Antigonish Landing
Year 1 (2016) Post-Enhancement Monitoring Report

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Prepared for:

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Executive Summary

Year 1 (2016) post-restoration monitoring of the Antigonish Landing wetland complex has been completed by ECA following the completion of restoration activities at the site in 2015. The monitoring protocols implemented, based on GPAC guidelines (1999), prior monitoring activities at the site, and scientific best practice have sought to assess the success of the restoration efforts and the current ecological status of the site. The 2016 monitoring included the sampling and comparative analysis of the adjacent Antigonish Landing Reference (ALR) site.

Restoration activities at the Antigonish Landing Wetland (AL) included removal of barriers to tidal exchange through the installation of larger diameter culverts and a bridge, and the construction of three wildlife habitat ponds and connecting channels. No appreciable post restoration restriction to tidal exchange was observed at AL and Antigonish Landing Ponds (ALP) located near the north end of the Landing Trail, in terms of timing and amplitude of tidal prism.

The three constructed wildlife ponds at AL were observed to have strong aquatic connectivity to tidal flushing from the Rights River in terms of changes in water levels, temperature and conductivity. The AL East Pond, located closest to the marsh outlet to the Rights River, had the greatest correlation in conditions, with decreasing marine effects at the Central and West Ponds with increasing distances from the tidal river, respectively.

Reflective of the baseline survey methods, 2016 quantitative vegetation surveys were completed through the sampling of seven transects at AL and three transects at ALR, together with meandering visual surveys at ALP and ALR. AL was observed to have extensive coverage of low diversity stands of *Phalaris arundinacea* (Reed canary grass). A comparable species mix was observed at ALR, with greater overall diversity and less extensive stands of *P. arundinacea*. Invasive alien species (*P. arundinacea* and *Lythrum salicaria* (Purple loosestrife)) and several exotic species were observed at both AL and ALR. These species, together with fine-scale topographic observations in the field and local oral history, suggest historic agriculture disturbance at both sites.

A limited water quality profile and fish sampling program was undertaken to characterize the conditions in the 2015-constructed ponds at AL and ALP. Waters within the West, Central and East Ponds at AL were found to be warm (19 to 23 °C), dilute to oligohaline (371 to 1930 mg/L TDS), low in dissolved oxygen (0.5 to 6.3 mg/L) and have near neutral pH (6.6 to 7.1).

The habitat restoration measures undertaken at AL showed promising initial results in terms of open water habitat gain and tidal exchange across the marsh surface. The removal of tidal barriers at AL and ALP have resulted in very limited to negligible residual restrictions on tidal exchange.

Introduction

The Antigonish Landing site is situated east of the Town of Antigonish and within the larger Antigonish Harbour estuary, formed by the Rights, West and South Rivers with a barrier beach at the seaward boundary. The Antigonish Landing wetland complex forms portion of the larger estuary, and is bounded by the Rights and West Rivers. The region is characterized by large seasonal oscillations in seawater temperature, ranging from +20°C in the summer to -1°C in the winter, with abundant sea ice reaching thicknesses of up 1.2 m (David and Browne, 1996). Intertidal zones, such as Antigonish Landing, are affected by ice from mid-December to April or May each year. The region has erratic diurnal or semi-diurnal tides, ranging from 1.1 to 2.9 m (David and Browne, 1996).

The Antigonish Landing, and much of the adjacent tidal marshlands, have undergone some modification and use for agriculture harvest of grasses in the past. This former use was verbally confirmed by local residents' (ECA 2015), and is evidenced by ditches and old access roadways on the marshlands. NSTIR engaged CBCL Ltd. in 2010 to develop a wetland compensation plan (CBCL 2010, 2011) for the area referred herein as Antigonish Landing (AL), and referred to as Antigonish Landing North in other reports (Figure 1). The compensation was to serve as part of the NSE permit approval conditions for the twinning of Highway 104 (NSE Approvals #2009-066003 and 2015-093928). The proposed Antigonish Wetlands Compensation Project, incorporated seven components (CBCL 2011):

a) Crown purchase and protection of 11.3 ha of wetlands and 13.7 ha of riparian buffer adjacent to the Antigonish Wildlife Management Area;
b) Bank stabilization work by Habitat Unlimited and DFO on the West River;
c) Bank stabilization by NSTIR on the Rights River (adjacent to the Antigonish Landing Trail);
d) Restoration of approximately 10.8 ha of tidal-influenced wetland habitat;
e) Creation and enhancement of approximately 4.8 ha of wetland habitat;
f) Development of a 765 m interpretive walking trail; and
g) An Invasive Alien Plant Program being conducted by the Nova Scotia Agricultural College (long-term applied research program to determine optimal control of Japanese knotweed; now part of Dalhousie University).

Proposed enhancement of the AL was to be accomplished by the creation of areas of shallow open water habitat within the wetland for waterfowl, improving tidal influence through the creation of channels and upgrades to two existing culvert crossings along the Antigonish Landing walking trail, and interpretive and physical improvements to the trail. Restored tidal influence was predicted to improve the flushing of the wetland system following a large flood event, decrease residency time for flood waters within the system, improve fish passage and transport of materials into and out of the wetland, and reduce flood risk of the adjacent properties (CBCL 2011).

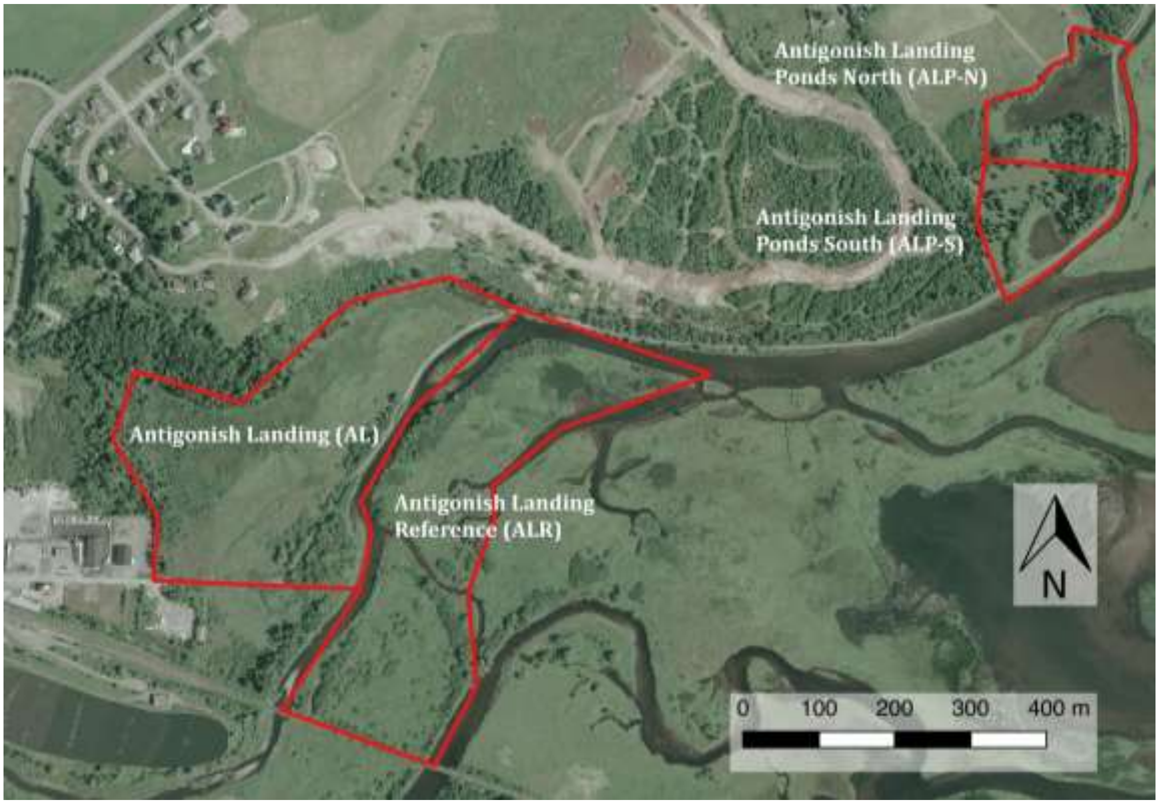

Figure 1: Antigonish Landing (AL), Reference (ALR), and Ponds (ALP) Study Area.

Remediation of tidal channel constrictions formed by culverts under the Antigonish Landing trail was designed by CBWES Ltd. (CBWES 2012, 2014) and completed at both the Antigonish Landing north (ALP north) and south (ALP south) ponds, and at two locations along the AL site prior to 2015.

The design of the ponds at AL was intended to maintain a central open water area, free of vegetation. The open water area was predicted to be surrounded by different plant communities, depending on their moisture regime (CBCL 2011). Design of gradual side slopes around the ponds was to allow a broad moisture gradient at the edge that would encourage the establishment of a greater diversity of wetland plant species. Final pond design was completed by CBWES Ltd. (CBWES 2014), and construction of three ponds (AL west pond, AL central pond, and AL east pond) and channel enhancements within the AL marsh site was carried out by East Coast Aquatics Inc. (ECA) in 2015 (ECA 2015).

Following the completion of the wetland compensation activities, NSTIR issued Request for Proposals (RFP) 601495 for Salt Marsh Monitoring at Antigonish in 2016. The RFP objectives were to conduct field surveys that adhered to specific monitoring protocols (detailed in the following section titled "Methods") and compare results at the AL compensation site to a nearby reference location, referred to within this report as Antigonish Landing Reference (ALR). The tender for monitoring was awarded to

ECA, and this report presents the Year 1 monitoring results of the 2016/17 field season.

Methods

Monitoring Objectives

As outlined in the tender for Salt Marsh Monitoring at Antigonish, the methods used were to be based on the GPAC Regional Monitoring Protocols (GPAC 1999) and to be comparable to baseline work for the project location (CBCL 2010, 2011, CBWES 2012, 2014). The contracted monitoring included: habitat mapping and digital elevation modeling (DEM), hydrology monitoring of tidal signal, sediment accretion monitoring, vegetation community monitoring, low altitude aerial photography, fish and vertical profile water chemistry surveys of ponds, and structured summer and winter walks of the project site. The 2016 monitoring program is summarized in Table 1.

Following the completion of wetland enhancements and the removal of tidal restrictions, the Year 1 monitoring program sought to:

- Quantify the biotic and abiotic changes at the AL and ALP sites;
- Determine if post-enhancement changes were toward a system that was more reflective of a natural tidally unrestricted coastal wetland system, such as the ecosystem reflected at the reference (ALR) location;
- Carry out a comparative analysis of baseline and Year 1 monitoring results;
- Qualitatively document seasonal changes and processes observed at the Antigonish Landing site; and,
- Make recommendations on the need and nature of additional restoration manipulations (adaptive management) if required to ensure that the goals of the compensation/offsetting plans are met.

The following sections detail the monitoring methodology used to achieve the project objectives for each monitoring parameter.

Habitat Mapping and Digital Elevation Model (DEM)

During the 2016 field season, a Real Time Kinematic (RTK) GPS system was used for recording surface elevations (Geneq SXPro Real Time Kinematic (RTK) field computer operating Micro Survey Field Genius 8 (version 8.3.17.4), with RTK processing provided by SmartNet). The horizontal datum used was UTM83-20 and vertical geoid model HTv2.0. The Geneq RTK has a reported horizontal accuracy of 0.008m +1ppm and vertical accuracy of 0.015m +1ppm. The field tolerances used by ECA in data collection were: horizontal 0.09m and vertical 0.05m. In order to improve consistency of observations, elevation observations were recorded at the same position at each quadrat (within the quadrat and immediately adjacent to the right-hand initial corner stake, when facing towards the end of the transect).

Table 1: Antigonish Landing Year 1 (2016/17) monitoring summary.

Category	Parameters	Sampling Method	Sampling Frequency	Sampling Array
Hydrology	Tidal signal	Automated water level recorders (5 min intervals)	Minimum 29 day period during the sampling year	Solinst Levelloggers: AL (5), ALP (3), ALR (1), barrologger (1).
Soils & Sediment	Marsh surface elevation	Digital elevation model (DEM). G8 GNSS RTK or equivalent. Soil density with penetrometer	Once per sampling year.	Minimum points at all veg. quadrats, pins, and wells at AL, ALP, and ALR. Series of points to document conditions (ALR)
	Sediment accretion	Sediment Pin	Once per year (August)	Sediment pins in each AL pond (3) and (1) in channel; (2) in ALP ponds; (1) in ALR channel
Vegetation	Composition Abundance Height	Transects with $1m^2$ quadrats; proposed area cover method as in CBCL baseline at AL and ALR. General inventory at ALP north and south.	Once per year (August)	6T's 23Q's at AL and one replicate T 4 Q's, plant inventory at ALP north and south, 3T's 16Q's ALR
	Habitat/surface cover map(s)	Low-altitude aerial DGPS/GIS photography	Once per sampling year (Summer).	AL, ALP, and ALR
Evaluation of Restoration Progress	Visual assessment of habitat condition, restoration recovery rate, wildlife usage	Structured summer walk; photo documentation. Discrete YSI multimeter vertical water profile in each pond. Minnow trap surveys within each pond habitat.	Once per year (August)	Photos at each T and other structures / observations of note. Conduct minnow trap and YSI chemistry profiles surveys at all AL and ALP ponds.
Winter Conditions	Ice/snow/wetland conditions	Structured winter walk; photographs along each transect	Once per year (Feb/March)	Photos at each T and other structures / observations of note.

Surface elevations were documented at every quadrat along every transect, as well as immediately adjacent to each stilling well and sediment pin. Surface elevations were also collected generally across the landscape at a ~25m grid at AL, ALP, and ALR. At AL, additional elevation points were collected around excavated channel features and spoil piles. A summary of the number of elevation points collected at each location to facilitate DEM production is presented in Table 2.

Table 2: Elevation point sampling intensity by location for DEM production.

Location	Number of Elevation Points Collected
Antigonish Landing (AL)	1841
Antigonish Landing Ponds (ALP-north)	115
Antigonish Landing Ponds (ALP-south)	54
Antigonish Landing Reference (ALR)	41

Aerial photography was recorded at the wetland on July 19, 2016 using a fixed-wing aircraft at a flight attitude of 971 m. A total of 409 images were captured using a Canon EOS-1DX camera, and stitched together to form a montage. The orthorectified image was then geo-referenced using ground control stations previously placed in the wetland, the locations of which had been determined using a high accuracy RTK-GPS system. Pixilation colour and density, together with logical assumptions concerning remote sensing of natural environments, allowed the generation of preliminary habitat boundaries and maps. Field-mapped vegetation boundaries and observed characteristics gathered were then used to refine the habitat map. A final quality control step involved comparing the generated habitat boundaries and classifications with the transect quadrat data at the wetland, allowing the production of the final habitat maps.

The DEM was created by combining RTK survey data collected in 2016 and the AGRG DEMo grid generated from LiDAR data flown in December of 2008. Elevation points were extracted from the DEMo grid at a spacing of 5 per square meter and combined with the 2016 RTK survey points. These points where then imported into SAGA GIS and gridded using Multilevel B-Spline Interpolation. The gridded elevation data was then cropped to the AOI and contoured at a 20cm interval.

Hydrology

The post-restoration hydroperiod (frequency and duration of tidal flooding) for AL was recorded using tidal signal data (pattern of water surface elevation) and the Digital Elevation Model (DEM). The tidal signal was recorded using Solinst Leveloggers deployed in stilling wells, with observations recorded at five-minute intervals between July 28, 2016 and September 1, 2016 (n=10037 observations). Three pairs of data loggers were deployed, each placed upslope and downslope of each of the former tidal obstructions at: AL, ALP North Pond, and ALP South Pond (see Figures 6 and 7).

In order to further characterize the tidal influence on the three wetland enhancement ponds at AL, a single data logger was placed in a stilling well at the west, central and east ponds. A single data logger was also deployed at the AL reference site.

All locations were fitted with Solinst Level Logger Junior (Model 3001) units, with the exception of the AL site, where ECA chose to install Solinst LTC Level Logger Edge units, recording water level, temperature and conductivity. The addition of conductivity logging in conjunction with vertical chemistry profiles in each of the AL constructed ponds was intended to allow ECA to better characterize the extent of influx of tidal water at the site, and not simply the tidal signal.

A Solinst Barologger Gold was deployed at AL in a vented above-ground pipe to record barometric pressure fluctuations in accordance with the manufacturer's instructions. The barometric pressure data was used with the Solinst Levelogger Series Software (version 4.3) (www.solinst.com/downloads) for post-processing and analysis of the tidal signal data. The UTM coordinates and vertical elevations of all data logger deployments were recorded using the RTK GPS system to within ± 0.05 m.

Analytical methods consistent with those used for the restoration design were employed to allow pre- and post-restoration comparisons to be made (CBWES, 2012 and 2014). Minimum, mean and maximum (min/mean/max) water levels for each location up and downslope of the former tidal restriction were calculated using all the readings from the water level recorders. Min/mean/max tide levels were also calculated, but were done so using only the high tide readings. Both water level and tide level were calculated as the min/mean/max tide levels provide average tidal coverage, whereas, mean water level provides the lower marsh boundary elevation and an indication of water retention between tidal events.

The HTv2.0 hybrid geoid model used in the RTK-GPS elevation surveys has a reported accuracy of +/- 0.05 m (with 95% confidence) (Loo, 2002). The vertical tolerance used in the RTK-GPS unit during the field collection of elevation data was 0.05 m. As part of the project quality assurance / quality control program, ECA performed manual observations of water levels at all wells to provide a comparison against the water levels recorded by the data loggers. The mean difference between the nine manual and logged water levels at Antigonish Landing in 2016 was +/- 0.042 m. Based on these factors, water level differences less than 0.05 m were considered insignificant given the accuracy and reproducibility of the observations and equipment used.

Soils and Sediments

ECA established a series of sediment pins across the Antigonish Landing site so as to document changes in ground surface as a result of soil accretion or erosion (USGS, 2012a). Sediment pins were established immediately adjacent to the water level monitoring wells. Two inch ABS pipe was driven into the substrate at each location to a depth of at least one meter or refusal. Each pin was then cut to a height of approximately 0.5-1m above the substrate. A total of seven pins were established and surveyed on August 27, 2016: Antigonish Landing Wetland outflow channel immediately upstream of the bridge; AL West, Central and East ponds; the adjacent reference site and at the North and South Ponds. The vertical elevations of pins were recorded using a high accuracy RTK GPS system.

As a component of the overall QA/QC program, ECA modified the methodology slightly to determine and limit methodological, spatial, and practitioner variability in data collection around sediment pins. Rather than a single measure, field staff collected measures from the top of the pin to surface substrate at each of four permanently marked locations on the pin. The modified approach was anticipated to improve replication of observations by establishing four permanent locations for data collection around the perimeter of the pin. The four observations were recorded at each pin, starting at a double hole drilled near the top of the pipe (Figure 2) and proceeding to record an observation on each side of the pipe in a clockwise direction. Collection and averaging of four observations around each pin, given that natural substrate elevation undulations can be on the order of several cm from one side of a pin to another, limits error due to spatial variability around the pin. Additionally, duplicate observations were recorded by two ECA staff members so as to provide a QA/QC check and to quantify the practitioner variability. Determining both spatial variability and practitioner variability allows ECA to determine the magnitude of change likely to be detected by the survey methods employed.

Figure 2: Top of sediment pin, with drill holes indicating sampling locations.

As part of a value added monitoring component, ECA investigated soil density across a portion of ALR wetland on August 31, 2016 to document natural conditions that could be used for comparison with other NSTIR monitoring projects at South River, Antigonish County. Density measures were collected using a Spectrum Technologies Inc. Field Scout SC900 Soil Compaction Meter fitted with a 0.5 inch (1.3 cm) drive cone. Soil penetrometer observations were recorded at a total of 20 locations across the central and northern portions of the ALR site. Soil compaction was recorded as pounds per square inch (PSI) at each location at one-inch (2.5 cm) depth increments from the ground surface to a depth of 18 inches (46 cm). Undisturbed salt marsh soil densities examined at the Antigonish Wetland 21 (South River) site, located approximately five kilometers to the southeast, were compared to the results.

Vegetation

ECA established a series of seven vegetation transects across the AL site. Six of the transects approximate those established by CBCL (2010) during the baseline studies. The exact locations of the originals could not be determined, but site homogeneity was expected to limit the impact of spatial variability. The seventh transect established at AL was a duplicate, established as a QA/QC measure. This transect allows spatial variability to be better quantified for the specific site. An additional three monitoring transects were established at ALR. Following the baseline methodology, an inventory of species around the perimeter of each of the ALP ponds was also completed.

Vegetation transects were at least 50 m in length, unless site conditions dictated otherwise. A continuous 50 m tape was used for quadrat placement, to reduce layout error. The beginning and end of each transect were permanently staked in the field, with the location of each quadrat also staked on two corners to facilitate future monitoring and proper placement of the monitoring quadrat. Beginning and end points of each transect, as well as the corner of each quadrat were documented with high accuracy RTK – GPS system. Furthermore, the bearing of each belt transect was documented. Wetland zones along each transect were visually identified, measured from the point of origin, and flagged, based on the qualitatively observed generalizations of wetland vegetation composition. The establishment of zones created a stratification of the wetland allowing for the placement of the monitoring quadrats. A series of 1 m x 1 m quadrats were located in each zone. The minimum target number of quadrats within each zone was three, in order to provide meaningful representation of the zone being assessed. In some cases, if the zone was very narrow, it was not feasible to place multiple quadrats in the narrow zone, and less than three were employed. Quadrats were sited within a zone by dividing the zone length by the number of quadrats, ensuring that they were equally and randomly spaced across the zone.

