Technical Memorandum

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Subject	Great Pond Targeted Watershed Management Plan – Technical Memorandum 3 Additional Site Characterizations of Allen Parcel, Beds 14 &15, and Augusta Parcel (GP TM-3) – Final		

1. Purpose of Memo

The purpose of this Technical Memorandum is to summarize additional site characterizations that were completed at three sites identified for potential future treated effluent disposal—Open Sand Beds 14 & 15, the Augusta Parcel, and the Allen Parcel. The information summarized in this memorandum will be used in the development of the centralized wastewater management scenarios evaluation (which will be summarized in future GP TM-4).

1.1 References, Regulations, and Design Guidelines

The references, regulations, and design guidelines listed below were used to develop this memorandum. Documents are referred to by the abbreviation indicated in parenthesis for the remainder of the memorandum.

– South Coast Embayments – Preliminary Evaluations and Notice of Project Change Update Project – Final Open Sand Beds 14 & 15 Hydraulic Load Testing Summary; prepared by GHD, dated May 24, 2021 (2020 Treated Effluent Hydraulic Load Testing Summary)

– Great Pond Targeted Watershed Management Plan – Draft Technical Memorandum 2 Groundwater Modeling Evaluation of Treated Effluent Recharge to Groundwater, Town of Falmouth MA rev0; prepared by GHD, dated June 17, 2021

– Great Pond Targeted Watershed Management Plan (TWMP) – Work Plan for Field Investigations at the Allen Property, Augusta Property and Open Sand Beds 14 & 15 – Final; prepared by GHD, dated December 22, 2020 (2020 Field Investigations Work Plan)

– TASA TM No. 3 – South Coast Embayments Preliminary Evaluations and Notice of Project Change Project – Final Teaticket / Acapesket Study Area Discharge Technologies Evaluation – Technical Memorandum No. 3; prepared by GHD, dated April 11, 2019 (TASA TM-3)

– TASA TM No. 5 – South Coast Embayments Preliminary Evaluations and Notice of Project Change Project – Hydraulic Load Tests at the Augusta Parcel and Allen Parcel – Technical Memorandum No. 5; prepared by GHD, dated April 11, 2019 (TASA TM-5)

– Technical Memorandum No. 8 – Hydraulic Load Tests at Sites 7 and 10; prepared by GHD and dated August 2011 (2011 TM-8)

- Unified Soil Classification System (USCS).
- American Association of State Highway and Transportation Officials (AASHTO) Soil Classification System

2. Open Sand Beds 14 & 15

2.1 Background and Summary of Prior Field Investigations

Open Sand Beds 14 & 15 are located on a municipal parcel that is adjacent to the existing Falmouth Wastewater Treatment Facility (WWTF) property. The parcel has been previously identified at “Site 7” in the 2013 CWMP/FEIR/TWMP. USDA maps indicate that the soils in the area are primarily Plymouth-Barnstable Complex (484). Plymouth-Barnstable Complexes are generally defined as hilly or rolling and boulder.

Nine (9) test borings were completed at the site in 2014, prior to construction of the two beds. The borings in closest proximity to the sand bed footprints indicated fairly consistent, sandy material at depth across a site that exhibited a hilly ground surface (prior to construction). Due to this rolling topography, portions of the subsurface soil had to be removed during construction prior to filling to final grade, while other areas required soil to be removed (cut) to reach the subgrade elevation of the bed. Cuts in grade were generally required in Open Sand Bed 14, while fill was generally required in Open Sand Bed 15.

Both open sand beds were sized based on a design hydraulic loading rate of 7 gpd/sf. In the Summer of 2020, treated effluent hydraulic load testing conducted at the beds indicated that a minimum infiltration rate of 11 gpd/sf was appropriate for the beds, as documented in the 2020 Treated Effluent Hydraulic Load Testing Summary. The testing was limited by the quantity of effluent produced by the Falmouth WWTF at the time of the testing (which was lower than typical in 2020 likely due to COVID-19 restrictions), so a maximum infiltration rate for the beds was not established during the testing. The results of the 2020 tests (summarized in the 2020 Treated Effluent Hydraulic Load Testing Summary), indicate that a higher hydraulic infiltration rate for the system is likely.

2.2 MassWildlife Rare Species Listing

A State-Listed Rare Species request was submitted in 2020 for the parcel that Open Sand Beds 14 & 15 are located on. A response letter (Attachment A) was received from the Massachusetts Division of Fisheries and Wildlife (DFW) on February 7, 2020 (NHESP Tracking No. 02-23886). The response letter noted that the Natural Heritage database indicates that the site is not currently mapped as a Priority or Estimated Habitat.

2.3 Subsurface Investigations

2.3.1 2020/2021 Borings and Test Pits

The 2020 treated effluent hydraulic load testing indicated a higher infiltration rate in Open Sand Bed 14 than in Open Sand Bed 15. In 2020, a subsurface investigation plan was developed to investigate whether subsurface conditions are potentially influencing the difference in performance between the two beds. The Work Plan is outlined in the 2020 Field Investigations Work Plan (Attachment B). Two (2) shallow geoprobe borings and three (3) test pits were conducted in Open Sand Bed 15 in January 2021. The geoprobe boring logs are provided in (Attachment C).

Trace silty brown sand (depth of 8 to 12 feet) and trace silt (12 to 16 feet) were identified in the soil boring ID No. 2020-SB14and15-B03. Trace silt (depth of 4 to 8 feet below grade) and silty brown sand (depth of 8 to 12 feet below grade) were identified in soil boring ID No. 2020-SB14and15-B04. Samples collected from 2020-SB14and15-B04 were selected for further soil testing to investigate whether the silt found in this sample is anticipated to influence infiltration rates. Findings from the soil testing are outlined in Section 2.3.2.

Test boring notes provided by the Town Soil Evaluator are summarized in Table 1. The full Soil Evaluation Report is provided in Attachment D. In Test Pit ID No. 2020-SB14and15-TP01, located in the western portion of the bed, parent material was detected approximately 5 feet down from the top of the bed. In Test Pit ID No. 2021-SB14and15-TP02 and Test Pit ID No. 2021-SB14and15-TP03, fill material was detected through the depth of the excavation. The soil evaluator notes for TP03 indicate that parent material may have been relocated as fill to this area.

Table 1 Summary of Town Soil Evaluator Test Pit Comments – Open Sand Bed 15

Test Pit	Soil Evaluator Notes
2020-SB14and15-TP01	"As expected, the upper layers were clean sand fill materials. The parent material beneath consisted of some stratification of layer of sand and gravel with cobbles present. The bottom C2 layer was less gravelly and had trace silt."
2020-SB14and15-TP02	"As expected, the upper layers were clean sand fill materials. While the second horizon may have been parent material, it looked more like it was relocated parent material. It held together and didn't cave in as much as the previous hole and the cobbles and gravel was not stratified, more mixed up. I am assuming this was original parent material used to fill in a low area. At the request of GHD this hole was relocated."
2020-SB14and15-TP03	"As expected, the upper layers were clean sand fill materials. While the second horizon may have been parent material, it looked more like it was relocated parent material. This hole caved in more than the previous hole. The cobbles and gravel was not stratified, more mixed up. I am assuming this was original parent material used to fill in a low area. At the request of GHD this hole was relocated."

Notes:

1. Table 1 represents a summary of the Town Soil Evaluator notes taken on January 8, 2021 by Scott Schluter, PE (see Attachment D for full notes).

2.3.2 2020/2021 Soil Testing

Soil testing was performed on three (3) samples to further characterize subsurface conditions.

The sample from Test Pit ID No. 2020-SB14and15-TP01 was selected from the western portion of existing Bed 15 where original site grades required a cut to reach the infiltration basin subgrade elevation. Therefore, it was anticipated that this sample would represent the in situ material located below the A and B Horizons that were removed during the bed's construction. It is assumed that this sample represents material that is performing better than predicted as an infiltration material and is similar to material below Existing Bed 14.

The sample from Test Pit ID No. 2020-OSB14and15-TP03 was selected from a more central area that required that fill be placed after removal of the A and B Horizon material to reach the infiltration basin subgrade elevation during the original sand bed construction. This sample represents the fill material that was placed (relocated from onsite) and selected for comparison to the TP01 sample.

The sample from Boring ID No. 2020-OSB14and15-B04 is similar to the sample from Test Pit ID No. 2020-OSB14and15-TP03. The soil samples from 12 to 16-feet in Boring ID No. 2020-OSB14and15-B04 were field classified in the boring log as "silty brown clay" and potentially serves as a restrictive layer to infiltration over the area where that material is present. This layer was not identified in Boring ID No. 2020-OSB14and15-B03 and may indicate that the restrictive layer was removed from this portion of the existing bed and that the overall extent of this layer may be limited/localized near Boring ID No. 2020-OSB14and15-B04.

2.3.2.1 Atterberg Limits Testing

Atterberg Limits testing was performed to help identify subtle differences in the sample that may not be evident from field classification (boring logs) or sieve analyses and which may affect long-term infiltration capacity. Atterberg limit testing measures soil plasticity, which is a metric used to establish how much clay or silt is in a soil, in accordance with the scale below:

– Soils with a high plasticity index (above 17) is typically characterized as a clay
– Soils with a lower plasticity index (>0 to 17) are typically characterized as a silt
– Non-plastic soils (plasticity index of 0) typically have little to no silt of clay.

All three soil samples from Open Sand Beds 14 &15 were determined to be non-plastic, which is indicative of little to no silt or clay in the sample.

2.3.2.2 Soil Particle Distribution

Soil particle distribution was used to characterize the range of particle sizes in the soils on each of these samples. Soil sampling results were classified using two methods:

– The Unified Soil Classification System (USCS)
– The American Association of State Highway and Transportation Officials (AASHTO)

The Hazen uniformity coefficient (C_u) and the coefficient of curvature (C_c) were also quantified. The Hazen uniformity coefficient indicates the general shape of the particle size distribution. Soils with a uniformity coefficient less than 4 or 5 are typically considered uniform in particle size. Well-graded soils have uniformity coefficients greater than 10 and typically include a continuous wide range of particle sizes. In general, soils that are more uniform tend to infiltrate more rapidly.

Soil sampling results are summarized in Table 2. The 2020-OSB14and15-TP01 sample serves as a “control” to which other results are compared (for all three sites). 2020-OSB14and15-TP01 was selected as a control since this sample represents well-performing parent infiltration material from below the original A and B horizons. The material is classified as “SP-SM” (poorly-graded sand with silt - USCS) and A-3 (fine sand - AASHTO). These classifications indicate a poorly graded sand with silt, but not enough silt to be classified as silty sand (SM). The particle size distribution (PSD) curve shows a coefficient of uniformity (C_u) of 5.9 and a Coefficient of Curvature (C_c) of 1.4. This material would generally be considered appropriate for infiltration purposes.

The samples from 2020-OSB14and15-TP03 and 2020-OSB14and15-B04 produced similar results to each other which likely confirms that both are relocated (fill) material. The samples were classified as “SM” (silty sand) and “A-2-4” (Silty or Clayey Gravel and Sand – AASHTO). The percentage of fines was slightly higher than 2020-OSB14and15-TP01, but the C_u for both samples was distinctly higher than 2020-OSB14and15-TP01, 13.8 and 17.1 respectively. The term Coefficient of Uniformity is a bit of a misnomer and the higher the value, the less uniform the material is. The higher C_u for these two samples indicates that the material is more well graded (greater distribution of particle sizes) and less uniform. The slightly higher fines content would also agree with the soil evaluation notes for TP02 which indicated that the material appeared to be relocated parent material, held together better, and didn’t cave-in as much. Therefore, this material may be contributing to the lower infiltration rate in Bed 15.

For clean sands with less than 5% passing the No. 200 sieve, Hazen developed an empirical equation that relates the coefficient of permeability of a soil to the effective grain size or D_{10} of the soil. None of the samples from Open Sand Bed 15 met the clean sand criteria (8.9% fines). A comparison of the estimate of permeability for Open Sand Bed 15, the Augusta Parcel, and the Allen Parcel is discussed in Section 4.3.2.

Table 2 Open Sand Bed 15 – Summary of Laboratory Test Results

Location	Material	Classification	% Gravel	% Sand	% Fines	Cu[3]	Cc[4]
2020-OSB14and15-TP01 6 to 13 feet	Original in situ (cut)	SP-SM[1] A-3[2]	7.5	83.6	8.9	5.9	1.4
2020-OSB14and15-TP03 6 to 14 feet	Relocated in situ (fill)	SM[1] A-2-4[2]	9.3	78.5	12.2	13.8	2.9
2020-OSB14and15-B04 4 to 14 feet	Relocated in situ (fill)	SM[1] A-2-4[2]	10.6	74.8	14.6	17.1	2.6

Notes:
1. Classifications are based on the Unified Soil Classification System (USCS).
2. Classifications are based on the American Association of State Highway and Transportation Officials (AASHTO).
3. Coefficient of Uniformity.
4. Coefficient of Curvature.
5. Full test results are included in Attachment E.

2.4 Potential Phosphorus Migration Evaluation

Groundwater modeling and particle tracking of treated water recharge at the Open Sand Beds 14 & 15 site conducted in 2011 indicated that flow from the open sand beds is anticipated to migrate through groundwater to Buzzards Bay. The groundwater model also indicated that a portion of the treated effluent would pass through Crocker Pond, a small freshwater kettle pond to the west of Recharge Beds 14 & 15, which is phosphorus limited. An evaluation conducted by EcoLogic in 2013 indicated that the aquifer soils downstream of Recharge Beds 14 & 15 have a large capacity to sequester phosphorus from the groundwater and significantly retard migration of phosphorus downstream to the kettle pond. The absorptive capacity of the soil (in years) was estimated to be between 100 to 1,400 years of phosphorus discharge, depending on the level of effluent treatment. The 2013 evaluation was simulated using an annual average effluent flow of 0.26 mgd at the site for three scenarios:

– Effluent total phosphorus concentration of 2.5 mg/L (average effluent WWTF total phosphorus concentration based on December 2010 – June 2014 WWTF data)
– Effluent total phosphorus concentration of 1.0 mg/L (representing an upgrade to enhanced secondary treatment, with chemical addition)
– Effluent total phosphorus concentration of 0.2 mg/L (representing an upgrade to tertiary treatment).

In 2021, EcoLogic ran an additional simulation within the existing Open Sand Beds 14 & 15 footprint, which increased the average annual flow discharged at the site to 0.55 mgd (Attachment F). The analysis was conducted using the 10-year average effluent Total Phosphorus concentration (2010 – 2020) from the Falmouth WWTF of 2.68 mg/L. A simulation was also conducted for the average annual flow of 0.26 mgd using the 10-year effluent phosphorus average. Both simulations are summarized in Table 3. In 2021, EcoLogic also reviewed groundwater monitoring well data downgradient of Open Sand Beds 14 & 15. The analysis indicated that phosphorus migration is consistent with the 2013 evaluation. Over the monitoring period (2016 – 2020) groundwater phosphorus concentrations remained consistent, with the exception of Monitoring Well 21A, which is a shallow well sited twelve feet directly downgradient of the open sand beds. As anticipated, phosphorus concentrations at this location are affected by the wells proximity to the beds and minimal contact time with the soil. The report also noted that samples collected at Monitoring Well 21B, which is a deep well located in the same vicinity, indicated a lower phosphorus concentration likely due to the increased opportunity for phosphorus attenuation within the soil profile at the lower depth.

Table 3 Open Sand Beds 14 & 15 – Estimated Soil Attenuation Capacity Time Period To Downgradient Freshwater Bodies

Downgradient Freshwater Bodies	Zone	Soil Attenuation Capacity Time Period (years) Between Open Sand Beds 14&15 and Downgradient Freshwater Bodies	
		Average Annual Treated Effluent Flow = 0.26 mgd	Average Annual Treated Effluent Flow = 0.55 mgd
Crocker Pond	Unsaturated	3.91	4.5
	Saturated	99.56	162.4
	Total	**103.47**	**166.9**

Notes:
1. Effluent TP Concentration = 2.68 mg/L (2010 through 2020 Falmouth WWTF data).

2.5 Groundwater Modeling

GHD developed a local-scale model for Open Sand Beds 14 & 15, based on the USGS regional flow model developed for the Sagamore Lens of the Cape Cod aquifer system (Walter, et. al., 2019). The local-scale model provides greater resolution in the vicinity of the site. A particle tracking simulation was conducted under this groundwater flow field to estimate potential effluent migration (advective migration only) from the proposed effluent discharge system. The results of each modeling scenario were analyzed as a percentage of total effluent recharge that reaches specific receptors.

The Groundwater Modeling Evaluation is outlined in GP-TM2 (Attachment G). Table 4 provides a comparison of flow scenarios that were simulated compared to the simulated currently permitted conditions. Table 4 shows that under these four scenarios, the total percent of discharge migrating to West Falmouth Harbor does not increase above current permit conditions with the increased flow to Open Sand Beds 14 & 15. The Table also shows an increase in the percent of particles that flow directly or indirectly to Herring Brook as the flow to beds 9-13 is increased. The groundwater model assumes particles that flow into a pond flow straight out the other side; under this assumption, the model indicates that no particles flow from Open Sand Beds 14-15 to Herring Brook via Crocker Pond under the 2015 permit condition. In actuality, after groundwater enters a pond, it mixes with other water in the pond, and “particles” can flow out of the pond in a location different from the one directly across from where they entered. Therefore, an evaluation will be conducted for all scenarios to evaluate potential nitrogen load introduced through mixing in Crocker Pond in the nutrient loading analysis (for all scenarios) as part of the centralized wastewater management evaluation.

Table 4 Treated Effluent Discharge Migration in Groundwater to Surface Water from Existing Open Sand Beds 9-15 (as a Percentage of Total Flow)

Scenario	Model Input		Model Output				
	Average Annual Flow (mgd)				West Falmouth Harbor Watershed		
	Open Sand Beds 9-13	Open Sand Beds 14-15	Herring Brook[2]	Buzzards Bay	Mashapaquit Creek	Snug Harbor	Outer Harbor
2021 Permit[1]	0.45	0.26	0%	54%	34%	0%	12%
Increased Flow to Existing Open Sand Beds 14 & 15 – Scenario A4[3]	0.45	0.76	11%	56%	22%	1%	9%
Increased Flow to Expanded Open Sand Beds 14 & 15 – Scenario B4[3]	0.45	0.76	16%	75%	3%	0%	6%
2021-OSB9to15-1.21mgd	0.66	0.55	7%	54%	27%	2%	10%
2021-OSB9to15-1.55mgd	1.00	0.55	11%	45%	26%	6%	12%

Notes:

1. Individual Groundwater Discharge Permit No. 16806, dated January 6, 2021.
2. Percentages represent treated effluent discharge migration in groundwater to surface water. As the treated effluent passes through Crocker Pond it is anticipated that this flow will mix with the pond water. Potential for treated effluent discharge load to Herring Brook through mixing in Crocker Pond will be evaluated in nutrient loading analyses for this site. An initial analysis of potential nitrogen loading from Crocker Pond to Herring Brook through mixing is summarized in 'Technical Memorandum 12 – Updated Groundwater Modeling for Site 7', prepared by GHD and dated July 30, 2013.
3. Scenario outlined in 'Groundwater Modeling Conducted in 2020 for Open Sand Beds 14 & 15 and the Allen Parcel – Final', prepared by GHD and Watershed Hydrogeologic, dated June 21 2021 (included as Attachment A).

3. Augusta Parcel

3.1 Background and Summary of Prior Field Investigations

The Augusta Parcel is approximately 20 acres and is Town-owned. It is surrounded by residential and commercial properties and is located in the Great Pond watershed. USDA maps indicate that the soils on the site are primarily Carver Sands (252C & 259B) and Merrimac Fine Sandy Loam (254A). A portion of the site has been previously disturbed and was previously used as an outdoor movie theatre and staging area for other Town projects. The majority of the movie theatre infrastructure has been removed from the site, with small portions of pavement remaining on the site.

The site has a topographic drop-off on the southeast portion of this property. The site was previously identified as a potential site for a new WWTF to serve this area of Town. The site was most recently identified as a location for a proposed booster station, as part of the TASA collection system conceptual layout.   This booster station would collect raw wastewater from the Teaticket / Acapesket Study (TASA) area (and possibly other services areas) and pump it to the Falmouth WWTF on Blacksmith Shop Road.

The deed to the Augusta Parcel currently limits the potential sewer service area of future wastewater treatment and disposal on the property to the Teaticket Water Quality Improvement District (TWQID). The TWQID is generally defined as the Maravista area between Little Pond and Green Pond, generally bounded by Sandwich Road on the west, Brick Kiln Road on the north, and Acapesket Road on the east. TWQID encompasses the majority of TASA, as well as an area north of Route 28 which is not currently under consideration for sewering, and the Maravista peninsula, most of which was connected to the sewer system under the Little Pond Sewer Service Area Project. In 2020, Falmouth Town Counsel confirmed that this deed restriction will expire in August 2033.

Hydraulic load testing, conducted in Fall of 2018, indicated that a design hydraulic loading rate of 7 gpd/sf was appropriate for potential open sand beds on this parcel. MassDEP has previously indicated that, if hydraulic load testing indicates a high infiltration rate (above 7 gpd/sf), the agency would consider a design loading rate of 7 gpd/sf for open sand beds until performance testing with actual treated effluent from a WWTF proved that a higher rate was warranted. Based on the 2018 hydraulic load test results, a design hydraulic loading rate of 7 gpd/sf was established for the site. If the site is developed, it is recommended that performance testing be conducted with actual treated effluent from a WWTF to evaluate the ability to request an increase in the rated capacity of the open sand beds.

3.2 MassWildlife Rare Species Listing

A State-Listed Rare Species request for the Augusta Parcel was submitted in 2020. A response letter (Attachment H) was received from the Massachusetts Division of Fisheries and Wildlife (DFW) on December 23, 2020 (NHESP Tracking No. 20-39770). The response letter noted that the Natural Heritage database indicates that the site is not currently mapped as a Priority or Estimated Habitat.

3.3 Subsurface Investigations

3.3.1 2020/2021 Borings and Test Pits

In accordance with the 2020 Field Investigations Work Plan (Attachment B) three (3) borings and seven (7) test pits were completed in January 2021. The borings and test pits were located across the extent of the site to investigate whether consistent subsurface conditions existed at the site.

The test borings (Attachment I) were drilled to groundwater, which was detected at 18 to 20 feet below grade at 2020-Augusta-B01, and 33 to 35 feet below grade at 2020-Augusta-B02 and 2020-Augusta-B03. 2020-Augusta-B01 is located on the northeastern portion of the property in a localized depression and near a drainage area that was wet during the field investigation work. These two factors contribute to the shallower depth to groundwater at this location. The borings consistently indicated brown sand, with a trace of cobble or gravel. These soils are typically highly favorable for treated effluent infiltration. Test pit notes provided by the Town Soil Evaluator are summarized in Table 5. The full Soil Evaluator Report is included in Attachment J. It was noted that parent material was removed in portions of the site. In general, sandy loam was detected in the first 2 to 3 feet of the excavation, with medium to coarse sand observed below.

Table 5 Summary of Town Soil Evaluator Test Pit Comments – Augusta Parcel

Test Pit	Soil Evaluator Notes[1]
2020-Augusta-TP01	"All topsoil was removed in the past. The parent material beneath consisted of some stratification of layers of sand and gravel with very little silt present."
2020-Augusta-TP02	"The parent material beneath consisted of some stratification of layer of sand and gravel with a little silt present."
2020-Augusta-TP03	"All topsoil was removed in the past. The parent material consisted of some stratification of layers of sand and gravel with very little silt present."
2020-Augusta-TP04	Not excavated.[2]
2020-Augusta-TP05	"All topsoil was removed in the past. The parent material beneath consisted of some stratification of layers of sand and gravel with very little silt present."
2020-Augusta-TP06	"All topsoil was removed in the past and a layer of sandy fill was placed. The parent material beneath consisted of some stratification of layers of sand and gravel with very little silt present. The previous C2 layer is not present in this hole (medium sand 2.5Y 7/4)."
2020-Augusta-TP07	"All topsoil was removed in the past and a layer of sandy fill was placed; some of this has been stripped after. The parent material beneath consisted of some stratification of layers of sand and gravel with very little silt present. The previous C2 layer is not present in this hole (medium sand 2.5Y 7/4)."

Notes:

1. Table 5 represents a summary of the Town Soil Evaluator notes taken on January 12, 2021 by Scott Schluter, PE (see Attachment J for full notes).
2. 2020-Augusta-TP04 was not excavated since it was identified to be on an adjacent parcel that had formerly been part of the Augusta Parcel.

3.3.2 2020/2021 Soil Testing

Soil testing was performed on two (2) samples to further characterize subsurface conditions. As described in Section 2.3 samples were analyzed for soil particle distribution and Atterberg Limits.

The sample from 2020-Augusta-TP07 was selected from the southern portion of the site to represent the in situ material below thinner surface horizons. The sample from 2020-Augusta-B01 was selected from the northern portion of the site to evaluate differences across the site. Both samples were collected from approximately the same depth range.

As both samples produced similar results, they will be discussed together. Both samples were classified as "SP" (poorly graded sand - USCS) and "A-1-b" (stone fragments gravel and sand - AASHTO). This indicates a poorly graded sand. The particle size distribution curve shows distinctly lower fines content (2.1 and 2.0 percent) and C_u (3.0 and 3.8) than the "control" sample from 2020-OSB14and15-TP01 at the Existing Bed 15. The C_c values were also slightly lower. The combination of fines content and curve characteristics would indicate that this material is somewhat different than the material collected from Open Sand Bed 15 and would infer that the material at the Augusta site should perform at least as well if not better than the material at the existing beds for infiltration purposes. The lower coefficient of uniformity indicates a more uniform sand which typically infiltrates better than well-graded sands. All samples collected were determined to be non-plastic, which is indicative of little to no silt or clay in the sample.

For clean sands with less than 5% passing the No. 200 sieve, Hazen developed an empirical equation that relates the coefficient of permeability of a soil to the effective grain size or D_{10} of the soil. D_{10} represents the diameter that only 10% of particles are finer than. Both samples met this criteria for clean sand, indicating a high permeability for the sample.

Table 6 Augusta Parcel – Summary of Laboratory Test Results

Location	Material	Classification	% Gravel	% Sand	% Fines	Cu[3]	Cc[4]
2020-Augusta-TP07 3 to 13 feet	In situ, south	SP[1] A-1-b[2]	14.7	83.3	2.0	3.8	0.9
2020-Augusta-B01 6 to 15 feet	In situ, north	SP[1] A-1-b[2]	3.0	94.9	2.1	3.0	1.0

Notes:
1. Classifications are based on the Unified Soil Classification System (USCS).
2. Classifications are based on the American Association of State Highway and Transportation Officials (AASHTO).
3. Coefficient of Uniformity.
4. Coefficient of Curvature.
5. Full test results are included in Attachment K.

3.4 Potential Phosphorus Migration Evaluation

Since no freshwater bodies were identified downgradient of the Augusta Parcel, a phosphorus migration evaluation has not been completed for this site.

3.5 Groundwater Modeling

GHD developed a local-scale model for the Augusta Parcel, based on the USGS regional flow model developed for the Sagamore Lens of the Cape Cod aquifer system (Walter, et. al., 2019). The local-scale model provides greater resolution in the vicinity of the Augusta Parcel. A particle tracking simulation was conducted under this groundwater flow field to estimate potential effluent migration from the proposed effluent discharge system. The results of each modeling scenario were analyzed as a percentage of total effluent recharge that reaches specific receptors.

The Groundwater Modeling Evaluation is outlined in GP-TM2 (Attachment F). The two scenarios that were simulated (and further described in GP-TM2) are summarized in Table 7. The modeling indicates that at a discharge rate of 0.5 mgd, 100 percent of treated effluent discharged at the Augusta parcel surfaces in Great Pond. The modelling also indicates that at a discharge rate of 1.03 mgd distributed as described in Table 4, a small percentage of treated effluent migration in groundwater surfaces in Perch Pond (which flows into Great Pond) and the majority flows directly to Great Pond.

Table 7 Treated Effluent Discharge Migration in Groundwater to Surface Water as a Percentage of Discharge from the Augusta Parcel

Scenario	Model Input		Model Output		Number of Particles Released
	Average Annual Flow to Open Sand Beds (mgd)	Average Annual Flow to Subsurface Leaching Trenches (mgd)	Great Pond	Perch Pond	
2021-Augusta-0.5 mgd	0.50	0	100%	0%	72
2021-Augusta-1.03 mgd	0.95	0.08	95%	5%	115 (open sand beds) 25 (leaching trenches)

Notes:

1. Scenario 2021-Augusta-0.5 mgd represents anticipated average annual treated effluent flow to the Augusta Parcel under Planning Flow 1.
2. Scenario 2021-Augusta-1.03 mgd represents anticipated average annual treated effluent flow to the Augusta Parcel under Planning Flow 3.

4. Allen Parcel

4.1 Background and Summary of Prior Field Investigations

The Allen Parcel is approximately 70 acres and is Town-owned. Fourteen acres in the southwest corner of the parcel—labeled as ‘Lot 3’ on the ‘2005 Allen Parcel Plan of Land’—has been identified for general municipal use. The property has a 100-foot-wide utility easement along the western boundary of the property. The “municipal use” portion of the property abuts residential neighborhoods to the south and west. The land immediately adjacent to the north and east of this area is held in conservation. USDA maps indicate that the soil at the site is predominately Enfield Silt Loam (265A) with a pocket of Merrimac Fine Sandy Loam (254B) in the southwest corner of the property.

Initial subsurface investigations were conducted at the site in 2010. A test pit indicated that soils are primarily outwash plain with sandy soils. A percolation test indicated that the underlying soils have a percolation rate of less than 2 minutes per inch. Further subsurface investigations were conducted in 2018 through a hydraulic load test and test pit as described in Section 4.3. During the 2018 investigations depth to groundwater was measured at 36 feet below ground surface, through the installation of a monitoring well.

Hydraulic load testing (documented in GP TM-2), conducted in Fall of 2018, indicated that a design hydraulic loading rate of 7 gpd/sf was appropriate for open sand beds on this parcel. MassDEP has previously indicated that, if hydraulic load testing indicates a high infiltration rate (above 7 gpd/sf), the agency would consider a design loading rate of 7 gpd/sf for open sand beds until performance testing with actual treated effluent from a WWTF proved that a higher rate was warranted. Based on the 2018 hydraulic load test results, a design hydraulic loading rate of 7 gpd/sf was established for the site. If the site is developed, it is recommended that performance testing be conducted with actual treated effluent from a WWTF to evaluate the ability to request an increase in the rated capacity of the open sand beds.

During the 2018 field investigations, a layer of lower-permeability soil was discovered approximately 10-inches thick at approximately 28-inches to 38-inches below grade. This layer (if found within the boundary of the proposed effluent recharge facilities) would need to be excavated and removed if the site were developed for treated effluent disposal. Further investigation of this layer was conducted in 2020 as described in section 4.3.

4.2 MassWildlife Rare Species Listing

A State-Listed Rare Species request was submitted for the Allen Parcel in January 2020. A response letter (Attachment L) was received from the Massachusetts Division of Fisheries and Wildlife (DFW) on February 7, 2020 (NHESP Tracking No. 20-39170). The response letter noted that a portion of the project site is located within Priority Habitat 223 (PH 223) for five state-listed rare species.

A pre-filing consultation request was submitted for the site in Spring 2021. Upon review of the submitted conceptual plans for the site, DFW indicated that the portion of the site under consideration for treated effluent disposal is not anticipated to have any state-listed species concerns due to the following reasons:

The four butterfly and moth species in the rare-species listing response (Herodias underwing moth, buck moth, frosted elfin, and pink sallow) are associated with the pine-dominated habitat in the northeastern and eastern portions of the property and not in the southwestern portion of the property, which is the proposed project area.

Eastern Whip-poor-will habitat is only mapped on lands that fall under an existing protection and the proposed project area does not fall under this category.

4.3 Subsurface Investigations

4.3.1 2020/2021 Borings and Test Pits

In 2020, a subsurface investigation plan was developed to evaluate the potential extent of the subsurface lower-permeability layer and to further characterize subsurface conditions at the site. The Work Plan is outlined in the 2020 Field Investigations Work Plan (Attachment B). Four (4) test borings and five (5) test pits were completed in January 2021.

The test borings (Attachment M) were located to collect subsurface information in the northwestern, northeastern, southeastern corners and the middle of the conceptual effluent discharge footprint. (the testing footprint was established based on the estimated area needed to discharge a proposed average annual flow of 0.5 mgd). The boring/monitoring well installed in 2018 was used to provide subsurface information in the southwestern corner of the conceptual footprint. The test boring log indicated the presence of silty clay, primarily within the first four feet of the boring. Borings were drilled to groundwater. Deeper elevations indicated primarily brown sand. Groundwater was detected at 38 to 40 feet below the ground surface.

A total of five test pits were excavated within the proposed footprint. The test pits were started in the southwestern corner of the footprint (where the shallow lower-permeability layer was found in 2018) and subsequent test pits were excavated along paths to the north and to the east in approximately 100-foot intervals. A soil evaluation for each test pit was provided by Scott Schluter (Town of Falmouth Soil Evaluator). The test pit soil evaluation notes are summarized in Table 8 (See Attachment N for full notes). The test pits generally indicated:

- Silt loam in the upper 3-feet of soil in all of the test pits,
- Loamy sand from approximately 3 feet to up to 11 feet below ground elevation, and
- Medium to coarse sand below the loamy sand.

Medium to coarse sand is typically highly favorable for treated effluent infiltration. Silt loam and loamy sand are anticipated to have a lower infiltration rate than medium to coarse sand. It is anticipated that the less permeable materials (silt loam) would need to be removed if the site were developed for infiltration of treated wastewater.

Table 8 Town Soil Evaluator Test Pit Comments – Allen Parcel

Test Pit	Soil Evaluator Notes
2020-Allen-TP01	"Soils went from silt loam to loamy sand, possibly sand with trace silt decreasing in silt content from top down. The underlying C layers were loose and increasing in stratification with layers of gravel and sands mixed in with some silt. No evidence of a perched water table. Hole was difficult to dig deep due to side stability."
2020-Allen-TP02	"Soils went from silt loam to loamy sand, possible sand with trace silt decreasing in silt content from top down. The underlying C layers were loose and increasing in stratification with layers of gravel and sands mixed in with some silt. There were some bright streaks most likely a pause in water moving through siltier pockets of materials. Hole was difficult to dig deep due to side stability."
2020-Allen-TP03	"Soils went from silt load to loamy sand to fairly clean medium and coarse sand decreasing in silt content from top down. The underlying C layers were loose and increasing in stratification with layers of gravel and sands mixed in with some silt. There were some pockets of very silty materials void of color. Samples were taken of both the main layer and the pocket materials. Hole was difficult to dig deep due to side stability."
2020-Allen-TP04	"Soils went from silt loam to loamy sand decreasing in silt content from top down. The underlying C layers were loose and increasing in stratification with layers of gravel and sands mixed in with some silt. Hole was too difficult to dig deep due to side stability. A shelf was not dug for safety reasons."
2020-Allen-TP05	"Soils went from silt loam to medium and coarse sand decreasing in silt content from top down. The underlying C layers were loose and increasing in stratification with layers of gravel and sands mixed in with some silt. Samples were taken of the C1 gray silt load as well as the main layer material. Hole was difficult to dig due to side stability."

Notes:

1. Table 8 represents a summary of the Town Soil Evaluator notes taken on January 7, 2021 by Scott Schluter, PE (see Attachment N for full notes).

4.3.2 20202021 Soil Testing

Soil testing was performed on two (2) samples to further characterize subsurface conditions. As described in Section 2.3 samples were analyzed for soil particle distribution and Atterberg Limits.

The sample from 2020-Allen-B04 was selected from near the center of the site as it was anticipated to represent the in-situ material at depth. The sample from 2020-Allen-TP03 was located in the south-central portion of the site and was selected to evaluate the shallow (silty loam) soils (1 to 3 feet below grade) that may have impacted the 2018 percolation test results.

Soil sampling results are summarized in Table 9. The sample from 2020-Allen-B04 was classified as "SP" (poorly- graded sand - USCS) and "A-1-b" (stone fragments gravel and sand - AASHTO). This indicates a poorly graded sand. The Particle Size Distribution Curve shows distinctly lower fines content (3.2 percent) and C_u (3.2) than the control sample (2020-OSB414and15-B04). The C_c value was also slightly lower. Based on similar results, it appears that the material at depth at the Allen site should perform similarly to the material at the Augusta site.

The sample from 2020-Allen-TP03 was different than any of the other samples that were analyzed, as expected. The soil sample was classified as "SM" (Silty sand - USCS) and "A-2-4" (silty or clayey gravel and sand - AASHTO). While these classifications are similar to the relocated fill material at the site of Open Sand Beds 14 & 15 (see Section 3.3.2), the two materials are at opposite ends of the range that the classification covers. The particle size distribution curve shows distinctly higher fines content (34.4 percent) and C_u (45.3) than any other material. These results confirm that a shallow layer of unsuitable material is located over at least a portion of the site and this material should be removed in areas where infiltration is proposed to maximize infiltration capacity and rates. The depth of this material appeared to range from 1 to 3--feet below ground surface. The material located below this deposit appears to be suitable for use in infiltration applications. Boring logs indicate that the suitable material extends to at least 40-feet below ground surface. 2021-Allen-TP3 was determined to have a plasticity index of 1, which is considered to have a low plasticity. The low plasticity indicates a potentially silty soil. All other samples from the site were determined to be non-plastic, indicating little to no silt or clay in the sample.

For clean sands (sands with minimal fines) with less than 5% passing the No. 200 sieve, Hazen developed an empirical equation that relates the coefficient of permeability of a soil to the effective grain size or D_{10} of the soil. Sample 2020-Allen-B04 is the only sample of the two collected that met the criteria for a clean sand. Based on a D10 of 0.22 mm and constant, C, of 1.0, the estimated permeability for this soil deposit is between $1x10^{-2}$ and $1x10^{-1}$ cm/sec (0.01 to 0.1 cm/sec). By comparison 2020-OBS14and15-TP01 from Open Sand Bed 15 has an estimated permeability between $1x10^{-3}$ and $1x10^{-2}$ cm/sec (0.001 to 0.01 cm/sec). This is an order of magnitude lower than the material from the Augusta and Allen sites.

Table 9 Allen Parcel – Summary of Laboratory Test Results

Location	Material	Classification	% Gravel	% Sand	% Fines	Cu[3]	Cc[4]
2020-Allen-B04 6 to 20 feet	Shallow, Central	SP[1] A-1-b[2]	8.7	88.1	3.2	3.2	1.1
2020-Allen-TP03 1 to 3 feet	In situ, south central	SM[1] A-2-4[2]	10.2	55.4	34.4	45.3	0.7

Notes:
1. Classifications are based on the Unified Soil Classification System (USCS).
2. Classifications are based on the American Association of State Highway and Transportation Officials (AASHTO).
3. Coefficient of Uniformity.
4. Coefficient of Curvature.
5. Full test results are included in Attachment O.

4.4 Potential Phosphorus Migration Evaluation

Fresh-water bodies are typically phosphorus limited. Four fresh-water bodies were identified down-gradient of the proposed Allen Parcel site:

– Coonamessett River
– Flax Pond
– Mill Pond
– Backus Brook

In 2021 an evaluation was conducted by EcoLogic to assess the potential soil attenuation capacity of the soil between the Allen Parcel and each down-gradient fresh-water body (Attachment P).

Three (3) composite soil samples (representing separate soil horizons) were collected from 2020-Allen-B04 and submitted to the Cornell University Nutrient Analysis Laboratory to quantify soil characteristics related to a soil's capacity to absorb phosphorus. The analysis indicated that the soils are composed predominately of sand-sized particles, low in organic matter, oxic (oxygen is present) in the unsaturated zone, and slightly acidic. These soil characteristics are considered highly favorable for phosphorus adsorption.

EcoLogic used an empirical model to estimate the phosphorus retention capacity of the soils within the anticipated flow path of the treated effluent (soil prism), using the estimated quantities of reactive aluminum present in the analyzed samples and parameters established through literature reviews. Estimated saturated and unsaturated soil prism quantities were estimated using the groundwater model developed by GHD for the site. The estimated soil attenuation capacity was calculated for two average annual treated effluent flow rates –

0.5 mgd and 1.03 mgd. The analysis was conducted using the 10-year average effluent Total Phosphorus concentration (2010 – 2020) from the Falmouth WWTF of 2.68 mg/L.

The analysis indicated a 50 to 60 year soil attenuation capacity between the Allen Parcel and the Coonamessett River, and over 100 years of soil attenuation capacity between the Allen Parcel and Flax Pond, Mill Pond, and Backus Brook in both flow scenarios.

Table 10 Allen Parcel Estimated Soil Attenuation Capacity to Downgradient Freshwater Bodies

Downgradient Freshwater Body	Zone	Soil Attenuation Capacity Time Period (years) Between the Allen Parcel and Downgradient Freshwater Bodies	
		Average Annual Treated Effluent Flow = 0.5 mgd	Average Annual Treated Effluent Flow = 1.03 mgd
Coonamessett River	Unsaturated	0.16	0.49
	Saturated	49.58	60.07
	Total	**49.74**	**60.56**
Flax Pond	Unsaturated	2.16	2.67
	Saturated	139.60	112.97
	Total	**141.76**	**115.64**
Mill Pond	Unsaturated	1.02	0.99
	Saturated	309.82	208.09
	Total	**310.84**	**209.08**
Backus Brook	Unsaturated	2.15	1.84
	Saturated	478.54	174.59
	Total	**480.69**	**176.43**

Notes:

1. Effluent TP concentration = 2.68 mg/L (2010 through 2020 Falmouth WWTF data).

4.5 Groundwater Modeling

GHD developed a local-scale model for the Allen Parcel, based on the USGS regional flow model developed for the Sagamore Lens of the Cape Cod aquifer system (Walter, et. al., 2019). The local-scale model provides greater resolution in the vicinity of the Allen Parcel. A particle tracking simulation was conducted under this groundwater flow field to estimate potential effluent migration (advective migration only) from the proposed effluent discharge system. The results of each modeling scenario were analyzed as a percentage of total effluent recharge that reaches specific receptors.

The Groundwater Modeling Evaluation is outlined in GP-TM2 (Attachment G). The two scenarios that were simulated are summarized in Table 11. In both scenarios, particles flow to Great Pond via Flax Pond and/or the Coonamessett River, and particles flow to Green Pond via Flax Pond, Backus Brook, and/or Mill Pond. Under both scenarios, approximately 65% of the discharge at the Allen parcel ultimately flows to Great Pond, and 35% ultimately flows to Green Pond. However, the “route” that the particles take to the coastal ponds is different in the two scenarios. For example, the model indicates in the higher effluent discharge scenario, a larger percentage of flow surfaces directly in the Coonamessett River and Backus Brook.

Table 11 Treated Effluent Discharge Migration in Groundwater to Surface Water from Allen Parcel (as a Percentage of Total Discharge)

Model Inputs		Model Outputs									
		Great Pond Watershed				Green Pond Watershed					Total Number of Particles Released
Scenario	Average Annual Flow (mgd)	Coonamessett River		Great Pond		Directly to Backus Brook	Green Pond		Mill Pond		
		Through Flax Pond to River	Directly to River	Through Flax Pond to Great Pond	Directly to Great Pond		Though Flax Pond to Mill Pone	Directly to Mill Pond	Though Flax Pond to Green Pond	Directly to Green Pond	
2021-Allen-0.5 mgd	0.5	47%	10%	9%	0%	8%	10%	14%	2%	0%	264
2021-Allen - 1.03 mgd	1.03	29%	30%	5%	1%	18%	7%	10%	1%	1%	531

5. Next Steps

The field investigation findings outlined in this memo will be reviewed at a workshop with the Town and WQMC Working Group and will be incorporated in the centralized wastewater management alternatives evaluation. The finalized version of this technical memorandum is anticipated to be included as an Appendix to the Great Pond Targeted Watershed Management Plan.

List of Attachments:

A. Site 7 MassWildlife Response Letter
B. 2020 Field Investigations Work Pl
C. Open Sand Bed 15 Boring Logs
D. Open Sand Bed 15 Soil Evaluator Field Notes
E. Open Sand Bed 15 Lab Results
F. Crocker Pond, Falmouth Potential Soil Attenuation of Phosphorus Migration from Infiltration Treated Wastewater at Falmouth WWTF Open Sand Beds 14 & 15; Prepared by EcoLogic
G. Great Pond Targeted Watershed Management Plan – Technical Memorandum 2, Groundwater Modeling Evaluation of Treated Effluent Recharge to Groundwater, Town of Falmouth MA; Prepared by GHD
H. Augusta Parcel MassWildlife Response Letter
I. Augusta Parcel Boring Logs
J. Augusta Parcel Soil Evaluator Field Notes
K. Augusta Parcel Soil Lab Results
L. Allen Parcel NHESP Response
M. Allen Parcel Boring Logs
N. Allen Parcel Soil Evaluator Field Notes
O. Allen Parcel Lab Results
P. Potential Migration of Infiltrated Wastewater Phosphorus Downgradient of Allen Parcel; Prepared by EcoLogic

Attachments

Attachment A.

Site 7 MassWildlife Response Letter

MASSWILDLIFE

DIVISION OF
FISHERIES & WILDLIFE

1 Rabbit Hill Road, Westborough, MA 01581
p: (508) 389-6300 | f: (508) 389-7890
MASS.GOV/MASSWILDLIFE

February 07, 2020

Anastasia Rudenko
GHD Inc.
1545 Iyannough Road
Hyannis MA 02601

RE:	Project Location:	Site 7, off Thomas B Landers Road
	Town:	FALMOUTH
	NHESP Tracking No.:	**08-23886**

To Whom It May Concern:

Thank you for contacting the Natural Heritage and Endangered Species Program of the MA Division of Fisheries & Wildlife (the "Division") for information regarding state-listed rare species in the vicinity of the above referenced site. Based on the information provided, the Division has determined that at this time the site is not mapped as Priority or Estimated Habitat.

This evaluation is based on the most recent information available in the Natural Heritage database, which is constantly being expanded and updated through ongoing research and inventory. If you have any questions regarding this letter please contact Melany Cheeseman, Endangered Species Review Assistant, at (508) 389-6357.

Sincerely,

Everose Schlüter

Everose Schlüter, Ph.D.
Assistant Director

Attachment B.

2020 Field Investigations Work Plan

December 22, 2020

To:	Town of Falmouth, MA	Ref. No.:	11153041
From:	Anastasia Rudenko, P.E., BCEE, ENV SP J. Jefferson Gregg, P.E., BCEE Bradford Smith, P.E., BCEE	Tel:	774-470-1637 774-470-1640
CC:	File; Project Team		

Subject: **Great Pond Targeted Watershed Management Plan (TWMP)– Work Plan for Field Investigations at the Allen Property, Augusta Property and Open Sand Beds 14 & 15 (GP TWMP TM-1) – Final**

1. Purpose of Memo

The purpose of this Technical Memorandum is to serve as a Work Plan for completing additional field investigations at three potential effluent disposal sites to further delineate subsurface conditions and verify the suitability for receiving and infiltrating effluent from a wastewater treatment facility (WWTF). Two of the sites are the Augusta Parcel and Allen Parcel (Figures 1 and 2), which were the subject of preliminary field evaluations in 2018 the results of which were presented in TASA TM-5. The final site is at existing Open Sand Beds 14 & 15 (Figure 3).

2. Background

The Town is currently undertaking a preliminary evaluation of sewer project alternatives for the Teaticket Acapesket Study Area (TASA) which includes portions of the Great Pond watershed and the Green Pond watershed. Several field investigations have been conducted for two potential new effluent disposal sites chosen by the Town and the Water Quality Management Committee (WQMC)—the Augusta Parcel and the Allen Parcel. Both parcels were identified as potential effluent disposal locations in the 2007 ASAR. Both sites are municipally owned and were purchased by the Town as possible treated wastewater recharge sites. Additionally the Town is exploring the potential to increase the treated effluent recharge capacity of existing Open Sand Beds 14 and 15 at the Falmouth WWTF.

A summary of the field investigations conducted to-date as follows.

- Allen Parcel
    - 2010 – one percolation test
    - 2018
        - One test boring completed as a groundwater monitoring well
        - One deep test pit (hole)
        - One percolation test
        - Hydraulic load testing – constant and falling head

- Augusta Parcel
  - 2018
    - Two test borings completed as groundwater monitoring wells
    - One deep test pit (hole)
    - Two percolation tests
    - Hydraulic load testing - constant and falling head
- Existing Infiltration Beds
  - 2014
    - Nine test borings

The findings of the investigations at each site indicate their suitability for the construction of infiltration beds. Hydraulic load testing at each site demonstrated infiltration capacity rates that exceed regulatory criteria. The previous investigations did identify a less permeable layer at the Allen Parcel at about 3-feet below the ground surface that is unsuitable for the intended use. Previous investigations at the site of the existing infiltration beds 14 and 15 identified upper layers (horizons) at the site that were also unsuitable for the intended use.

3. References

The references and guidelines listed below were used to develop this memorandum.

References:

- 310 CMR 15.000 Title 5 of the State Environmental Code
- TASA TM-5 Teaticket / Acapesket Study Area Technical Memorandum No. 5 – Hydraulic Load Tests at the Augusta Parcel and Allen Parcel; prepared by GHD and dated April 11, 2019 (TASA-TM5)
- Technical Memorandum No. 8 – Hydraulic Load Tests at Sites 7 and 10; prepared by GHD and dated August 2011 (2011 TM-8)

Guidelines:

- Guidelines for the Design, Construction, Operation and Maintenance of Small Wastewater Treatment Facilities with Land Disposal; prepared by MassDEP and revised in July 2018 (2018 MassDEP Small WWTF Guidelines)
- Process Design Manual – Land Treatment of Municipal Wastewater Effluents (EPA/625/R-06/016); prepared by EPA, dated September 2006 (EPA/625/R-06/016)

4. Additional Field Investigation Work Plan

The primary goal of the additional field investigations is to confirm the suitability of each site for use as constructed treated effluent open sand beds and to determine the extent of any shallow layers of unsuitable material, where encountered, which may limit the availability of portions of a given site for the intended use or which may require removal prior to using the site.

Additional field investigations will consist of test borings and shallow test pits. Test borings will be completed by a qualified subcontractor. Test pits will be excavated by the Town using their own staff and equipment. Where appropriate, the field investigation at a given site will be phased and/or adjusted in the field as conditions are encountered and previous assumptions are confirmed or changed. The field investigation work plan for each site is outlined in this section.

4.1 Allen Parcel

The field investigation for the Allen Parcel will focus on the southwest portion of the parcel. A phased approach will be implemented at the site using both test borings and test pits. Initially, four (4) test borings will be completed by a qualified subcontractor. One test boring will be located near each corner of the area of interest while one test boring will be completed near the center of the area (the existing monitoring well will be used to provide data on the southeast corner of the area of interest). Each boring will be completed to a minimum depth of 40-feet or until groundwater is encountered. Samples will be collected by the driller continuously from the surface to 10-feet below grade at which point sampling will increase to 5-foot intervals to completion. One goal of the investigation is to confirm the presence of suitable soil to the groundwater interface. A secondary goal will be to determine if the potentially unsuitable layer that was identified in the 2018 field investigation extends to the limits of the area of interest. Figure 1 depicts the proposed layout of the initial four test borings.

If the results of the first five test borings indicate consistent subsurface results, then additional test borings will not be completed. If a portion of the site produces inconsistent results, up to five (5) additional test borings may be drilled to better define the subsurface stratigraphy.

Test pits, utilizing Town equipment and personnel, will also be used in an effort to delineate the extent of the unsuitable layer of material identified in the 2018 field investigation. Test pits should extend north and east from the identified location of unsuitable material in approximately 100-foot increments. The general concept/layout for test pits is shown on Figure 1. Test pits should extend approximately 10 feet below grade, or to the reach of the excavator. If the unsuitable material is encountered, test pits should continue every 100 feet until the lateral extent is identified. Once the lateral extent of the material is identified along a given line the distance between the most recent two test pits can be split (50-ft) to better delineate the extent, if time allows based on the number of test pits completed. Test pits should then continue along another perpendicular line.

Soil samples will be collected by GHD for analysis related to the phosphorus attenuation evaluation for this site.

4.2 Augusta Parcel

Though no unsuitable material has been identified at the Augusta Parcel to date, additional field investigation is proposed to confirm that finding at a greater number of locations on this long site that has some land use history. In addition, field work is intended to focus on the soils along the east side of the property, near the adjacent slope. To supplement the two testing borings that were completed during the 2018 field investigation, four (4) additional borings will be completed to verify conditions across the site, with a focus on the northern portion of the property which is wider in the east-west direction. Each boring will be completed by a qualified subcontractor to a minimum depth of 40-feet or until groundwater is encountered. Samples will be collected continuously from the surface to 10-feet below grade at which point sampling will increase to 5-foot intervals to completion. Figure 2 depicts the proposed layout of the initial four test borings.

To further define the site, a series of test pits will be used between test boring locations to further investigate the more surficial soil at the site. A total of seven (7) test pits are proposed, as shown in Figure 2, and will be completed by the Town. Although there is no indication of unsuitable, shallow soils at the site, any issues with unsuitable soil appear to occur fairly close to the surface based on findings at other sites. Test pits will be excavated to a depth of 10-feet, or to the extent of the reach of the excavator.

4.3 Existing Infiltration Bed Site

Two existing infiltration beds, Beds 14 and 15, are located at this site. Nine (9) test borings were completed at the site of the existing infiltration beds in 2014. The most relevant borings to the infiltration beds showed consistent, suitable material at depth across a site that exhibited a hummocky ground surface. In order to obtain the desired performance for the infiltration beds, portions of the subsurface soil had to be removed prior to filling to final grade, while other areas required soil to be removed (cut) to reach the subgrade elevation of the bed. Cuts in grade were generally required in Bed 14 while fill was required in Bed 15. Both beds are performing as designed, with Bed 14 performing above design parameters. A single, thin continuous layer of material can control the performance of the entire bed, which could contribute to the difference in performance between the two beds. This could be confirmed with a test boring within existing Bed 15. However, it may be difficult to identify a thin layer of unsuitable material, even with continuous sampling. The use of geoprobes with continuous sampling may provide a better opportunity to observe the unsuitable material. Geoprobe equipment is typically smaller, more maneuverable and better suited to working on the sand in the existing beds. However, this method results in less material being collected in the barrel. In order to evaluate whether less suitable material was placed to achieve final grades, laboratory testing may be required to compare the characteristics of the material to that from deeper material. Recommendations for laboratory testing will be prepared by GHD and reviewed with the Town prior to implementation.

To evaluate conditions which may be impacting the perceived performance of Bed 15, two geoprobe "borings" will be drilled within the bed itself. The geoprobes will be completed by a qualified subcontractor. One geoprobe will be located in an area where removal of unsuitable material, followed by filling to the infiltration bed subgrade elevation was required. This geoprobe should be completed to a depth of 25-feet. The second geoprobe will be located in an area where existing grade was above the infiltration bed subgrade elevation and required a cut to obtain the specified grade. This test geoprobe should be completed to a depth of 15-feet. Samples from each geoprobe will be collected continuously the surface (bgs) to the bottom of the geoprobe depth and observed for any unsuitable layers. Samples will be collected and testing for particle-size distribution and Atterberg Limits to determine: 1) if the original Horizon "A" and "B" material were removed; 2) if distinctly different soil types remain in place below Bed 15 (i.e., improper backfill); and 3) if the material immediately below the 4-feet of infiltration bed material (screened Horizon "C" material) is different between the two locations.

In addition, up to four test pits will be dug in Bed 15 to further evaluate the subsurface conditions.

Figure 3 depicts the proposed layout of the initial two test borings outside the existing beds and two test borings within Bed 15, and potential test pit sites

5. Summary

The following table lists total number of borings and test pits proposed for each location. The final number of each will depend on field conditions observed during the work.

Location	Number of Borings	Number of Test Pits
Augusta	3	6
Allen	4	5
Existing Beds 14 and 15	2	3
Total	9	14

Attachment C.

