Frost Fish Creek Restoration Assessment Report

Chatham, Massachusetts

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Prepared by the Association to Preserve Cape Cod's Restoration Coordination Center
for the Chatham Conservation Foundation

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Introduction

Frost Fish Creek, named after the presumably once abundant frost fish or tomcod (*Microgadus tomcod*), is a brackish sub embayment of the greater Pleasant Bay estuary, which extends from the south end of Bassing Harbor southward beyond the crossing of state Route 28 for approximately 0.57-miles toward the intersection of Stony Hill and Crowell Roads. From an aerial view, Frost Fish Creek forms an inverted Y-shape with a small branch to the west that narrows into a freshwater stream and the main branch continuing southward where it culminates at a large freshwater wetland, referred to as "the stream" and "the bog" from here onward. See Field Survey Map (Appendix A) for site overview.

Natural hydrologic connectivity between inner Frost Fish Creek and Bassing Harbor is significantly restricted at the crossing of Route 28 and other points further upstream, where water flowing, both into and out of the Creek is partially blocked, or restricted, by a series of earthen berms fitted with culvert pipes and water control structures. The bog at the south end of the creek is maintained as a freshwater system, likely a remnant of historic cranberry farming in the area, by means of an earthen berm fitted with a metal culvert and concrete weir structure with adjustable wooden boards to maintain water surface elevation above the elevation of tidal influence. Despite these restrictions to water flow, the entirety of Frost Fish Creek (not including the bog) is tidally influenced in that both water surface elevation, salinity and temperature fluctuate with tidal cycles, albeit with reduced range when compared with historic unrestricted conditions.

[1] Image from https://northatlanticlcc.org/atlantic-salmon-recovery-project/resources/fact-sheets/atlantic-tomcod-microgadus-tomcod

Severe tidal restrictions such as this commonly result in degradation of various ecosystem components and functions and often cause other undesirable impacts. Due to concerns about the health of this system and with desire to be responsible stewards, the Chatham Conservation Foundation, the predominant landowner and manager of this area, contracted the Association to Preserve Cape Cod's (APCC) Restoration Coordination Center to conduct an assessment of the system and define alternatives for ecological improvements. This includes the potential for and feasibility of ecological restoration. The following report describes tasks completed by APCC, discusses findings, offers considerations and recommended next steps to understand a range of ecological restoration alternatives.

It is important to note that there have been multiple previous studies and associated reports (e.g. Analysis of the Potential Ecological Impacts of Petroleum Hydrocarbons from Acme Laundry Company 1989 Report, 2005 Bacteria TMDL Reports for Muddy Creek and Frost Fish Creek, MEP 2006 Pleasant Bay System Final Report, and the Pleasant Bay System 2007 Total Nitrogen TMDL Report), produced regarding the tidal restriction and water quality of Frost Fish Creek but it is the intention that this assessment and associated report will provide both a necessary update to and expansion of the existing data and will address different topics that are considered to be of value at this early stage in assessing restoration potential that other studies had not previously addressed. The objectives of this assessment and report are to provide information necessary to consider tidal or other forms of ecological restoration and to aid in development of specific goals and objectives. This information will also help support funding sources for further assessment and planning of a potential restoration.

<u>Assessment Tasks and Findings</u>

Task 1. Time-Series Monitoring of Tidal Hydrology and Physical Parameters

Solinst Levelogger LTC data loggers were deployed at six locations throughout Frost Fish Creek (FFC), to collect data on water level, temperature and conductivity every 10-minutes from September 28, 2018 to November 1, 2018, a full lunar-driven tidal cycle. See Field Survey Map in Appendix A for locations of data logger deployment. The resulting data was downloaded from the loggers using Solinst Levelogger 4.4.0 software and adjusted for changes in barometric pressure during the deployment period using data from a barometric pressure data logger that was deployed to a tree adjacent to FFC for the same period. Water pressure data, initially recorded in pounds per square inch (PSI) and was then converted to water level in feet and was finally calibrated to the North American Vertical Datum of 1988 (NAVD88) using measurements taken in the field with an RTK GPS device with survey-grade vertical accuracy (+/- 1cm). The adjusted and calibrated data was then exported into an Excel spreadsheet and results were graphed (Appendix E).

It is important to note that previous water surface elevation data for FFC reported in the 2003 Massachusetts Estuaries Project (MEP) report[2] used the older National Geodetic Vertical Datum of 1929

[2] Massachusetts Estuaries Project. *Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for Stage Harbor, Sulphur Springs, Taylors Pond, Bassing Harbor, and Muddy Creek, Chatham, Massachusetts.* Massachusetts Department of Environmental Protection and the University of Massachusetts

(NGVD29) which differs significantly from the 1988 datum in this area of the country.[3] Heights in NAV88 are 0.886-feet lower than that of the NGVD29. Thus, to convert from the NGVD29 water surface elevations in the 2003 MEP report to compare with the 2018 APCC report, 0.886-feet should be subtracted from the 2003 MEP report elevations. This conversion allows for more direct comparison of the two data sets.

The resulting graph of water surface elevation (WSE) across all six locations confirms expected tidal restrictions between logger locations (Appendix E). The following table (Table 1) summarizes differences in average, maximum, minimum, and range of water surface elevation between monitoring locations in vertical feet relative to the NAVD 1988 vertical datum. Note that the total range as reported here differs significantly from the average daily range within each tidal cycle. For example, the average daily range in water surface elevation for logger FFC1 is approximately 4-ft, ranging in elevation from around 3ft to 1ft as opposed to the 6.81ft total range of the entire month-long data set, which accounts for the difference between the most extreme high and low tide events. To ascertain approximate average tidal range, or prism as it is often referred, refer to the WSE graph in Appendix E.

As expected, the most significant restriction was identified at the crossing of Route 28 where average tidal range for the full deployment period was reduced by 3.58-ft when comparing data from logger FFC1 with that of FFC2. At the Route 28 crossing, water ebbs and floods with the tides through concrete culverts. According to the 2006 Massachusetts Estuaries Project (MEP) report, there were three 1.5-ft diameter culverts beneath Route 28,[4] although during our recent survey we only located two functional culverts. The third may be collapsed or clogged and does not appear to be conveying water in any significant amount, thus it is likely that the extent of the tidal restriction has increased since the last hydrologic assessment as documented in the 2003 MEP report.

A secondary tidal restriction was identified at an earthen berm approximately 200-ft upstream from Route 28 where tidal range is further reduced by an additional 1.32-ft based on comparison of average tidal range between loggers FFC2 and FFC3 during our survey period. This second restriction occurs just upstream of the area referred to as “the pond” for this report where water flows swiftly through an earthen berm via a single 30-inch concrete culvert pipe. During our survey we observed evidence that high water may occasionally breach the top of this berm (see photo titled “Pond berm eroded channel”) and found the culvert to be in poor condition as water was observed gurgling out of the top of the culvert pipe and around the concrete weir structure and headwall. It’s also worthy to note that the powerful flow rate through this culvert is a significant hazard to both humans and animals. There is no protective fencing and an animal, child, or adult human could easily be drawn into the culvert if venturing too close during peak tidal flow.

Dartmouth School of Marine Science and Technology. December 2003. Section V. Hydrodynamic Modeling. Page 94. Retrieved from https://www.chatham-ma.gov/sites/chathamma/files/uploads/v_hydrodynamic_modeling.pdf

[3] National Geodetic Survey. *VERTCON – North American Vertical Datum Conversion*. Last modified May 16, 2017. Retrieved from https://www.ngs.noaa.gov/TOOLS/Vertcon/vertcon.html

[4] Massachusetts Estuaries Project. *Linked Watershed-Embayment Model to Determine Critical Nitrogen Thresholds for the Pleasant Bay System, Orleans, Chatham, Brewster and Harwich, Massachusetts*. MA Department of Environmental Protection and the UMASS Dartmouth School of Marine Science and Technology. May 2006. Page 113. Retrieved from https://www.mass.gov/files/documents/2018/08/01/mep-pleasant-lc.pdf

A third hydrologic restriction exists approximately 2,300-ft further upstream where tidal influence is stopped and water surface elevation is held artificially high in the bog area by another earthen berm fitted with a corrugated metal culvert and concrete weir structure. Water surface elevation in the bog can be controlled by adding or removing wooden weir boards. The water control structure at this site appears to be in functional condition although the metal culvert pipe is rusted and may not be structurally sound throughout its length beneath the berm. Due to complete separation from any tidal influence logger FFC6 located in the bog just upstream of the third restriction is not included in the following discussion of results unless specifically referred to. See Field Survey Map for locations of tidal restrictions indicated by red bars (Appendix A).

Water Surface Elevation Data Summary						
Logger ID	FFC1	FFC2	FFC3	FFC4	FFC5	FFC6
Average	0.74	1.04	1.15	1.19	1.16	2.99
Maximum	5.19	2.74	2.45	2.47	2.42	3.39
Minimum	-1.63	-0.49	0.54	0.59	0.68	2.89
Range	6.81	3.23	1.91	1.88	1.74	0.50

Table 1. Summary of water surface elevation data in feet above sea level using the NAVD 1988 vertical datum as recorded during APCC monitoring from September 28, 2018 to November 1, 2018.

Logger FFC1 was located north of Route 28 in outer Frost Fish Creek and represents unrestricted tidal hydrology in this area of Pleasant Bay. The data collected at logger FFC1 can be used to approximate tidal range inside Frost Fish Creek if tidal restrictions (culverts and earthen berms) were completely removed. It is important to note though, that even without man-made tidal restrictions reduction of tidal effects would occur upstream in a restored scenario due to natural restrictions to flow as channel width narrows and benthic elevation increases as the estuary extends inland. Thus, it can be assumed, for planning purposes, that maximum high tides and tidal range as documented at logger FFC1 even in a restored or unrestricted scenario would be greater than at locations upstream within inner Frost Fish Creek.