Following the establishment of the wetland zones and quadrat points, vegetation composition was analyzed at each quadrat. Herb and shrub stratum were assessed by documenting all species and their absolute percent cover within each quadrat. A rigid 1 m x 1 m sampling frame placed over the two corner quadrat marker stakes was used to clearly delineate the boundaries of the quadrat. Sapling stem counts were made within an estimated 5 m radius of the quadrat sampling position. Trees were counted via a prism count from each quadrat sampling location. These methods directly tie to NS Wetland Delineation methods, those used in the baseline studies (CBCL 2010), and the GPAC (1999) monitoring protocols. The vegetation cover in and immediately around each quadrat was documented with a digital photograph.

Experienced staff were utilized in conducting field assessments and data analysis. The same field staff will be used annually in conducting all botanical assessments in order to ensure consistency and reduce variance associated with practitioner bias. In addition to GPAC and baseline methodologies, ECA recorded environmental characteristics of the substrate for each quadrat, including percent water, muck, moss, and exposed stone or mineral soil. Finally, average shrub/herb plant height and water depth in each quadrat were recorded. All field collected data was entered on a standardized field data collection sheet for later entry into a custom-designed database. All data collected through the wetland monitoring project is available in spreadsheet format (Excel) from NSTIR.

For the herb, shrub, sapling and tree strata, the dominant species within each wetland zone was determined using the 50/20 rule (MCFT, 2009). The indicator status of wetland plants was assigned based on the Nova Scotia Wetland Indicator Plant List (Nova Scotia Environment, 2011) with Zinck (1998) used as a taxonomic reference.

Alien invasive species present in the wetland were identified using a list compiled from several sources: Hill and Blaney (2009), CARP (2007), Nova Scotia Weed Control Act (Revised 1989), Brazner (2011) and MTRI (2012).

Fish and Pond Water Profiles

Water quality profile measurements were recorded in open pond water areas at each wetland (AL and ALP) using a YSI ProPlus multiprobe water meter, calibrated as per the manufacturer's instructions. Parameters recorded included pH, Dissolved Oxygen (mg/L), Dissolved Oxygen (Percent Saturation), Water Temperature (°C) and Specific Conductivity (µS/cm). Surface turbidity measurements were made in the field using a LaMotte 2020i turbidity meter. A small kayak was used to access the five ponds so as to record undisturbed water quality observations near the center of the ponds (Figure 3). YSI depth profile readings were recorded at 0.2 m, 0.5 m, and 0.8 m. Measures were collected at all sites within approximately a 3 hour time span. The pond profiles were intended to provide further description of the habitat conditions presented by each pond, and to identify similarities and differences that may exist across the sampled sites. Water profile sampling was conducted within the time frame of the fish survey such that it could be determined if there may be significant water chemistry differences at the various ponds that might influence the fish community.

A limited fish sampling program was undertaken to identify if and to what degree the construction of the three ponds at AL represented a habitat gain for fish. The sampling was not designed to be quantitative in nature, nor to determine abundance. Instead, the sampling was intended to confirm use of the new habitat by fish, and to provide some indication of diversity of species using the pond habitats.

Figure 3: A small kayak was used to record water quality observations at various depths in each of the ponds.

One sampling event for small-bodied fish was undertaken on July 25/26, 2016, with the deployment of a single minnow trap overnight for approximately 14 hours at each of the ponds. A total of five traps were deployed at: ALP (North and South ponds), AL (West, Central and East ponds). Traps were baited with sardines in soy oil. On the morning of July 26th, traps were retrieved, species identified, counted and released alive.

Structured Summer and Winter Walks

Structure habitat walks were conducted on August 31, 2016 and March 2, 2017 at the Antigonish Landing Wetland (AL), the Antigonish Landing Reference (ALR) and the Antigonish Landing Ponds (ALP). Landscape photographs were taken along each transect from each end, as well as notable features including sediment erosion or deposition and ice. Utilization of the sites by aquatic and terrestrial wildlife were also noted.

Digital Elevation Model (DEM) and Habitat Map

ECA retained Mike Dembeck Photography to complete a high-resolution aerial survey of the Antigonish Landing site on July 19, 2016. A habitat map for the site was prepared using the July photography, with input from the 2016 vegetation surveys and observations from numerous visits to the site (Figures 4 and 5). The habitat mapping sought to delineate the boundaries of major vegetation classes and site features. Notable at the AL site were the extensive low-diversity stands of *Phalaris arundinacea* (Reed canary grass) across much of the site. The invasive alien species *Polygonum cuspidatum* (Japanese knotweed) was observed at numerous locations at both the AL and ALR sites. In general, habitats at the reference site (ALR) were more variable, with greater overall plant diversity richness. The North and South ponds (ALP) contained limited wetland habitats, restricted mainly to intertidal mudflats and thin bands of perimeter salt marsh, incorporating *P. arundinacea, Typha latifolia, Spartina alterniflora* and *Calamagrostis canadensis*.

A digital elevation model for the site was prepared through the integration of LiDAR data (Webster, 2008) with 2051 spot elevations recorded between July and October 2016 using a high-accuracy RTK-GPS system (Figures 6 and 7). The anticipated area to be flooded throughout the tidal prism at ALR for the minimum (0.021 m), intermediate (0.707 m) and maximum (1.213 m) (NAD83 UTM Zone 20N) water levels are shown at Figures 8, 9 and 10).

The DEM for the Antigonish Landing site was interrogated using the Zonal Statistics function within QGIS to generate a number of summary metrics (Table 3). AL and ALR had similar mean ground surface elevations, with ALR being slightly lower. The mean ground elevation for AL was skewed lowered with respect to the median, most likely due to the invert elevations of the three ponds and outlet channel. The minimum ground elevation value for AL was -1.17 m occurred in the outlet channel to the Rights River.

Table 3: DEM Summary metrics.

Site	AL	ALR	ALP-S	ALP-N
Mean ground elevation (m)	1.34	1.23	0.29	-0.31
Median ground elevation (m)	1.48	1.23	0.48	-0.25
Minimum ground elevation (m)	-1.17	0.25	-1.14	-1.21
Maximum ground elevation (m)	2.62	2.80	1.65	1.03
Standard deviation	0.57	0.27	0.62	0.56

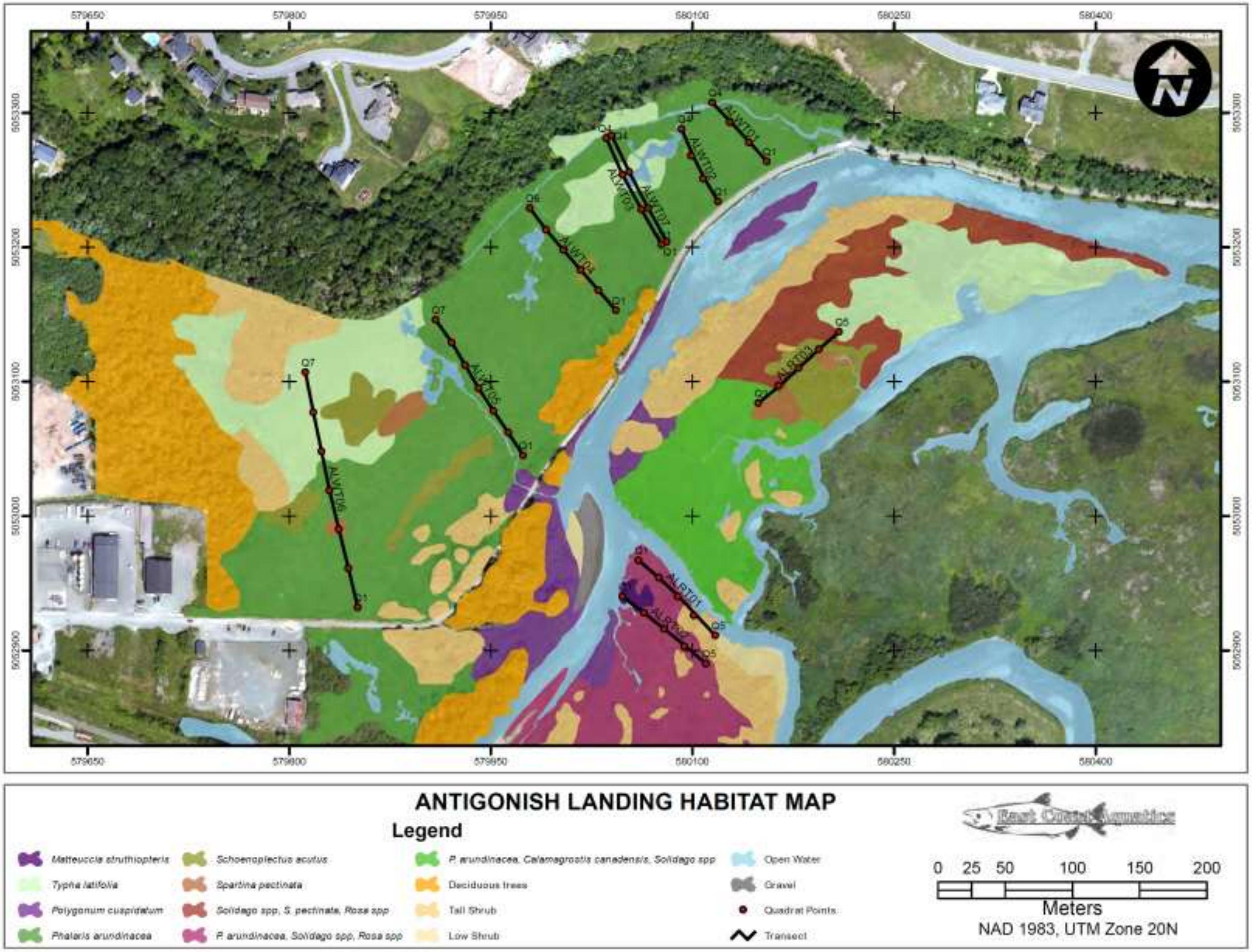

Figure 4: Habitat map for Antigonish Landing and Reference site, based on July 2016 low altitude photography, vegetation surveys and site observations.

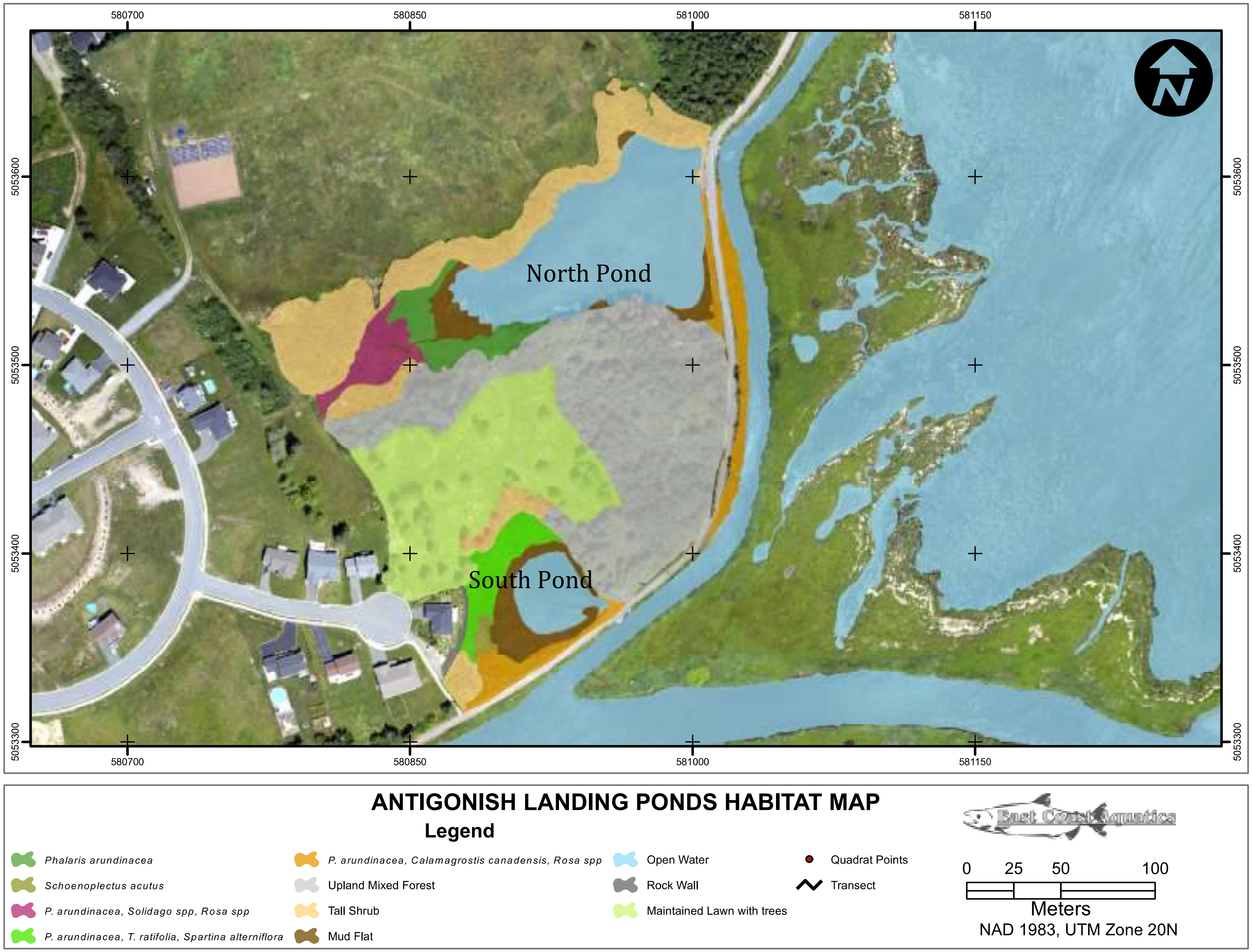

Figure 5: Habitat map for Antigonish Landing North and South Ponds, based on July 2016 low altitude photography, vegetation surveys and site observations.

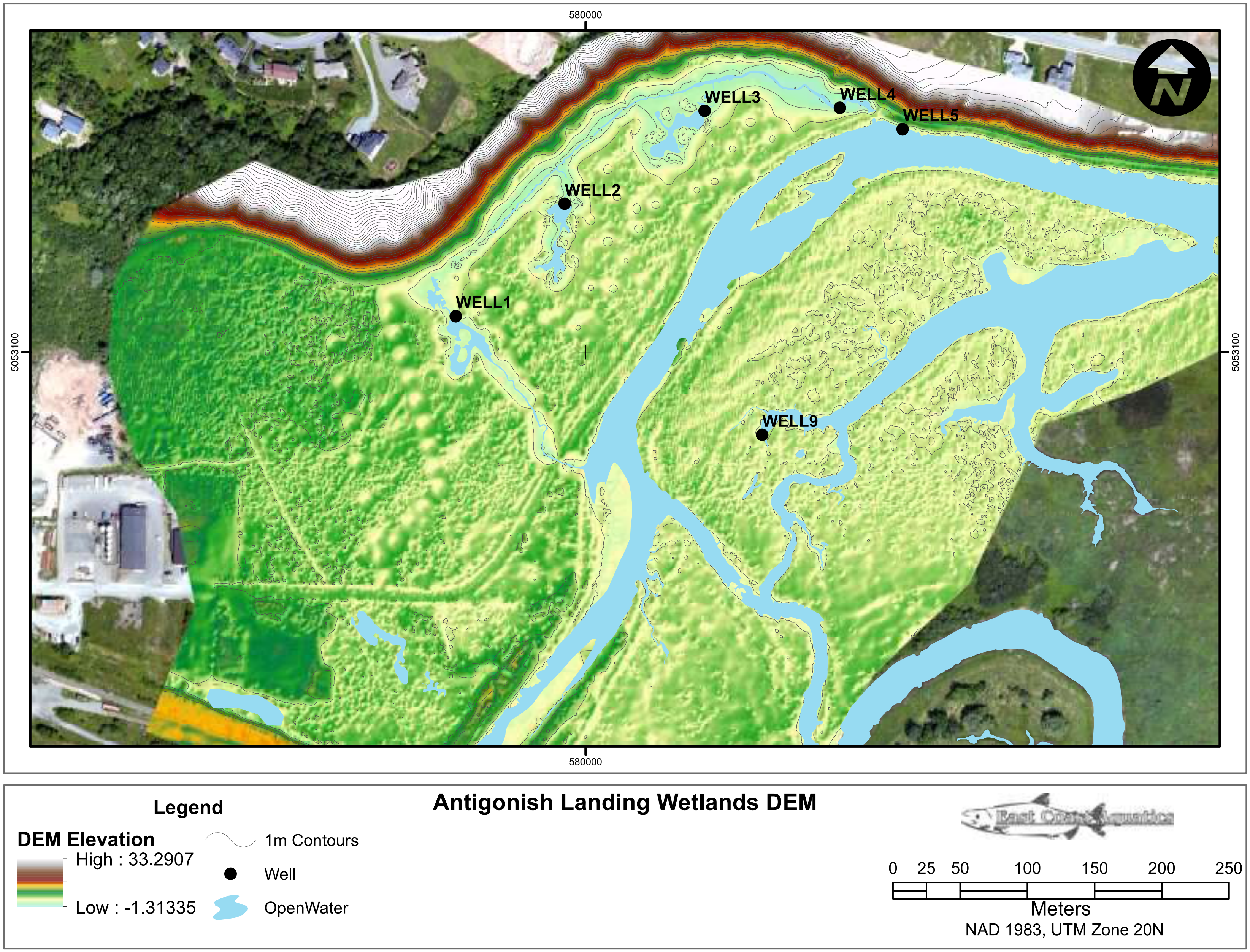

Figure 6: DEM for Antigonish Landing (AL) and Reference site (ALR)

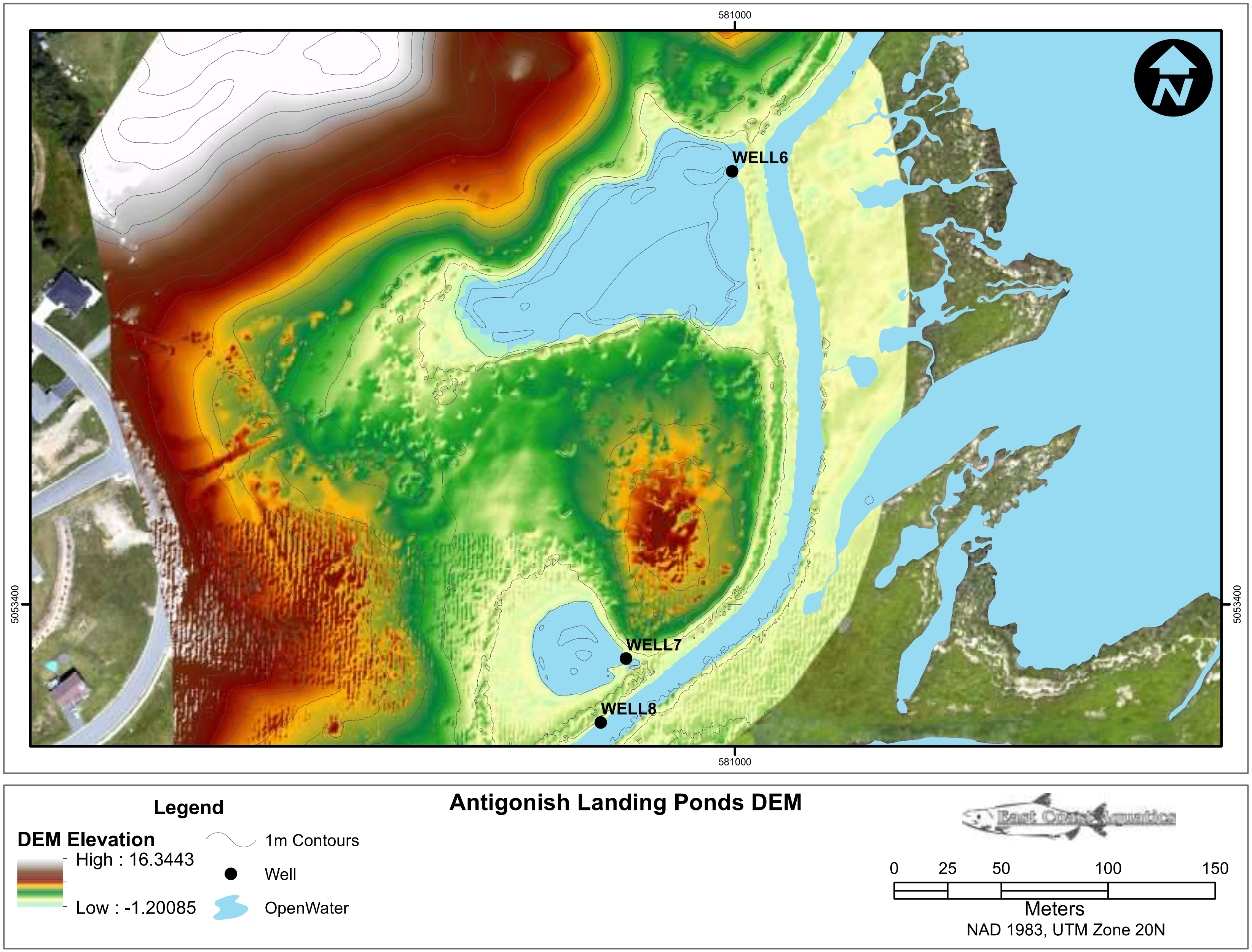

Figure 7: DEM for Antigonish Landing Ponds (ALP)