Open Sand Bed 15 Boring Logs

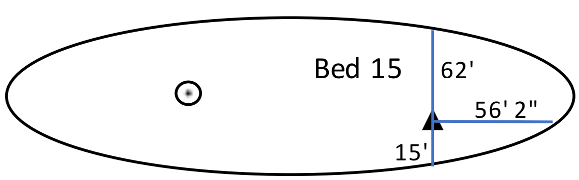
Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div. Desmond Well Drilling, Inc.	Project GHD, Inc. Falmouth South Coast CWMP Update Falmouth	Boring No. B03 Bed15 Sheet 1 of 1

Driller:	Sean Morgan	Boring location:	Existing beds, 0 Research Road
Helper:	Derek Goodlin	Ground Surface Elevation:	
Inspector:	Ana Cristea	Date start: 01/05/2021	Date end: 01/05/2021

Direct push sampler consists of 4' x 2 3/8" G3 dual tube direct push steel tooling with 4' x 1 1/2" PVC liner with 201 ft lb hydraulic hammer (percussion rate 2200 bpm)

Direct push steel tooling: 2 3/8" G3 dual tube
Casing Size: N/A
Screen Size: N/A

Depth (FT)	Sample NO	PEN/REC	DEPTH/FT	BLOWS 6"	Sample Description
0	1		0 - 4		F-M brown sand; trace C brown sand. Dry.
-2					
-4	2		4 - 8		F-M-C brown sand; trace gravel. Dry.
-6					
-8	3		8 - 12		F-M-C brown sand; trace silty brown sand. Dry.
-10					
-12	4		12 - 16		F-M-C brown sand; trace gravel; trace silt. Dry.
-14					
-16	5		16 - 20		F-M-C silty brown sand; trace gravel. Dry.
-18					
-20	6		20 - 24		F-M-C silty brown sand; trace gravel. Dry.
-22					
-24	7		24 - 28		F-M-C silty brown sand; little gravel. Dry
-26					
-28					
-30					
-32					
-34					
-36					
-38					
-40					
-42					
-44					
-46					
-48					
-50					
-52					
-54					
-56					



End of probe: 24'
End of sample: 28'
Groundwater encountered: None.
Sketch not to scale

Granular Soils BLOWS/FT	DENSITY	Cohesive Soils BLOWS/FT	DENSITY	Proportions Used
0 - 4	V. LOOSE	> 2	V. SOFT	Trace 0 - 10%
4 - 10	LOOSE	2 - 4	SOFT	Little 10 - 20%
10 - 30	M. DENSE	4 - 8	M. STIFF	Some 20 - 35%
30 - 50	DENSE	8 - 15	STIFF	And 35 - 50%
> 50	V. DENSE	15 - 30	V. STIFF	
		> 30	HARD	

Well Installation Key
- CONCRETE
- SAND PACK
Z - SOIL BACKFILL
- BENTONITE
- SCREEN
- APPROX. WATER LEVEL

CAPE COD TEST BORING **BORING NO. B03 Bed15**

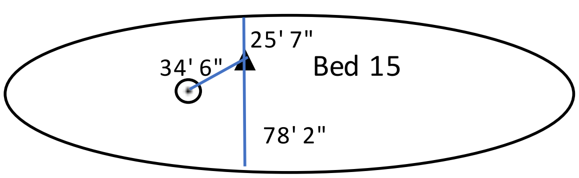
Cape Cod Test Boring	Project	Boring No.	BO4 Bed15
5 Rayber Road, Orleans, MA 02653	GHD, Inc.		
(508) 240-1000	Falmouth South Coast CWMP Update	Sheet 1 of	1
div. Desmond Well Drilling, Inc.	Falmouth		

Driller:	Sean Morgan	Boring location:	Existing beds, 0 Research Road
Helper:	Derek Goodlin	Ground Surface Elevation:	
Inspector:	Ana Cristea	Date start: 01/05/2021	Date end: 01/05/2021

Direct push sampler consists of 4' x 2 3/8" G3 dual tube direct push steel tooling with 4' x 1 1/2" PVC liner with 201 ft lb hydraulic hammer (percussion rate 2200 bpm)

Direct push steel tooling: 2 3/8" G3 dual tube
Casing Size: N/A
Screen Size: N/A

Depth (FT)	Sample NO	PEN/REC	DEPTH/FT	BLOWS 6"	Sample Description
0	1		0 - 4		F-M brown sand; trace C brown sand. Dry.
-2					
-4	2		4 - 8		F-M brown sand; trace C brown sand; trace silty. Dry.
-6					
-8	3		8 - 12		F-M brown sand; trace C brown sand; trace gravel; silty brown sand. Dry.
-10					
-12	4		12 - 16		F-M-C brown sand; trace gravel; silty brown clay. Dry.
-14					
-16	5		16 - 20		F-M-C brown sand; silty brown sand; little gravel. Dry.
-18					
-20	6		20 - 24		F-M-C brown sand. Dry.
-22					
-24	7		24 - 28		F-M-C brown sand; trace gravel; silty brown sand. Dry.
-26					
-28					
-30					
-32					
-34					
-36					
-38					
-40					
-42					
-44					
-46					
-48					
-50					
-52					
-54					
-56					



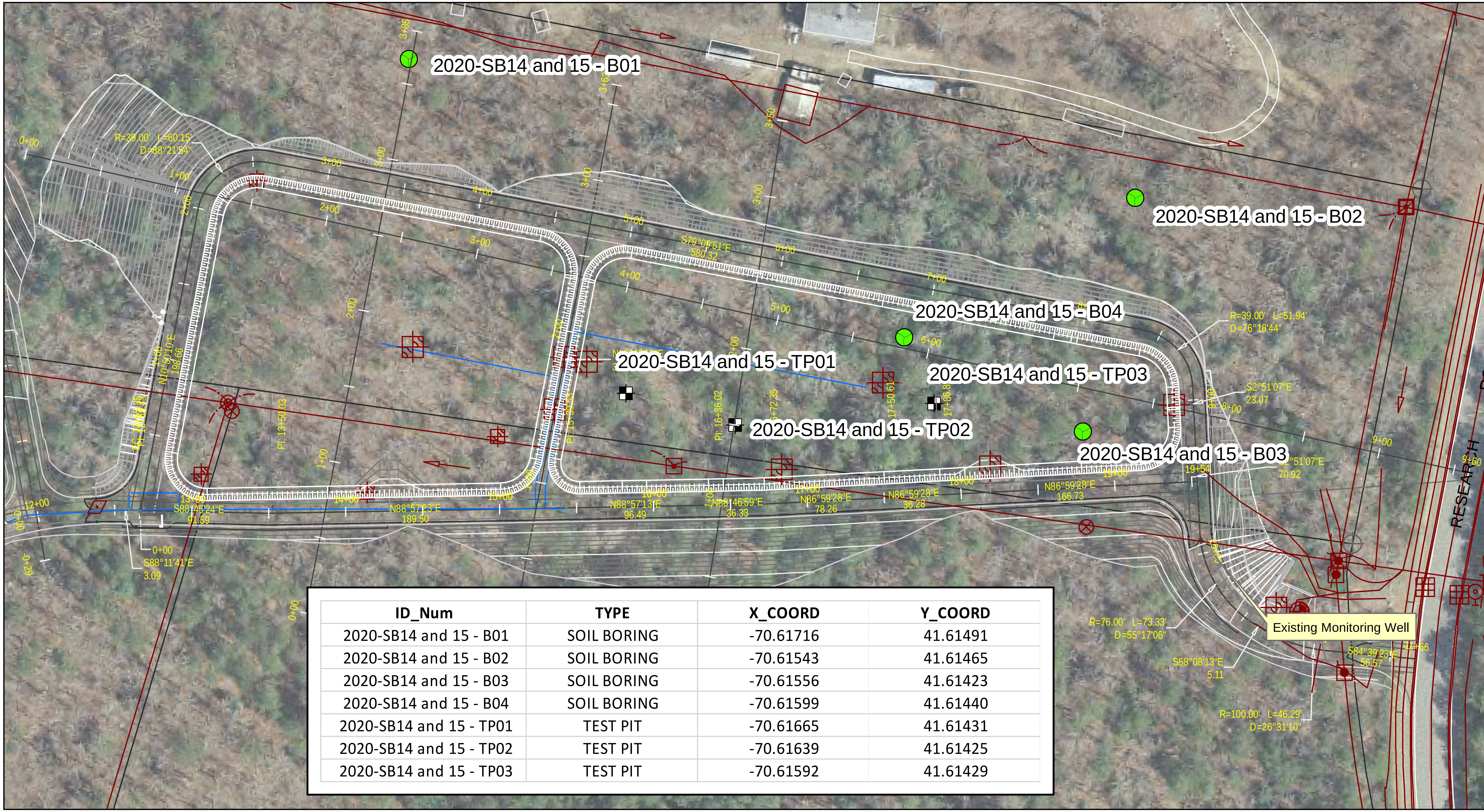
End of probe: 24'
End of sample: 28'
Groundwater encountered: None.
Sketch not to scale

Granular Soils BLOWS/FT	DENSITY	Cohesive Soils BLOWS/FT	DENSITY	Proportions Used
0 - 4	V. LOOSE	> 2	V. SOFT	Trace 0 - 10%
4 - 10	LOOSE	2 - 4	SOFT	Little 10 - 20%
10 - 30	M. DENSE	4 - 8	M. STIFF	Some 20 - 35%
30 - 50	DENSE	8 - 15	STIFF	And 35 - 50%
> 50	V. DENSE	15 - 30	V. STIFF	
		> 30	HARD	

Well Installation Key
- CONCRETE
- SAND PACK
Z - SOIL BACKFILL
- BENTONITE
- SCREEN
- APPROX. WATER LEVEL

Attachment D.

Open Sand Bed 15 Soil Evaluator Field Notes



ID_Num	TYPE	X_COORD	Y_COORD
2020-SB14 and 15 - B01	SOIL BORING	-70.61716	41.61491
2020-SB14 and 15 - B02	SOIL BORING	-70.61543	41.61465
2020-SB14 and 15 - B03	SOIL BORING	-70.61556	41.61423
2020-SB14 and 15 - B04	SOIL BORING	-70.61599	41.61440
2020-SB14 and 15 - TP01	TEST PIT	-70.61665	41.61431
2020-SB14 and 15 - TP02	TEST PIT	-70.61639	41.61425
2020-SB14 and 15 - TP03	TEST PIT	-70.61592	41.61429

Paper Size ANSI B

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

N

LEGEND

GHD

TOWN FALMOUTH, MASSACHUSETTS

Job Number 111-53041
Revision A
Date 01 Dec 2020

Open Sand Beds 14 and 15
2020 Field Investigations Work Plan

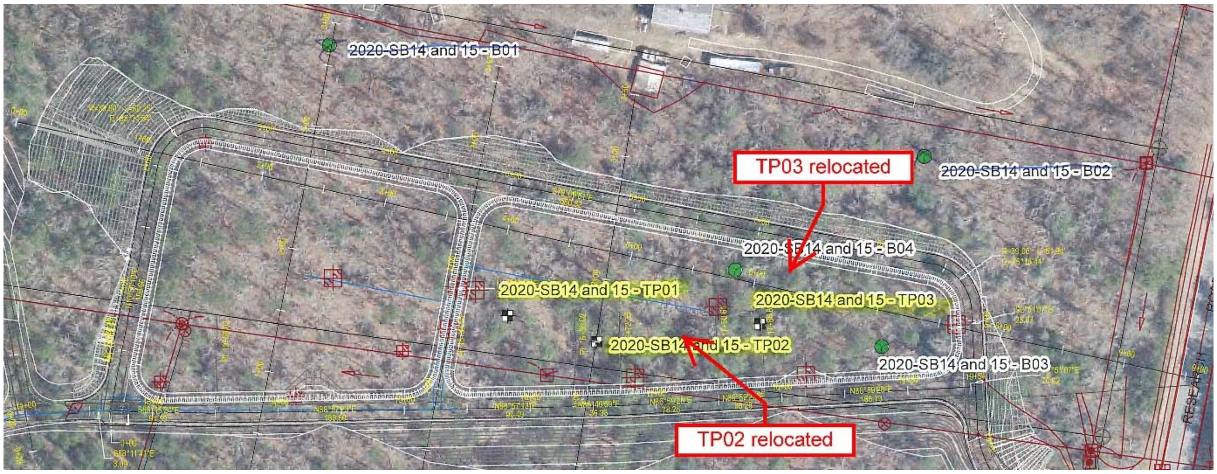
Figure 3

C:\data\Falmouth\Open Sand Beds_Borings.mxd

Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by:jjobrien

180 Lonsdale Street Melbourne VIC 3000 Australia T 61 3 8687 8000 F 61 3 8687 8111 E melmail@ghd.com W www.ghd.com

Bed 15


2020-SB14 and 15 - B01
TP03 relocated
2020-SB14 and 15 - B02
2020-SB14 and 15 - B04
2020-SB14 and 15 - TP01
2020-SB14 and 15 - TP03
2020-SB14 and 15 - TP02
2020-SB14 and 15 - B03
TP02 relocated

USDA maps this area as Plymouth-Barnstable complex (484). Both the Barnstable and Plymouth soils are categorized as outwash. The main difference between the soils is the content in Plymouth soils is greater. Samples were taken of the various layers for some of the holes. It was difficult to distinguish between the upper sand fill areas used to construct the bed and the underlying sandy parent material with the biggest difference being the lack of gravel and cobbles in the upper fill layers. It appears parent material may have been moved and placed on top of parent material in lower elevation areas. We were looking for a potential restrictive soil layer found in the boring B04, but we did not encounter it. These holes caved in very easily so advancing deep was a challenge. It was very cold and I had trouble keeping my fingers working without gloves on to feel the soil and write the logs. In all holes the underlying materials were sandy, gravelly materials with cobbles mixed in; very good for leaching.

Location: **Bed 15** Deep Hole #: **2020-SB14 and 15-TP01**
Date: **1/8/2021** Time: **8:00**
Weather: **Sunny, 30s**

Depth from Surface (inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other
0-64	Fill1	Medium to Coarse Sand	2.5 Y 6/8	-	Loose, clean sand
64-76	C1	Medium to Coarse Sand	2.5 Y 5/6	-	Cobbles, 20% gravel
76-156	C2	Medium to Coarse Sand	2.5 Y 5/6	-	Trace silt

As expected, the upper layers were clean sand fill materials. The parent material beneath consisted of some stratification of layer of sand and gravel with cobbles present. The bottom C2 layer was less gravelly and had trace silt.

Location of TP01

Note visible cobbles, difficult to determine layers due to very similar materials. Gravel and cobbles present and some stratification used to differentiate between fill and parent materials.

Location: **Bed 15** Deep Hole #: **2020-SB14 and 15-TP02**
Date: **1/8/2021** Time: **9:20**
Weather: **Sunny, 30s**

Depth from Surface (inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other
0-73	Fill1	Medium to Coarse Sand	2.5 Y 5/6	-	Loose, clean sand
73-180	Fill2	Medium to Coarse Sand	2.5 Y 5/6	-	Cobbles, 20% gravel

As expected, the upper layers were clean sand fill materials. While the second horizon may have been parent material, it looked more like it was relocated parent material. It held together and didn't cave in as much as the previous hole and the cobbles and gravel was not stratified, more mixed up. I am assuming this was original parent material used to fill in a low area. At the request of GHD this hole was relocated.

Location of TP02

This hole held together better without collapsing in.

Location: **Bed 15** Deep Hole #: **2020-SB14 and 15-TP03**
Date: **1/8/2021** Time: 9**:30**
Weather: **Sunny, 30s**

Depth from Surface (inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other
0-72	Fill1	Medium to Coarse Sand	2.5 Y 5/6	-	Loose, clean sand
72-167	Fill 2	Medium to Coarse Sand	2.5 Y 5/6	-	Cobbles, 20% gravel

As expected, the upper layers were clean sand fill materials. While the second horizon may have been parent material, it looked more like it was relocated parent material. This hole caved in more than the previous hole. The cobbles and gravel was not stratified, more mixed up. I am assuming this was original parent material used to fill in a low area. At the request of GHD this hole was relocated.

GHD Notes:

1. Compare fill 2 material from TP-3, compare with C1 & C2 soil from TP-1

2. Sample from 6-13 ft (non-silty material) from probe in B04.

4 tests total

TP03 location.

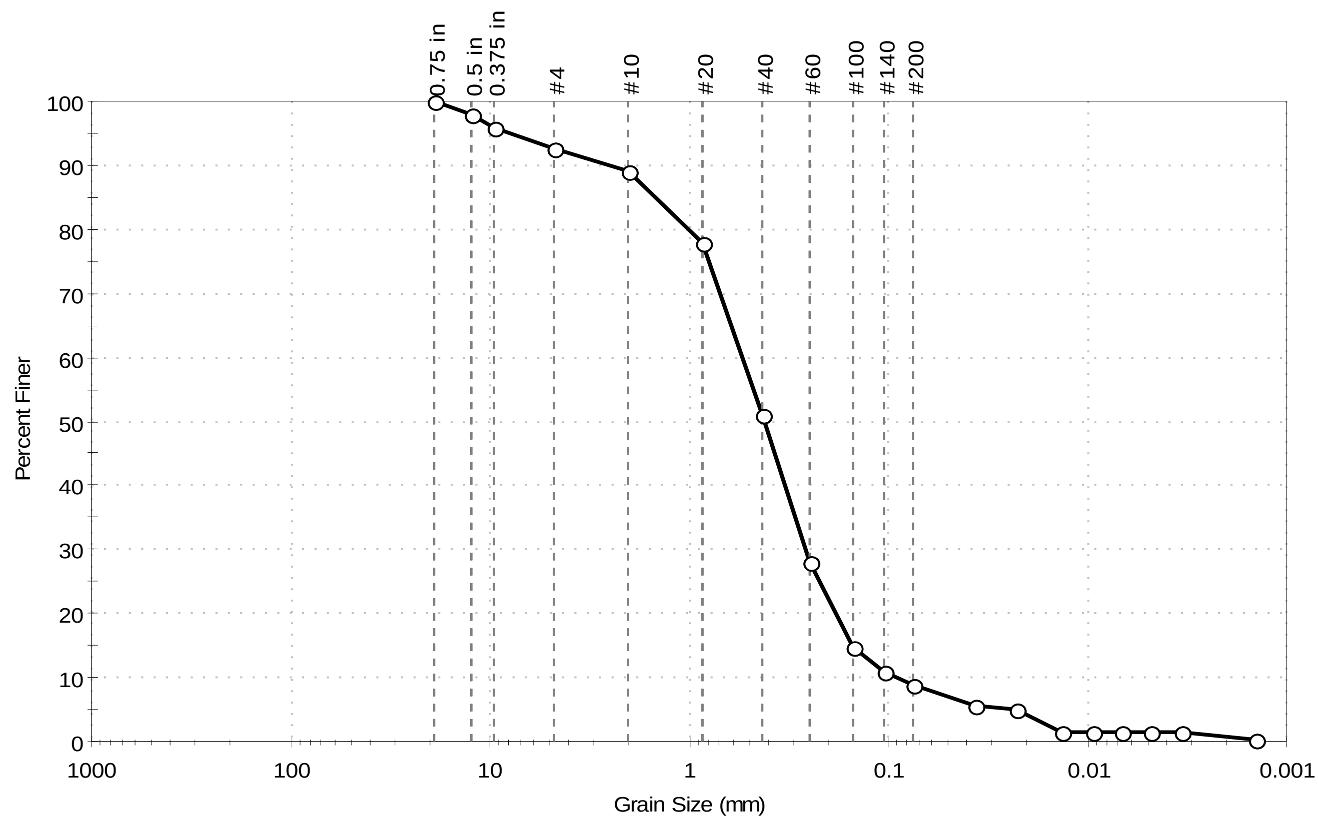
It appears this was parent material moved from a higher location into this lower area before the sand material was placed on top. No confining material was found.

Attachment E.

Open Sand Bed 15 Lab Results

Client: GHD Engineering			
Project: Great Pond TWMP Field Invest.			
Location: Falmouth, MA		Project No:	GTX-313651
Boring ID: TP01	Sample Type: bag	Tested By:	ckg
Sample ID: 2020-SB14 & 15-TP01	Test Date: 05/27/21	Checked By:	bfs
Depth : 6-13 ft	Test Id: 618483		
Test Comment: ---			
Visual Description: Moist, grayish brown sand with silt			
Sample Comment: ---			

Particle Size Analysis - ASTM D6913/D7928



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	7.5	83.6	8.9

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
0.75 in	19.00	100		
0.5 in	12.50	98		
0.375 in	9.50	96		
#4	4.75	92		
#10	2.00	89		
#20	0.85	78		
#40	0.42	51		
#60	0.25	28		
#100	0.15	15		
#140	0.11	11		
#200	0.075	8.9		
Hydrometer	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0363	6		
---	0.0227	5		
---	0.0134	1		
---	0.0095	1		
---	0.0067	1		
---	0.0048	1		
---	0.0034	1		
---	0.0014	0		

Coefficients

D_{85} = 1.4574 mm | D_{30} = 0.2610 mm

D_{60} = 0.5363 mm | D_{15} = 0.1511 mm

D_{50} = 0.4153 mm | D_{10} = 0.0907 mm

C_u = 5.913 | C_c = 1.400

Classification

ASTM Poorly graded SAND with Silt (SP-SM)

AASHTO Fine Sand (A-3 (1))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

Dispersion Device : Apparatus A - Mech Mixer

Dispersion Period : 1 minute

Est. Specific Gravity : 2.65

Separation of Sample: #200 Sieve

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Client:	GHD Engineering				
Project:	Great Pond TWMP Field Invest.				
Location:	Falmouth, MA			Project No:	GTX-313651
Boring ID:	TP01	Sample Type:	bag	Tested By:	cam
Sample ID:	2020-SB14 & 15-TP01	Test Date:	05/24/21	Checked By:	bfs
Depth :	6-13 ft	Test Id:	618476		

Test Comment: ---
Visual Description: Moist, grayish brown sand with silt
Sample Comment: ---

Atterberg Limits - ASTM D4318

Sample Determined to be non-plastic

Symbol	Sample ID	Boring	Depth	Natural Moisture Content,%	Liquid Limit	Plastic Limit	Plasticity Index	Liquidity Index	Soil Classification
◆	2020-SB14 15-TP01	TP01	6-13 ft	5	n/a	n/a	n/a	n/a	Poorly graded SAND with Silt (SP-SM)

49% Retained on #40 Sieve
Dry Strength: LOW
Dilatancy: RAPID
Toughness: n/a
The sample was determined to be Non-Plastic

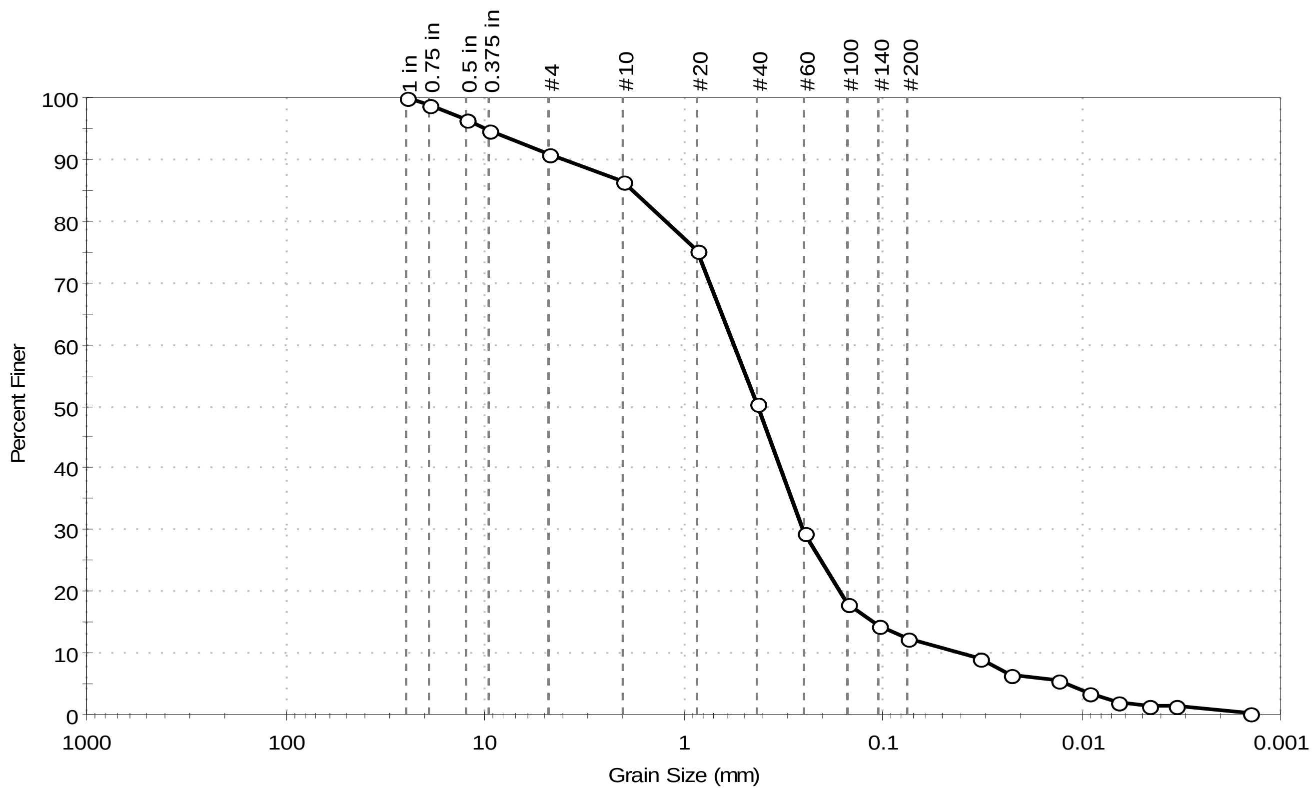
Client:	GHD Engineering		
Project:	Great Pond TWMP Field Invest.		
Location:	Falmouth, MA	Project No:	GTX-313651
Boring ID: TP03	Sample Type: bag	Tested By:	ckg
Sample ID: 2020-SB14 & 15-TP03	Test Date: 05/27/21	Checked By:	bfs
Depth : 6-14 ft	Test Id: 618482		

Test Comment: ---

Visual Description: Moist, dark grayish brown silty sand

Sample Comment: ---

Particle Size Analysis - ASTM D6913/D7928



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	9.3	78.5	12.2

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
1 in	25.00	100		
0.75 in	19.00	99		
0.5 in	12.50	96		
0.375 in	9.50	95		
#4	4.75	91		
#10	2.00	87		
#20	0.85	75		
#40	0.42	50		
#60	0.25	29		
#100	0.15	18		
#140	0.11	14		
#200	0.075	12		
Hydrometer	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0323	9		
---	0.0230	6		
---	0.0131	6		
---	0.0091	4		
---	0.0066	2		
---	0.0046	1		
---	0.0034	1		
---	0.0014	0		

Coefficients

D_{85} = 1.7777 mm | D_{30} = 0.2533 mm

D_{60} = 0.5560 mm | D_{15} = 0.1121 mm

D_{50} = 0.4212 mm | D_{10} = 0.0401 mm

C_u = 13.865 | C_c = 2.878

Classification

ASTM Silty SAND (SM)

AASHTO Silty Gravel and Sand (A-2-4 (0))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

Dispersion Device : Apparatus A - Mech Mixer

Dispersion Period : 1 minute

Est. Specific Gravity : 2.65

Separation of Sample: #200 Sieve

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Client:	GHD Engineering				
Project:	Great Pond TWMP Field Invest.				
Location:	Falmouth, MA			Project No:	GTX-313651
Boring ID:	TP03	Sample Type:	bag	Tested By:	cam
Sample ID:	2020-SB14 & 15-TP03	Test Date:	05/24/21	Checked By:	bfs
Depth :	6-14 ft	Test Id:	618475		

Test Comment: ---
Visual Description: Moist, dark grayish brown silty sand
Sample Comment: ---

Atterberg Limits - ASTM D4318

Sample Determined to be non-plastic

Symbol	Sample ID	Boring	Depth	Natural Moisture Content,%	Liquid Limit	Plastic Limit	Plasticity Index	Liquidity Index	Soil Classification
◆	2020-SB14 15-TP03	TP03	6-14 ft	6	n/a	n/a	n/a	n/a	Silty SAND (SM)

50% Retained on #40 Sieve
Dry Strength: LOW
Dilatancy: RAPID
Toughness: n/a
The sample was determined to be Non-Plastic

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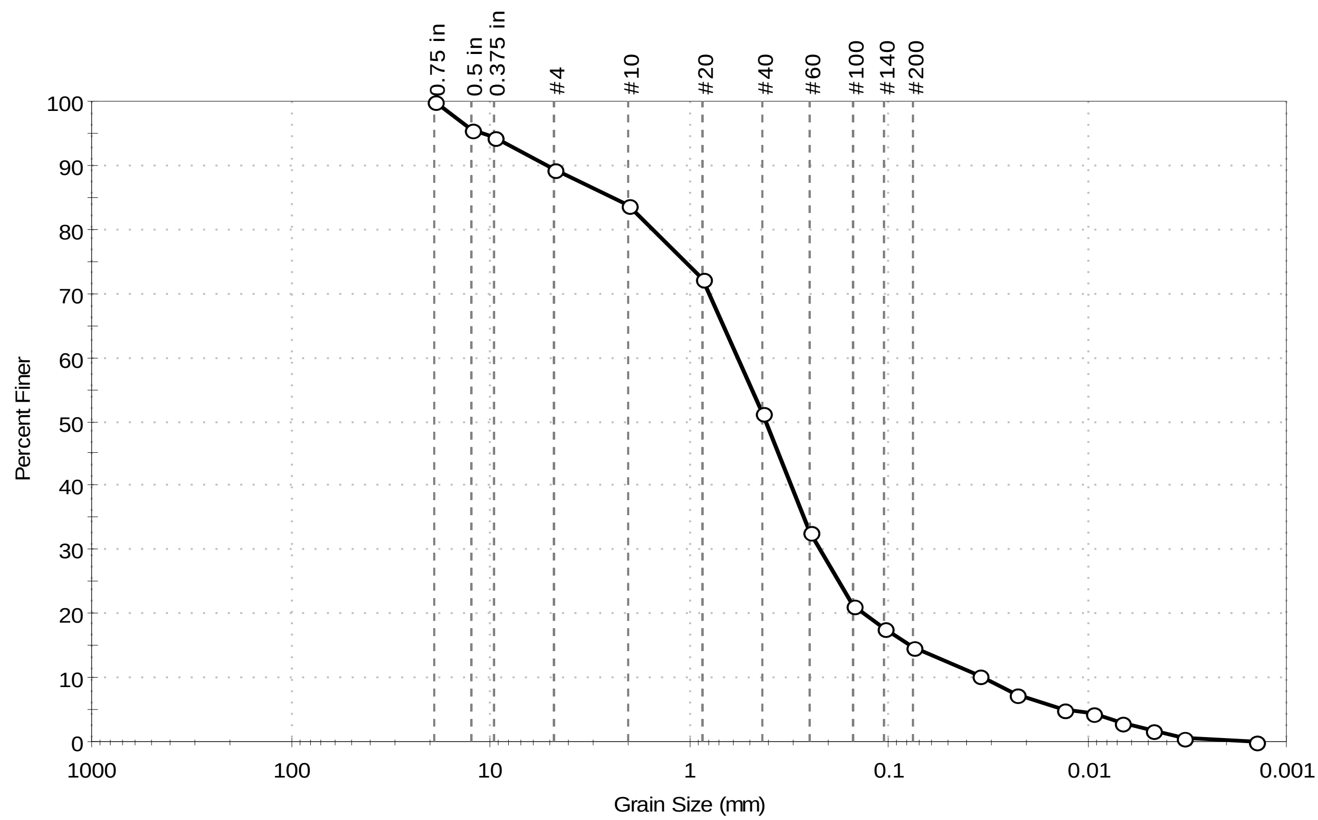
Client:	GHD Engineering				
Project:	Great Pond TWMP Field Invest.				
Location:	Falmouth, MA			Project No:	GTX-313651
Boring ID:	B04	Sample Type:	bag	Tested By:	ckg
Sample ID:	2020-SB14 & 15-B04	Test Date:	05/27/21	Checked By:	bfs
Depth :	4-12 ft	Test Id:	618484		

Test Comment: ---
Visual Description: Moist, grayish brown silty sand
Sample Comment: ---

Particle Size Analysis - ASTM D6913/D7928



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	10.6	74.8	14.6

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
0.75 in	19.00	100		
0.5 in	12.50	95		
0.375 in	9.50	94		
#4	4.75	89		
#10	2.00	84		
#20	0.85	72		
#40	0.42	51		
#60	0.25	33		
#100	0.15	21		
#140	0.11	18		
#200	0.075	15		
Hydrometer	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0352	10		
---	0.0228	7		
---	0.0132	5		
---	0.0093	4		
---	0.0067	3		
---	0.0047	2		
---	0.0033	1		
---	0.0014	0		

Coefficients

D_{85} = 2.4295 mm
D_{30} = 0.2209 mm
D_{60} = 0.5654 mm
D_{15} = 0.0785 mm
D_{50} = 0.4078 mm
D_{10} = 0.0331 mm
C_u = 17.082
C_c = 2.607

Classification

ASTM Silty SAND (SM)

AASHTO Silty Gravel and Sand (A-2-4 (0))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR
Sand/Gravel Hardness : HARD
Dispersion Device : Apparatus A - Mech Mixer
Dispersion Period : 1 minute
Est. Specific Gravity : 2.65
Separation of Sample: #200 Sieve

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Client:	GHD Engineering				
Project:	Great Pond TWMP Field Invest.				
Location:	Falmouth, MA			Project No:	GTX-313651
Boring ID:	B04	Sample Type:	bag	Tested By:	cam
Sample ID:	2020-SB14 & 15-B04	Test Date:	05/24/21	Checked By:	bfs
Depth :	4-12 ft	Test Id:	618477		

Test Comment: ---
Visual Description: Moist, grayish brown silty sand
Sample Comment: ---

Atterberg Limits - ASTM D4318

Sample Determined to be non-plastic

Symbol	Sample ID	Boring	Depth	Natural Moisture Content,%	Liquid Limit	Plastic Limit	Plasticity Index	Liquidity Index	Soil Classification
◆	2020-SB14 15-B04	B04	4-12 ft	3	n/a	n/a	n/a	n/a	Silty SAND (SM)

49% Retained on #40 Sieve
Dry Strength: LOW
Dilatancy: RAPID
Toughness: n/a
The sample was determined to be Non-Plastic

Attachment F.

Crocker Pond, Falmouth Potential Soil Attenuation of Phosphorus Migration from Infiltration Treated Wastewater at Falmouth WWTF Open Sand Beds 14 & 15; Prepared by EcoLogic

June 2021
Crocker Pond, Falmouth

Appendix X

Crocker Pond, Falmouth Potential Soil Attenuation of Phosphorus Migration from Infiltrating Treated Wastewater at Site 7

Prepared by
EcoLogic, LLC
Cazenovia NY

Prepared for
GHD, Inc.

TABLE OF CONTENTS

TABLES

FIGURES

1 Project Objective

This technical memorandum summarizes the potential environmental impact of expanding wastewater infiltration beds at the Falmouth Wastewater Treatment Facility (WWTF). The issue of primary interest is migration of wastewater phosphorus through the soil matrix and impact on downgradient freshwater resources, including Crocker Pond.

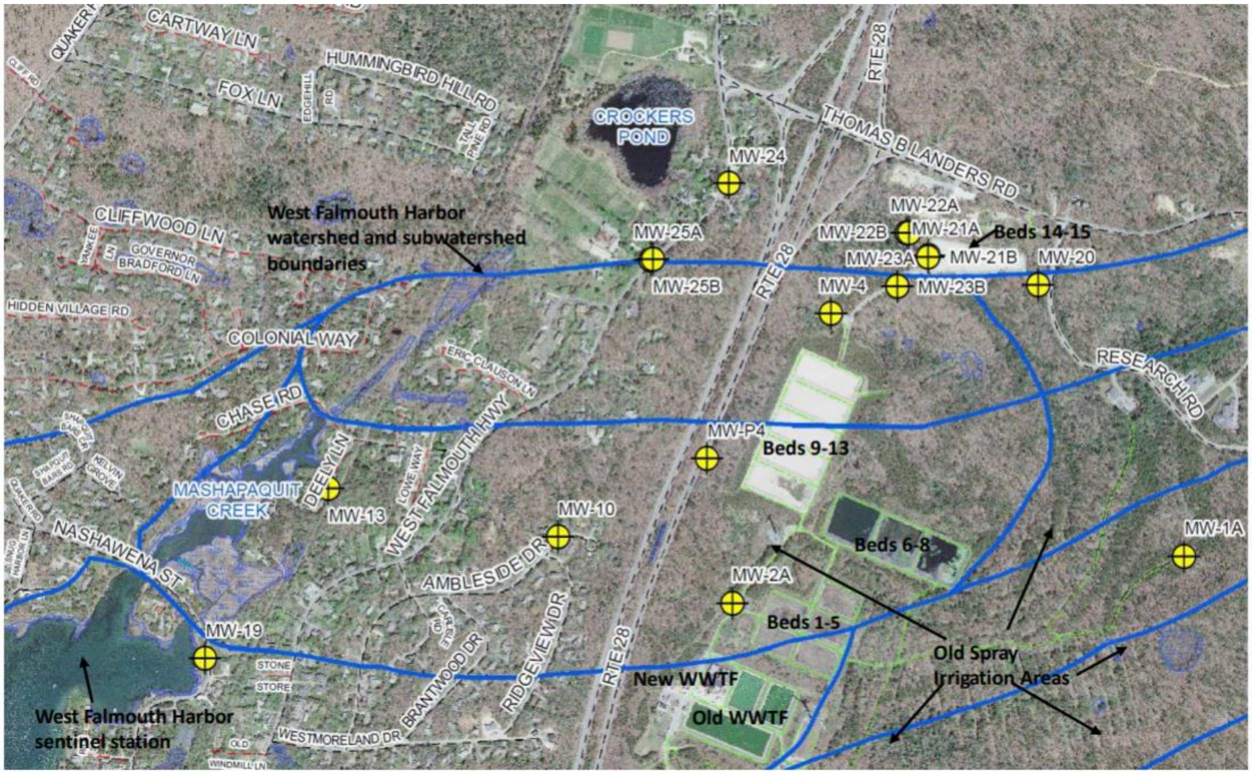
Our analysis builds on a report we completed in 2013 on behalf of GHD and their ongoing wastewater management planning support to the Town of Falmouth (EcoLogic 2013). This memorandum reviews the estimated phosphorus adsorption capacity downgradient of wastewater infiltration at Site 7 and evaluates recent water quality monitoring data in downgradient monitoring wells and Crocker Pond with respect to the 2013 projections. In addition, we evaluate the potential impact of modified effluent phosphorus loading rates at Site 7 on downgradient phosphorus adsorption capacity.

2 Current Conditions

2.1 Monitoring Wells

Since publication of the 2013 study, infiltration beds designated as beds 14 and 15 were installed at Site 7 and began operation in early 2017. Monitoring wells have been constructed along the predicted flow path of infiltrated wastewater (**Figure 1);** the wells are monitored routinely for a suite of indicator parameters including phosphorus. Details of the monitoring wells, including the depth of screened interval and distance downgradient of the infiltration beds, are listed in **Table 1.**

Figure 1
Falmouth Main WWTF – Locations of Recharge Beds 1-15 and Monitoring Wells



Source: Falmouth WWTF

Table 1
Monitoring Wells Associated with Beds 14 & 15

Town Well ID	GHD Well ID	Well Depth (ft)	Distance from Sand Bed (ft)
MW25A	GHD-3A	97.9	1847.81
MW25B	GHD-3B	117.75	1858.59
MW21A	GHD-4A	69	12.14
MW21B	GHD-4B	97	11.64
MW22A	GHD-5A	46.16	180.68
MW22B	GHD-5B	74.5	170.98
MW23A	GHD-6A	72	225.76
MW23B	GHD-6B	98	238.69

Town Well ID	GHD Well ID	Well Depth (ft)	Distance from Sand Bed (ft)
MW20	GHD-1	85.25	130.42 (upgradient)
MW24	GHD-2	95	1437.71

Source: GHD, Drawing of Overall Site Plan – Proposed Recharge Beds 14 & 15, Town of Falmouth, MA

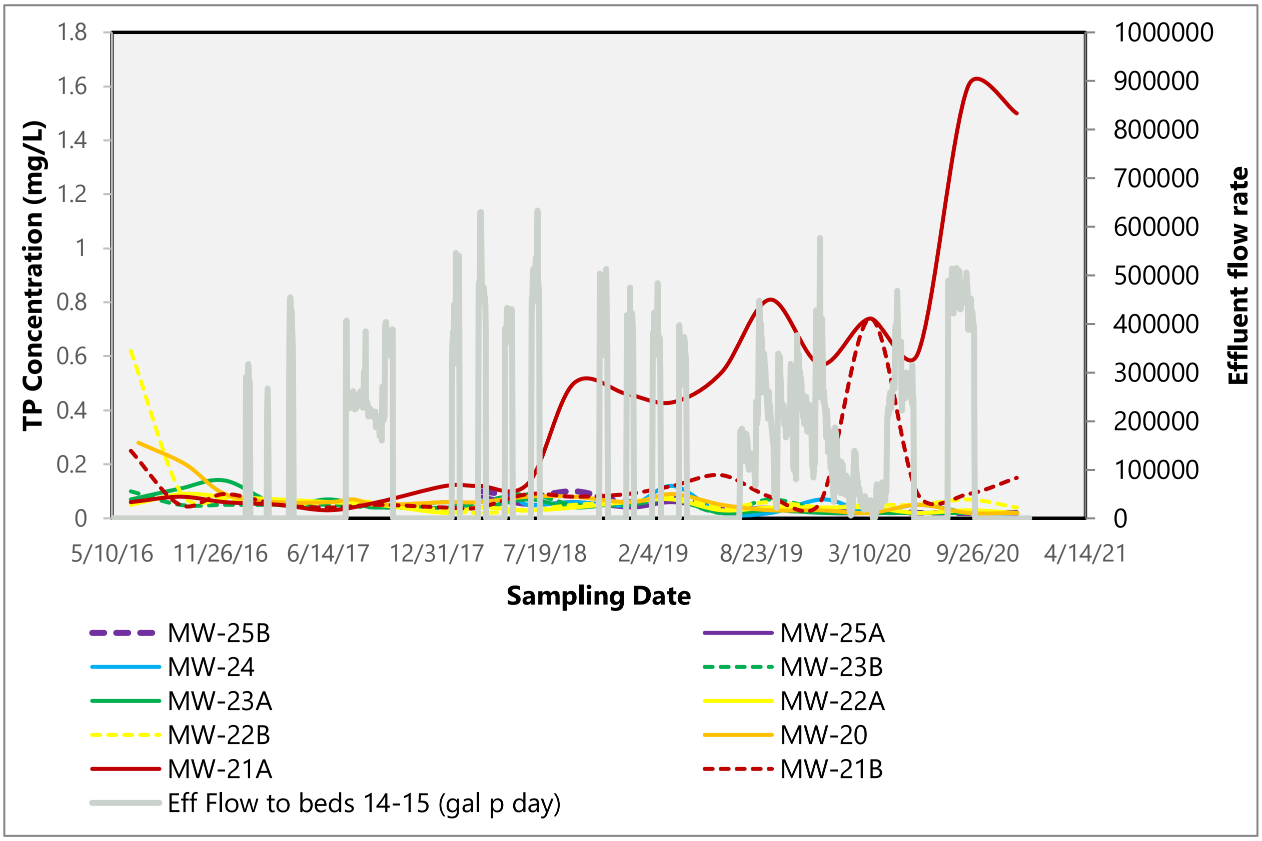
The Falmouth WWTF operates under permit conditions specified in permit 168-6 (Mass DEP, 2020). Flow to sand beds 14 and 15 are capped at 260,000 gallons per day (GPD) as an annual average, with a maximum daily limit of 470,000 GPD. Flow through sand beds 14 and 15 are monitored daily. Total phosphorus and orthophosphate are sampled quarterly. In addition, monitoring wells were sampled quarterly for total phosphorus and orthophosphate.

Results of quarterly total phosphorus testing of monitoring wells downgradient of infiltration beds 14 & 15 are displayed in **Figure 2** along with effluent application rates. As evident from the graph, the infiltration beds do not receive constant flow of treated effluent. Rather, the Falmouth WWTF sequences effluent application among its permitted infiltration beds. Testing of the monitoring wells began in mid-2016; wastewater application to infiltration beds 14 and 15 began in January 2017.

In general, groundwater phosphorus concentrations have remained consistent over the monitoring period to date. The one exception is monitoring well 21A; this well is sited 12 ft. directly downgradient of the infiltration beds. Phosphorus concentrations in this monitoring well are directly affected by infiltrating wastewater due to the flux rate and minimal contact with native soils. However, phosphorus concentrations measured in monitoring well 21B do not exhibit the same reactivity, likely because of the increased depth to the screened interval and associated increased opportunity for phosphorus attenuation within the soil profile.

Monitoring data collected to date indicate no issues of potential concern related to downgradient phosphorus migration based on operating conditions of the Falmouth WWTF. Wastewater volume and loading vary seasonally with population served.

Figure 2
TP Concentrations in Monitoring Wells Associated with Sand Beds 14 & 15



Source: Falmouth WWTF

2.2 Crocker Pond

Crocker Pond is currently monitored annually to track productivity and water quality conditions. Samples are collected monthly during the summer recreational season (July, August, and September) and submitted for laboratory analysis of total phosphorus, total inorganic nitrogen, total organic nitrogen, and chlorophyll-a. The field sampling team also measures Secchi disk transparency, an indication of water clarity. Results of trophic state indicator parameters measured between 2016 and 2020 are summarized in **Table 2**.

Table 2
Crocker Pond Water Trophic State Indicator Parameters, 2016-2020

Month-Year	pH	TP at 0.5 m (mg/L)	Chlorophyll-a (ug/L)	Secchi depth (m)
Jul-16	6.32	0.025	1.06	3.5
Aug-16	6.59	0.013	1.82	4.5

Month-Year	pH	TP at 0.5 m (mg/L)	Chlorophyll-a (ug/L)	Secchi depth (m)
Sep-16	6.5	0.013	1.14	3.6
Jul-17	6.48	0.018	1.02	4.3
Aug-17	6.52	0.015	2.27	5.15
Sep-17	6.58	0.018	1.27	6.2
Jul-18	6.82	0.021	1.27	2.4
Aug-18	6.59	0.022	1.14	4.3
Sep-18	6.52	0.016	1.86	4
Jul-19	6.39	0.013	3.16	4.09
Aug-19	6.48	0.012	3.4	4.55
Sep-19	6.38	0.022	3.35	6.1
Jul-20	6.71	0.042	1.99	4.2
Aug-20	6.95	0.017	1.96	3.92
Sep-20	6.58	0.017	2.06	4.1

Source: Falmouth WWTF

Phosphorus concentrations differ between the surface and deep layers of Crocker Pond (**Figure 3**). This pattern is typical of kettle ponds that are deep enough to develop stable thermal stratification; deeper waters remain isolated from atmospheric exchange during summer. Depletion of dissolved oxygen in the deeper waters can result in chemical changes at the sediment surface and the release of legacy phosphorus. The impact is evident in the higher phosphorus concentrations measured in Crocker Pond during August and September sampling events.

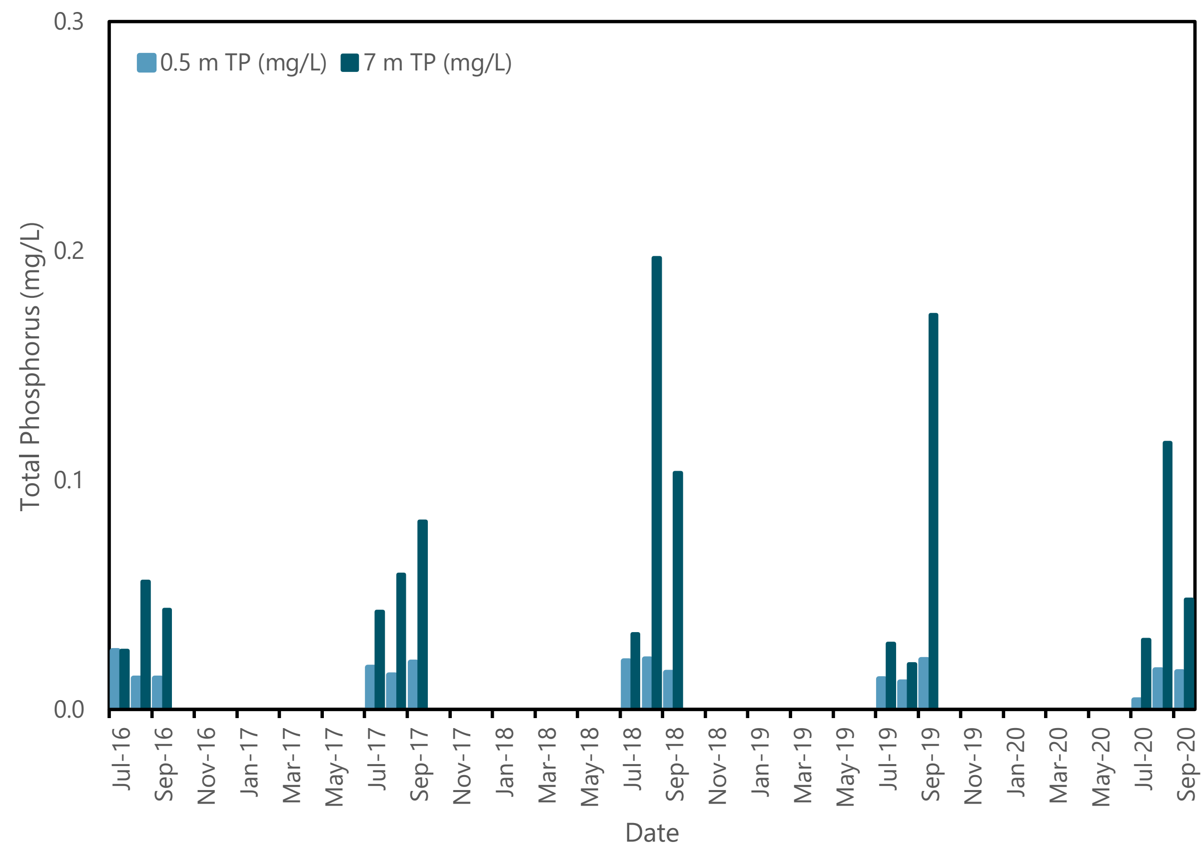
Baseline data for Crocker Pond's trophic state indicator parameters were compiled as part of the 2013 evaluation. These data were collected under the PALS program in 2001, 2004-2007 using comparable sampling and analytical protocols in place since 2016. Data collected between 2016 and 2020 indicate the interannual variability in pond water quality conditions.

Table 3
Crocker Pond Trophic State Parameter Tracking

Year	Total P, ug/L	Chlor-a, ug/L	Secchi disk transparency, m
2001	15.1	1.65	4.3
2004	12.9	2.07	4.0
2005	7.9	2.41	4.7
2006	16.7	3.22	4.7
2007	7.7	2.40	1.5
2016	13.0	1.14	3.3

2017	17.0	1.52	5.2
2018	19.6	1.42	3.6
2019	15.7	3.30	4.9
2020	25.3	2.00	4.1

Figure 3
Baseline Total Phosphorus Concentrations at Crocker Pond, 2016-2020



Source: Falmouth WWTF (sent by Amy Lowell, allcrockerpond.xlsx

3 Testing Scenarios

Downgradient phosphorus attenuation of infiltrated effluent is governed by the volume of soil to which the infiltrating treated wastewater effluent is exposed (soil prism), the mass and concentration of phosphorus present in the treated wastewater, the rate of infiltration and groundwater flux, and the adsorptive capacity of the soil prism.

3.1 Retention Capacity Calculations

An empirical model was applied to estimate phosphorus retention capacity of the soil. Model projections are primarily driven by the amount of reactive aluminum present in the soils and the downgradient prisms through which the applied effluent will migrate. GHD identified an effluent flow rate of 0.5 MGD for this empirical groundwater modeling scenario. We evaluated this scenario at different total phosphorus effluent concentrations to support a sensitivity analysis. Model input parameters and results are provided in **Table 4**.

Table 4
Model Input Parameters and Results

Input	Scenario 0.5 at 0.2 mg/L	Scenario 0.5 at 2.5 mg/L	Scenario 0.5 at 3.14 mg/L	Source or Calculation
P Loading Characteristics				
Proposed volume of infiltrated wastewater at Allen Parcel (MGD)	0.55			GHD Scenario Proposal
Proposed volume of infiltrated wastewater at Allen Parcel (L/d)	2,081,976			GHD Scenario Proposal (unit conversion)
Current effluent concentration (mg/L)	0.2	2.5	3.14	Falmouth WWTF (WWTF eff flow N-P.xlsx)
Estimated TP load at specified effluent concentration mg/L (kg/yr)	151.98	1,899.80	2,386.15	Proposed volume of infiltrated wastewater at Allen Parcel * Projected Effluent concentration * 365 d
Soil Characteristics				
Soil Porosity (g/cm^3)	1.6			Average bulk density based on soil texture data
Al content of unsaturated soils (mg/kg)	732			2013 Crocker Pond Soil Boring
Al content of saturated soils (mg/kg)	773			2013 Crocker Pond Soil Boring

Input	Scenario 0.5 at 0.2 mg/L	Scenario 0.5 at 2.5 mg/L	Scenario 0.5 at 3.14 mg/L	Source or Calculation
% of reactive Al in unsaturated soils (%)	10			2013 EcoLogic Report, Crocker Pond
% of reactive Al in saturated soils (%)	5			2013 EcoLogic Report, Crocker Pond
Molar ratio of reactive Al to P binding sites (kg P/kg Al)	0.3			2013 EcoLogic Report, Crocker Pond
Crocker Pond				
% of Plume intercepting Crocker Pond	21.9			GHD particle track analysis
Unsaturated prism (m^3)	56,878.32			GHD calculation
Saturated prism (m^3)	3,903,535.30			GHD calculation
Capacity of unsaturated zone to sequester P (years)	60.04	4.80	3.82	Bound P to Al in unsaturated soil / Estimated TP load
Capacity of saturated zone to sequester P (years)	2,175.74	174.06	138.58	Bound P to Al in saturated soil / Estimated TP load

3.2 Phosphorus Sequestration Capacity

The volume of soil interacting with the infiltrating wastewater plume (the soil prism) can be estimated using various assumptions. For this assignment, the volume of the soil prism was estimated using a particle tracking model to project the flow path of infiltrated effluent toward Crocker Pond. The particle track analysis estimates that 21.9% of infiltrated wastewater will enter Crocker Pond under the 0.55 MGD scenario.

The soil prism calculation incorporates the three dimensions (depth of vertical penetration, lateral plume width and horizontal distance to each waterbody). The soil prism was multiplied by the soil's bulk density (1.6×10^6 g/cm^3) to estimate the mass of soil within the flow path of the infiltrating wastewater plume. We estimated the phosphorus sequestration capacity using site-specific data (aluminum content), aluminum reactivity, and the mass of soil to calculate potential phosphate binding sites. The soil prism was divided into saturated and unsaturated zones to differentiate aerobic and anaerobic processes governing phosphorus sequestration. The result of this calculation is provided in **Table 3**.

The potential contributions of other reactive minerals that play a role in phosphorous sequestration (notably iron and manganese) are not included in the model calculations. Inclusion of these other minerals would increase capacity even further.

With an effluent flow rate of 0.55 MGD and a TP effluent concentration of 2.5 mg/L, it is estimated that the soil has a phosphorus attenuation capacity of nearly 180 years.

3.3 Sensitivity Analysis

There are numerous assumptions that affect the calculated phosphorus binding capacity downgradient of the Allen Parcel. Because the phosphorus concentration in wastewater effluent determines the amount of phosphorus molecules that need to be adsorbed or precipitated, a sensitivity analysis was performed under various total phosphorus effluent concentrations. To ensure that the sensitivity analysis is based on relevant environmental conditions, a total phosphorus effluent concentration of 0.2 mg/L (anticipated under tertiary treatment) was used, as well as a TP effluent concentration of 3.14 mg/L, consistent with current TP effluent concentrations from the Falmouth WWTF. Results of the sensitivity analysis at each concentration is provided in **Table 4**. Under the 0.2 mg/L and the 3.14 mg/L TP effluent concentration, the soil has a phosphorus attenuation capacity of 2,200 years and 140 years, respectively.

4 Recommendations for Monitoring

It is recommended that the Falmouth WWTF continue monitoring Crocker Pond to track trends in water quality and habitat. Consistent field and laboratory protocols will facilitate trend analysis. Annual monitoring can help document year-to-year variability and build upon the existing baseline characterization. The recommended long term monitoring program is described in **Table 5**.

Table 5
Recommended Long-Term Monitoring Program

Parameter	Rationale	Sampling Protocol
Water temperature and dissolved oxygen profile	Aquatic habitat, evidence of DO depletion	Sample at 1 m intervals at deepest point in pond in summer months (June-Sept)
Nearshore (littoral zone) habitat plant community, algal abundance, sediment types	Establish baseline, consider whether recreational access is impaired	Single survey, July
Trophic state parameters: total P, total N, chlorophyll-a, secchi disk transparency	Baseline productivity level	Two depths: surface and deep. Sample in summer months (June-September)

Parameter	Rationale	Sampling Protocol
Current recreational access points and protected lands	Document how the resource is used	Field observations and mapping
Septic systems within 300 ft. of waterbodies	Estimate potential for phosphorus contribution from septic systems	Field observations and mapping
Land use and impervious surfaces in watershed	Estimate potential for phosphorus contribution from stormwater	Field observations and mapping

5 References

EcoLogic, 2013. Potential Soil Attenuation of Phosphorus Migration from Infiltrating Treated Water Recharge at Site 7.

Mass DEP, 2020. Individual Groundwater Discharge permit. Falmouth WWTF: Permit No. 168-6.

Attachment G.

Great Pond Targeted Watershed Management Plan – Technical Memorandum 2, Groundwater Modeling Evaluation of Treated Effluent Recharge to Groundwater, Town of Falmouth MA; Prepared by GHD

Technical Memorandum

June 10, 2022

To	Amy Lowell, Town of Falmouth, MA	**Tel**	774-470-1637 774-470-1640
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From	Anastasia Rudenko, PE, BCEE J. Jefferson Gregg, PE, BCEE Hongze Gao, Ph.D;, P.Eng.	**Ref. No.**	11153041
Subject	Great Pond Targeted Watershed Management Plan – Technical Memorandum 2 Groundwater Modeling of Treated Effluent Recharge to 3 Sites - Final		

1. Introduction

The Town of Falmouth, Massachusetts (Falmouth) is undertaking a Comprehensive Wastewater Management Planning (CWMP) process to develop strategies for addressing wastewater needs and nutrient impacts to the Town's coastal estuaries. A key element of that planning process is to identify and evaluate sites where treated wastewater effluent can be recharged to groundwater. Four sets of discharge scenarios were modeled by Watershed Hydrogeologic in January 2020. The results of that modeling are documented in 'Groundwater Modeling Conducted in 2020 for Open Sand Beds 14 & 15 and the Allen Parcel – Final', prepared by GHD and Watershed Hydrogeologic, dated June 21 2021 (Attachment A).

This technical memorandum describes additional groundwater modeling conducted by GHD in May 2021 to evaluate effluent recharge to the following three sites:

– Existing Open Sand Beds at the Falmouth Wastewater Treatment Facility
– The Allen Parcel and,
– The Augusta Parcel.

The groundwater model was used to predict groundwater mounding from treated effluent recharge at each site and to predict the migration of effluent from the open sand beds to downgradient surface water bodies. The findings will be used to develop unattenuated and attenuated nitrogen load estimates for each of the recharge scenarios.

To conduct the groundwater modeling, GHD constructed a three-dimensional (3D) numerical groundwater model of the groundwater flow system in the vicinity of the sites based on the regional groundwater flow model developed by the United States Geological Survey (USGS) for the Sagamore Lens portion of the Cape Cod aquifer system Walter et al. (2019)[1] that is a further development of the previous regional USGS model by Walter and Whealan (2005)[2].

[1] Walter, D.A., McCobb, T.D., and Fienen, M.N., 2019, Use of a numerical model to simulate the hydrologic system and transport of contaminants near Joint Base Cape Cod, western Cape Cod, Massachusetts: U.S. Geological Survey Scientific Investigations Report 2018–5139, 98 p., https://doi.org/10.3133/sir20185139.

[2] Walter, D.A., and Whealan, A.T., 2005, Simulated Water Sources and Effects of Pumping on Surface and Ground Water, Sagamore and Monomoy Flow Lenses, Cape Cod, Massachusetts: U.S. Geological Survey Scientific Investigations Report 2004-5181, 85 p.

