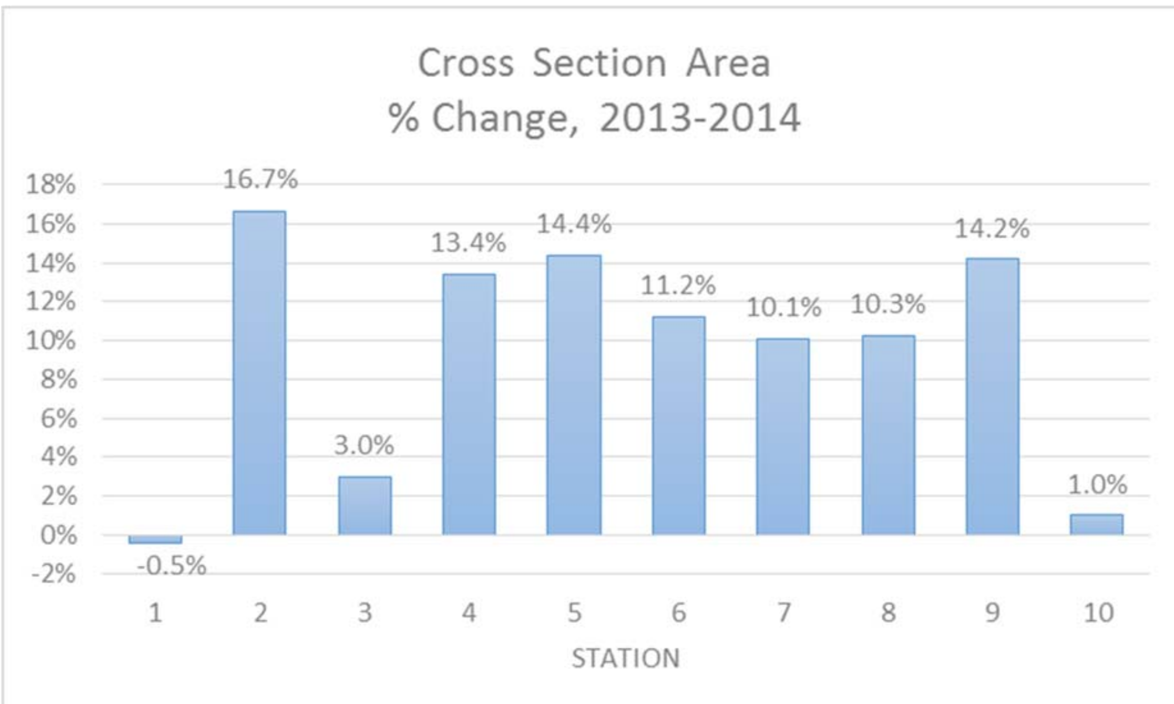


Figure 39. Percent change in cross sectional area by Station, 2013 and 2014. (Derived from Mecklenburg 2006)..