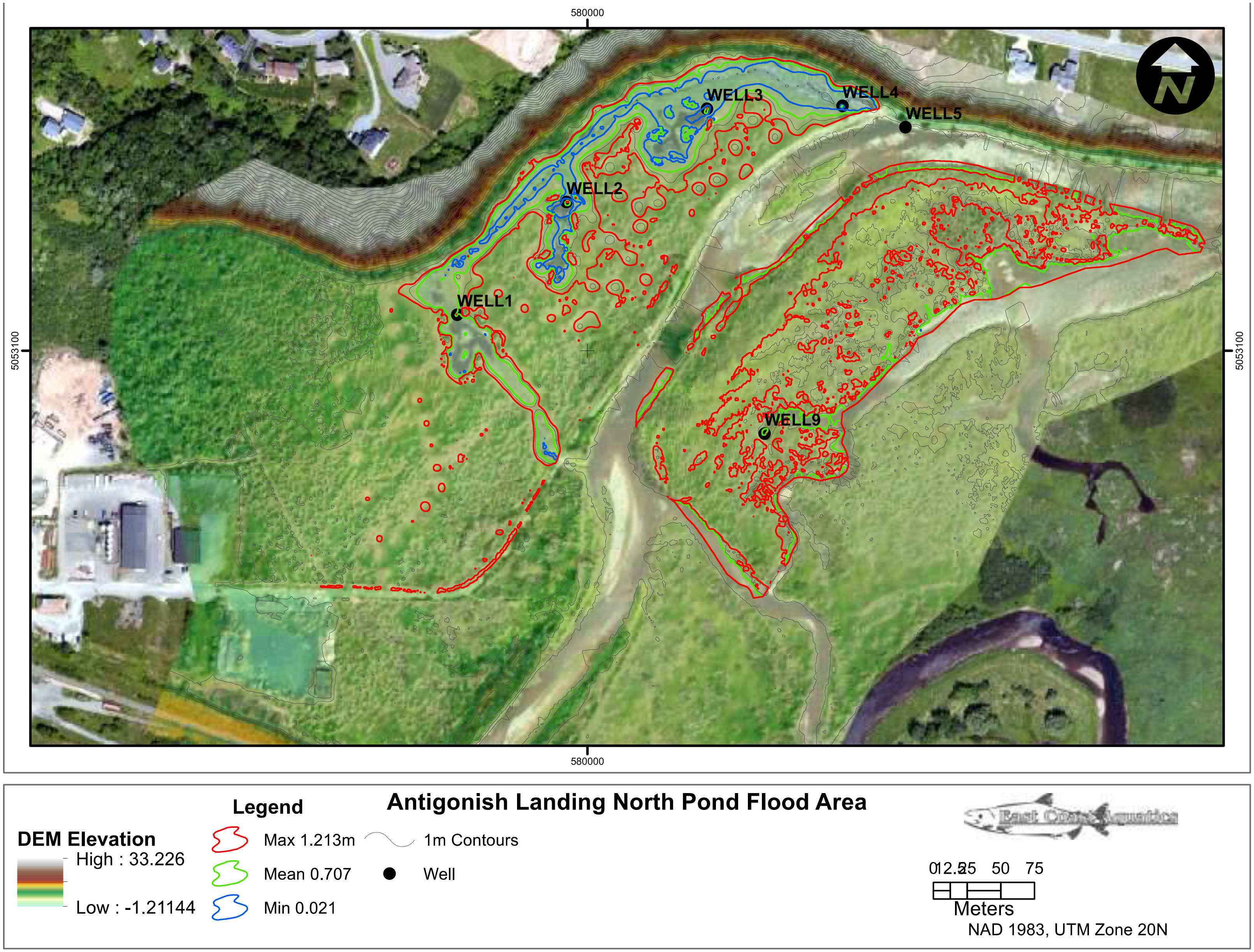

Figure 8: Flood map for Antigonish Landing (AL) and adjacent Reference site (ALR).

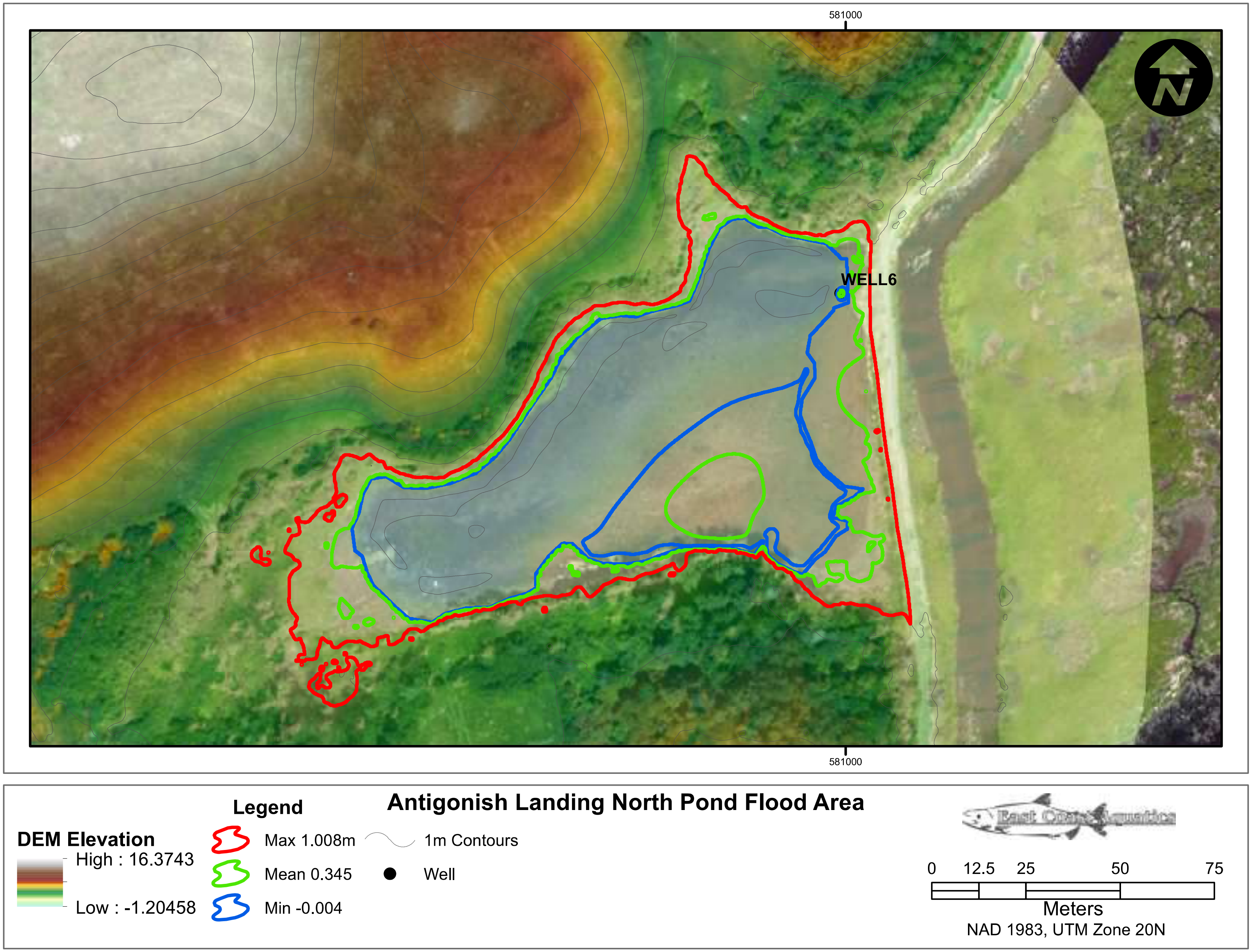

Figure 9: Flood map for Antigonish Landing Pond (ALP) – North Pond.

Figure 10: Flood map for Antigonish Landing Pond (ALP) - South Pond.

Hydrology

Tidal Restriction Analysis for Antigonish Landing as well as North and South Ponds

The principal driver for the structure and function of salt marsh habitat is the frequency and duration of tidal flooding with salt water (Mitsch and Gosselink 2007). The hydroperiod of a salt marsh is determined by the location-specific tidal signal and marsh surface elevation. Wetland hydrology enhancement activities at the site have included the installation of a bridge crossing at the outlet from the AL marsh and installation of larger culverts at the AL, ALP North and South Pond outlets. Each location has been examined using three approaches to assess for the presence of persisting tidal restrictions. Where appropriate, water level data from the Antigonish Landing Reference site was also used for comparison. The three analysis approaches include:

- The use of an Excel-based tidal restriction calculator,
- Plotting and determining best-fit correlations for water levels above and below each outlet; and,
- Calculation of a series of tidal metrics, with a comparison against pre-enhancement values.

The tidal restriction calculator (Bowron and Fitzpatrick, 2001; Purinton and Mountain, 1998) was used to compare the upstream and downstream water levels at the Antigonish Landing outlet as well as the North and South Ponds. The 30-day dataset for the each location was examined and a 24-hour period bracketing each the spring and neap tides was selected for analysis. For the deployment of water level data loggers at Antigonish Landing, these events occurred on August 10 and 30, 2016, respectively. The neap and spring tidal periods were selected for analysis so as maximize the breadth of conditions examined.

Very similar tidal ranges were observed upstream and downstream of Antigonish Landing bridge outlet during both neap and spring tides (Table 4). The range ratio for the neap and spring analysis periods were 0.99 and 0.96, respectively. Theoretically, the range ratio for non-restrictive crossings should equal one (Bowron and Fitzpatrick, 2001). Prior to the Antigonish Landing wetland restoration activities, CBCL (2011) documented delays in the tidal peaks across the crossing location of 5 to 25 minutes. No time lag was observed between the high tide peaks at the up and downstream monitoring points with the 2016 dataset. Based on the analysis, there is no indication that a tidal restriction was occurring at the bridge outlet from the Antigonish Landing marsh.

No time lag was observed between the peaks at high tide on the up and downstream sides of the concrete outlet culvert from the ALP South Pond. The culvert invert appears, however, to be set approximately 0.2 m above the minimum low tide level, resulting in the perching of water within the pond, as was observed at neap tide (Figures 11 and 12). This condition was indicated by the flattening of the upstream water level curve for approximately four hours at low tide. The maximum tidal flux was thus not being experienced by the pond, resulting in reduced water exchange and possible accumulation of sediments. Prior to culvert replacement as part of the larger wetland enhancement, only 55% of high tides recorded in the river flooded the South Pond, with the average time lag between tidal peaks of 41 minutes (CBWES, 2014). While not perfect, the new culvert makes a significant improvement in the restoration of salt marsh tidal conditions at the South Pond.

Similar tidal ranges were observed upstream and downstream of the ALP North Pond concrete outlet culvert for both the neap and spring tide analysis. The range ratio values of 0.99 and 0.94 were very close to 1.0, indicating no tidal restriction. Unlike the South Pond outlet, the North Pond outlet culvert invert was set low enough to allow full drainage throughout the entire tidal cycle. No time lag was observed between the peaks at high tide on the up and downstream sides of the crossing. Prior to culvert replacement as part of the larger wetland enhancement, only 53% of high tides recorded in the river flooded the North Pond, with the average time lag between tidal peaks of 92 minutes (CBWES, 2014). The replacement culvert at the North Pond thus has significantly improved tidal exchange at this location.

Table 4: Tidal Restriction Analysis Summary.

Location	Tidal Condition	Upstream Tidal Range (m)	Downstream Tidal Range (m)	Range Ratio	Comment
Antigonish Landing Outlet at bridge	Neap	0.459	0.461	0.99	No evidence of tidal restriction
	Spring	0.998	1.04	0.96	
South Pond	Neap	0.271	0.377	0.72	No tidal restriction, perched culvert
	Spring	0.788	1.053	0.75	
North Pond	Neap	0.374	0.377	0.99	No evidence of tidal restriction
	Spring	0.986	1.053	0.94	

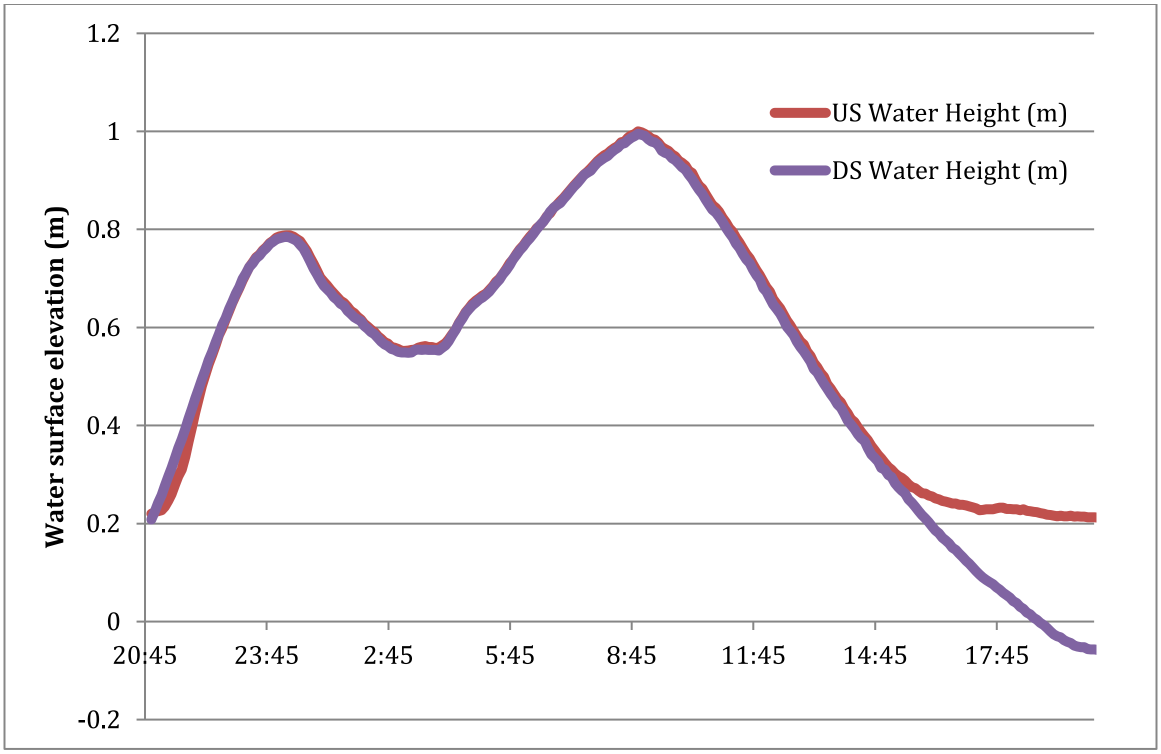

Figure 11: ALP South Pond outlet spring tide analysis, August 30, 2016, showing water levels upstream (US) and downstream (DS) of the outlet.

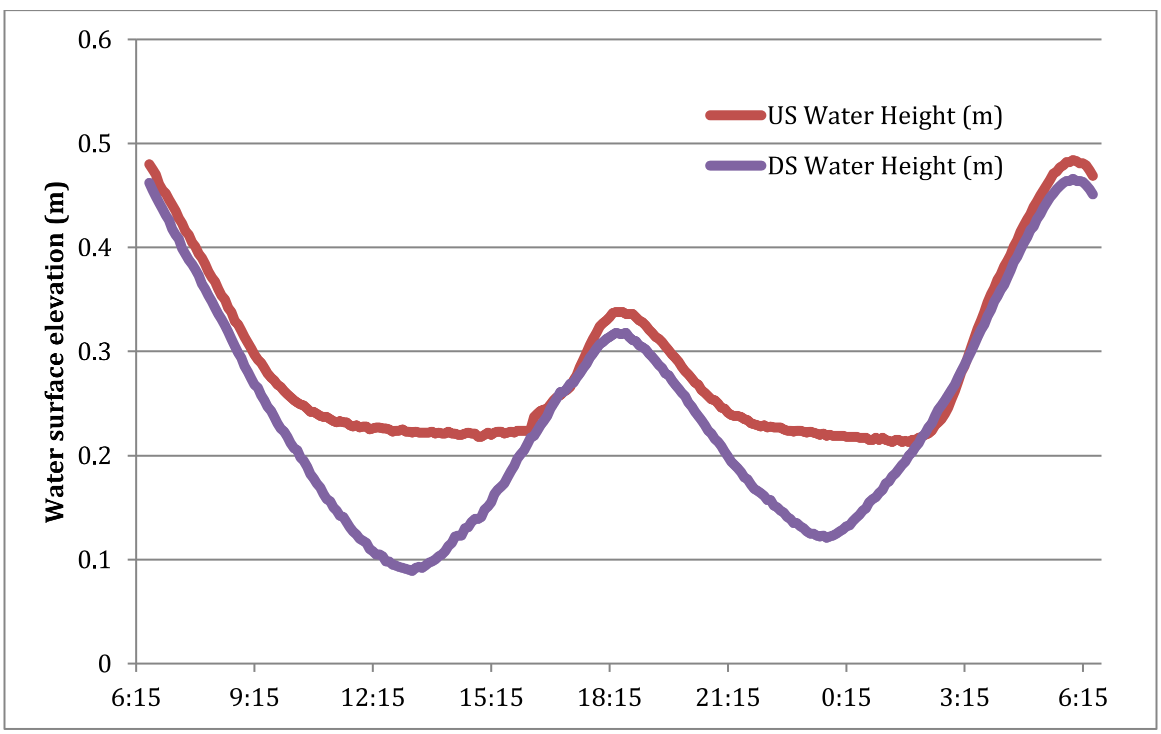

Figure 12: ALP South Pond outlet neap tide analysis, August 10, 2016, showing water levels upstream (US) and downstream (DS) of the outlet.

The water surface elevations (tide heights) above and below each of the three crossings (Antigonish Landing bridge outlet, North Pond culvert, South Pond culvert) have been plotted and best-fit correlations performed to allow graphical examination for any restrictions. Water levels above and below the bridge outlet at the Antigonish Landing wetland had a strongly linear relationship with high correlation value (R^2) of 0.999. This would suggest no tidal restriction at this crossing (Figures 13).

The plot of water levels above and below the ALP South Pond outlet culvert was quite distinctive, being strongly linear at higher water levels and non-linear at lower water levels (R^2 = 0.923). As was discussed above, this nonlinearity was due to the invert of the South culvert being set too high, resulting in water being perched within the pond at low tide (Figure 14). Water levels above and below the ALP North Pond outlet culvert (Figure 15), while following a linear relationship with a high correlation value (R^2 = 0.978), showed some scattering, particularly at lower tidal elevations. The cause of this scattering is unclear, but may have been due to occasional partial blockages of the culvert by debris.

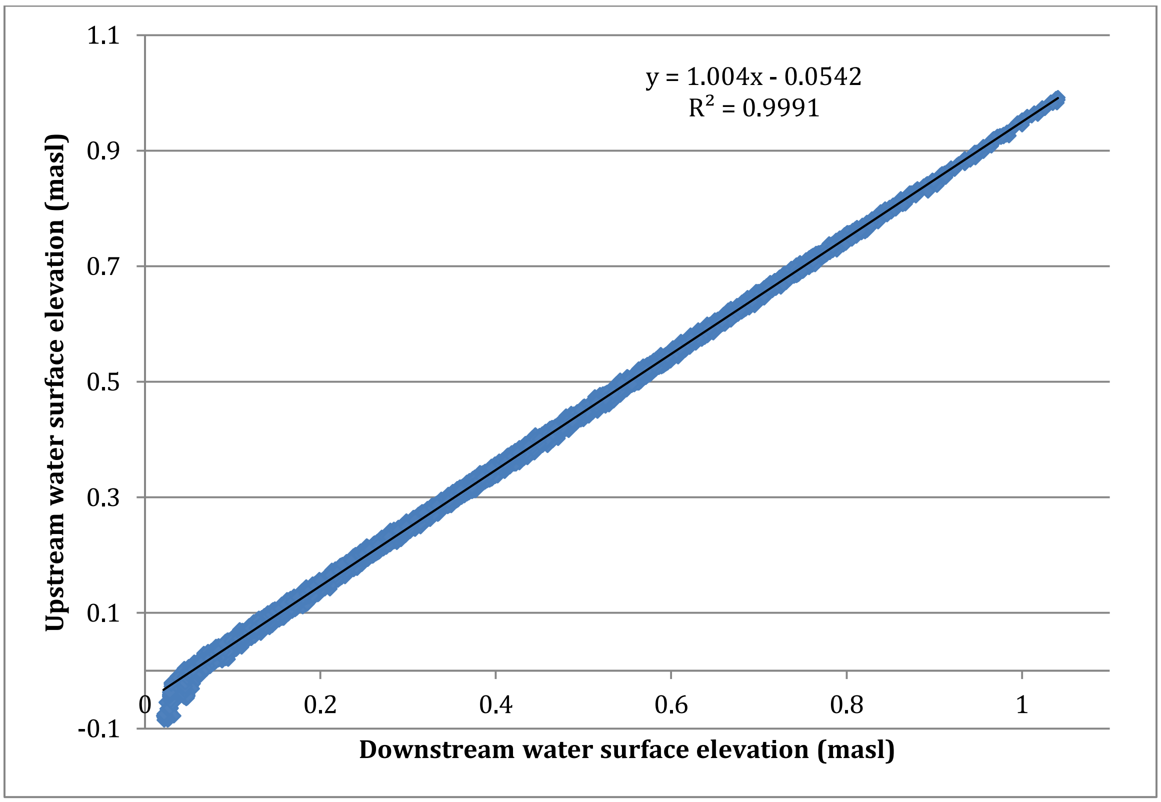

Figure 13: Tide height (elevation) upstream and downstream of the Antigonish Landing wetland outlet bridge.

