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Technical Memorandum

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RE: Town of Nantucket Long Pond/Madaket Harbor 2019 MEP Scenarios

I. Background

In 2015, the Massachusetts Department of Environmental Protection finalized a nitrogen Total Maximum Daily Load (TMDL) for Madaket Harbor/Long Pond estuary system that established nitrogen limits/thresholds to restore water and habitat quality throughout the system.[1] A TMDL is a regulatory limit required under the federal Clean Water Act for all surface waters that are impaired and failing to meet state standards. The Madaket Harbor/Long Pond system (**Figure 1**) was identified as having impaired water quality due to excessive nitrogen through a 2010 Massachusetts Estuaries Project (MEP) report that provided the scientific basis for the Madaket Harbor System habitat assessment and the MassDEP TMDL.[2] Since the release of the MEP report and the TMDL, the County & Town of Nantucket (Town) has been discussing options to reduce watershed nitrogen loads to and nitrogen concentrations within the Madaket Harbor/Long Pond system.

One of the key features of the MEP project was the development of estuary-specific linked watershed/embayment water quality models that were validated with collected water data in each estuary system so that the models could be reliably used to predict the water quality impacts of watershed or in-system changes. For example, in the 2010 MEP report, the MEP Technical Team, in coordination with the Town, evaluated a scenario that completely removed the nitrogen load from the Town landfill on the Madaket Harbor/Long Pond system.[3]

[1] MassDEP. 2015. Final Madaket Harbor and Long Pond Estuarine System Total Maximum Daily Loads For Total Nitrogen (CN-283.0). 41 pp.

[2] Howes B.L., J. S. Ramsey, E.M. Eichner, R.I. Samimy, R. Acker, D.R. Schlezinger (2010). Linked Watershed-Embayment Model to Determine the Critical Nitrogen Loading Threshold for the Madaket Harbor and Long Pond Estuarine System, Nantucket, Massachusetts. SMAST/DEP Massachusetts Estuaries Project, Massachusetts. Department of Environmental Protection. Boston, MA. 169 pp.

[3] See Chapter IX in MEP report

Recently, the Town asked the Coastal Systems Program from the School for Marine Science and Technology at UMass-Dartmouth (CSP/SMAST), the MEP technical lead, and the rest of the MEP Technical Team to evaluate five additional scenarios in the Madaket Harbor/Long Pond system. The results of these five scenarios are listed below and are:

1. Landfill Change (based upon an updated nitrogen load by CDM) scenario,
2. I/A System Use and Landfill Change scenario,
3. Updated Land Use scenario,
4. Enhanced Aquaculture scenario, and
5. Dredging of Hither Creek scenario

II. Scenario Details and Results

Each scenario included changes in watershed nitrogen loads, often evaluating impacts from changing one significant source (*e.g.*, using I/A systems on current septic system wastewater nitrogen loads). Some of the scenarios also included changes within the system to reduce water column nitrogen concentrations by removing nitrogen already in the water column (*i.e.*, enhanced aquaculture) or reducing how long water collects nitrogen by increasing tidal flushing (*i.e.*, Hither Creek dredging). Any reductions in nitrogen would also necessarily reduce sediment deposition and regeneration of nitrogen, which was also incorporated into each scenario. **Table 1** summarizes the whole watershed nitrogen loads by source for each scenario, while **Table 2** summarizes the subwatershed/subembayment nitrogen loads for each scenario. **Table 3** summarizes the modeled total nitrogen concentrations for each of the scenarios and compares the results to the restoration target threshold developed by the MEP (0.450 mg/L TN at monitoring station M11).[4] The following sections discuss the results from each scenario:

Scenario 1: Landfill Change

Scenario 1 was designed to evaluate the impact of reduced nitrogen loads from recent upgrades at the Town landfill on the MEP results. The Town landfill is fully within the Long Pond watershed, so all of its associated groundwater nitrogen load is discharged to Long Pond (see **Figure 1**). The MEP assessment reviewed and used available town landfill monitoring data, and other landfill data to develop the final nitrogen load to Long Pond. It was determined that the landfill had annual nitrogen load of 777 kg/yr and accounted for 24% of the total controllable watershed N load to the Long Pond.[5]

Since 2009, when the MEP analysis was completed, the Town has undertaken several landfill management activities including mining portions to recover recyclable and reusable materials and reclaim previously used space. These activities have also included installation of leachate liners for sections that have been recovered.