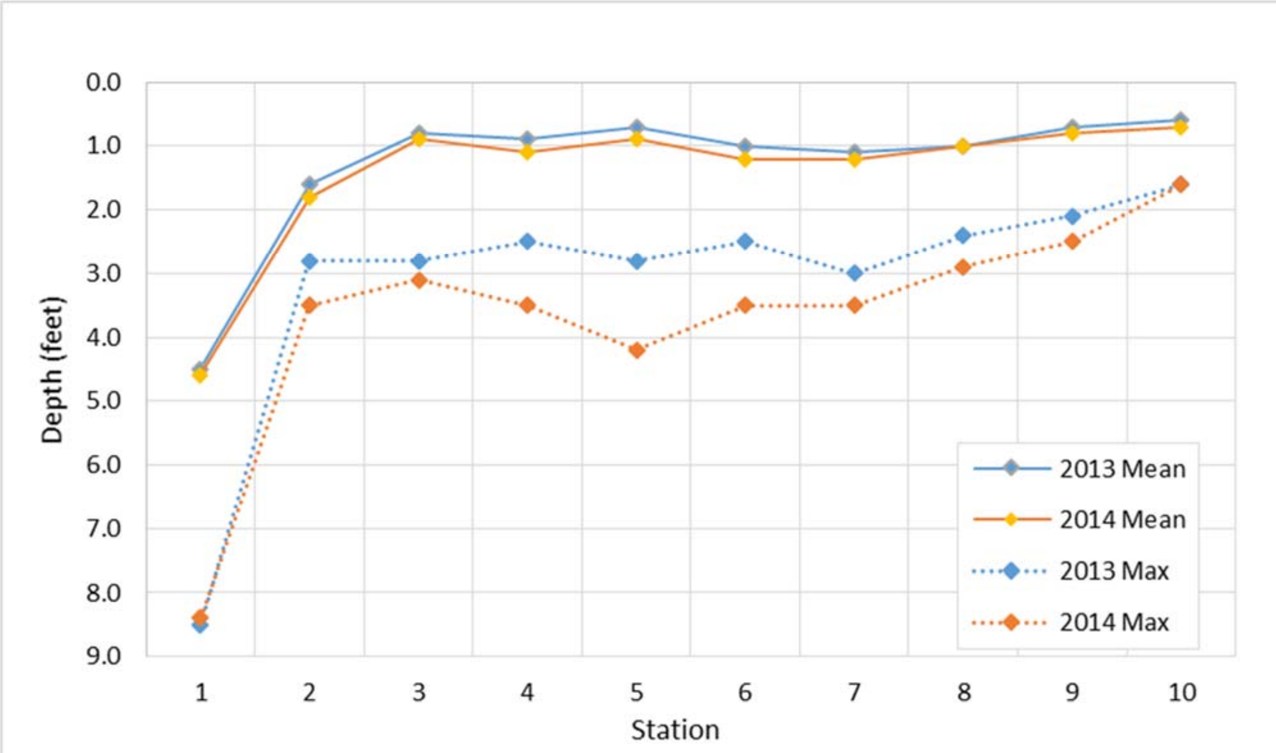


Figure 40. Comparison of mean and maximum channel depths by Station, 2013 and 2014 (derived from Mecklenburg 2006).

3.6 Plant Species of Concern

Incidence of invasive plant species were documented during vegetation transect surveys, meander surveys of the high marsh and marsh perimeter, and incidental observations during the course of monitoring in 2013 and 2014. The meander surveys did not cover the forested area upslope of the upland edge, an area which is determined to be outside of the Project Area, and which is notable due to the fact that invasive plant species appear to be abundant in the adjacent forest based on incidental anecdotal observations traveling through the woods.

Within the Project Area, the only invasive plant species observed the Project Area in the two monitoring seasons was Purple Loosestrife (*Lythrum salicaria*). Although invasive Common Reed (*Phragmites australis*) continues to grow in three distinct patches downstream (south) of Station 10 (visible on Figure 1), and there is anecdotal visual evidence that these stands may be stressed by increased salt water delivery south of the “narrows”, there continue to be no observations of *Phragmites* within the Project Area.

In 2013, loosestrife was documented on the high marsh, and along the upland edge, beginning at Station 4, and moving south to Station 10 (Figure 41). A cluster of plants were documented

on the east side of the marsh adjacent to Station 4, and extending southward to Station 5, and on both sides of the marsh from Station 6 to 10 in 2013. Although the 2013 meander survey took place when loosestrife was observed to be in flower, several individual plants within the Project Area were missing flowers and the flowers appeared to have been either eaten or cut off.

In 2014, observations of invasive plants were limited to a handful of individual loosestrife plants observed during the meander survey along the perimeter of the eastern side of the marsh near Station 4 (Figure 41). One of these plants appeared to have been clipped, with the flowers lying on the marsh surface at the base of the plant. CBEP field staff hand pulled these plants.

The greater extent, higher frequency, and increased depth and duration of tidal inundation appears to have had an immediate impact on Purple Loosestrife, consistent with what we would expect to see. The new hydrological regime may eliminate loosestrife altogether from the Project Area over time. CBEP will continue to intensively monitor for loosestrife and other plant species of concern.