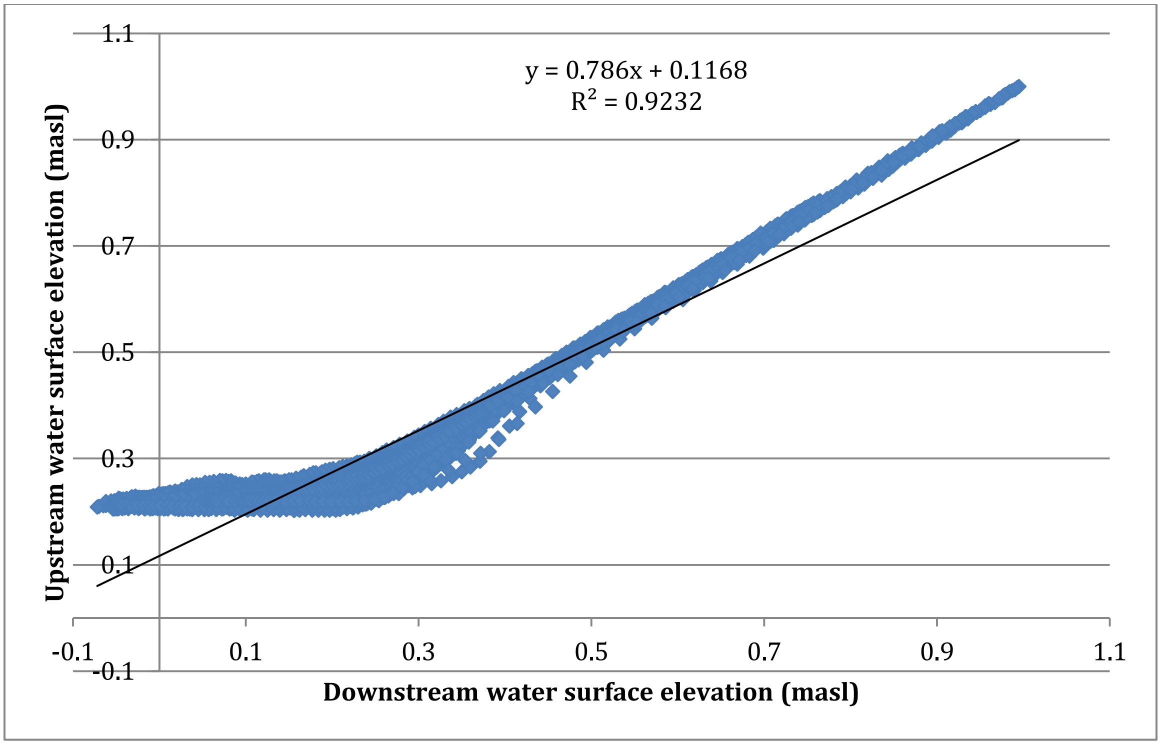

Figure 14: Tide height (elevation) upstream and downstream of the ALP South Pond outlet culvert.

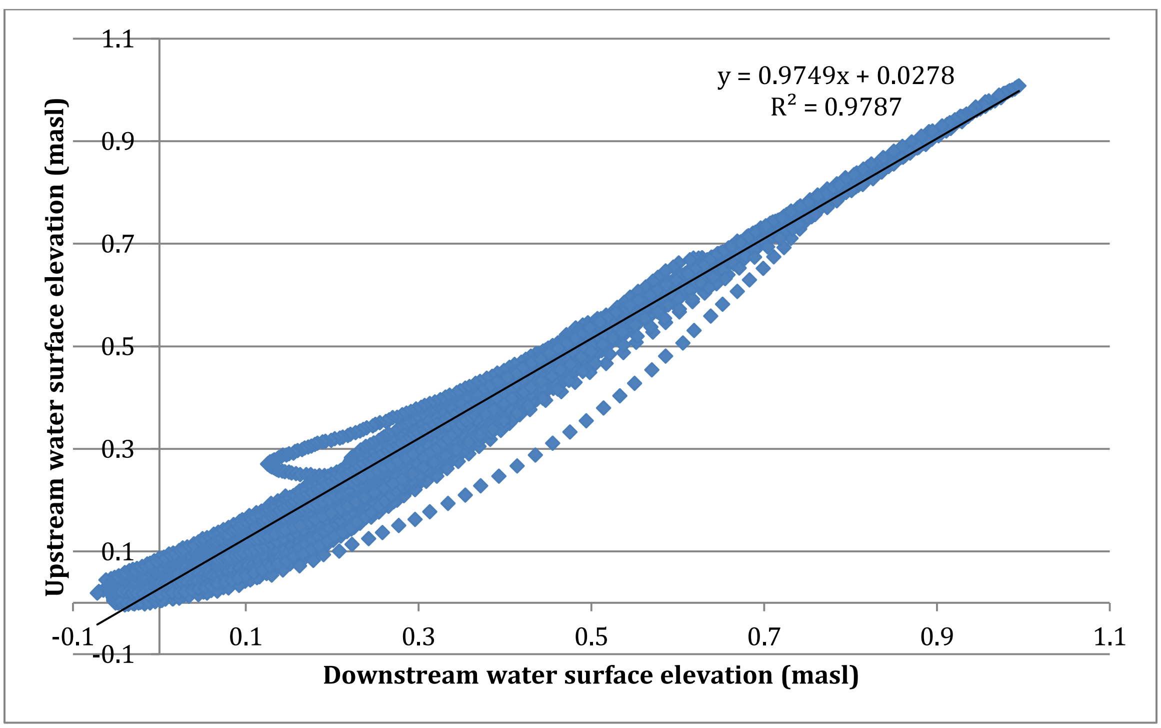

Figure 15: Tide height (elevation) upstream and downstream of the ALP North Pond outlet culvert.

Tidal metrics were calculated for up and downstream of the Antigonish Landing outlet bridge, using the same methodology utilized by CBCL (2011). Comparable values were calculated for the AR Reference Site for comparison (Table 5). A subset of the data, focusing on the August 30, 2016 monthly spring tide, is shown at Figure 16.

As was described in methodology section, given the equipment and survey techniques used, the minimum difference in water levels considered to be significantly different was 0.05 m. No meaningful difference was observed for the mean and maximum water levels from above and below the Antigonish Landing outlet bridge. The minimum water level was slightly higher for the upstream location when compared with the downstream and reference sites, which can be clearly seen at Figure 16. The water level differences may have been due to a slight degree of perching within the outlet channel due to the natural channel morphology and the presence of debris; alternatively, it may been due to the natural incline of the channel. Slightly higher high tides were observed at the monitoring location upstream of the outlet. No lag (time shift) was observed in the high and low tide maxima and minima between the upstream, downstream and reference locations, suggesting the bridge opening was sufficient large so as to not impede the passage of spring tide flows.

Table 5: Minimum, mean and maximum water levels for the Antigonish Landing outlet (bridge), July 28 to September 1, 2016, with comparable values from CBCL (2010 and 2011)* shown in brackets.

		Upstream of bridge crossing	**Downstream of bridge crossing (Rights River)**	**Reference Site**
Water Level (m)	Min	0.02 (0.0)[a] (0.06)[b]	-0.09 (0.5)[a] (0.06)[b]	-0.12
	Mean	0.38 (0.5)[a] (0.73)[b]	0.33 (0.9)[a] (0.61)[b]	0.30
	Max	1.04 (1.2)[a]	0.99 (1.8)[a]	0.95
High Tide (m)	Min	0.38	0.32	0.31
	Mean	0.72 (1.00)[b]	0.67(0.89)[b]	0.64
	Max	1.04 (1.49)[b]	0.99 (1.40)[b]	0.95

a: CBCL (2010), observations recorded 07/09/10 to 05/10/10 for Antigonish Landing and 19/10/10 to 29/10/10 for Rights River.
b: CBWES (2011) as reported at CBCL (2011), observations recorded 18/11/2010 to 3/12/2010.
*CBCL (2010, 2011) elevations were reported with respect to the CGVD28 datum. ECA 2016 elevation observations were made using the HTv2.0 hybrid geoid model, which was based on an earlier geoid model (CGG2000) that had been distorted to fit with the CGVD28 benchmarks published elevations (NRCAN, 2017).

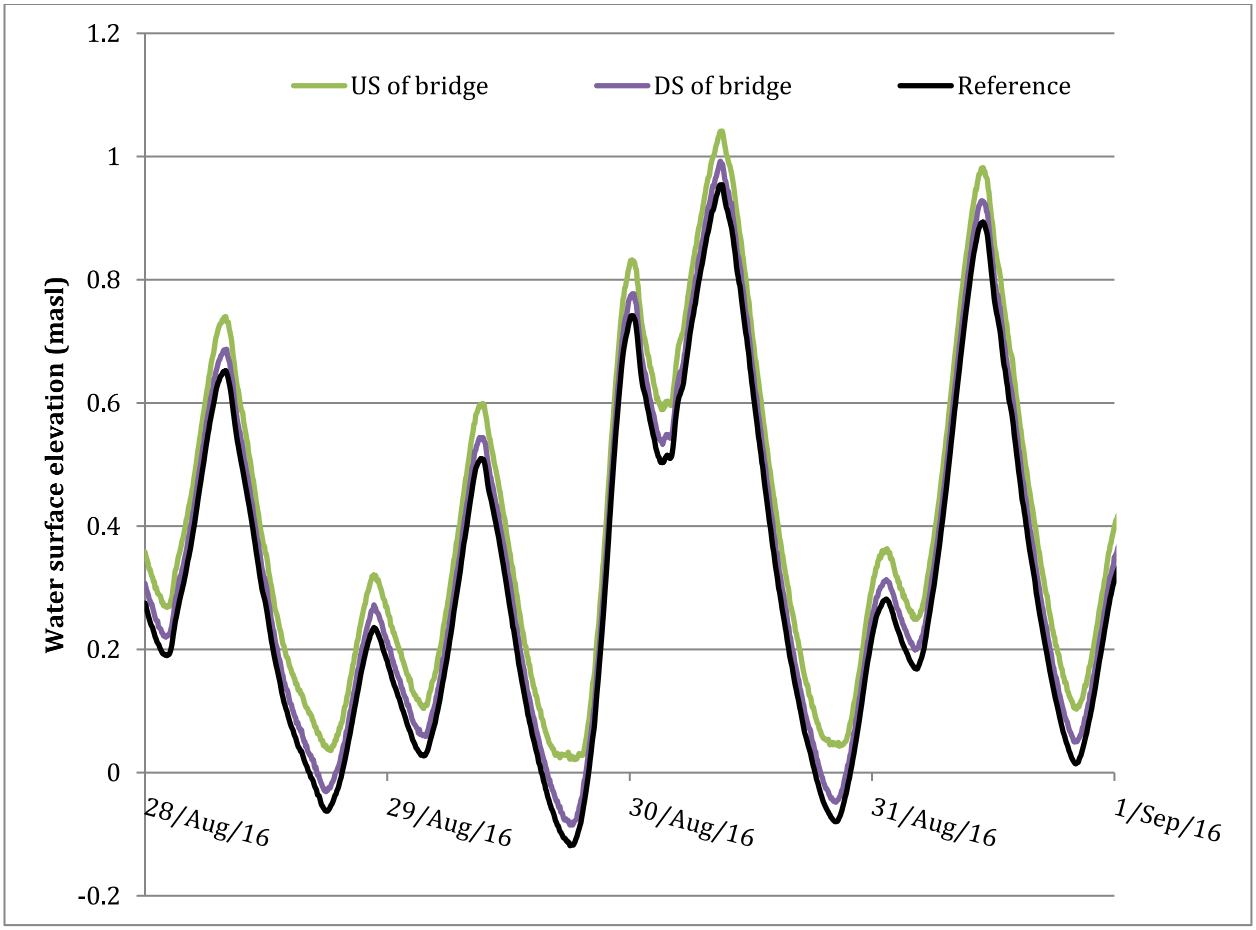

Figure 16: Water surface profiles for Antigonish Landing wetland outlet, Rights River and Reference Site during monthly spring tide.

CBWES (2014) performed a one-month deployment of water level loggers above and below the outlets from the North and South Ponds in September 2014. The replacement of the undersized corrugated steel culvert at the North Pond with a larger concrete culvert occurred during this period. Three failing outflow culverts at the South Pond were replaced after September 2014 and prior to the 2016 monitoring completed by ECA (Table 6). Notable in the 2016 data was the minimum water levels observed for the South Pond, suggesting the culvert invert was set too high to allow full tidal flushing.

Three approaches were used to assess for the existence of tidal restrictions across the three enhanced crossings at the Antigonish Landing site. The results from the three approaches were consistent in indicating no restriction at the outlets from the Antigonish Landing wetland and North Pond. While sufficiently large to convey tidal fluxes, the invert elevation of the new culvert at the South Pond outlet appears to be 0.2 to 0.3 m higher than the low tide levels at this location, resulting in the perching of water within the pond at low tide. The placement of the culvert may therefore limit tidal and sediment exchange between the pond and the adjacent Rights River. The culvert replacement at the South pond does however provide for significantly greater tidal exchange than existed prior to the restoration program, contributing to the re-establishment of salt marsh conditions at the South Pond.

Table 6: Minimum, mean and maximum water levels for the Antigonish Landing Ponds, July 28 to September 1, 2016, the values for CBWES (2014)* shown in brackets.

		South Pond	North Pond	Rights River Estuary
Water Level (m)	Min	0.20 (0.31)	0.00 (0.09)	-0.07 (-0.31)
	Mean	0.37 (0.37)	0.35 (0.40)	0.33 (0.25)
	Max	1.00 (0.74)	1.01 (0.92)	1.00 (0.85)
High Tide (m)	Min	0.34 (0.38)	0.34 (0.15)	0.32 (0.15)
	Mean	0.34 (0.53)	0.69 (0.54)	0.31 (0.54)
	Max	1.00 (0.74)	1.00 (0.85)	0.99 (0.85)

*CBWES (2014) elevations were reported with respect to the CGVD28 datum. ECA 2016 elevation observations were made using the HTv2.0 hybrid geoid model, which was based on an earlier geoid model (CGG2000) that had been distorted to fit with the CGVD28 benchmarks published elevations (NRCAN, 2017). CBWES (2014) observations recorded 3/09/2014 to 3/10/2014.

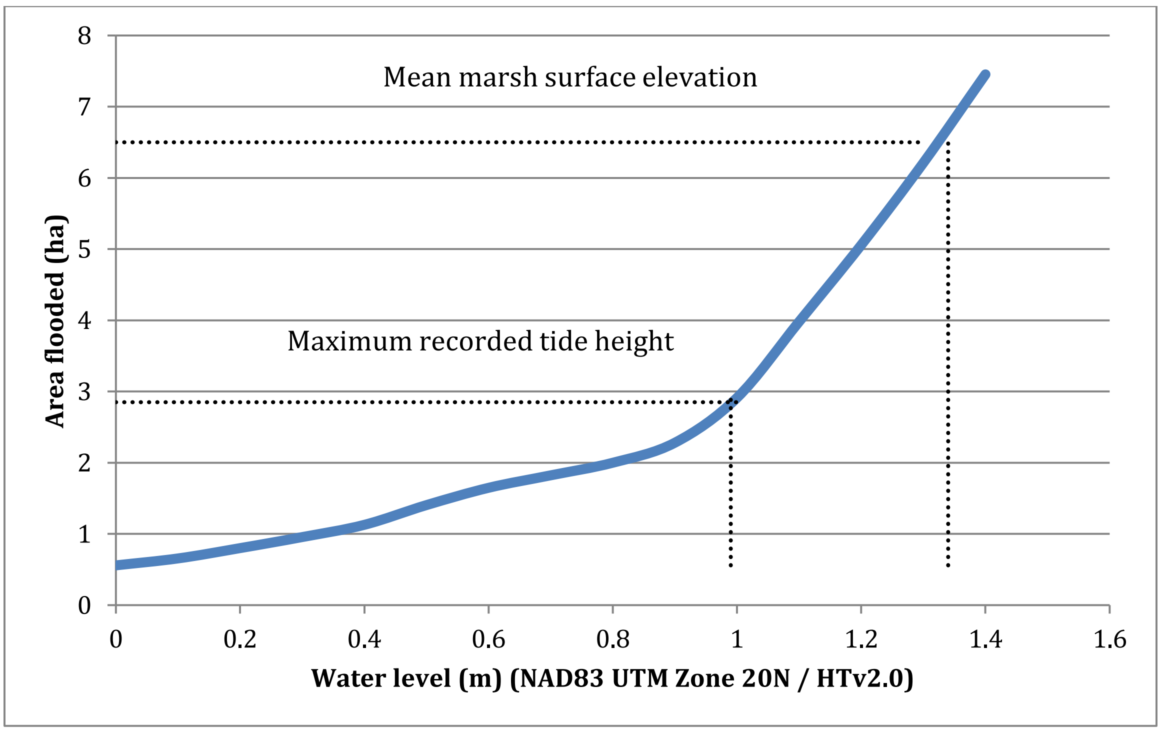

Figure 17: Hypsometric curve for AL.

The area flooded at AL throughout the tidal prism was examined through the preparation of a hypsometric curve for the site (Figure 17). The maximum recorded tide height at the AL outlet channel (Well 4) during the August 2016 monitoring period was 0.74 m, which resulted in slightly less than two hectares of the marsh surface being flooded. The hyposmetric curves suggests that for much of the tidal cycle, flooding at the AL is confined to the channel entering the site from the Rights River and the immediately adjacent lower-elevation areas. Tidal water levels in excess of ~0.9 m begin to flood a significantly large area of the marsh. The average ground surface elevation in the vicinity of the most upslope AL west pond is 1.03 m, suggesting that this area would only be flooded at extreme tides.

Hypsometric curves were also prepared for the ALP north and south ponds (Figure 18). At the maximum tide height recorded in the Rights River adjacent to ALP during the August 2016 monitoring period (1.00 m), the flooded areas were 0.42 and 1.07 ha, for the south and north ponds, respectively. Increasing tide heights would result in a gradual increase in the flooded area at both locations.

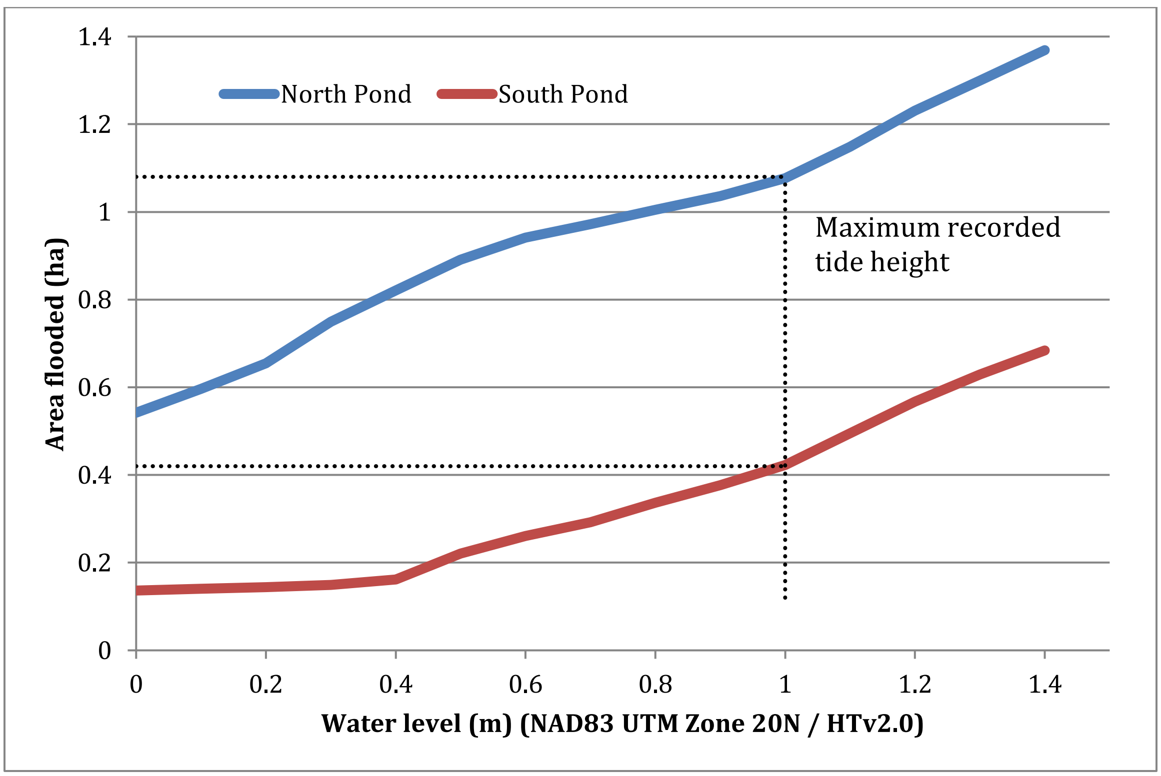

Figure 18: Hypsometric curves for ALP.