The Town contracted CDM Smith in 2018-19 to review current landfill impacts including groundwater monitoring data. After consultation with CSP/SMAST and TMDL Solutions staff, CDM Smith estimated that the current landfill nitrogen load had been reduced to 431 kg/yr (**Table 4**). This updated load was incorporated into the Madaket Harbor/Long Pond MEP linked

[4] See Section VIII.2 of MEP report

[5] See Figure IV-6 in MEP report

models to evaluate the impact of this load reduction on water quality throughout the Madaket Harbor System. This updated load was the only change in the existing conditions watershed nitrogen loads used in the original MEP assessment (see **Table 1**). No adjustments/updates were made to buildout loads or the MEP hydrodynamic/tidal flushing conditions in this scenario.

The reduction in the landfill nitrogen load reduces the Madaket Harbor system watershed load in Scenario 1 by -9% compared to the MEP load (see **Table 2**). The resulting TN concentration at the Hither Creek threshold station was reduced to 0.489 mg/L (-4% compared to MEP). The resulting TN concentration is greater than the 0.450 mg/L threshold concentration (see **Table 3**) and, therefore, Scenario 1 does not attain the Madaket Harbor EPA/MassDEP TMDL nitrogen level.

Scenario 2: I/A Septic Systems and Landfill Change

Scenario 2 was designed to evaluate the combined impact of reduced nitrogen loads from the Town landfill and watershed-wide installation of nitrogen-reducing innovative/alternative (I/A) septic systems. One of the standard nitrogen reduction strategies considered in watersheds to nitrogen enriched estuaries where sewer connections are not available is the implementation of I/A denitrifying septic systems for on-site wastewater treatment. In this scenario, it was assumed that all developed properties in the Madaket Harbor/Long Pond watershed would install I/A septic systems and that all I/A septic system effluent would have a total nitrogen concentration of 19 mg/L.[6] In addition, the 2019 landfill nitrogen load from Scenario 1 was also included; no other changes to the MEP existing conditions watershed nitrogen loads were included in this scenario (see **Table 1**). No adjustments/updates were made to buildout loads or the MEP hydrodynamic/tidal flushing conditions in this scenario.

The combined reduction in the landfill nitrogen load and the use of denitrifying I/A septic systems throughout the watershed in Scenario 2 reduces the Madaket Harbor system watershed load by -22% compared to the MEP load (see **Table 2**). The resulting TN concentration at the Hither Creek threshold station was reduced to 0.468 mg/L (-8% compared to MEP). The resulting TN concentration is greater than the 0.450 mg/L threshold concentration (see **Table 3**) and, therefore, Scenario 2 does not attain the Madaket Harbor nitrogen TMDL.

Scenario 3: Updated Land Use

Scenario 3 was designed to evaluate the change in watershed nitrogen loading since the MEP analysis by reviewing changes in watershed land uses. Scenarios 1 and 2 used MEP "existing conditions" watershed land use and accompanying nitrogen loads with the specified changes to the landfill load and wastewater treatment, respectively. These MEP existing conditions were developed based on 2009 Town parcels and assessor's data, water use for selected properties from 2009 to 2010, and available MassGIS impervious surface estimates (*i.e.*, road and building areas). Watershed nitrogen loads in Scenario 3 were updated to 2018 conditions. The MEP Technical Team received 2018 parcels with accompanying assessor's data and available water use for individual parcels from the Town. This information was combined with updated building areas and road surfaces from MassGIS.