This Technical Memorandum is organized as follows:

- Section 1 – Introduction
- Section 2 – Regulations, References and Guidelines
- Section 3 – Modeling Approach and Software Selection
- Section 4 – Model Development and Verification
- Section 5 – Evaluation of Treated Effluent Recharge to Groundwater
- Section 6 – Summary and Conclusions

2. References, Regulation and Guidelines

The references, regulations, and design guidelines listed below were used to develop this technical memorandum. Documents are referred to by the abbreviation indicated in parenthesis for the remainder of the technical memorandum.

References:

- 'Groundwater Modeling Conducted in 2020 for Open Sand Beds 14 & 15 and the Allen Parcel – Final', prepared by GHD and Watershed Hydrogeologic, dated June 21 2021 (included as Attachment A)
- TASA TM No. 3 – South Coast Embayments Preliminary Evaluations and Notice of Project Change Project – Final Teaticket / Acapesket Study Area Discharge Technologies Evaluation – Technical Memorandum No. 3, prepared by GHD, dated April 11, 2019 (TASA TM-3)
- TASA TM No. 5- South Coast Embayments Preliminary Evaluations and Notice of Project Change Project – Hydraulic Load Tests at the Augusta Parcel and Allen Parcel – Technical Memorandum No. 5, prepared by GHD, dated April 11, 2019 (TASA TM-5)
- TASA TM No. 7 – South Coast Embayments Preliminary Evaluations and Notice of Project Change Project – Final Teaticket / Acapesket Study Area Conceptual Layouts and Preliminary Cost Estimates Evaluation – Technical Memorandum No. 7, prepared by GHD, dated April 11, 2019 (TASA TM-7)
- Town of Falmouth, Massachusetts Recharge Beds 14 &15 Contract No. WW-14-04 CW SRF No. 3928 Record Drawings, prepared by GHD, dated June 2017
- Modified Individual Groundwater Discharge Permit No. 168-5, effective date December 22, 2015 (2015 Permit)
- TM-8 - Falmouth Nutrient Management Plan – Hydraulic Load Tests at Sites 7 and 10, prepared by GHD, dated August 31, 2011 (2011 TM-8)
- 'Technical Memorandum No. 12 – Updated Groundwater Modeling for site 7 Falmouth Comprehensive Wastewater Management Planning (CWMP) Project', prepared by GHD and Watershed Hydrogeologic and dated July 30, 2013

3. Modeling Approach and Software Selection

GHD adopted the USGS regional groundwater flow model developed for the Sagamore Lens of the Cape Cod aquifer system (Walter, et.al., 2019). From this regional model, GHD applied Telescopic Mesh Refinement (TMR) to create a local-scale model for the three sites and their surrounding areas to conduct the groundwater modeling evaluations. The TMR method is the process of creating a more refined model within a subregion (or local-scale) of a larger-scale model or the regional model. The local-scale model is not linked to the regional model but, rather, is a separate refined model that adopts the input parameters and boundary conditions applied in the regional model. This is done to obtain a local-scale model with greater resolution focused on the key area of interest for the groundwater modeling evaluation (i.e., the three sites).

The USGS regional model employed MODFLOW-2005 (Harbaugh, 2005)[3] to represent the groundwater flow within the Sagamore Lens of the Cape Cod aquifer system. GHD applied MODFLOW-2005 to develop the local-scale model for the groundwater flow system containing the three sites. MODFLOW-2005 uses the finite-difference method, leading to a numerical approximation that allows for the description of, and solution to, groundwater flow systems. A rectangular finite-difference grid is superimposed over the study area to horizontally subdivide the region of interest into rectangular model cells. Layers are used to subdivide the study area vertically into units of common hydrogeologic properties. The groundwater flow equation is then formulated using the finite-difference method as a water balance in terms of the hydraulic head, or groundwater elevation, at the center of every model cell. MODFLOW-2005 allows for the specification of flows associated with wells, groundwater recharge, rivers, drains, streams, and other groundwater sources/sinks. It is commonly used within the groundwater modeling industry given that it has been extensively verified and is readily accepted by many regulatory agencies throughout North America. MODFLOW-2005 can represent the hydrogeologic components present at and surrounding the open sand beds proposed at each site.

Particle tracking simulations were performed using MODPATH (Pollock, 1994)[4] to evaluate the groundwater flow pathways originating from the proposed effluent recharge areas. Particle tracking provides a means to evaluate advective migration of the recharged effluent within the groundwater flow field simulated by MODFLOW-2005. The advective migration represented by particle tracking does not take into account attenuation processes that may occur along the groundwater flow path that can reduce constituent concentrations, such as retardation due constituent adsorption onto soil particles, biological or chemical degradation, and geochemical processes.

GHD used the graphical user interface (GUI) Groundwater Vistas version 8 (Rumbaugh, 2020)[5] as the interface between the assembled hydrogeologic data and the required MODFLOW-2005/MODPATH input files. The GUI enabled pre-processing and post-processing of the MODFLOW-2005/MODPATH input/output files.

4. Model Development and Verification

4.1 Summary of the USGS Regional Model

The USGS regional model covers the Sagamore Lens which underlies the southwest portion of Cape Cod including the Town of Falmouth, as shown on Figure 1. The primary features of the USGS regional model are as follows:

– The finite-differences grid extends from the Cape Cod Canal to the Bass River and consists of 246 rows and 365 columns with a uniform horizontal discretization of 400 ft. The grid is coincident with the grids of existing regional models of the Sagamore flow lens. There are 801,307 active cells in the model.
– The regional model consists of 20 layers that extend from the groundwater table to bedrock which is to a maximum depth of -500 ft. NGVD (for National Geodetic Vertical Datum of 1929).
– The general head boundary condition was used to represent the saltwater bodies surrounding the Sagamore lens.
– The drain boundary condition was used for the estuaries and wetlands within the aquifer system.
– The stream boundary condition was used for the rivers/creeks within the aquifer system.
– The recharge boundary was applied over the groundwater table to represent precipitation (i.e., freshwater) infiltration.
– The no-flow boundary was applied at the bottom of the model.

[3] Harbaugh, A.W., 2005. MODFLOW-2005, The U.S. Geological Survey modular ground-water model—the Ground-Water Flow Process: U.S. Geological Survey Techniques and Methods 6-A16, variously p.
[4] Pollock, D.W., 1994. User's Guide for MODPATH/MODPATH-PLOT, Version 3: A Particle Tracking Post-Processing Package for MODFLOW, the U.S. Geological Survey Finite-Difference Ground-Water Flow Model, United States Geological Survey Open-File Report 94-464, Reston, Virginia.
[5] Rumbaugh, J., 2020. Guide to Using Groundwater Vistas, Version 8 (2000-2020), Environmental Simulations, Inc.

4.2 Development of Local Model and Model Comparison/Verification

As described in Section 3, GHD used TMR to develop the local-scale model from the regional model for the three sites (Falmouth WWTF Open Sand Beds 9-15, Allen Parcel, and Augusta Parcel) in the Town of Falmouth, as shown on Figure 2.

The model grid was refined to model cells having uniform dimensions of 100 ft. by 100 ft. initially and then further refined to be 50 ft. by 50 ft. locally at the three sites. All aquifer properties and existing recharge, constant head, drain, general head boundary conditions that were aligned with the regional model were kept unchanged except for the stream boundaries that had to be reassigned due to the incapability of the TMR refinement utilities provided by GWV8. The recharge distribution applied in the regional model was retained in the local-scale model. The freshwater ponds were represented using a combination of horizontal flow barrier and a high hydraulic conductivity zone as they are in the regional model. At the northern and southern limits of the local-scale model, where no boundary conditions are present in the regional model, constant head boundary conditions were applied that were extracted at these boundary locations from the groundwater flow field simulated regional model. Figure 2 shows the boundary conditions applied in the local-scale model.

Figure 2 also shows that the simulated groundwater elevation contours are comparable between the USGS regional model and the GHD local-scale model. Only minor differences occur, which are expected due to the refinement of the local-scale model. Figure 2 shows that the local-scale model essentially reproduces the simulated groundwater flow conditions simulated by the regional model within the Sagamore flow lens (i.e., in the Town of Falmouth area). Thus, the local-scale model provides a suitable tool for evaluating effluent discharge scenarios.

5. Evaluation of Treated Effluent Recharge to Groundwater

5.1 Simulation Results for Augusta Parcel Scenarios

5.1.1 Scenario Description and Groundwater Mounding Analysis

5.1.1.1 Scenario-Augusta-0.5mgd

Scenario 2021-Augusta-0.5mgd simulates 0.5 mgd of average annual effluent recharge to the Augusta Parcel. A conceptual layout was developed with six (6) open sand beds on the north end of the site, discharging an average annual flow of 0.5 mgd over an area of approximately 180,000 square feet (Figure 3).

Figure 3 presents the simulated groundwater elevation increase (or mounding) due to the discharge relative to baseline (non-discharging) conditions. Figure 3 shows that the discharge is predicted to create a maximum groundwater elevation increase of 1.0 feet relative baseline (non-discharging) conditions at the center of the Open Sand Bed.

The estimated depth to groundwater at the site is approximately 30 feet. With this separation, an increase of 1.3 feet above baseline would still leave adequate separation between the anticipated groundwater mound and surface elevation of the open sand beds (the minimum DEP-required separation distance between discharge elevation and groundwater elevation is four feet).

The proposed location of the subsurface leaching trenches in the vicinity of a relatively steep gradient (the proposed leaching trench area is higher than the neighboring property). Three scenarios were simulated to assess potential for treated effluent breakout at this location. Figure 4 shows simulated water table depth below ground surface under three conditions. Baseline conditions were simulated to represent average annual conditions prior to the development of the site for treated effluent discharge. Simulations were also conducted recharging 0.5 mgd of treated effluent at average annual and spring wet weather (typical highest annual groundwater) groundwater conditions. Both treated effluent groundwater simulations indicate more than 4 feet of separation distance between ground elevations and groundwater (indicating no treated effluent groundwater mound breakthrough).

5.1.1.2 Scenario-Augusta-1.03mgd

Scenario 2021-Augusta-1.03mgd simulates effluent recharge of 1.03 mgd to the Augusta Parcel. A conceptual layout was developed for ten (10) open sand beds and a subsurface leaching field, which combined discharge an average annual flow of 1.03 mgd over an area of approximately 363,000 square feet (Figure 5). A sub-surface leaching field was included in the conceptual layout, above which the Town could consider developing recreational uses such as grass playing fields and/or playgrounds.

Figure 5 presents the simulated groundwater elevation increase (or mounding) due to the discharge effluent relative to baseline (non-discharging) conditions. Figure 5 shows that groundwater mounding at the center of the Sand Bed/Leaching Trenches has a maximum groundwater elevation increase of 1.5 ft. relative to baseline (non-discharging) conditions.

The estimated depth to groundwater at the site is approximately 30 feet. The model indicates adequate separation between the anticipated groundwater mound and surface elevation of the open sand beds under average annual conditions (the minimum DEP-required separation distance is four feet).

Figure 6 shows simulated water table depth below ground surface under three conditions. Baseline conditions were simulated to represent average annual conditions prior to the development of the site for treated effluent discharge. Simulations were also conducted recharging 1.03 mgd of treated effluent at average annual and spring wet weather (typical highest annual groundwater) groundwater conditions. Both treated effluent groundwater simulations indicate more than 4 feet of separation distance between ground elevations and groundwater (indicating no treated effluent groundwater mound breakthrough).

5.1.2 Anticipated Treated Effluent Discharge Migration in Groundwater to Surface Water as a Percentage of Recharge

A particle tracking simulation was conducted under this groundwater flow field to estimate potential effluent migration (advective migration only) from the proposed effluent discharge system(s). The results of each modeling scenario were analyzed as a percentage of total effluent recharge that reaches specific surface water bodies. Anticipated treated effluent discharge migration in groundwater to each surface water body, as a percentage of total effluent recharge for each scenario is summarized in Table 1. Figures 7 and 8 show particle tracks for the two modeling scenarios.

Table 1 Treated Effluent Discharge Migration in Groundwater to Surface Water as a Percentage of Discharge from the Augusta Parcel, at Two Discharge Rates

	Model Input		Model Output		Number of Particles Released
Scenario	Average Annual Flow to Open Sand Beds (mgd)	Average Annual Flow to Subsurface Leaching Trenches (mgd)	Great Pond	Perch Pond	
2021-Augusta-0.5 mgd	0.50	0	100%	0%	72
2021-Augusta-1.03 mgd	0.95	0.08	95%	5%	115 (open sand beds) 25 (leaching trenches)

The modeling indicates that at a discharge rate of 0.5 mgd, 100 percent of treated effluent discharged at the Augusta parcel surfaces in Great Pond. The modeling indicates that at a discharge rate of 1.03 mgd distributed as described in Table 1, a small percentage of treated effluent migration in groundwater surfaces in Perch Pond (which flows into Great Pond) and the majority flows directly to Great Pond.

5.2 Simulation Results for Open Sand Beds 9-15 Parcel Scenarios

5.2.1 Scenario Description and Groundwater Mounding Analysis

5.2.1.1 2020 Modeling Scenarios

In January 2020 two modeling scenarios were conducted simulating recharge from Open Sand Beds 14 & 15 at 0.76 mgd, which represents the estimated average annual flow of LPSA + TASA + ESRA. The two scenarios are outlined in Attachment A and summarized in the tables below.

Table 2 Treated Effluent Discharge Migration in Groundwater to Surface Water from Existing Open Sand Beds 9-13 (as a Percentage of Total Flow)

Scenario	Model Input		Model Output					
	Average Annual Flow (mgd)		Outside West Falmouth Harbor Watershed			Inside West Falmouth Harbor Watershed		
				Buzzards Bay				
	Open Sand Beds 9-13	Open Sand Beds 14-15	Herring Brook	North of West Falmouth Harbor Boundary	South of West Falmouth Harbor Boundary	Mashapaquit Creek	Snug Harbor	Outer Harbor
Existing Open Sand Beds - A4[1]	0.45	0.76	0%	14%	0%	60%	3%	23%
Expanded Open Sand Beds - B4[1]	0.45	0.76	0%	75%	0%	8%	0%	17%

Notes:

1. Scenario outlined in ‘Groundwater Modeling Conducted in 2020 for Open Sand Beds 14 & 15 and the Allen Parcel – Final’, prepared by GHD and Watershed Hydrogeologic, dated June 21 2021 (included as Attachment A).
2. Percentages represent treated effluent discharge migration in groundwater to surface water. As the treated effluent passes through Crocker Pond it is anticipated that this flow will mix with the pond water. Potential for treated effluent discharge load to Herring Brook through mixing in Crocker Pond will be evaluated in nutrient loading analyses for this site. An initial analysis of potential nitrogen loading from Crocker Pond to Herring Brook through mixing is summarized in ‘Technical Memorandum 12 – Updated Groundwater Modeling for Site 7’, prepared by GHD and dated July 30, 2013.

Table 3 Treated Effluent Discharge Migration in Groundwater to Surface Water from Existing Open Sand Beds 14-15 (as a Percentage of Total Flow)

Scenario	Model Input		Model Output					
	Average Annual Flow (mgd)		Outside West Falmouth Harbor Watershed			Inside West Falmouth Harbor Watershed		
				Buzzards Bay				
	Open Sand Beds 9-13	Open Sand Beds 14-15	Herring Brook[2]	North of West Falmouth Harbor Boundary	South of West Falmouth Harbor Boundary	Mashapaquit Creek	Snug Harbor	Outer Harbor
2021 Permit[1]	0.45	0.26	0%	100%	0%	0%	0%	0%
Increased Flow to Existing Open Sand Beds 14 & 15 – Scenario A4[3]	0.45	0.76	18%	81%	0%	0%	0%	1%
Increased Flow to Expanded Open Sand Beds 14 & 15 – Scenario B4[3]	0.45	0.76	25%	75%	0%	0%	0%	0%

Notes:

1. Individual Groundwater Discharge Permit No. 16806, dated January 6, 2021.
2. Percentages represent treated effluent discharge migration in groundwater to surface water. As the treated effluent passes through Crocker Pond it is anticipated that this flow will mix with the pond water. Potential for treated effluent discharge load to Herring Brook through mixing in Crocker Pond will be evaluated in nutrient loading analyses for this site. An initial analysis of potential nitrogen loading from Crocker Pond to Herring Brook through mixing is summarized in 'Technical Memorandum 12 – Updated Groundwater Modeling for Site 7', prepared by GHD and dated July 30, 2013.
3. Scenario outlined in 'Groundwater Modeling Conducted in 2020 for Open Sand Beds 14 & 15 and the Allen Parcel – Final', prepared by GHD and Watershed Hydrogeologic, dated June 21 2021 (included as Attachment A).

Table 4 Treated Effluent Discharge Migration in Groundwater to Surface Water from Existing Open Sand Beds 9-15 (as a Percentage of Total Flow)

Scenario	Model Input		Model Output				
	Average Annual Flow (mgd)				West Falmouth Harbor Watershed		
	Open Sand Beds 9-13	Open Sand Beds 14-15	Herring Brook[2]	Buzzards Bay	Mashapaquit Creek	Snug Harbor	Outer Harbor
2021 Permit[1]	0.45	0.26	0%	54%	34%	0%	12%
Increased Flow to Existing Open Sand Beds 14 & 15 – Scenario A4[3]	0.45	0.76	11%	56%	22%	1%	9%
Increased Flow to Expanded Open Sand Beds 14 & 15 – Scenario B4[3]	0.45	0.76	16%	75%	3%	0%	6%

Notes:

1. Individual Groundwater Discharge Permit No. 16806, dated January 6, 2021.
2. Percentages represent treated effluent discharge migration in groundwater to surface water. As the treated effluent passes through Crocker Pond it is anticipated that this flow will mix with the pond water. Potential for treated effluent discharge load to Herring Brook through mixing in Crocker Pond will be evaluated in nutrient loading analyses for this site. An initial analysis of potential nitrogen loading from Crocker Pond to Herring Brook through mixing is summarized in 'Technical Memorandum 12 – Updated Groundwater Modeling for Site 7', prepared by GHD and dated July 30, 2013.
3. Scenario outlined in 'Groundwater Modeling Conducted in 2020 for Open Sand Beds 14 & 15 and the Allen Parcel – Final', prepared by GHD and Watershed Hydrogeologic, dated June 21 2021 (included as Attachment A).

5.2.1.2 Scenario 2021-OSB 9 to 15-1.21 mgd

In 2021 a scenario was run to examine treated effluent migration through groundwater to surface water at a higher discharge flow rate.

Scenario 2021-OSB 9 to 15-1.21 mgd simulates 1.21 mgd of effluent recharge to Open Sand Beds 9 to 15 distributed as follows: discharge to Open Sand Beds 9 to 13 (existing footprint) at a total flow rate of 0.66 mgd over an area of approximately 400,000 sq. ft., together with 0.55 mgd discharged to Open Sand Beds 14 and 15 (existing footprint) over an area of 78,940 sq. ft.

Figure 9 shows the simulated groundwater mounding at the center of the open sand beds. The simulated maximum groundwater elevation increases under this scenario are 2.0 ft. and 2.5 ft., relative to baseline (non-discharging) conditions, at the centers of Open Sand Beds 9 to 13 and Open Sand Beds 14 to 15, respectively. Since the water table is approximately 55 – 85 feet[6] below ground surface at these locations under average annual conditions, an increase of 2-2.5 feet of elevation above background will maintain more than adequate separation between the anticipated groundwater mound and surface elevation of the open sand beds (the minimum DEP-required separation distance is four feet).

5.2.1.3 Scenario 2021-OSB 9 to 15-1.55 mgd

Scenario 2021-OSB 9 to 15-1.55 mgd simulates the proposed effluent recharge assigned to Open Sand Beds 9 to 15 as follows: discharge to Open Sand Beds 9 to 13 at a total flow rate of 1.0 mgd over an area of

[6] Average ground surface elevation at Open Sand Beds 9-13 is estimated at approximately 100 feet above mean sea level. Average ground surface elevation at Open Sand Bed 14-15 is estimated at approximately 70 feet above mean sea level. Groundwater elevation estimated at approximately 15 feet above mean sea level (estimated from measurements recorded during Summer 2020 treated effluent hydraulic load tests).

approximately 400,000 sq. ft., together with 0.55 mgd discharged to the Open Sand Beds 14 and 15 over an area of 78,940 sq. ft.

Figure 10 shows the anticipated groundwater mounding at the center of the open sand beds. The simulated maximum groundwater elevation increase is 3.0 ft., relative to baseline (non-discharging) conditions, at the centers of both Open Sand Beds 9 to 13 and Open Sand Beds 14 to 15. Since the water table is approximately 55-85 feet below ground surface at these locations under average annual conditions, an increase of 3 feet of elevation above background will maintain more than adequate separation between the anticipated groundwater mound and surface elevation of the open sand beds (the minimum DEP-required separation distance is four feet).

5.2.2 Anticipated Treated Effluent Discharge Migration in Groundwater to Surface Water as a Percentage of Recharge

Particle tracking simulations were conducted for these scenarios to predict effluent migration (advective migration only) from the proposed effluent discharge system. Figure 11 shows the particle tracks for the 1.21 mgd discharge scenario. Figure 12 shows the particle tracks for the 1.55 mgd scenario. Based on the particle tracking simulations, anticipated treated effluent discharge migration in groundwater to each surface water body, as a percentage of total effluent recharge for each scenario are summarized in the tables below.

Table 5 provides the percent breakdown for particle tracks originating only at Open Sand Beds 14 & 15. Table 5 shows that under these three scenarios, none of the particles discharged to Beds 14 and 15 flow to the West Falmouth Harbor Watershed, that 40-59% of the particles flow directly to Buzzards Bay, and that 28-41% of the particles flow through Crocker Pond and then to Buzzards Bay. The Table also shows an increase in the percent of particles that flow directly or indirectly to Herring Brook as the flow to beds 9-13 is increased. The groundwater model assumes particles that flow into a pond flow straight out the other side; under this assumption, the model indicates that no particles flow from Open Sand Beds 14-15 to Herring Brook via Crocker Pond under the 2015 permit condition. After groundwater enters a pond, it mixes with other water in the pond, and “particles” can flow out of the pond in a location different from the one directly across from where they entered. Therefore, an evaluation will be conducted for all scenarios to evaluate potential nitrogen load introduced through mixing in Crocker Pond in the nutrient loading analysis (for all scenarios).

Table 5 Treated Effluent Discharge Migration in Groundwater to Surface Water from Existing Open Sand Beds 14-15 (as a Percentage of Total Flow)

Scenario	Model Input		Model Output							
	Average Annual Flow (mgd)		Outside West Falmouth Harbor Watershed					Inside West Falmouth Harbor Watershed		
			Herring Brook		Buzzards Bay					
					North of West Falmouth Harbor Boundary					
	Open Sand Beds 9-13	Open Sand Beds 14-15	Through Crocker Pond to Herring Brook[2]	Directly to Herring Brook	Through Crocker Pond to Buzzards Bay	Directly to Buzzards Bay	South of West Falmouth Harbor Boundary	Mashapaquit Creek	Snug Harbor	Outer Harbor
2021 Permit[1]	0.45	0.26	0%	0%	41%	59%	0%	0%	0%	0%
2021-OSB 9 to 15-1.21mgd	0.66	0.55	11%	5%	30%	53%	0%	0%	0%	0%
2021-OSB 9 to 15-1.55mgd	1.00	0.55	21%	11%	28%	40%	0%	0%	0%	0%

Notes:

1. Individual Groundwater Discharge Permit No. 16806, dated January 6, 2021.
2. Percentages represent treated effluent discharge migration in groundwater to surface water. As the treated effluent passes through Crocker Pond it is anticipated that this flow will mix with the pond water. Potential for treated effluent discharge load to Herring Brook through mixing in Crocker Pond will be evaluated in nutrient loading analyses for this site. An initial analysis of potential nitrogen loading from Crocker Pond to Herring Brook through mixing is summarized in 'Technical Memorandum 12 – Updated Groundwater Modeling for Site 7', prepared by GHD and dated July 30, 2013.

Table 6 provides the percent breakdown for particle tracks originating only at Open Sand Beds 9-13. This Table shows that no particles discharged at beds 9-13 flow north of the northern boundary of the West Falmouth Harbor watershed (none to Herring Brook or Crocker Pond), that 27%-32% of the particles flow directly to Buzzards Bay, and that the distribution of the particles among the subareas of West Falmouth Harbor shifts slightly among the three scenarios.

Table 6 Treated Effluent Discharge Migration in Groundwater to Surface Water from Existing Open Sand Beds 9-13 (as a Percentage of Total Flow)

Scenario	Model Input		Model Output							
	Average Annual Flow (mgd)		Outside West Falmouth Harbor Watershed					Inside West Falmouth Harbor Watershed		
			Herring Brook		Buzzards Bay					
					North of West Falmouth Harbor Boundary					
	Open Sand Beds 9-13	Open Sand Beds 14-15	Through Crocker Pond to Herring Brook[2]	Directly to Herring Brook	Through Crocker Pond to Buzzards Bay	Directly to Buzzards Bay	South of West Falmouth Harbor Boundary	Mashapaquit Creek	Snug Harbor	Outer Harbor
2021 Permit[1]	0.45	0.26	0%	0%	0%	0%	27%	54%	0%	19%
2021-OSB9to15-1.21 mgd	0.66	0.55	0%	0%	0%	0%	29%	49%	3%	19%
2021-OSB9to15-1.55 mgd	1.00	0.55	0%	0%	0%	0%	32%	40%	9%	19%

Notes:

1. Individual Groundwater Discharge Permit No. 16806, dated January 6, 2021.
2. Percentages represent treated effluent discharge migration in groundwater to surface water. As the treated effluent passes through Crocker Pond it is anticipated that this flow will mix with the pond water. Potential for treated effluent discharge load to Herring Brook through mixing in Crocker Pond will be evaluated in nutrient loading analyses for this site. An initial analysis of potential nitrogen loading from Crocker Pond to Herring Brook through mixing is summarized in 'Technical Memorandum 12 – Updated Groundwater Modeling for Site 7', prepared by GHD and dated July 30, 2013.

Table 7 provides the percent breakdown for all particle tracks for the combined system (particles originating at Open Sand Beds 9-13 and at 14-15). This table shows that the distribution of the particles among the water bodies shifts from one scenario to another, with the percent of particles discharging directly or indirectly to Herring Brook increasing to 11% for the 1.55 mgd scenario.

Table 7 *Treated Effluent Discharge Migration in Groundwater to Surface Water from Existing Open Sand Beds 9-15 (as a Percentage of Total Flow)*

Scenario	Model Input		Model Output							
	Average Annual Flow (mgd)		Outside West Falmouth Harbor Watershed					Inside West Falmouth Harbor Watershed		
			Herring Brook		Buzzards Bay					
					North of West Falmouth Harbor Boundary					
	Open Sand Beds 9-13	Open Sand Beds 14-15	Through Crocker Pond to Herring Brook[2]	Directly to Herring Brook	Through Crocker Pond to Buzzards Bay	Directly to Buzzards Bay	South of West Falmouth Harbor Boundary	Mashapaquit Creek	Snug Harbor	Outer Harbor
2021 Permit[1]	0.45	0.26	0%	0%	15%	22%	17%	34%	0%	12%
2021-OSB9to15-1.21 mgd	0.66	0.55	5%	2%	14%	24%	16%	27%	2%	10%
2021-OSB9to15-1.55 mgd	1.00	0.55	7%	4%	10%	14%	21%	26%	6%	12%

Notes:

1. Individual Groundwater Discharge Permit No. 16806, dated January 6, 2021.
2. Percentages represent treated effluent discharge migration in groundwater to surface water. As the treated effluent passes through Crocker Pond it is anticipated that this flow will mix with the pond water. Potential for treated effluent discharge load to Herring Brook through mixing in Crocker Pond will be evaluated in nutrient loading analyses for this site. An initial analysis of potential nitrogen loading from Crocker Pond to Herring Brook through mixing is summarized in 'Technical Memorandum 12 – Updated Groundwater Modeling for Site 7', prepared by GHD and dated July 30, 2013.

5.3 Simulation Results for Allen Parcel Scenarios

5.3.1 Scenario Description and Groundwater Mounding Analysis

5.3.1.1 Scenario 2021-Allen-0.5mgd

Scenario 2021-Allen-0.5 mgd simulates effluent recharge of 0.5 mgd to the Allen Parcel. A conceptual layout was developed for four (4) open sand beds discharging an average annual flow of 0.5 mgd over an area of approximately 160,000 square feet (the four southern rectangular beds shown in Figure 13).

Figure 13 presents the simulated groundwater elevation increase (or mounding) relative to baseline (non-discharging) conditions, due to the effluent discharge. The simulated maximum groundwater elevation increase is less than 1 foot relative to baseline (non-discharging) conditions. The estimated depth to groundwater at the site is approximately 35 feet. The model indicates adequate separation between the anticipated groundwater mound and surface elevation of the open sand beds under average annual conditions (the minimum DEP-required separation distance is four feet).

5.3.1.2 Scenario 2021-Allen-1.03mgd

Scenario 2021-Allen-1.03 mgd simulates effluent recharge of 1.03 mgd to the Allen Parcel. A conceptual layout was developed for seven (7) open sand beds discharging an average annual flow of 1.03 mgd over an area of approximately 332,500 square feet.

Figure 14 presents the simulated groundwater elevation increase due to the effluent discharge, relative to baseline (non-discharging) conditions. Figure 14 shows that the simulated maximum groundwater elevation increase is less than 2 feet, relative to baseline (non-discharging) conditions. The estimated depth to groundwater at the site is approximately 30 feet. The model indicates adequate separation between the anticipated groundwater mound and surface elevation of the open sand beds under average annual conditions (the minimum DEP-required separation distance is four feet).

5.3.2 Anticipated Treated Effluent Discharge Migration in Groundwater to Surface Water as a Percentage of Recharge

Particle tracking simulations were conducted to predict effluent migration (advective migration only) from the proposed effluent discharge system. Particle tracks the 0.5 mgd scenario are shown on Figure 15. Particle tracks for the 1.03 mgd scenario are shown on Figure 16. The results of each modeling scenario were analyzed to calculate the percentage of total effluent recharge that reaches each surface water body. These results are tabulated in Table 8. In both scenarios, particles flow to Great Pond via Flax Pond and/or the Coonamesset River, and particles flow to Green Pond via Flax Pond, Backus Brook, and/or Mill Pond. Under both scenarios, approximately 65% of the discharge at the Allen parcel ultimately flows to Great Pond, and 35% ultimately flows to Green Pond. However, the “route” that the particles take to the coastal ponds is different in the two scenarios. For example, the model indicates in the higher effluent discharge scenario, a larger percentage of flow surfaces directly in the Coonamessett River and Backus Brook.

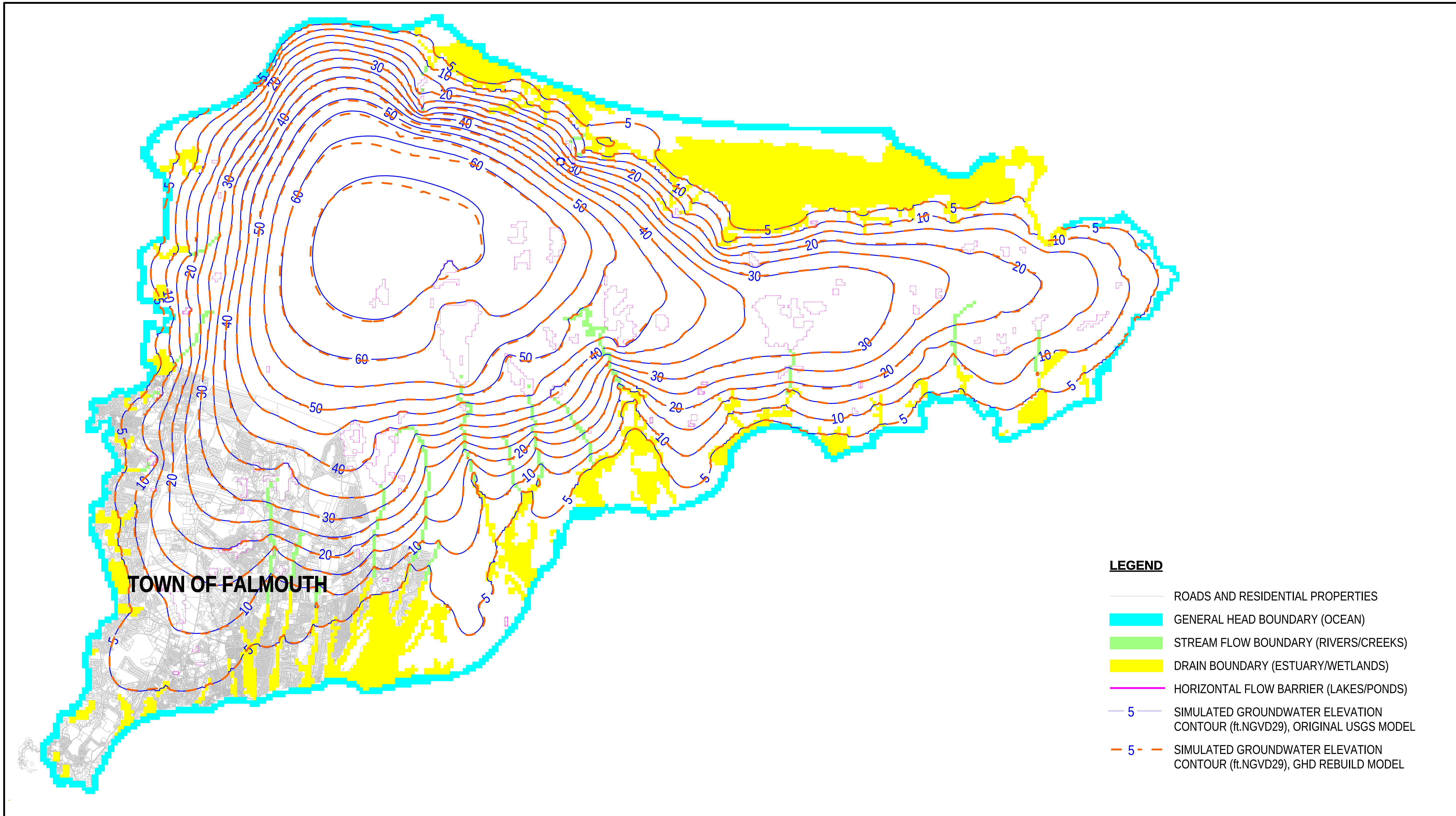
Table 8 Treated Effluent Discharge Migration in Groundwater to Surface Water from Allen Parcel (as a Percentage of Total Discharge)

Model Inputs		Model Outputs									
		Great Pond Watershed				Green Pond Watershed					
		Coonamesset River		Great Pond			Mill Pond		Green Pond		
Scenario	Average Annual Flow (mgd)	Through Flax Pond to River	Directly to River	Through Flax Pond to Great Pond	Directly to Great Pond	Directly to Backus Brook	Though Flax Pond to Mill Pond	Directly to Mill Pond	Though Flax Pond to Green Pond	Directly to Green Pond	Total Number of Particles Released
2021-Allen-0.5 mgd	0.5	47%	10%	9%	0%	8%	10%	14%	2%	0%	264
2021-Allen - 1.03 mgd	1.03	29%	30%	5%	1%	18%	7%	10%	1%	1%	531

6. Summary and Next Steps

The May 2021 groundwater modeling findings will be incorporated into the centralized wastewater management alternatives evaluation. The centralized wastewater management alternatives evaluation will use the particle track data to evaluate anticipated attenuated nitrogen load to down-gradient waterbodies and to assess potential impacts to down-gradient water bodies. The finalized version of this technical memorandum is anticipated to be included as an Appendix to the Great Pond Targeted Watershed Management Plan.

Figures



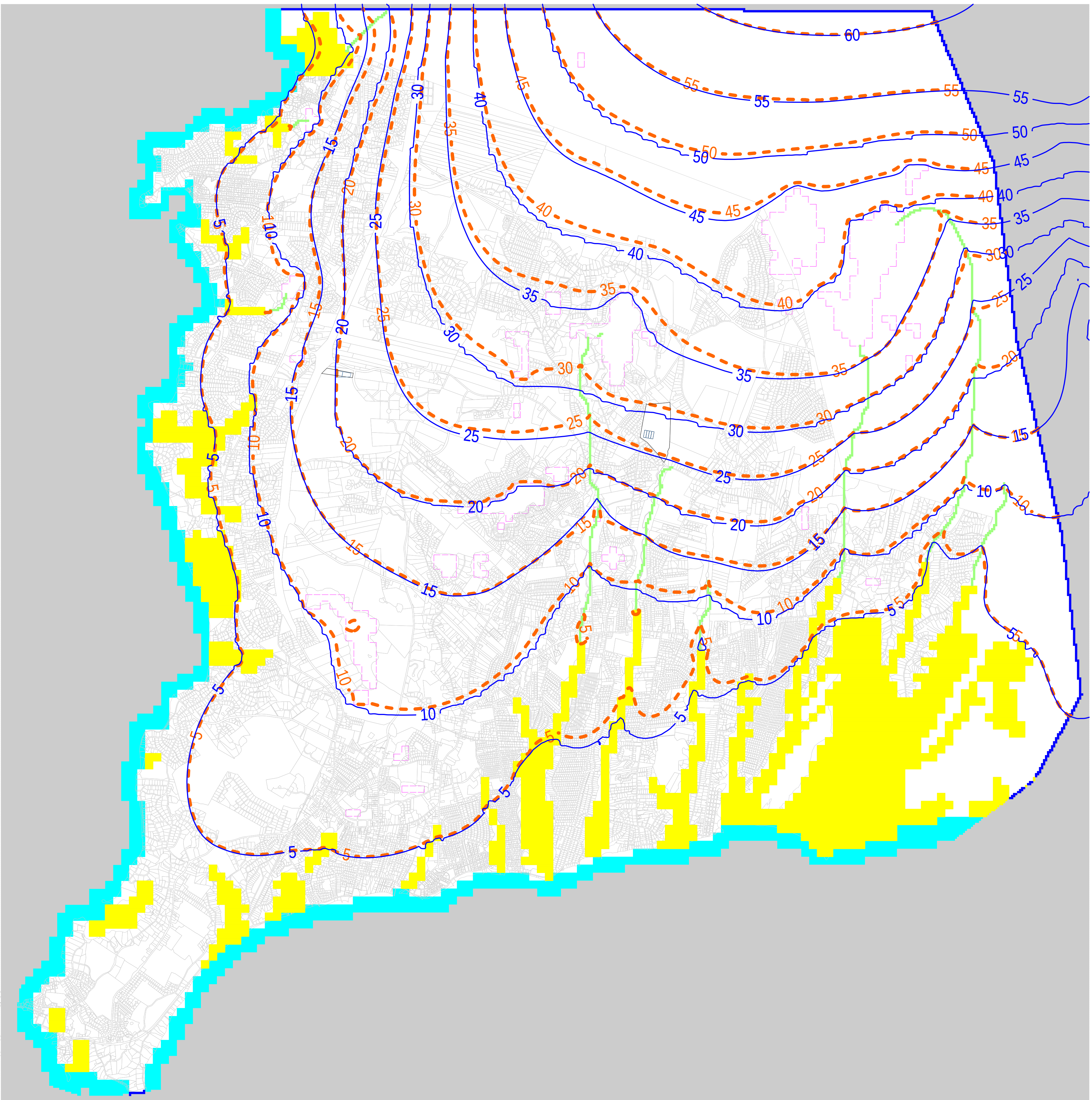
0 2,250 4,500ft

TOWN OF FALMOUTH
FALMOUTH, MASSACHUSETTS

11218691
May 25, 2021

REGIONAL MODEL DOMAIN AND SIMULATED GROUNDWATER ELEVATIONS
COMPARISON OF USGS MODEL AND GHD REBUILD GWV MODEL

FIGURE 1



LEGEND

ROADS AND RESIDENTIAL PROPERTIES

NO-FLOW CELL (REFINED LOCAL MODEL)

GENERAL HEAD BOUNDARY (OCEAN)

STREAM FLOW BOUNDARY (RIVERS/CREEKS)

DRAIN BOUNDARY (WETLAND/ESTUARY)

SPECIFIED HEAD BOUNDARY(EXTRACTED FROM USGS MODEL)

HORIZONTAL FLOW BARRIER (LAKES/PONDS)

5 SIMULATED GROUNDWATER ELEVATION CONTOUR (ft.NGVD29), 2019 USGS REGIONAL MODEL

5 SIMULATED GROUNDWATER ELEVATION CONTOUR (ft.NGVD29), GHD REFINED LOCAL MODEL

0 2,800 5,600ft

N

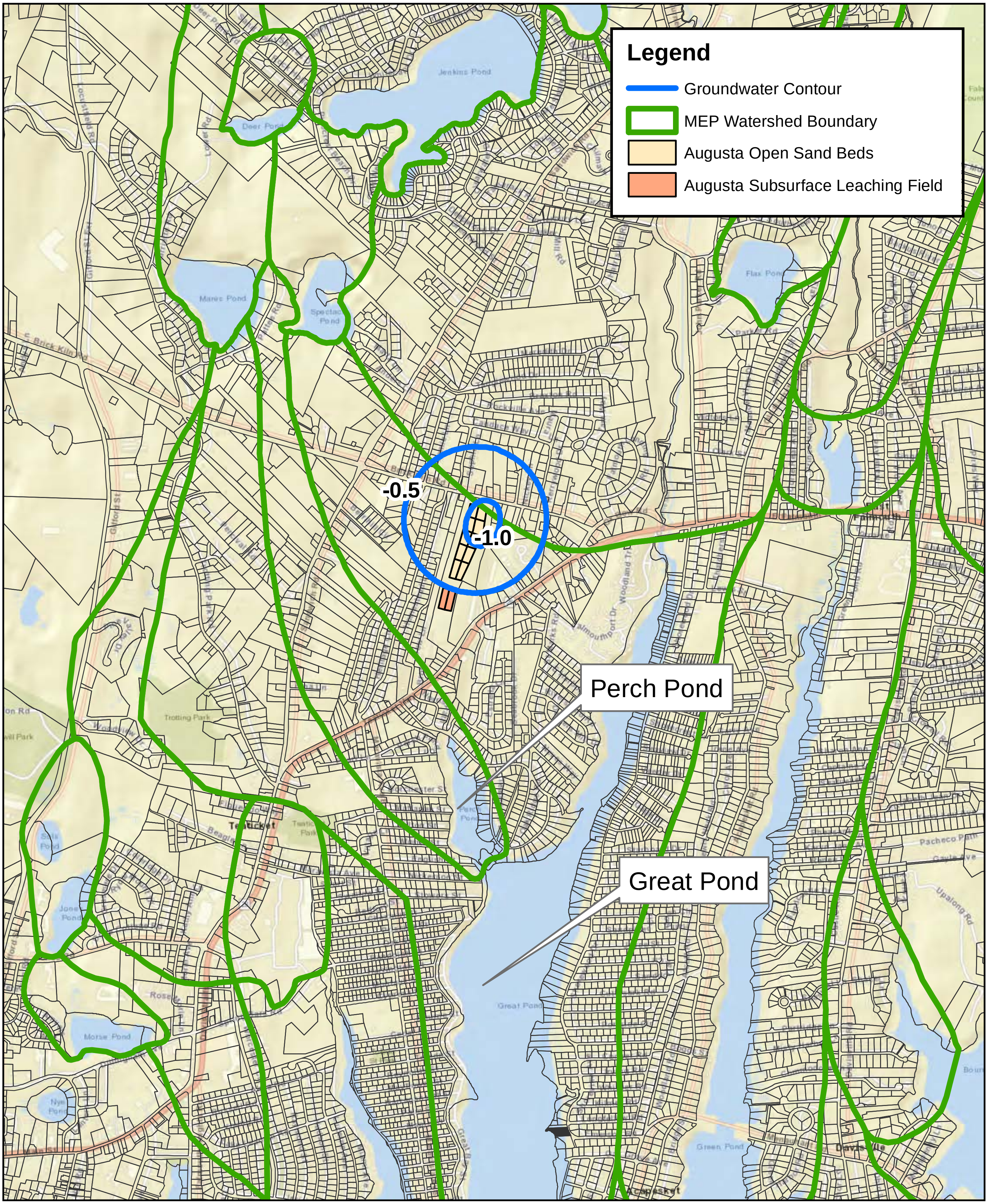
GHD

TOWN OF FALMOUTH
FALMOUTH EFFLUENT DISCHRGE SITE
CAPE COD, MASSACHUSETTS

SIMULATED GROUNDWATER ELEVATIONS
REFINED LOCAL MODEL VS. REGIONAL MODEL

11153401
May 25, 2021

FIGURE 2



Paper Size ANSI A

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Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1927
Grid: NAD 1927 StatePlane Massachusetts Mainland FIPS 2001

N

GHD

TOWN OF FALMOUTH
Hydrological Evaluations

Anticipated Groundwater Mounding:
Scenario 2021-Augusta-0.5mgd

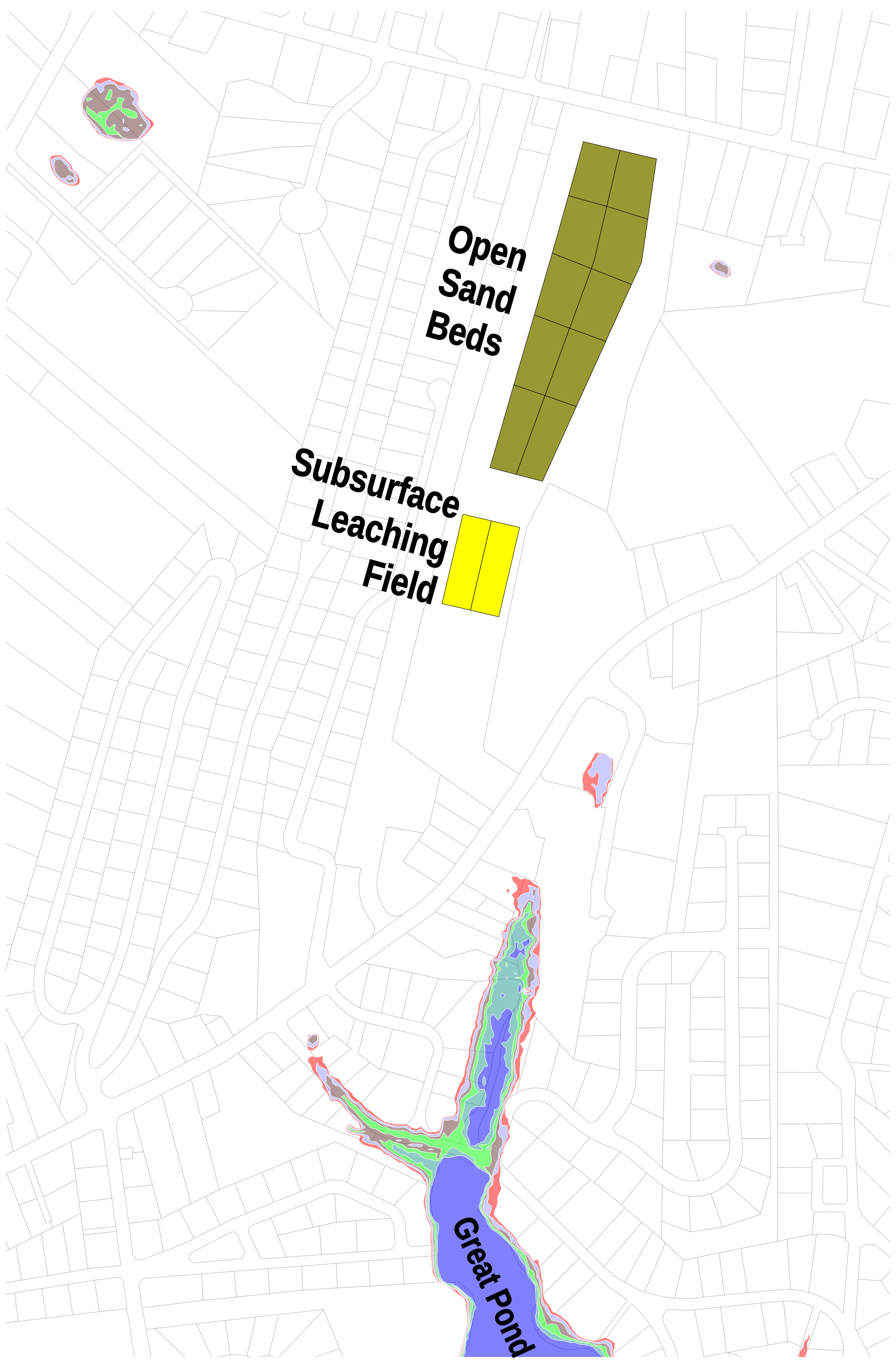
Project No. 11153041
Revision No. -
Date 07/19/2021

FIGURE 3

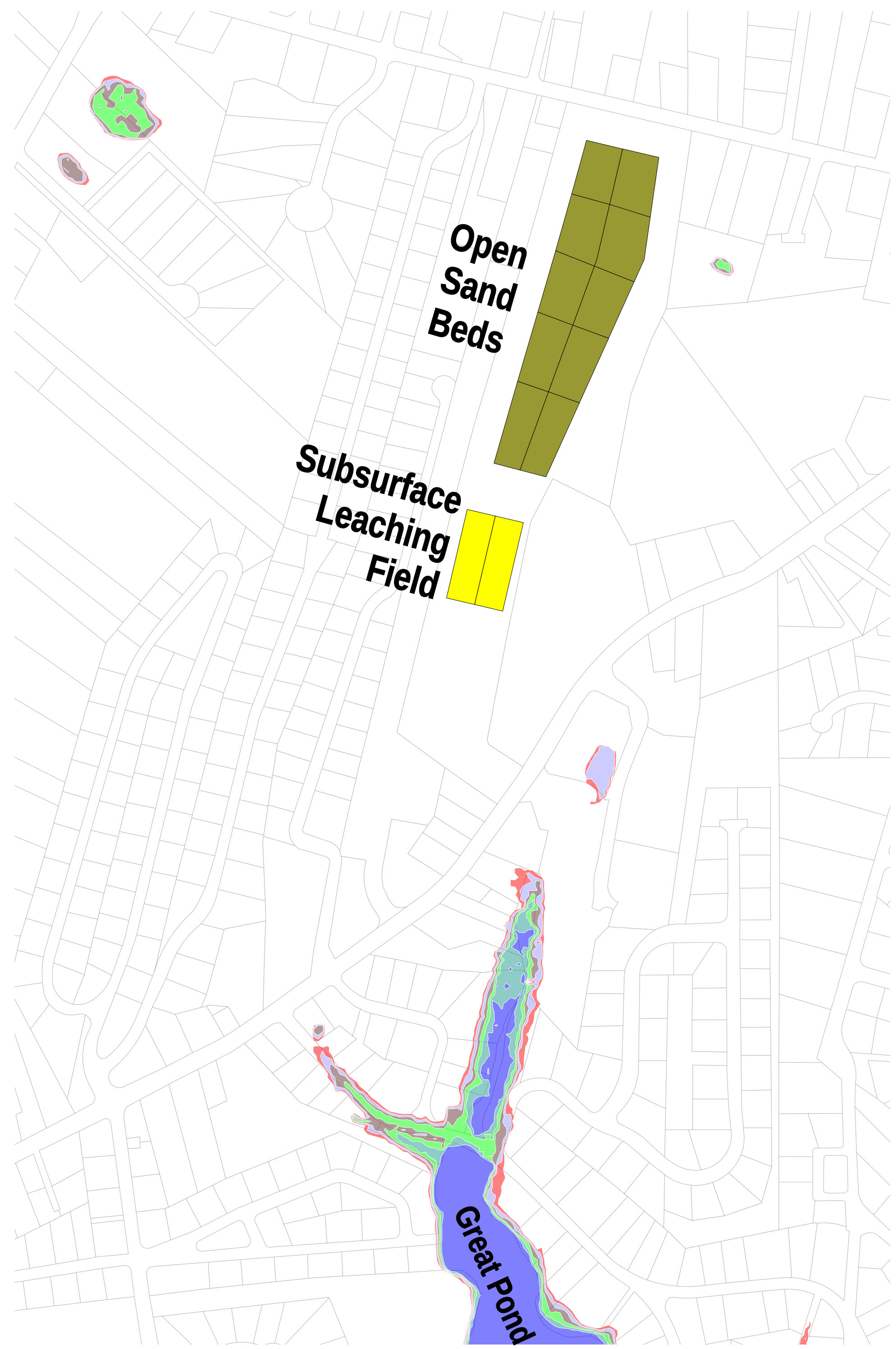
G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\04 29 2021 Particle Tracts\Revised July 19 2021\Figure 3 Augusta Mounding 0.5.mxd
Print date: 22 Jul 2021 - 15:16

Data source: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community. Created by: jjobrien

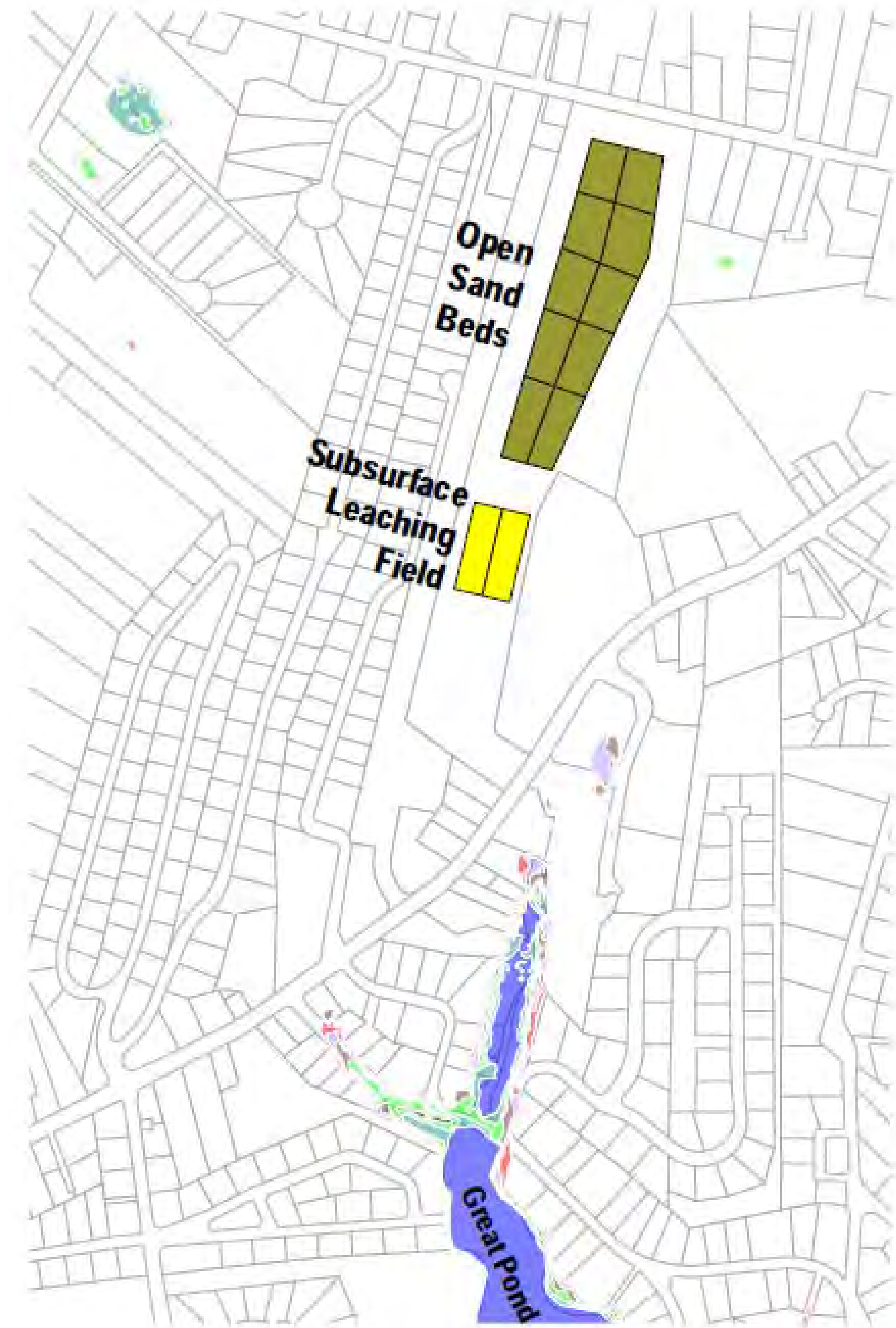
AUGUSTA PRE-EFFLUENT DISCHARGE: BASELINE CONDITION



SCENARIO 2021 AUGUSTA - 0.5 MGD (AVERAGE CONDITION)



SCENARIO 2021 AUGUSTA - 0.5 MGD (WET CONDITION)



LEGEND

- ROADS AND RESIDENTIAL PROPERTIES
- OPEN SAND BEDS
- SUBSURFACE LEACHING FIELD

Simulated Water Table Depth (ft.BGS)