Aquatic Connectivity of Antigonish Landing Wetland Enhancements

Within the Antigonish Landing Wetland site, the compensation proposal (CBCL, 2011) set out to undertake a number of enhancements, including the construction of three wildlife ponds and connecting channels (ECA, 2015b), upgrading of the trail crossing to a bridge and installation of a culvert. The objectives of these measures were:

- to improve tidal flushing of the wetland,
- decrease residency time for flood waters,
- improve fish passage
- improve transport of materials into and out of the wetland,
- provide open water habitat for wildlife, and
- reduce flood risk to adjacent properties

Within the context of the wetland enhancement program, one of the central monitoring questions was the degree of connectivity between the three constructed ponds and the tidewaters of adjacent Rights River. This connectivity can be assessed in terms of hydrology (water level), water chemistry and fauna. The deployment of water level data loggers in the three ponds provided a useful insight on the degree and magnitude of the connectivity between the Antigonish Landing Wetland and tidal influences from the Rights River estuary (Figure 19).

The channel distances between the Rights River at the Antigonish Landing Trail bridge upslope to the AL West, Central and East Ponds were 436, 297 and 153 m, respectively. As would be expected, the water surface elevations observed in the three ponds follow the overall gradient of the site. The West Pond, located furthest upslope from the Rights River estuary, had a median water surface elevation of 1.10 m, with the Central and East Ponds being lower at 0.71 and 0.66 m, respectively.

An approximate midpoint in the monthly tidal cycle (July 30 to August 2, 2016) of neither neap or spring tides was examined to assess the tidal influence on the three ponds. During this period when tidal peaks in the Rights River were reaching an elevation of approximately 0.75 m, corresponding fluctuations were observed within the hydrographs of the three ponds. The greatest tidal increase in water levels was observed at the East Pond (0.04 to 0.08 m), which was closest to the Rights River. The time lag between the Rights River tidal peaks and that of the East Pond was approximately one hour. The Central and West Ponds had very small yet quantifiable tidal fluctuations in the range of 0.01 to 0.02 m, occurring with a five to eight hour lag behind the Rights River tidal peak. There was no significant difference in the small tidal fluctuations observed at the Central and West Ponds.

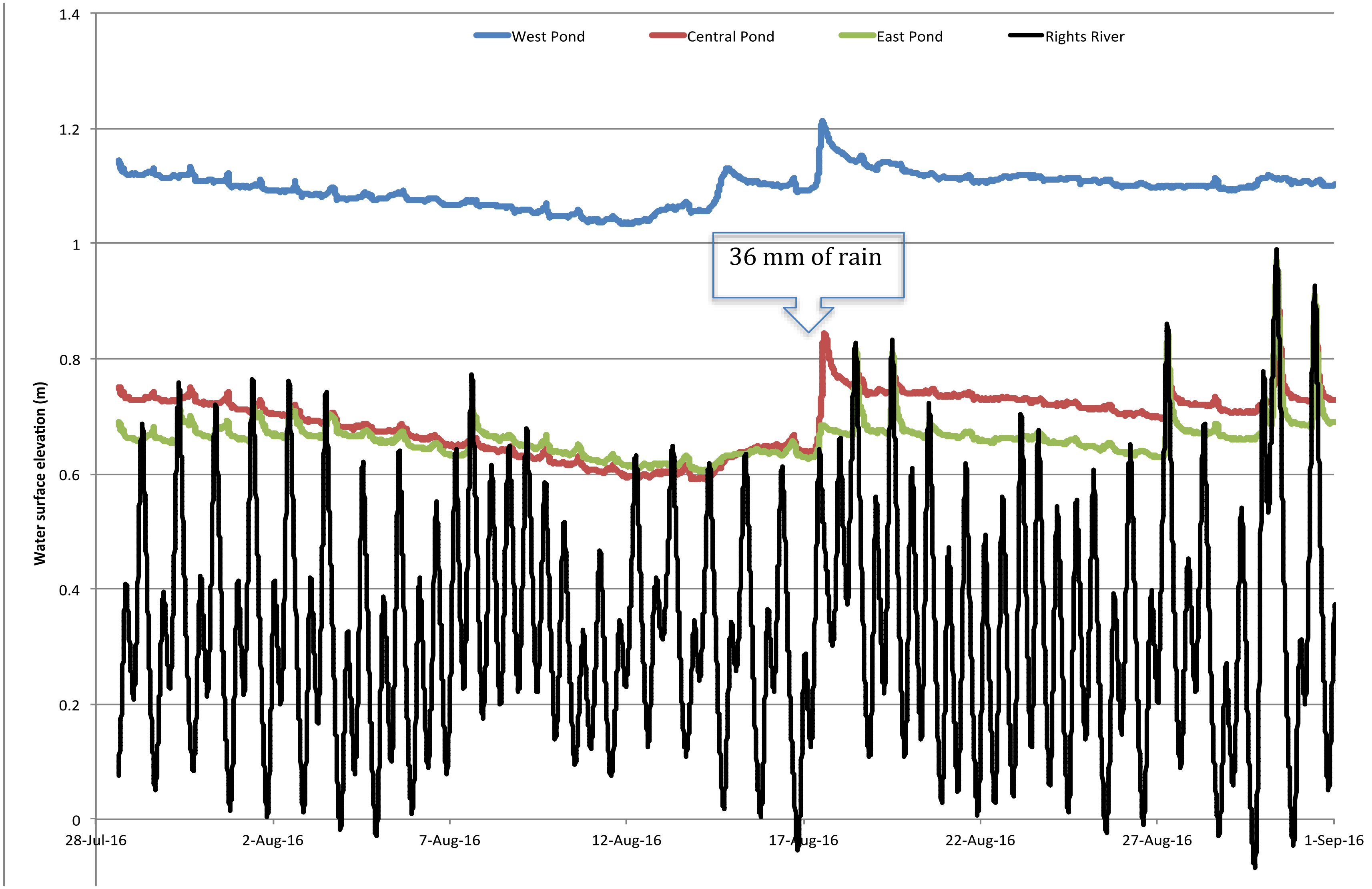

Figure 19: Water surface profiles for West, Central and East Ponds, as well as the adjacent Rights River.

Beyond the tidal influence observed across the three ponds, a precipitation event on August 17, 2016 highlighted the degree of connectively of water levels to the upslope catchments. Following a 36.2 mm of rain recorded at the Environment Canada Tracadie weather station, water levels in the West, Central and East Ponds increased by 0.12, 0.21 and 0.06 m, respectively, over a five hour period. It is unclear why the Central Pond had the greatest increase in water levels of the three ponds. The Central Pond may have a proportionally greater catchment area or a smaller / more restricted outlet channel. During the structured winter habitat walk, two locations were observed where the West Pond and adjacent channel had overtopped and flowed across the marsh surface towards the Central Pond. The Central Pond receiving its own precipitation plus overland flow from the West Pond would be consistent with the water level record from the August 2016 precipitation event. These observations provide added indication of the value of informal observations and habitat walks occurring at the site.

The monthly spring tide, which occurred on August 30, 2016 at Antigonish Landing, provided a useful point of comparison when examining the tidal influence on the three constructed AL ponds (Figure 20). High tide peaks exceeding 0.8 m within the Rights River had an obvious impact on water levels within the Central and East Ponds, with very little to no observable impact on the West Pond. The amplitude of the tidal peaks at the Central and East Ponds very closely matched that within the Rights River, with a time lag of 30 to 60 minutes.

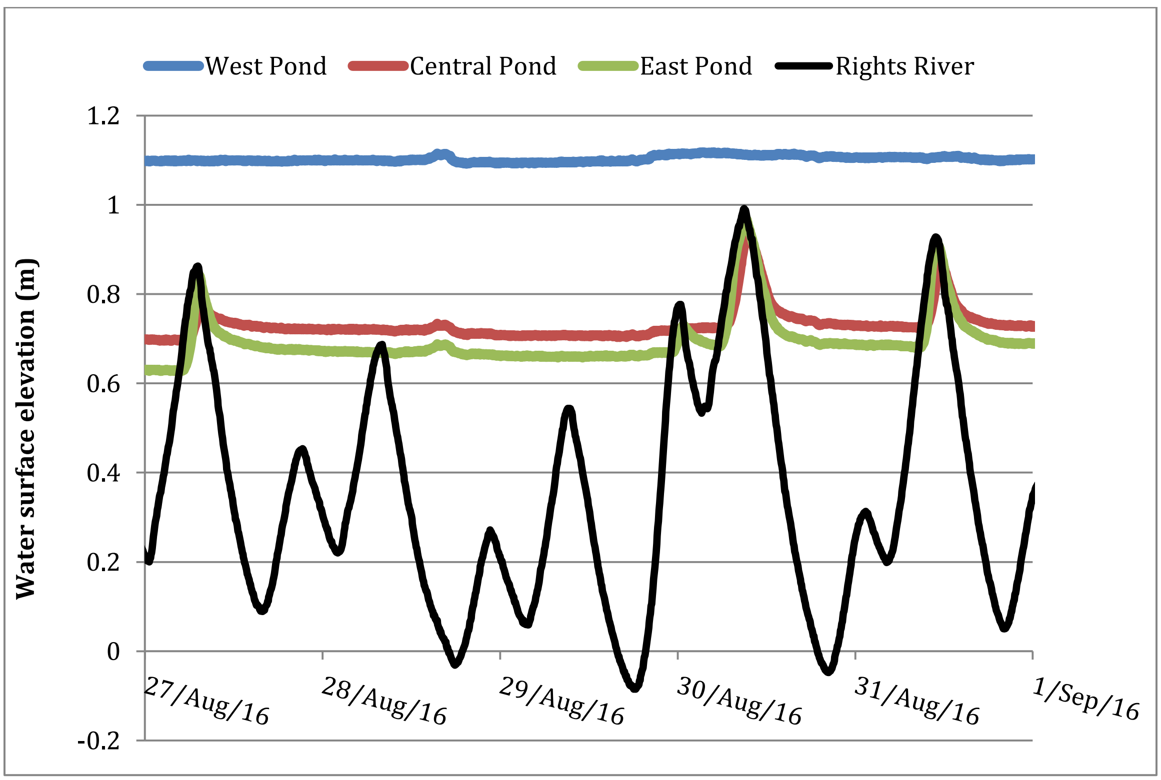

Figure 20: Spring tide hydrograph detail for West, Central and East Ponds, as well as the adjacent Rights River

Water temperature, recorded by the water level data loggers, provided another means of examining conditions at the Antigonish Landing site. Median water temperature for the site, over the July 28 to September 1, 2016 period, are shown at Table 7. The water temperatures for the West Pond and Reference site were distinctly lower than those observed in the Central and East Pond as well as the Rights River. A detail of the temperature data set is shown at Figure 21. A strong diurnal pattern of water temperature change was observed for the Central and East Ponds as well as the Rights River, with the daily maximum temperatures occurring between 4 and 8 pm each day. Water temperatures appear to track the daily mean air temperatures, but with a lag of several days.

Table 7: Median water temperatures, July 28 to September 1, 2016, Antigonish Landing.

Location	Median Water Temperature (°C)
West Pond	16.5
Central Pond	21.6
East Pond	22.5
Rights River	21.6
Reference Site	17.8

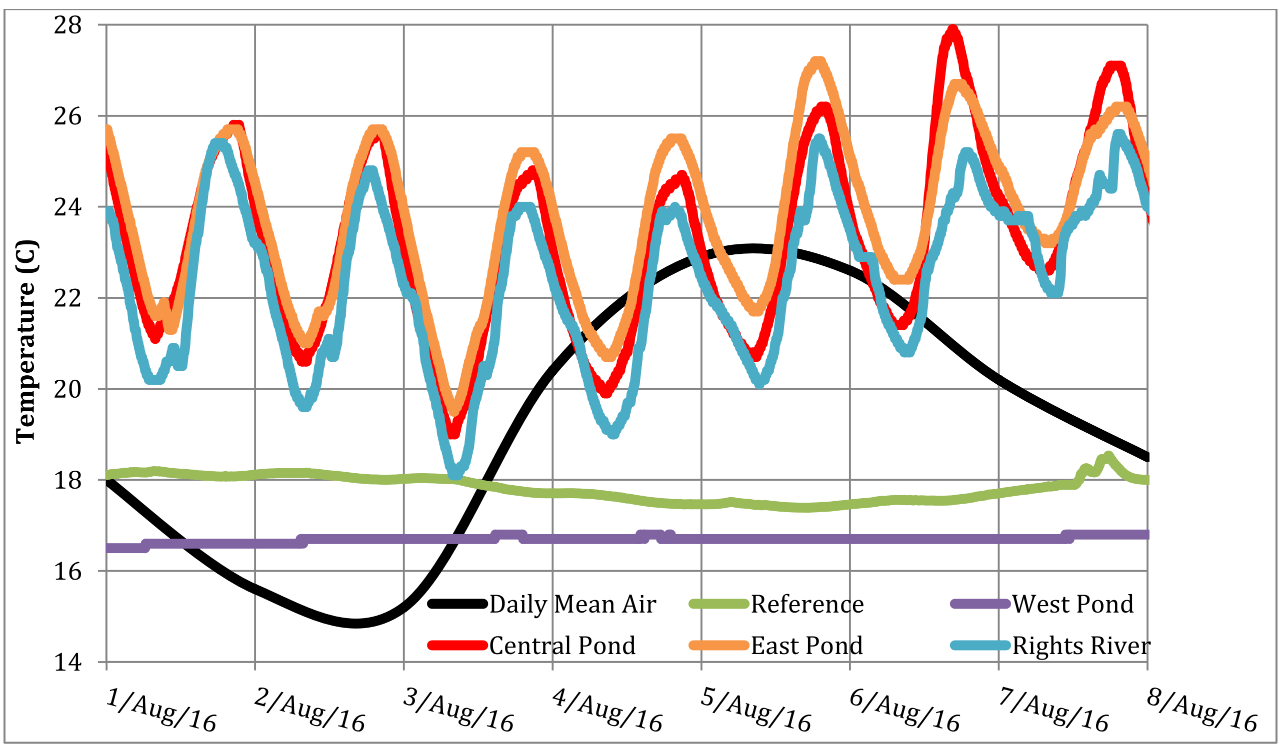

Figure 21: Detail of temperature record for August 1 to 8, 2016.

The temperature record for the Reference site and West Pond were unusual in their absence of diurnal fluctuations, with no immediate reasons apparent. One possible explanation was instrument failure, although the probability of having two data logger sensors fail during the same deployment is low. An alternate, and more likely, explanation was the position of the data logger with respect to the water and ground surface within the stilling well (Table 8). Augered holes were used to aid in placement of the stilling wells at all locations. Data loggers at the West Pond, Antigonish Landing outlet, Reference site and North Pond were hung within the stilling well and below the elevation of the adjacent ground surface, resulting in the sensor being at a location that receives insufficient water exchange to accurately represent short-term (e.g. hourly) changes in conditions. The placement of the data loggers below the adjacent ground surface may also have been impacted by any localized groundwater discharge, which would have been cooler. These placements impacted only temperature and conductivity datasets, with the water surface profile data being unaffected.

Table 8: Location of temperature sensors with respect to water surface and pond bottom.

Location	Median Water surface elevation (m)	Ground surface elevation (m)	Sensor elevation (m)	Sensor depth below median water surface (m)	Sensor Below Ground Surface?
West Pond	1.10	0.83	0.37	0.73	Yes
Central Pond	0.71	0.35	0.38	0.33	No
East Pond	0.66	0.30	0.28	0.38	No
AL Outlet	0.34	0.14	-0.12	0.46	Yes
Rights River	0.29	-0.27	-0.26	0.55	No
Reference	0.25	-0.21	-0.56	0.81	Yes
North Pond	0.30	-0.13	-0.50	0.80	Yes
South Pond	0.30	0.10	0.20	0.10	No

Conductivity Observations

Salinity, and its correlate, conductivity, together with elevation and inundation period are the principal drivers in the segmentation of the salt marshes into distinct zones (Porter *et al*, 2015). These drivers control the formation and maintenance of the unique floral and faunal communities within salt marshes. It was for these reasons that ECA chose to add conductivity monitoring to the Antigonish Landing program, as a no-cost added value option.

Water conductivity data loggers were deployed at two locations (AL Wetland Outlet upstream of bridge and Rights River adjacent to the outlet) in order to gain a better understanding of the tidal dynamics at the site. The conductivity values for the two locations are summarized at Table 9. The two locations experienced a similar range of conductivity values from fresh to mesohaline estuarine condition. The mean conductivity for the Rights River was skewed up by a relatively small number of elevated values that occurred near the monthly spring tide (Figure 22). A moderate to high degree of similarity was observed in the conductivity conditions at the outlet from the Antigonish Landing and the adjacent Rights River, suggesting the bridge crossing was not limiting the exchange, and that brackish water was entering into the wetland.

Table 9: Summary of water conductivity data for Antigonish Landing.

Metric	Antigonish Landing Outlet upstream of bridge (Well 4) (µS/cm)	Rights River adjacent to bridge (Well 5) (µS/cm)
Minimum	37	40
Maximum	15,099	17,946
Median	966	967
Mean	1820	3727

Conductivity levels at both locations were observed to be low (<1000 µS/cm) from July 28 to August 5, at which point values began to increase to approximately 15,000 µS/cm, before falling abruptly on August 14 / 15. This decline in conductivity coincided with approximately 36 mm of precipitation within the catchment. While gauging data was not available for the Rights River, the Environment Canada South River gauging station, located 9 km to the southeast, recorded an approximate 75% increase in water levels in association with August 14 to 17 precipitation. The abrupt decrease in conductivity levels was very likely due to increased freshwater discharge from the Rights River, pushing saline water further down the estuary. Conductivity levels remained low until August 27, at which point values increased to almost 18,000 µS/cm, coinciding with the monthly spring tides on August 30.

The 32-day monitoring of conductivity levels at the Antigonish Landing site has provided an indication of the wide fluctuations in conditions, ranging from fresh to mesohaline. River discharge and the tidal cycle appear to be principal drivers in the water conductivity at the site.

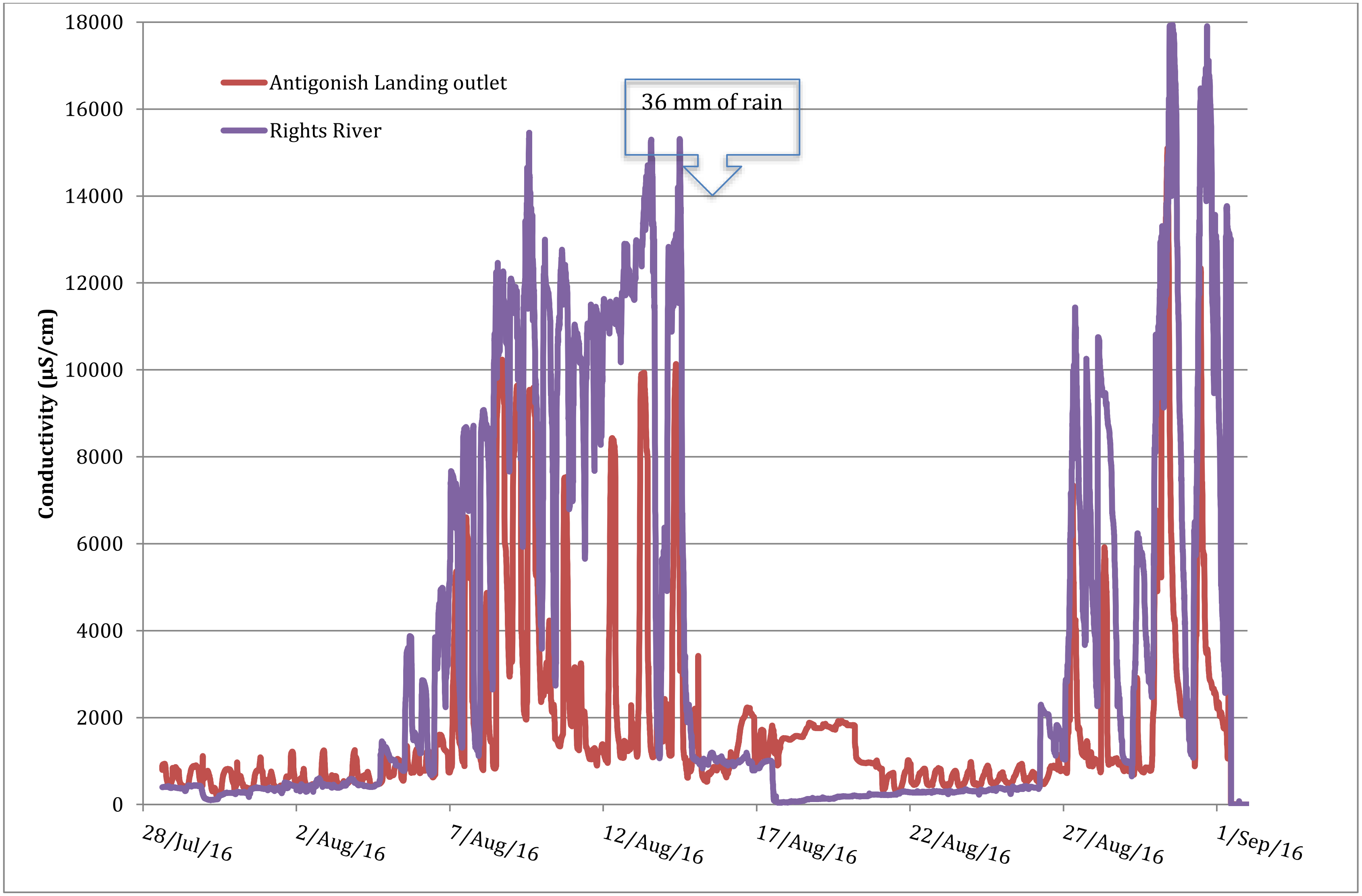

Figure 22: Conductivity values for the outlet from the Antigonish Landing marsh (Well 4) and the adjacent Rights River (Well 5).