[6] Selection of this concentration was based on Town guidance and the Town Board of Health I/A Tracking Program regulation (local BOH regulation 65.00)

In MEP assessments, wastewater generation is generally estimated from the measured water use of individual parcels as provided by public water suppliers. In the Madaket Harbor/Long Pond watershed, public water supply is only available for a limited number of properties (*i.e.*, within the Fisher's Landing subdivision), while the majority of developed properties utilize on-site private wells for water supply. During the MEP Madaket Harbor/Long Pond assessment, monthly water consumption rates were available for the Fisher's Landing properties, so seasonal impacts of irrigation water use, as opposed to wastewater generation, could be evaluated. This review showed that individual Fisher's Landing properties averaged 229 gpd per property, but the estimated annual average wastewater rate was 89 gpd per property after accounting for irrigation.[7] This rate was reasonably consistent with US Census occupancy information and was used for estimating wastewater load among all the other developed properties within the Madaket Harbor/Long Pond watershed.

For Scenario 3, updated water use from the Fisher's Landing properties was available from February 2016 to April 2019. This data showed that average water use was 188 gpd per property. Review and comparison of precipitation rates during this current period and the MEP period showed that the difference between the average water use could be reasonably explained by greater precipitation during the most recent period. For this reason, the 89 gpd per property used in the MEP analyses still seemed to be a valid estimate for wastewater generation among the properties using private wells and therefore was used in the Scenario 3 watershed nitrogen loading update.

Comparison of the original MEP and 2018 parcels/assessor's data showed that the parcel layout and total number of parcels had changed (see **Figure 1**). The total number of single-family residences (state land use code 101) was generally stable (343 in MEP, 342 in 2018), but the total parcel count had decreased by 45. Most of these changes were due to combining of adjacent small properties. Aside from the removal of these parcel lines, the comparison also found that many parcel layouts were slightly, but significantly, altered. As a result of the updates, watershed-wide wastewater and impervious surface nitrogen loadings increased and fertilizer loads slightly decreased. With the addition of the reduced landfill nitrogen load developed for Scenario 1, the overall watershed load for updated watershed land use decreased by ~1% (see **Table 1**). No adjustments/updates were made to buildout loads or the MEP hydrodynamic/tidal flushing conditions in this scenario.

Scenario 3 presents updated current watershed nitrogen loading conditions by incorporating 2018 land use, water use, and updated landfill nitrogen load. The combined effect reduces the Madaket Harbor system watershed load by -2% compared to the MEP load (see **Table 2**). The resulting modeled TN concentration at the Hither Creek threshold station was reduced to 0.499 mg/L (-2%). Based on this result, water quality conditions in the system should be similar to what they were at the time of the MEP. The modeled TN concentration was greater than the 0.450 mg/L threshold concentration (see **Table 3**) and, therefore, Scenario 3 does not attain the Madaket Harbor nitrogen TMDL.

[7] See Chapter IV in MEP report

Scenario 4: Enhanced Aquaculture

Scenario 4 was designed to evaluate the impact of deploying shellfish in Hither Creek for nitrogen removal when combined with the other nitrogen management changes in Scenarios 1, 2, and 3. A number of communities within the MEP study area are evaluating how the addition of shellfish to impaired estuaries may be a useful component of overall strategies to reduce estuarine nitrogen concentrations and attain TMDL compliance. There are a number of considerations in deploying shellfish including: 1) the number and species of shellfish to be deployed, 2) the specific deployment location and conditions, 3) whether deployment occurs on the surface or bottom, 4) the size/age of shellfish initially deployed and when they are harvested/removed (*e.g.*, single cohort or multiple ages).

CSP/SMAST staff have been actively involved in the assessment of the nitrogen removals by oyster aquaculture and have reviewed these various factors in a number of estuaries, as well as assisting a number of towns in the development of state and local regulatory compliance for nitrogen removal.[8] Town and CSP/SMAST staff discussed how these factors might impact shellfish deployment in Hither Creek and agreed to the following strategy for incorporation into Scenario 4:

a. Use of floating bags to keep bottom areas open for other shellfish and to protect the oysters from any low dissolved oxygen events,
b. An initial (Year 1) deployment of 2.1 million 25 mm seed over a 0.4 acre area,
c. Another similar deployment in Year 2 in order to yield a continuous annual harvest of 2-year-old oysters with approximately 210 kg N removed during each harvest (additional N removal by sediment N retention processes below the floating bags may be approved in the future).