0 0 1 2 3 4 5 49

0 300 600ft

N

GHD

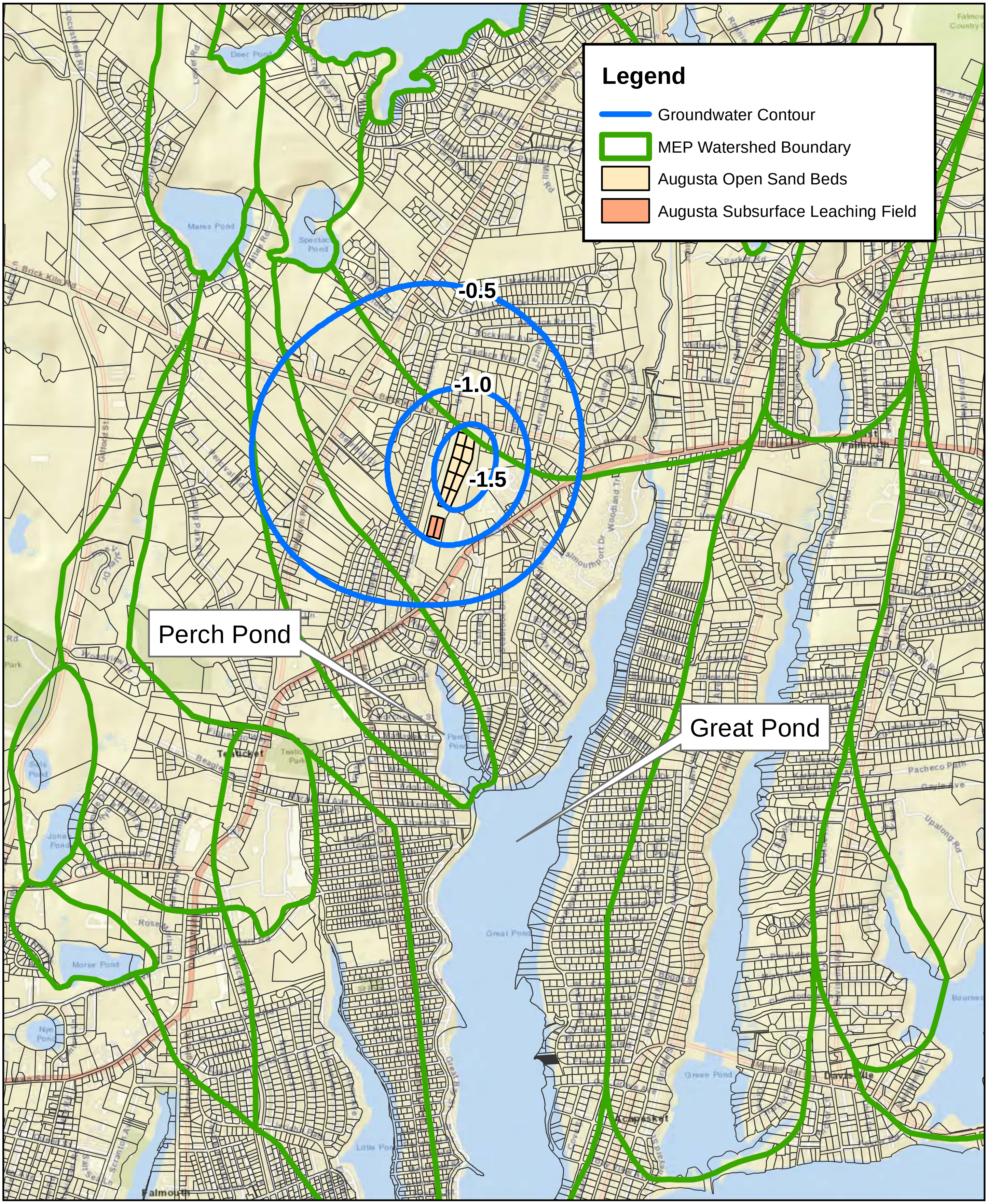
TOWN OF FALMOUTH
FALMOUTH, MASSACHUSETTS

SIMULATED WATER TABLE DEPTH
0.5 MGD AVG ANNUAL FLOW

Project No. 11153041-01
Date July 2021

FIGURE 4

Data Source



Paper Size ANSI A

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Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1927
Grid: NAD 1927 StatePlane Massachusetts Mainland FIPS 2001

N

GHD

TOWN OF FALMOUTH
Hydrological Evaluations

Anticipated Groundwater Mounding:
Scenario-2021-Augusta-1.03mgd

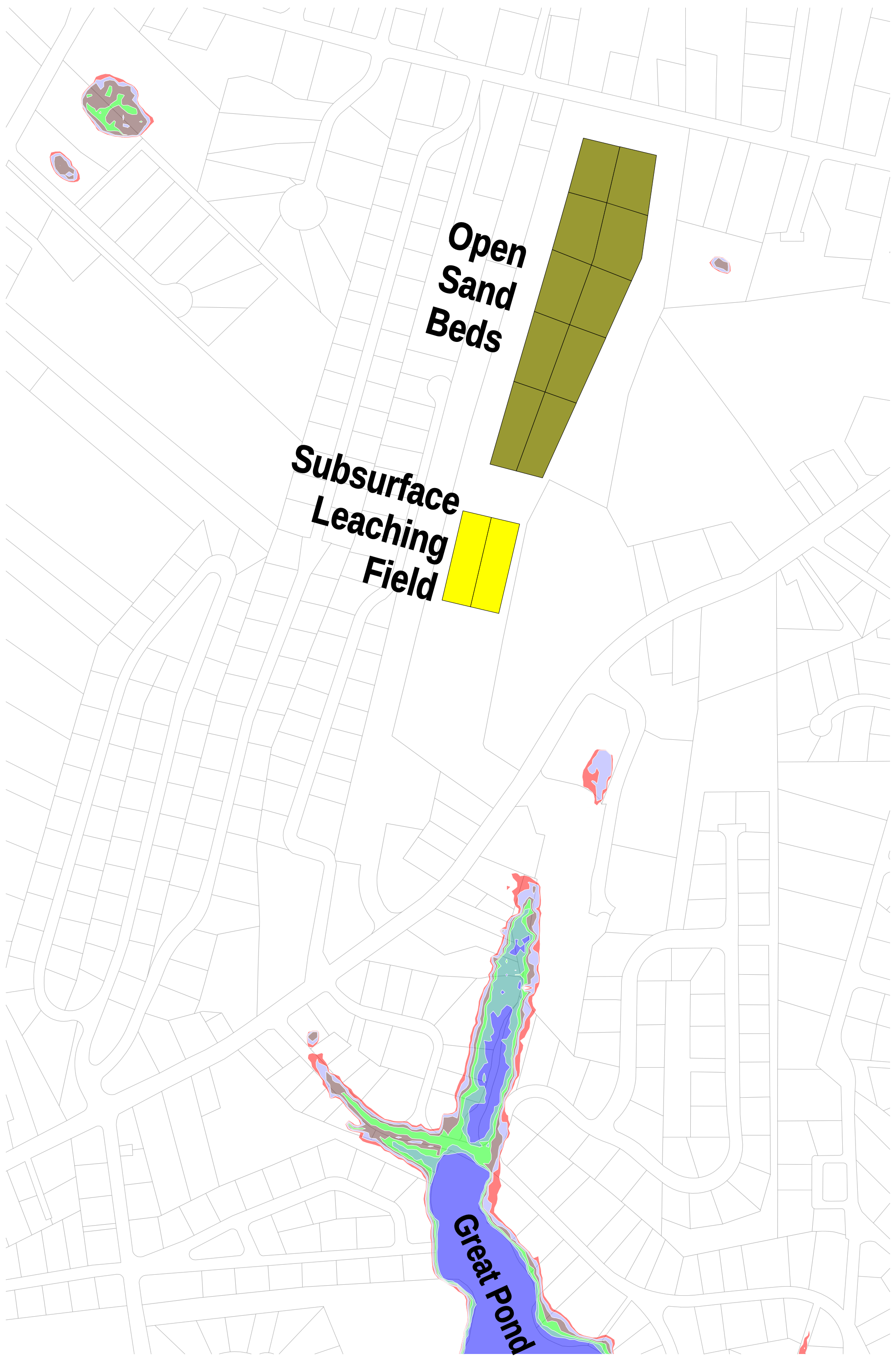
Project No. 11153041
Revision No. -
Date 07/19/2021

FIGURE 5

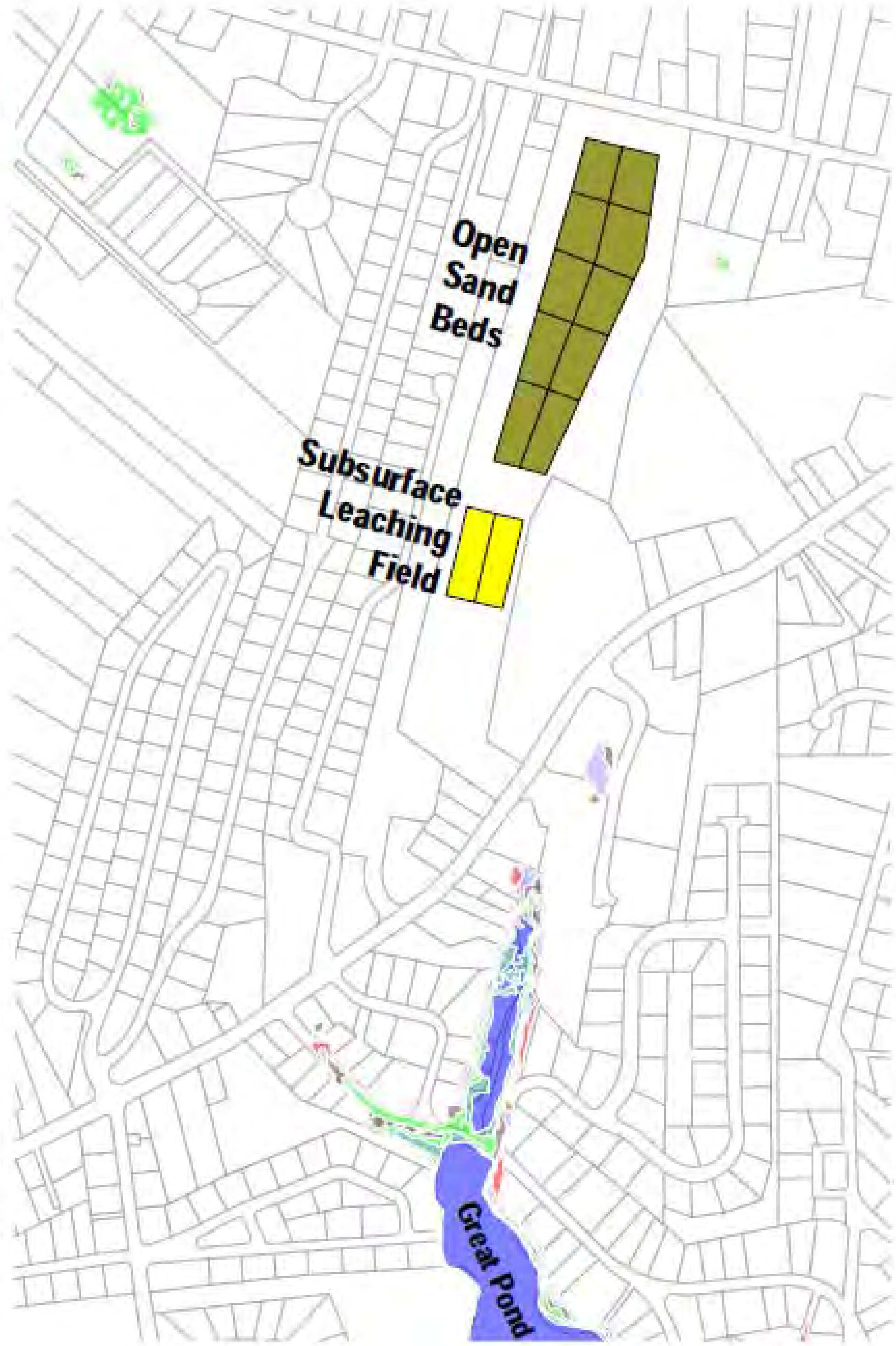
G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\04 29 2021 Particle Tracts\Revised mxd june 18 2021\Figure 5 Augusta Mounding 1.03 .mxd
Print date: 19 Jul 2021 - 15:08

Data source: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community. Created by: jjobrien

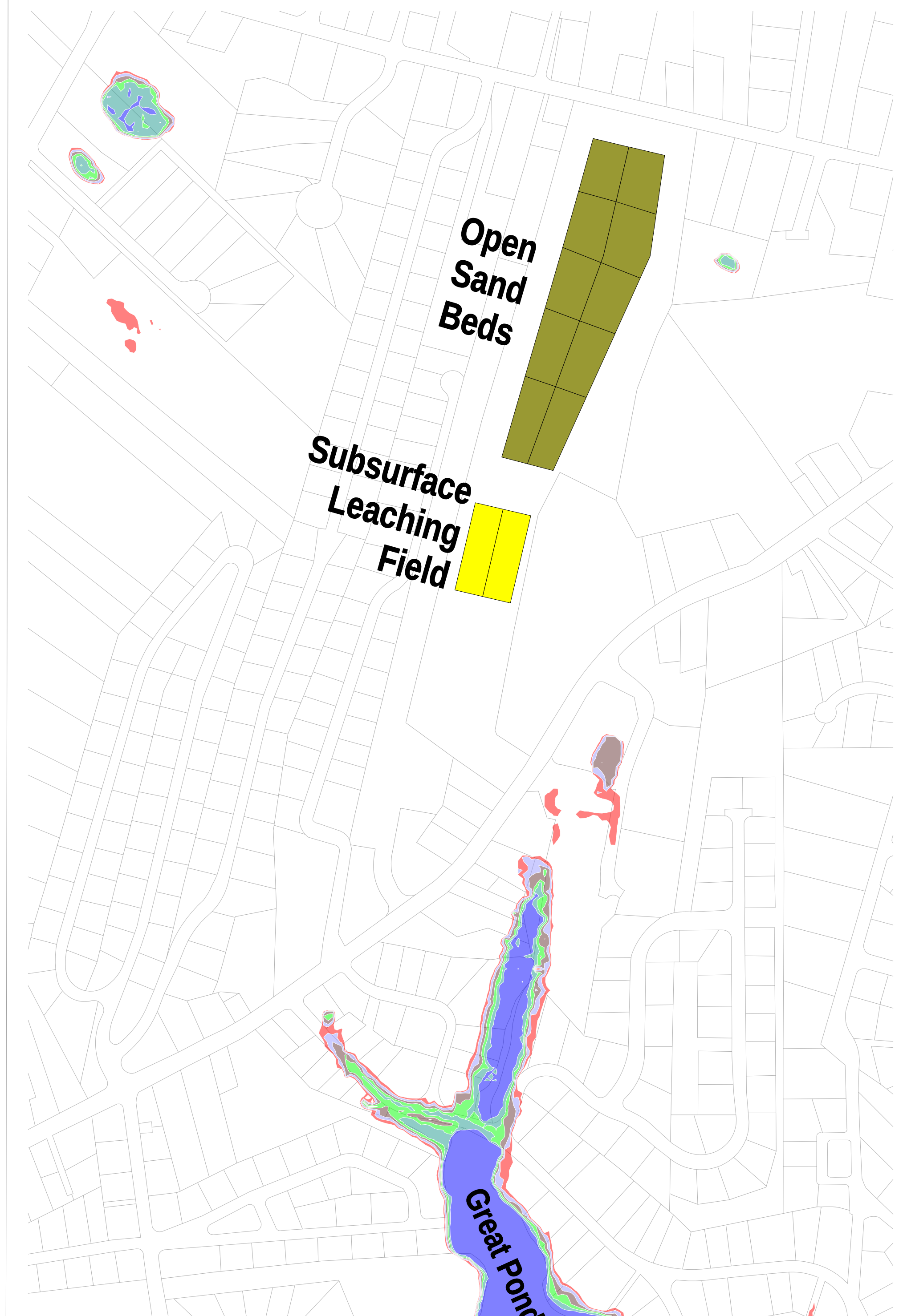
AUGUSTA PRE-EFFLUENT DISCHARGE: BASELINE CONDITION



SCENARIO 2021 AUGUSTA - 1.03 MGD (AVERAGE CONDITION)



SCENARIO 2021 AUGUSTA - 1.03 MGD (WET CONDITION)



LEGEND

- ROADS AND RESIDENTIAL PROPERTIES
- OPEN SAND BEDS
- SUBSURFACE LEACHING FIELD

Simulated Water Table Depth (ft.BGS)

0 0 1 2 3 4 5 49

0 300 600ft

N

GHD

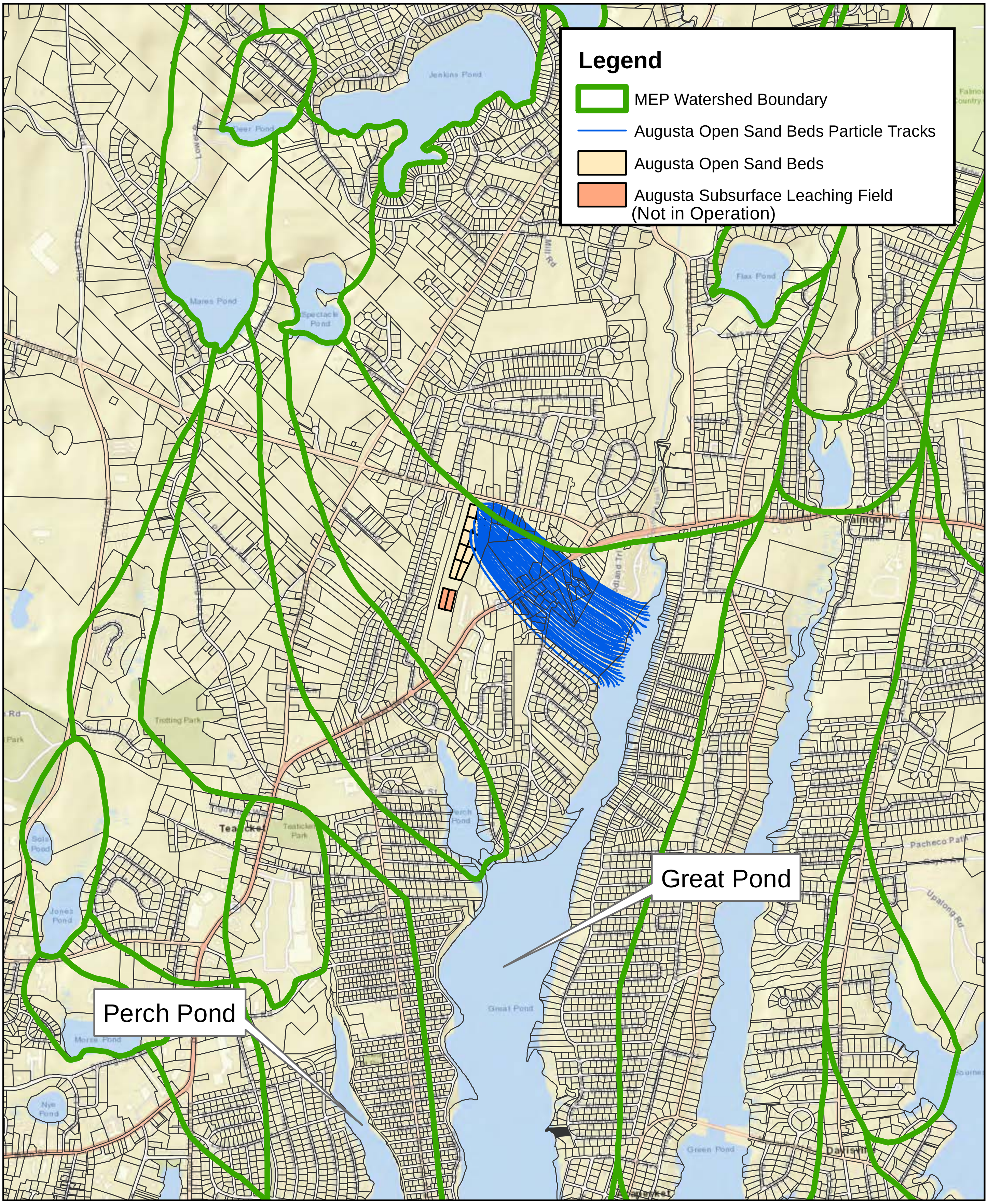
TOWN OF FALMOUTH
FALMOUTH, MASSACHUSETTS

Project No. 11153041-01
Date July 2021

SIMULATED WATER TABLE DEPTH
1.03 MGD AVG ANNUAL FLOW

FIGURE 6

Data Source



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Map Projection: Lambert Conformal Conic
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Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

GHD

TOWN OF FALMOUTH
Hydrological Evaluations

Anticipated Treated Effluent Discharge Migration in Groundwater to Surface Water: Scenario 2021-Augusta-0.5 mgd

Project No. 11153041
Revision No. -
Date 06/18/2021

FIGURE 7

G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\04 29 2021 Particle Tracts\Revised mxd june 18 2021\Figure6 Augusta Tracts 0.5 .mxd
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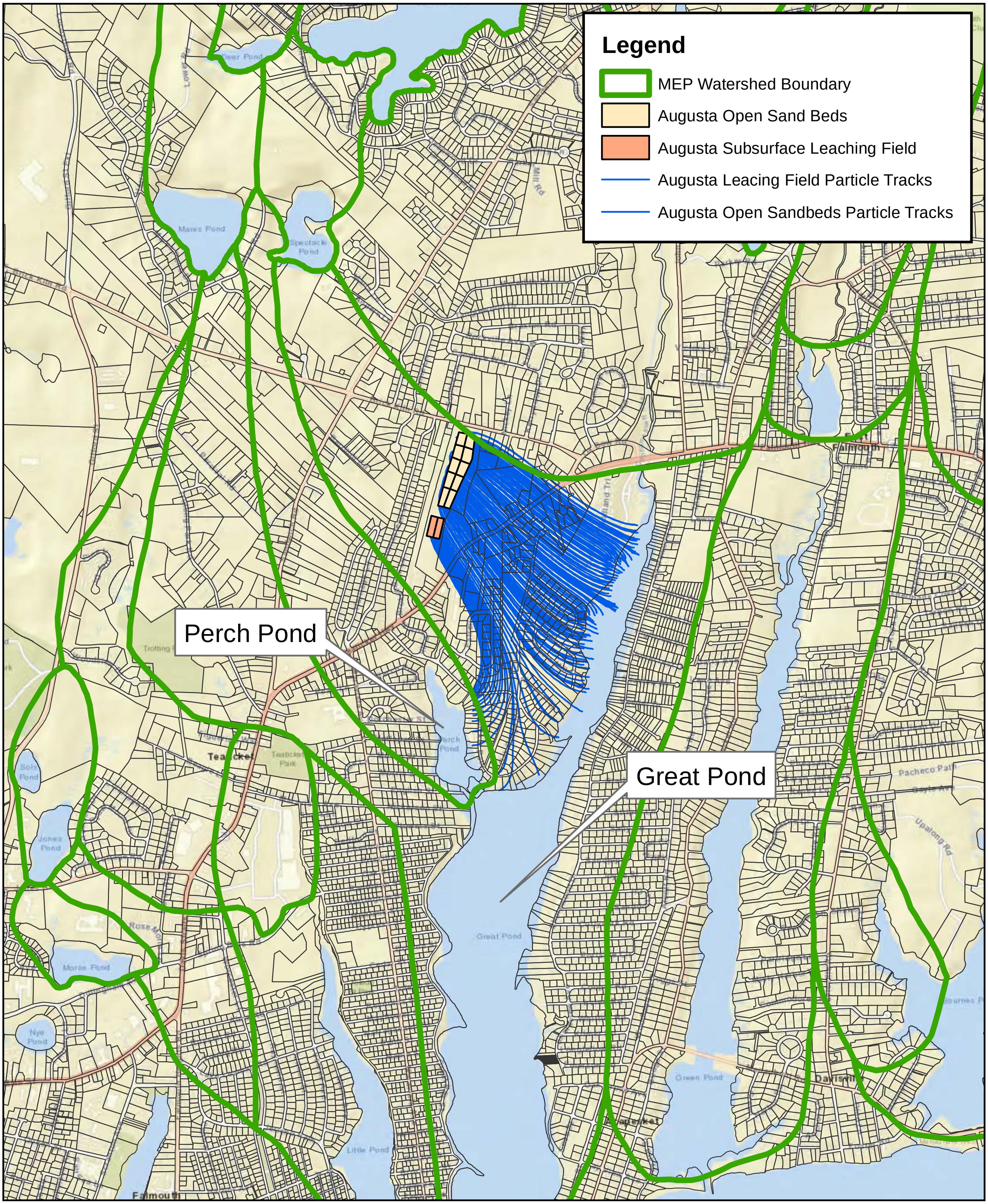
Data source: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community. Created by: jjobrien



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GHD

TOWN OF FALMOUTH
Hydrological Evaluations

Anticipated Treated Effluent Discharge Migration in Groundwater to Surface Water Scenario 2021-Augusta-1.03 mgd

Project No. 11153041
Revision No. -
Date 07/19/2021

FIGURE 8

G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\04 29 2021 Particle Tracts\Revised July 19 2021\Figure 8 Augusta Tracts 1.03.mxd
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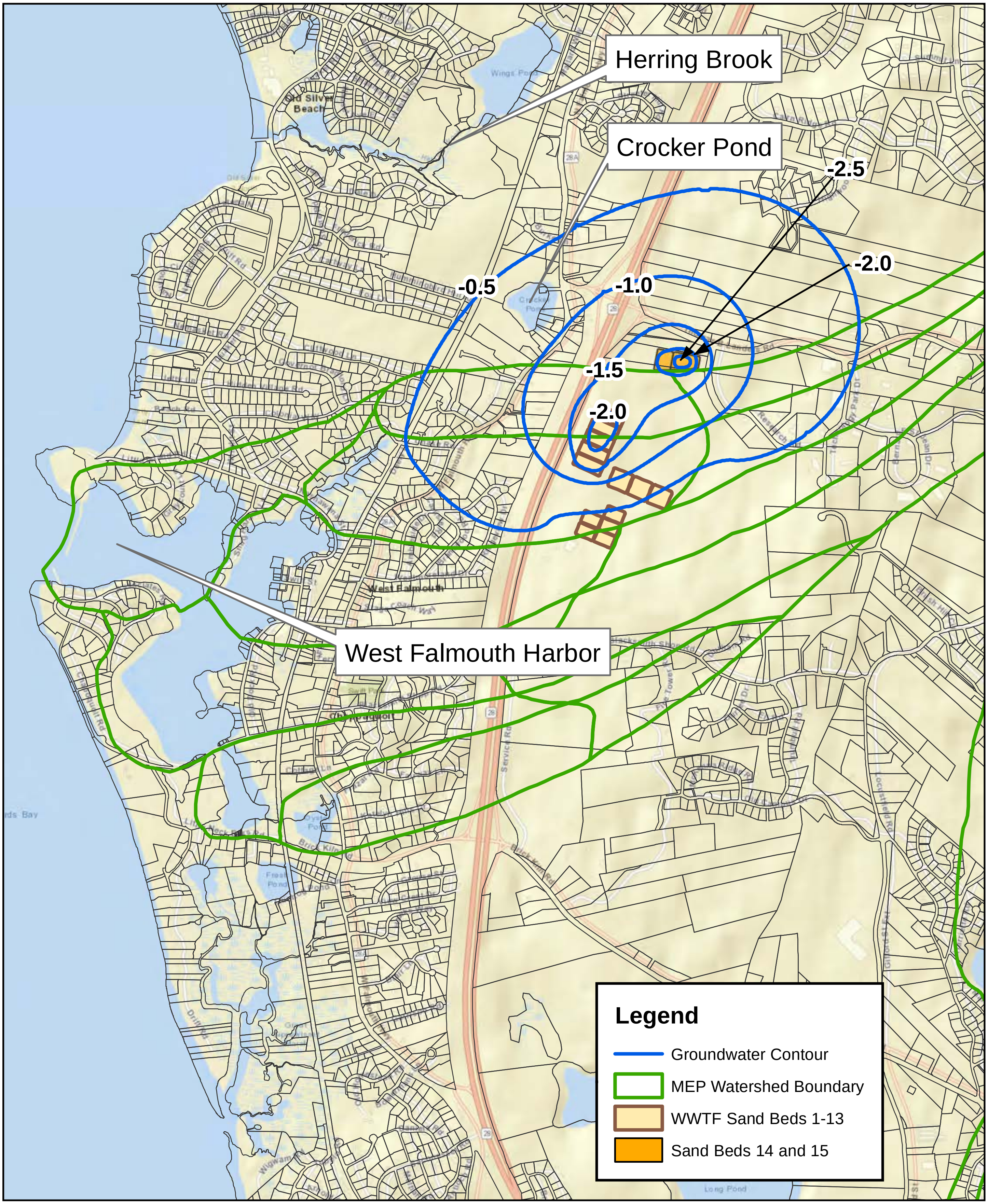
Data source: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community. Created by: jjobrien



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Feet

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Horizontal Datum: North American 1927
Grid: NAD 1927 StatePlane Massachusetts Mainland FIPS 2001

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GHD

TOWN OF FALMOUTH
Hydrological Evaluations

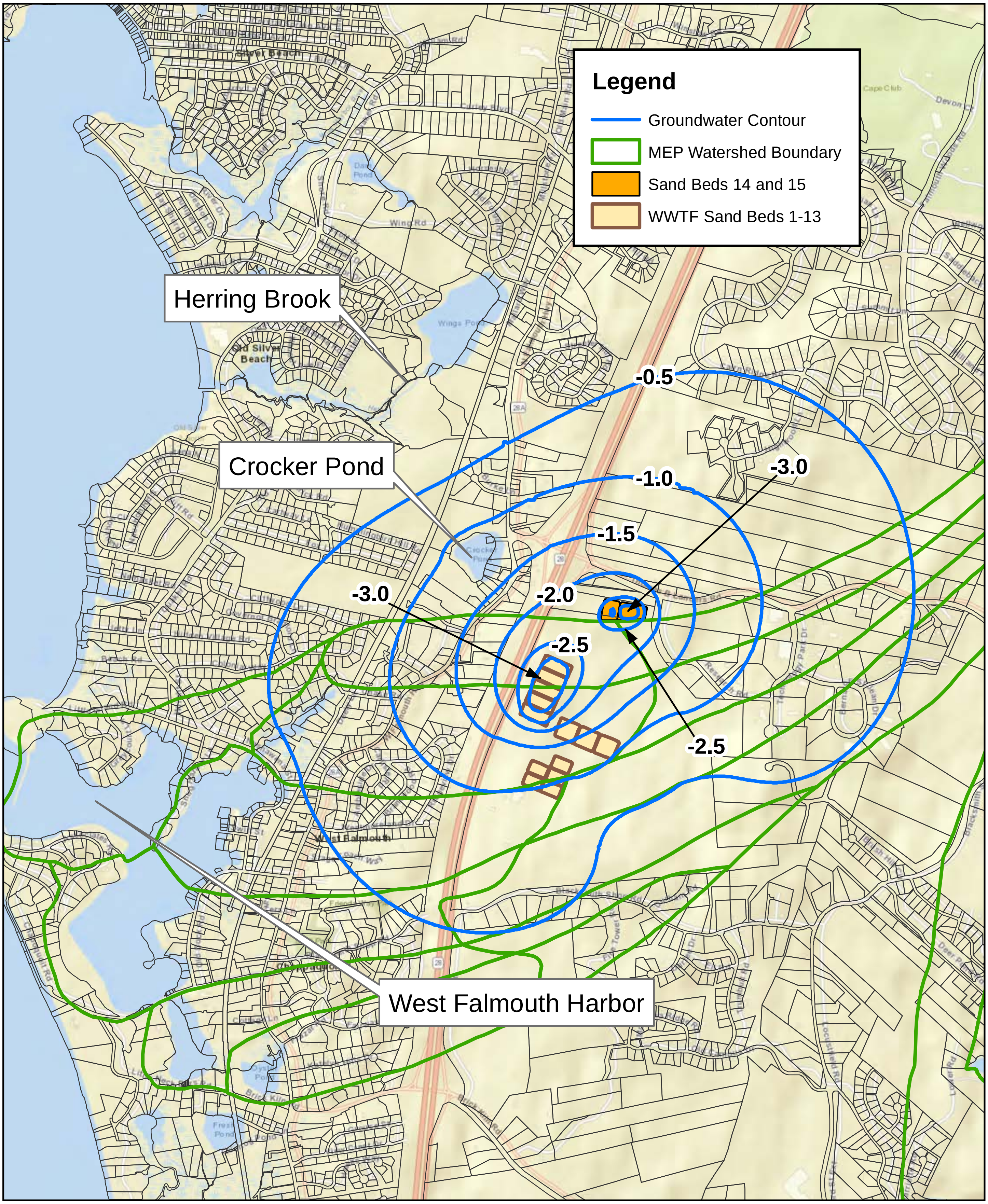
Anticipated Groundwater Mounding:
Scenario 2021 - Open Sand
Beds 9 to15 - 1.21 mgd

Project No. 11153041
Revision No. -
Date 04/29/2021

FIGURE 9

G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\04 29 2021 Particle Tracts\Revised July 19 2021\Figure 9 Falmouth WWTF Mounding 1.21.mxd
Print date: 19 Jul 2021 - 17:01

Data source: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community. Created by: jjobrien



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N

GHD

TOWN OF FALMOUTH
Hydrological Evaluations

Anticipated Groundwater Mounding:
Scenario 2021 - Open Sand Beds
9 to15 - 1.55mgd

Project No. 11153041
Revision No. -
Date 06/18/2021

FIGURE 10

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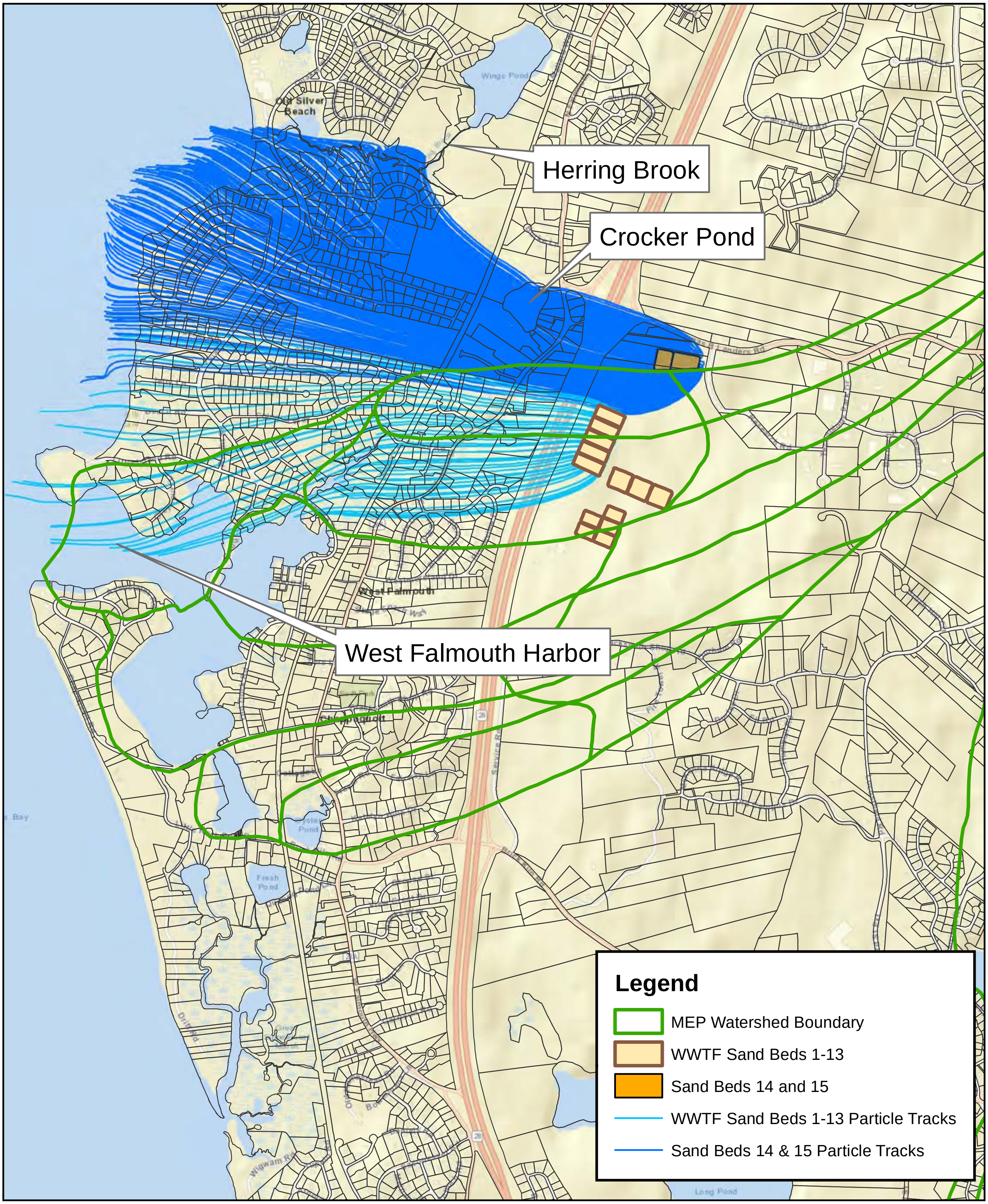
Print date: 19 Jul 2021 - 16:03

Data source: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community. Created by: jjobrien



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Feet

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N

GHD

TOWN OF FALMOUTH
Hydrological Evaluations

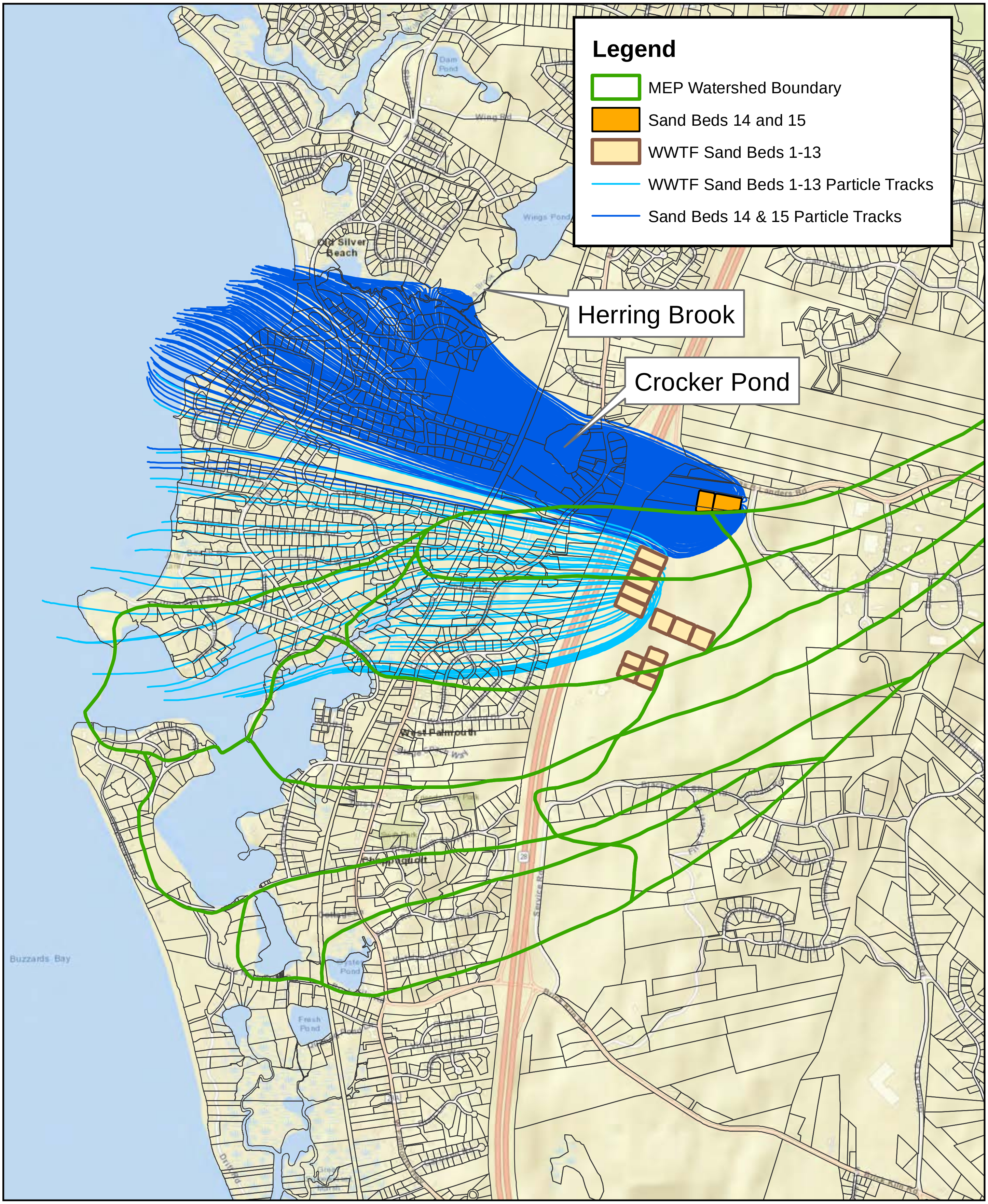
Anticipated Treated Effluent Discharge
Migration in Groundwater to Surface Water:
Scenario 2021 Open Sand Beds
9 to 15 - 1.21 mgd

Project No. 11153041
Revision No. -
Date 07/19/2021

FIGURE 11

G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\04 29 2021 Particle Tracts\Revised July 19 2021\Figure 11 Falmouth WWTF Effluent Discharge Scenario1.21.mxd

Data source: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community. Created by: jjobrien



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Feet

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Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

N

GHD

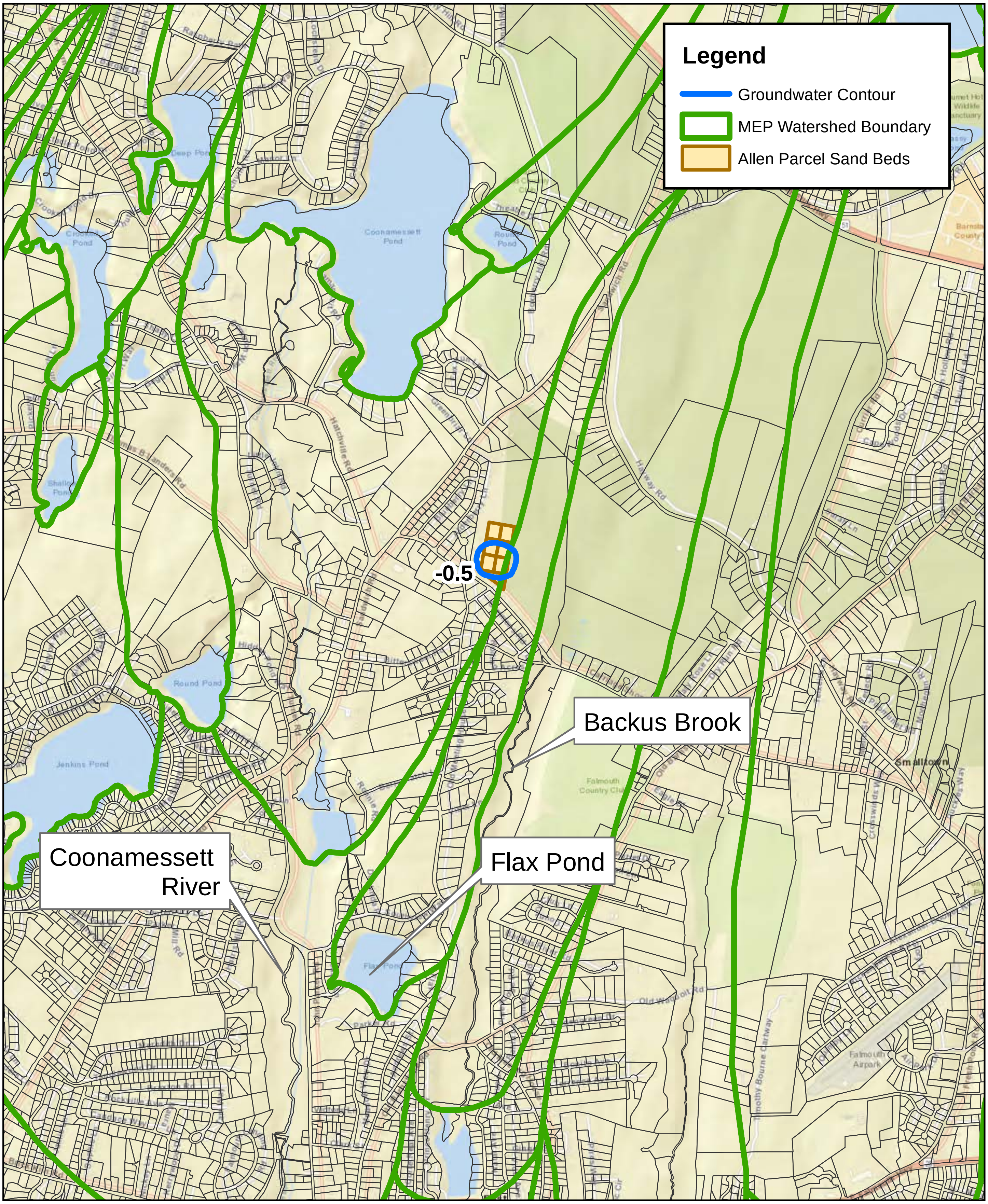
TOWN OF FALMOUTH
Hydrological Evaluations

Anticipated Treated Effluent Discharge
Migration in Groundwater to Surface Water
Scenario 2021-Open Sand Beds 9 to15 - 1.55 mgd

Project No. 11153041
Revision No. -
Date 07/19/2021

FIGURE 12

G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\04 29 2021 Particle Tracts\Revised July 19 2021\Figure 12 Falmouth WWTF Effluent Discharge Scenario1.55.mxd



Paper Size ANSI A

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Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1927
Grid: NAD 1927 StatePlane Massachusetts Mainland FIPS 2001

GHD

TOWN OF FALMOUTH
Hydrological Evaluations

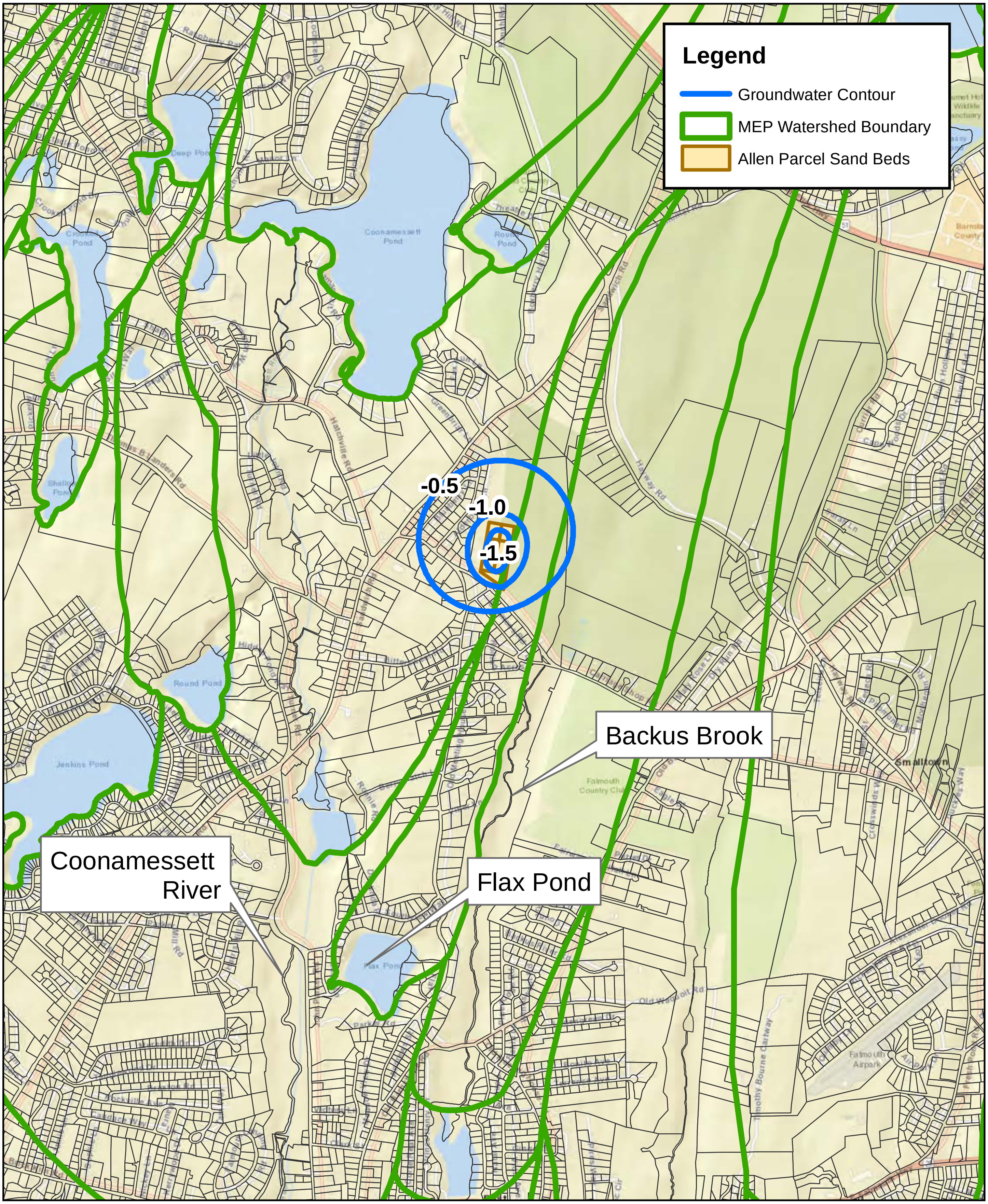
Anticipated Groundwater Mounding
Scenario 2021-Allen- 0.5 mgd

Project No. 11153041
Revision No. -
Date 07/19/2021

FIGURE 13

G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\04 29 2021 Particle Tracts\Revised July 19 2021\Figure 13 Allen Mounding 0.5.mxd
Print date: 19 Jul 2021 - 16:32

Data source: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community. Created by: jjobrien



Paper Size ANSI A

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Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1927
Grid: NAD 1927 StatePlane Massachusetts Mainland FIPS 2001

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GHD

TOWN OF FALMOUTH
Hydrological Evaluations

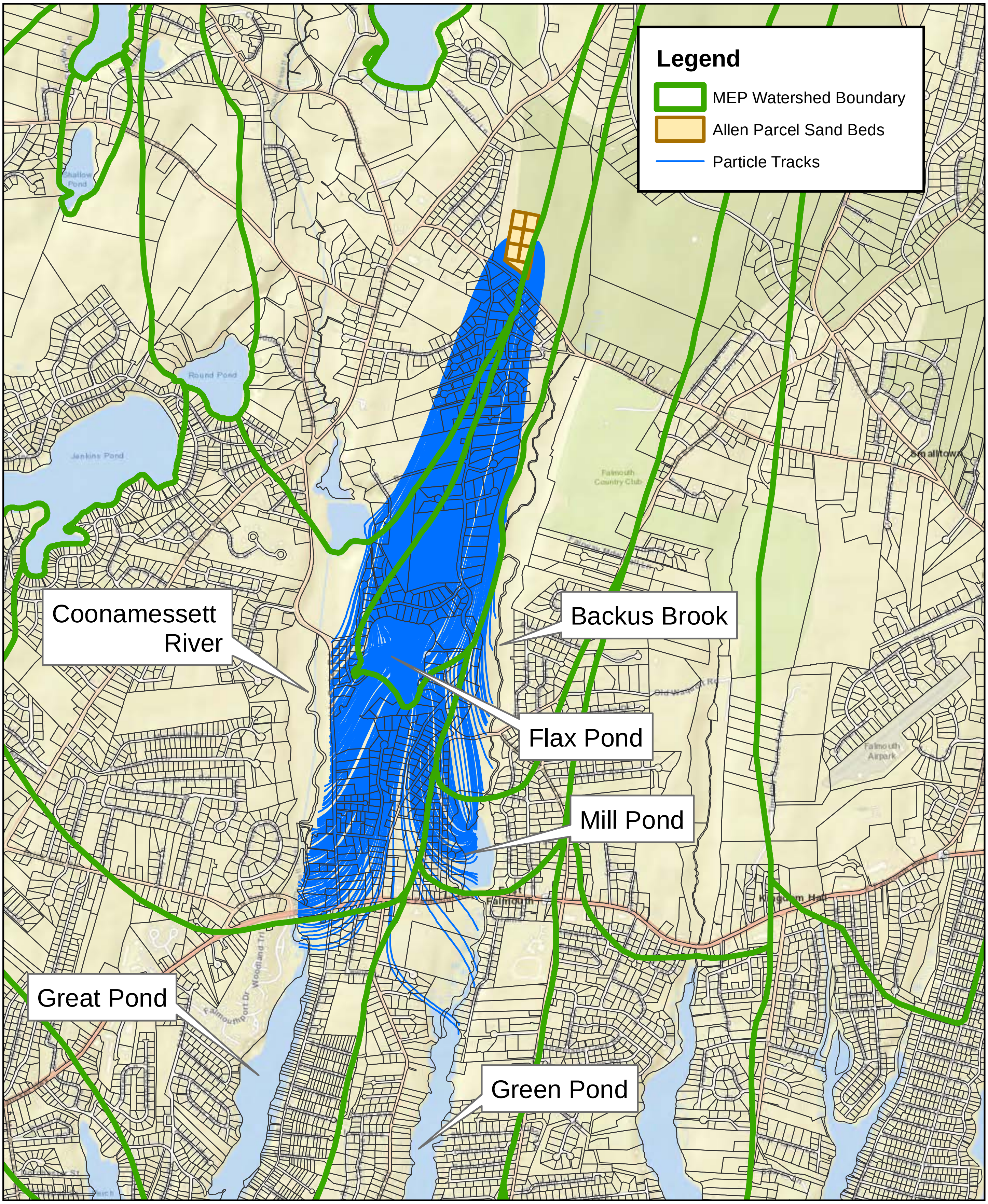
Anticipated Groundwater Mounding
Scenario 2021-Allen-1.03 mgd

Project No. 11153041
Revision No. -
Date 07/19/2021

FIGURE 14

G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\04 29 2021 Particle Tracts\Revised July 19 2021\Figure 14 Allen Mounding 1.03.mxd
Print date: 19 Jul 2021 - 16:30

Data source: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community. Created by: jjobrien



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Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

GHD

TOWN OF FALMOUTH
Hydrological Evaluations

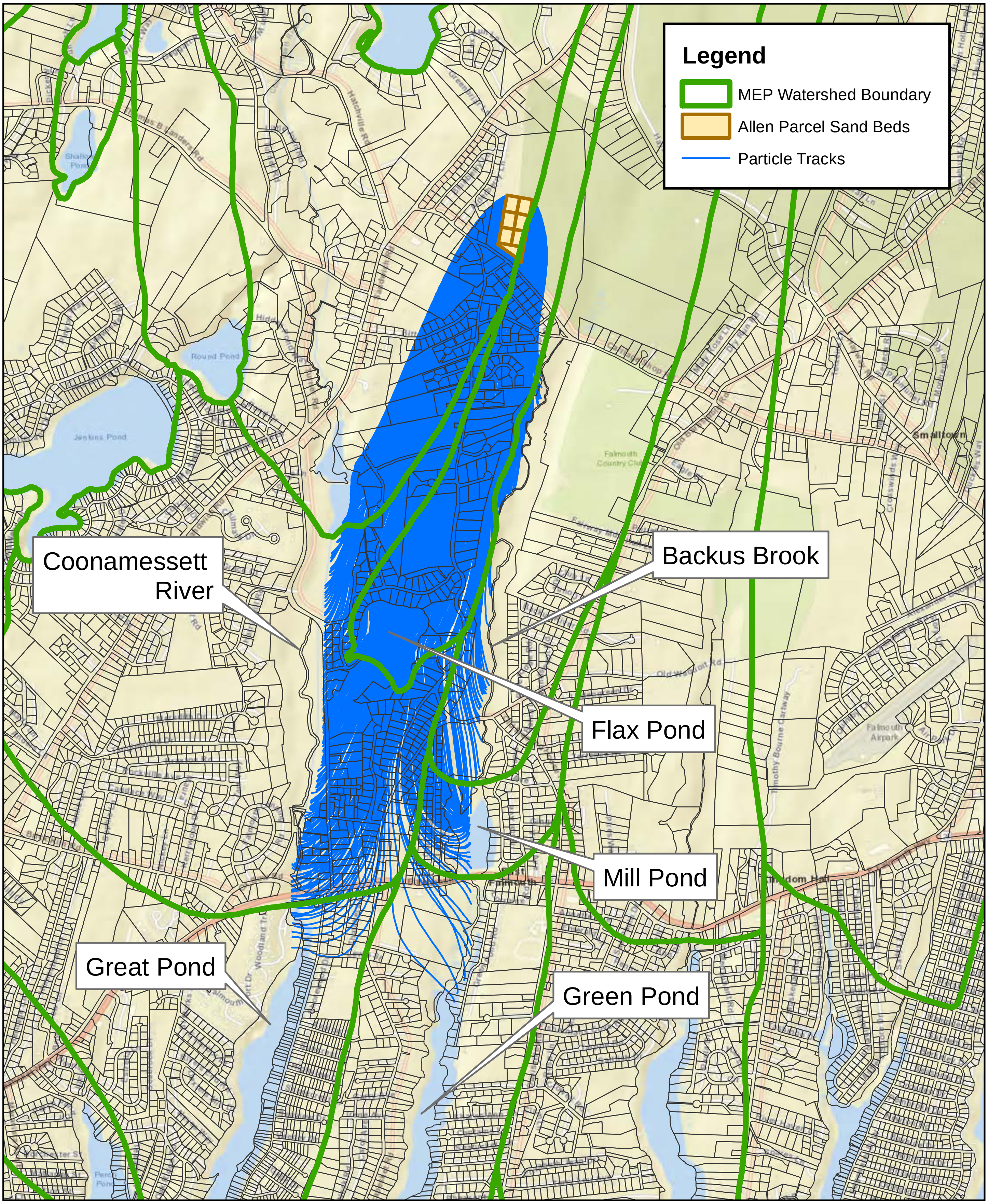
Anticipated Treated Effluent Discharge Migration in Groundwater to Surface Water: Scenario 2021-Allen-0.5 mgd

Project No.	11153041
Revision No.	-
Date	07/19/2021

FIGURE 15

G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\04 29 2021 Particle Tracts\Revised July 19 2021\Figure 15 Allen Tracts 0.5.mxd
Print date: 19 Jul 2021 - 16:39

Data source: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community. Created by: jjobrien



Paper Size ANSI A

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Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1927
Grid: NAD 1927 StatePlane Massachusetts Mainland FIPS 2001

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GHD

TOWN OF FALMOUTH
Hydrological Evaluations

Anticipated Treated Effluent Discharge Migration in Groundwater to Surface Water: Scenario 2021 Allen - 1.03 mgd

Project No. 11153041
Revision No. -
Date 07/19/2021

FIGURE 16

G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\04 29 2021 Particle Tracts\Revised mxd june 18 2021\Figure 16 Allen Tracts 1.03.mxd
Print date: 19 Jul 2021 - 16:53

Data source: Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community. Created by: jjobrien

Attachments

Attachment 1

[Attachment Title]

Memorandum

June 21, 2021

To:	Town of Falmouth, MA	Ref. No.:	11153041
From:	Anastasia Rudenko, P.E., BCEE, ENV SP J. Jefferson Gregg, P.E., BCEE Jesse Schwalbaum, Watershed Hydrogeologic	Tel:	774-470-1637 774-470-1640
CC:	File; Project Team		
Subject:	**South Coast Embayments – Preliminary Evaluations and Notice of Project Change Project** **Summary of Groundwater Modeling Evaluations for Open Sand Beds 14 & 15 and the Allen Parcel – Four Planning Groundwater Modeling Scenarios – Final**		

1. Purpose of Memo

The purpose of this memorandum is to summarize four sets of groundwater modeling scenarios that were conducted for Open Sand Beds 14 & 15 and the Allen Parcel in January 2020.