As expected, maximum water surface elevation (WSE) was significantly higher at the unrestricted logger FFC1 than at any other logger. Max WSE at logger FFC1 was 5.19-ft as compared with the next highest at logger FFC2 of 2.74-ft. When compared with topographic elevation contours on the Elevation Survey Map (Appendix B) this highest WSE would have flooded all salt marsh areas within inner Frost Fish Creek and would likely have extended onto some privately-owned properties if the two primary manmade tidal restrictions were completely removed. Although, as mentioned above, due to natural tidal restriction of land forms and attenuation of flooding by marsh areas, it is unlikely that WSE would reach this maximum elevation throughout inner Frost Fish Creek. A complete hydraulic and hydrologic study (H&H) would be the recommended next step to thoroughly model and assess effects of different tidal restoration scenarios and to best understand potential negative impacts on private landowners, natural habitat areas, and infrastructure.

Looking to the average and minimum WSEs across the 5 tidally influenced loggers it is apparent that the tidal restrictions serve to artificially raise WSE inside Frost Fish Creek. Average WSE from logger FFC1 to logger FFC2 increases by 0.30-ft (3.6-inches) and from logger FFC1 to logger FFC5 by 0.42-ft (5.0-inches).

Minimum WSE was significantly lower at logger FFC1 than at any other logger in this study, a difference of greater than 1-ft from the next closest minimum elevation at FFC2, which indicates that the tidal restrictions are currently limiting the ability of inner Frost Fish Creek to fully drain at low tides. If the tidal restriction at Route 28 (between logger FFC1 and logger FFC2) were removed or reduced it is a safe assumption that average and minimum WSEs inside Frost Fish Creek would be reduced. This effect was also concluded in the 2003 MEP hydrology report. This expected result of tidal restoration may offer a significant benefit to adjacent landowners in terms of mitigation of flood waters that currently back-up at the flow restrictions within inner FFC. This effect of water piling-up inside of FFC is evident on the WSE graph (Appendix E), where both a daily lag in time of ebbing tidal elevation and two multi-day periods of above average WSEs around October 13th and 28th are evident in the data for the study period.

Since no tidal signal was documented, nor any significant sources of salinity, at logger FFC6 it was assumed that variation in WSE range (0.5-ft) was due to significant rainfall events and/or debris accumulation at the weir structure.

Water Temperature Data Summary						
Logger ID	FFC1	FFC2	FFC3	FFC4	FFC5	FFC6
Average	58.74	58.93	60.02	62.36	53.81	53.30
Maximum	70.89	72.61	72.76	74.24	68.72	64.76
Minimum	40.30	40.33	45.43	49.10	40.82	41.54
Range	30.58	32.28	27.33	25.14	27.90	23.22

Table 2. Summary of water temperature at each data logger in degrees Fahrenheit as recorded by APCC monitoring from September 28, 2018 to November 1, 2018.

As expected, water temperature at all six loggers varied daily due to tides, solar energy and weather and followed an overarching decreasing trend throughout the survey period as the summer's warmth radiated out into the cooler fall air. Interestingly, water temperature in the bog at FFC6 and immediately downstream of the bog at logger FFC5 was consistently the lowest in the system (Table 2). FFC5 showed spikes in temperature when tidal water warmed the upper reaches of the system but otherwise mirrored temps reported at FFC6 (Appendix E). This finding suggests that there is significant groundwater flow entering the bog area, which has a consistent cool temperature in the mid-50's Fahrenheit in Cape Cod's aquifer. Much of the bog area is surrounded by steep hillsides, which often coincide with areas of steep water table elevation gradient where groundwater enters surface waters at higher rates. In the absence of precipitation and with no other surface water inputs, the water flow exiting the bog at the water control structure by FFC5 and FFC6 may be a good approximation of the rate of groundwater entering the bog.

Salinity Data Summary						
Logger ID	FFC1	FFC2	FFC3	FFC4	FFC5	FFC6
Average	27.71	24.70	23.79	23.89	5.15	0.12
Maximum	32.02	32.86	28.96	28.01	26.98	0.15
Minimum	0.00	4.75	0.00	8.26	0.03	0.01
Range	32.02	28.11	28.96	19.75	26.95	0.15

Table 3. Summary of water salinity at each data logger in parts per thousand (ppt), which is equivalent to grams/liter, as recorded during APCC monitoring from September 28, 2018 to November 1, 2018.

Conductivity, as recorded by the data loggers, was converted to specific conductance using the formula: specific conductance (mS/cm) = conductivity (mS/cm) / (1 + 0.02 (temperature (Celsius) – 25)) and then to salinity using: salinity (ppt) = (conductivity (uS/cm) $^{1.0878}$) x 0.4665.[5] In a tidally influenced estuary, such as Frost Fish Creek, water salinity can range from fresh (nearly zero ppt) to full ocean salinity (35ppt) but is predominantly brackish (ranging from 0.5 to 35ppt).[6]

Salinity data helped to confirm that tidal influence reaches as far upstream as FFC5 where the earthen berm separates Frost Fish Creek from the bog area. Looking at graphs of this data (Appendix E) it is apparent that water at FFC5 is primarily fresh until saline water reaches the area at the peak of the highest high tides, which does not occur during lower high tides. Salinity in the lower reaches of Frost Fish Creek (FFC2) and outside of the restricted area (FFC1) reach to nearly full oceanic salinity levels (35ppt) when incoming waters build toward high tides, while brackish salinity dominates during outgoing and low tides (15 to 30ppt). FFC3 and FFC4 in the middle sections of the Creek tended to remain consistently brackish in the range of 20 to 25ppt due to mixing of freshwater from the bog and salt from outside in the bay. As expected, water in the bog was fresh with only minor traces due to naturally existing mineral composition and potentially some salty stormwater runoff from roadways.

Task 2. Elevation Survey

Assessment of land surface elevation throughout the Frost Fish Creek system was conducted both in the field, using an RTK GPS unit, and in the office, using ArcGIS Desktop software with various GIS data layers. The objective of the survey was to conduct a preliminary assessment of potential impacts of tidal restoration on low lying properties including impacts on existing vegetation communities, private properties, and other infrastructure. The GPS field survey also served to collect accurate measurements of data logger deployment elevations to allow calibration with the NAVD 1988 vertical datum and to document elevations of key components throughout the system including roadways, earthen berms, culverts, water control structures, and the toxic spill area at the site of the previous ACME Laundry business.

APCC subcontracted with Horsley Witten Group working with their surveyor to conduct the elevation field survey. Using an RTK GPS device elevations were collected at 50 points throughout the system with an average vertical accuracy of 0.05-ft (0.6-in). Elevation survey results were provided in multiple formats including: spreadsheet, GIS shapefile and field notes. A spreadsheet of elevation data and associated maps are included in Appendix F. This data will be valuable moving forward to know elevations of key components throughout the system and to aid in future elevation surveys from newly established elevation benchmarks.

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[5] Sciencing. *How to Convert Specific Conductivity to Salinity*. April 24, 2017. Retrieved from https://sciencing.com/convert-specific-conductivity-salinity-5915328.html
[6] NOAA Ocean Service Education. *Estuaries.* July 6, 2017. Retrieved from https://oceanservice.noaa.gov/education/kits/estuaries/estuaries01_whatis.html

Using water surface elevation (WSE) data from the time-series monitoring and accurate land surface elevations from light detection and ranging (LiDAR) GIS data we can approximate extent of inundation during high water levels within inner Frost Fish Creek. Existing WSE within inner Frost Fish Creek rarely exceeded 2-ft, which only occurred at two periods during our monitoring coinciding with significant storm events around Oct 12th and 28th. Existing WSE at logger FFC1 in unrestricted outer Frost Fish Creek rarely exceeded 4-ft, which only occurred during the same two storm events mentioned above. One extreme high tide of 5.19-ft occurred at FFC1 on October 27, 2018 which resulted due to combination of a significant storm event including high wind from the east, heavy rain, and low barometric pressure; proximity of the moon (perigee occurred on Oct 31); and phase of the moon (full on Oct 24). Piling-up of wind driven water against the manmade berm at the crossing of Route 28 also likely influenced this tide. If this berm did not exist, the wind driven water would likely have pushed further upstream into inner Frost Fish Creek, where much of the water and energy would have spread out and been absorbed into surrounding wetlands.

Based on the range of WSEs documented during the time-series monitoring, LiDAR based topographic contour lines were derived at 2-ft and 5-ft above sea level relative to the NAVD88 vertical datum using ArcGIS Desktop software. The inclusion of the 5-ft contour line is intended to approximate this extreme high tide scenario for inner Frost Fish Creek. An Elevation Survey Map (Appendix B) and Salt Marsh Migration Map (Appendix D) were created with these contour lines to allow visual examination to identify potential low-lying property conflicts and marsh migration locations throughout the project area. Working with the project file in ArcGIS, or using the town GIS webmap, the addresses and ownership of low-lying parcels can be obtained.

Based on initial assessment looking at both the 2-ft and 5-ft contour lines relative to existing residential structures, we found that relatively few privately-owned parcels would be affected if high tides were modestly increased within Frost Fish Creek and no above ground structures were identified as likely to be impacted. Two low-lying privately-owned properties that appeared most likely to be impacted by tidal restoration included: 43 Wells Hollow and 597 Orleans Road. This finding would support restoration as a feasible option for this site though as mentioned previously a more thorough hydraulic and hydrologic analysis to model different restoration scenarios will provide more definitive information to determine potential impacts on low-lying properties.