As a result of this strategy, CSP/SMAST staff estimated that the reduction in nitrogen load would be 210 kg/yr and it would be applied within the Hither Creek section of the Madaket Harbor/Long Pond system. Refinement of this option and determination of actual nitrogen removal would require implementation of the deployment with an accompanying monitoring program similar to those previously utilized in the other towns.

Scenario 4 uses the 2018 updated current watershed nitrogen loading conditions developed in Scenario 3 and applies a) watershed-wide use of denitrifying I/A systems and b) enhanced aquaculture in Hither Creek. No adjustments/updates were made to buildout loads or the MEP hydrodynamic/tidal flushing conditions in this scenario. The combined effect reduces the Madaket Harbor system watershed load by -10% compared to the 2018 updated watershed load developed in Scenario 3 (see **Table 2**). The resulting modeled TN concentration at the Hither Creek threshold station was reduced to 0.466 mg/L (-7% compared to Scenario 3 results). Comparison of the results in Scenario 2 (I/As with MEP landuse) and Scenario 4 (I/As with 2018 updated landuse) showed that the modeled TN concentration at the threshold station were essentially the same. The modeled TN concentration in this scenario was greater than the 0.450 mg/L threshold concentration (see **Table 3**) and, therefore, Scenario 4 does not attain the Madaket Harbor nitrogen TMDL.

[8] Howes, B. and E. Eichner. 2018. Town of Orleans Lonnie's Pond Aquaculture and Nitrogen Management Plan. Coastal Systems Program, School of Marine Science and Technology (CSP/SMAST), University of Massachusetts-Dartmouth. New Bedford, MA. 128 pp.

Scenario 5: Dredging of Hither Creek

Scenario 5 was designed to evaluate the impact of dredging Hither Creek on nitrogen concentrations when combined with the nitrogen changes based on the updated watershed nitrogen loading developed in Scenarios 1 and 3. During the development of the MEP, project staff completed bathymetric surveys throughout the system for incorporation into the hydrodynamic model.[9] Following discussion with Town staff including the Harbormaster, ACRE staff adjusted the MEP bathymetry to establish a dredging footprint for the navigational channel to the Hither Creek Boatyard based on a channel bottom width of 30 feet and depth of -8 feet MLLW (**Figure 2**).[10] This generalized footprint is not an engineering final version, which would require additional review to consider design issues, such as slope stability, and permitting issues, such as saltmarsh impacts and dredge disposal. No changes in MEP tidal range, culverts in the rest of the system, or other tidal factors were made in this scenario.

In this scenario, the estimated dredging of Hither Creek was combined with the 2018 updated watershed nitrogen loads developed in Scenario 3, including the updated landfill nitrogen load from Scenario 1. No adjustments/updates were made to buildout loads in this scenario. The resulting modeled TN concentration at the Hither Creek threshold station was reduced to 0.497 mg/L (-0.4% compared to Scenario 3 results). Comparison of the results in Scenario 3 (2018 updated landuse) and Scenario 5 (2018 updated landuse with dredging in Hither Creek) showed that the modeled TN concentration at the threshold station were essentially the same. The modeled TN concentration in this scenario was greater than the 0.450 mg/L threshold concentration (see **Table 3**) and, therefore, Scenario 5 does not attain the Madaket Harbor nitrogen TMDL.

III. Conclusions/Discussion

Though none of the scenarios attained the Madaket Harbor nitrogen TMDL, comparison between the scenario results provided a number of insights for the Town to consider for future development of nitrogen management strategies:

a. Watershed nitrogen loads have not increased since the MEP assessment (based on 2009 land use). Wastewater loads did increase, but this was offset by nitrogen loading reductions at the Town landfill.
b. The scenarios with results closest to the TMDL were those that included reduction of wastewater nitrogen loads. Scenarios 2 and 4, which utilized installation of denitrifying I/A septic systems throughout the watershed, had total nitrogen concentrations closest to the 0.450 mg/L TMDL concentration. These scenario results, combined with the other scenario results, suggest that wastewater nitrogen reductions provide the most significant improvements in TN concentrations in the Harbor. The results of the scenarios also indicate that total nitrogen reductions assumed for the I/A systems will have to be increased if wastewater treatment is the only nitrogen management strategy that is utilized. It should also be noted that some I/A systems are discharging effluent at TN levels <19 mg/L, so large-scale implementation of these systems would result in even lower TN levels. However, lower effluent nitrogen concentrations would require MassDEP approval to ensure regulatory compliance.