1.1 References, Regulations, and Guidelines

The references, regulations, and design guidelines listed below were used to develop this memorandum. Documents are referred to by the abbreviation indicated in parenthesis for the remainder of the memorandum.

References:

- TASA TM No. 3 – South Coast Embayments Preliminary Evaluations and Notice of Project Change Project – Final Teaticket / Acapesket Study Area Discharge Technologies Evaluation – Technical Memorandum No. 3, prepared by GHD, dated April 11, 2019 (TASA TM-3)
- TASA TM No. 5- South Coast Embayments Preliminary Evaluations and Notice of Project Change Project – Hydraulic Load Tests at the Augusta Parcel and Allen Parcel – Technical Memorandum No. 5, prepared by GHD, dated April 11, 2019 (TASA TM-5)
- TASA TM No. 7 – South Coast Embayments Preliminary Evaluations and Notice of Project Change Project – Final Teaticket / Acapesket Study Area Conceptual Layouts and Preliminary Cost Estimates Evaluation – Technical Memorandum No. 7, prepared by GHD, dated April 11, 2019 (TASA TM-7)
- Town of Falmouth, Massachusetts Recharge Beds 14 &15 Contract No. WW-14-04 CW SRF No. 3928 Record Drawings, prepared by GHD, dated June 2017

- Modified Individual Groundwater Discharge Permit No. 168-5, effective date December 22, 2015 (2015 Permit)
- TM-8 - Falmouth Nutrient Management Plan – Hydraulic Load Tests at Sites 7 and 10, prepared by GHD, dated August 31, 2011 (2011 TM-8)
- Harbaugh, Arlen W., 2005, MODFLOW-2005, The U.S. Geological Survey
- Modular Ground-Water Model—the Ground-Water Flow Process, U.S. Geological Survey Techniques and Methods 6-A16
- Walter, D. A. and A. T. Whealan, 2004, Simulated Water Sources and Effects of Pumping on Surface and Ground Water, Sagamore and Monomoy Flow Lenses, Cape Cod, Massachusetts, Scientific Investigations Report 2004-5181
- Environmental Simulations, Inc., 2004, Groundwater Vistas Manual
- Harbaugh, Arlen W., Edward R. Banta, Mary C. Hill and Michael G. McDonald, 2000, “MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model, U.S. Geological Survey Open-File Report 00-92
- Masterson, J.P., B.D. Stone, D.A. Walter, and J. Savoie, 1997, Hydrogeologic Framework of Western Cape Cod, Massachusetts, U.S. Geological Survey, Hydrologic Atlas HA-741
- Anderson, M.P. and W.W. Woessner, 1992, Applied Groundwater Modeling, AcadPress, Inc., San Diego, California
- Pollock, D.W., 1994, User’s Guide for MODPATH/MODPATH-PLOT, Version 3: A particle tracking post processing package for MODFLOW, the U.S Geological Survey finite difference ground-water flow model, Open File Report 94-464
- McDonald, M.G. and A.W. Harbaugh, 1988, A Modular Three-Dimensional Finite Difference Groundwater Flow Model, Techniques of Water Resources Investigations 06-Al, USGS

2. Modeling Methodology

Groundwater modeling was conducted by Watershed Hydrogeologic. The ultimate basis for all of the modeling scenarios outlined in this memorandum is the USGS groundwater flow model of the Sagamore Lens of the Cape Cod Aquifer (Walters and Whealan, 2004). This model was developed using the USGS three-dimensional groundwater flow model MODFLOW (2000). The input and output model files for the Sagamore Lens Model (the portion of the Cape Cod Model that covers the Town of Falmouth) were obtained directly from the USGS.

The groundwater modeling simulations were conducted using a sub-regional version of the Sagamore Lens Model that included only the southwestern portion of the Sagamore Lens—the Town of Falmouth and surrounding areas. The sub-regional model was generated using a technique known as telescopic mesh refinement. The sub-regional model area is extracted from the larger model and the new boundaries are represented by constant head nodes that are equivalent to the water levels at those nodes in the original model.

The sub-regional model was further revised by tightening the grid spacing in the areas of interest. The original Sagamore Model had uniform grid sizes of 400 by 400 feet. In the sub-regional model, the grids were revised to 50 by 50 feet in the recharge areas. This also required modifying some of the boundary conditions, particularly the stream nodes. The MODFLOW stream package requires that stream nodes be numbered sequentially without gaps or duplications. The sub-regional model was then run without changes and compared to the regional Sagamore Model. Minor changes in the stream conductivities were required to better match the water levels and water budget to the original model, but a satisfactory calibration was obtained without any significant modifications.

The groundwater model simulations were conducted using the USGS model MODFLOW 2005 (Harbaugh, 2005). Particle tracking, to determine anticipated treated effluent discharge migration in groundwater to surface water was conducted using the USGS particle tracking code MODPATH (Pollock, 1994) which interfaces directly with the MODFLOW outputs.

3. Overview of Scenario Sets

Four layouts were modeled as part of this evaluation in four scenario sets:

- A Scenarios – Existing Open Sand Beds 14 & 15
- B Scenarios – Expanded Open Sand Beds 14 & 15 (Conceptual Layout)
- C Scenarios – Allen Parcel Open Sand Beds 1 – 4 (Conceptual Layout)
- D Scenarios – Allen Parcel Open Sand Beds 1 -12 (Conceptual Layout)

Subsequent sections of this memo provide a description of each set of scenarios and an analysis of modeling results. An initial simulation was conducted for each scenario using a hydraulic loading rate of 7 gpd/sf, which hydraulic load testing has indicated is an appropriate design hydraulic loading rate for each site (TASA TM-7 and 2011 TM-8). Hydraulic loading rates for each scenario set were increased at intervals of 4 gpd/sf for the two additional runs. One additional simulation was selected for each scenario based on the findings of the initial three simulations.

4. A Scenarios – Existing Open Sand Beds 14 & 15

4.1 A Scenarios Description

Four modeling scenarios were conducted for the existing Open Sand Beds 14 & 15 (the layout of these sand beds is shown on Attachment 1 – Existing Open Sand Beds As-Built Drawing. The first three scenarios involved effluent discharge to (recharge from) Beds 14 & 15 ranging from 0.55 to 1.1 million gallons per day (based on hydraulic load rates from 7 to 14 gallons per day per square foot). A fourth scenario was then run with recharge from Beds 14 & 15 of 0.76 million gallons per day, representing the estimated flow from LPSA + TASA + ESRA. Each of the four scenarios also assumed effluent discharge to (recharge from) Open Sand

Beds 9 through 13 at an annual average rate of 450,000 gpd. The anticipated treated effluent discharge migration in groundwater to surface water was evaluated using particle tracking. Particles within each model scenario were tracked down-gradient from the recharge beds through groundwater to the following surface waterbodies:

- Sub-watersheds within the West Falmouth Harbor Watershed:
  - Mashapaquit Creek, from its origin southwest of Crocker Pond to Snug Harbor
  - Snug Harbor (inner West Falmouth Harbor)
  - Outer West Falmouth Harbor
- Sub-watersheds outside of the West Falmouth Harbor watershed:
  - Herring Brook, including Crocker Pond
  - Buzzards Bay (west or north of the West Falmouth Harbor watershed)

4.2 Anticipated Treated Effluent Discharge Migration in Groundwater To Surface Water as a Percentage of Recharge

The results of each modeling scenario were analyzed as a percentage of effluent recharge that reaches specific receptors. The Falmouth Wastewater Treatment Facility (WWTF) open sand beds were modeled as two systems:

- Open Sand Beds 9-13
- Open Sand Beds 14-15

Due to the proximity of the two open sand bed systems to each other, expanded recharge in Open Sand Beds 14 & 15 is anticipated to have an impact on the anticipated treated effluent discharge migration in groundwater to surface water from Open Sand Beds 9 through 13, even though the annual average flow rate to the latter set of beds is consistent (0.45 mgd) in all scenarios. Effluent flow from the Open Sand Beds 1 - 13 system was modeled as discharging to Open Sand Beds 9-13 only, as these are the beds that are currently in use by the WWTF. For ease of presentation and understanding, the anticipated treated effluent discharge migration in groundwater to surface water discharged to each of the two systems of sand beds is shown in two separate tables. Table 4.1 summarizes the anticipated treated effluent discharge migration in groundwater to surface water recharged from Open Sand Beds 9-13 (as a percentage of the total effluent recharged from Open Sand Beds 9 through 13) for each of the four scenarios.

Table 4.1 A Scenarios: Treated Effluent Discharge Migration in Groundwater to Surface Water from Existing Open Sand Beds 9- 13 (as a Percentage of Total Recharge from Existing Open Sand Beds 9 – 13)

Scenario	Model Input		Model Output					
	Average Annual Flow (mgd)		Outside West Falmouth Harbor Watershed			Inside West Falmouth Harbor Watershed		
	Open Sand Beds 9 - 13	Open Sand Beds 14 - 15	Herring Brook	Buzzards Bay				
				North of West Falmouth Harbor Boundary	South of West Falmouth Harbor Boundary	Mashapa-quit Creek	Snug Harbor	Outer Harbor
A1	0.45	0.55	0%	26%	0%	55%	1%	18%
A2	0.45	0.87	0%	10%	0%	59%	2%	29%
A3	0.45	1.11	0%	6%	0%	64%	2%	28%
A4	0.45	0.76	0%	14%	0%	60%	3%	23%

Table 4.2 summarizes the anticipated treated effluent discharge migration in groundwater to surface water of nitrogen recharged from Open Sand Beds 14 & 15 (as a percentage of the total effluent recharged from Open Sand Beds 14 &15) for each of the four scenarios. In addition, Table 4.2 includes for comparison the results of a scenario previously run in 2013 (which is called here Scenario A0). Scenario A0 modeled the flow conditions permitted in the 2015 groundwater discharge permit for the WWTF (‘Modified Individual Groundwater Discharge Permit 168-5’, issuance date March 31, 2015). Figures showing particle tracks for each modeling scenario are included in Attachment 2.

Memorandum

Table 4.2 A Scenarios: Treated Effluent Discharge Migration in Groundwater to Surface Water from Existing Open Sand Beds 14 & 15 (as a Percentage of Total Recharge from Existing Open Sand Beds 14 & 15)

Scenario	Model Input		Model Output					
	Average Annual Flow (mgd)		Outside West Falmouth Harbor Watershed			Inside West Falmouth Harbor Watershed		
	Open Sand Beds 9 - 13	Open Sand Beds 14 – 15[1]	Herring Brook	Buzzards Bay				
				North of West Falmouth Harbor Boundary	South of West Falmouth Harbor Boundary	Mashapa-quit Creek	Snug Harbor	Outer Harbor
A0[3]	0.45	0.26	0%	100%	0%	0%	0%	0%
A1	0.45	0.55	11%	89%	0%	0%	0%	0%
A2	0.45	0.87	20%	76%	0%	0%	0%	4%
A3	0.45	1.11	22%	67%	0%	0%	5%	6%
A4	0.45	0.76[4]	18%	81%	0%	0%	0%	1%

Notes:

1. Estimated effluent flow rate to Open Sand Beds 14 & 15 is calculated based on an active surface area of 78,940 square feet.
2. Scenario A0 represents the average annual flow conditions outlined in ‘Modified Individual Groundwater Discharge Permit 168-5’, date of issuance March 31, 2015. Scenario A0 modeling simulations are summarized in ‘Updated Groundwater Modeling for Site 7 Falmouth Comprehensive Wastewater Management Planning (CWMP) Project’, prepared by GHD and dated July 31, 2013.The groundwater modeling indicated that no particles from Open Sand Beds 14 and 15 go directly to Herring Brook in this scenario. The percent of flow from Open Sand Beds 14 and 15 that flows through Crocker Pond in this Scenario is 42%. It is estimated that approximately 15% of the recharge to Open Sand Beds 14 and 15 could flow to Herring Brook after the water flows through Crocker Pond. The flow balance of groundwater flow to Herring Brook indicated that the flow from Crocker Pond represents 3.7% of the total Herring Brook watershed flow.
3. 0.76 mgd represents the anticipated average annual flow rate of LPSA + TASA + ESRA

4.3 Anticipated Groundwater Mounding

The model results provide estimates of the rise in the water table as a result of proposed recharge. Table 4.3 presents the projected groundwater mound for each scenario with respect to elevation. Estimated groundwater contours under the A Scenarios are depicted in Attachment 3. The model indicates a separation of over 40-feet between the anticipated groundwater mound and the recharge beds for all scenarios. The minimum DEP-required separation distance is 4-feet.

Table 4.3 A Scenarios: Elevation of Simulated Groundwater Mound

Scenario[2]	Elevation of Groundwater Mound (feet)	Separation Between Anticipated Groundwater Mound and Recharge Elevation (ft)[1]	Estimated Change in Groundwater Mound Elevation Between Scenario and Estimated Groundwater Elevation with No Effluent Recharge (ft)[3]
A1	22.1	45.5	3.2
A2	23.5	44.1	4.6
A3	24.5	43.1	5.6
A4	23.0	44.6	4.1

Notes:

1. The elevation of the bottom of Open Sand Beds 14 & 15 is 67.6 feet.
2. All elevations are presented in NAVD 88.
3. Estimated groundwater elevation with no effluent recharge is 18.9 ft above mean sea level.

5. Scenario B – Expanded Open Sand Beds 14 & 15

5.1 B Scenarios Description

Four additional modeling scenarios were conducted for the expanded Open Sand Beds 14 & 15 conceptual layout outlined in TASA TM-7 Figure 7 (see Attachment 4 – Expanded Open Sand Beds 14 & 15 Conceptual Layout). The area of the Expanded Open Sand Beds 14 & 15 evaluated is a total of 125,440 square feet, compared to their current bed area of 78,940 square feet. The first three B Scenarios involved effluent flow to (recharge from) Expanded Open Sand Beds 14 & 15 ranging from 0.88 to 1.76 million gallons per day (based on hydraulic load rates from 7 to 14 gallons per day per square foot). A fourth scenario was then run with recharge from Beds 14 & 15 of 0.76 million gallons per day, representing the estimated flow from LPSA + TASA + ESRA. Each of the four B Scenarios also assumed effluent flow to Open Sand Beds 9 through 13 at an annual average rate of 450,000 gpd. The anticipated treated effluent discharge migration in groundwater to surface water of effluent recharge within the groundwater system was evaluated using particle tracking, in the same way in which the "A" Scenarios were evaluated.

5.2 Anticipated Treated Effluent Discharge Migration In Groundwater To Surface Water as a Percentage of Recharge

The results of each modeling scenario were analyzed as a percentage of effluent recharge that reaches specific receptors. For ease of presentation and understanding, the anticipated treated effluent discharge migration in groundwater to surface water discharged to each the two systems of sand beds (Beds 9-13 and Expanded Beds 14&15) is shown in two separate tables. Table 5.1 summarizes the anticipated treated effluent discharge migration in groundwater to surface water recharged from Open Sand Beds 9-13 (as a percentage of the total effluent recharged from Open Sand Beds 9 through 13) for each of the four scenarios.

Table 5.1 B Scenarios: Treated Effluent Discharge Migration in Groundwater to Surface Water from Existing Open Sand Beds 9-13 (as a Percentage of Total Recharge from Existing Open Sand Beds 9 – 13)

Scenario	Model Input		Model Output					
	Average Annual Flow (mgd)		Outside West Falmouth Harbor Watershed			Inside West Falmouth Harbor Watershed		
	Open Sand Beds 9 - 13	Open Sand Beds 14 – 15[1]	Herring Brook	Buzzards Bay				
				North of West Falmouth Harbor Boundary	South of West Falmouth Harbor Boundary	Mashapa-quit Creek	Snug Harbor	Outer Harbor
B1	0.45	0.88	0%	61%	0%	20%	1%	18%
B2	0.45	1.38	0%	22%	0%	55%	1%	22%
B3	0.45	1.76	0%	7%	0%	71%	3%	19%
B4	045	0.76[1]	0%	75%	0%	8%	0%	17%

Notes:

1. 0.76 mgd represents the anticipated average annual flow rate of LPSA + TASA + ESRA

Table 5.2 summarizes the anticipated treated effluent discharge migration in groundwater to surface water recharged from Expanded Open Sand Beds 14 & 15 (as a percentage of the total effluent recharged from Expanded Open Sand Beds 14 &15) for each of the four B Scenarios. Figures showing particle track figures for each modeling scenario are included in Attachment 5.

Table 5.2 B Scenarios: Treated Effluent Discharge Migration in Groundwater to Surface Water from Expanded Open Sand Beds 14 and 15 (as a Percentage of Total Recharge from Expanded Open Sand Beds 14 & 15)

Scenario	Model Input		Model Output					
	Average Annual Flow (mgd)		Outside West Falmouth Harbor Watershed			Inside West Falmouth Harbor Watershed		
	Open Sand Beds 9 - 13	Open Sand Beds 14 – 15[1]	Herring Brook	Buzzards Bay				
				North of West Falmouth Harbor Boundary	South of West Falmouth Harbor Boundary	Mashapa-quit Creek	Snug Harbor	Outer Harbor
B1	0.45	0.88	39%	55%	0%	0%	0%	6%
B2	0.45	1.38	39%	36%	0%	0%	12%	13%
B3	0.45	1.76	43%	28%	0%	0%	18%	11%
B4	045	0.76[1]	25%	75%	0%	0%	0%	0%

Notes:
1. 0.76 mgd represents the anticipated average annual flow rate of LPSA + TASA + ESRA

5.3 Anticipated Groundwater Mounding

The model results provide estimates of the rise in the water table as a result of proposed recharge. The groundwater mound for each scenario was tabulated and is presented with respect to elevation in Table 5.3. Estimated groundwater contours for the B Scenarios are depicted in Attachment 6. The model indicates a separation of over 40-feet between the anticipated groundwater mound and the recharge beds for all scenarios. The minimum DEP-required separation distance is 4-feet.

Table 5.3 B Scenarios: Elevation of Simulated Groundwater Mound[1]

Scenario	Elevation of Groundwater Mound (feet)	Separation Between Anticipated Groundwater Mound and Recharge Elevation (ft)[2]	Estimated Change in Groundwater Mound Elevation Between Scenario and Estimated Groundwater Elevation with No Effluent Recharge (ft)[3]
B1	23.3	44.3	4.4
B2	25.2	42.4	6.3
B3	26.7	40.9	7.8
B4	22.8	44.8	3.9

Notes:
1. All elevations are presented in NAVD 88.
2. The elevation of the bottom of Open Sand Beds 14 & 15 is 67.6 feet.
3. Estimated groundwater elevation with no effluent recharge is 18.9 ft above mean sea level.

6. Scenario C – Allen Parcel Open Sand Beds 1 through 4

6.1 C Scenarios Description

Four initial modeling scenarios were conducted for the Allen Parcel based on Open Sand Beds 1 through 4 Conceptual Layout (See Attachment 7 for Allen Parcel Open Sand Beds 1 through 4 Conceptual Layout). The first three scenarios involved effluent discharge to (recharge from) Allen Parcel Beds 1 through 4 ranging from 1.12 to 2.24 million gallons per day (based on hydraulic load rates from 7 to 14 gallons per day per square foot). A fourth scenario was then run with recharge from Allen Parcel Beds 1 through 4 of 0.50 million gallons per day, representing the estimated flow from TASA + ESRA.

The anticipated treated effluent discharge migration in groundwater to surface water was evaluated using particle tracking. Particles within each model scenario were tracked down-gradient from the recharge beds to the following sub-watersheds:

- Sub-watersheds within the Great Pond watershed:
  - Coonamessett River, including Flax Pond
  - Great Pond
- Sub-watersheds within the Green Pond watershed:
  - Backus Brook
  - Green Pond

6.2 Anticipated Treated Effluent Discharge Migration in Groundwater To Surface Water as a Percentage of Recharge

The results of each modeling scenario were analyzed as a percentage of total effluent recharge that reaches specific receptors. Anticipated treated effluent discharge migration in groundwater to surface water recharged from Allen Parcel Beds 1 through 4 that reaches each subwatershed, as a percentage of total effluent recharge for each scenario is summarized in Table 6.1. Figures showing particle track figures for each modeling scenario are included in Attachment 8.

Table 6.1 C Scenarios: Treated Effluent Discharge Migration in Groundwater to Surface Water from Allen Parcel Open Sand Beds 1-4, as a Percentage of Total Flow Discharged

	Model Input	Model Output			
Scenario	Effluent Flow Rate to Proposed Allen Parcel Open Sand Beds 1-4 (mgd)[2,3]	Great Pond Watershed		Green Pond Watershed	
		Coonamessett River (Flax Pond in Parenthesis)[4]	Great Pond	Backus Brook	Green Pond
C1	1.12	58% (28%)	0%	20%	22%
C2	1.76	52% (22%)	5%	28%	15%
C3	2.24	50% (19%)	3%	31%	16%
C4	0.5[5]	69% (45%)	0%	8%	23%

	Model Input	Model Output			
Scenario	Effluent Flow Rate to Proposed Allen Parcel Open Sand Beds 1-4 (mgd)[2,3]	Great Pond Watershed		Green Pond Watershed	
		Coonamessett River (Flax Pond in Parenthesis)[4]	Great Pond	Backus Brook	Green Pond

Notes:

1. Estimated effluent flow rate is calculated based on an active surface area of 160,000 square feet (four open sand beds, each with an active surface are of 40,000 square feet).
2. For the simulation, the capture wells in the vicinity of the parcel that are operated by Joint Base Cape Cod were shut off in the model.
3. It is assumed that all open sand beds are in service at simulated average annual conditions.
4. Flax Pond nitrogen is a subset of the total nitrogen to Coonamessett River (.
5. 0.5 mgd represents the anticipated average annual flow rate of TASA + ESRA.

As shown in Table 6.1, these modeling results indicate that at the lowest recharge rate modeled (0.5 mgd), the fate of almost 70% of the recharged flow is the Coonamessett River (which flows to Great Pond), and the remainder ultimate flows to the Green Pond watershed, either through Backus Brook or directly to Green Pond. As effluent recharge increases, the fate shifts more eastward, so that the distribution between the watersheds is close to 50:50 at the highest recharge rate modeled (2.24 mgd).

6.3 Anticipated Groundwater Mounding

The model results provide estimates of the rise in the water table as a result of proposed recharge. The groundwater mound for each scenario was tabulated and is presented with respect to elevation in Table 6.3. Estimated groundwater contours for the C Scenarios are depicted in Attachment 9. The model indicates a separation of over 30-feet between the anticipated groundwater mound and the recharge beds for all scenarios. The minimum DEP-required separation distance is 4-feet.

Table 6.3 C Scenarios: Elevation of Simulated Groundwater Mound[1]

Scenario	Elevation of Groundwater Mound (feet)	Separation Between Anticipated Groundwater Mound and Recharge Elevation (ft)[2]	Estimated Change in Groundwater Mound Elevation Between Scenario and Estimated Groundwater Elevation with No Effluent Recharge (ft)[3]
C1	29.2	32.8	1.8
C2	30.4	31.6	3.0
C3	31.7	30.3	4.3
C4	28.0	34.0	0.6

Notes:

1. All elevations are presented in NAVD 88.
2. The elevation of the bottom of Open Sand Beds 1 through 4 is estimated to be approximately 60 feet.
3. Estimated groundwater elevation with no effluent recharge is 28.9 ft above mean sea level.

7. Scenario D – Allen Parcel Open Sand Beds 1 through 12

7.1 D Scenarios Description

Three additional modeling scenarios were conducted for a potential future expanded total bed area at the Allen Parcel based on the Open Sand Beds 1 through 12 Conceptual Layout (Attachment 10 – Allen Parcel Open Sand Beds 1 through 12 Conceptual Layout). The total area of the potential future expanded Allen Parcel Sand Beds is 380,000 square feet, compared to 160,000 square feet modeled in the "C" Scenarios. The three "D" Scenarios involved effluent discharge to (recharge from) Allen Parcel Beds 1 through 4 ranging from 2.66 to 5.32 million gallons per day (based on hydraulic load rates from 7 to 14 gallons per day per square foot).

The anticipated treated effluent discharge migration in groundwater to surface water was evaluated using particle tracking. Particles within each model scenario were tracked down-gradient from the recharge beds to the following sub-watersheds:

- Sub-watersheds within the Great Pond watershed:
  - Coonamessett River, including Flax Pond
  - Great Pond
- Sub-watersheds within the Green Pond watershed:
  - Backus Brook
  - Green Pond

7.2 Anticipated Treated Effluent Discharge Migration In Groundwater To Surface Water as a Percentage of Recharge

The results of each modeling scenario were analyzed as a percentage of effluent recharge that reaches specific receptors. Anticipated effluent recharge for each scenario is summarized in Table 7.1. Figures showing particle track figures for each modeling scenario are included in Attachment 11.

Table 7.1 D Scenarios: Treated Effluent Discharge Migration in Groundwater to Surface Water from Allen Parcel Open Sand Beds as a Percentage of Recharge from Proposed Allen Parcel Open Sand Beds 1 - 12

	Model Inputs	Model Output			
Scenario	Effluent Flow Rate to Proposed Allen Parcel Open Sand Beds 1-4 (mgd)[2,3]	Great Pond Watershed		Green Pond Watershed	
		Coonamessett River (Flax Pond in Parenthesis)[4]	Great Pond	Backus Brook	Green Pond
D1	2.66	49% (10%)	2%	36%	13%
D2	4.18	48% (9%)	2%	44%	6%
D3	5.32	41% (9%)	3%	49%	7%

Notes:
1. Estimated effluent flow rate is calculated based on an active surface area of 380,000 square feet (four open sand beds with an active surface area of 40,000 and eight open sand beds with an active surface area of 27,500).
2. For the simulation the capture wells in the vicinity of the parcel that are operated by Joint Base Cape Cod were shut off in the model.
3. It is assumed that all open sand beds are in service at simulated average annual conditions.
4. Flax Pond nitrogen is a subset of the total nitrogen to Coonamessett River

7.3 Anticipated Groundwater Mounding

The model results provide estimates of the rise in the water table as a result of proposed recharge. The groundwater mound for each scenario was tabulated and is presented with respect to elevation in Table 7.3. Estimated groundwater contours for the D Scenarios are depicted in Attachment 12. The model indicates a separation of over 25-feet between the anticipated groundwater mound and the recharge beds for all scenarios. The minimum DEP-required separation distance is 4-feet.

Table 7.3 D Scenarios: Elevation of Simulated Groundwater Mound

Scenario[2]	Elevation of Groundwater Mound (feet)	Separation Between Anticipated Groundwater Mound and Recharge Elevation (ft)[1]	Estimated Change in Groundwater Mound Elevation Between Scenario and Estimated Groundwater Elevation with No Effluent Recharge (ft)[3]
D1	32.0	30.0	4.6
D2	34.3	27.7	6.9
D3	36.3	25.7	8.9

Notes:
1. The elevation of the bottom of Open Sand Beds 1 through 4 is estimated to be approximately 60-feet.
2. All elevations are presented in NAVD 88.
3. Estimated groundwater elevation with no effluent recharge is 28.9 ft above mean sea level.

8. Summary of Groundwater Evaluations

This memorandum outlines 11 groundwater modeling simulations that were conducted to evaluate the treated effluent discharge migration in groundwater to surface water and groundwater mounding for four effluent recharge options.

Attachment 1

Existing Open Sands 14 & 15 As-Built Drawings

TIE LEGEND

1	NORTHWEST CORNER ACCESS HATCH RISER
2	SOUTHWEST CORNER ACCESS HATCH RISER
3	NORTHEAST CORNER ACCESS HATCH RISER
4	SOUTHEAST CORNER ACCESS HATCH RISER
A	18" GATE VALVE
B	18" BYPASS GATE VALVE
C	18" GATE VALVE
D	18" BYPASS GATE VALVE
E	6" DIA. PVC VENT
F	4" X 4" PT WOOD POST

AS-BUILT TIES (FT)

	A	B	C	D	E	F
1	14.08	12.00	95	-35	10	111
2	13.92	10.25	115	-55	10	111
3	74.15	72.19	72	8.15	10	111
4	74.13	72.17	92	-19.87	10	111

LEGEND

- MONITORING WELL
- SEWER CLEANOUT
- GATE VALVE
- EXISTING STONE RUNNEL
- EXISTING RIPRAP RUNNEL

Green Seal Environmental, Inc.
114 State Road, Building B
Sagamore Beach, MA 02562
Tel: (508) 888-6034
Fax: (508) 888-1506
www.gseenv.com

GRAPHIC SCALE 1" = 40' (0 / 20 / 40 / 60 METERS; 0 / 40 / 80 / 120 / 160 FEET)

RECORD DRAWING

THESE DRAWINGS HAVE BEEN REVISED TO REFLECT MAJOR CHANGES, IF ANY, WHICH OCCURRED DURING CONSTRUCTION. REVISIONS ARE BASED UPON INFORMATION SUPPLIED BY CONTRACTOR.

DATE: 6/15/17 PER: SCT

No	Revision	Drawn	Job Manager	Project Director	Date
2	RECORD DRAWINGS	JDF	SLT	SCT	6/17
1	CONFORMED PER ADDENDUM NO. 1	JDF	MRD	WRH	06/15
0	FOR CONSTRUCTION	JDF	MRD	WRH	2/15

Note: * indicates signatures on original issue of drawing or last revision of drawing

NOTES: UNDERGROUND FACILITIES, STRUCTURES, AND UTILITIES HAVE BEEN PLOTTED FROM AVAILABLE SURVEYS AND RECORDS, AND THEREFORE THEIR LOCATIONS MUST BE CONSIDERED APPROXIMATE ONLY. THERE MAY BE OTHERS, THE EXISTENCE OF WHICH IS PRESENTLY NOT KNOWN. ANYONE USING UTILITY INFORMATION AND DATA PROVIDED HEREIN SHALL CALL DIG SAFE AT 811 SEVENTY TWO (72) HOURS, 3 BUSINESS DAYS IN ADVANCE TO VERIFY THE LOCATION OF UTILITIES PRIOR TO START OF CONSTRUCTION.

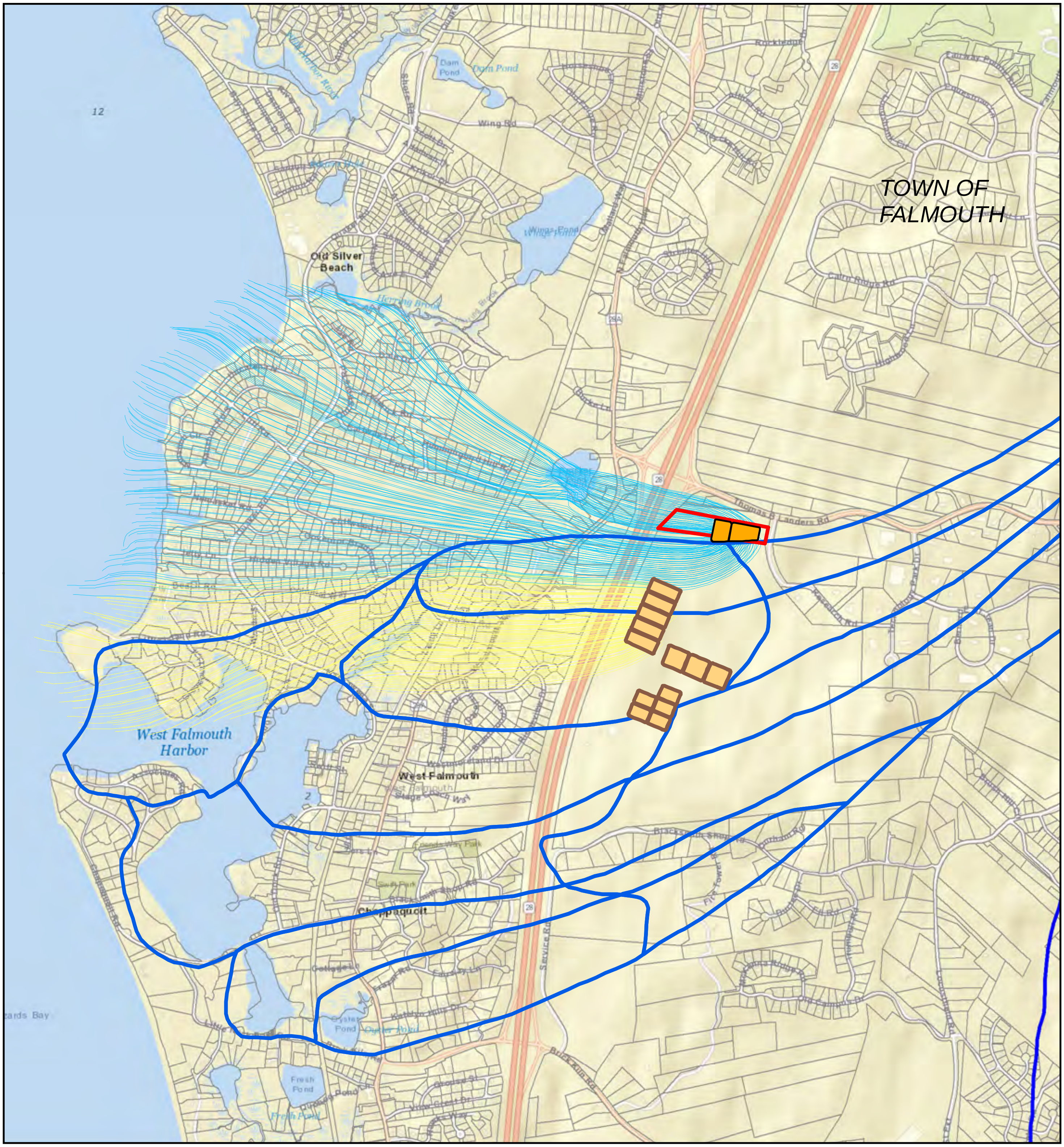
GHD Inc.
1545 Iyannough Road, Hyannis Massachusetts 02601 USA
T 1 774 470 1630 F 1 774 470 1631
E hyamail@ghd.com W www.ghd.com

Drawn JDF | Designer JDF
Drafting Check JDF | Design Check MRD
Approved (Project Director)
Date
Scale AS SHOWN
This Drawing shall not be used for Construction unless Signed and Sealed For Construction

Client **TOWN OF FALMOUTH, MASSACHUSETTS**
Project **RECHARGE BEDS 14 & 15**
Title **AS-BUILT SURVEY PLAN, DETAIL AND LEGEND**
Contract No. WW-14-04
Original Size Arch D
Drawing No: **86-16576-C018**
Rev: 2

Plot Date: 27 July 2017 - 4:27 PM Plotted by: James Fosdick Cad File No: G:\86\18813\CADD\Drawings\Record Drawings\Civil\86-16576-C018.dwg

Attachment 2
A Scenario Particle Track Map Figures



LEGEND

- Sand Beds 1-13
- Site 7 Sand Beds
- Site 7
- MEP Watershed Boundaries
- Particle Tracks - Site 7
- Particle Tracts Sand Beds 1-13

Notes: Estimated Flow Rate = 0.55 mgd,
Active Surface Area = 78,940 sf,
Hydraulic Loading Rate = 7 gpd/sf)

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

N

GHD

TOWN OF FALMOUTH
Hydrological Evaluations

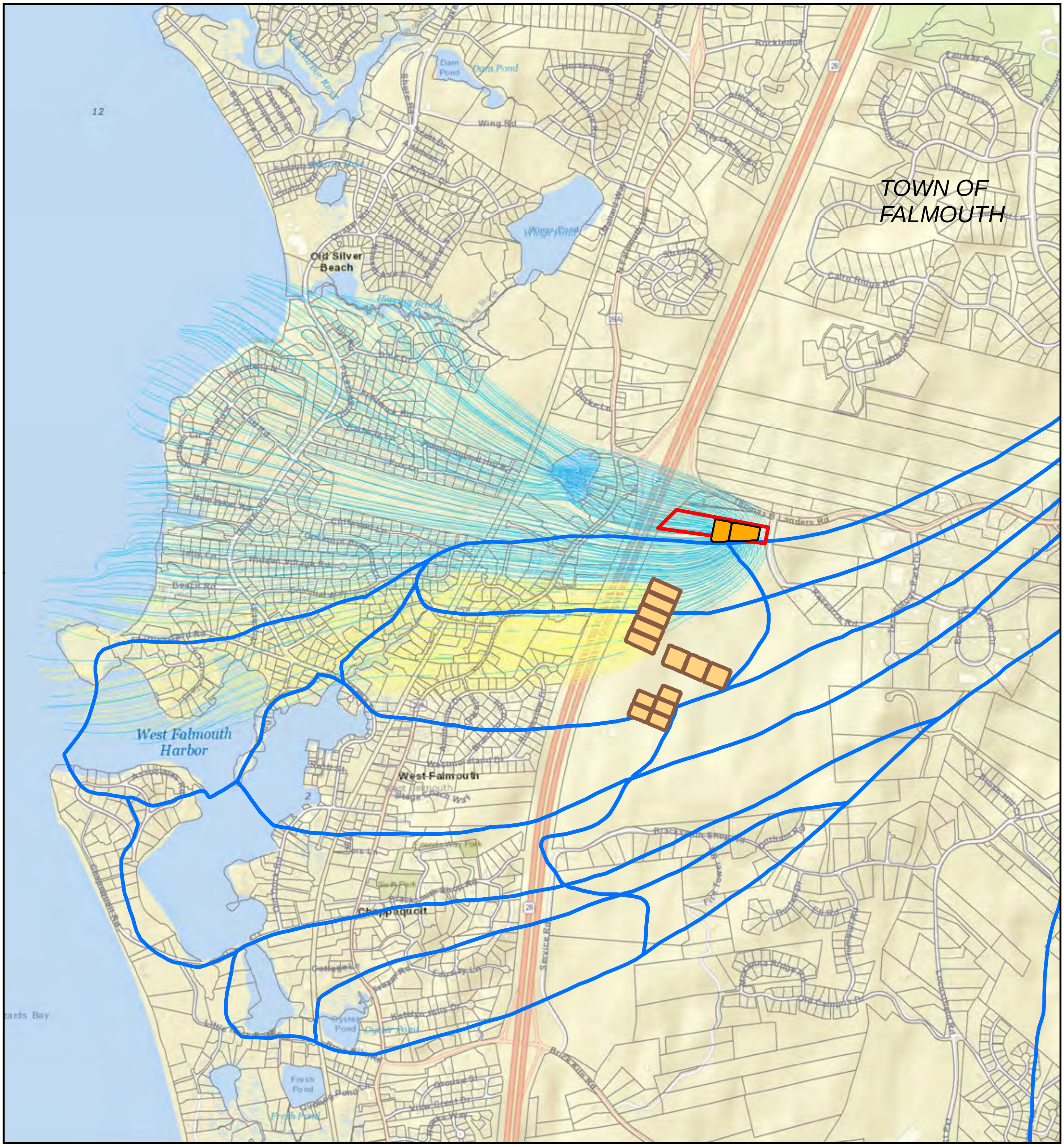
SCENARIO A1 - EXISTING OPEN SAND BEDS 14 &15 - PARTICLE TRACK MAP

Job Number	111-53041
Revision	-
Date	21 Apr 2021

Figure 1

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\January 2020 - Particle tracks\Particle Tracks Allen Parcel\Scenario 1 Site 7.mxd



LEGEND

Sand Beds 1-13		MEP Watershed Boundaries	
Site 7 Sand Beds		Particle Tracts Sand Beds 1-13	
Site 7		Particle Tracks Site 7	

Notes:Estimated Flow Rate = 0.87 mgd, Active Surface Area = 78,940 sf, Hydraulic Loading Rate = 11 gpd/sf

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

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GHD

TOWN OF FALMOUTH
Hydrological Evaluations

SCENARIO A2 - EXISTING OPEN SAND BEDS 14 &15 - PARTICLE TRACK MAP

Job Number 111-53041
Revision -
Date 21 Apr 2021

Figure 2

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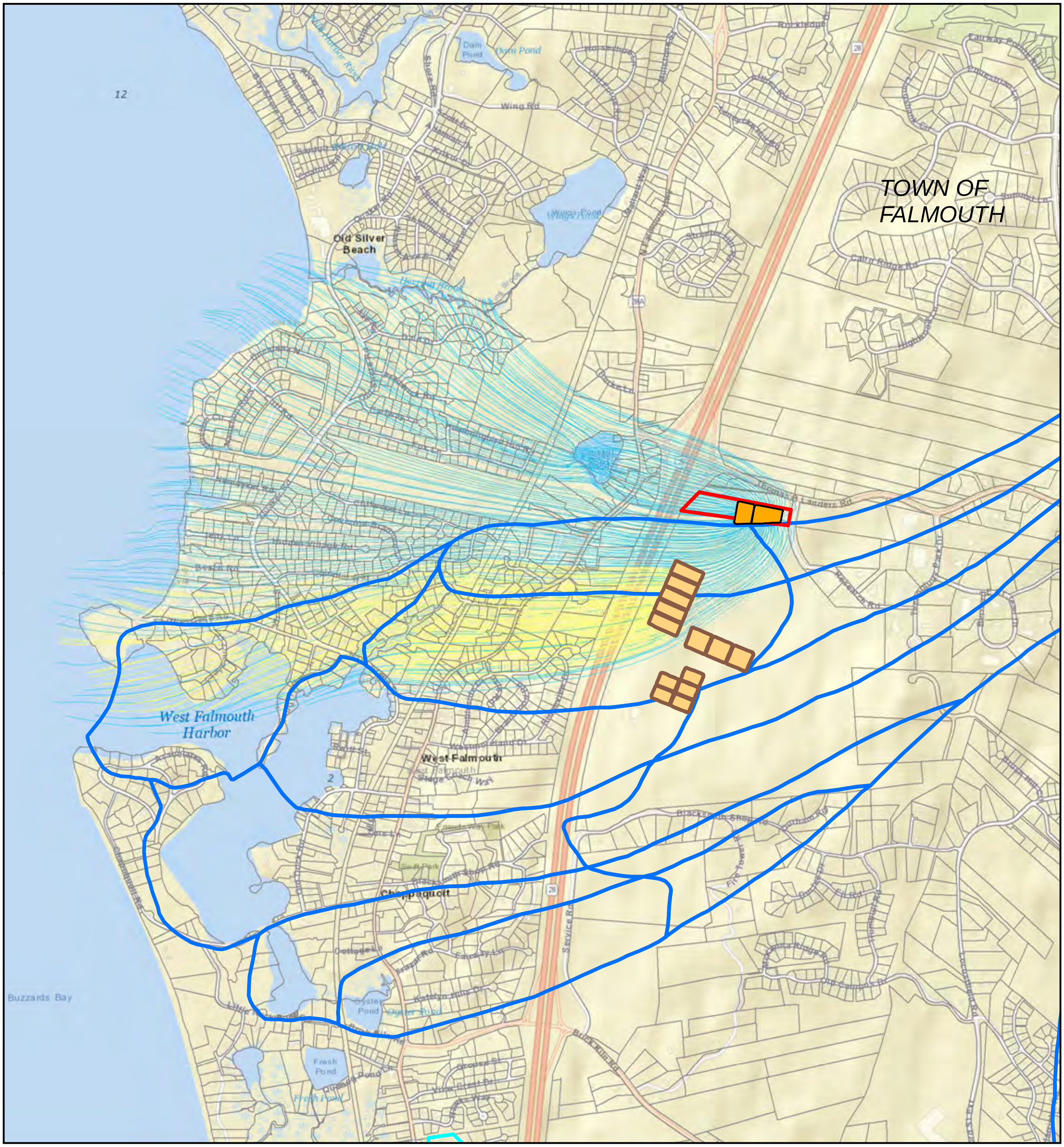

LEGEND

	Site 7 Sand Beds		MEP Watershed Boundaries
	Sand Beds 1-13		Particle Tracts - Sand Beds 1-13
	Site 7		Particle Tracks - Site 7

Notes: Estimated Flow Rate = 1.11 mgd,
Active Surface Area = 78,940 sf,
Hydraulic Loading Rate = 14 gpd/sf

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

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TOWN OF FALMOUTH
Hydrological Evaluations

SCENARIO A3 - EXISTING OPEN SAND BEDS 14 &15 - PARTICLE TRACK MAP

Job Number	111-53041
Revision	-
Date	21 Apr 2021

Figure 3

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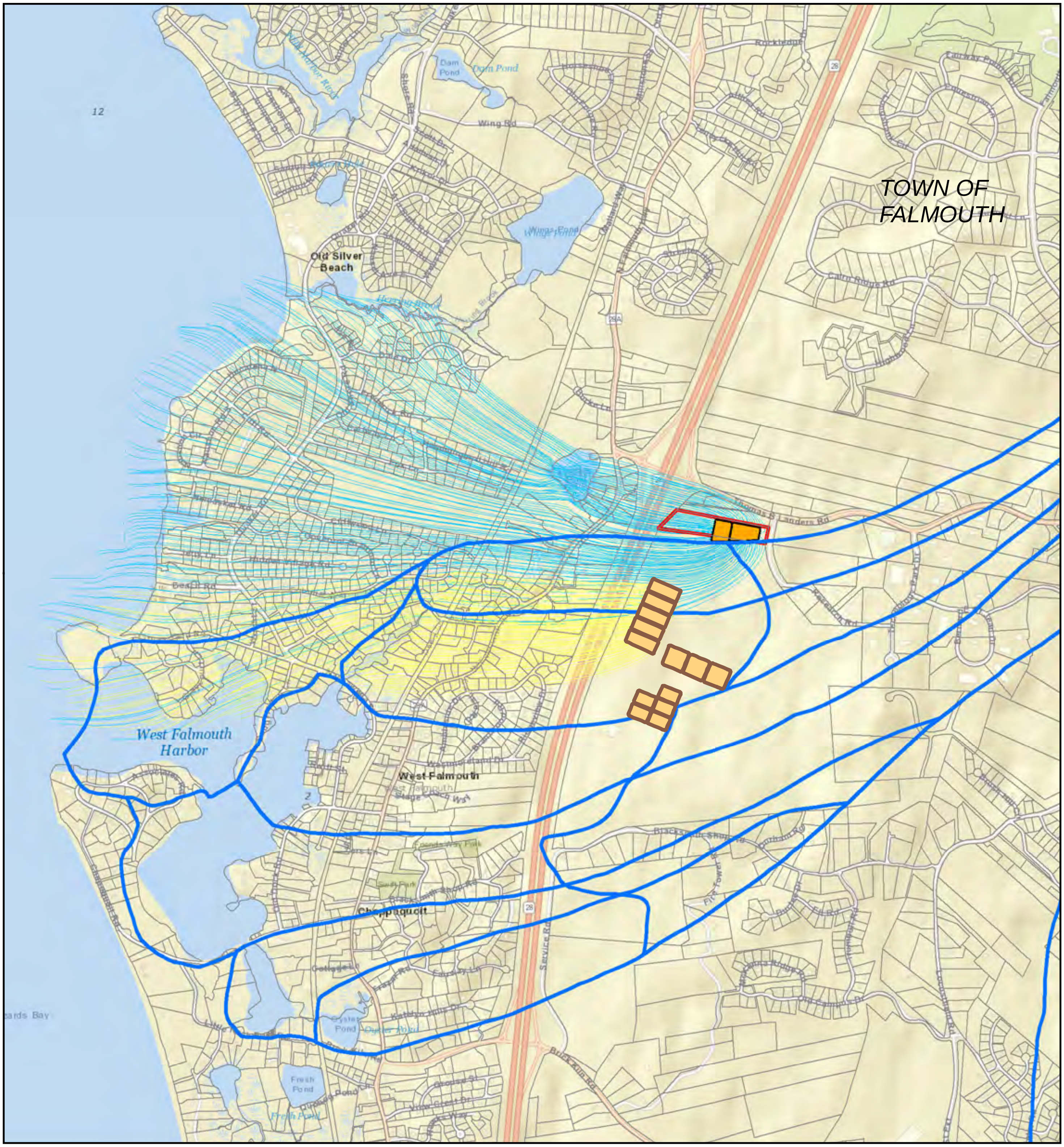
G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\January 2020 - Particle tracks\Particle Tracks Allen Parcel\Scenario 3 Site 7.mxd



LEGEND

- Site 7
- Site 7 Sand Beds
- Sand Beds 1-13
- MEP Watershed Boundaries
- Particle Tracts - Sand Beds 1-13
- Particle Tracks - Site 7

Notes: Estimated Flow Rate to
Open Sandbeds 14 & 15 = 0.76 mgd
Active Surface Area = 78,940 sf
Average Annual Hydraulic Loading Rate = 9.5 gpd/sf

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

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TOWN OF FALMOUTH
Hydrological Evaluations

SCENARIO A4 - EXISTING OPEN SAND BEDS 14&15 - PARTICLE TRACK MAP

Job Number	111-53041
Revision	-
Date	20 Apr 2021

Figure 4

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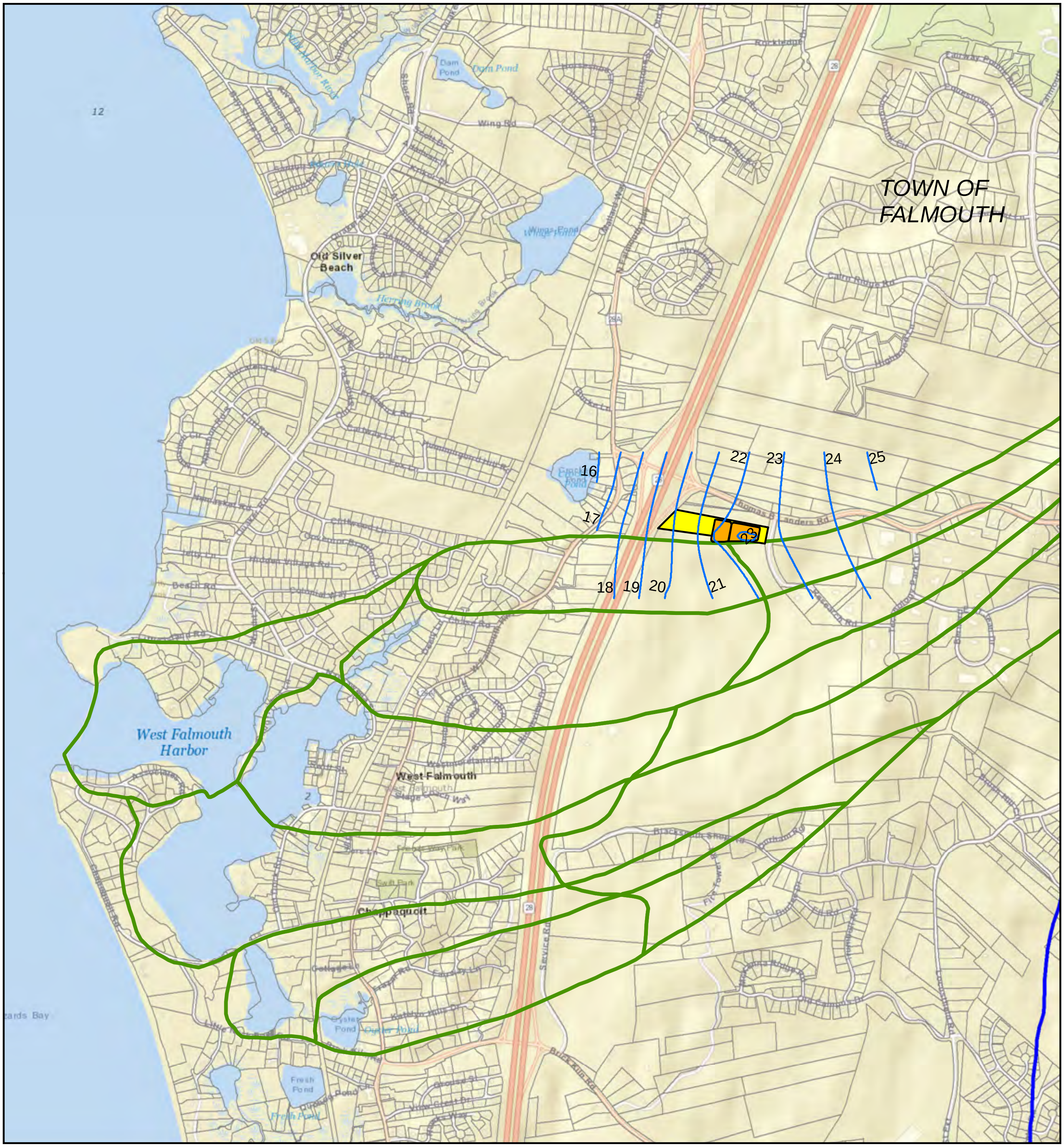
G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\January 2020 - Particle tracks\April 2020 Particle Tracks\Scenario 7 Site 7.mxd

Attachment 3
Existing Open Sand Beds 14 & 15
Groundwater Elevation Contour Figures



LEGEND

Notes: Estimated Flow Rate = 0.55 mgd, Active Surface Area = 78,940 sf, Hydraulic Loading Rate = 7 gpd/sf)

- Groundwater Elevation Contours
- Site 7
- Site 7 Sandbeds
- MEP Watershed Boundaries

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

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TOWN OF FALMOUTH
Hydrological Evaluations

Job Number	111-53041
Revision	-
Date	30 Jul 2020

SCENARIO A1 - EXISTING OPEN SAND BEDS 14&15 - GROUNDWATER ELEVATION CONTOURS

Figure 5

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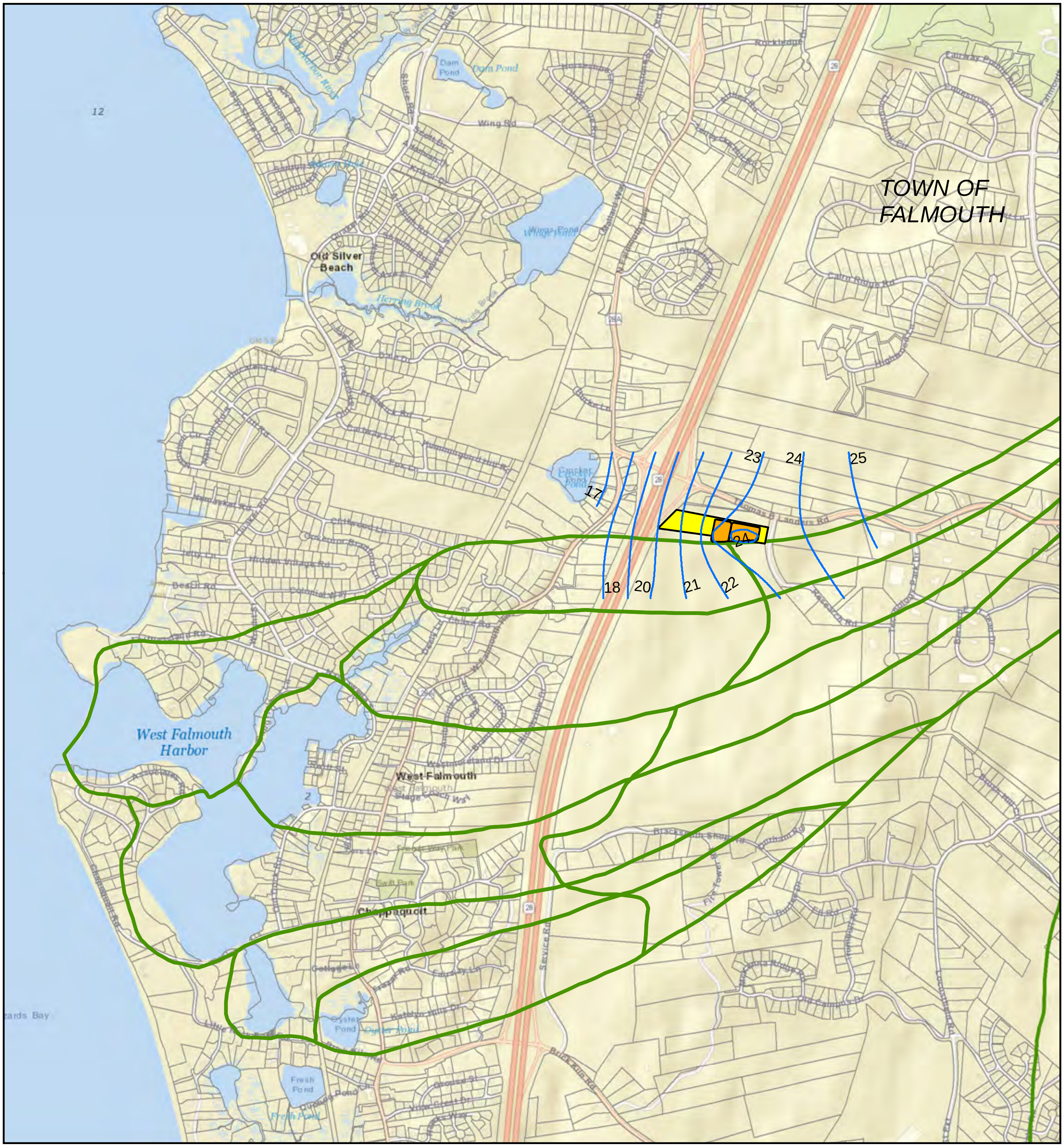
G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\January 2020 - Particle tracks\Particle Tracks Allen Parcel\Scenario 1 Site 7 - GW Elevation Contours.mxd



LEGEND

Notes:Estimated Flow Rate = 0.87 mgd, Active Surface Area = 78,940 sf,
Hydraulic Loading Rate = 11 gpd/sf

- Groundwater Elevation Contours
- Site 7
- Site 7 Sandbeds
- MEP Watershed Boundaries

Paper Size ANSI A

0 1,000 2,000 4,000
Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

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TOWN OF FALMOUTH
Hydrological Evaluations