The site of a previous toxic oil spill from the ACME Laundry Company exists just south of Route 28 and east of the Pond area of inner Frost Fish Creek at 497 Orleans Road. Based on MADEP records the spill has been properly contained and remediated and does not present a threat to environmental health or public safety.[7] Despite this, plans to enlarge culverts and alter tidal elevations adjacent to this site may raise concern, so we included the edge of this site in our elevation survey. An earthen berm was constructed along the side of the dirt access road to the Chatham Conservation Foundation's property and trail network to isolate the contaminated area. Referring to our GIS and LiDAR based contour lines the entire spill site is well above the 5-ft elevation (Appendix B) and RTK GPS survey found the top of the spill containment berm to be 9.95-ft (Appendix F, Point ID 4).

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[7] Massachusetts Executive Office of Energy and Environmental Affairs. *Waste Site and Reportable Releases Information.* 2018. Retrieved from https://eeaonline.eea.state.ma.us/portal#!/wastesite/4-0000406

Cutting off or restricting tidal flow to salt marsh areas is known to cause salt marsh peat to decompose, which results in lowering of the salt marsh surface elevation over time. This process has been thoroughly documented at marsh research and restoration sites including the Herring River estuary in Wellfleet, MA.[8] In ideal circumstances, healthy salt marsh areas are able to accrete, or build up elevation by trapping sediment and decomposing plant material, to maintain pace with rising sea level. Using a combination of RTK GPS and automatic level survey equipment we collected multiple elevation points at the surface of salt marsh areas immediately north of Route 28 and just inside of Frost Fish Creek nearby logger FFC3. Average elevation of points collected on the marsh north of Route 28 was 1.73-ft and on the marsh inside of Frost Fish was 1.22-ft. This initial assessment found that the marsh area inside of Frost Fish Creek was 0.51-ft, or about 6-inches, lower than the salt marsh immediately on the other side of the tidal restriction at Route 28 (all vertical elevation measurements are reported in the NAVD 1988 vertical datum) suggesting that the marsh areas inside of the tidally restricted Frost Fish Creek may be degraded and subsiding. Further assessment of this issue is recommended, and this topic should be addressed as restoration options are considered.

During the elevation survey, photos and a qualitative description of the condition of structures was captured. Existing culverts and berms generally appear to be in degraded condition and work to repair and stabilize the roadway at Route 28 is imminent. The asphalt road surface atop the manmade isthmus of earth and riprap is cracked and uneven. Erosion on the northern side of the embankment has resulted in vertical cliffs of sand that threaten to undermine the road and utility infrastructure. One of the original three culvert pipes is likely collapsed and/or buried, while the remaining two convey minimal tidal exchange creating a whirlpool on one end while blasting out aerated water at the other. One of these remaining functional culverts is invisible beneath piles of marine debris, wrack and the eroding embankment. Roadway managers (the town and MADOT) will need to address these issues soon and it would be beneficial to advance assessment and planning for replacement of culverts with ideal upgrades to meet ecological restoration goals for inner Frost Fish Creek before they are hastily replaced in-kind without consideration for the health of the estuary. The center of the Route 28 road surface over the top of the culverts was found to be 9.60-ft (Appendix F, Point ID 6).

Task 3. Bog Assessment

Cranberry farming on Cape Cod was historically widespread and the process of preparing and maintaining bogs for farming resulted in various impacts to the natural environment including altering natural hydrology, introduction of pesticides and fertilizers, and addition of sand overtop of natural wetland soils (peat) to raise bog surface elevation. Reduced economic feasibility of cranberry farming on Cape Cod has resulted in widespread abandonment of bogs, providing opportunity for wetland restoration, which generally includes restoring hydrology, remediating pesticides and nutrients, and removing sand and breaking-up the underlying peat to re-wet surface soils. Based on assessment of aerial maps and site visits, the headwaters of Frost Fish Creek appear to be an abandoned cranberry bog atop of a natural kettle hole wetland. To confirm and to aid in restoration planning, we collected soil core samples to document presence and thickness of sand over the peat surface. Samples were collected at four locations throughout the bog using a soil probe and auger. At each sample site the

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[8] Friends of Herring River. 2016. Retrieved from http://herringriver.org/

probe was pushed down into the soil to the depth of refusal (DOR), the maximum depth it could be driven by hand, which gave an approximate measurement of total depth of peat above denser mineral dominant soils. A soil auger was then used to collect a core sample in sections of increasing depth (core 1, core 2, core 3 – core 3 being the deepest) with the goal of locating and documenting the depth and thickness of the sand layer and describing soil composition. As each core section was brought to the surface, the depth of each soil horizon (change in soil type) was measured and recorded along with a description of composition. See the Field Survey Map (Appendix A) for sample locations. Following is a table showing results of depth measurements and soil core samples (Table 4).

Bog Soil Sample Results				
Sample Site	A	B	C	D
Depth of refusal measured from water surface (in)	54	57	52	56
Water depth over soil (in)	10	9	32	14
Core 1 depth (in)	0-10	0-4	0-20	0-2
Core 1 composition	sand	organic sediment	peat	organic sediment
Core 2 depth (in)	10-20	4-9	20+	2-8
Core 2 composition	peat	Peat	sand	sand
Core 3 depth (in)	NA	9-13+	NA	8-16+
Core 3 composition	NA	peat	NA	peat
Summary	44-in peat depth. 10-in sand atop peat.	48-in peat depth. No sand found.	20-in peat depth. Layer of sand from 20-in depth downward.	32-in peat depth. 6-in layer of sand atop peat.

Table 4. Bog soil sample results in inches.

Analysis of bog core samples found that while there is sand atop peat in areas, it's presence and depth is variable. When restoring fallow cranberry bogs back into natural wetland systems one of the key objectives is to restore moisture to the soil surface, which generally entails a combination of sand removal and tilling to break-up the peat surface and lower elevation to near the water table elevation. Currently this bog is maintained as a flooded system and does not have the usual issue of encroachment of upland vegetation, although, if alteration of existing hydrology is desired it will be necessary to conduct both a hydraulic and hydrologic study and further soil analysis in this area to direct restoration planning and activities. A ground penetrating radar (GPR) survey would provide valuable information about the full depth and extent of peat and sand in this bog, which would provide understanding of the location of the natural wetlands in this area. This work could potentially be done in partnership with the local USDA Natural Resource Conservation Service (NRCS) at low to no cost if they become involved with the project through one of their easement programs.

With existing condition of tidal restriction, water surface elevation at logger FFC5 reached a maximum 2.42-ft, which is only about 6-inches lower than the current average water surface elevation in the bog area (2.99-ft). Based on the LiDAR based elevation contours it is apparent that there are areas in the center of the bog as low as 2-ft and the entirety of the bog is less than 5-ft elevation (Appendices B & D). Depending on restoration goals this upstream bog could be maintained as a freshwater wetland or the berm and weir structure could be removed. If the berm and weir were removed the existing water level would be lowered and perhaps a more natural stream channel could be reconstructed, which would receive cold groundwater from the surrounding hills and saline tidal influence at least in its lower reaches. If tidal restrictions at Route 28 and the Pond berm were also opened (a full tidal restoration of the system), it is likely that even more saline tidal water would enter the bog area more frequently. With continued sea level rise in the forecast for decades to come it is feasible that this bog area could support a salt marsh habitat in the future and tidal restoration at the three manmade restrictions in this system would facilitate that transition.

Task 4. Vegetation Survey

Based on field and aerial imagery-based surveys it was confirmed that the shorelines of Frost Fish Creek are comprised of diverse wetland vegetation communities that transition from salt marsh to freshwater marsh as you move upstream and inland. Using the Cape Cod Commission's Wetlands GIS datalayer,[9] which is based on the MADEP Wetlands layer, the following wetland types were identified in the project area: shrub swamp, shallow marsh or fen, and wooded deciduous swamp. During our field survey, the entirety of the upper bog area was confirmed to be freshwater shrub swamp. This wetland type extends throughout much of the inner Frost Fish Creek area. However, based on our field surveys, some of the areas in the Wetlands datalayer labeled as shrub swamp and shallow marsh or fen were instead found to be salt marsh, which is not surprising since this data layer was created based on aerial imagery with only limited field confirmation. The shrub swamp on the western and northern shores in particular was found to be interspersed with patches of salt marsh. These larger areas of salt marsh were noted, but not mapped during our field survey. We also noted salt marsh cordgrass, *Spartina alterniflora*, along much of the immediate shoreline edge, although not extending inland away from water's edge in most cases. To capture the approximate location and extent of salt marsh, APCC used aerial imagery along with field observations to map the larger areas of salt marsh using ArcGIS Desktop software and were included on the Field Survey Map (Appendix A). These areas of salt marsh were then overlaid on the Wetlands datalayer showing approximate extent of shallow marsh/fen, shrub swamp and wooded swamp in the Vegetation Survey Map (Appendix C).