Soils and Sediments

Sediment Accretion Pins

A series of sediment accretion pins were establish across the Antigonish Landing site to monitor for the erosion or accretion of soil. Observations were recorded following establishment of the pins on August 27, 2016 (Table 10), with the vertical distance from the top of the pin to the sediment surface recorded. The vertical distance was based on when the ruler made contact with the sediment surface, which was sometimes quite subjective in soft, partly liquefied muck with high organics content. As a QA/QC measure and to evaluate observer bias, two ECA staff members each recorded four observations each at each sediment pin. The average difference between the two observers was -0.016 m (Minimum -0.003 m, Maximum -0.029 m). This limited comparison confirmed the existence of observer bias in the sediment measurements and establish a threshold for the detection of actual change in the sediment surface elevation.

Table 10: 2016 Sediment pin results.

Sediment Pin Number	Location	UTM (NAD83)	Sediment surface elevation (masl)*
1	ALP North next to Well 6	581006 5053576	0.158
2	ALP South next to Well 7	580937 5053356	0.322
3	ALR next to Well 9	580132 5053039	-0.020
4	AL-Outlet channel at Well 4	580189 5053281	0.191
5	AL-East Pond at Well 3	580088 503276	0.602
6	AL-Central Pond at Well 2	579986 5053210	0.656
7	AL-West Pond at Well 1	579903 5053127	0.632

* Average of eight observations around pin, four each by two staff members.

Soil Compaction

The degree of compaction of minimally disturbed soils at the Antigonish Landing Reference site and that at the nearby Wetland 21 (South River) site were examined in August 2016 (Figure 23). Soils from the ground surface to a depth of 46 cm were examined at multiple locations. The mean compaction values for the two sites across three depth ranges: 0 to 15 cm, 18 to 30 cm and 33 to 46 cm were quite similar, providing a baseline for undisturbed sites.

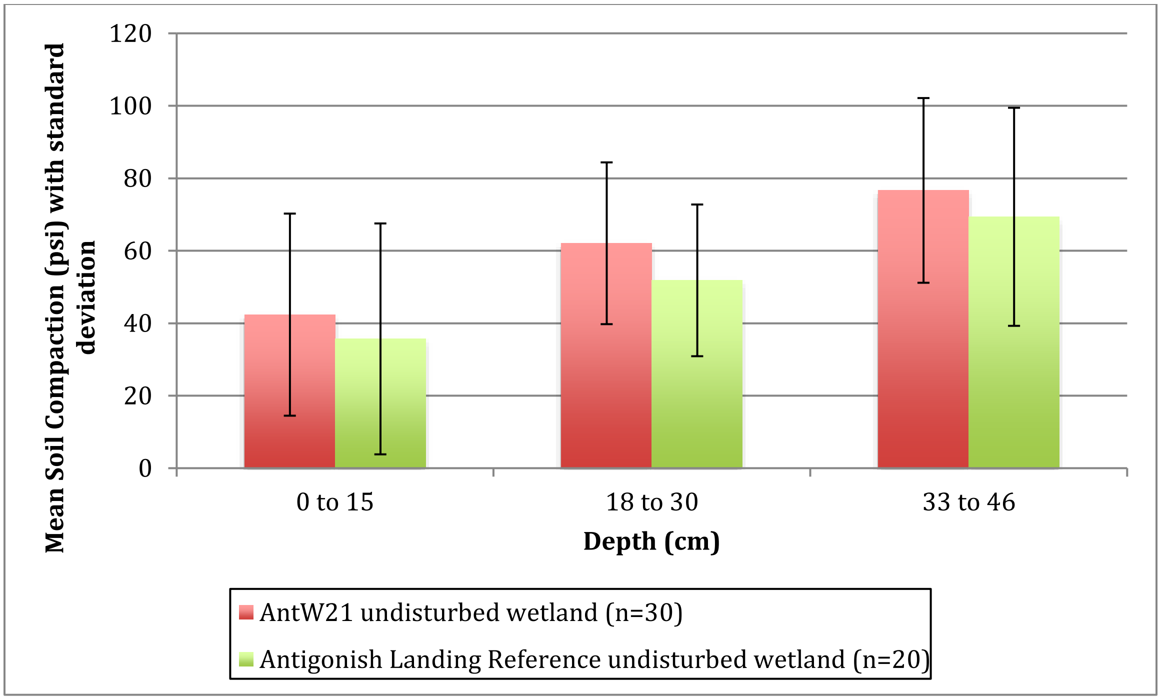

Figure 23: Mean saltmarsh soil compaction values for three soil horizons: 0 to 15 cm, 18 to 30 cm and 33 to 46 cm.

Vegetation

The vegetation community across the Antigonish Landing (AL) site was characterized by examining the plants species and their respective abundances at 40 sampling quadrats, along seven transects, with a total linear distance of 700 m. Similar surveys were conducted on the adjacent Antigonish Landing Reference (ALR) site, along three transects (240 m) at 15 sampling quadrats. These surveys are summarized using a number of metrics in Table 11. The herbaceous vegetation community at AL was found to be generally uniform with moderately low diversity, with the site dominated by extensive, near uniform, stands of *Phalaris arundinacea* (Figures 24 and 25). ALR, in comparison, had higher richness and greater spatial variability, with *Calamagrositis canadensis, Impatiens capensis*, *P. arundinacea* and *Matteuccia struthiopteris* dominant.

The mean Prevalence Index (PI) values across the two sites were similar (Figure 26), with the value of AL slightly lower, indicating a plant community more typically found in wetter conditions. PI values for the ten individual transects are shown at Table 12. The PI values for the seven transects at the Antigonish Landing site ranged from 1.81 to 2.07. There appears to be no spatial pattern in PI values for the Antigonish Landing site with respect to proximity of the transect to the salt water influx to the wetland. The PI values for the three reference transects ranged from 1.84 to 2.3, and reflect qualitative observations of dryer conditions at transects 1 and 2, with transect 3 being at a lower elevation and subject to more frequent tidal inundation.

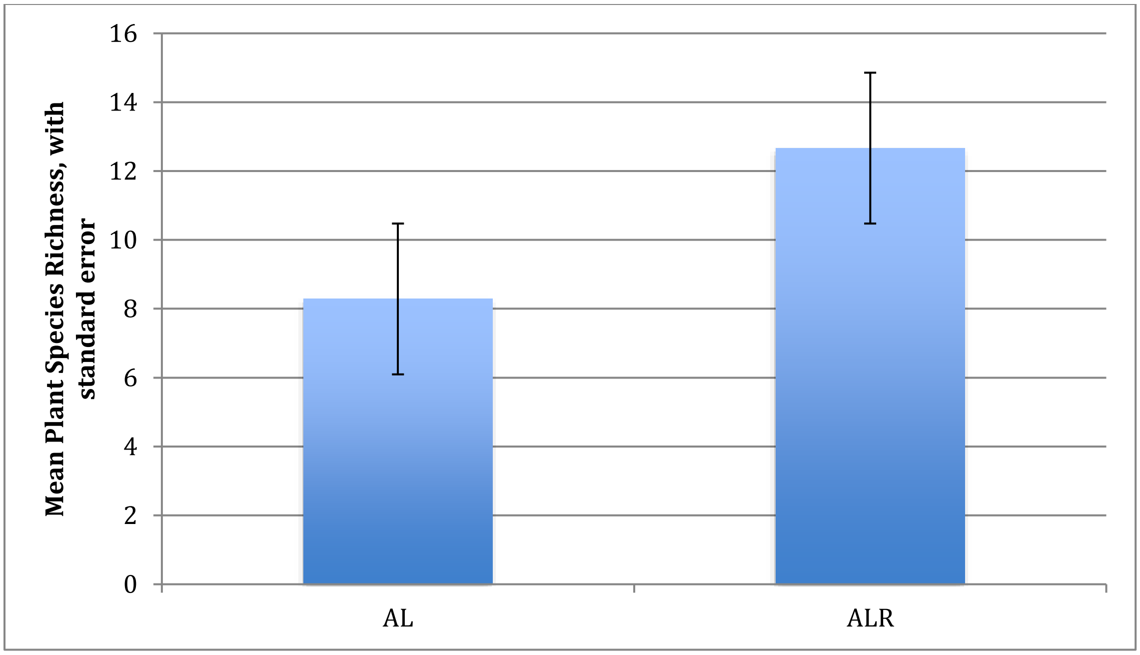

Figure 24: Mean quadrat richness, 2016 vegetation surveys.

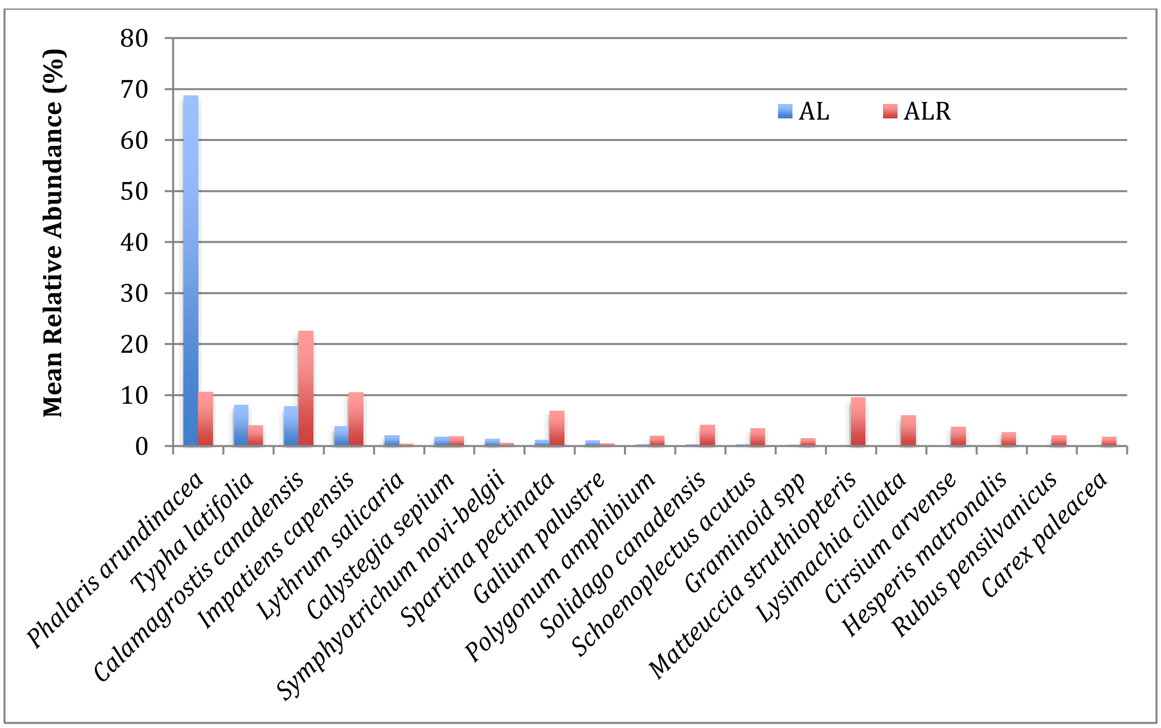

Figure 25: Mean relative abundance for individual plant species, Antigonish Landing Wetland (AL) and Antigonish Landing Reference (ALR), 2016. This graph highlights the relative diversity and eveness of species at the two locations.

Table 11: Summary of vegetation surveys for Antigonish Landing Wetlands and adjacent Reference site.

	Antigonish Landing Wetland (AL) (ECA)	Antigonish Landing Reference (ALR) (ECA)	Antigonish Landing North and South Pond sites (ALP)*
Survey Year	**2016**	**2016**	**2011**
Dominant Species	*Phalaris arundinacea* (Reed canary grass)	*Calamagrostis canadensis* (Blue-joint reedgrass) *Impatiens capensis* (Spotted jewel weed) *Phalaris arundinacea* *Matteuccia struthiopteris* (Ostrich fern)	*Phalaris arundinacea*
Mean Quadrat Richness	8	13	Not available
Mean Prevalence Index	1.95	2.15	2.00
Halophytes observed, with mean absolute abundance per quadrat	*Calystegia sepium* (Hedge bindweed) (1%) *Juncus balticus* (Baltic rush) (1%) *Spartina pectinata* (Fresh water cordgrass) (1%)	*Calystegia sepium* (Hedge bindweed) (2%) *Spartina pectinata* (Fresh water cordgrass) (8%)	*Ligusticum scoticum* (Scot's Lovage), *Calystegia sepium*, *Lathyrus palustris* (Vetchling peavine), *Juncus balticus* (Baltic rush), *Juncus bufonius* (Toad rush), *Juncus gerardii* (Black-grass rush), Agrostis stolonifera (Spreading bentgrass), *Spartina pectinata*
IAS observed, with mean absolute abundance per quadrat	*Lythrum salicaria* (Purple loosestrife) (2%) *Phalaris arundinacea* (Reed canary grass)(62%)	*Lythrum salicaria* (Purple loosestrife) (1%) *Phalaris arundinacea* (Reed canary grass)(13%)	*Acer platanoides* (Norway maple), *Lythrum salicaria*, *Phalaris arundinacea*, *Polygonum cuspidatum* (Japanese knotweed), *Rosa multiflora* (Multiflora rose),
Number of Exotic Species	1	6	36

*CBCL (2011) Prevalence Index based on nine wetland sample plots surveyed September 29, 2010.

A total of three halophyte species were recorded at the AL site, all at low abundances. Two halophyte species were documented at ALR at slightly higher abundances, suggesting only occasional tidal inundation at both sites.

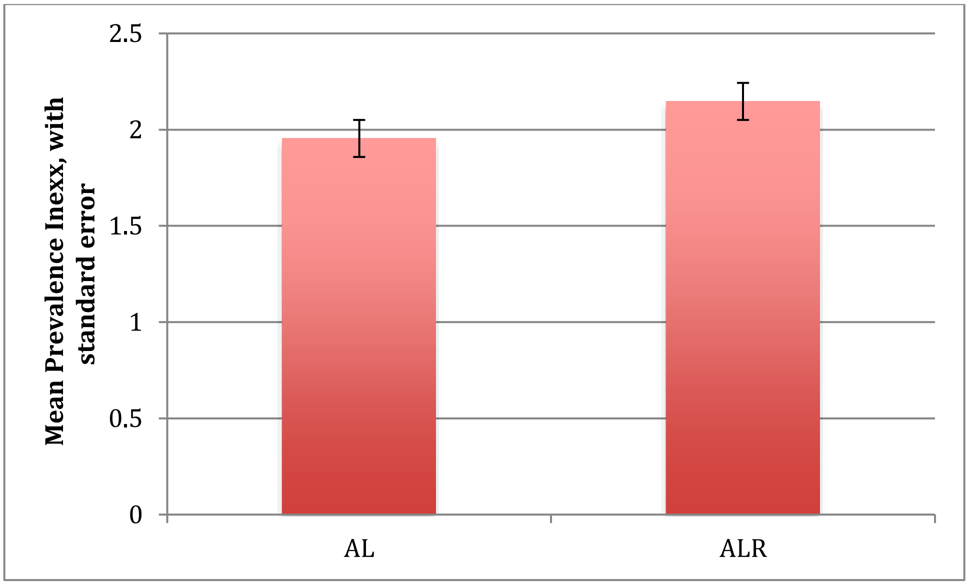

Figure 26: Prevalence Index values, 2016 vegetation surveys.

Table 12: Transect Prevalence Index (PI) values for 2016 surveys.

Location	Transect	PI
Antigonish Landing Wetland (AL)	T1	1.95
	T2	2.07
	T3	1.96
	T4	1.95
	T5	1.95
	T6	1.81
	T7	1.99
Antigonish Landing Reference (ALR)	T1	2.3
	T2	2.3
	T3	1.84

Phalaris arundinacea (Reed canary grass) was found to occur widely across the AL, ALP and ALR sites, forming large uniform stands. Native and non-native forms of *P. arundinacea* are ecologically similar and difficult to distinguish in the field (Hill and Blaney, 2009). Following consultations with regional botanists, it was concluded that *P. arundinacea*, in Nova Scotia sites that have been disturbed or subject to ongoing anthropogenic influence, should be considered as the invasive form (S. Blaney, pers. comm.; N. Hill, pers. comm.). Based on the oral history of agricultural practices at AL and ALR, the presence of topography features such as drainage ditches and the presence of numerous exotic species, it is concluded that both AL and ALR have been disturbed in the past, with the *P. arundinadea* considered the invasive form.

Lavergne and Molofsky (2004), in a comprehensive examination of *P. arundinacea*, its biology and invasiveness, concluded that the species can outcompete native wetland species across a range of settings resulting in monospecific stands, loss of plant and insect diversity and alteration of ecosystem function. The competitive dominance of *P. arundinacea* over native species is in part due to its ability to thrive in conjunction with disturbance, respond rapidly to nutrient inputs, in particular nitrogen and tolerate a wide range of water regimes. Lavergne and Molofsky (2004) provided few viable options for addressing invasive introductions of *P. arundinacea* once it had become established.

Over the course of the 2016 field season, ECA staff noted numerous small patches of *Typha latifolia*, *Scirpus acutus* and other wetland species across the AL site, which in many cases were not documented using the transect and quadrat sampling methodology. The patches, ranging in size from <10 m^2 to 100 - 500 m^2 were qualitatively observed to occur in topographic depressions with standing water frequently observed. While the extensive low-diversity stands of *Phalaris arundinacea* were well represented by the placement and orientation of the sampling transects, small inclusions and micro-habitats may have been under-represented. This deficiency could be addressed by employing a stratified random sampling approach, and deployment of additional quadrats within wet topographic depressions.

Porter *et al* (2015) examined eight undisturbed salt marshes on the Atlantic, Bay of Fundy and Northumberland Strait coasts of New Brunswick and Nova Scotia and identified inundation period, elevation, soil salinity and organic matter content as key correlates in plant community patterns. The authors examined a number of environmental characteristics with respect to the spatial distribution of distinctive plant communities across salt marshes. Table 13 provides a selective comparison of the 2016 Antigonish Landing results to several of the environmental characteristics identified by Porter *et al* (2015).

Spartina pectinata was only found to be dominant at one Antigonish Landing transect (ALRT3) and it occurred at a higher surface elevation within the tidal prism compared to that reported by Porter *et al* (2015). Several transects at the Antigonish Landing site had surface elevations within the range where *S. alterniflora* and *S. pectinata* might be expected, based on Porter *et al* (2015). *Phalaris arundinacea* was however found to be the dominant herb at transects ALT1, T2 and T5, highlighting the wide elevation range and tidal conditions in which the species can thrive. Porter *et al* (2015) highlight the need for additional sampling in the Northumberland Strait and Atlantic wetlands to confirm the generality of the patterns observed. The establishment and long term monitoring at the Antigonish Landing Reference site could provide an opportunity to contribute to this body of knowledge.

Table 13: Selective comparison of plant associations and environmental characteristics for Antigonish Landing and Porter *et al* (2015).

	ALT1	**ALT2**	**ALT5**	**ALRT3**	**Porter *et al*, 2015**	**Porter *et al*, 2015**
Dominant herb/ Association	*Phalaris arundinacea*	*Phalaris arundinacea*	*Phalaris arundinacea*	*Spartina pectinata*	*Spartina alterniflora*	*Spartina pectinata*
Mean +/-SE elevation (m)*	0.44+/-0.03	0.85+/-0.03	1.23+/-0.01	1.08+/-0.01	0.33+/-0.11	0.82+/-0.03
Elevation range (m)*	-0.57 – 0.98	-0.51 – 1.34	0.79 – 1.83	0.84 – 1.51	0.22 – 0.44	0.66 – 0.89
Mean +/-SE vegetation height (cm)	98+/-21	98+/-13	97+/-6	106+/-12	106+/-7	142+/-9

* Porter et al (2015) values reported with respect to CGVD28 vertical datum. ECA 2016 elevation observations were made using the HTv2.0 hybrid geoid model, which was based on an earlier geoid model (CGG2000) that had been distorted to fit with the CGVD28 benchmarks published elevations (NRCAN, 2017).

Through the course of the Antigonish Landing Reference site vegetation surveys, ECA staff documented the presence of what is strongly suspected to be *Cuscuta cephalanthi* (Buttonbush dodder) (NS General Status: Red / S2?) at six locations in 2016 (Figures 27 and 28). The habitat setting was similar to that of the South River (Antigonish Wetland 21) estuary, located ~5 km to the southeast, where the species had previously been encountered. In both cases, *C. cephalanthi* was found at the upland edge transition from the saltmarsh where wetland obligates (e.g., *Spartina* spp) give way to facultative species (e.g., *Rosa* spp). The marine influences for the two sites are very similar, being located in protected estuaries off the Northumberland Strait.