[9] See Section V.2.1 in MEP report

[10] NOAA the offshore channel depths in Madaket Harbor are ~7 feet MLLW

c. Enhanced aquaculture would need to be more extensive than what was applied in Scenario 4. The total nitrogen concentrations in Scenario 4 were essentially the same as Scenario 2, which did not include the enhanced aquaculture, likely due to the aquaculture area being so close to Madaket Harbor and the system inlet. It should be noted that the proposed enhanced aquaculture removed 210 kg/yr of N would be the equivalent of completely removing ~10% of the overall watershed wastewater N load, so significant removals could be achieved through utilizing enhanced aquaculture of an integrated nitrogen management approach.
d. Dredging within Hither Creek also had only a small impact on total nitrogen concentrations. Scenario 5 included the dredging with the updated 2018 watershed land use, while Scenario 3 only included the updated land use. The total nitrogen concentration results in these two scenarios were essentially the same, indicating that the dredging had only minimal impact. It should be noted, however, that optimization of dredging as part of an integrated nitrogen management approach may have significant benefits beyond the Scenario 5 configuration.

Table 1. 2019 Madaket Harbor/Long Pond Scenarios: Overall Watershed Nitrogen Loads. System-wide annual nitrogen loads in kilograms are shown for each scenario with loads within each of the categories used in the 2010 MEP watershed nitrogen load (also shown for comparison and described in Chapter IV of the MEP Report).

		Wastewater	Landfill	Fertilizers	Impervious Surfaces	Water Surface	Natural Surfaces	Total N Load
Scenario	Description	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr
MEP	Baseline – 2010	1,904	777	272	346	4,128	387	7,814
1	MEP Landuse + Landfill Update	1,904	431	272	346	4,128	387	7,468
2	MEP Landuse + Watershed-wide I/A denitrifying septic systems + Landfill Update	1,378	431	272	346	4,128	387	6,942
3	2018 Landuse + Landfill Update	2,153	431	274	367	4,141	389	7,755
4	Enhanced Aquaculture + 2018 Landuse + Watershed-wide I/A denitrifying septic systems + Landfill Update	1,559	431	274	367	4,141	389	6,950* *includes -210 kg/yr for aquaculture
5	Hither Creek Dredging + 2018 Landuse + Landfill Update	2,153	431	274	367	4,141	389	7,755

Table 2. 2019 Madaket Harbor/Long Pond Scenarios: Watershed, Benthic Flux, and Direct Atmospheric Nitrogen Loads. These are the nitrogen loads used in the water quality modeling of each scenario. Subwatershed loads include all nitrogen sources, including septic wastewater loads, impervious surface runoff, and lawn fertilizers. Direct atmospheric deposition loads are nitrogen loads on the surface of each of the subembayments. Net benthic flux loads are nitrogen regenerated from sediments within each subembayment. MEP present conditions nitrogen loads from the 2010 Report are also shown for comparison. All nitrogen loads are presented as kilograms per day.

	Total watershed loads (kg/d N)						direct atmospheric deposition (kg/day N)	benthic flux net (kg/d N)					
Sub-Embayment	MEP	Scen. 1	Scen. 2	Scen. 3	Scen. 4	Scen. 5	MEP & All scenarios	MEP	Scen. 1	Scen. 2	Scen. 3	Scen. 4	Scen. 5
Madaket Bay	0.663	0.663	0.559	0.811	0.674	0.811	8.603	17.952	17.952	17.485	17.952	17.485	17.952
Hither Creek	4.041	4.041	3.238	4.052	2.679	4.052	0.534	-0.583	-0.583	-0.583	-0.583	-0.583	-0.583
Madaket Ditch	2.433	2.433	2.016	3.112	2.507	3.112	-	0.061	0.049	0.043	0.055	0.043	0.055
North Head Long Pond	0.238	0.238	0.219	0.241	0.222	0.241	0.693	0.995	0.995	0.829	0.995	0.829	0.995
Long Pond	3.230	2.282	2.186	2.192	2.121	2.192	0.975	3.065	2.627	2.408	2.846	2.408	2.846
SYSTEM TOTAL	**10.605**	**9.658**	**8.219**	**10.408**	**8.203**	**10.408**	**10.805**	**21.490**	**21.040**	**20.182**	**21.264**	**20.182**	**21.264**