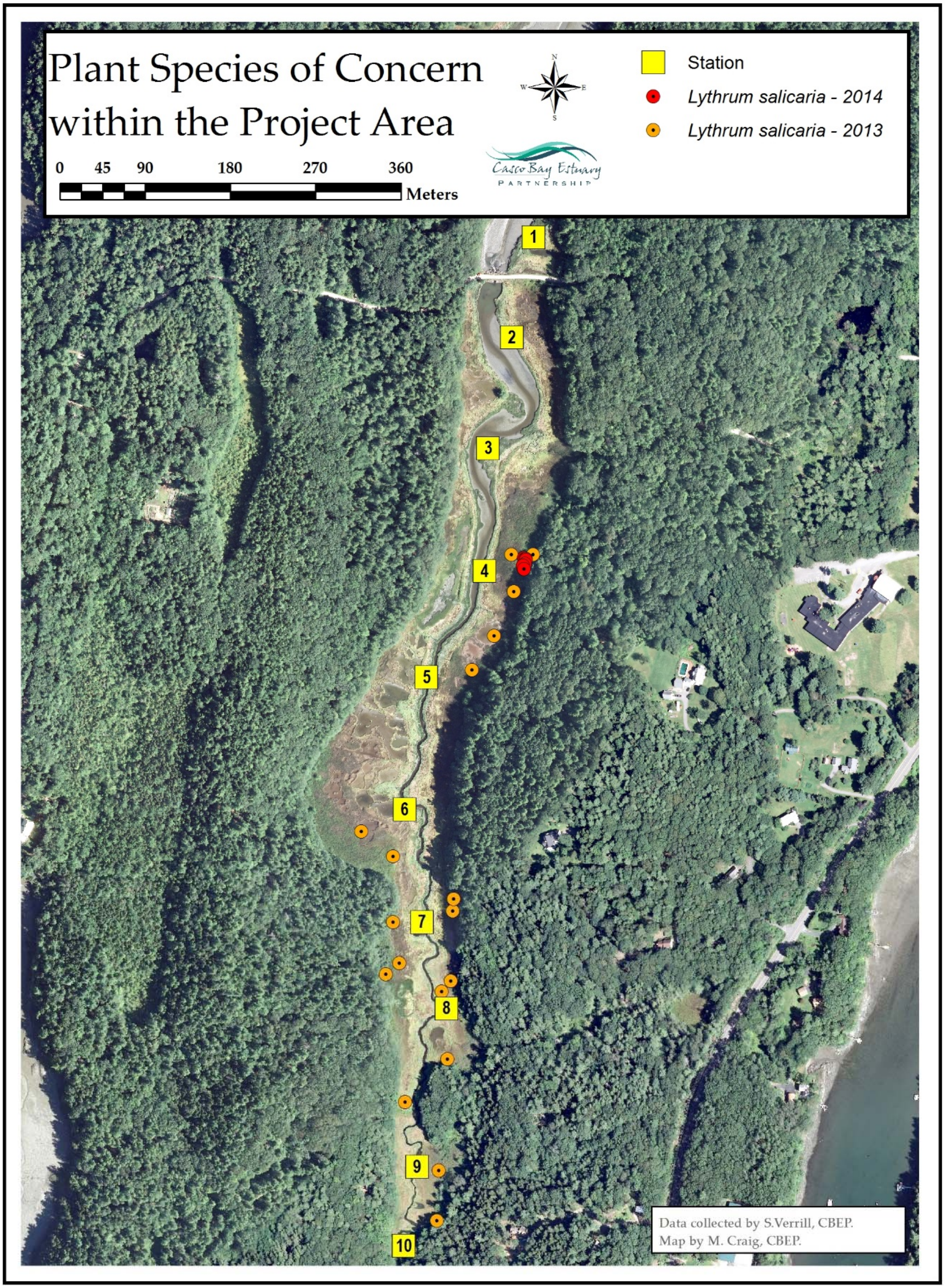


Figure 41. Map of invasive plant species observations, 2013 and 2014.

3.7 Photo Stations

Photographic documentation is being used to visually record conditions at fixed locations at the road crossing, and at each Station. Table 10 shows photo stations associated with the road crossing, before and after construction.

At most Stations, photographs were taken during cross section surveys looking upstream, downstream, and from each channel bank, providing a visual record of each Station (Table 11). At some Stations, additional photos were taken showing views to the upland edge.

During vegetation surveys, photographs were taken from the 0’ (creek channel) looking to the end of the transect (upland edge), and from the upland edge looking back at the creek channel. Many of the 2014 photographs clearly show standing dead vegetation, particularly cattails (Table 12).

Table 10. Photo stations at the construction site, 2013 and 2014.