Contrary to the salt marsh mapping method, patches of invasive *Phragmites australis* (phrag) were mapped in the field using a handheld Trimble GPS device. When feasible, the entire perimeter of phrag patches were mapped in the field although, due to challenging terrain, water depth and dense vegetation, in some cases only the most accessible outer edges were field mapped. Specifically, the

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[9] Cape Cod Commission. *Wetlands*. October 2018. Retrieved from https://gis-cccommission.opendata.arcgis.com/datasets/wetlands

largest phrag polygon in the bog area was field mapped on the northern and western edges with the remainder being completed in the office. Other phrag polygons further downstream along the Creek were field mapped on all edges except for the edges furthest from water's edge, where vegetation was generally dense, prickly, and containing poison ivy. In these cases, enclosed polygons were later completed by digitizing over an aerial photo using ArcGIS Desktop software. The small polygon to the south of FFC4 on the eastern shoreline was field mapped completely. Phrag polygons created during this survey were created using standard APCC field mapping methods and are of sufficient quality for comparison with future field surveys to track changes in expansion, reduction, or movement within the system to inform management planning. Whether or not a tidal restoration project is advanced for Frost Fish Creek, it is recommended that future phrag surveys be conducted, perhaps every few years, for comparison with this baseline data and to inform any desired management actions to control its spread. Total area of phrag within inner FFC documented during our survey was 100,741-square feet (2.31-acres), with the largest patch in the bog area accounting for nearly half of the total at 49,421-square feet (1.13-acres).

Native cattail reeds, genus *Typha*, were noted throughout the system, which is indicative of a healthy native wetland vegetation community. In many marsh areas throughout Cape Cod, native cattails have been outcompeted by invasive phrag and reduction of phrag to allow reestablishment of native species like cattail is often a goal of tidal restoration projects. Unfortunately, it seems to be the case though, based on observation of completed tidal restoration projects (namely Muddy Creek in Chatham), that cattails often succumb to increases in water surface elevation and salinity more readily than phrag, which may be considered an undesirable negative impact of tidal restoration. This potential effect should be considered when assessing pros and cons of tidal restoration in Frost Fish Creek. Improperly planned tidal restoration could result in significant loss of cattail (and other desirable native vegetation and associated habitats) and could lower competition and spur the spread of phragmites to areas not currently colonized. This being said, if properly designed, a tidal restoration in Frost Fish Creek could serve to successfully replace areas of invasive phrag and freshwater wetland with highly diverse and desirable high salt marsh communities, which could expand over time as sea level rises.

Prior to any restoration work it is recommended that more comprehensive vegetation mapping and surveys be conducted to more thoroughly document existing conditions, to allow quantitative tracking of changes over time and, when intervention work is complete, to assess whether restoration goals are met and if adaptive management/additional intervention is needed to achieve goals.

Potential Restoration Objectives

To guide development of an ecological restoration project it is helpful to first identify specific concerns and desired outcomes or objectives to provide a foundation to work from. Following is a list and discussion of concerns and potential restoration objectives specific to Frost Fish Creek.

1. Water Quality

   The waters of Frost Fish Creek are impaired for fecal coliform bacteria and nitrogen, as documented in the Massachusetts Department of Environmental Protection's (DEP) Proposed Year 2016

Integrated List of Waters.[10] Bacterial contamination presents hazards to recreational and commercial users and excess nitrogen can result in habitat degradation stemming from excessive algal growth, low dissolved oxygen and salt marsh die-back. Various factors contribute to these water quality impairments including wastewater and stormwater inputs, pet and wildlife waste, atmospheric deposition, and other sources. While the only way to completely resolve the problem is to control the sources of pollution, the restriction of water flow through the system is a significant factor and perhaps the most feasible to address in the near term. The 2006 MEP report states that "culverts restricting tidal flow under Route 28 have had a negative influence on water quality in Frost Fish Creek."[11] Restoration to reduce or eliminate the Route 28 and other upstream restrictions would help increase tidal flow and flushing thus improving the water quality in the Frost Fish Creek system.

2. Invasive Vegetation

The common reed, *Phragmites australis* (phrag), exists throughout Frost Fish Creek, as discussed above and shown on the Field and Vegetation Survey Maps (Appendices A and C). If tidal elevation and salinity within inner Frost Fish Creek were increased by enlarging culverts beneath Route 28 and the other two tidal restrictions (Field Survey Map, Appendix A) it is likely that some of the areas currently colonized by phrag would die back. It is also likely that other existing vegetation communities that are less tolerant of inundation and salinity (such as *Typha*) would also die back, which may be undesirable. Whether or not tidal restoration is completed it may be desirable to make efforts to remove/control phrag by other means including cutting, blanketing, mechanical removal, or as a last resort, cut and drip herbicide application. APCC is against use of herbicides. But, when deemed essential by other organizations, APCC recommends use of application methods with the least potential for detrimental effects on the surrounding environment and organisms. All other management practices, including doing nothing, should be considered before resorting to chemical treatment for the sake of environmental health and human safety. Further vegetation surveys should be conducted to identify other invasive vegetation so that potential effects on them stemming from restoration actions can be considered.

3. Salt Marsh Degradation and Loss

As mentioned above, our measurements of salt marsh surface elevation suggested that marshes inside of the restricted FFC have subsided, which is a sign of degradation and is likely due to reduced tidal range associated with the restriction. Also, while not specifically studied or documented in this assessment it was noted when reviewing aerial and historic maps that salt marsh may have historically extended further into the waters of inner FFC. While the cause of the reduction in salt

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[10] Massachusetts Department of Environmental Protection. Proposed Massachusetts Year 2016 Integrated List of Waters. June, 2017. Page 113. Retrieved from https://www.mass.gov/files/documents/2017/08/zu/16ilwplist.pdf
[11] Massachusetts Estuaries Project. *Linked Watershed-Embayment Model to Determine Critical Nitrogen Thresholds for the Pleasant Bay System, Orleans, Chatham, Brewster and Harwich, Massachusetts*. MA Department of Environmental Protection and the UMASS Dartmouth School of Marine Science and Technology. May 2006. Page 86. Retrieved from https://www.mass.gov/files/documents/2018/08/01/mep-pleasant-lc.pdf

marsh area is not known (i.e. sea level rise, reduction in tidal prism, increased water elevation internal to the system due to the restriction, or erosion or subsidence of the fringing salt marsh) loss of salt marsh in this and other similar systems is a concern.

While earlier scientific studies raised concern about salt marshes being drowned out with increasing sea level, more recent studies including work currently underway by Kevin Kroeger USGS-Woods Hole Science Center, Stephen Smith of Cape Cod National Seashore and others have shown our marshes are currently keeping up with the rate of sea level rise. This a result of the rapid growth rate and accumulation of biomass of *Spartina alterniflora*, dominant in low marsh habitat, on the marsh surface. However, while low marsh has been able to accrete and increase elevation to be maintained in the face of sea level rise the negative result has been expansion of low marsh into areas previously dominated by the more diverse high marsh which also serves as important habitat for birds and other wildlife. Thus, while from a functional level marshes across the Cape appear to be keeping pace with rising sea level we are seeing overall a loss of high marsh as low marsh expands and high marsh gets squeezed out with nowhere to migrate due to loss and development of the upland. Subsidence of marsh elevation due to tidal restriction further exacerbates this issue as low marsh vegetation communities dominate lower elevation marshes.

Thus, as mentioned above, restoration of Frost Fish Creek by removing barriers to tidal flow and modifying the upstream abandoned cranberry bog could provide opportunity to protect existing salt marsh and allow for migration inland with sea level rise. Likewise, removing downstream restrictions while increasing the overall tidal range including high water levels would also reduce the water surface elevation at low tide. This could reduce the period and extent of flooding and inundation helping to improve the health of existing marsh and promoting expansion of high marsh communities.

4. Fish Passage and Habitat Fragmentation

Based on historic maps, the intermittent stream to the northwestern edge of the Frost Fish Creek system likely connected to Lovers Lake in the past and may have supported an anadromous fish run. However, at present, efforts are underway to restore and improve the herring run to Lovers Lake via Ryder's Cove and Stillwater Pond. This has been determined to currently be the primary anadromous fish connection to Lovers Lake. Thus, while there may be some benefits to river herring and American eel it is assumed that restoration of this stream for connection to Lovers Lake is not a priority and should not be considered a primary objective for restoration of Frost Fish Creek. That being said, the historic presence of tomcod at this creek would suggest potential benefits to this fish species with restoration. An initial recommended step would be a fish and/or nekton survey to determine if any residual tomcod population remains or whether restoration would require restocking of the fish. Many other estuarine organisms would likely benefit from improved habitat connectivity including everything from zooplankton to stripers and shorebirds.

5. Flood Mitigation

At points of significant restriction to water flow like those in Frost Fish Creek there is potential for both positive and negative effects during extreme weather events. The most common extreme weather experienced on Cape Cod are hurricanes and nor'easters, which are generally comprised of high winds, heavy rainfall, and excessively high tides due to low barometric pressure and wind driven water over multiple days. During very heavy rain events water level inside of inner FFC would rise and the restriction of flow would slow the release of floodwaters, potentially threatening buildings and infrastructure on the upstream side of the restrictions. During extreme high tide events, sea water from the Pleasant Bay side of Route 28 could feasibly overtop Route 28 and flood inner FFC. The restriction to water flow back out of inner FFC could, in this case, result in significantly higher water surface elevations and increased duration of flooding, both of which tend to produce greater damage and expense to human infrastructure. In other cases, the restrictions may provide protection to upstream properties as incoming tidal flood water is blocked. Various scenarios should be further assessed in combination with a hydraulic and hydrologic study to weigh pros and cons of tidal restoration at this site. Historical research on past flooding and storm events at this site would also be very informative to the decision-making process.

6. Recreational and Educational Opportunities

Inner Frost Fish Creek is a beautiful and interesting place to explore both on surrounding footpaths and by kayak or canoe but improvements could certainly benefit recreational and educational interests if ecological restoration is well planned and executed. Recreational access, opportunities and enjoyment of the area could be significantly improved. Improved water quality and habitat would attract more wildlife, both aquatic and terrestrial for the enjoyment of visitors and for enhanced educational experiences for naturalist guides and students of the nearby public school. Diversity of fish, shellfish and crab species could increase to enhance recreational and commercial take. Restoration of natural hydrology could improve downstream sediment transport and deepen channels for navigation in small boats. Water quality could be improved to support more diverse aquatic organisms and create safe conditions for swimming and playing by the shore. Footpaths could be extended and improved, and access could be optimized. If a large enough culvert or bridge were installed beneath Route 28 recreational connectivity could be restored to allow small boats to pass beneath. By restoring health to this valuable ecosystem the experience of visitors could be enhanced in numerous ways and this should be a core goal in any ecological restoration project.