The confirmation of *C. cephalanthi* at Antigonish Landing and Antigonish Wetland 21 is of considerable botanical and scientific interest, given the species' rarity and unusual life history. As is ECA's standard practice, the findings will be shared with the Atlantic Canada Conservation Data Centre (ACCDC) to contribute to the improved understanding of species at risk.

CBCL (2010) documented the presence of the rare species *Triosteum aurantiacum* (Coffee tinkers-weed)(S2/Sensitive) along the northern boundary of the Antigonish Landing wetland within the mixed upland forest. While rare throughout its range, it was reported as well represented within the West, South and Pomquet River systems. ECA recorded an incidental observation of *T. aurantiacum*, in the same habitat as reported by CBCL (2010), near the end of transect 5.

Figure 27: The species at risk *C. cephalanthi* in bloom on *Solidago* spp host.

Figure 28*:* Typical habitat for *C. cephalanthi* at the Antigonish Landing Reference site. Much of the *Solidago* spp at the centre of the image is heavily infested with *C. cephalanthi*.

ECA implemented a quality assurance/quality control (QA/QC) program throughout the Antigonish Landing wetland vegetation monitoring program in order to ensure the accuracy and precision of the results. The QA/QC program included a series of controls within the methodology in order to limit variability, as well as replicate surveys to assess the reliability and reproducibility of the data collection methods. The implementation of the QA/QC program has both reduced methodological variability to a minimum while allowing a meaningful estimate of ecological change to be determined.

In order to better understand the level of spatial variability within wetland plant communities at the scale of 1 to 10 meters, ECA has made use of replicate surveys within the plot-based vegetation monitoring. The term replicate is used here to describe where two transects are placed in visually identical vegetation communities (parallel transects separated by 5 to 10 m) and surveyed using the same personnel on the same day. The purpose of the replicate was to better understand the heterogeneity and spatial variability in wetland plant communities and hence, the basic assumptions made as part of the sampling methodology. Transects 3 and 7 were established as replicates at the Antigonish Landing wetland in 2016.

A high degree of similarity was observed between the replicate transects in terms of plant richness, species abundance, Prevalence Index and the Bray Curtis Index of similarity (Table 14). These findings suggest the use of a consistent sample methodology, low observer bias and reproducibility of the findings across multiple locations.

Table 14: Comparison of replicate transects at Antigonish Landing.

Metric	Transect 3	Transect 7
Richness (No. of plant species)	10	8
Cumulative herbaceous abundance	364	388
Prevalence Index	1.96	1.99
Dominant herbaceous species	*Phalaris arundinacea*	*Phalaris arundinacea*
Bray Curtis Index (BCI) of similarity	0.71	

Due to the relatively small size of the Antigonish Landing North and South Ponds, and so as to maintain consistency with prior surveys (CBWES, 2014), a meandering habitat characterization was used to collectively document vegetation species at ALP north and south (Table 15). A total of 43 species were documented, of which ten were considered halophytes. No species at risk or species of conservation concern were recorded. Two invasive alien species (*Phalaris arundinacea* and *Lythrum salicaria)* were recorded along with eight exotic species.

Table 15: ALP North and South Ponds Species List, August 17, 2016.

Species	Name	S-Rank	NS Wetland Indicator Rank	Halophyte	Notes	CBWES Recorded (2014)*
Alnus incana	Speckled Alder	S5	FACW			Yes
Angelica atropurpurea	Great Angelica	S3	OBL			
Atriplex spp	Orache / saltbush	N/A	N/A			Yes
Bidens frondosa	Devil's Beggar-Tick	S5	FACW			
Calamagrostis canadensis	Bluejoint Reed Grass	S5	FACW			
Calystegia sepium	Hedge Bindweed	S5	FACW	X		Yes
Carex paleacea	Chaffy Sedge	S5	OBL	X		Yes
Cicuta maculatum	Spotted Water-Hemlock	S5	OBL			Yes
Daucus carota	Wild Carrot	SNA	FACU		Exotic	Yes
Dryopteris cristata	Crested Shield-Fern	S5	FACW			
Eleocharis palustris	Creeping Spike-Rush	S5	OBL			Yes
Elymus spp	Wheatgrass	N/A	N/A			Yes
Epilobium spp	Willow-Herb	N/A	N/A			Yes
Eupatorium maculatum	Spotted Joe-Pye Weed	S2	FACW			
Galium palustre	Marsh Bedstraw	S5	FACW+			Yes
Impatiens capensis	Spotted Jewel-Weed	S5	FAC			Yes
Juncus gerardii	Black-Grass Rush	S5	OBL	X		Yes
Lolium perenee	Perennial Ryegrass	SNA	FAC		Exotic	
Lysimachia ciliata	Fringed Loosestrife	S4	FACW			
Lythrum salicaria	Purple Loosestrife	SNA	FACW		IAS	
Persicaria spp	Smartweed	N/A	N/A			
Phalaris arundinacea	Reed Canary Grass	S5	FACW		IAS	Yes
Plantago major	Nipple-Seed Plantain	SNA	FAC		Exotic	
Polygonum persicaria	Lady's Thumb	SNA	FAC		Exotic	Yes
Polygonum sagittatum	Arrow-Leaved Tearthumb	S5	OBL			Yes
Potentilla anserina	Common Silverweed	S5	FACW	B		Yes
Rosa spp	Rose	N/A	N/A			Yes

Sambucus nigra ssp. canadensis	Common Elderberry	S5	FACW			
Schoenoplectus acutus	Hard-stemmed Bulrush	S4	OBL	B		
Schoenoplectus pungens	Three-Square Bulrush	S5	OBL	B		Yes
Solanum dulcamara	Climbing Nightshade	SNA	FAC		Exotic	
Solidago canadensis	Canada Goldenrod	S5	FAC			Yes
Solidago sempervirens	Seaside Goldenrod	S5	FACW+	X		Yes
Sonchus arvensis	Field Sow Thistle	SNA	FAC		Exotic	
Spartina alterniflora	Saltwater Cordgrass	S5	OBL	X		Yes
Spartina patens	Salt-Meadow Cordgrass	S5	OBL	X		
Spartina pectinata	Fresh Water Cordgrass	S5	FACW+	B		Yes
Symphyotrichum novi-belgii	New York Aster	S5	FAC			Yes
Symphyotrichum puniceum	Swamp Aster	S5	FACW			
Toxicodendron radicans	Poison Ivy	S4	FAC			
Trifolium arvense	Rabbit-Foot Clover	SNA	UPL		Exotic	
Typha angustifolia	Narrow-Leaved Cattail	S5	OBL			Yes
Typha latifolia	Broad-leaved Cattail	S5	OBL			Yes

* CBWES (2014) field surveys conducted September 2014.

Notes

NS Wetland Indicator Rank	
obl	Obligate Wetland; occurs almost always (estimated probability 99%) under natural conditions in wetlands.
facw	Facultative Wetland; usually occurs in wetlands (estimated probability 67%-99%), but occasionally found in non-wetlands.
fac	Facultative; equally likely to occur in wetlands or non-wetlands (estimated probability 34%-66%).
facu	Facultative Upland; occurs in non-wetlands (estimated probability 67%-99%), but occasionally found on wetlands (estimated probability 1%-33%).
upl	Obligate Upland; occurs almost always (estimated probability 99%) under natural conditions in non-wetlands.
NI	No indicator; insufficient information was available to determine an indicator status.
Halophyte	
X	occurring in strongly saline conditions
B	occurring in brackish conditions but typically excluded from full salinity sites

Table 16: Antigonish Landing Reference (ALR) Site Species List, August 16, 2016

Species	Name	S-Rank	NS Wetland Indicator Rank	Halophyte	Notes
Agrimonia stricta	Woodland Agrimony	S5	FAC		
Arisaema triphyllum	Jack-in-the-pulpit	S4S5	FACW		
Calamagrostis canadensis	Bluejoint Reed Grass	S5	FACW		
Callitriche palustris	Marsh Water-starwort	S5	OBL		
Calystegia sepium	Hedge Bindweed	S5	FACW	X	
Carex lurida	Sallow Sedge	S5	OBL		
Carex paleacea	Chaffy Sedge	S5	OBL	X	
Carex projecta	Necklace Sedge	S5	FACW		
Carex vulpinoidea	Fox Sedge	S4?	FACW+		
Carum carvi	Wild Caraway	SNA	FACU		Exotic
Cirsium arvense	Canada Thistle	SNA	FAC		Exotic
Conium maculatum	Poison Hemlock	SNA	FAC		Exotic
Cuscuta cephalanthi	Buttonbush Dodder	S1	FACW	B	
Echinocystis lobata	Wild Cucumber	SNA	FAC		Exotic
Elymus virginicus	Virginia Wild Rye	S5	FACW	B	
Epilobium cillatum	Northern Willowherb	S5	FAC		
Epilobium palustre	Marsh Willow-Herb	S5	OBL		
Eupatorium maculatum	Spotted Joe-Pye Weed	S2	FACW		
Galeopsis tetrahit	Common Hemp-nettle	SNA	FAC		Exotic
Galium palustre	Marsh Bedstraw	S5	FACW+		
Geum aleppicum	Yellow Avens	S5	FAC		
Heracleum maximum	Common Cow Parsnip	S5	FAC		
Impatiens capensis	Spotted Jewel-Weed	S5	FAC		
Juncus canadensis	Canada Rush	S5	OBL		
Juncus effusus	Soft Rush	S5	FACW		
Leersia oryzoides	Rice Cut Grass	S5	OBL		
Ludwigia palustris	Marsh Seedbox	S5	OBL		
Lysimachia nummularia	Creeping Yellow Loosestrife	SNA	FACW		Exotic

Lythrum salicaria	Purple Loosestrife	SNA	FACW		IAS
Matteuccia struthiopteris	Ostrich Fern	S5	FACW		
Mentha spp	Mint	N/A	N/A		
Mimulus ringens	Square-stemmed Monkeyflower	S4S5	OBL		
Myosotis laxa	Small Forget Me Not	S5	OBL		
Myosotis sylvatica	Woodland Forget-me-not	SNA	UPL		Exotic
Oxalis montana	Common Wood Sorrel	S5	FAC		
Pastinaca sativa	Wild Parsnip	SNA	FACU		Exotic
Persicaria amphibian	Water Smartweed	S4S5	OBL		
Persicaria hydropiper	Marshpepper Smartweed	SNA	FACW		Exotic
Phalaris arundinacea	Reed Canary Grass	S5	FACW		IAS
Platanthera grandiflora	Large Purge Fringed Orchid	S3	FACW		
Polygonum sagittatum	Arrow-Leaved Tearthumb	S5	OBL		
Prunus virginiana	Chokecherry	S5	FAC		
Rosa spp	Rose	N/A	N/A		
Rubus idaeus	Red Raspberry	S5	FAC		
Sagittraria cuneata	Northern Arrowhead	S5	OBL		
Schoenoplectus acutus	Hard-stemmed Bulrush	S4	OBL	B	
Sinapis arvensis	Corn Mustard	SNA	FACU		Exotic
Solidago canadensis	Canada Goldenrod	S5	FAC		
Spartina pectinata	Fresh Water Cordgrass	S5	FACW+	B	
Symphyotrichum lateriflorum	Calico Aster	S5	FAC		
Symphyotrichum novi-belgii	New York Aster	S5	FAC		
Typha latifolia	Broad-leaved Cattail	S5	OBL		
Urtica urens	Burning Nettle	SNA	FACU		Exotic
Verbena hastate	Blue Vervain	S3	FACW		
Vicia cracca	Tufted Vetch	SNA	FAC		Exotic

A similar meandering habitat survey was also completed at the large Antigonish Landing Reference (ALR) site to more fully characterized the vegetation community (Table 16) that was sampled using three transects. A total of 55 species were documented, of which six were considered halophytes. Two invasive alien species (Phalaris arundinacea and Lythrum salicaria) were recorded along with twelve exotic species. The frequency with which exotic and other weedy species were encountered at the Reference site suggestions historic anthropogenic activities, such as agriculture, across the site.

Water Quality and Fish

Water quality observations were made across the three newly constructed (May 2015) ponds within the Antigonish Landing site (West, Central and East) as well as the ALP North and South ponds. This sampling was carried out to determine if any basic condition might limit the presence of fish, or influence the composition of one sampled community relative to that of another pond. As collection of depth profiles measures could not be collected at exactly the same time, given the need to move boat and equipment between sites and carry out measures, sampling occurred over approximately a three hour time span from high tide during the falling tide. Although conditions should have been relatively similar given a period of slack tide within the sampling timeframe, variations could exist associated with changing water levels. A summary of the in situ water chemistry profiles of the ponds is shown in Table 17.

The ALP North pond was highly turbid on the day of sampling, with a turbidity plume 5 to 10 cm thick covering the entire pond. It appeared that a turbid fresh water layer from upslope drainage around a subdivision construction site was carried to the pond following heavy rains earlier in the day, laying on top of the more dense tidal inflow layer. The inflow at the peak of tide had held the freshwater layer within the pond, allowing the turbid water to accumulate. The turbidity in this layer was measured at 600-655 NTU.

In general, water chemistry conditions in all of the ponds was marginal for salmonid species such as Atlantic Salmon and Brook trout that may have estuarine periods of their life cycle. Water temperature above 20 ^{o}C, and dissolved oxygen less than 9.5 mg/L for young and 6.5 mg/L for adults in freshwater is not sustainable as a chronic exposure for these typically cold water species (CCME 1999). The created wetland pond habitats were not intended to support such species, and the observed chemistry and lack of presence of these species was not unexpected. The impact of low DO on aquatic invertebrates is not as severe physiologically as it is for salmonids, however, behavior and production impacts are observed at somewhat similar levels of depressed oxygen. In marine conditions the Canadian dissolved oxygen guideline for the Protection of Aquatic Life is >8.0mg/L (CCME 1999). As saline water does not hold as much oxygen as freshwater, hypoxic and anoxic conditions may occur more often where salinity is higher. Hypoxia occurs when the amount of dissolved oxygen in water becomes too low to support virtually all aquatic life (typically below 2 mg/l). As can be seen in Table 17, hypoxic conditions were measured in the deeper portions of the newly constructed AL west and east ponds at Antigonish Landing. Slightly less severe, anoxic conditions (DO <0.5 mg/L) are still acutely lethal to most higher-level aquatic organisms (excludes microbial and some meiofauna communities).

Table 17: Summary of in situ water chemistry measures along a depth profile for pond habitats.

	Depth (m)	**Temp** (°C)	**DO** (mg/L)	**Conductivity** (µS/cm)	**Dissolved Solids** (mg/L)	**pH**
ALP North*	0.2	23.2	7.0	5987	3945	7.58
	0.5	23.1	6.3	6821	4446	7.54
	0.8	23.0	6.2	7106	4610	7.5
ALP South	0.2	22.2	6.6	1481	962	7.51
	0.5	22.4	6.1	2072	1410	7.17
	0.8	-	-	-	-	-
ALP Avg. @ 0.5 m	0.5	22.7	6.2	4446	2928	7.35
AL East	0.2	22.6	3.4	571	371	6.82
	0.5	22.5	3.1	572	370	6.93
	0.8	-	-	-	-	-
AL Center	0.2	22.0	6.3	812	526	7.13
	0.5	21.7	6.0	870	585	7.05
	0.8	-	-	-	-	-
AL West	0.2	20.9	5.5	996	650	7.10
	0.5	20.6	0.5	1176	767	6.59
	0.8	19.3	1.6	2984	1930	7.12
AL Avg. @ 0.5 m	0.5	21.6	3.2	873	574	6.86

*North pond was highly turbid on day of sampling (600-650NTU).

In shallower waters, the bulk of oxygen loss that is attributable to oxidation occurs at the sediment–water interface, where microbial activity and organic matter are concentrated. A considerable amount of oxygen depletion may also occur by direct chemical oxidation of dissolved organic matter (DOM) and reduced ions (sulfides and metals). Construction of the new wetland ponds could be expected to expose new organic soils to the ponded water, increasing DOM and reduced ion levels within the ponds, particularly during times of low water turnover. More broad spectrum water chemistry analysis would be required to determine if the new ponds did in fact have higher DOM concentrations. Water column stratification, or layering of less dense water over more dense water, can also contribute to low oxygen levels as mixing between more oxygenated surface and less oxygenated bottom layers does not occur. This layering is most apt to occur where warm fresh water lays on top of more dense colder saline waters in an area of weak water flows and movement. Although true stratification was not observed within the profile data, all of the ponds at both the AL and ALP sites had warmer and fresher water underlain by slightly cooler and more saline water as can be seen in Table 17.

Higher conductivity generally indicates a greater amount of dissolved salts, which at Antigonish Landing may be influenced by marine water or sediment disturbance. Sediment disturbance could be an artifact of the recent construction of AL ponds, observed construction-related sedimentation at ALP north pond, or freshwater erosion runoff transported down the Rights River to the various pond sites. Typical freshwater streams have a conductivity of 100-2000 μS/cm, very brackish systems are on the order of 25,000 μS/cm, while full marine environments are typically in the 55,000 μS/cm range. Based on the conductivity values collected and shown in Table 17, the various ponds assessed at Antigonish Landing range from characteristically fresh at the AL east pond, to predominantly fresh at the AL central and west ponds, to weakly estuarine at the ALP north and south ponds.

Notable within the data are the slightly higher conductivity values observed in the AL west pond compared to the east pond, the latter of which is closer to the saline source of the Rights River. This counter-intuitive finding prompted additional water sampling to be conducted during the winter structured habitat walk on March 2, 2017. During the March 2017 sampling, the AL west pond again had the highest conductivity values (1513 μS/cm) of the three ponds. Standing water on the wetland surface to the west (upslope) of the AL west pond was also found to have elevated conductivity (1395 μS/cm). This would suggest that the source of elevated conductivity at the west pond may be upslope of the wetland rather than saline tidal inflows from the Rights River. Separate monitoring conducted by ECA along the new Highway 104 alignment in Antigonish has recorded surface water conductivity values in the range of 651 to 896 μS/cm (ECA, 2016). Pre-construction water quality monitoring for the Environmental Assessment report of the Highway 104 twinning recorded conductivity values in the range of 34 to 1830 μS/cm at the 15 planned watercourse crossings along the alignment (Stantec, 2005, Appendix D). These findings suggest that the elevated conductivity values in the AL ponds may equally be due to a naturally occurring source upslope of the wetland as to tidal influence.

Few organisms can adapt to a range of salinities, and instead are either classed as marine or freshwater species. Those that can tolerate a range are anadromous, catadromous or true euryhaline. True euryhaline species can be found in saltwater or freshwater at any point in their life cycle, and these are estuarine organisms. Euryhaline species might be anticipated to be both most common and first inhabitants in the newly constructed tidal ponds at AL. A limited fish sampling program was undertaken to qualitatively assess the degree to which the construction of the three ponds at AL represented a fish habitat gain. Furthermore, sampling was intended to qualitatively examine whether the species composition present at the AL ponds was similar to the longer established species ALP ponds species composition.

Species captured and identified from the July 25/26, 2016 deployment of five minnow traps are shown at Table 18. The presence of four fish species in two of the three AL ponds (Stickleback, Dace, Chub and Killifish) represents a quantitative fish habitat gain as a direct result of the wetland enhancement measures taken to date at the site. The greatest diversity and abundance of individuals caught was at the AL center pond. AL west pond was the only newly constructed pond where no fish were caught. Similarly, no fish were caught at the ALP north pond that had a high turbidity event at the time of sampling. The absence of any fish caught at these sites may or may not be a significant result, given the variability of aquatic conditions in a tidal setting and the methodological challenges of catching fish. Relatively small numbers of species, and high catches of just a few species has been noted as typical of fish assemblages in temperate estuaries off eastern Canada and New England (Bremner *et al* 2015).

Table 18: Nekton minnow trap sampling results, July 2016.

Location	Species Caught	Number	Notes
ALP-North Pond	None	None	Small-bodied fish observed near trap
ALP-South Pond	Three-spine stickleback (*Gasterosteus aculeatus*)	1	Spawning colouration
AL-East Pond	Three-spine stickleback (*Gasterosteus aculeatus*)	1	
	Northern Redbelly Dace (*Chrosomus eos*)	15	
AL-Central Pond	Northern Redbelly Dace (*Chrosomus eos*)	38	
	Cheek chub (*Semotilus atromaculatus*)	2	
	Banded killifish (*Fundulus diaphanus*)	7	
AL-West Pond	Giant water bug (*Lethocerus americanus*)	3	No fish caught

Of the fish species captured, Three-spine stickleback (Figure 29) are a true euryhaline species with freshwater and marine presence (Scott 1986). This species was captured at both the ALP South Pond and the newly constructed AL East Pond. The fish captured at South Pond was a male in bright spawning colors (see Figure 29).

Redbelly Dace were the species caught in greatest abundance, making up 84% of all fish caught. It should be cautioned that this does not mean dace are the most abundant species found in the ponds, only that they may be the most easily caught in minnow traps with the bait that was used. Dace are relatively adapted to thick ice cover and low oxygen levels, and are somewhat tolerant of warm water conditions, such as boggy cool freshwater with minimal movement (Wooding 1997).