PRE-CONSTRUCTION	**POST-CONSTRUCTION (YEAR 1)**
View Downstream (North)	
	
View to Outlet (South)	
	
View to Inlet (North)	
	
View Upstream (South)	
	

Table 11. Photos stations at channel cross section transects, 2013 and 2014.

<table>
<tr><th>PRE-CONSTRUCTION (2013)</th><th>YEAR 1 POST-CONSTRUCTION (2014)</th></tr>
<tr><td colspan="2">Station 1 Cross Section (view downstream)</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td colspan="2">Station 2 Cross Section (view upstream)</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td colspan="2">Station 3 Cross Section (view west)</td></tr>
<tr><td></td><td>
</td></tr>
</table>

PRE-CONSTRUCTION (2013)	YEAR 1 POST-CONSTRUCTION (2014)
Station 4 Cross Section (view upstream)	
	
Station 5 Cross Section (view upstream)	
	
Station 6 Cross Section (view upstream)	
	

<table>
<tr><th>Pre-Construction (2013)</th><th>Year 1 Post-Construction (2014)</th></tr>
<tr><td colspan="2">Station 7 Cross Section (view upstream)</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td colspan="2">Station 8 Cross Section (view upstream)</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td colspan="2">Station 9 Cross Section (view upstream)</td></tr>
<tr><td></td><td>
</td></tr>
</table>

PRE-CONSTRUCTION (2013)	YEAR 1 POST-CONSTRUCTION (2014)
Station 10 Cross Section (view upstream)	
	

Table 12. Photo stations at vegetation transects, 2013 and 2014.

PRE-CONSTRUCTION (2013)	**YEAR 1 POST-CONSTRUCTION (2014)**
Station 1 Vegetation Transect (view from channel)	
	
Station 2 Vegetation Transect (view from channel)	
	
Station 2 Vegetation Transect (view from upland)	
	

<table>
<tr><th>PRE-CONSTRUCTION (2013)</th><th>YEAR 1 POST-CONSTRUCTION (2014)</th></tr>
<tr><td colspan="2">Station 3 Vegetation Transect (view from channel)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Station 3 Vegetation Transect (view from upland)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Station 4 Vegetation Transect (view from channel)</td></tr>
<tr><td></td><td></td></tr>
</table>

PRE-CONSTRUCTION (2013)	YEAR 1 POST-CONSTRUCTION (2014)
Station 5 Vegetation Transect (view from channel)	
	
Station 6 Vegetation Transect (view from channel)	
	
Station 7 Vegetation Transect (view from channel)	
	

<table>
<tr><th>PRE-CONSTRUCTION (2013)</th><th>YEAR 1 POST-CONSTRUCTION (2014)</th></tr>
<tr><td colspan="2">Station 7 Vegetation Transect (view from upland)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Station 8 Vegetation Transect (view from channel)</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Station 9 Vegetation Transect (view from channel)</td></tr>
<tr><td></td><td></td></tr>
</table>

PRE-CONSTRUCTION (2013)	YEAR 1 POST-CONSTRUCTION (2014)
Station 10 Vegetation Transect (view from channel)	
	

3.8 Wildlife use

CBEP recorded use of the Project Area by fish and wildlife incidentally when circumstances permitted but generally, time and energy was focused on collecting data for the core parameters. These observations are listed in Table 13. Additional anecdotes were also provided to CBEP. In 2014, DOT staff observed a harbor seal in the creek upstream of Long Reach Lane, and local residents saw a large fish that they believed to be a sturgeon in the upstream creek channel at high tide. Other incidental observations of fish and wildlife are listed in Table 13.

Table 13. Incidental observations of fish and wildlife during monitoring.