Summary of Assessment and Feasibility of Restoration

Human induced degradation of this system including impaired water quality, loss of salt marsh, reduced salinity, limited habitat connectivity and fish passage, presence of invasive common reed, and reduced recreational access and opportunities could potentially be improved by restoring tidal flow to this system. The goal of this assessment and report was to update and expand upon existing data to determine the feasibility of restoration of Frost Fish Creek and inform future planning and funding proposals. When planning for a tidal restoration issues to consider include: extent of restriction of tidal flow, condition of culverts and water control structures, condition of roadways and recency of road work at existing restrictions, potential impact on low lying properties, condition of vegetation, extent and impact of invasive species, water quality, potential benefit to fish and other wildlife, recreational opportunities, and potential negative impacts. Following is a summary of findings relating to these issues which broadly support the conclusion that restoration at this site is feasible with no significant barriers that would make completion impracticable or improbable.

The time series monitoring of tidal hydrology indicate overall restriction by the culverts and upstream water control structures resulting not only in reduced tidal flow and flushing contributing to decline in salinity and poor water quality, but also elevated water levels at low tide and increased residence time of water after storm events increasing flood risk upstream of Route 28. The condition of both the culverts and roadway at Route 28 are degraded. Thus, the opportunity presents itself for replacement of the failing culverts and repaving of the road in tandem with a tidal restoration. While further modeling is needed, our initial elevation survey indicates minimal to no expected impact on structures (homes) on low-lying properties. One concern when starting this project was proximity to the existing Acme Laundry spill containment and potential for tidal restoration to impact the site. However, the elevation survey along with tidal hydrology demonstrate the berm and containment area are located beyond the extent of potential flooding. Thus, this initial assessment would suggest there would be minimal to no impact of a full or partial tidal restoration on structures on neighboring properties or contamination from this contained spill.

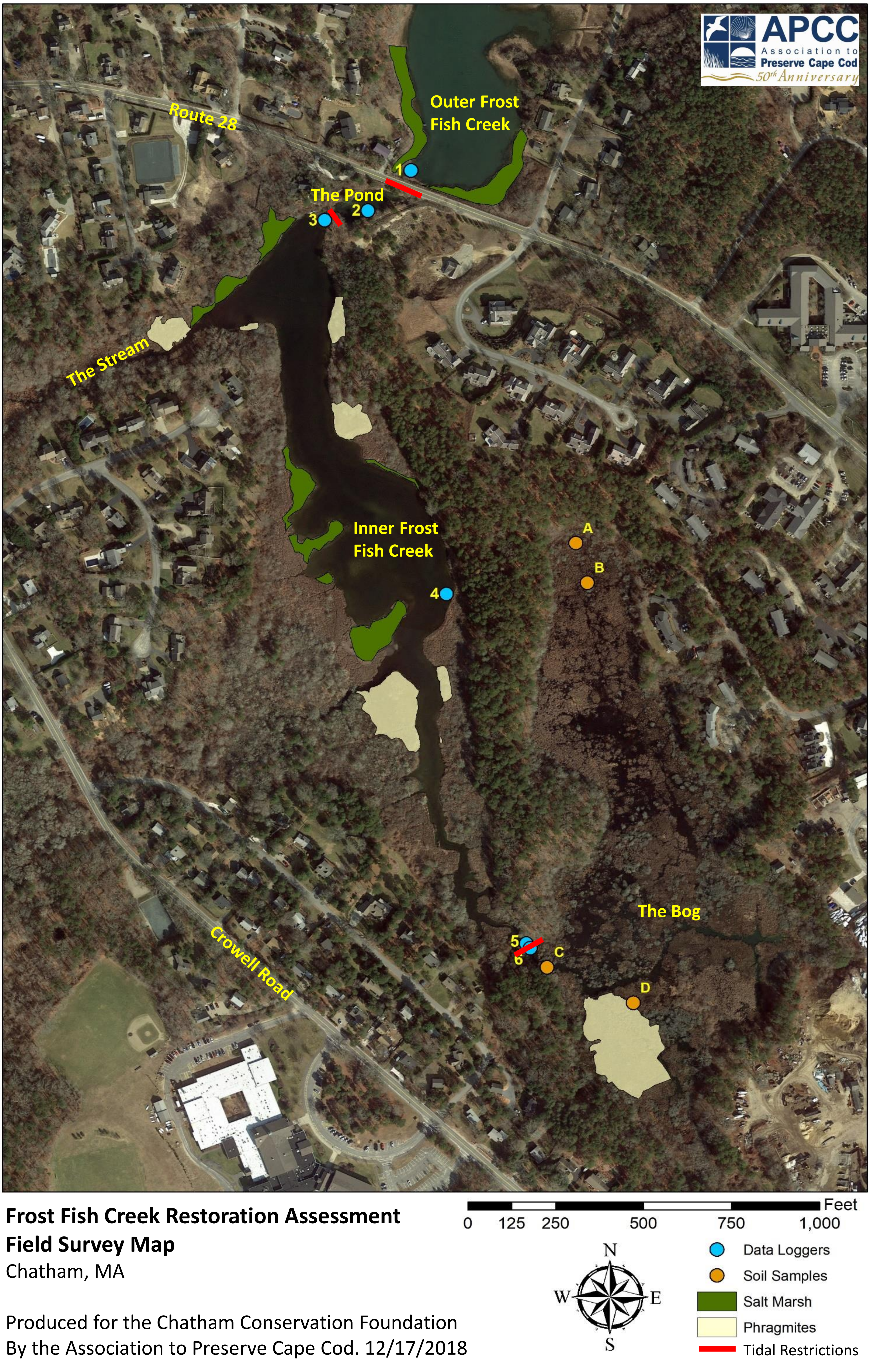
The vegetation survey indicated some loss and degradation of salt marsh, presence of invasive *Phragmites*, and shallowing of the creek. Restoration of tidal flow would increase tidal prism and salinity supporting salt marsh health and potentially expansion/migration in the bog area while reducing the presence and extent of *Phragmites*, a salt-intolerant species. Increased flushing and tidal exchange would likely also improve sediment movement reducing the problem of creek shallowing due to impoundment of sediment behind the restrictions. However, reduction in *Phragmites* and improvement to salt marsh should be weighed against expected loss of other salt intolerant habitats or species like *Typha* when setting goals and objectives for preservation or restoration of Frost Fish Creek. While fish and wildlife were not surveyed, restoration of this site could also provide opportunity for restoration of species like the tomcod and improved water quality and habitat would also provide improved recreational opportunities for the community.

<u>Summary of Recommended Next Steps</u>

1. Review this report and associated data alongside earlier reports (MEP et. al) comparing findings to confirm and more specifically document any changes from earlier data as this could be useful to show increasing degradation or impairment of the system thus further supporting arguments for restoration.
2. Develop a brief (1-4 page) project plan including the goals, objectives and proposed approach to achieving the desired ecological improvements.
3. Use this draft project plan and existing assessments and reports for development of funding proposals for next phases of project planning and development.
4. Complete hydraulic and hydrologic modeling (H&H) to determine options for tidal restoration, culvert sizing/design and expected extent of flooding under different scenarios.

5. Complete a ground penetrating radar (GPR) survey of the entire bog area to better understand extent and depth of sand and peat.
6. Survey for tom cod (*Microgadus tomcod*) to determine if present or absent and help inform whether restoration of this fish might be part of the restoration objectives you seek to achieve.
7. Expanded vegetation mapping to more accurately measure the extent of salt marsh and other vegetation communities.
8. Establish long-term vegetation monitoring transects to get baseline data of species presence and abundance to track changes over time and pre- to post-restoration.
9. Explore various alternatives to meet restoration objectives:
    a. Do nothing
    b. Full tidal restoration
    c. Partial tidal restoration
    d. Pollution source controls
    e. Vegetation management
    f. Sediment management
    g. Install tide gate to turn system completely freshwater
    h. Others…