Table 3. 2019 Madaket Harbor/Long Pond Scenarios: Average Model Total N Concentrations. Comparison of model average total N concentrations resulting from each of the indicated N loading scenarios. During the MEP, project staff identified a threshold station where achieving the selected total N concentration would restore benthic infauna communities throughout the estuary system. The threshold station in Hither Creek is shown in **bold** print and the total nitrogen threshold to restore benthic infauna communities at this station is **0.450 mg N L-1**.

Sub-Embayment	Monitoring Station	MEP baseline (mg/L N)	Scen. 1 (mg/L N)	Scen. 2 (mg/L N)	Scen. 3 ((mg/L N)	Scen. 4 (mg/L N)	Scen. 5 (mg/L N)
Madaket Bay	M1	0.311	0.310	0.310	0.311	0.310	0.311
Madaket Bay	M2	0.321	0.320	0.319	0.320	0.319	0.320
Madaket Bay	M3	0.328	0.327	0.325	0.327	0.325	0.328
Hither Creek	M4	0.464	0.447	0.431	0.455	0.430	0.458
Hither Creek	M5	0.613	0.579	0.549	0.595	0.552	0.589
Madaket Bay	M6	0.316	0.315	0.315	0.316	0.315	0.316
Madaket Bay	M10	0.327	0.325	0.324	0.326	0.324	0.326
Hither Creek	**M11**	**0.511**	**0.489**	**0.468**	**0.499**	**0.466**	**0.497**
Long Pond	LOPO1	1.040	0.934	0.883	0.955	0.882	0.947
Long Pond	LOPO2	0.983	0.888	0.840	0.908	0.839	0.899
Long Pond	LOPO3	0.883	0.807	0.763	0.826	0.764	0.814
Long Pond	LOPO4	0.852	0.782	0.739	0.802	0.740	0.789
North Head Long Pond	LOPO5	0.894	0.828	0.779	0.846	0.780	0.835

Table 4. 2019 Update of Nitrogen Loading from Town of Nantucket Landfill. Factors for determining the landfill nitrogen load were based on an updated review conducted through coordination between CDM Smith, CSP/SMAST, and TMDL Solutions staff. MEP estimated annual nitrogen load from the landfill was 777 kg/yr. CDM Smith divided the estimated landfill nitrogen plume among north and south flow paths and a shallow and deep portions of the aquifer thickness. TN concentrations within the plume were based on groundwater monitoring in 2018 and 2019 and were adjusted to account for upgradient, background concentrations.

	Plume Section	North-Deep	North-Shallow	South-Deep	South-Shallow
Factor	Factor Units				
Hydraulic conductivity (K)	ft/d	75	34	39	80
Hydraulic gradient (i)	ft/ft	0.0012	0.0009	0.0011	0.001
Portion of aquifer thickness	ft	81	30	81	30
Portion of cross-sectional width	ft	580	580	580	580
Plume cross-sectional area (A)	ft^2	46,980	17,400	46,980	17,400
Plume flow (Q=KiA)	ft^3/d	4,235	528	2,015	1,392
Total N concentration	mg/L	0.8	1.8	3.9	21.2
TN loading (Q*TN conc)	kg/yr	35.0	9.8	81.2	305.0
TOTAL Landfill TN Load (∑ plume quadrant loads)	kg/yr	431			