Common name	Scientific name	Notes
Great blue heron	*Ardea herodias*	Pannes; outlet
Snowy egret	*Egretta thula*	Pannes; outlet
Bald eagle	*Haliaeetus leucocephalus*	2013 nest in pine
Osprey	*Pandion haliaetus*	
Greater yellowlegs	*Tringa melanoleuca*	Pannes; outlet
Sandpipers	*Scolopacidae spp.*	Pannes
Black duck	*Anas rubripes*	Creek channel
Mallard	*Anas platyrhynchos*	Creek channel
Canada goose	*Branta canadensis*	Creek channel
Belted Kingfisher	*Megaceryle alcyon*	
Black-crowned night heron	*Nycticorax nycticorax*	Pannes
Mink	*Neovison vison*	
Fisher	*Martes pennanti*	Found dead in spring trap
White-tailed deer	*Odocoileus virginianus*	
Coyote	*Canis latrans*	
Black bear	*Ursus americanus*	
Moose	*Alces alces*	
Raccoon	*Procyon lotor*	Tracks in channel flats
Soft shell clam	*Mya arenaria*	Upstream flats
Quahog	*Mercenaria mercenaria*	Upstream flats
Ribbed mussel	*Geukensia demissa*	
Mud snail	*Hydrobiidae spp.*	
Horseshoe crab	*Limulus polyphemus*	
Silverside	*Menidia menidia*	
Mummichog	*Fundulus heteroclitus*	
Green crab	*Carcinus maenas*	
American eel	*Anguilla rostrate*	
Moon jelly	*Aurelia spp.*	High marsh, 2014

4. MANAGEMENT RECOMMENDATIONS

Year 1 monitoring data for all parameters show that conditions in the Project Area are on track to meet the mitigation goals and objectives. Separately from remedial actions, we suggest that there are opportunities to further enhance the wetland system outside of the goals of this mitigation project:

(1) Modify accumulated coarse sediment deposits in the scour pool immediately upstream of the new culvert inlet. These deposits are presumed to be slugs from erosion associated with the 36" concrete pipe that was in place prior to the mitigation project. The location and elevation of the deposits results in a series of pools and ripples in the scour pool at low water, and could be moved by hand rake to match the slope from the culvert to the upstream channel bottom. Although these pools and ripples are not likely to be problematic for nekton using the marsh, the uneven channel bottom is likely affecting both the way that sediment transport is occurring out of the marsh, and could also affect the location, extent, and rate of erosion in the scour pool and the adjacent banks.

(2) Explore local support for removing large rocks from a remnant ford (Figure 42) from the stream channel near Station 8. Hydrology in the southern Project Area is affected by this historic ford that crosses the marsh at a narrow point between Station 8 and Station 9. This ford, which is approximately 20 feet wide, impounds water upstream and although its historic purpose is not well documented, CBEP encountered hunters using the structure to cross the marsh to duck hunt during the fall of 2014. The new tidal regime is causing the channel banks at this location, and the adjacent high marsh, to erode in order to accommodate the increased volume and velocity of water passing through this narrow point in the

Figure 42. Photo of the "old road bed" draining during an outgoing tide.

marsh. Over time, we expect that the rock bed beneath the high marsh vegetation will be exposed from ongoing erosion. Removing the rock from the creek channel would reduce erosion and maximize the benefits of the culvert for the southernmost wetland within the Project Area, as well as the wetland area to the south of the Project Area. It would also improve aquatic organism passage.

5. REFERENCES

Abbott, A. Personal communication, 2/2014. Contractor with the US Fish and Wildlife Service, Gulf of Maine Coastal Program, Falmouth, Maine.

Konisky, R., D.M. Burdick, M. Dionne, and H.A. Neckles. 2006. *A Regional Assessment of Salt Marsh Restoration and Monitoring in the Gulf of Maine.* Restoration Ecology, 14:4 (516-525).

Maine Department of Transportation, 2012. *Wetland Mitigation Plan: Martin's Point Bridge, Falmouth-Portland. PIN 16731.00.*

Mecklenburg, D., 2006. *The Reference Reach Spreadsheet: Version 4.3 L*. Ohio Department of Natural Resources.

Neckles, H., and M. Dionne, Eds., 1999. *Regional Standards to Identify and Evaluate Tidal Wetland Restoration in the Gulf of Maine.* Wells National Estuarine Research Reserve. https://www.pwrc.usgs.gov/resshow/neckles/Gpac.pdf.

Timer, R. 2009. *Field Guide to Tidal Wetland Plants of the Northeastern United States and Neighboring Canada: Vegetation of Beaches, Tidal Flats, Rocky Shores, Marshes, Swamps, and Coastal Ponds.* University of Massachusetts Press.

Wake, C., E. Burakowski, K. Hayhoe, C. Watson, E. Douglas, J. VanDorn, V. Naik, and C. Keating, 2009. *Climate Change in the Casco Bay Watershed: Past, Present, and Future.* Casco Bay Estuary Partnership. http://www.cascobayestuary.org/wp-content/uploads/2014/08/2009_cbep_climate_change_report.pdf