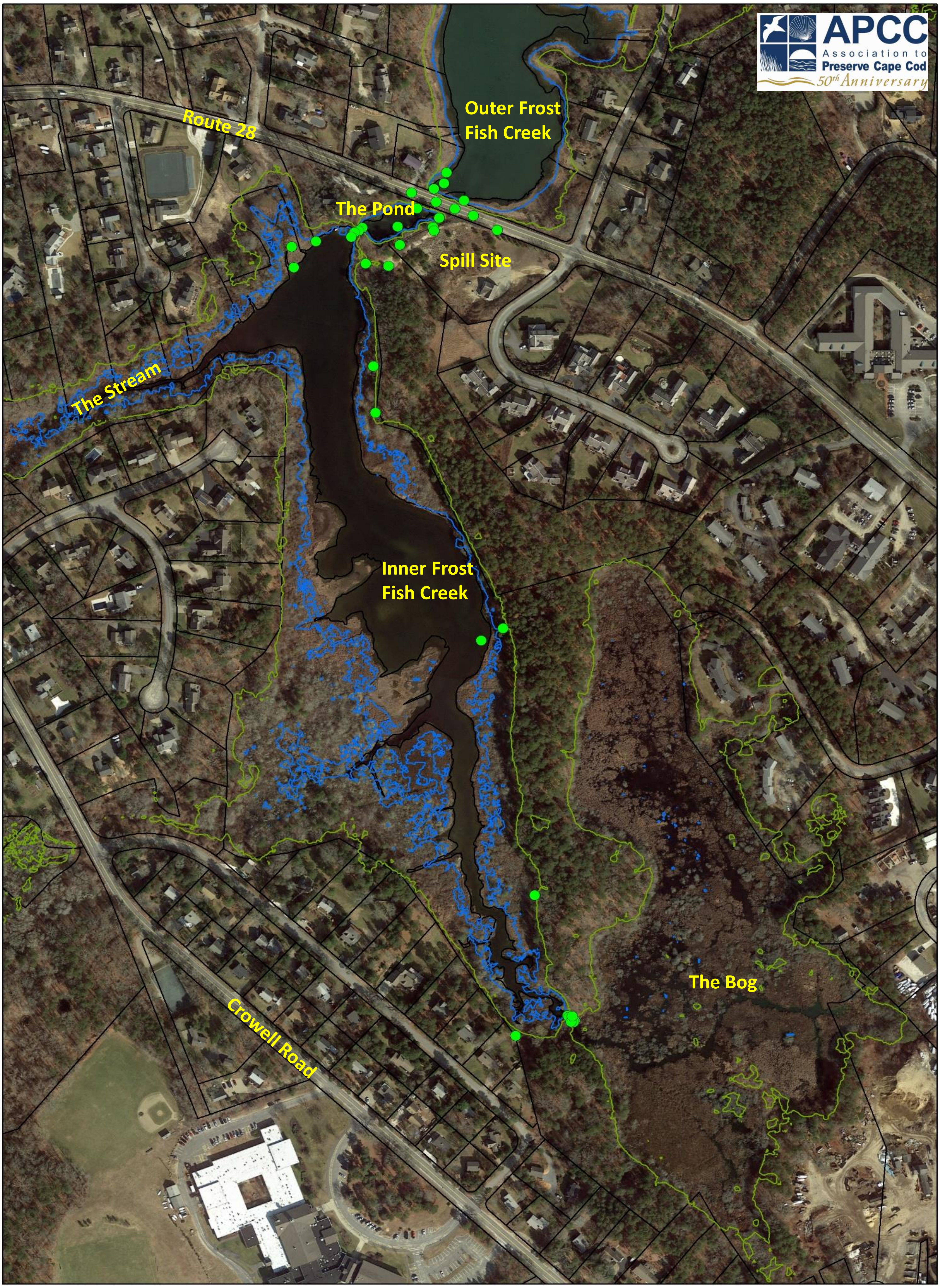
Appendix A. Field Survey Map



Frost Fish Creek Restoration Assessment
Field Survey Map
Chatham, MA

Produced for the Chatham Conservation Foundation
By the Association to Preserve Cape Cod. 12/17/2018

Appendix B. Elevation Survey Map



Frost Fish Creek Restoration Assessment
Elevation Survey Map
Chatham, MA

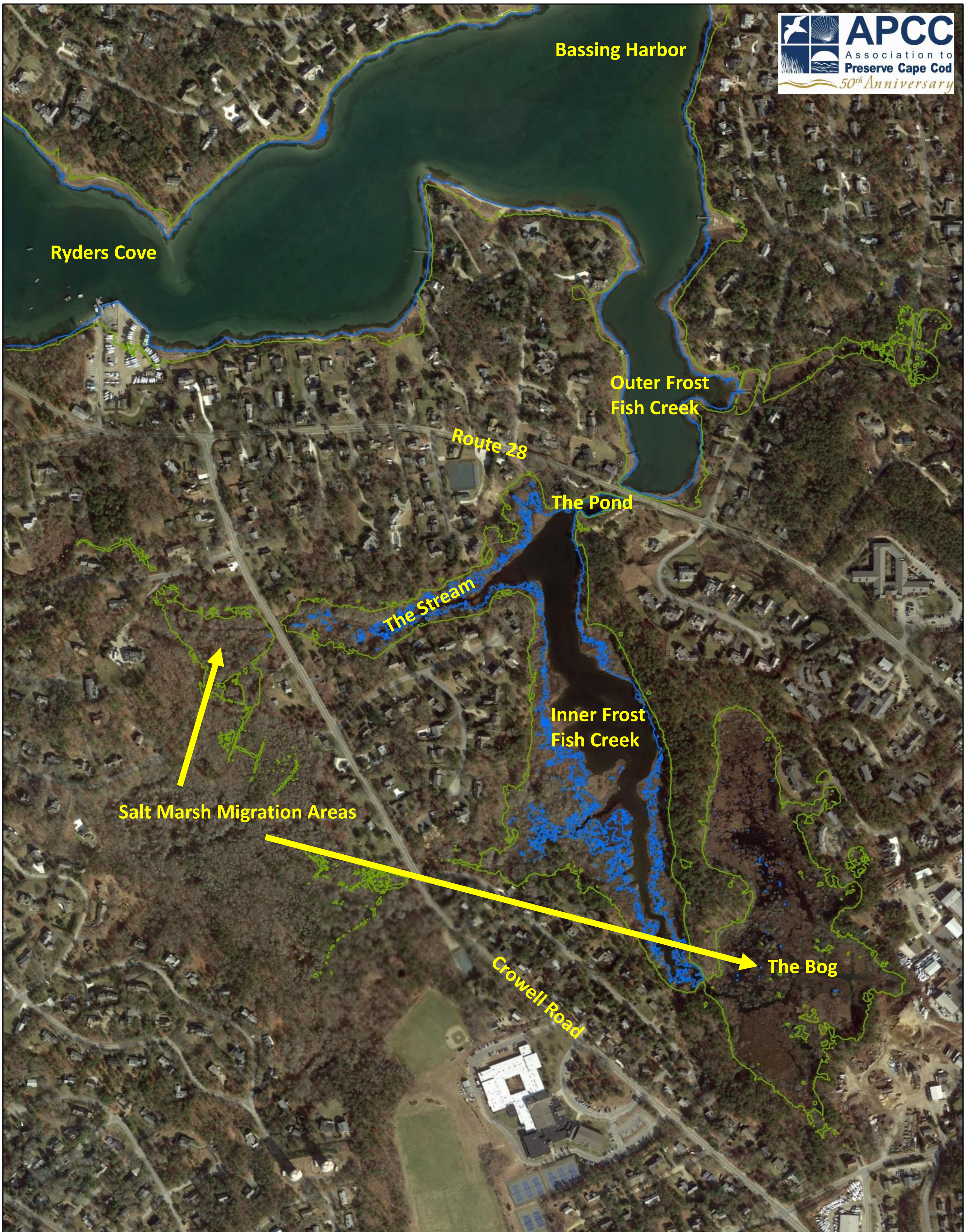
Produced for the Chatham Conservation Foundation
By the Association to Preserve Cape Cod. 12/17/2018

Appendix C. Vegetation Survey Map

Frost Fish Creek Restoration Assessment
Vegetation Survey Map
Chatham, MA

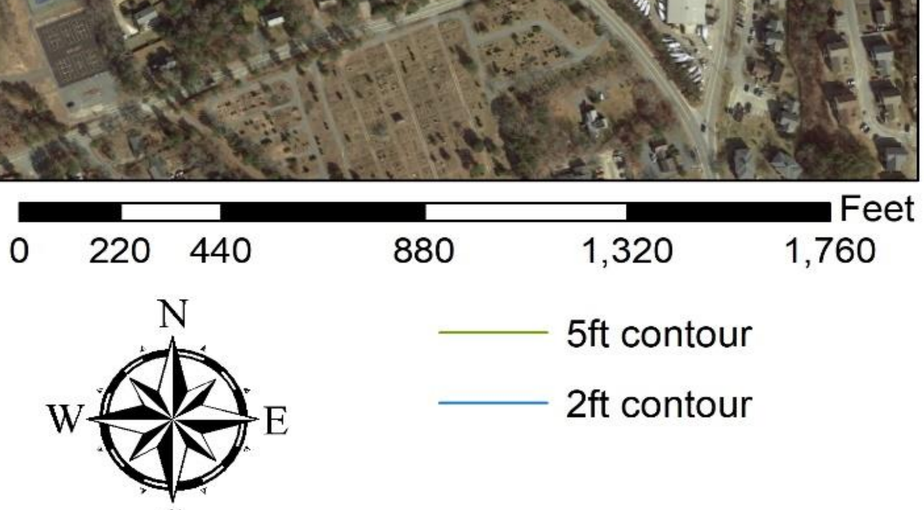
Produced for the Chatham Conservation Foundation
By the Association to Preserve Cape Cod. 12/17/2018