Job Number | 111-53041
Revision | -
Date | 20 Jul 2020

SCENARIO A2 - EXISTING OPEN SAND BEDS
14&15 - GROUNDWATER ELEVATION CONTOURS

Figure 6

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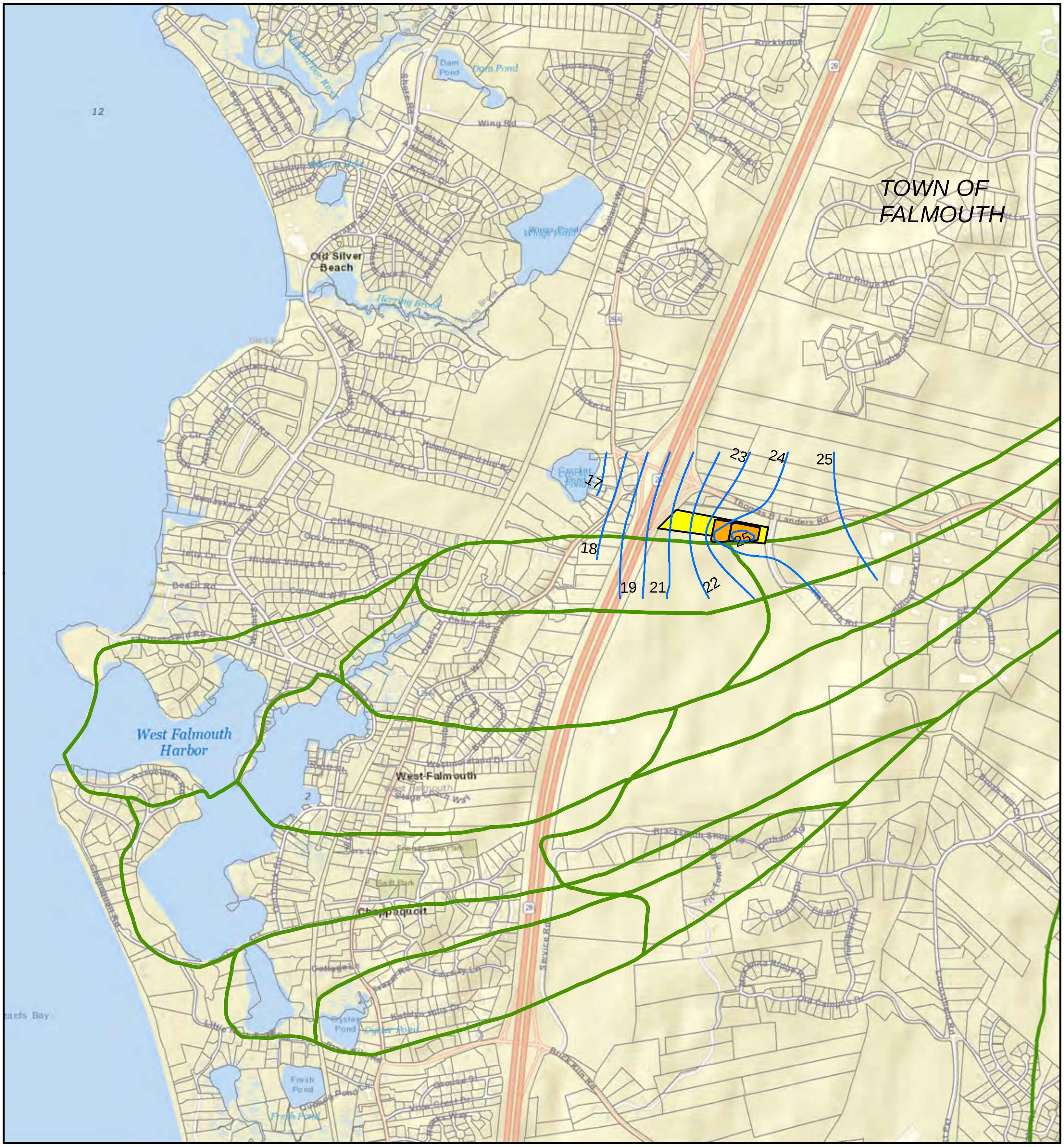

LEGEND

Notes: Estimated Flow Rate = 1.11 mgd, Active Surface Area = 78,940 sf, Hydraulic Loading Rate = 14 gpd/sf

- Groundwater Elevation Contours
- Site 7
- Site 7 Sandbeds
- MEP Watershed Boundaries

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

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TOWN OF FALMOUTH
Hydrological Evaluations

Job Number	111-53041
Revision	-
Date	20 Jul 2020

SCENARIO A3 - EXISTING OPEN SAND BEDS 14&15 - GROUNDWATER ELEVATION CONTOURS

Figure 7

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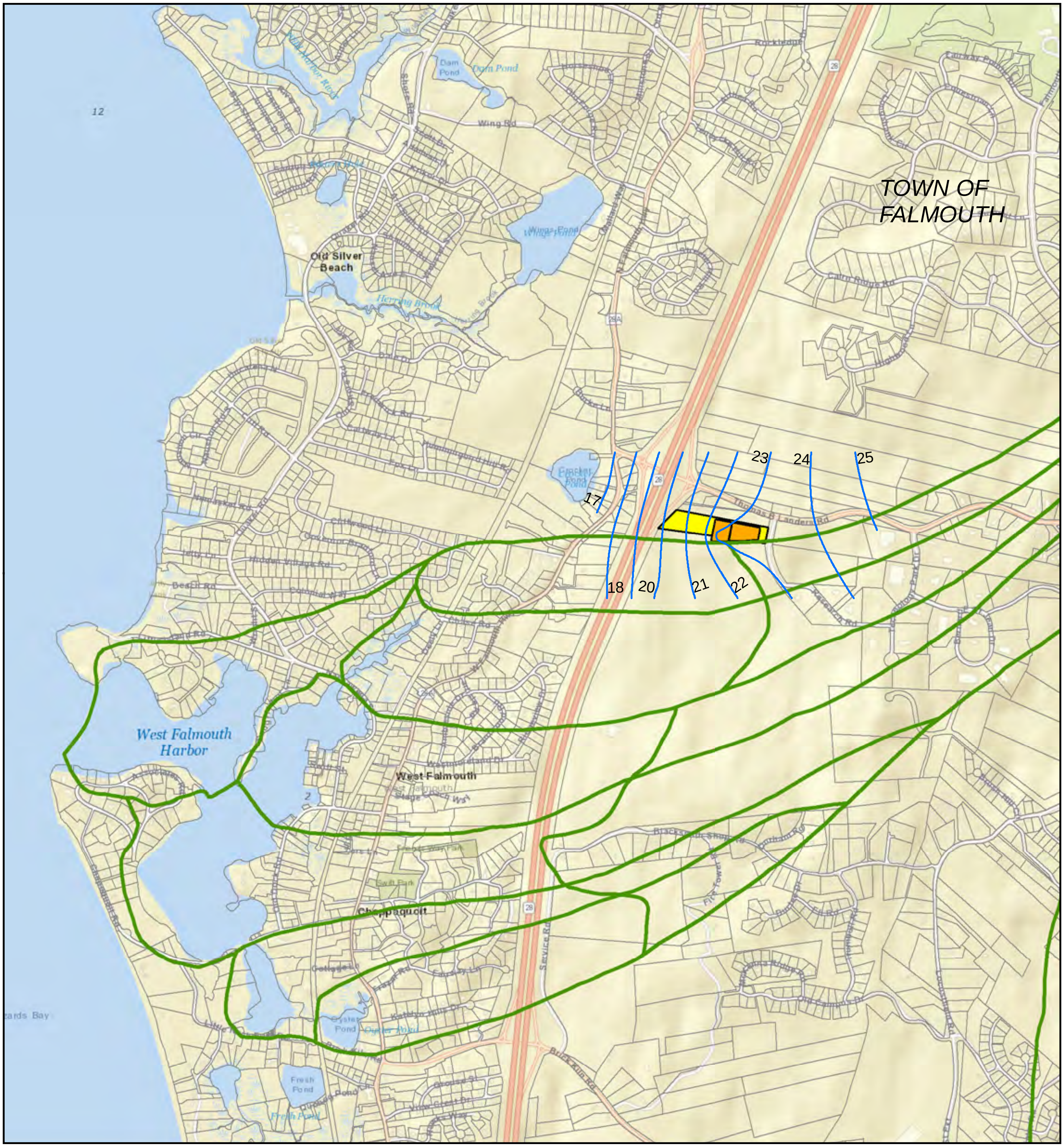

LEGEND

Notes: Estimated Flow Rate to Open Sandbeds 14 & 15 = 0.76 mgd
Active Surface Area = 78,940 sf
Average Annual Hydraulic Loading Rate = 9.5 gpd/sf

- Groundwater Elevation Contours
- Site 7
- Site 7 Sandbeds
- MEP Watershed Boundaries

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

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TOWN OF FALMOUTH
Hydrological Evaluations

Job Number	111-53041
Revision	-
Date	20 Jul 2020

SCENARIO A4 - EXISTING OPEN SAND BEDS 14&15 - GROUNDWATER ELEVATION CONTOURS

Figure 8

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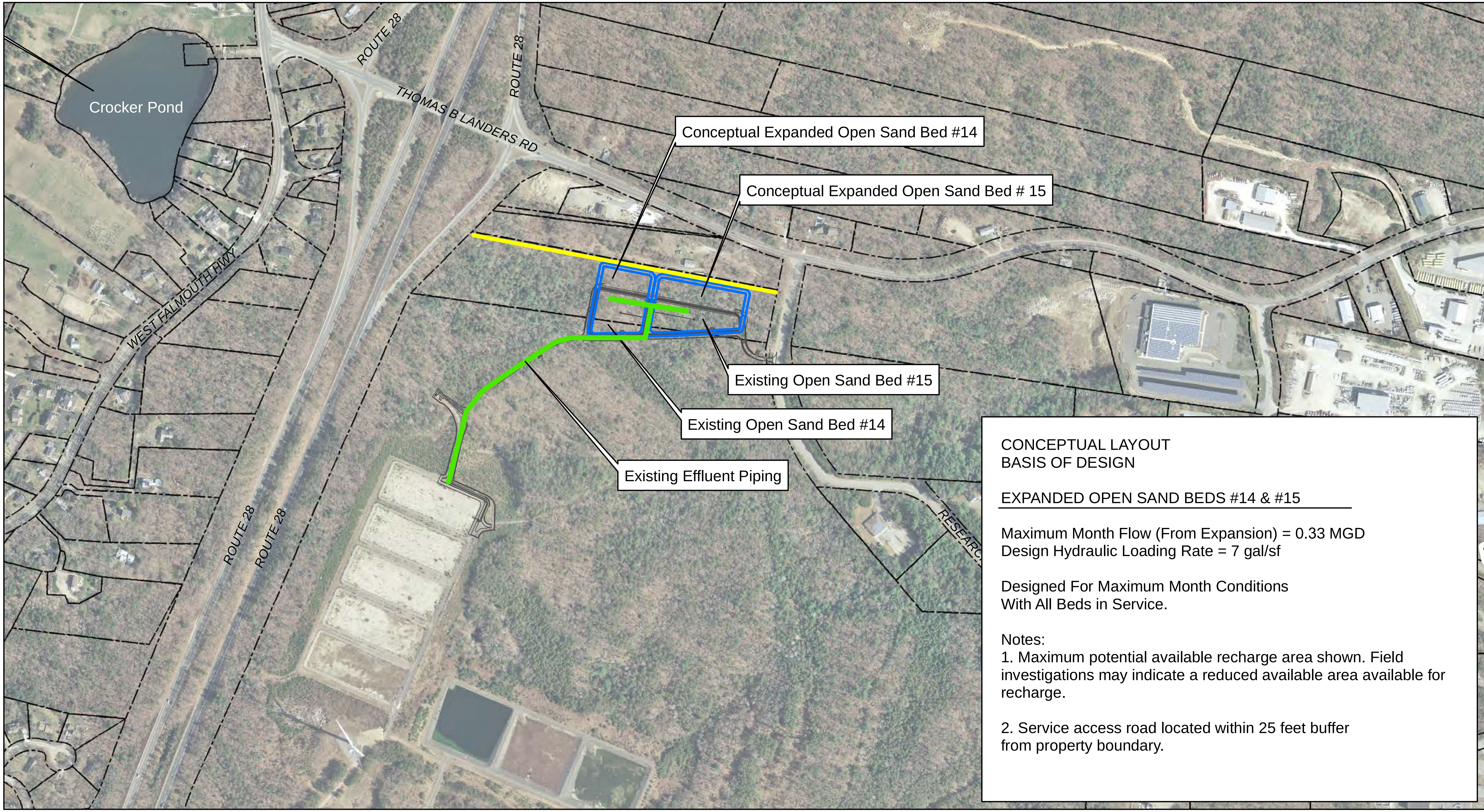
G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\January 2020 - Particle tracks\April 2020 Particle Tracks\Scenario 7 Site 7 - GW Elevation Contours.mxd

Attachment 4
Expanded Open Sand Beds 14 & 15
Conceptual Layout



CONCEPTUAL LAYOUT
BASIS OF DESIGN

EXPANDED OPEN SAND BEDS #14 & #15

Maximum Month Flow (From Expansion) = 0.33 MGD
Design Hydraulic Loading Rate = 7 gal/sf

Designed For Maximum Month Conditions
With All Beds in Service.

Notes:
1. Maximum potential available recharge area shown. Field investigations may indicate a reduced available area available for recharge.

2. Service access road located within 25 feet buffer from property boundary.

Paper Size ANSI B

0 200 400 800 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

N

LEGEND
Conceptual Expanded Open Sand Bed
Existing Effluent Piping
25' Buffer From Property Line

TOWN OF FALMOUTH, MA
Teaticket/Acapesket Preliminary Evaluation TASA (TM-7)

Conceptual Layout 3 -
Expanded Open Sand Beds 14 & 15

Job Number	111-53041
Revision	A
Date	14 Feb 2019

Figure 9

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G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\TASA TM-7\Figures\111-53041-F07_WWTF_SB.mxd

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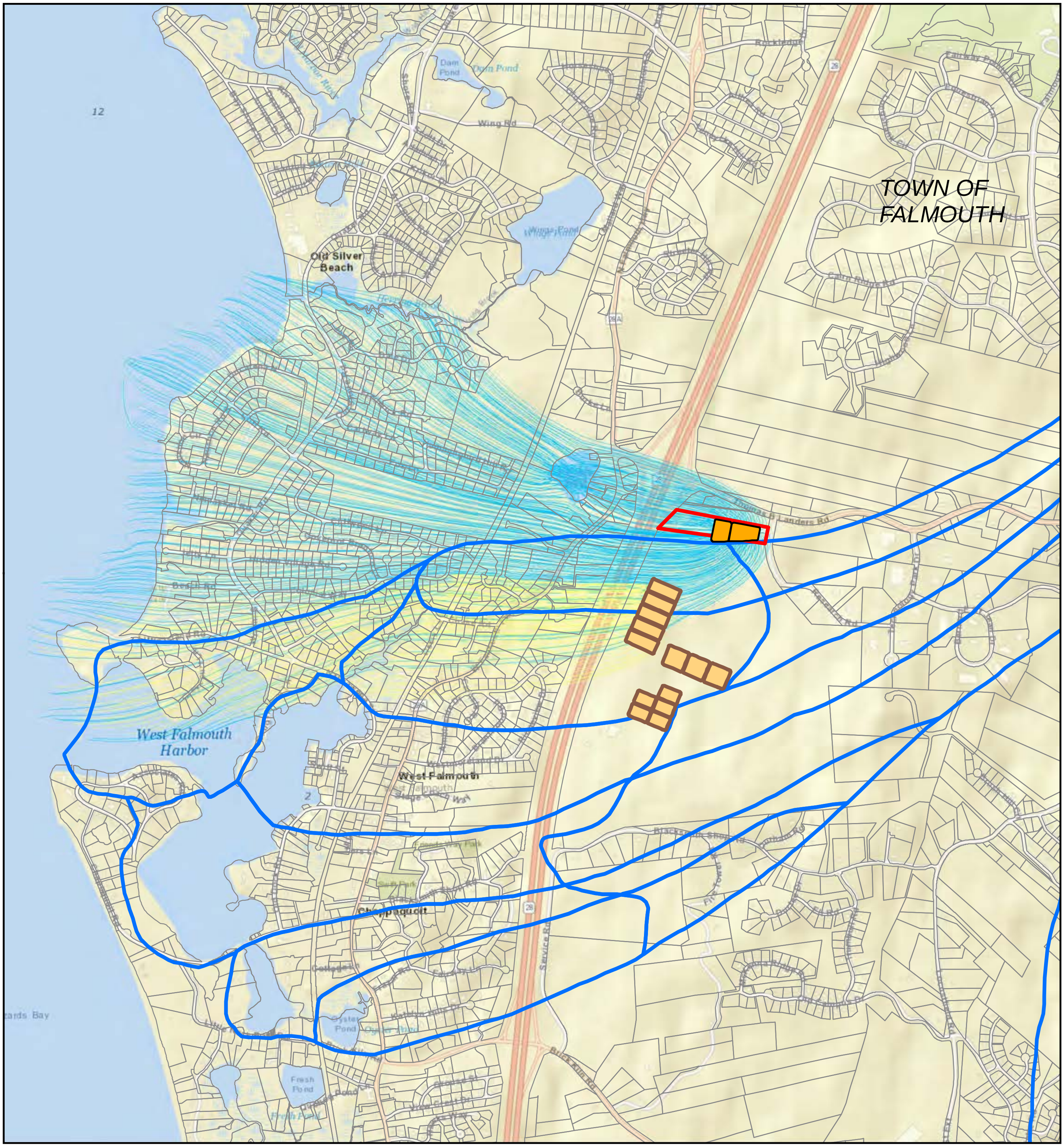
Attachment 5

B Scenario Particle Track Map Figures



LEGEND

Sand Beds 1-13
Site 7 Sand Beds
Site 7
MEP Watershed Boundaries
Particle Tracts - Sand Beds 1-13
Particle Tracks - Site 7

Notes: Estimated Flow Rate = 0.88 mgd,
Active Surface Area = 125,440 sf,
Hydraulic Loading Rate = 7 gpd/sf

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

N

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TOWN OF FALMOUTH
Hydrological Evaluations

SCENARIO B1 - EXPANDED OPEN SAND BEDS 14 &15 - PARTICLE TRACK MAP

Job Number 111-53041
Revision -
Date 20 Apr 2021

Figure 10

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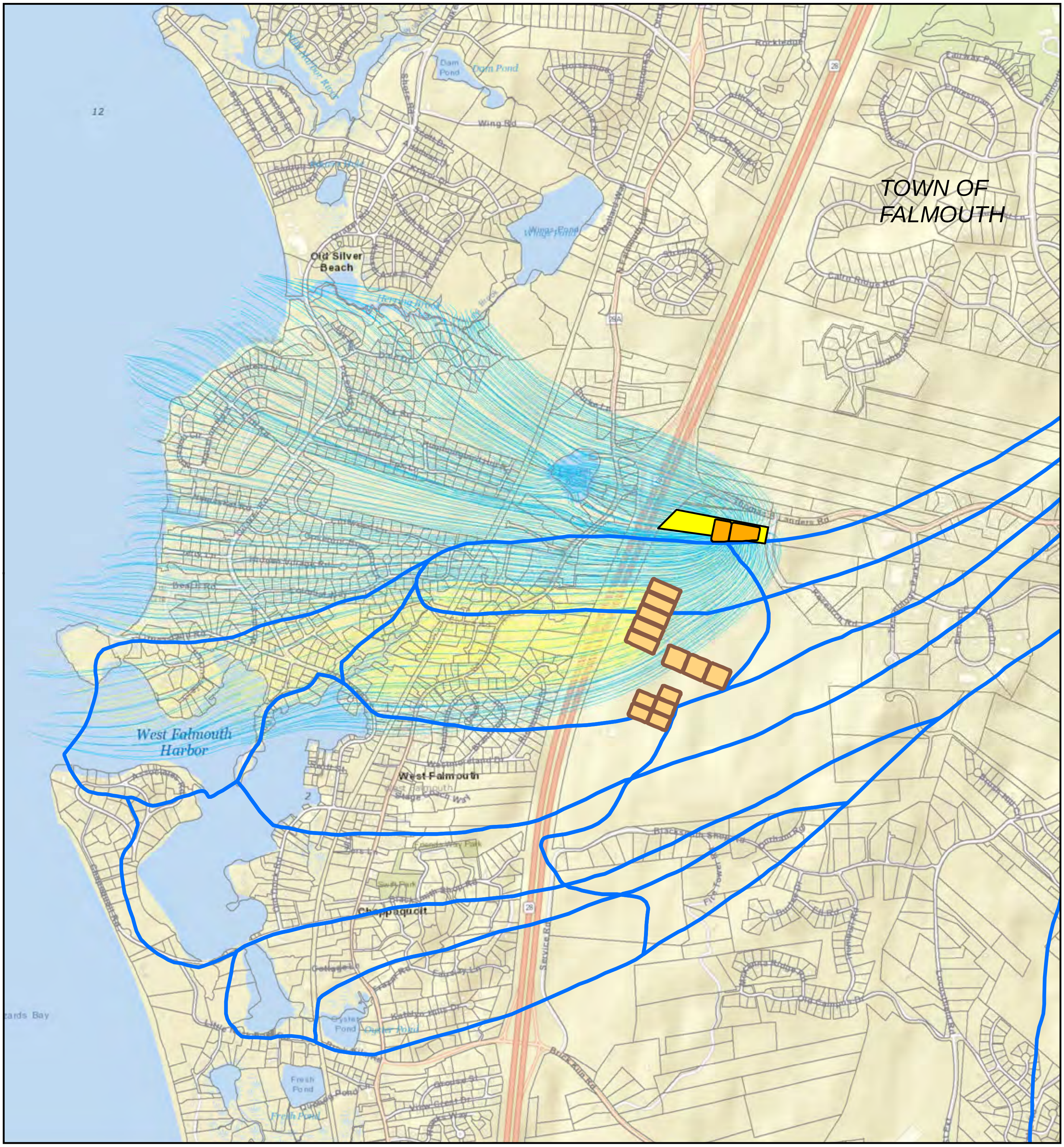
G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\January 2020 - Particle tracks\Particle Tracks Allen Parcel\Scenario 4 Site 7.mxd



LEGEND

- Sand Beds 1-13
- Site 7 Sand Beds
- Site 7
- MEP Watershed Boundaries
- Particle Tracts - Sand Beds 1-13
- Particle Tracks -Site 7

Notes: Estimated Flow Rate = 1.38 mgd,
Active Surface Area = 125,440 sf,
Hydraulic Loading Rate = 11 gpd/sf

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

N

TOWN OF FALMOUTH
Hydrological Evaluations

SCENARIO B2 - EXPANDED OPEN SAND BEDS 14&15 - PARTICLE TRACK MAP

Job Number	111-53041
Revision	-
Date	20 Apr 2021

Figure 11

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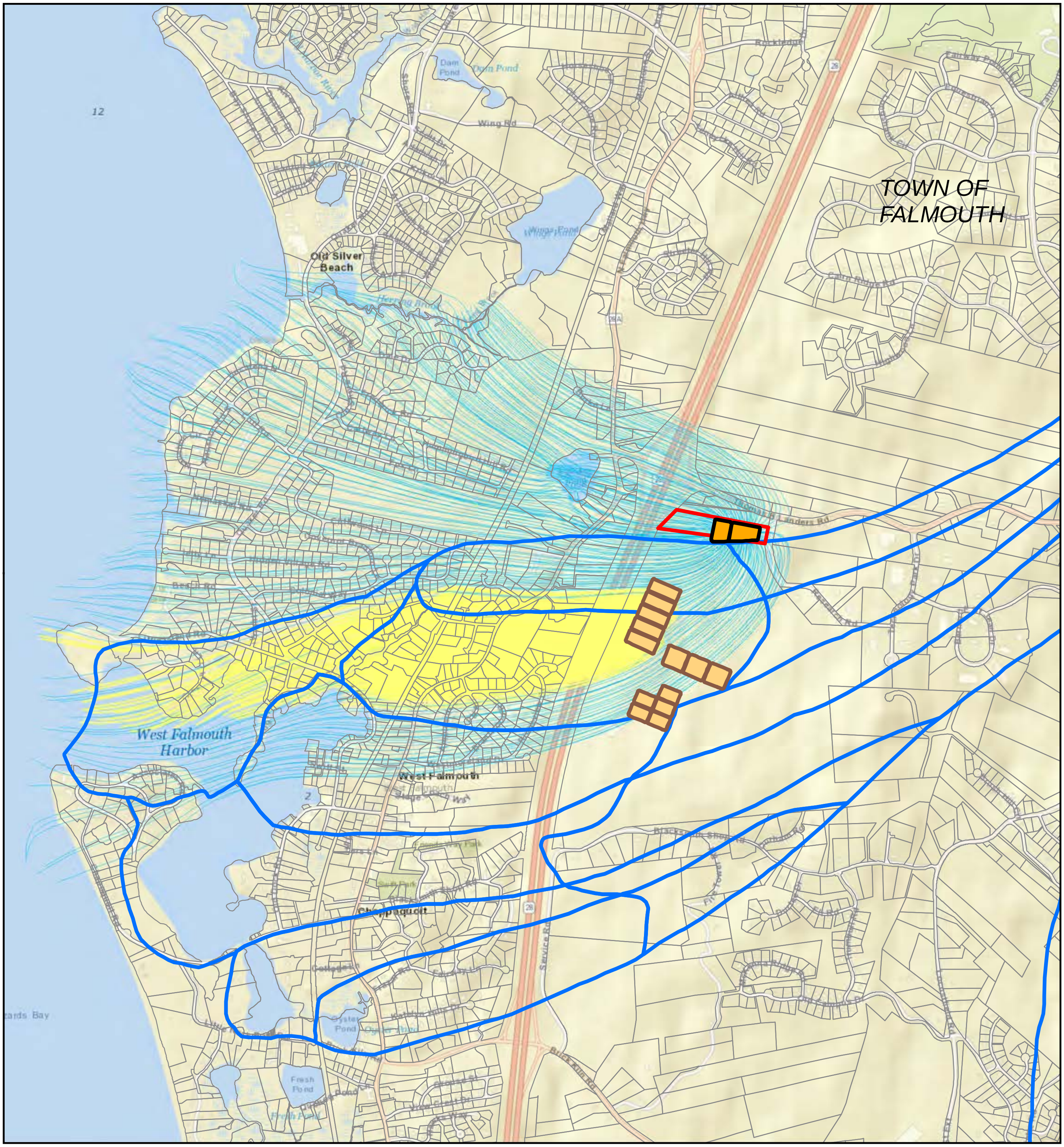
G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\January 2020 - Particle tracks\Particle Tracks Allen Parcel\Scenario 5 Site 7.mxd



LEGEND

- Sand Beds 1-13
- Site 7 Sand Beds
- Site 7
- MEP Watershed Boundaries
- Particle Tracts - Sand Beds 1-13
- Particle Tracks - Site 7

Notes: Estimated Flow Rate = 1.76 mgd,
Active Surface Area = 125,440 sf,
Hydraulic Loading Rate = 14 gpd/sf

Paper Size ANSI A

0 950 1,900 3,800 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

N

GHD

TOWN OF FALMOUTH
Hydrological Evaluations

SCENARIO B3 - EXPANDED OPEN SAND BEDS 14&15 - PARTICLE TRACK MAP

Job Number	111-53041
Revision	-
Date	20 Apr 2021

Figure 12

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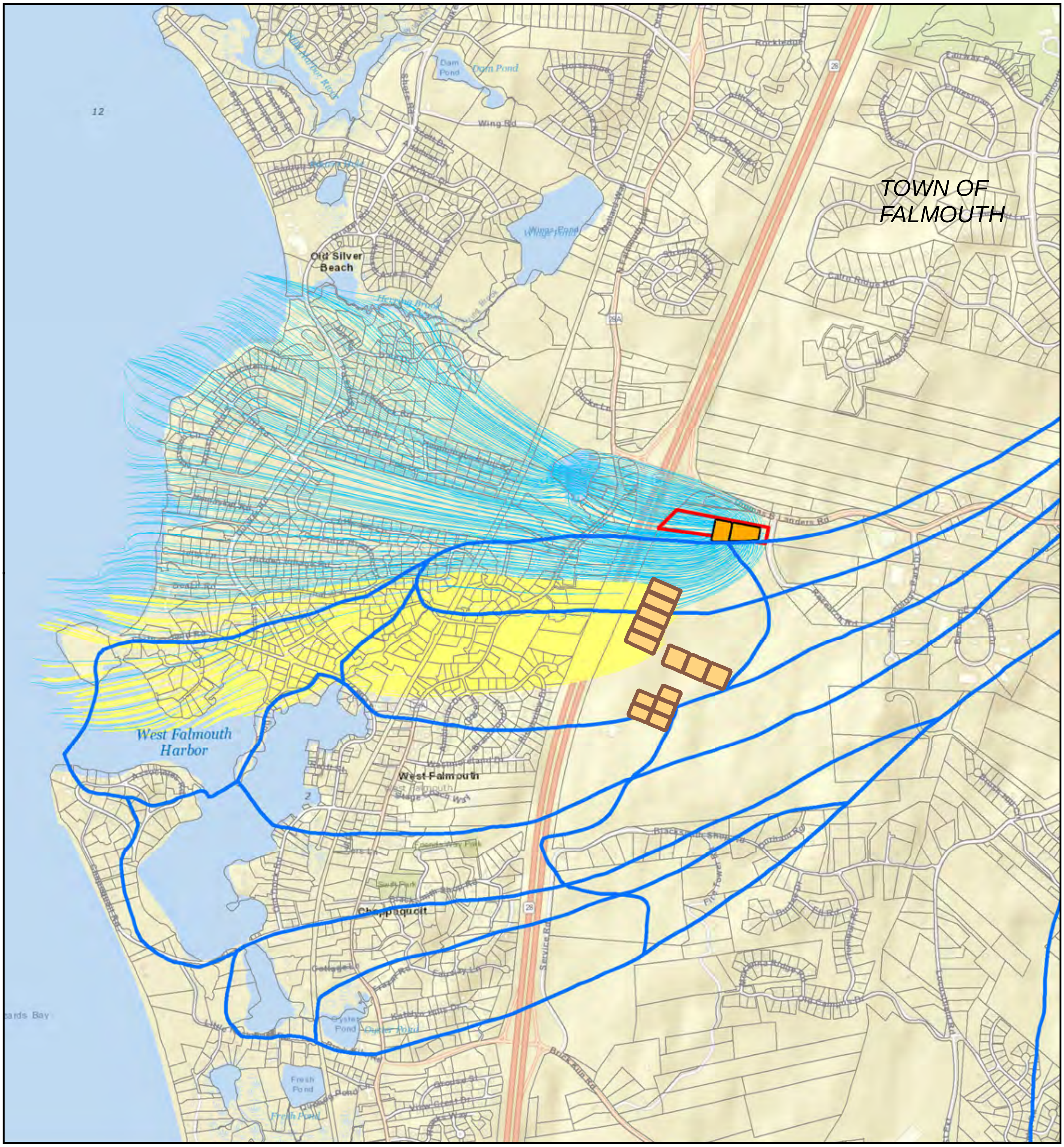
G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\January 2020 - Particle tracks\Particle Tracks Allen Parcel\Scenario 6 Site 7.mxd



LEGEND

Site 7
Site 7 Sand Beds
Sand Beds 1-13
MEP Watershed Boundaries
Particle Track - Site 7
Particle Tracts - Sand Beds 1-13

Notes: Estimated Flow Rate to
Open Sandbeds 14 & 15 = 0.76 mgd
Active Surface Area = 125,440 sf
Average Annual Hydraulic Loading Rate = 6.1 gpd/sf

Paper Size ANSI A
0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

TOWN OF FALMOUTH
Hydrological Evaluations

SCENARIO B4 - EXPANDED OPEN SAND BEDS 14&15 - PARTICLE TRACK MAP

Job Number 111-53041
Revision -
Date 20 Apr 2021

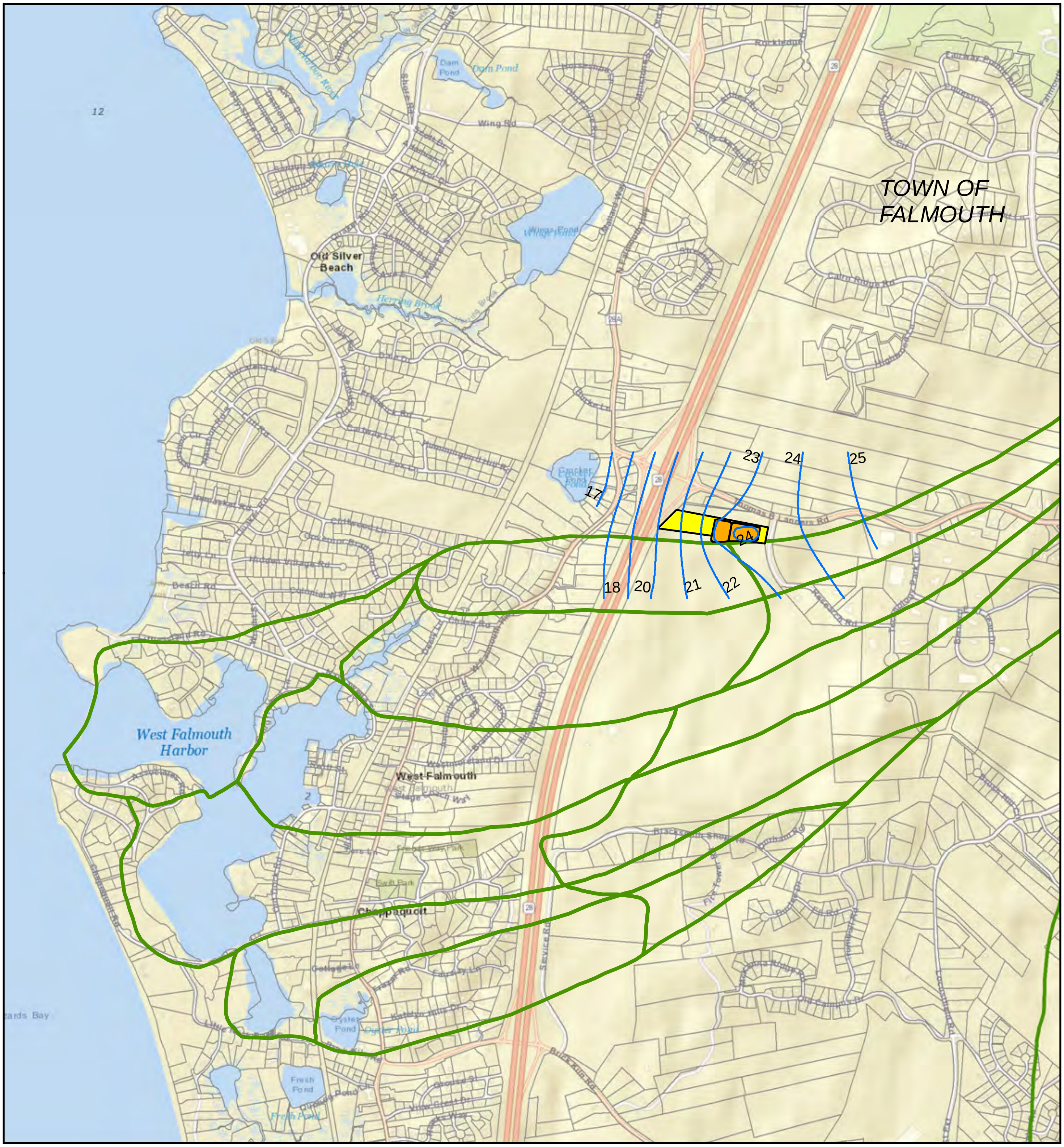
Figure 13

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\January 2020 - Particle tracks\April 2020 Particle Tracks\Scenario 8 Site 7.mxd

Attachment 6

B Scenario Groundwater Elevation Contour Figures



LEGEND

Notes: Estimated Flow Rate = 0.88 mgd, Active Surface Area = 125,440 sf, Hydraulic Loading Rate = 7 gpd/sf

- Groundwater Elevation Contours
- Site 7
- Site 7 Sandbeds
- MEP Watershed Boundaries

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

N

GHD

TOWN OF FALMOUTH
Hydrological Evaluations

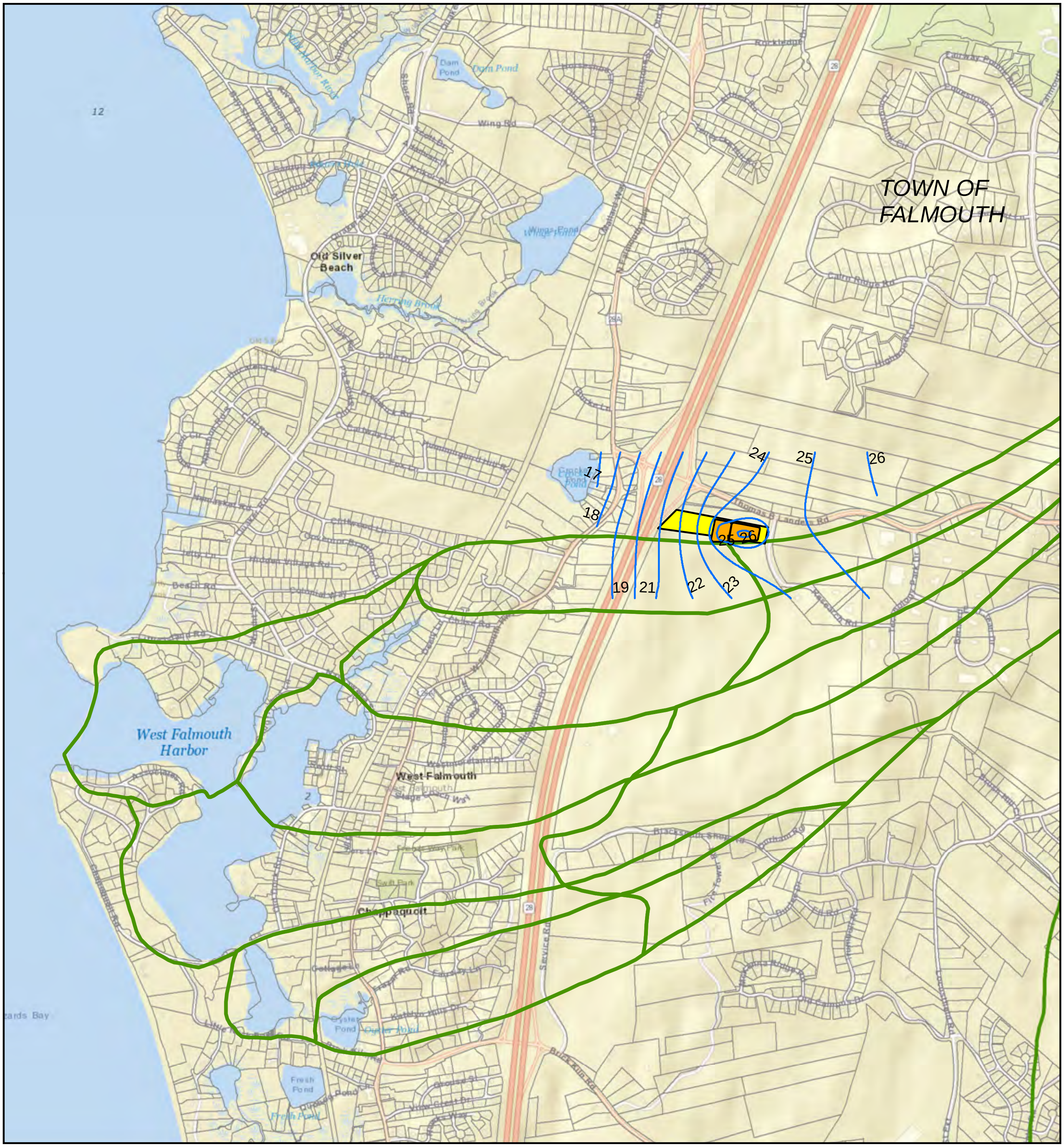
SCENARIO B1 - EXPANDED OPEN SAND BEDS 14&15 - GROUNDWATER ELEVATION CONTOURS

Job Number	111-53041
Revision	-
Date	20 Jul 2020

Figure 14

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\January 2020 - Particle tracks\Particle Tracks Allen Parcel\Scenario 4 Site 7 - GW Elevation Contour.mxd



LEGEND

Notes: Estimated Flow Rate = 1.38 mgd, Active Surface Area = 125,440 sf,
Hydraulic Loading Rate = 11 gpd/sf

- Groundwater Elevation Contours
- Site 7
- Site 7 Sandbeds
- MEP Watershed Boundaries

Paper Size ANSI A

0 1,000 2,000 4,000
Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

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GHD

TOWN OF FALMOUTH
Hydrological Evaluations

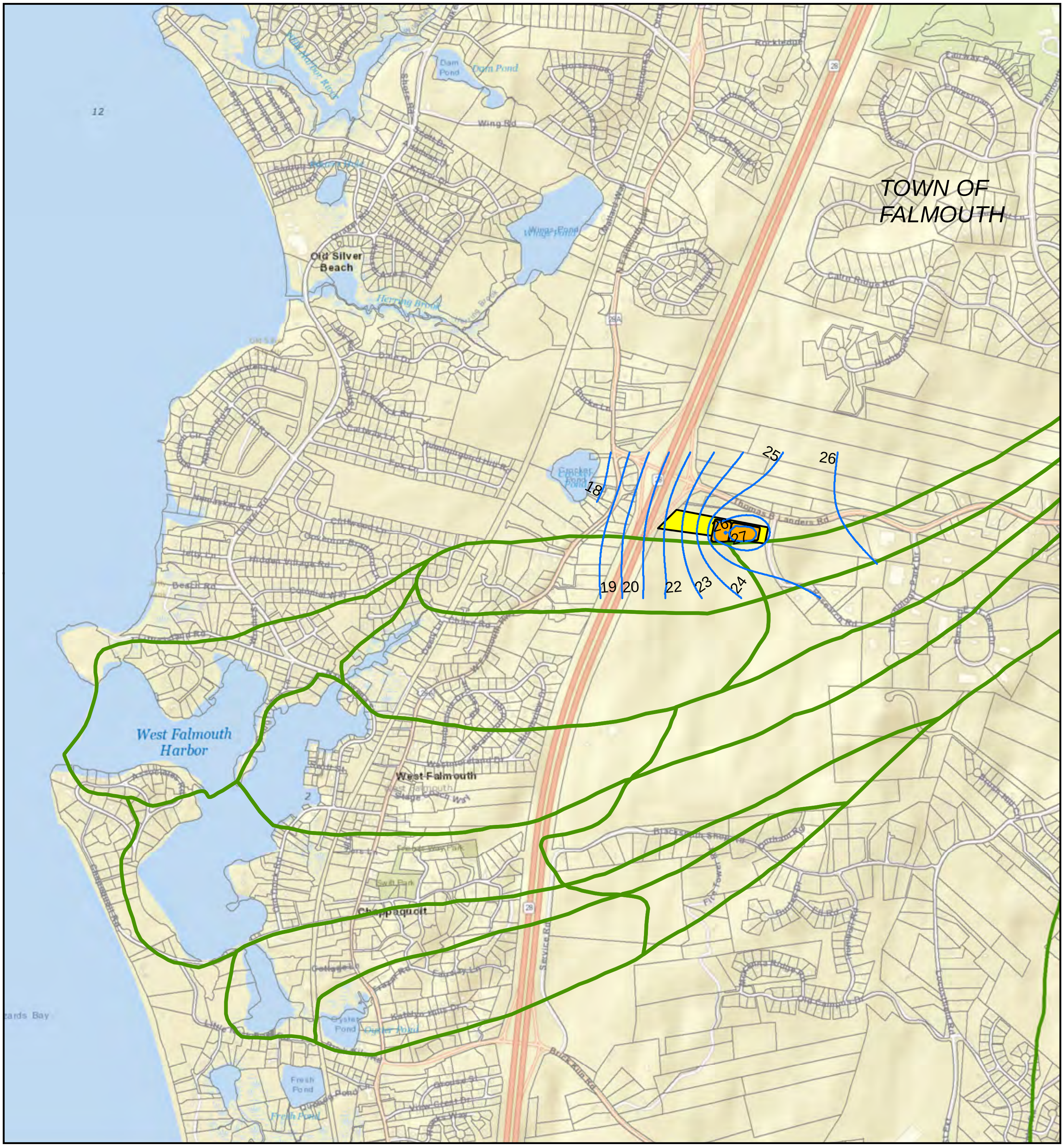
SCENARIO B2 - EXPANDED OPEN SAND BEDS
14&15 - GROUNDWATER ELEVATION CONTOURS

Job Number	111-53041
Revision	-
Date	30 Jul 2020

Figure 15

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\January 2020 - Particle tracks\Particle Tracks Allen Parcel\Scenario 5 Site 7 - GW Elevation Contour.mxd



LEGEND

Notes: Estimated Flow Rate = 1.76 mgd, Active Surface Area = 125,440 sf, Hydraulic Loading Rate = 14 gpd/sf

- Groundwater Elevation Contours
- Site 7
- Site 7 Sandbeds
- MEP Watershed Boundaries

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

N

GHD

TOWN OF FALMOUTH
Hydrological Evaluations

SCENARIO B3 - EXPANDED OPEN SAND BEDS 14&15 - GROUNDWATER ELEVATION CONTOURS

Job Number	111-53041
Revision	-
Date	30 Jul 2020

Figure 16

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

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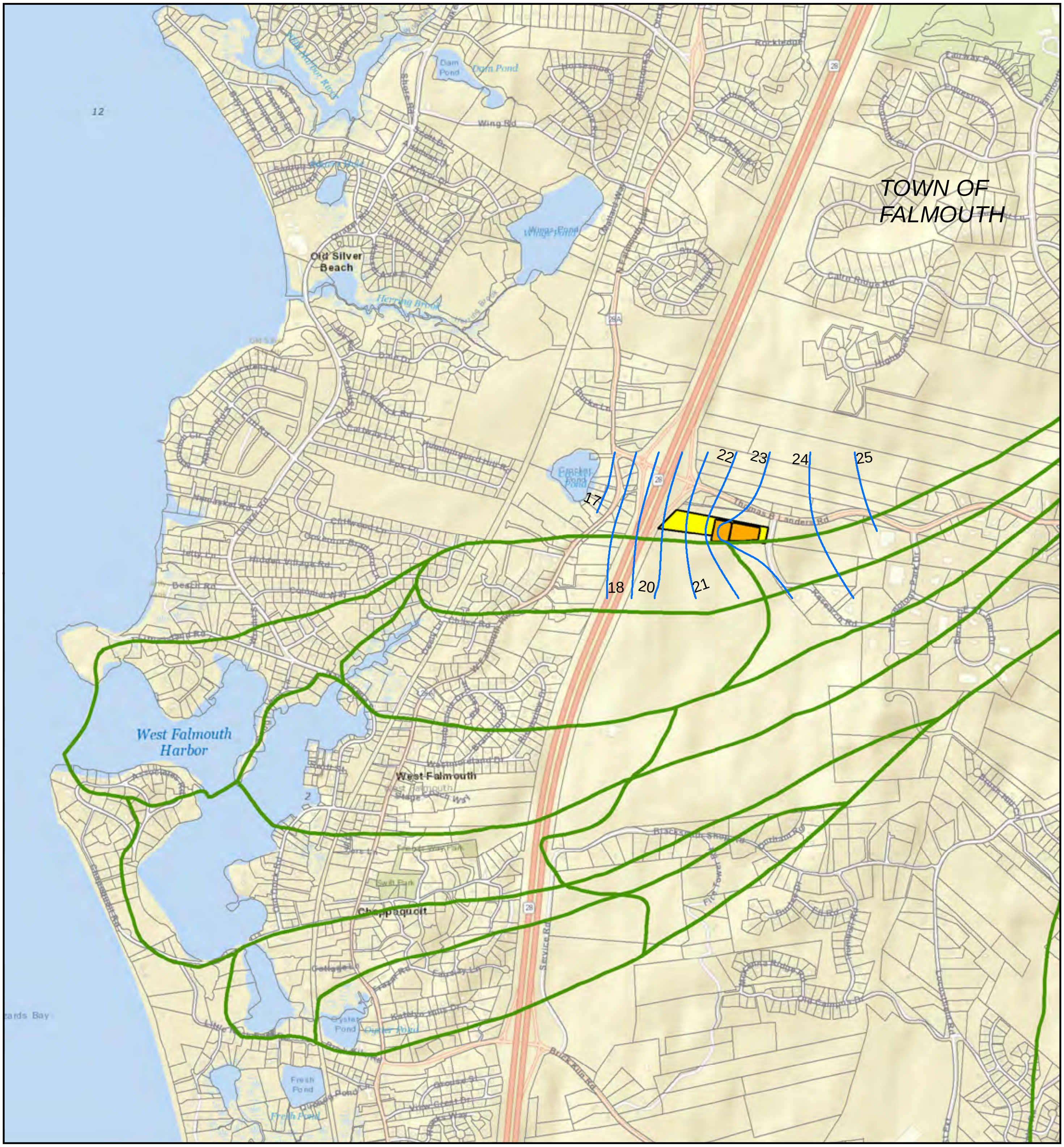


LEGEND

- Groundwater Elevation Contours
- Site 7
- Site 7 Sandbeds
- MEP Watershed Boundaries

Notes: Estimated Flow Rate to Open Sandbeds 14 & 15 = 0.76 mgd
Active Surface Area = 125,440 sf
Average Annual Hydraulic Loading Rate = 6.1 gpd/sf

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

N

TOWN OF FALMOUTH
Hydrological Evaluations

SCENARIO B4 - EXPANDED OPEN SAND BEDS 14&15 - GROUNDWATER ELEVATION CONTOURS

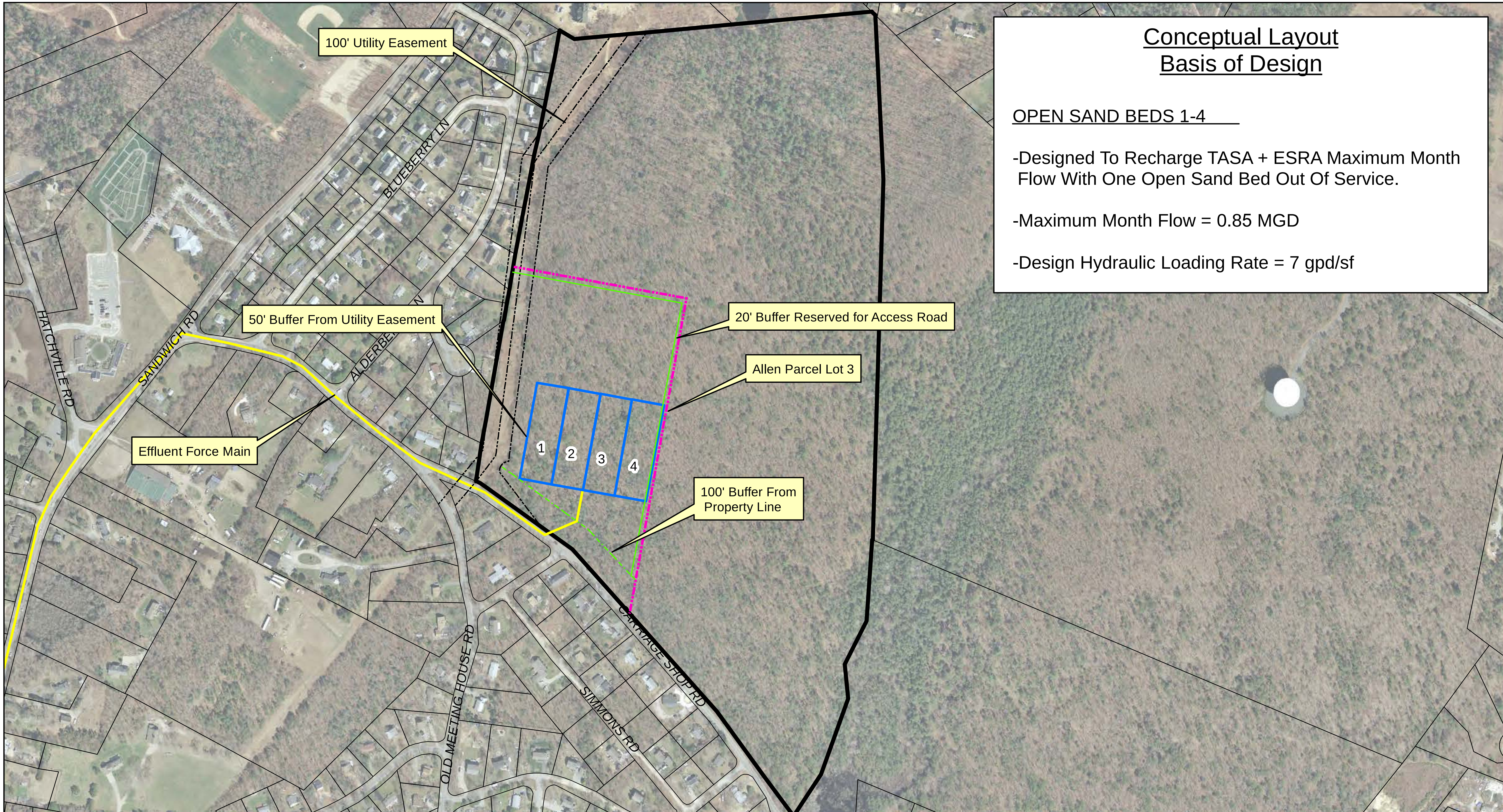
Job Number 111-53041
Revision -
Date 30 Jul 2020

Figure 17

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\January 2020 - Particle tracks\April 2020 Particle Tracks\Scenario 8 Site 7 - GW Elevation Contours.mxd

Attachment 7
Allen Parcel Open Sand Beds 1 through 4 Conceptual Layout



Paper Size ANSI B

0 175 350 700 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

N

LEGEND

Roads_CL
- Allen Parcel Lot 1 Border
- Access road
- Lot 3 Border (General Municipal Use -Plan 2005)

Roads_CL
- Force Main
- Conceptual Open Sand Beds
- Utility Easement

TOWN OF FALMOUTH, MA
Teaticket/Acapesket Preliminary Evaluation TASA (TM-7)

Conceptual Layout 1 - Open Sand Beds at Allen Parcel

Job Number	111-53041
Revision	A
Date	14 Feb 2019

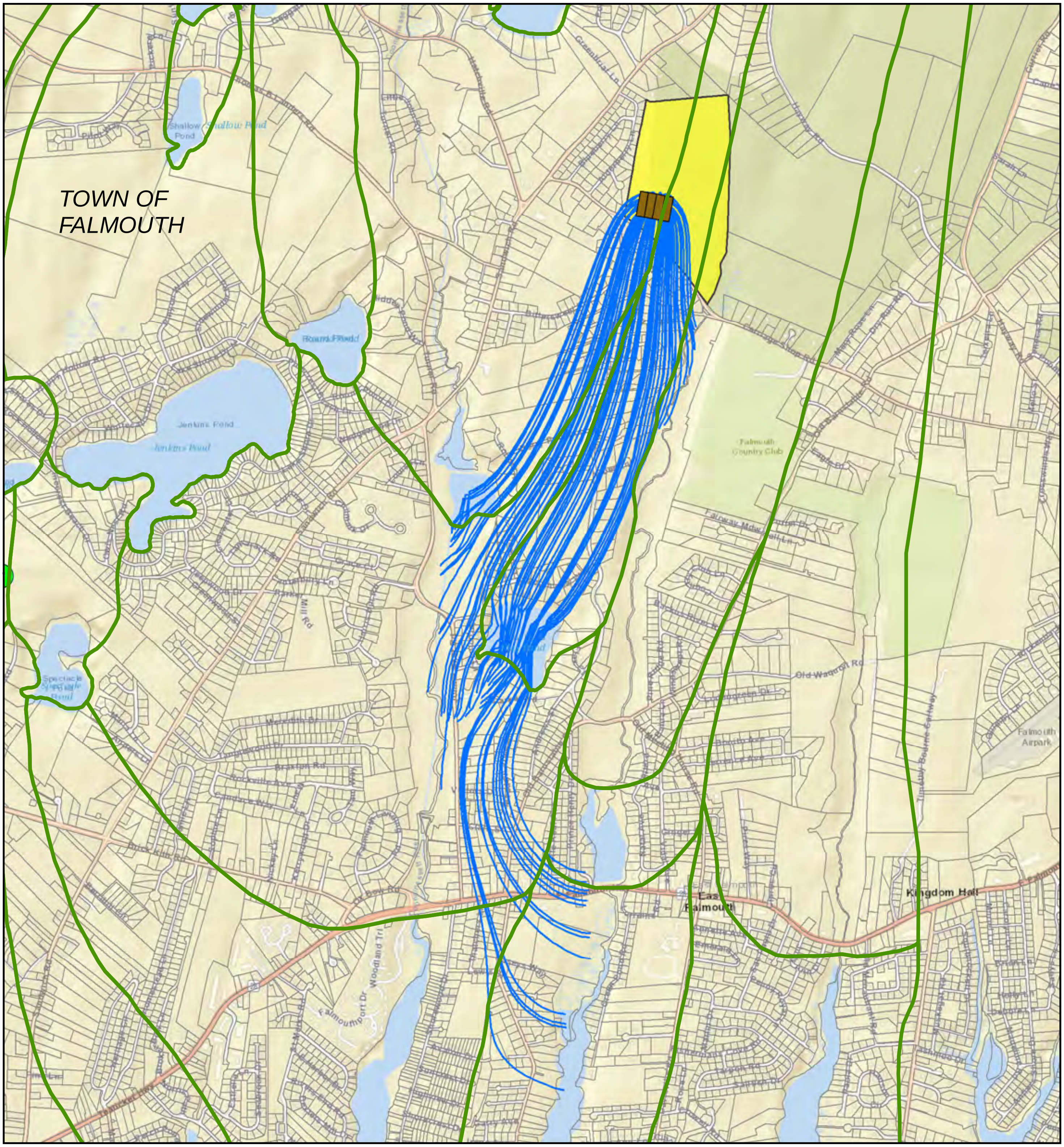
Figure 18

G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\TASA TM-7\Figures\111-53041-F05_Allen.mxd

Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by:jjobrien

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

Attachment 8
C Scenario Particle Track Map Figures



LEGEND

Notes: (Estimated Flow Rate = 1.12 mgd, Active Surface Area = 160,000 sf, Hydraulic Loading Rate = 7 gpd/sf)