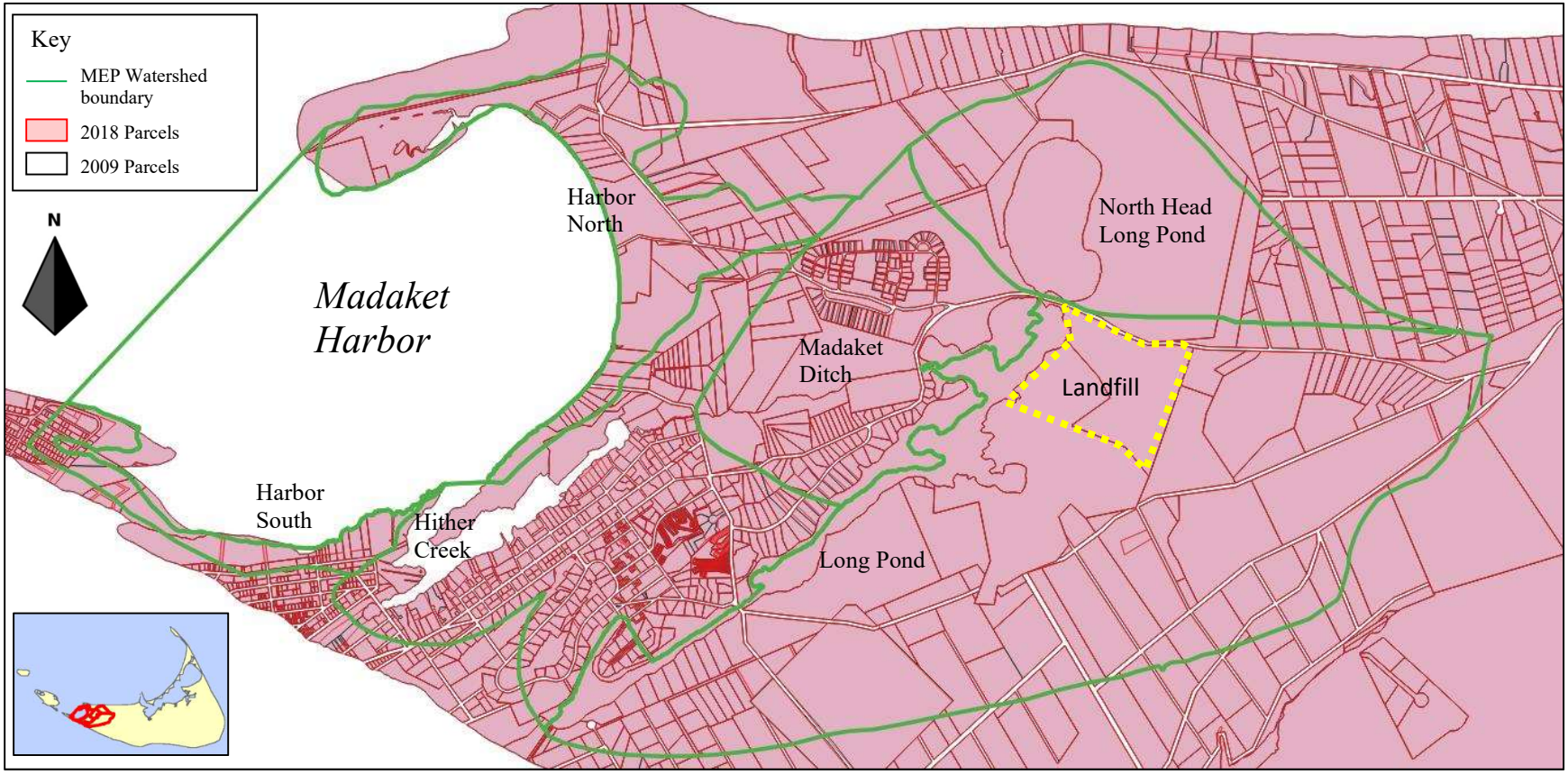

Figure 1. Madaket Harbor/Long Pond Watershed, Town Parcels, and Landfill Location. The MEP watershed is outlined in green and subwatersheds are labeled. 2009 Town parcels were used in the MEP assessment and are overlaid on the 2018 Town parcels that were used for the scenario updates. Parcels where black outlines of 2009 parcels are visible were adjusted in the 2018 parcel coverage. The approximate outline of the Town landfill is shown within the Long Pond subwatershed.