Appendix D. Salt Marsh Migration Map



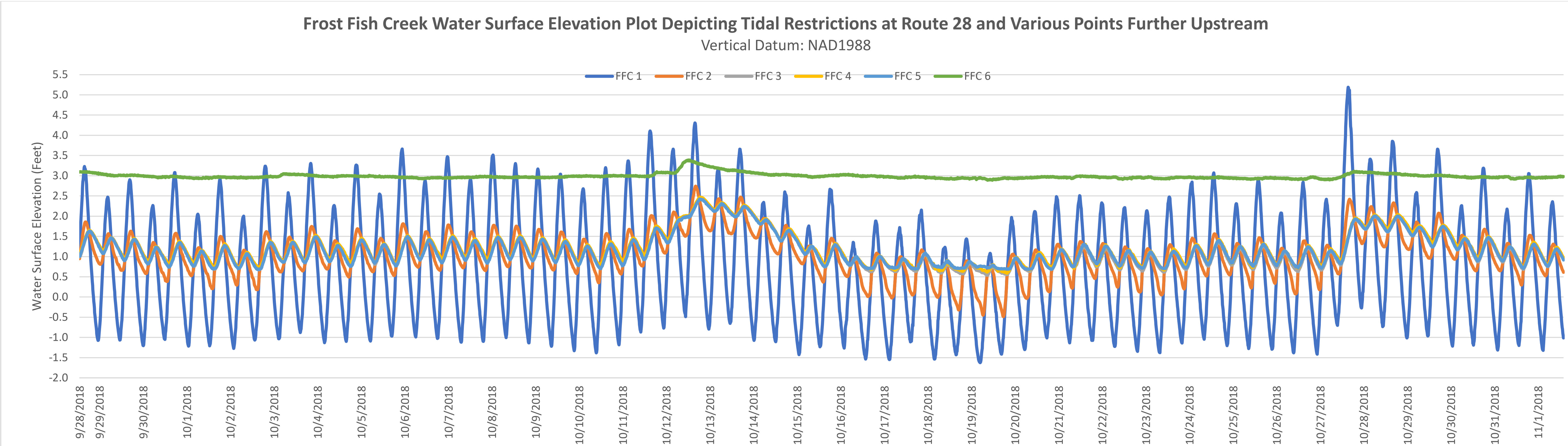
Frost Fish Creek Restoration Assessment
Salt Marsh Migration Map
Chatham, MA

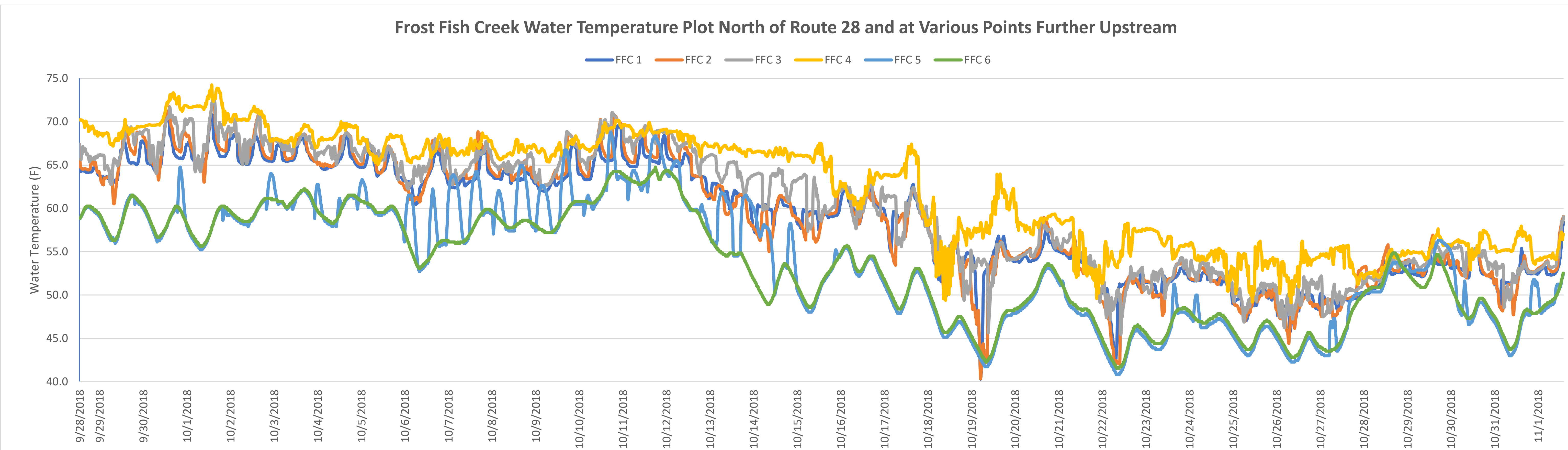
Produced for the Chatham Conservation Foundation
By the Association to Preserve Cape Cod. 12/17/2018

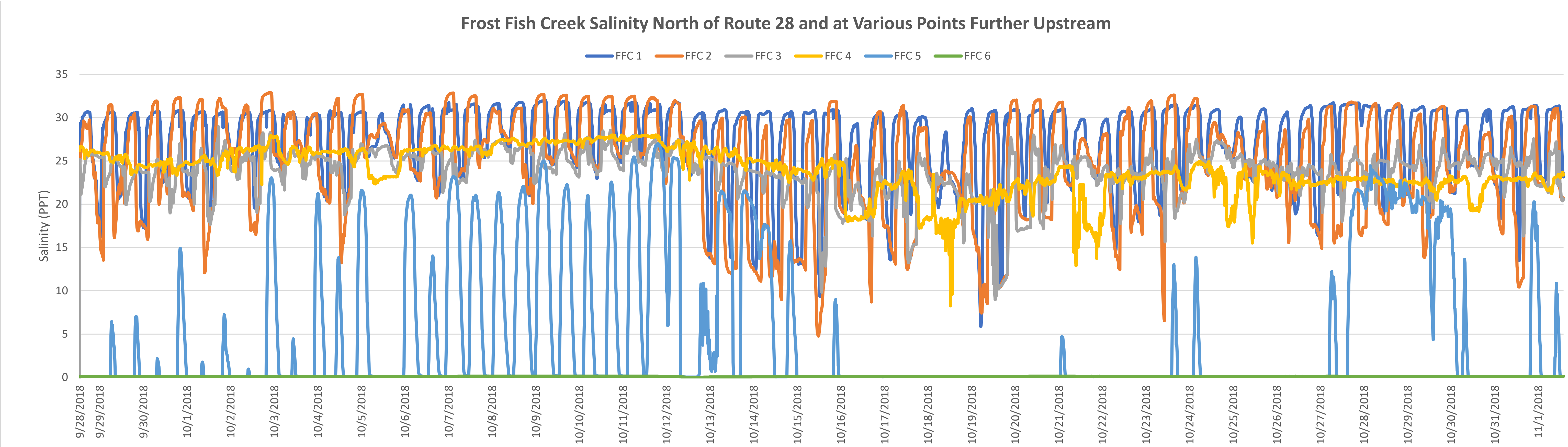


Appendix E. Time Series Monitoring Results

Results of time-series monitoring of water level, temperature, and salinity at six locations throughout Frost Fish Creek, Chatham, MA. Note: See project overview map for location of data loggers (Appendix A).






Frost Fish Creek Salinity North of Route 28 and at Various Points Further Upstream
FFC 1
FFC 2
FFC 3
FFC 4
FFC 5
FFC 6
Salinity (PPT)
35
30
25
20
15
10
5
0
9/28/2018
9/29/2018
9/30/2018
10/1/2018
10/2/2018
10/3/2018
10/4/2018
10/5/2018
10/6/2018
10/7/2018
10/8/2018
10/9/2018
10/10/2018
10/11/2018
10/12/2018
10/13/2018
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10/15/2018
10/16/2018
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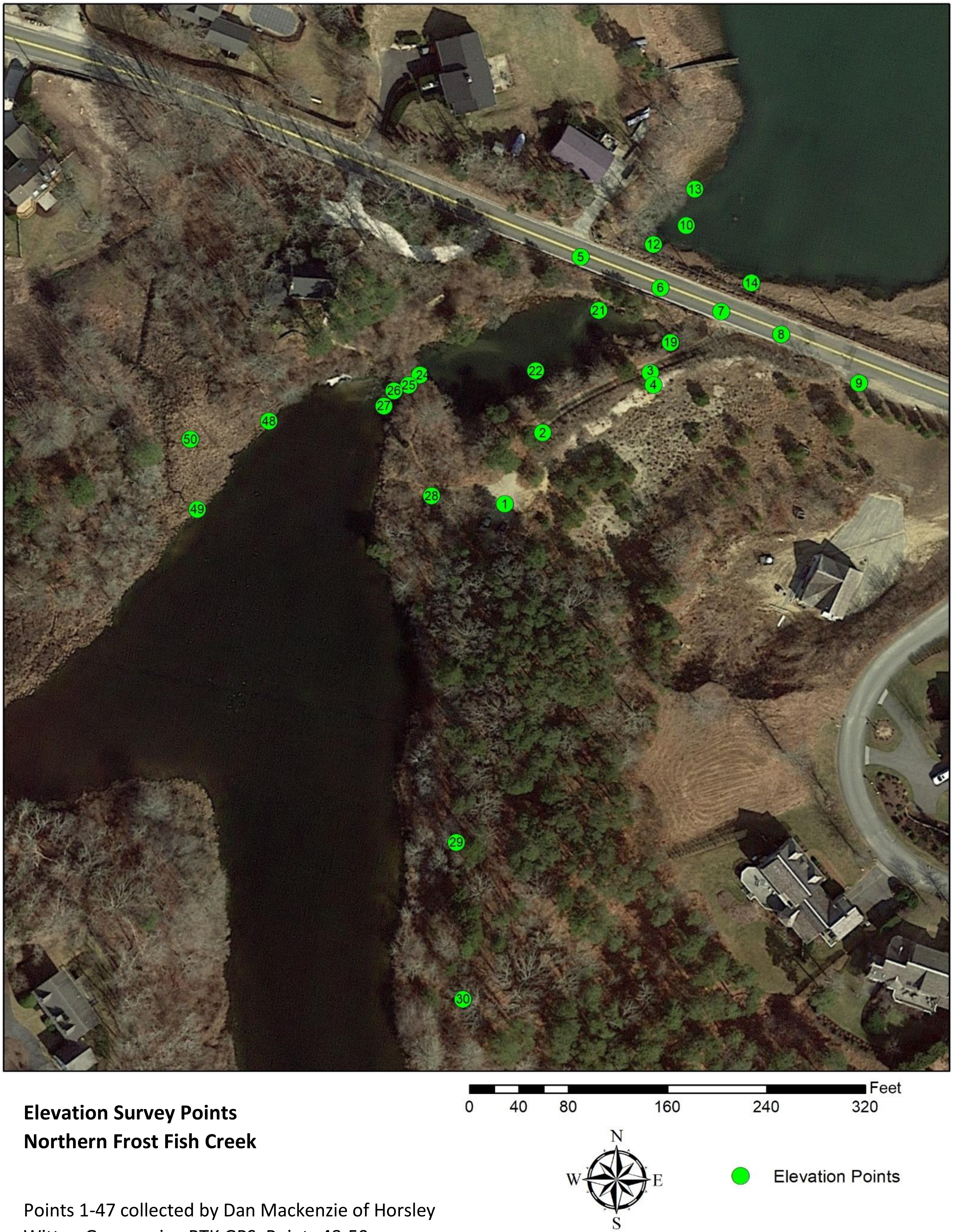
10/20/2018
10/21/2018
10/22/2018
10/23/2018
10/24/2018
10/25/2018
10/26/2018
10/27/2018
10/28/2018
10/29/2018
10/30/2018
10/31/2018
11/1/2018