- MEP Watershed Boundaries
- Allen Parcel
- Allen Sandbeds
- Particle Track

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

N

TOWN OF FALMOUTH
Hydrological Evaluations

SCENARIO C1 - ALLEN PARCEL OPEN SAND BEDS 1 TO 4 - PARTICLE TRACK MAP

Job Number	111-53041
Revision	-
Date	30 Jul 2020

Figure 19

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

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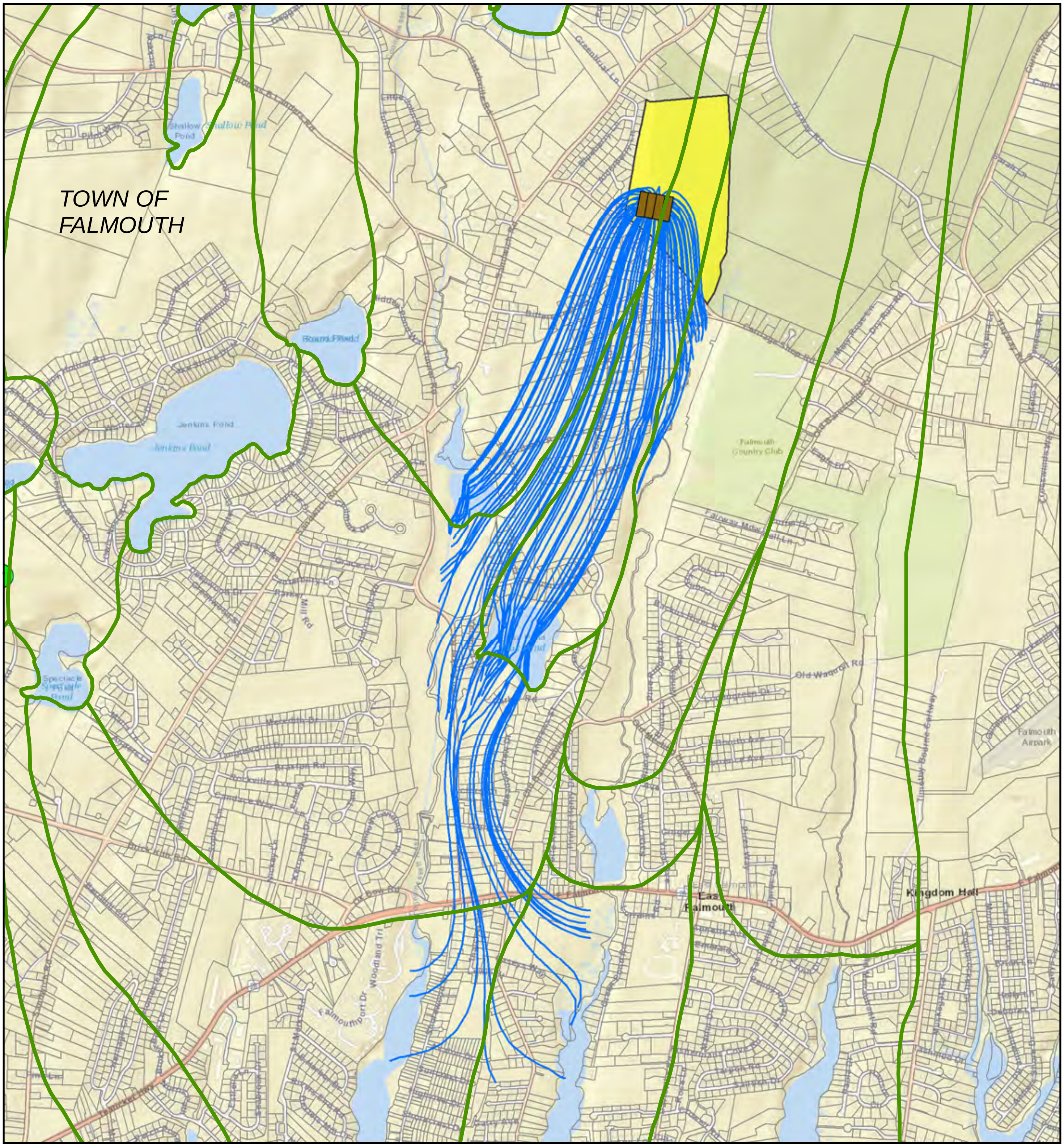

LEGEND

Notes: Estimated Flow Rate = 1.76 mgd, Active Surface Area = 160,000 sf, Hydraulic Loading Rate = 11 gpd/sf)

- MEP Watershed Boundaries
- Allen Sandbeds
- Allen Parcel
- Particle Track

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

N

GHD

TOWN OF FALMOUTH
Hydrological Evaluations

SCENARIO C2 - ALLEN PARCEL OPEN SAND BEDS 1 TO 4 - PARTICLE TRACK MAP

Job Number | 111-53041
Revision | -
Date | 30 Jul 2020

Figure 20

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

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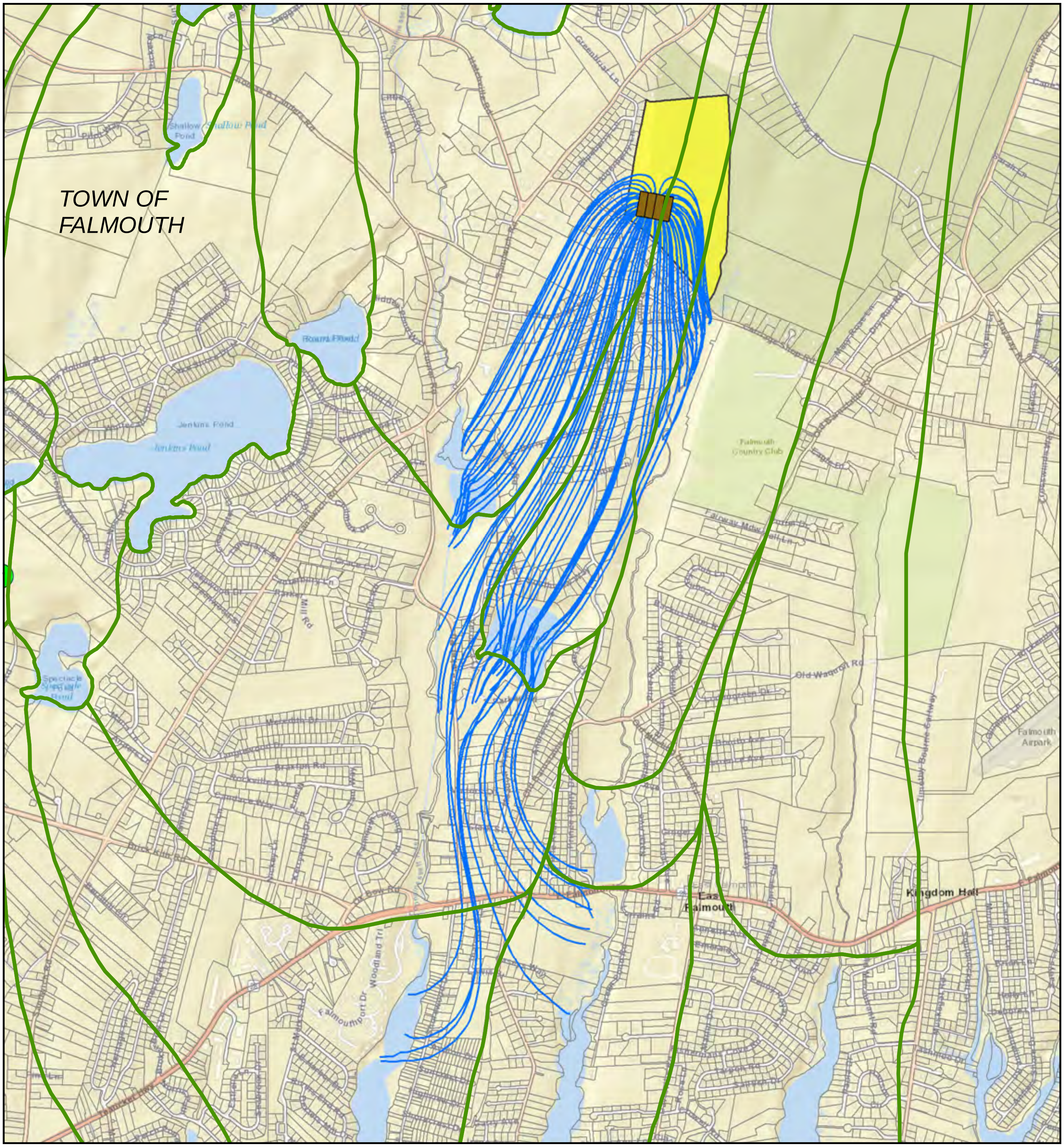

LEGEND

Notes:Estimated Flow Rate = 2.24 mgd, Active Surface Area = 160,000 sf, Hydraulic Loading Rate = 14 gpd/sf

- MEP Watershed Boundaries
- Allen Sandbeds
- Allen Parcel
- Particle Track

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

N

GHD

TOWN OF FALMOUTH
Hydrological Evaluations

Job Number 111-53041
Revision -
Date 30 Jul 2020

SCENARIO C3 - ALLEN PARCEL OPEN SAND BEDS 1 TO 4 - PARTICLE TRACK MAP

Figure 21

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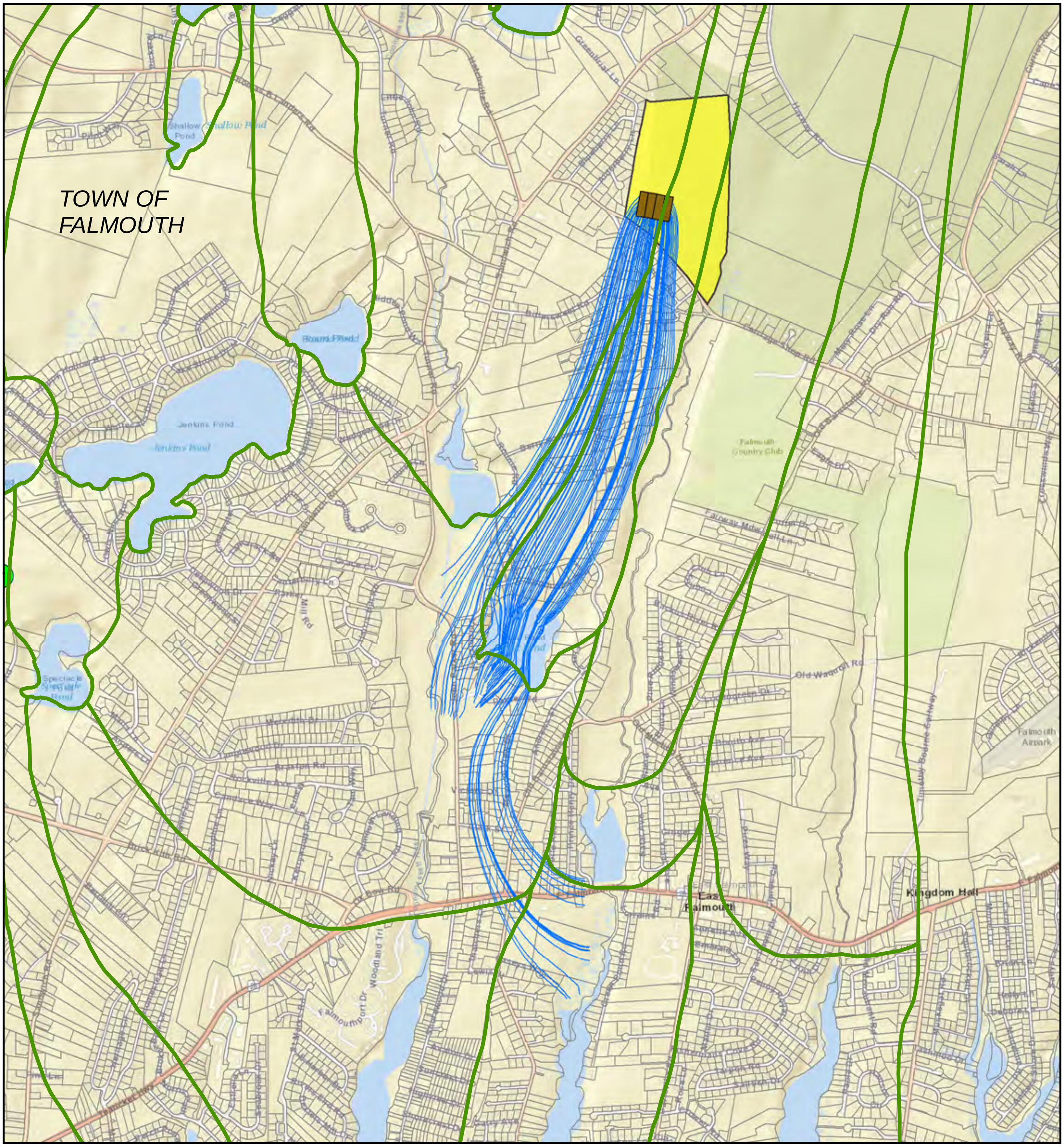

LEGEND

MEP Watershed Boundaries — Particle Track

Allen Sandbeds — Allen Parcel

Notes: Estimated Flow Rate to Open sand Beds 1-4 = 0.50 mgd
Active Surface Area = 160,000 sf,
Average Annual Hydraulic Loading Rate = 3.1 gpd/sf

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

N

GHD

TOWN OF FALMOUTH
Hydrological Evaluations

SCENARIO C4 - ALLEN PARCEL OPEN SAND BEDS 1 TO 4 - PARTICLE TRACK MAP

Job Number	111-53041
Revision	-
Date	30 Jul 2020

Figure 22

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

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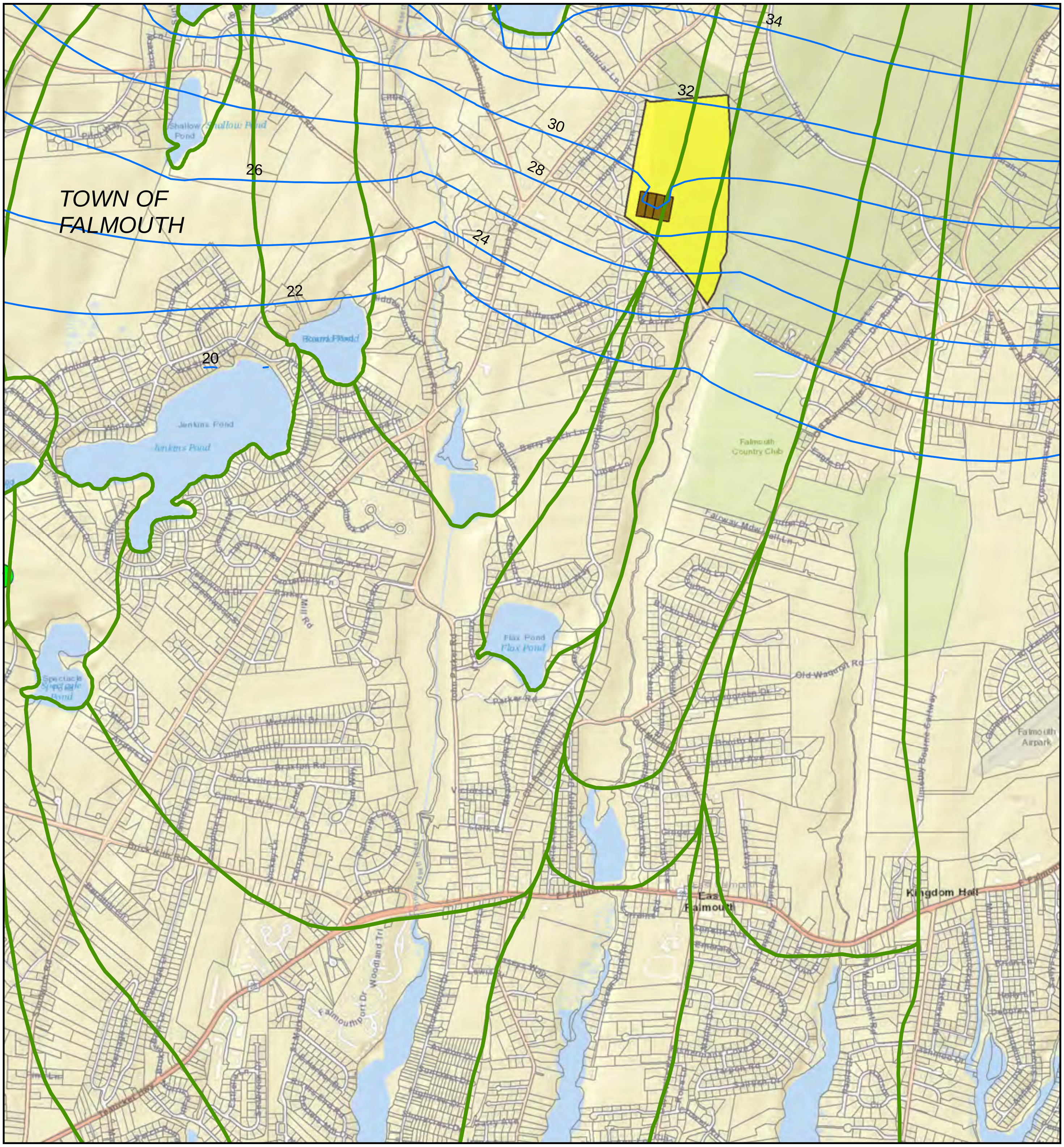
Attachment 9
C Scenario Groundwater Elevation Contour Figures



LEGEND

Notes: (Estimated Flow Rate = 1.12 mgd, Active Surface Area = 160,000 sf, Hydraulic Loading Rate = 7 gpd/sf)

- Groundwater Elevation Contours
- MEP Watershed Boundaries
- Allen Sandbeds
- Allen Parcel

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

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GHD

TOWN OF FALMOUTH
Hydrological Evaluations

Job Number 111-53041
Revision -
Date 30 Jul 2020

SCENARIO C1 - ALLEN PARCEL OPEN SAND BEDS
1 TO 4 - GROUNDWATER ELEVATION CONTOURS

Figure 23

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

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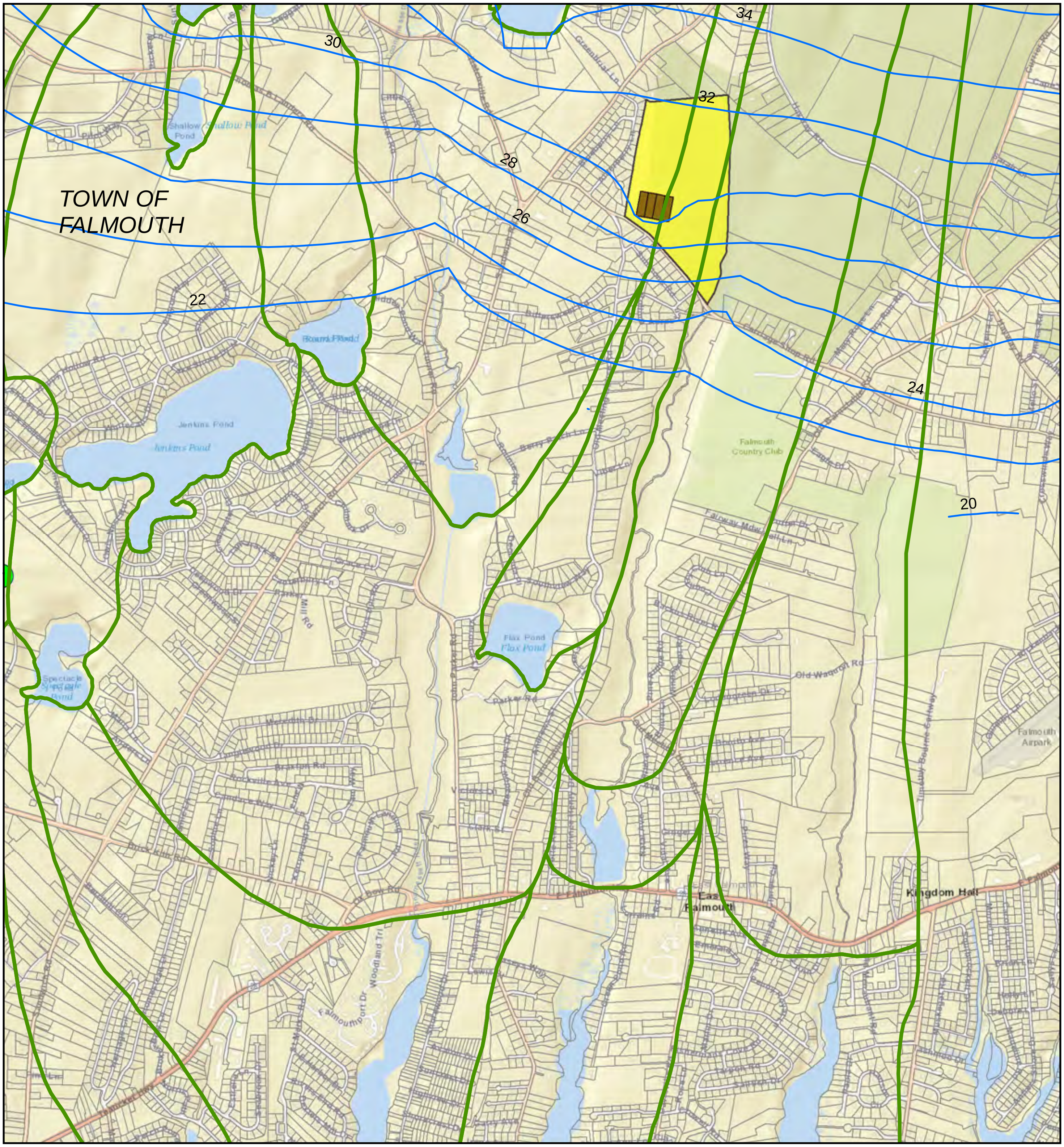

LEGEND

Notes: Estimated Flow Rate = 1.76 mgd, Active Surface Area = 160,000 sf, Hydraulic Loading Rate = 11 gpd/sf)

- Groundwater Elevation Contour
- MEP Watershed Boundaries
- Allen Sandbeds
- Allen Parcel

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

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GHD

TOWN OF FALMOUTH
Hydrological Evaluations

SCENARIO C2 - ALLEN PARCEL OPEN SAND BEDS
1 TO 4 - GROUNDWATER ELEVATION CONTOURS

Job Number	111-53041
Revision	-
Date	30 Jul 2020

Figure 24

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

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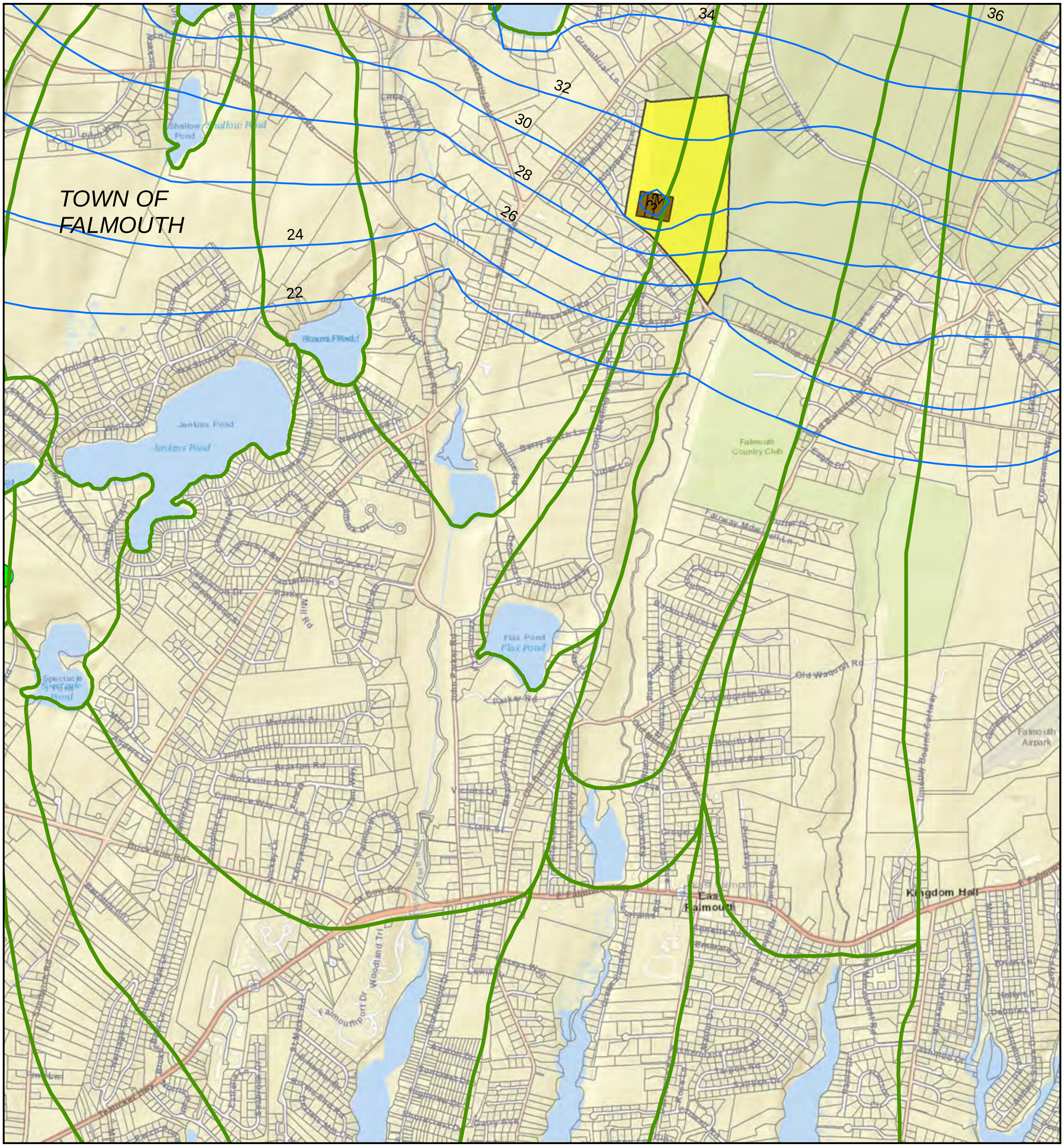

LEGEND

Notes:Estimated Flow Rate = 2.24 mgd, Active Surface Area = 160,000 sf, Hydraulic Loading Rate = 14 gpd/sf

- Groundwater Elevation Contours
- MEP Watershed Boundaries
- Allen Sandbeds
- Allen Parcel

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

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GHD

TOWN OF FALMOUTH
Hydrological Evaluations

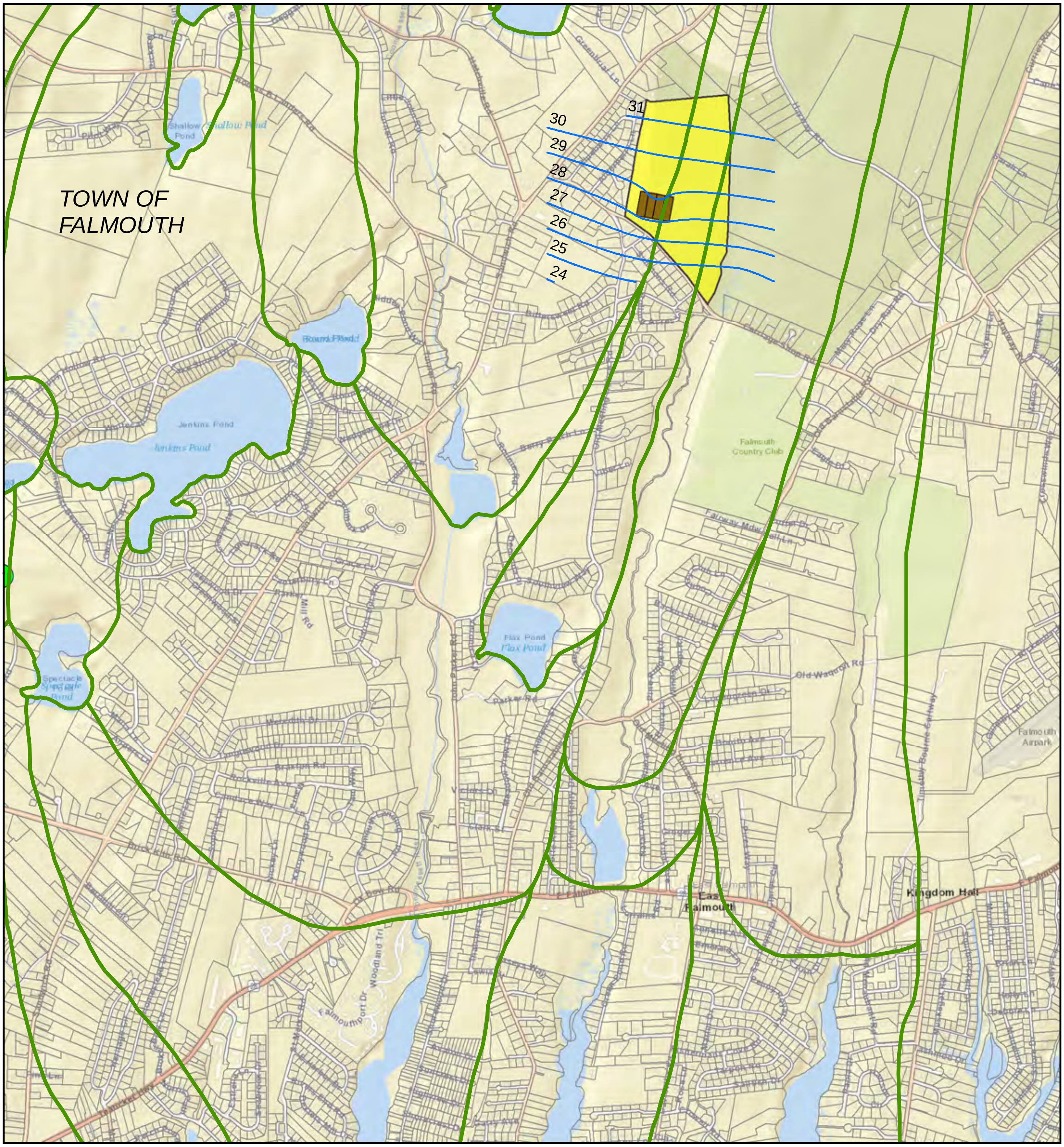
Job Number	111-53041
Revision	-
Date	30 Jul 2020

SCENARIO C3 - ALLEN PARCEL OPEN SAND BEDS 1 TO 4 - GROUNDWATER ELEVATION CONTOURS

Figure 25

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\January 2020 - Particle tracks\Particle Tracks Allen Parcel\Scenario 3 Allen - GW Elevation Contours.mxd



LEGEND

Groundwater Elevation Contours

MEP Watershed Boundaries

Allen Sandbeds

Allen Parcel

Notes: Estimated Flow Rate to Open sand Beds 1-4 = 0.76 mgd
Active Surface Area = 160,000 sf,
Average Annual Hydraulic Loading Rate = 4.5 gpd/sf

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

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GHD

TOWN OF FALMOUTH
Hydrological Evaluations

SCENARIO C4 - ALLEN PARCEL OPEN SAND BEDS 1 TO 4 - GROUNDWATER ELEVATION CONTOURS

Job Number	111-53041
Revision	-
Date	10 Aug 2020

Figure 26

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

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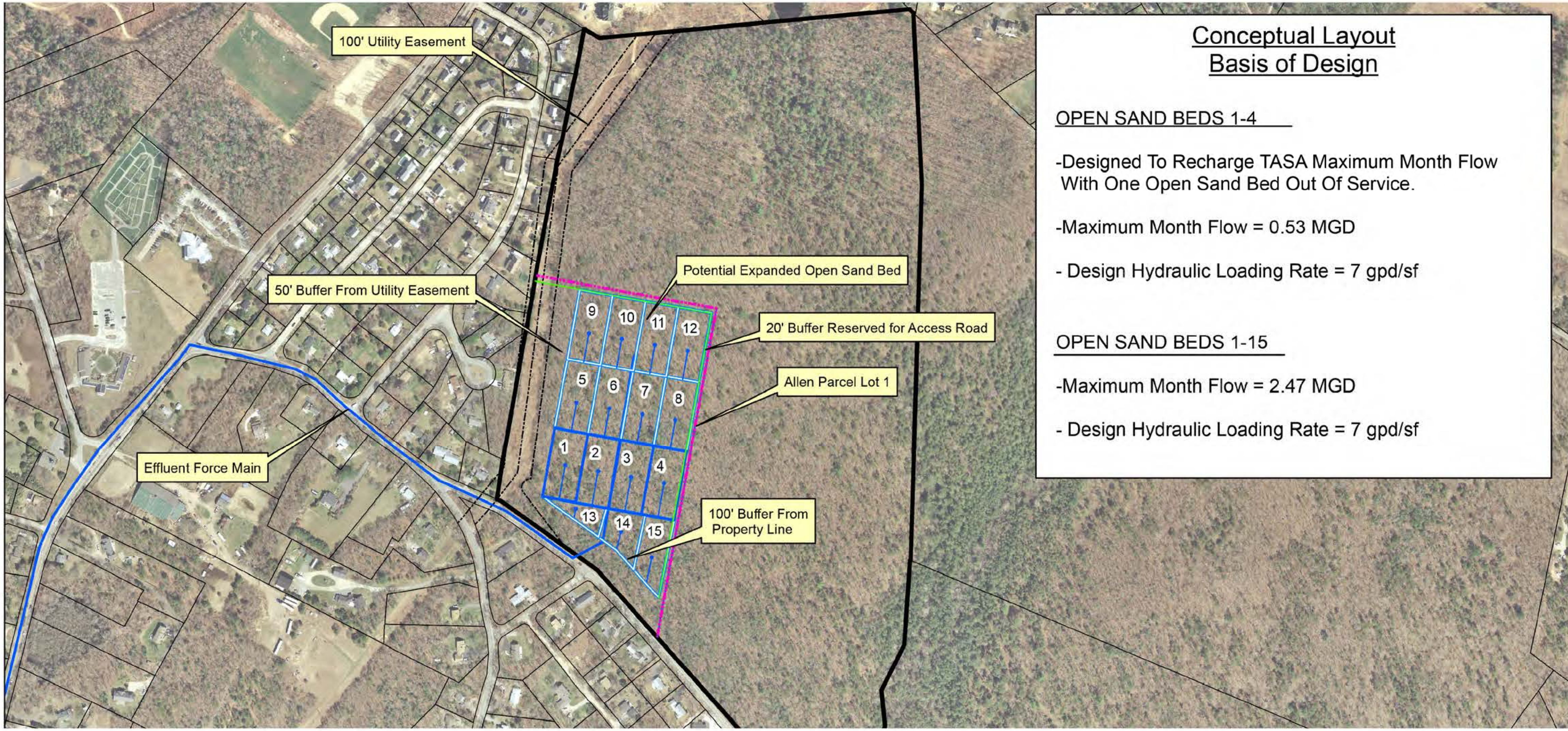
Attachment 10
Allen Parcel Open Sand Beds 1 - 12
Conceptual Layout



Note: For the D Scenario groundwater models it was assumed that the overall open sand bed area designated at 1 through 15 in Figure 4 was subdivided into 12 equivalent area open sand basins (each open sand bed = 30,000 active surface area)

Paper Size ANSI B

Not To Scale

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

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LEGEND

- Access road
- Lot 3 Border (General Municipal Use -Plan 2005)
- Conceptual Force Main
- Allen Parcel Lot 1 Border
- Conceptual Open Sand Beds
- Utility Easement
- Potential Expanded Open Sand Bed

GHD

TOWN OF FALMOUTH, MA
Teaticket/Acapesket Preliminary Evaluation (TASA TM-3)

Conceptual Layout - Open Sand Beds at Allen Parcel

Job Number	111-53041
Revision	A
Date	14 Feb 2019

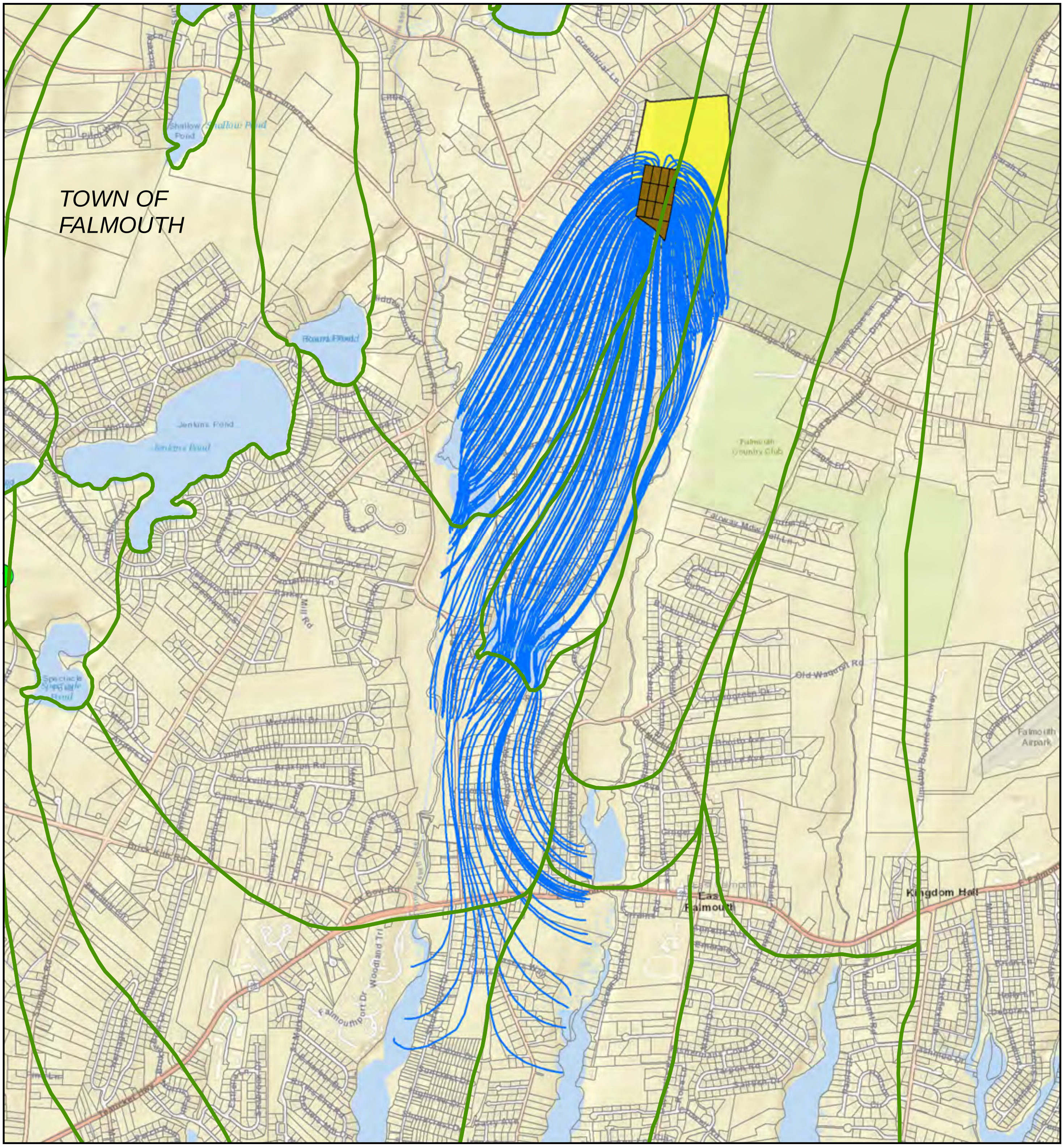
Figure 27

G:\111\11153041 Town of Falmouth South Coast CWMP Update\GIS\Maps\MXD_Deliverables\TASA TM-3\111-53041-F04_Allen_old revision.mxd

Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by:jjobrien

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

Attachment 11
Allen Parcel Open Sand Beds 1 - 12
Particle Track Map Figures



LEGEND

Notes: Estimated Flow Rate = 2.66 mgd, Active Surface Area = 380,000 sf,
Hydraulic Loading Rate = 7 gpd/sf

- MEP Watershed Boundaries
- Allen Sandbeds
- Allen Parcel
- Particle Track

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

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GHD

TOWN OF FALMOUTH
Hydrological Evaluations

SCENARIO D1 - ALLEN PARCEL OPEN
SAND BEDS 1 TO 12 - PARTICLE TRACK MAP

Job Number	111-53041
Revision	-
Date	30 Jul 2020

Figure 28

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

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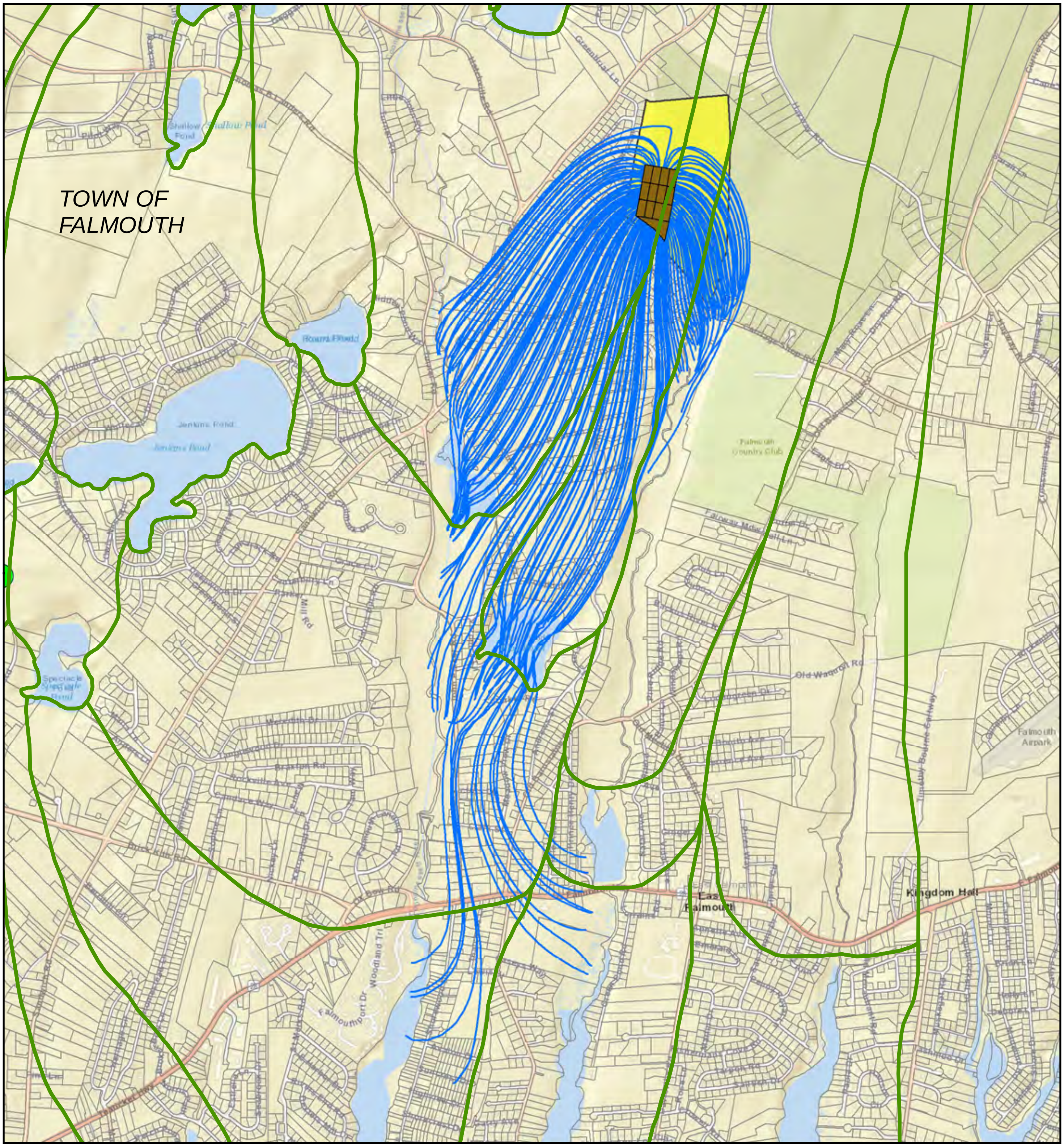

LEGEND

Notes: Estimated Flow Rate = 4.18 mgd, Active Surface Area = 380,000 sf, Hydraulic Loading Rate = 11 gpd/sf

- MEP Watershed Boundaries
- Allen Parcel
- Allen Sandbeds
- Particle Track

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

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GHD

TOWN OF FALMOUTH
Hydrological Evaluations

Job Number	111-53041
Revision	-
Date	30 Jul 2020

SCENARIO D2 - ALLEN PARCEL OPEN SAND BEDS 1 TO 12 - PARTICLE TRACK MAP

Figure 29

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

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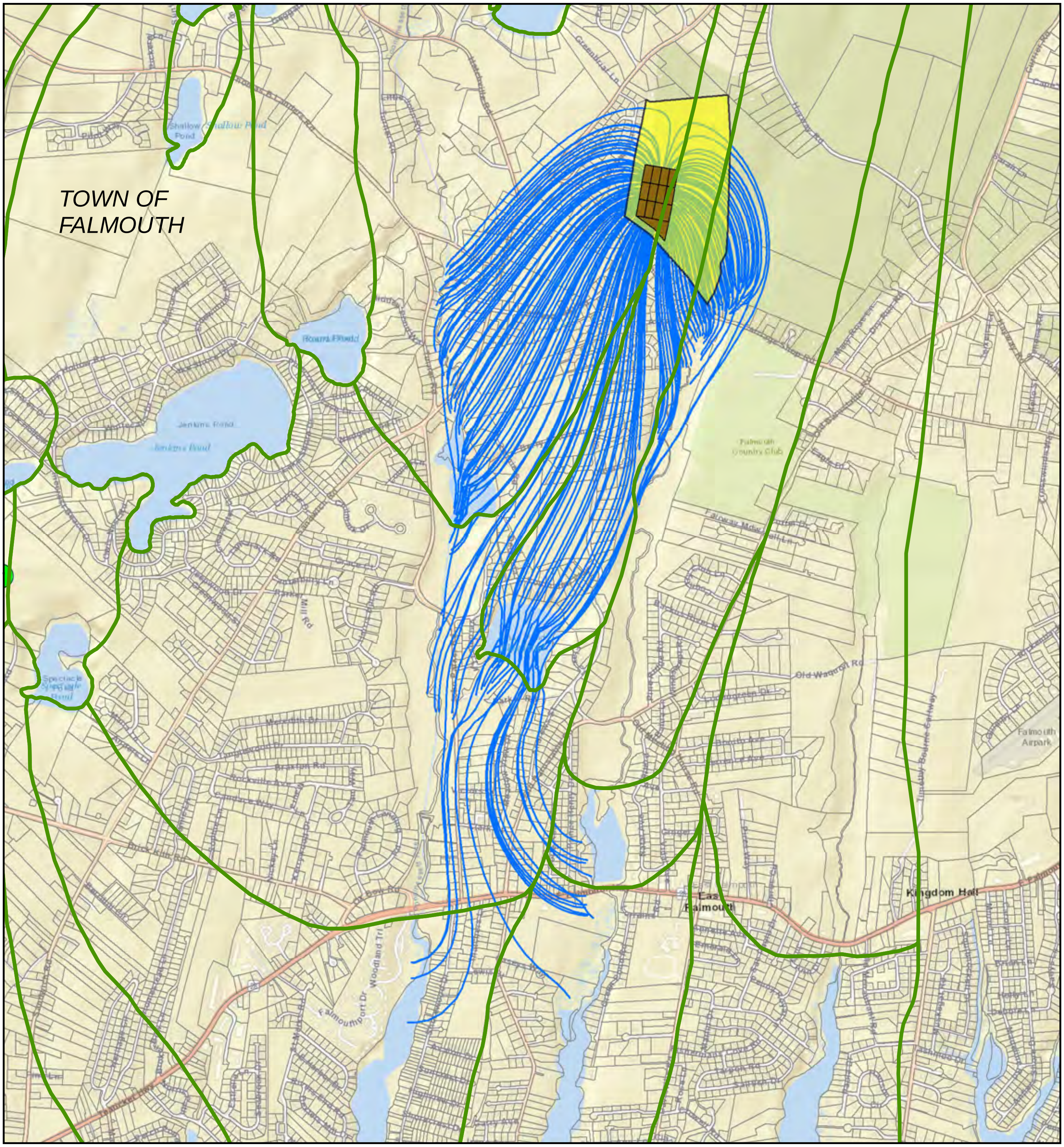

LEGEND

Notes: Estimated Flow Rate = 5.32 mgd, Active Surface Area = 380,000 sf, Hydraulic Loading Rate = 14 gpd/sf

- MEP Watershed Boundaries
- Allen Parcel
- Allen Sandbeds
- Particle Track

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

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GHD

TOWN OF FALMOUTH
Hydrological Evaluations

SCENARIO D3 - ALLEN PARCEL OPEN SAND BEDS 1 TO 12 - PARTICLE TRACK MAP

Job Number	111-53041
Revision	-
Date	30 Jul 2020

Figure 30

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

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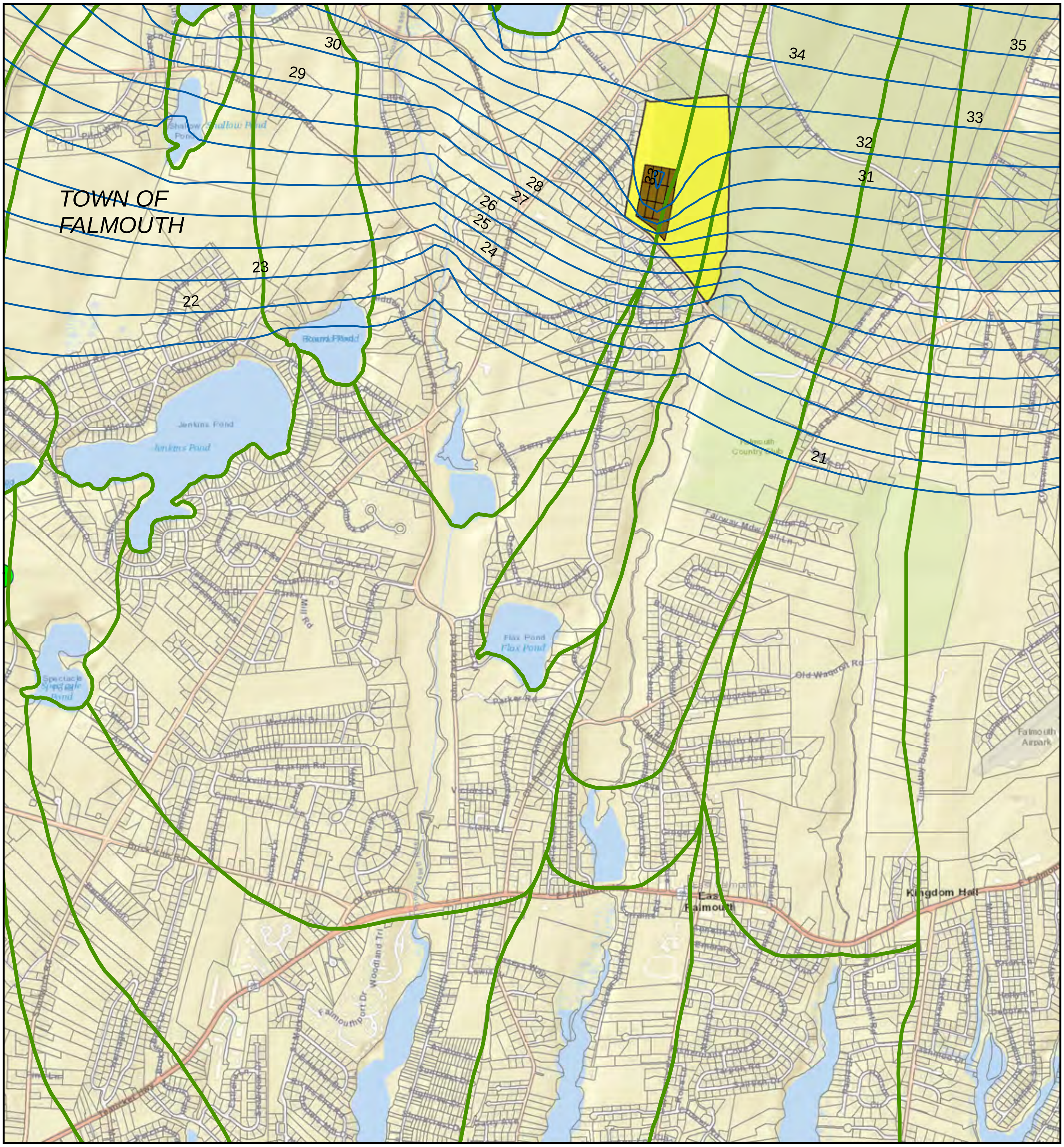
Attachment 12
Allen Parcel Open Sand Beds 1 - 12
Groundwater Elevation Contour Figures



LEGEND

Notes: Estimated Flow Rate = 2.66 mgd, Active Surface Area = 380,000 sf,
Hydraulic Loading Rate = 7 gpd/sf

- Groundwater Elevation Contours
- MEP Watershed Boundaries
- Allen Sandbeds
- Allen Parcel

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

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TOWN OF FALMOUTH
Hydrological Evaluations

SCENARIO D1 - ALLEN PARCEL OPEN SAND BEDS 1 TO 12 - GROUNDWATER ELEVATION CONTOURS

Job Number	111-53041
Revision	-
Date	30 Jul 2020

Figure 31

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

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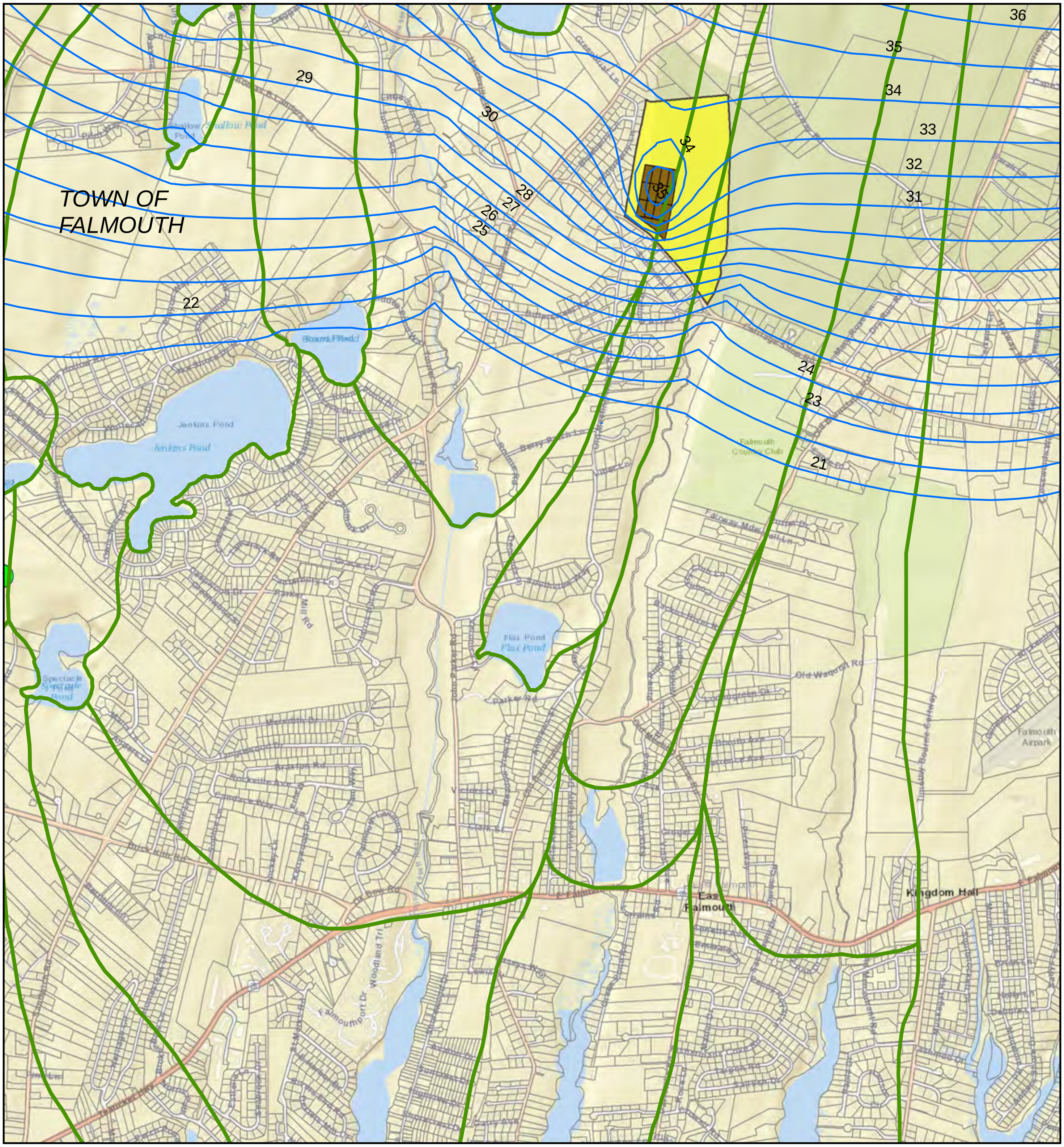

LEGEND

Notes: Estimated Flow Rate = 4.18 mgd, Active Surface Area = 380,000 sf, Hydraulic Loading Rate = 11 gpd/sf

- Groundwater Elevation Contours
- MEP Watershed Boundaries
- Allen Sandbeds
- Allen Parcel

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

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GHD

TOWN OF FALMOUTH
Hydrological Evaluations

Job Number	111-53041
Revision	-
Date	30 Jul 2020

SCENARIO D2 - ALLEN PARCEL OPEN SAND BEDS 1 TO 12 - GROUNDWATER ELEVATION CONTOURS

Figure 32

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

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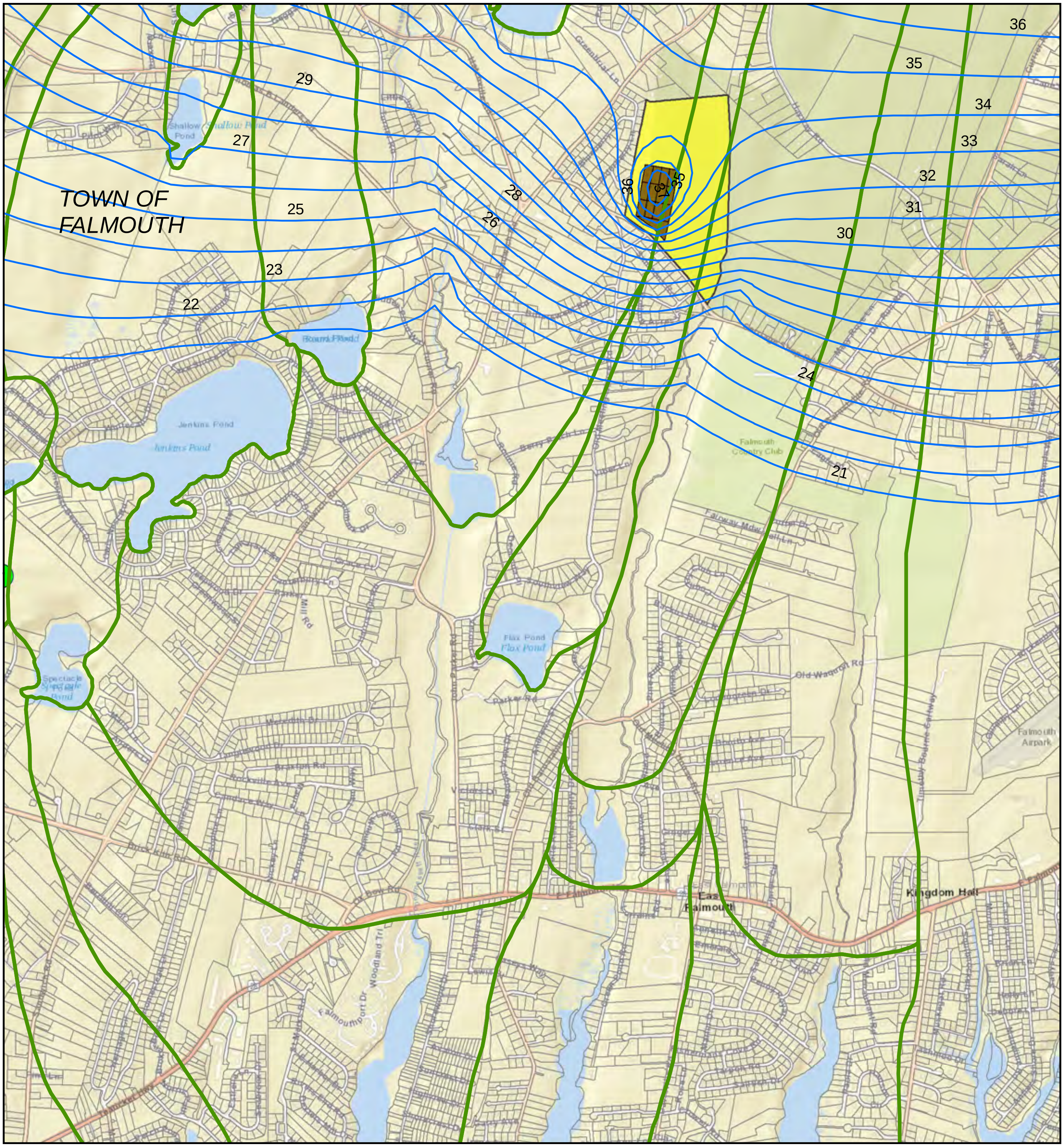

LEGEND

Notes: Estimated Flow Rate = 5.32 mgd, Active Surface Area = 380,000 sf, Hydraulic Loading Rate = 14 gpd/sf

- Groundwater Elevation Contours
- MEP Watershed Boundaries
- Allen Sandbeds
- Allen Parcel

Paper Size ANSI A

0 1,000 2,000 4,000 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

N

GHD

TOWN OF FALMOUTH
Hydrological Evaluations

SCENARIO D3 - ALLEN PARCEL OPEN SAND BEDS
1 TO 12 - GROUNDWATER ELEVATION CONTOURS

Job Number 111-53041
Revision -
Date 30 Jul 2020

Figure 33

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

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Attachment H.