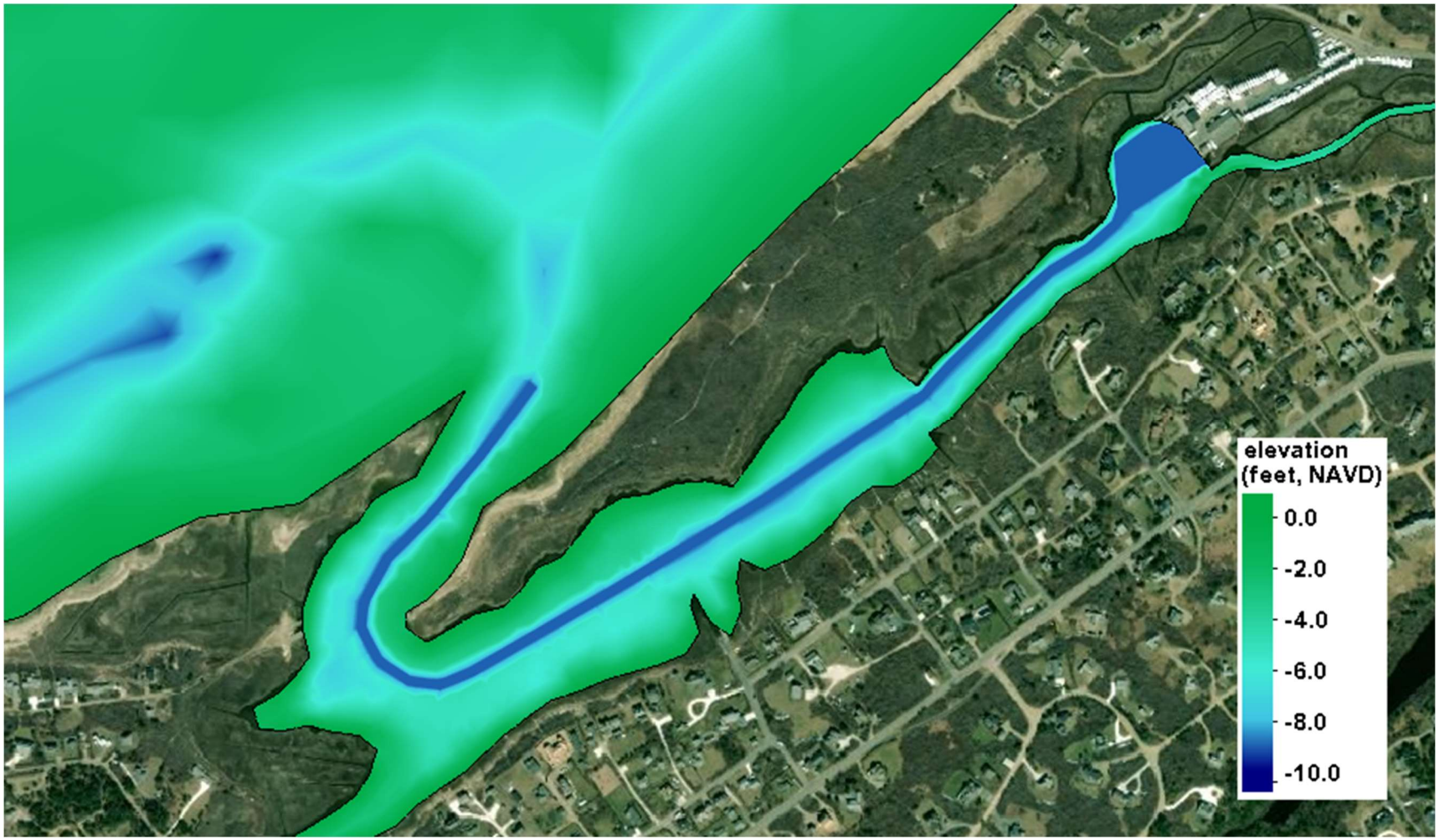

Figure 2. Scenario 5 Hither Creek Dredging Depth Contours. Following consultation with Town staff, project staff adjusted the measured MEP bathymetry to establish an estimated dredging footprint for the navigational channel to the Hither Creek Boatyard based on a 30-foot-wide channel dredged to -8 feet MLLW between the inlet of Hither Creek and the Madaket Marine boat basin. Based on this approximate footprint, 44,800 cubic yards would be dredged for the 4,300 feet of channel and deepening of existing boat basin at Madaket Marine.