Appendix F. Elevation Survey Data and Maps

Point Id	Northing	Easting	Orth. height	Code	Quality pos.	Quality hgt.
1	2720101.64	1073929.76	5.46	GS	0.02	0.03
2	2720159.35	1073960.21	6.66	CL RD	0.02	0.04
3	2720207.77	1074047.26	8.22	CL RD	0.03	0.05
4	2720197.88	1074049.68	9.95	CL TOP BERM	0.02	0.04
5	2720301.27	1073990.88	12.09	CL RD	0.02	0.04
6	2720276.4	1074055.5	9.6	CL RD	0.02	0.03
7	2720257.39	1074104.65	8.62	CL RD	0.02	0.03
8	2720238.78	1074153.05	8.04	CL RD	0.02	0.03
9	2720199.26	1074216.03	7.67	MAG BM	0.02	0.03
10	2720326.89	1074076.32	-0.05	LOGGER 1	0.02	0.05
11	2720311.61	1074050.12	-2.51	INV 12 RC	0.03	0.06
12	2720311.47	1074049.96	-0.95	TOP RCP	0.03	0.05
13	2720356.02	1074083.2	1.73	SALTMARSH SURFACE	0.03	0.06
14	2720280.37	1074128.85	-1.7	GSOUTLET	0.02	0.03
17	2720232.26	1074063.74	0.42	TOP 24 RCP	0.03	0.05
19	2720232.31	1074063.65	-1.5	INV 24 RCP	0.02	0.04
20	2720258.13	1074005.55	-2.25	INV 12 RCP	0.03	0.05
21	2720258.24	1074005.57	-0.87	TOP 12 RCP	0.03	0.06
22	2720209.42	1073954.58	0.92	LOGGER 2	0.03	0.05
23	2720206.25	1073861.58	-1.98	INV 30 RCP	0.02	0.05
24	2720205.94	1073861.16	0.7	TOP 30 RCP	0.03	0.05
25	2720197.84	1073852.13	3.12	LOW PT PEAK	0.03	0.06
26	2720193.21	1073840.23	2.26	TOP HEADWALL	0.03	0.04
27	2720180.99	1073832.09	1	LOGGER 3	0.02	0.04
28	2720108.26	1073870.37	5	CL PATH	0.03	0.04
29	2719828.38	1073890.68	4.19	CB DH FND	0.01	0.01
30	2719701.55	1073895.85	5.07	CL PATH	0.04	0.06
32	2719113.95	1074231.85	3.67	BENCH	0.06	0.08
33	2719080.88	1074174.24	1.1	LOGGER 4	0.03	0.04
34	2718386.68	1074314.66	3.51	CL PATH	0.05	0.07
35	2718386.66	1074314.68	3.48	CL PATH SWAMPY	0.04	0.05
36	2718044.54	1074419.8	5.88	HW CORNER	0.03	0.04
37	2718040.81	1074417.16	3.29	LOGGER 6	0.03	0.04
38	2718058.14	1074401.07	2.58	LOGGER 5	0.01	0
40	2718054.02	1074404.2	1.15	TOP 18 CMP	0.02	0.02
41	2718041.87	1074410.45	4.61	GS	0.05	0.07
42	2718056.73	1074413.1	5.04	GS	0.03	0.05
43	2718003.69	1074264.9	8.26	CBDH FND	0.05	0.07
44	2719659.71	1072537.01	8.91	MH RIM	0.03	0.06
45	2719657.37	1072543.95	8.78	CB RIM	0.03	0.06
46	2719657.73	1072528.24	9.29	CL RD	0	0
47	2719679.66	1072550.66	4.15	TOP CTR HEADWALL	0.03	0.07
48	2720168.58	1073739.02	1.23	SALTMARSH SURFACE	0.04+	0.04+
49	2720097.4	1073681.03	1.21	SALTMARSH SURFACE	0.04+	0.04+
50	2720153.92	1073675.45	1.38	SALTMARSH SURFACE	0.04+	0.04+

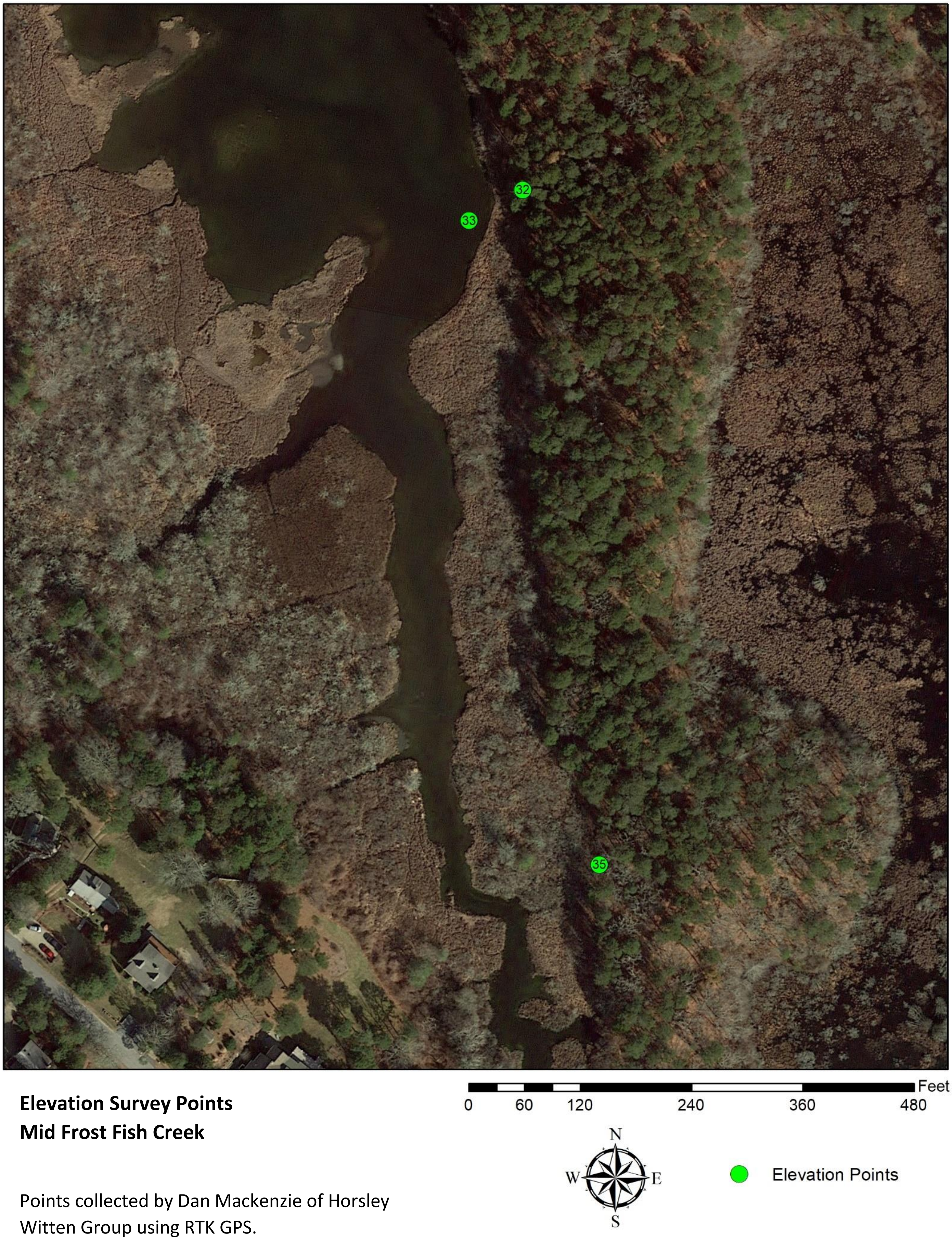


Elevation Survey Points
Northern Frost Fish Creek

Points 1-47 collected by Dan Mackenzie of Horsley Witten Group using RTK GPS. Points 48-50 collected by Bryan Horsley of APCC using auto level in reference to point 26 on southeast corner of concrete headwall structure.

Elevation Survey Points
Stream Crossing of Crowell Road
Western Frost Fish Creek

Points collected by Dan Mackenzie of Horsley Witten Group using RTK GPS.



Elevation Survey Points
Mid Frost Fish Creek

Points collected by Dan Mackenzie of Horsley Witten Group using RTK GPS.

Elevation Survey Points
Southern Frost Fish Creek

Points collected by Dan Mackenzie of Horsley Witten Group using RTK GPS.