Significantly larger than the other species captured, two Creek chub approaching 12 cm in length were captured in the AL Central Pond. This is a tolerant species that can withstand a wide variety of water conditions, and is often a predator on other small-bodied fish species.

Figure 29: A male Three-spine stickleback in spawning colors sampled at ALP south pond.

The fourth species captured during the fish sampling was the Banded killifish, *Fundulus diaphanous*. It is very similar to the more marine oriented Mummichog *Fundulus heteroclitus.* The Banded killifish is a euryhaline species that differs visually from the Mummichog primarily by having thin dark bars on a light side, whereas in the mummichog the bars are thin and light on a dark side. The two species may overlap in their choice of habitat, but in general the Banded killifish is more commonly found in freshwater. Seven individuals were captured in the newly created AL Central Pond.

Although no fish were captured in the most upslope, and newly constructed, AL West Pond, three Giant Water Bugs *Lethocerus americanus* were captured. The Giant Water Bug is of the family *Belostomatidae*. This family of hemipteran insects is found in freshwater, so its capture is a good confirmation that the habitat is freshwater in nature. A number of frogs have also been incidentally observed within the pond by field biologists completing various surveys, a further indication that water salinity could be characterized as freshwater habitat. Unlike all other pond habitats sampled, no fish were visually observed at AWL West Pond.

Although the minnow trap surveys carried out at Antigonish Landing were not intended to be quantitative in nature, the visual observation of many fish within each of the ponds coupled with the limited capture within the traps reflects the ineffective nature of the sampling method. These findings suggest that a full or near full diversity of species present may not be reflected in the collected data. Barry Taylor (2016), in the monitoring of the nearby Antigonish Wetland 1, reported on the very limited success in trapping small-bodied fish, including Northern Redbelly Dace and Three-Spined Stickleback. Researchers at the Antigonish Wetland 1 site examined the use of various baits (including light sticks), finer mesh on the traps and aeration of traps in an attempt to improve catch rates, particularly in situations where fish were observed in the water column adjacent to the trap. Taylor (2016) was unable to offer recommendations to improving catch efficiency sufficiently to allow for quantitative population estimates. These challenges were echoed in the findings for the ALP North pond, where numerous small-bodied fish were observed in water column adjacent to the trap at placement and retrieval, yet none were caught. Beach seine netting or electrofishing could provide a higher catch rate in the sampled Antigonish Landing Ponds, and allow a better characterization of the species assemblage within each pond.

Variability in fish observations at the various pond sites is anticipated. A study of the spatial and temporal variation in fish assemblages in three estuarine rivers and associated ponds at Kouchibouguac National Park identified similar species to those at Antigonish Landing. Bremner *et al* (2015) showed a spatial gradient in abundance of dominant species from upstream to lagoon sites and a temporal gradient from spring to fall. The authors found variation within fish populations was related to site and seasonal changes in environmental conditions and species' tolerance of water temperature, salinity, vegetation coverage, and fine sediments. As many of these parameters are likely in a state of change following restoration of tidal exchange at Antigonish Landing, it could be expected that fish species assemblages may change over a number of years, and that they furthermore are likely with time to exhibit spatial and temporal variability as has been observed in Kouchibouguac National Park.

Structured Habitat Walks

Summer

A structured summer habitat walk was completed on August 31, 2016, with all transects, as well as the Antigonish Landing Ponds, examined and photographed. Wildlife observations are summarized in Table 19. Although spoil piles from the pond construction at AL were generally well vegetated, small areas (0.5 to 1 m^2) of bare organic soil were visible at a number of piles. High turbidity had been observed at the ALP north pond, appearing to originate at the west end of the pond closest to nearby residential development. No heavy sediment loads were observed deposited around the pond margin.

As part of the summer 2016 habitat observations, construction debris was observed in the western portion of the ALP North Pond (Figures 30 and 31). Silt fabric and a series of floating booms, made from blue Styrofoam insulation, were observed in ~0.4 m of water and deep mud. While the origin and purpose of the equipment is unclear, the North Pond does receive surface runoff from nearby construction, including an adjacent residential development. It is suspected that the equipment was put in place as a floating siltation barrier, but never removed. Given the vegetation growth on the floating booms, the equipment has likely been in place for several years.

Table 19: Wildlife observations during summer structured habitat walk.

Species	Species	Notes
American beaver	*Castor Canadensis*	Peeled sticks in channel at ALT1
Swamp sparrow	*Melospiza georgiana*	Near ALT4 pond
Double-crested cormorant	*Phalacrocorax auritus*	Rights River near ALT5, ALP-North
Great blue heron	*Ardea Herodias*	ALRT2Q1
Black ducks	*Anas rubripes*	ALRT2, ALP-South
White tailed deer	*Odocoileus virginianus*	Numerous beds near ALRT3
Savannah sparrow	*Passerculus sandwichensis*	Near ALRT3
Belted kingfisher	*Magaceryle alcyon*	ALP-North
Small-bodied minnow (very abundant)	Unknown	ALP-South

Figure 30: Construction debris composed of matted, muck encrusted silt fabric with floating booms at the ALP North Pond. The walking trail and culvert outflow from the pond are located at the top right of the image.

Figure 31: Floating booms composed of blue Styrofoam insulation with silt fabric, ALP North Pond.

Winter

During the March 2, 2017 structured winter walk, the west, central and east ponds at AL were ice-covered. Large sections of ice had recently been lifted and partially dislodged out of the ponds, suggesting at least partial tidal inundation of the site accompanied by strong winds. The freezing and lifting action of ice was observed to have displaced clods of marsh vegetation and soil at the newly excavated pond sites. These were typically no larger than 0.5 m^3. It appeared likely that the mud and vegetation lifted with the ice pans was from the shallow pond areas and immediate margins, rather than from the marsh surface or the adjacent spoil piles (Figure 32). In one location where snow and ice cover was minimal a small fracture (5 cm wide by 1.5 m long) in the sod adjacent to the pond was observed. Evidence of recent overland flow entering the AL West pond on its northwest side and exiting on the southwest side was observed. This surface sheet flow generally runs parallel to three observed historic access roads that originate at the walking trail and extend into the field at a low elevation profile not visible during the growing season when vegetation is high. Only the West Pond monitoring well was observed during the winter surveys. The ice formation and movement across the survey site appeared to likely have flattened or dislodged all of the other wells and sediment pins.

Figure 32: Ice pans and mud clumps are visible at the margins of the central pond at AL.

The east end of AL outlet channel from the northern end of transect 3 to the bridge was completely ice covered at the March 2, 2017 visit. Further upstream, the outlet channel was open and mineral to gravel sediment was observable on some of the streambed. Moderate sediment deposition was observed near the north end of transect 5 adjacent to the beginning of the outlet channel. This sediment appeared to be dominated by organics. Still further to the western end of AL, sediments visible on patches of snow and ice were more mineral based, and appeared likely to be originating from the drainage entering the wetland from the northwest corner. Moderate sediment deposition was observed on the flattened vegetation and ice surface near the south end of transect 5 (Figure 33). Tidal flooding of the marsh from the adjacent Rights River was believed to the source of the sediment, although it was unclear whether the sediment had marine or upland origins.

Figure 33: Sediment deposition at AL, near the south end of transect 5. Photo March 2, 2017.

An adult Bald eagle (*Haliaeetus leucocephalus*) was observed on the wing above the AL. Waterfowl observed on the Rights River between the AL and the ALR included Hooded mergansers (*Lophodytes cucullatus*) and Black ducks (*Anas rubripes*). Deer scat was observed adjacent to the wetland on the north margin, and a game trail that appeared to be used predominantly by deer ran northwest to southeast across the western end of the AL site. A single fish was observed in the north channel near the outlet of the AL west pond. Estimated to be 12-15cm in length, it could not be identified. No other small-bodied fish were observed in the channel or any open water areas of any of the ponds. This may be an indication that the ponds do not currently provide overwinter habitat for fish.

At ALP South and North, small areas near the outlet culverts remained open water at the time of the winter walk, although the majority of each pond was ice covered. Although some ice fractures existed at each site, tidal activity had not lifted pans nor caused stacking of pans along the pond margins. A minimal and localized silt deposit could be seen on the ice surface at ALP North pond; the location where heavy turbidity had been observed during the summer. Neither sediment pins nor monitoring wells at either of the ALP sites nor the adjacent river site were observed, and appear likely to have been impacted by ice movement.

The ALR transects 1 and 2 were almost completely covered by ice up to 1.0 m deep, with extensive ice deposition observed across much of the ALR site (Figure 34). It was not possible to complete the survey of ALR transect 3 as a deep, rapidly flowing tidal channel could not be safely crossed. A man-hole on a buried sewage pipe located north of the railway tracks at ALR had its cover displaced and remnants of sewage were visible on the marsh surface (Figure 35).

Figure 34: Heavy ice deposition across ALR T2 will have destroyed most of the quadrat stakes. Photo March 2, 2017.

Figure 35: A sewage pipe access cover north of the railway tracks at ALR had lifted its cover over the winter and remnants of sewage was visible across the immediate area around the pipe.

Summary of Year 1 (2016) Post-Restoration Monitoring of Antigonish Landing Marsh

Year 1 (2016) post-restoration monitoring of the Antigonish Landing wetland complex has been completed by ECA following the completion of restoration activities at the site in 2015. The monitoring protocols implemented, based on GPAC guidelines (1999), prior monitoring activities at the site and scientific best practice, have sought to assess the success of the restoration efforts and current ecological status of the site. An adjacent reference site was characterized in 2016 to provide a point of comparison in gauging the long-term success of the restoration efforts at the Antigonish Landing site.

Low altitude aerial photography of the site, completed in July 2016, was combined within vegetation surveys and field observations to develop revised habitat maps for the site. Extensive ground surface elevation surveys, also completed in 2016, were integrated with prior LiDAR studies to develop a Digital Elevation Model.

Restoration activities at AL included removal of barriers to tidal exchange with the installation of larger diameter culverts and a bridge, together with the construction of three wildlife habitat ponds and connecting channels. Monitoring of water levels above and below the historic tidal barriers through the deployment of water level data loggers has been used to assess the success of the restoration efforts. No appreciable restriction to tidal exchange was observed at AL and ALP North Pond, in terms of timing and amplitude of tidal prism. No time lag in tidal peaks was observed above and below the ALP South Pond culvert, although the culvert invert was observed to be set at approximately 0.15 m above the minimum tide levels, resulting in water being perched in the pond at low tide.

The three constructed wildlife ponds at AL were observed to have moderate aquatic connectivity to tidal flushing within the Rights River, in terms of changes in water levels, temperature and conductivity. The AL East Pond, located closest to the marsh outlet to the Rights River, had the greatest correlation in conditions, with decreasing marine effects with increasing distances at the Central and West Ponds, respectively.

Quantitative vegetation surveys were completed through the sampling of seven transects at AL and three transects at ALR, together with meandering visual surveys at ALP and ALR. AL was observed to have extensive coverage of low diversity stands of *Phalaris arundinacea* (Reed canary grass) with variable inclusions of *Juncus balticus* (Baltic rush), *Spartina pectinata* (Fresh water cordgrass) and *Typha latifolia* (Broad-leaved cattail). A comparable species mix was observed at ALR, with greater overall diversity and less extensive stands of *P. arundinacea*. Invasive alien species (*P. arundinacea* and *Lythrum salicaria* (Purple loosestrife)) and several exotic species were observed at both AL and ALR. These species, together with fine-scale topographic observations in the field and local oral history, suggest historic agriculture disturbance at the sites. ECA staff documented the presence of what is strongly suspected to be *Cuscuta cephalanthi* (Buttonbush dodder) (NS General Status: Red / S2?) at six locations in 2016. The habitat setting was similar to that of the South River (Antigonish Wetland 21) estuary, located ~5 km to the southeast, where the species had previously been encountered.

A limited water quality and fish sampling program was undertaken to characterize the conditions in the 2015-constructed ponds at AL, and at ALP. Waters within the AL West, Central and East Ponds were found to be warm (19 to 23 °C), dilute to oligohaline (371 to 1930 mg/L TDS) and have near neutral pH (6.6 to 7.1) during the July sample time. The ALP were notable for their oligo to mesohaline conditions (962 to 4610 mg/L TDS). Four small-bodied fish species (Three-spine stickleback (*Gasterosteus aculeatus*), Northern Redbelly Dace (*Chrosomus eos*), Cheek chub (*Semotilus atromaculatus*), Banded killifish (*Fundulus daphanus*)) were caught and released through the deployment of minnow traps at five locations.

Summer and winter structured habitat walks were completed at the site to document general habitat conditions. Notable in the early March 2017 visit was the extensive ice coverage over the eastern portion of AL, with extensive rafting of wind-driven ice across portions of ALR. This ice destroyed sediment pins, monitoring well installations, and quadrat staking across the project area.

The habitat restoration measures undertaken at AL showed promising initial results in terms of open water habitat gain and tidal exchange across the marsh surface. The removal of tidal barriers at AL and ALP have resulted in very limited to negligible residual restrictions on tidal exchange.

Planned Future Monitoring and Recommendations

Pre-restoration monitoring of the Antigonish Landing site was completed by CBCL (2010, 2011) and CBWES (2012, 2014), with restoration activities being completed by several agencies, including ECA (2015) over the period of 2013 to 2015. The Year 1 post-restoration surveys completed by ECA in 2016 at the site occurred within the context of the generalized salt marsh monitoring program for Nova Scotia (Table 20) (Nova Scotia RFP 60149510, 2016). Year 2 monitoring is anticipated to occur in 2017 and will incorporate summer and winter structured habitat walks as outlined in the RFP for the project monitoring.

Within the context of future monitoring at the site, ECA makes the following recommendations with the goal of improving the overall effectiveness, efficiency and accuracy of survey activities.

Elevations

At least once per project year, record the coordinates and elevation of a nearby known survey benchmark using the RTK-GPS system. At least once per survey day, record coordinates and elevation at temporary on-site benchmark (e.g. culvert). These two actions would serve to validate the spot elevations generated across the site, provide an estimate of error in these daily elevation values, and maintain a link with provincial survey benchmarks.

Hydrology

For well placements that will be used to record temperature and/or conductivity, ensure that the logger sensor is placed within the well above the ground surface but below the lowest anticipated tidal water level, in a location with un-restricted water exchange. This approach would minimize potential for methodological errors associated with loggers recording measures from relatively stagnant water held within the well length below ground level. In cases where reduced water exchange exists within the below ground well casing, error is introduced to temperature and conductivity readings. This error could be further quantified by adding a second logger to a well, placing one slightly (<~5cm) above the ground and one below the ground and comparatively analyzing data to determine the effect of placement on collected measures. Such a comparative evaluation should be considered. Black well casings may not be appropriate due to increased solar radiation. White PVC tubing could be used to limit this potential methodological error. Finally, conductivity logging should be considered for all monitoring well placements as it adds further detail on the magnitude and temporal inundation of saline water at monitoring sites, rather than simply tidal signal. Salinity has a profound effect on the flora and fauna present at a site, and conductivity logging would allow for a better description of pre-restoration conditions and better prediction of post-restoration communities.

Sediment Pins

Based on the winter structured walk and a subsequent site visit on April 14, 2017, five of the seven sediment pins installed in July 2017 were either destroyed or dislodged by heavy winter ice. One sediment pin at the AL-West Pond appeared intact and undisturbed. The sediment pin at the reference site could not be safely accessed due to high river flows, and its status is unknown. As there is no indication that the ice conditions in the Antigonish Harbour area were unusually heavy during 2017, it is plausible that comparable ice conditions could be expected at the Antigonish Landing site in future years.

While replacement sediment pins could be established and re-surveyed in 2017, ECA does not recommend this. Firstly, replacement sediment pins would be subject to the same risk of destruction by winter ice in 2018, with no sediment accretion data being generated. Sediment pins may therefore not be a good approach to use in locations subject to heavy icing. Secondly, with a minimum elevation error 0.05 m, a considerable amount of sediment would need to accrete/erode before a meaningful change could be recorded. Such sediment loads may be expected in actively eroding/deposition areas, and areas like the inner Bay of Fundy where high natural loads occur. Such is not the case for the Antigonish Landing site. Alternate methods for the examination of accretion and erosion in salt marshes include Rod Surface Elevation Tables (RSET) with feldspar marker horizons and sediment plates. The establishment, maintenance and sampling of RSETs are methodologically and equipment intensive, making the deployment at multiple locations within a site impractical. Sediment plates represent a lower-cost alternative to examine sedimentation processes, providing the option for the deployment of more stations across a site to evaluate spatial variability (USGS, 2012b; Pasternack and Brush 1998). As the plates lie flush with the ground, they are less likely to be disturbed by ice flows. The technique has been used successfully in the Bay of Fundy at a location subject to heavy icing (van Proosdij, 2006).

The winter structured walk documented localized sedimentation at the AL (Figure 32), and ice transport of mud and vegetation. Sedimentation may therefore be an important feature in the overall ecological processes at the AL and ALR sites. It is therefore recommended that sediment plates be considered for deployment in 2017 as an alternative replacement for ice destroyed sediment pins to evaluate accretion and erosion processes.

Vegetation

The 2016 survey data indicated the AL vegetation community to be highly uniform and dominated by *Phalaris arundicancea*. ECA noted however numerous small patches (~5 to 100 m^2) of other wetland species within the larger *P. arundicancea* stands, which did not intersect within the monitoring transects and thus were not documented. In many cases, these patches occurred in shallow (<0.15 m) topographical depressions. This represents a limitation of transect and quadrat method to accurately document the spatial variability of the vegetation community where a single species has very high dominance. While repetitive annual sampling in a setting such as this may be of limited value, repeating the transect surveys in Year 5 (2020), as planned, will serve to characterize any medium-term changes in the distribution of *P. arundicancea*.

An alternate approach may be to examine a new site in late winter / early spring (before vegetation growth) for subtle elevation changes and wet depressions. Microtopographic zones within the wetland could be recorded with a GPS, allowing a stratified sampling strategy to be employed based on topography. The layout of sample quadrats within each zone could be either through a representative number of transects established within these elevation-stratified zones or 2) random placement of quadrats across each zone.

Mapping of habitats across the site using repeat high-resolution aerial photography has the potential to quantitatively track large-scale changes and the overall trajectory of the restoration effort. This potential has not, however, been fully realized as the methodologies used in baseline images and requested approach have not been explicit, leaving certain aspects of the process open to interpretation. This lack of detail methodology limits the reproducibility and effectiveness of comparison of a time series of habitat mapping. A supervised classification procedure, with defined habitat classifications and determination of assignment error overall and for each habitat, could provide a more standardized approach between consultants. This in turn would allow for the comparative analysis of change over time at a defined scale that occurs at salt marsh sites such as Antigonish Landing. Therefore, it is recommended that a more fully defined methodology of habitat mapping be developed to facilitate future comparative analysis of change.

Table 20: Pre- and post-restoration monitoring program for Antigonish Landing salt marsh, based on NSTIR generalized salt marsh monitoring program.

Category	Parameter	Sampling Method	Annual Sampling Frequency	Monitoring Year					
				Pre-	Post-restoration				
				Yr 0 - 2010	Yr 1 - 2016	Yr 2 – 2017	Yr 3 – 2018	Yr 4 – 2019	Yr 5 - 2020
Hydrology	Tidal signal	Automated water level recorders (5 min intervals)	Minimum 29 day period during sampling year	Y	Y				X
Soils & Sediments	Marsh surface elevation	Digital Elevation Model (DEM)	Once per required sampling year	Y	Y		X		X
	Sediment accretion	Marker horizons	Annually	Y					
		Sediment pins	Annually (August)		Y				
		Sediment plates	Annually (August)			X	X	X	X
Vegetation	Composition, abundance and height	Transect based 1 m^2 quadrats	Once per sampling year (August)	Y	Y				X
	Habitat map	Aerial photograph DGSP/GIS, low altitude aerial photography	Low-altitude; Once per sampling year (Summer)	Y	Y		X		X
Evaluation of Restoration Progress	Visual assessment of habitat condition, restoration recovery rate, wildlife usage etc.	Structured summer walks and photo-documentation	Once per sampling year (August)		Y	X	X	X	X
Winter Conditions	Visual assessment of ice/snow and habitat conditions	Structured winter walk; photo-documentation	Once per sampling year (Feb/March)		Y	X	X	X	X

Y = Activity completed; X = To be completed

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Appendix 1: Structured Winter Walk

Photo 1: AL transect 1, view to the north, March 2, 2017.

Photo 2: AL transect 2, view to the south, March 2, 2017.

Photo 3: AL transect 3, view to the north, March 2, 2017.

Photo 4: AL transect 4, view to the north, March 2, 2017.

Photo 5: AL transect 5, view to the north, March 2, 2017.

Photo 6: AL transect 6, view to the north, March 2, 2017.

Photo 7: AL transect 7, view to the north, March 2, 2017.

Photo 8: AL West Pond, view to the south, March 2, 2017.

Photo 9: ALR transect 1, view to the east, March 2, 2017.

Photo 10: ALR transect 2, view to the north, March 2, 2017.

Photo 11: ALP, view to the south with South Pond on the right, March 2, 2017.

Photo 12: ALP, view to the west across the North Pond, March 2, 2017. Note sediment deposition on ice surface.