Augusta Parcel MassWildlife Response Letter

MASSWILDLIFE

DIVISION OF
FISHERIES & WILDLIFE

1 Rabbit Hill Road, Westborough, MA 01581
p: (508) 389-6300 | f: (508) 389-7890
MASS.GOV/MASSWILDLIFE

December 23, 2020

Anastasia Rudenko
GHD Inc.
1545 Iyannough Road
Hyannis MA 02601

RE: Project Location: 632 Teaticket Highway
Town: FALMOUTH
NHESP Tracking No.: 20-39770

To Whom It May Concern:

Thank you for contacting the Natural Heritage and Endangered Species Program of the MA Division of Fisheries & Wildlife (the "Division") for information regarding state-listed rare species in the vicinity of the above referenced site. Based on the information provided, the Division has determined that at this time the site is not mapped as Priority or Estimated Habitat.

This evaluation is based on the most recent information available in the Natural Heritage database, which is constantly being expanded and updated through ongoing research and inventory. If you have any questions regarding this letter please contact Emily Holt, Endangered Species Review Assistant, at (508) 389-6385.

Sincerely,

Everose Schlüter

Everose Schlüter, Ph.D.
Assistant Director

Attachment I.

Augusta Parcel Boring Logs

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div. Desmond Well Drilling, Inc.	Project GHD, Inc. Falmouth South Coast CWMP Update Falmouth	Boring No. AU-BO1 Sheet 1 of 1

Driller: Sean Morgan	Boring location: Augusta Property, 0 Brick Kiln Road
Helper: Derek Goodlin	Ground Surface Elevation:
Inspector: Ana Cristea	Date start: 01/11/2021 Date end: 01/11/2021

Sampler consists of a two inch split spoon driven using a 140 lb. hammer falling thirty inches	Notes: 41.5784821°, -70.5832355°	Auger Size: 6 1/4" x 4" H.S.A Casing Size: N/A Screen Size: N/A

Depth	Sample				Sample Description
(FT)	NO	PEN/REC	DEPTH/FT	BLOWS 6"	
0	1	24/22	0 - 2	4-12-12-9	F-M-C brown sand; trace gravel. Dry.
-2	2	24/17	2 - 4	4-3-3-3	F-M-C brown sand; trace gravel. Dry.
-4	3	24/15	4 - 6	2-3-3-4	F-M-C brown sand; trace cobble. Dry.
-6	4	24/18	6 - 8	3-3-2-2	F-M-C brown sand; trace gravel. Dry.
-8	5	24/19	8 - 10	2-3-3-3	F-M-C brown sand. Dry.
-10	6				
-12					
-14	7	24/18	13 - 15	2-4-3-5	F-M-C brown sand. Dry.
-16					
-18	8	24/14	18 - 20	1-2-3-4	F-M-C brown sand. Wet.
-20					
-22					
-24					
-26					
-28					
-30					
-32					
-34					
-36					
-38					
-40					
-42					
-44					
-46					
-48					
-50					
-52					
-54					
-56					

End of boring: 18'
End of sample: 20'
Groundwater encountered:10'±
Sketch not to scale

Granular Soils		Cohesive Soils		Proportions Used	Well Installation Key
BLOWS/FT	DENSITY	BLOWS/FT	DENSITY		
0 - 4	V. LOOSE	> 2	V. SOFT	Trace 0 - 10%	- CONCRETE
4 - 10	LOOSE	2 - 4	SOFT	Little 10 - 20%	- SAND PACK
10 - 30	M. DENSE	4 - 8	M. STIFF	Some 20 - 35%	- SOIL BACKFILL
30 - 50	DENSE	8 - 15	STIFF	And 35 - 50%	- BENTONITE
> 50	V. DENSE	15 - 30	V. STIFF		- SCREEN
		> 30	HARD		- APPROX. WATER LEVEL

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div. Desmond Well Drilling, Inc.	Project GHD, Inc. Falmouth South Coast CWMP Update Falmouth	Boring No. AU-B02 Sheet 1 of 1

Driller: Sean Morgan	Boring location: Augusta Property, 0 Brick Kiln Road
Helper: Derek Goodlin	Ground Surface Elevation:
Inspector: Ana Cristea	Date start: 01/08/2021 — Date end: 01/08/2021

Sampler consists of a two inch split spoon driven using a 140 lb. hammer falling thirty inches	Notes: 41.5770631°, 70.5846765°	Auger Size: 6 1/4" x 4" H.S.A Casing Size: N/A Screen Size: N/A

Depth	Sample				Sample Description
(FT)	NO	PEN/REC	DEPTH/FT	BLOWS 6"	
0	1	24/17	0 - 2	4-8-10-14	F-M-C brown sand; trace gravel. Dry.
-2	2	24/16	2 - 4	4-14-14-17	F-M-C brown sand; little gravel. Dry.
-4	3	24/17	4 - 6	7-12-13-13	F-M-C brown sand; little gravel. Dry.
-6	4	24/17	6 - 8	2-6-7-7	F-M-C brown sand; trace gravel. Dry.
-8	5	24/18	8 - 10	3-5-7-6	F-M-C brown sand; trace gravel; trace cobble. Dry.
-10					
-12					
-14	6	24/16	13 - 15	2-4-7-6	F-M-C brown sand; trace gravel. Dry.
-16					
-18	7	24/17	18 - 20	3-4-4-5	F-M-C brown sand; trace gravel. Dry.
-20					
-22					
-24	8	24/17	23 - 25	2-7-8-11	F-M-C brown sand. Dry.
-26					
-28	9	24-19	28 - 30	4-8-7-5	F-M-C brown sand. Dry.
-30					
-32					
-34	10	24/13	33 - 35	2-8-5-8	F-M-C brown sand. Wet.
-36					
-38					
-40					
-42					
-44					
-46					
-48					
-50					
-52					
-54					
-56					

End of boring: 33'
End of sample: 35'
Groundwater encountered: 35'±
Sketch not to scale

Granular Soils		Cohesive Soils		Proportions Used	Well Installation Key
BLOWS/FT	DENSITY	BLOWS/FT	DENSITY		
0 - 4	V. LOOSE	> 2	V. SOFT	Trace 0 - 10%	- CONCRETE
4 - 10	LOOSE	2 - 4	SOFT	Little 10 - 20%	- SAND PACK
10 - 30	M. DENSE	4 - 8	M. STIFF	Some 20 - 35%	Z - SOIL BACKFILL
30 - 50	DENSE	8 - 15	STIFF	And 35 - 50%	- BENTONITE
> 50	V. DENSE	15 - 30	V. STIFF		- SCREEN
		> 30	HARD		- APPROX. WATER LEVEL

CAPE COD TEST BORING — **BORING NO. AU-B02**

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div. Desmond Well Drilling, Inc.	Project GHD, Inc. Falmouth South Coast CWMP Update Falmouth	Boring No. AU-BO4 Sheet 1 of 1

Driller:	Sean Morgan	Boring location:	Augusta Property, 0 Brick Kiln Road
Helper:	Derek Goodlin	Ground Surface Elevation:	
Inspector:	Ana Cristea	Date start: 01/11/2021	Date end: 01/11/2021

Sampler consists of a two inch split spoon driven using a 140 lb. hammer falling thirty inches	Notes: 41.5739743°, -70.5858174°	Auger Size: 6 1/4" x 4" H.S.A Casing Size: N/A Screen Size: N/A

Depth (FT)	Sample NO	PEN/REC	DEPTH/FT	BLOWS 6"	Sample Description
0	1	24/18	0 - 2	2-7-13-10	F-M-C brown sand; trace silty brown sand. Dry.
-2	2	24/17	2 - 4	3-6-11-8	F-M-C brown sand; trace cobble; trace silty brown sand. Dry.
-4	3	24/20	4 - 6	9-8-11-12	F-M-C brown sand; little gravel. Dry.
-6	4	24/18	6 - 8	3-7-8-9	F-M-C brown sand; some gravel. Dry.
-8	5	24/16	8 - 10	2-4-6-7	F-M-C brown sand; little gravel; trace cobble. Dry.
-10	6				
-12					
-14	7	24/18	13 - 15	3-5-6-5	F-M-C brown sand. Dry.
-16					
-18	8	24/17	18 - 20	2-2-7-7	F-M-C brown sand; trace gravel. Dry.
-20					
-22	9	24/17	23 - 25	2-3-7-9	F-M-C brown sand; little gravel. Dry.
-24					
-26					
-28	10	24/20	28 - 30	5-5-5-6	F-M-C brown sand. Dry.
-30					
-32					
-34	11	24/15	33 - 35	2-6-7-10	F-M-C brown sand. Wet.
-36					
-38					
-40					
-42					
-44					
-46					
-48					
-50					
-52					
-54					
-56					

End of boring: 33'
End of sample: 35'
Groundwater encountered:35'±
Sketch not to scale

Granular Soils BLOWS/FT	DENSITY	Cohesive Soils BLOWS/FT	DENSITY	Proportions Used
0 - 4	V. LOOSE	> 2	V. SOFT	Trace 0 - 10%
4 - 10	LOOSE	2 - 4	SOFT	Little 10 - 20%
10 - 30	M. DENSE	4 - 8	M. STIFF	Some 20 - 35%
30 - 50	DENSE	8 - 15	STIFF	And 35 - 50%
> 50	V. DENSE	15 - 30	V. STIFF	
		> 30	HARD	

Well Installation Key
- CONCRETE
- SAND PACK
Z - SOIL BACKFILL
- BENTONITE
- SCREEN
- APPROX. WATER LEVEL

Attachment J.

Augusta Parcel Soil Evaluator Field Notes

ID_Num	NORTHING	EASTING	TYPE	EL
2020-Augusta-TP01	2672875.520020	906779.005582	TEST PIT	0
2020-Augusta-TP02	2672749.044110	907009.078238	TEST PIT	0
2020-Augusta-TP03	2672081.805620	906469.952086	TEST PIT	0
2020-Augusta-TP05	2671950.990090	906627.544753	TEST PIT	0
2020-Augusta-TP06	2671440.257490	906471.697027	TEST PIT	0
2020-Augusta-TP07	2671189.727900	906381.498100	TEST PIT	36
2020-Augusta-B01	2672749.732310	907024.097200	SOIL BORING	0
2020-Augusta-B02	2672432.715950	906605.725402	SOIL BORING	0
2020-Augusta-B04	2671120.634480	906317.930934	SOIL BORING	0

2019 USGS Color Orthophoto

LEGEND

- MONITORING WELL
- PERC TEST
- SOIL BORING
- TEST PIT
- 25 Foot Buffer

Paper Size ANSI B

0 100 200 400 Feet

Map Projection: Lambert Conformal Conic
Horizontal Datum: North American 1983
Grid: NAD 1983 StatePlane Massachusetts Mainland FIPS 2001 Feet

N

GHD

TOWN FALMOUTH, MASSACHUSETTS

Job Number 111-53041
Revision -
Date 21 Dec 2020

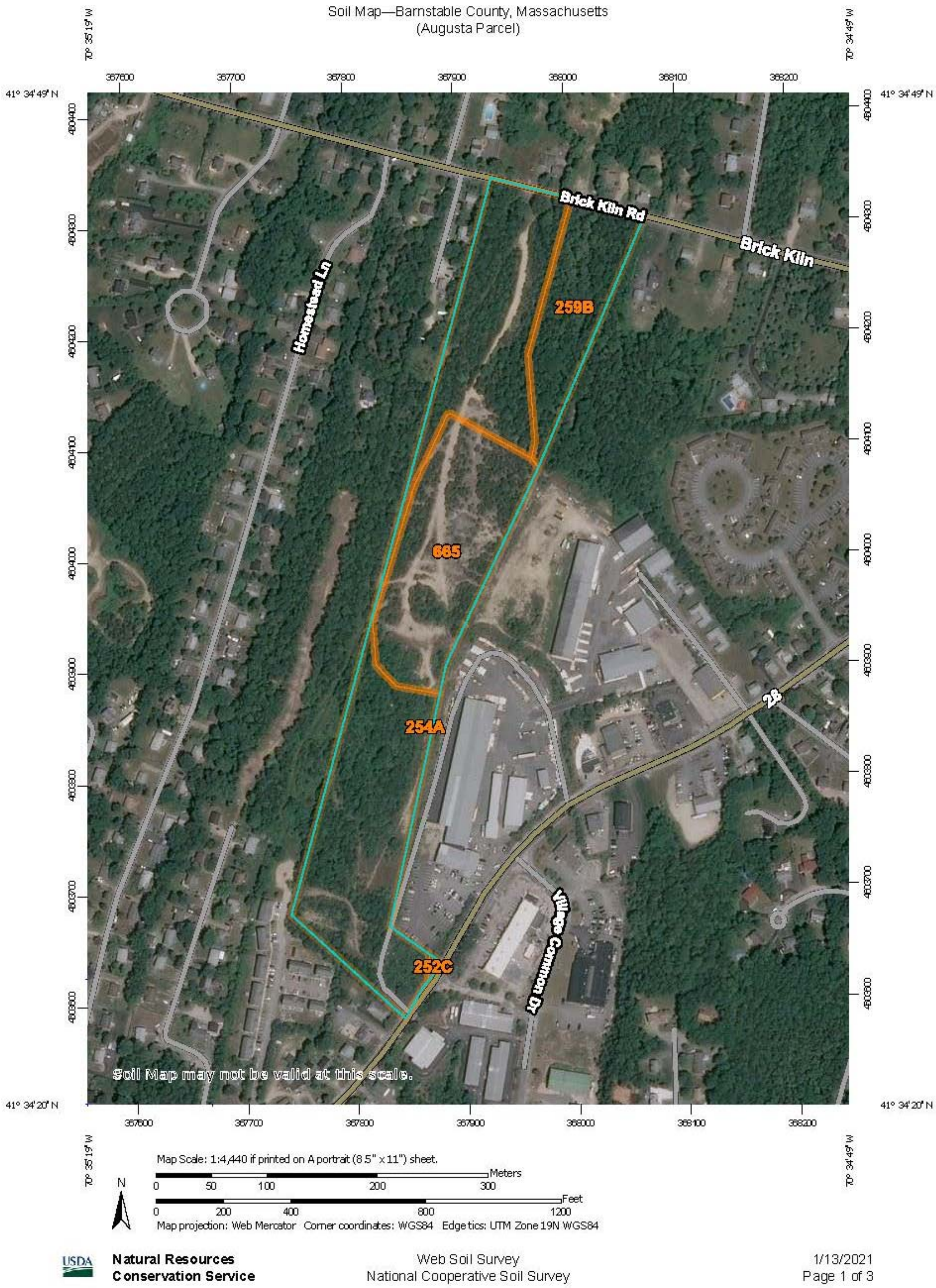
Augusta Parcel 2020 Field Investigations Work Plan

Figure 1

C:\data\Falmouth\Augusta_Parcel_Borings.mxd

1545 Iyannough Road, Hyannis Massachusetts 02601 USA T 1 508 362 5680 F 1 508 362 5684 E hyamail@ghd.com W www.ghd.com

Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by:jjobrien



USDA maps this area as Carver Sands (252C & 259B), and Merrimac Fine Sandy Loam (254A), with the middle of the site mapped as disturbed. Both the Carver and Merrimac soils are categorized as outwash. The main difference between the soils is the silt content in Merrimac soils in the subsoil is greater. A bottom of excavation sample was taken at the final hole. With the exception of TP02 in the woods, all test pit areas were heavily disturbed with the topsoil stripped out at some point. These holes caved in very easily so advancing deep was a challenge. In all holes the underlying materials were sandy, gravelly materials; very good for leaching. No evidence of perched water or groundwater was encountered.

Location: **Augusta Parcel** Deep Hole #: **2020-Augusta-TP01**
Date: **1/12/2021** Time: **9:20**
Weather: **Overcast, 30s**

Depth from Surface (inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other
0-20	B	Sandy Loam	7.5 YR 6/8	-	Massive. Firm in place.
20-163	C	Coarse Sand and Gravel	2.5 Y 7/6	-	15% gravel. Loose. Stratified. Very little silt.

All topsoil was removed in the past. The parent material beneath consisted of some stratification of layers of sand and gravel with very little silt present.


Location of TP01

Note lack of topsoil. Stratification of C layer visible.

Location: **Augusta Parcel** Deep Hole #: **2020-Augusta-TP02**
Date: **1/12/2021** Time: **8:20**
Weather: **Overcast, 30s**

Depth from Surface (inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other
0-18	A	Sandy Loam	10 YR 2/2	-	Loose. 2% gravel.
18-24	B	Sandy Loam	7.5 YR 6/8	-	Loose. 2% gravel.
24-132	C	Coarse Sand and Gravel	2.5 Y 8/6	-	Very loose. 5% gravel. Some silt. Stratified.

The parent material beneath consisted of some stratification of layer of sand and gravel with a little silt present.

Location of TP02


This hole was collapsing in.

Location: **Augusta Parcel** Deep Hole #: **2020-Augusta-TP03**
Date: **1/12/2021** Time: **9:50**
Weather: **Sunny, 40s**

Depth from Surface (inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other
0-18	B	Sandy Loam	7.5 YR 6/8	-	Massive. Firm in place.
18-39	C1	Coarse Sand and Gravel	2.5 Y 7/6		20%+ gravel. Mixed. Some silt.
39-80	C2	Medium to Coarse Sand	2.5 Y 7/4		5-10% gravel. Stratified. Very little silt. Loose.
80-148	C3	Coarse Sand and Gravel	2.5 Y 8/4	-	Stratified. 20% gravel.

All topsoil was removed in the past. The parent material beneath consisted of some stratification of layers of sand and gravel with very little silt present.

TP03 location.

Note the difference in C1 and C2+C3, above is mixed with gravel, below is stratified.

Hole collapsing in.

Location: **Augusta Parcel**
Date: **1/12/2021**
Weather: **Sunny, 40s**

Deep Hole #: **2020-Augusta-TP05**
Time: **10:16**

Depth from Surface (inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other
0-8	B	Sandy Loam	7.5 YR 6/8	-	Massive. Firm in place.
8-20	C1	Coarse Sand and Gravel	2.5 Y 7/6		20%+ gravel. Mixed. Some silt.
20-78	C2	Medium to Coarse Sand	2.5 Y 7/4		5-10% gravel. Stratified. Very little silt. Loose.
78-144	C3	Coarse Sand and Gravel	2.5 Y 8/4	-	Stratified. 20% gravel.

All topsoil was removed in the past. The parent material beneath consisted of some stratification of layers of sand and gravel with very little silt present.

NOTE: There is no TP04

Location of TP05

More of the same.

More of the same. This photo shows the color progression from brighter on top to lighter on bottom. Also stratification layers visible and the mixed C1 layer on top.

Location: **Augusta Parcel** Deep Hole #: **2020-Augusta-TP06**
Date: **1/12/2021** Time: **11:00**
Weather: **Overcast, 40s**

Depth from Surface (inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other
0-15	Fill			-	
15-25	B	Sandy Loam	2.5 Y 7/6		Firm in place. Massive.
25-38	C1	Medium to Coarse Sand	2.5 Y 7/6		20%+ gravel. Mixed. Some silt.5-10% gravel. Stratified. Very little silt. Loose.
38-161	C2	Coarse Sand and Gravel	2.5 Y 8/4	-	Stratified. 20% gravel.

All topsoil was removed in the past and a layer of sandy fill was placed. The parent material beneath consisted of some stratification of layers of sand and gravel with very little silt present. The previous C2 layer is not present in this hole (medium sand 2.5Y 7/4).

TP06 location.

It appears that fill was placed on top of the B layer after topsoil was removed. The middle C layer from previous holes not present.

Location: **Augusta Parcel**
Date: **1/12/2021**
Weather: **Sunny, 40s**

Deep Hole #: **2020-Augusta-TP07**
Time: **12:45**

Depth from Surface (inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other
0-6	Fill			-	
6-30	C1	Sandy Loam	2.5 Y 7/6		Firm in place. Massive.
30-148	C2	Medium to Coarse Sand	2.5 Y 7/6		20%+ gravel. Mixed. Some silt.5-10% gravel. Stratified. Very little silt. Loose.

All topsoil was removed in the past and a layer of sandy fill was placed; some of this has been stripped after. The parent material beneath consisted of some stratification of layers of sand and gravel with very little silt present. The previous C2 layer is not present in this hole (medium sand 2.5Y 7/4).

TP07 location.

Note how loose it is, hole collapsing in, difficult to dig.

More of the same.

Attachment K.

Augusta Parcel Soil Lab Results

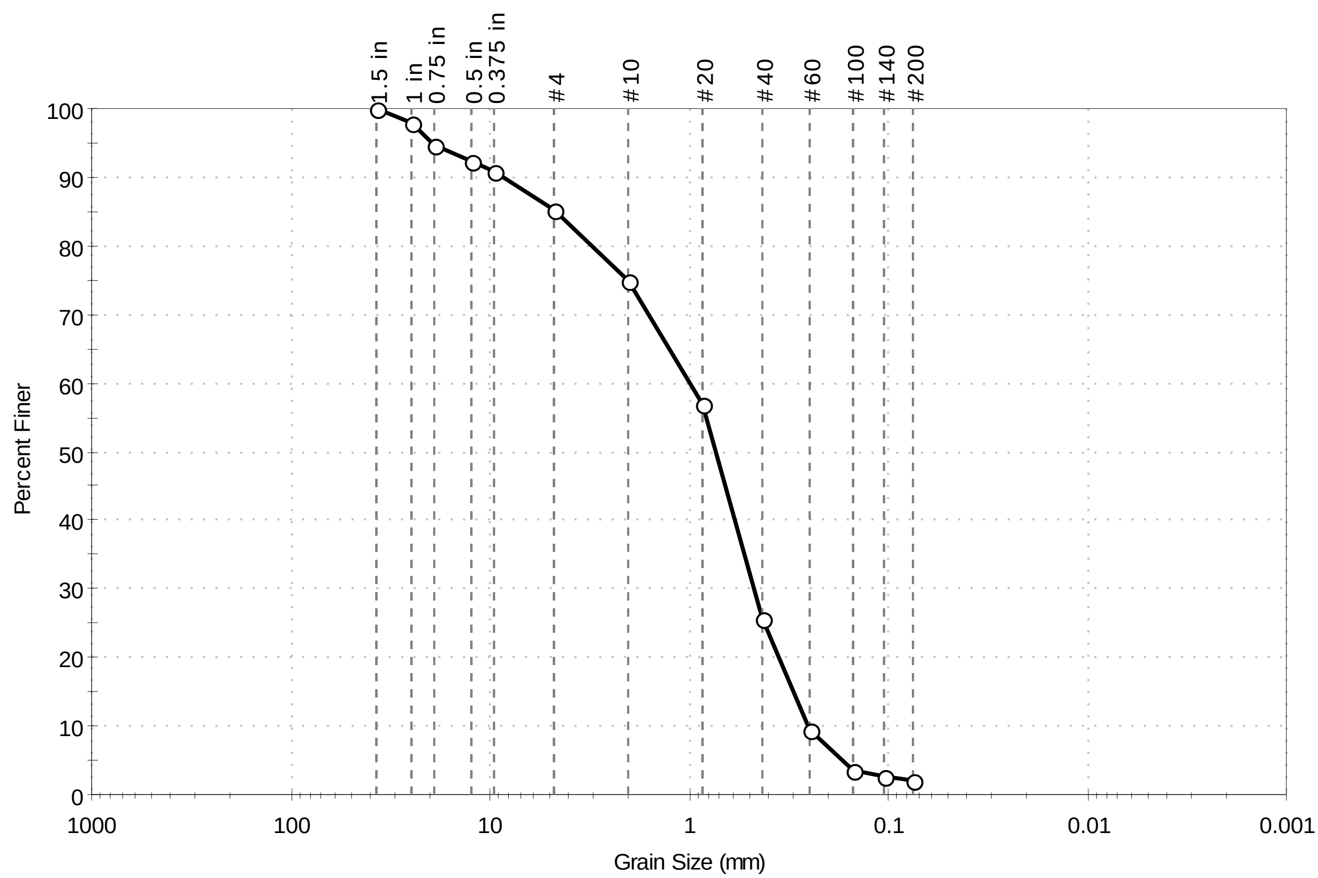
Client:	GHD Engineering		
Project:	Great Pond TWMP Field Invest.		
Location:	Falmouth, MA	Project No:	GTX-313651
Boring ID: TP07	Sample Type: bag	Tested By:	ckg
Sample ID: 2020-Augusta-TP07	Test Date: 05/24/21	Checked By:	bfs
Depth : 3-13 ft	Test Id: 618480		

Test Comment: ---

Visual Description: Moist, grayish brown sand

Sample Comment: ---

Particle Size Analysis - ASTM D6913/D7928



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	14.7	83.3	2.0

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
1.5 in	37.50	100		
1 in	25.00	98		
0.75 in	19.00	95		
0.5 in	12.50	92		
0.375 in	9.50	91		
#4	4.75	85		
#10	2.00	75		
#20	0.85	57		
#40	0.42	26		
#60	0.25	9		
#100	0.15	4		
#140	0.11	3		
#200	0.075	2.0		

Coefficients

D_{85} = 4.6242 mm D_{30} = 0.4685 mm

D_{60} = 0.9808 mm D_{15} = 0.3010 mm

D_{50} = 0.7285 mm D_{10} = 0.2557 mm

C_u = 3.836 C_c = 0.875

Classification

ASTM: Poorly graded SAND (SP)

AASHTO: Stone Fragments, Gravel and Sand (A-1-b (1))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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Client:	GHD Engineering
Project:	Great Pond TWMP Field Invest.
Location:	Falmouth, MA
Project No:	GTX-313651
Boring ID:	TP07
Sample Type:	bag
Tested By:	cam
Sample ID:	2020-Augusta-TP07
Test Date:	05/21/21
Checked By:	bfs
Depth :	3-13 ft
Test Id:	618473
Test Comment:	---
Visual Description:	Moist, grayish brown sand
Sample Comment:	---

Atterberg Limits - ASTM D4318

Sample Determined to be non-plastic

Symbol	Sample ID	Boring	Depth	Natural Moisture Content,%	Liquid Limit	Plastic Limit	Plasticity Index	Liquidity Index	Soil Classification
◆	2020-Augusta-TP07	TP07	3-13 ft	2	n/a	n/a	n/a	n/a	Poorly graded SAND (SP)

74% Retained on #40 Sieve

Dry Strength: LOW

Dilatancy: RAPID

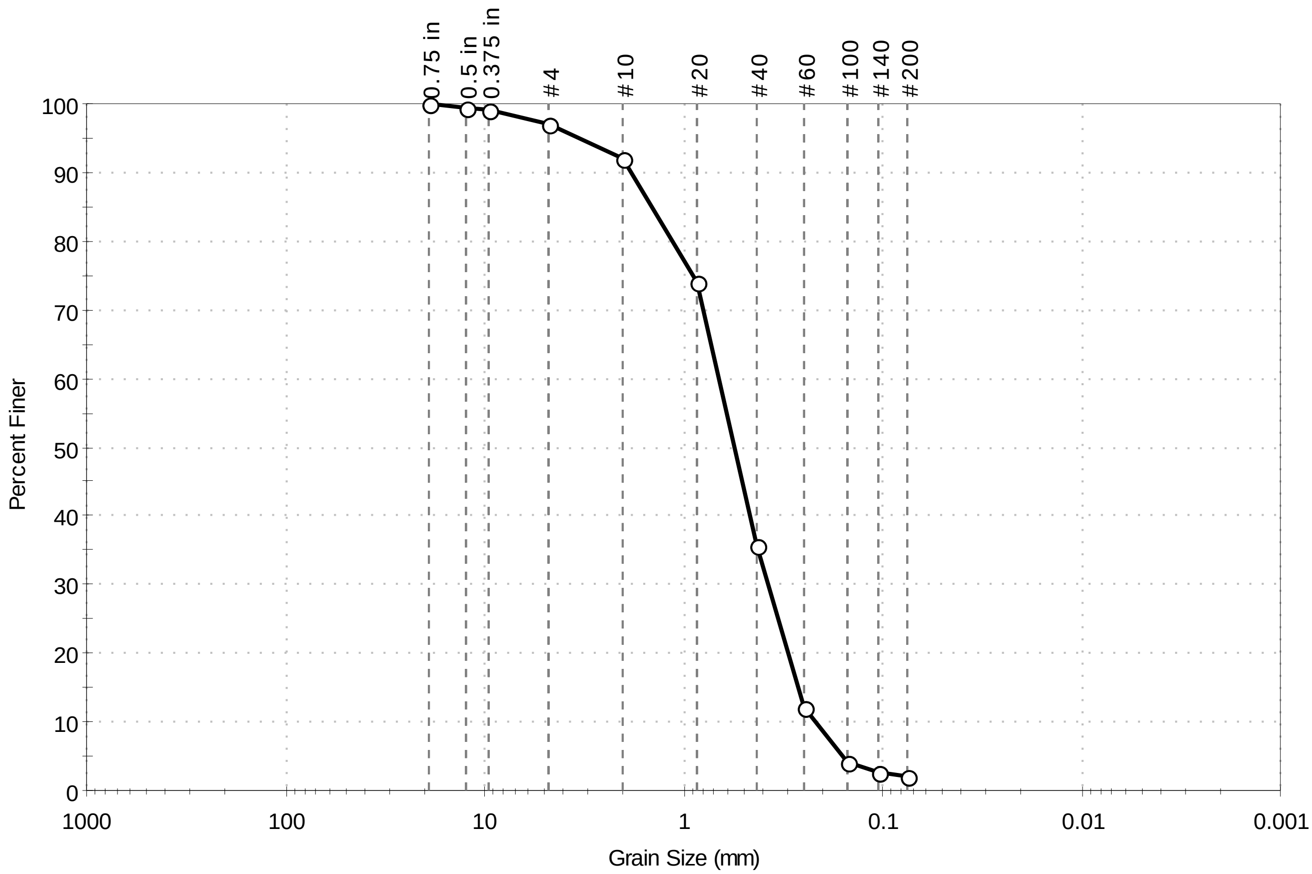
Toughness: n/a

The sample was determined to be Non-Plastic

GeoTesting EXPRESS

Client:	GHD Engineering				
Project:	Great Pond TWMP Field Invest.				
Location:	Falmouth, MA			Project No:	GTX-313651
Boring ID:	B01	Sample Type:	bag	Tested By:	ckg
Sample ID:	2020-Augusta-B01	Test Date:	05/27/21	Checked By:	bfs
Depth :	6-15 ft	Test Id:	618481		
Test Comment:	---				
Visual Description:	Moist, grayish brown sand				
Sample Comment:	---				

Particle Size Analysis - ASTM D6913/D7928



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	3.0	94.9	2.1

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
0.75 in	19.00	100		
0.5 in	12.50	99		
0.375 in	9.50	99		
#4	4.75	97		
#10	2.00	92		
#20	0.85	74		
#40	0.42	36		
#60	0.25	12		
#100	0.15	4		
#140	0.11	3		
#200	0.075	2.1		

Coefficients

D_{85} = 1.4337 mm　D_{30} = 0.3738 mm

D_{60} = 0.6593 mm　D_{15} = 0.2667 mm

D_{50} = 0.5503 mm　D_{10} = 0.2184 mm

C_u = 3.019　C_c = 0.970

Classification

ASTM　Poorly graded SAND (SP)

AASHTO　Stone Fragments, Gravel and Sand (A-1-b (1))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

printed 5/27/2021 10:53:11 AM

Client:	GHD Engineering				
Project:	Great Pond TWMP Field Invest.				
Location:	Falmouth, MA			Project No:	GTX-313651
Boring ID:	B01	Sample Type:	bag	Tested By:	cam
Sample ID:	2020-Augusta-B01	Test Date:	05/21/21	Checked By:	bfs
Depth :	6-15 ft	Test Id:	618474		
Test Comment:	---				
Visual Description:	Moist, grayish brown sand				
Sample Comment:	---				

Atterberg Limits - ASTM D4318

Sample Determined to be non-plastic

Symbol	Sample ID	Boring	Depth	Natural Moisture Content, %	Liquid Limit	Plastic Limit	Plasticity Index	Liquidity Index	Soil Classification
◆	2020-Augusta-B01	B01	6-15 ft	1	n/a	n/a	n/a	n/a	Poorly graded SAND (SP)

64% Retained on #40 Sieve

Dry Strength: LOW

Dilatancy: RAPID

Toughness: n/a

The sample was determined to be Non-Plastic

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Attachment L.

Allen Parcel NHESP Response

DIVISION OF
FISHERIES & WILDLIFE

1 Rabbit Hill Road, Westborough, MA 01581
p: (508) 389-6300 | f: (508) 389-7890
MASS.GOV/MASSWILDLIFE

February 07, 2020

Anastasia Rudenko
GHD Inc.
1545 Iyannough Road
Hyannis MA 02601

RE: Project Location: Allen parcel off Carriage Shop Road
Town: FALMOUTH
NHESP Tracking No.: 20-39170

To Whom It May Concern:

Thank you for contacting the Natural Heritage and Endangered Species Program of the MA Division of Fisheries & Wildlife (the "Division") for information regarding state-listed rare species in the vicinity of the above referenced site. Based on the information provided, this project site, or a portion thereof, is located **within** *Priority Habitat 223* (PH 223) as indicated in the *Massachusetts Natural Heritage Atlas* (14^{th} Edition) for the following state-listed rare species:

Scientific name	Common Name	Taxonomic Group	State Status
Catocala herodias	Herodias Underwing Moth	Butterflies and Moths	Special Concern
Hemileuca maia	Buck Moth	Butterflies and Moths	Special Concern
Callophrys irus	Frosted Elfin	Butterflies and Moths	Special Concern
Psectraglaea carnosa	Pink Sallow	Butterflies and Moths	Special Concern
Antrostomus vociferus	Eastern Whip-poor-will	Bird	Special Concern

The species listed above are protected under the Massachusetts Endangered Species Act (MESA) (M.G.L. c. 131A) and its implementing regulations (321 CMR 10.00). State-listed wildlife are also protected under the state's Wetlands Protection Act (WPA) (M.G.L. c. 131, s. 40) and its implementing regulations (310 CMR 10.00). Fact sheets for most state-listed rare species can be found on our website (www.mass.gov/nhesp).

Please note that projects and activities located within Priority and/or Estimated Habitat **must** be reviewed by the Division for compliance with the state-listed rare species protection provisions of MESA (321 CMR 10.00) and/or the WPA (310 CMR 10.00).

Wetlands Protection Act (WPA)

If the project site is within Estimated Habitat and a Notice of Intent (NOI) is required, then a copy of the NOI must be submitted to the Division so that it is received at the same time as the local conservation commission. If the Division determines that the proposed project will adversely affect the actual Resource Area habitat of state-protected wildlife, then the proposed project may not be permitted (310 CMR 10.37, 10.58(4)(b) & 10.59). In such a case, the project proponent may request a consultation with the Division to discuss potential project design modifications that would avoid adverse effects to rare wildlife habitat.

A streamlined joint MESA/WPA review process is now available. When filing a Notice of Intent (NOI), the applicant may now file concurrently under the MESA on the same NOI form and qualify for a 30-day streamlined joint review. For a copy of the revised NOI form, please visit the MA Department of Environmental Protection's website:
http://www.mass.gov/eea/agencies/massdep/service/approvals/wpa-form-3.html.

MA Endangered Species Act (MESA)
If the proposed project is located within Priority Habitat and is not exempt from review (see 321 CMR 10.14), then project plans, a fee, and other required materials must be sent to Natural Heritage Regulatory Review to determine whether a probable Take under the MA Endangered Species Act would occur (321 CMR 10.18). Please note that all proposed and anticipated development must be disclosed, as MESA does not allow project segmentation (321 CMR 10.16). For a MESA filing checklist and additional information please see our website: www.mass.gov/regulatory-review.

We recommend that rare species habitat concerns be addressed during the project design phase prior to submission of a formal MESA filing, as avoidance and minimization of impacts to rare species and their habitats is likely to expedite endangered species regulatory review.

This evaluation is based on the most recent information available in the Natural Heritage database, which is constantly being expanded and updated through ongoing research and inventory. If the purpose of your inquiry is to generate a species list to fulfill the federal Endangered Species Act (16 U.S.C. 1531 et seq.) information requirements for a permit, proposal, or authorization of any kind from a federal agency, we recommend that you contact the National Marine Fisheries Service at (978)281-9328 and use the U.S. Fish and Wildlife Service's Information for Planning and Conservation website (https://ecos.fws.gov/ipac). If you have any questions regarding this letter please contact Melany Cheeseman, Endangered Species Review Assistant, at (508) 389-6357.

Sincerely,

Everose Schlüter

Everose Schlüter, Ph.D.
Assistant Director

Attachment M.

Allen Parcel Boring Logs

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div. Desmond Well Drilling, Inc.	Project GHD, Inc. Falmouth South Coast CWMP Update Falmouth	Boring No. AL-BO1 Sheet 1 of 1

Driller: Sean Morgan	Boring location: Allen Property, 0 Carriage Shop Road
Helper: Derek Goodlin	Ground Surface Elevation:
Inspector: Ana Cristea	Date start: 01/06/2021 Date end: 01/06/2021

Sampler consists of a two inch split spoon driven using a 140 lb. hammer falling thirty inches	Notes: 41.6051955°/-70.5605202°	Auger Size: 6 1/4" x 4" H.S.A Casing Size: N/A Screen Size: N/A

Depth	Sample				Sample Description
(FT)	NO	PEN/REC	DEPTH/FT	BLOWS 6"	
0	1	24/24	0 - 2	1-1-2-2	F-M-C brown sand; some silty brown sand. Dry.
-2	2	24/18	2 - 4	1-2-5-7	F-M-C brown sand; silty brown sand. Dry.
-4	3	24/19	4 - 6	5-9-11-18	F-M-C brown sand; trace gravel. Dry.
-6	4	24/21	6 - 8	14-10-10-11	F-M-C brown sand; trace gravel. Dry.
-8	5	24/20	8 - 10	10-9-8-7	F-M-C brown sand; some gravel. Dry.
-10					
-12					
-14	6	24/15	13 - 15	4-5-4-6	F-M-C brown sand and gravel. Dry.
-16					
-18	7	24/16	18 - 20	3-4-8-9	F-M-C brown sand; trace silty brown sand. Perched water.
-20					
-22					
-24	8	24/19	23 - 25	4-7-10-9	F-M-C brown sand. Dry.
-26					
-28	9	24/18	28 - 30	5-7-8-9	F-M-C brown sand. Dry.
-30					
-32					
-34	10	24/17	33 - 35	4-7-10-14	F-M-C brown sand. Dry.
-36					
-38	11	24/5	38 - 40	3-3-6-8	F-M-C brown sand. Wet.
-40					
-42					
-44					
-46					
-48					
-50					
-52					
-54					
-56					

End of boring: 38'
End of sample: 40'
Groundwater encountered: 40'±
Sketch not to scale

Granular Soils		Cohesive Soils		Proportions Used	Well Installation Key
BLOWS/FT	DENSITY	BLOWS/FT	DENSITY		- CONCRETE
0 - 4	V. LOOSE	> 2	V. SOFT	Trace 0 - 10%	- SAND PACK
4 - 10	LOOSE	2 - 4	SOFT	Little 10 - 20%	Z - SOIL BACKFILL
10 - 30	M. DENSE	4 - 8	M. STIFF	Some 20 - 35%	- BENTONITE
30 - 50	DENSE	8 - 15	STIFF	And 35 - 50%	- SCREEN
> 50	V. DENSE	15 - 30	V. STIFF		▽ - APPROX. WATER LEVEL
		> 30	HARD		

CAPE COD TEST BORING **BORING NO. AL-BO1**

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div. Desmond Well Drilling, Inc.	Project GHD, Inc. Falmouth South Coast CWMP Update Falmouth	Boring No. AL-BO2 Sheet 1 of 1

Driller: Sean Morgan	Boring location: Allen Property, 0 Carriage Shop Road
Helper: Derek Goodlin	Ground Surface Elevation:
Inspector: Ana Cristea	Date start: 01/05/2021 Date end: 01/06/2021

Sampler consists of a two inch split spoon driven using a 140 lb. hammer falling thirty inches	Notes: 41.606071°/-70.560320°	Auger Size: 6 1/4" x 4" H.S.A Casing Size: N/A Screen Size: N/A

Depth	Sample				Sample Description
(FT)	NO	PEN/REC	DEPTH/FT	BLOWS 6"	
0	1	24/22	0 - 2	1-1-2-5	Loamy top soil. Silty clay. Dry.
-2	2	24/17	2 - 4	3-5-11-14	Silty clay; F-M-C brown sand; trace gravel. Dry.
-4	3	24/13	4 - 6	1-4-16-15	F-M-C brown sand; little gravel. Dry.
-6	4	24/18	6 - 8	5-8-8-9	F-M-C brown sand; trace gravel. Dry.
-8					
-10	5	24/17	8 - 10	2-6-9-7	F-M-C brown sand; trace gravel. Dry.
-12					
-14	6	24/15	13 - 15	4-6-4-3	F-M-C brown sand; trace gravel. Dry.
-16					
-18	7	24/17	18 - 20	5-7-7-10	F-M-C brown sand; trace gravel. Dry.
-20					
-22					
-24	8	24/16	23 - 25	3-12-14-13	F-M-C brown sand. Dry.
-26					
-28	9	24/17	28 - 30	5-7-6-10	F-M-C brown sand. Dry.
-30					
-32					
-34	10	24/18	33 - 35	5-6-9-7	F-M-C brown sand. Dry.
-36					
-38	11	24/17	38 - 40	4-5-7-5	F-M-C brown sand. Wet.
-40					
-42					
-44					
-46					
-48					
-50					
-52					
-54					
-56					

End of boring: 38'
End of sample: 40'
Groundwater encountered: 40'±
Sketch not to scale

Granular Soils		Cohesive Soils		Proportions Used	Well Installation Key
BLOWS/FT	DENSITY	BLOWS/FT	DENSITY		
0 - 4	V. LOOSE	> 2	V. SOFT	Trace 0 - 10%	- CONCRETE
4 - 10	LOOSE	2 - 4	SOFT	Little 10 - 20%	- SAND PACK
10 - 30	M. DENSE	4 - 8	M. STIFF	Some 20 - 35%	Z - SOIL BACKFILL
30 - 50	DENSE	8 - 15	STIFF	And 35 - 50%	- BENTONITE
> 50	V. DENSE	15 - 30	V. STIFF		- SCREEN
		> 30	HARD		- APPROX. WATER LEVEL

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div. Desmond Well Drilling, Inc.	Project GHD, Inc. Falmouth South Coast CWMP Update Falmouth	Boring No. AL-BO3 Sheet 1 of 1

Driller:	Sean Morgan	Boring location:	Allen Property, 0 Carriage Shop Road
Helper:	Derek Goodlin	Ground Surface Elevation:	
Inspector:	Ana Cristea	Date start: 01/07/2021	Date end: 01/07/2021

Sampler consists of a two inch split spoon driven using a 140 lb. hammer falling thirty inches	Notes: 41.6063821°, -70.5615612°	Auger Size: 6 1/4" x 4" H.S.A Casing Size: N/A Screen Size: N/A	

Depth	Sample				Sample Description
(FT)	NO	PEN/REC	DEPTH/FT	BLOWS 6"	
0	1	24/9	0 - 2	2-2-2-3	F-M-C brown sand; little silty brown sand. Dry.
-2	2	24/15	2 - 4	2-3-2-2	F-M-C red sand; trace silty red sand. Dry.
-4	3	24/18	4 - 6	2-2-2-2	F gray silt. Dry.
-6	4	24/17	6 - 8	2-3-5-4	F-M-C brown sand; some silty brown sand. Dry.
-8	5	24/12	8 - 10	3-3-7-8	F-M-C brown sand; trace gravel. Dry.
-10	6				
-12					
-14	7	24/10	13 - 15	3-5-5-6	F-M-C brown sand; trace gravel; trace cobble. Dry.
-16					
-18	8	24/16	18 - 20	2-6-9-11	F-M-C brown sand; trace gravel. Dry.
-20					
-22					
-24	9	24/17	23 - 25	12-30-13-11	F-M-C brown sand. Dry.
-26					
-28	10	24/16	28 - 30	3-5-5-5	F-M-C brown sand. Dry.
-30					
-32					
-34	11	24/16	33 - 35	4-6-9-9	F-M-C brown sand. Dry.
-36					
-38	12	24/15	38 - 40	2-2-2-5	F-M-C brown sand. Wet.
-40					
-42					
-44					
-46					
-48					
-50					
-52					
-54					
-56					

End of boring:38'
End of sample: 40'
Groundwater encountered:40±
Sketch not to scale

Granular Soils		Cohesive Soils		Proportions Used	Well Installation Key
BLOWS/FT	DENSITY	BLOWS/FT	DENSITY		
0 - 4	V. LOOSE	> 2	V. SOFT	Trace 0 - 10%	- CONCRETE
4 - 10	LOOSE	2 - 4	SOFT	Little 10 - 20%	- SAND PACK
10 - 30	M. DENSE	4 - 8	M. STIFF	Some 20 - 35%	Z - SOIL BACKFILL
30 - 50	DENSE	8 - 15	STIFF	And 35 - 50%	- BENTONITE
> 50	V. DENSE	15 - 30	V. STIFF		- SCREEN
		> 30	HARD		- APPROX. WATER LEVEL

Cape Cod Test Boring 5 Rayber Road, Orleans, MA 02653 (508) 240-1000 div. Desmond Well Drilling, Inc.	Project GHD, Inc. Falmouth South Coast CWMP Update Falmouth	Boring No. AL-BO4 Sheet 1 of 1

Driller:	Sean Morgan	Boring location:	Allen Property, 0 Carriage Shop Road
Helper:	Derek Goodlin	Ground Surface Elevation:	
Inspector:	Ana Cristea	Date start: 01/07/2021	Date end: 01/07/2021

Sampler consists of a two inch split spoon driven using a 140 lb. hammer falling thirty inches	Notes: 41.6058326°/-70.5608866°	Auger Size: 6 1/4" x 4" H.S.A Casing Size: N/A Screen Size: N/A

Depth	Sample				Sample Description
(FT)	NO	PEN/REC	DEPTH/FT	BLOWS 6"	
0	1	24/24	0 - 2	1-2-4-12	F-M-C brown sand and silty brown sand. Dry.
-2	2	24/16	2 - 4	4-8-9-10	F-M-C brown sand; trace gravel. Dry.
-4	3	24/17	4 - 6	5-12-12-14	F-M-C brown sand and gravel. Dry.
-6	4	24/17	6 - 8	1-2-8-11	F-M-C brown sand; trace gravel. Dry.
-8	5	24/16	8 - 10	2-3-5-6	F-M-C brown sand; trace gravel. Dry.
-10					
-12					
-14	6	24/15	13 - 15	3-4-6-6	F-M-C brown sand; trace gravel. Dry.
-16					
-18	7	24/17	18 - 20	3-5-8-10	F-M-C brown sand; trace gravel. Dry.
-20					
-22					
-24	8	24/16	23 - 25	2-6-9-10	F-M-C brown sand. Dry.
-26					
-28	9	24/17	28 - 30	3-6-9-11	F-M-C brown sand; trace gravel. Dry.
-30					
-32					
-34	10	24/16	33 - 35	4-9-12-15	F-M-C brown sand. Dry.
-36					
-38	11	24/12	38 - 40	3-6-6-7	F-M-C brown sand. Wet.
-40					
-42					
-44					
-46					
-48					
-50					
-52					
-54					
-56					

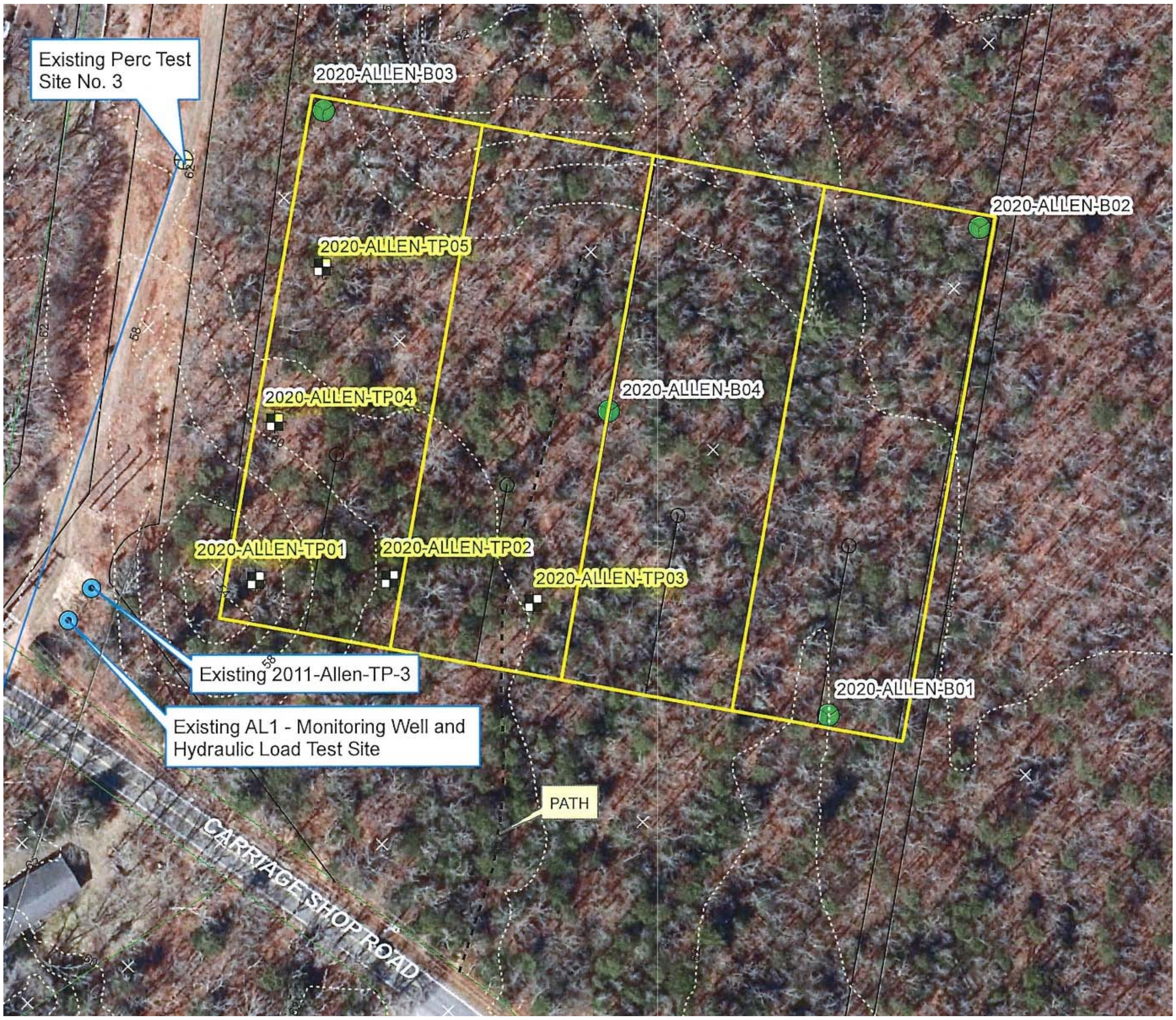
End of boring: 38'
End of sample: 40'
Groundwater encountered:39' ±
Sketch not to scale

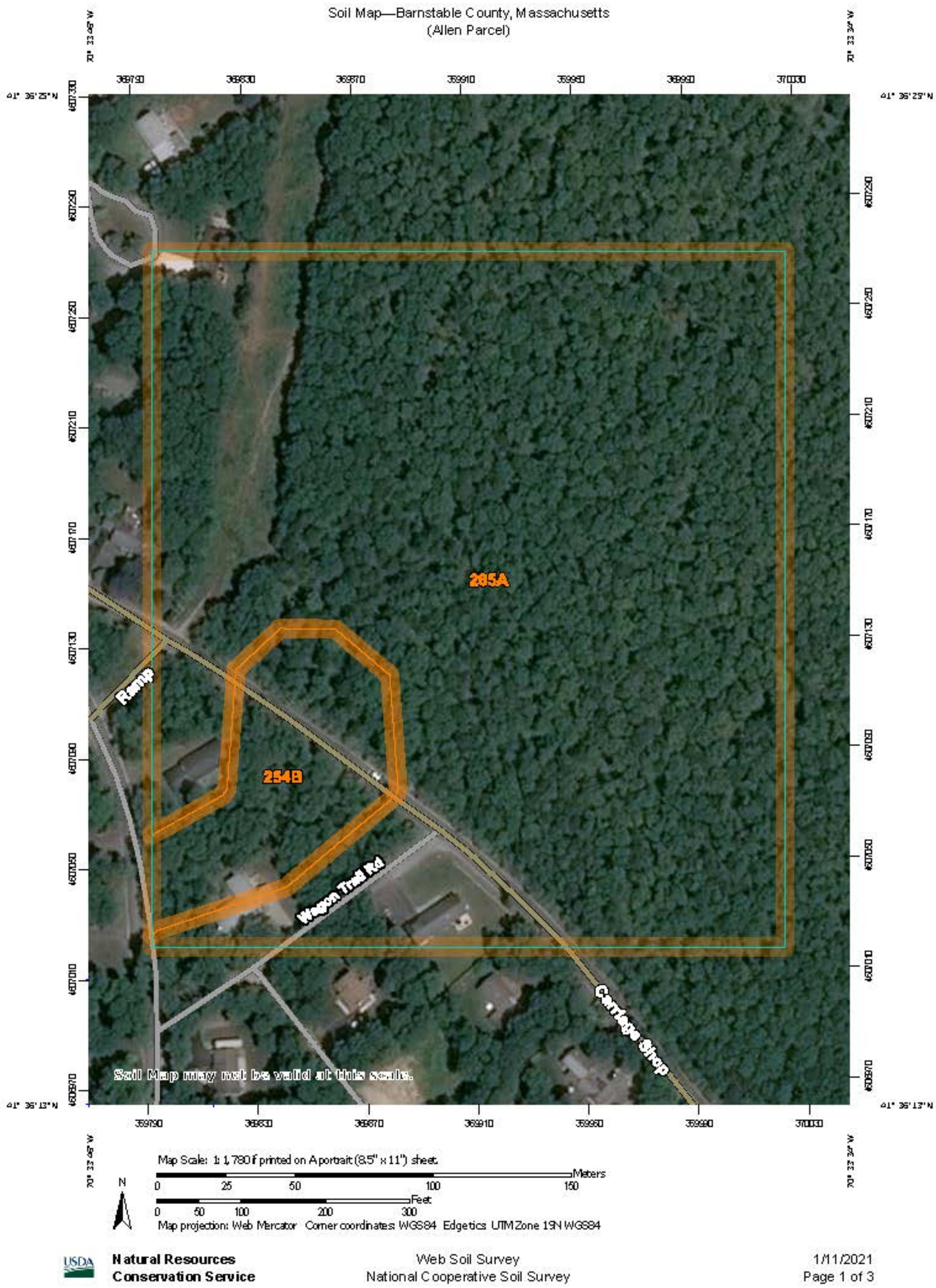
Granular Soils		Cohesive Soils		Proportions Used	Well Installation Key
BLOWS/FT	DENSITY	BLOWS/FT	DENSITY		
0 - 4	V. LOOSE	> 2	V. SOFT	Trace 0 - 10%	- CONCRETE
4 - 10	LOOSE	2 - 4	SOFT	Little 10 - 20%	- SAND PACK
10 - 30	M. DENSE	4 - 8	M. STIFF	Some 20 - 35%	Z - SOIL BACKFILL
30 - 50	DENSE	8 - 15	STIFF	And 35 - 50%	- BENTONITE
> 50	V. DENSE	15 - 30	V. STIFF		- SCREEN
		> 30	HARD		- APPROX. WATER LEVEL

Attachment N.

Allen Parcel Soil Evaluator Field Notes

Allen Parcel





USDA maps this area as predominately Enfield Silt Loam (265A) with a "thumb" of Merrimac Fine Sandy Loam (254B). Both soils are categorized as outwash. The main difference between the soils is the silt loam in the B layers and the amount of silt in the C layers. Based on the soils observed in the deep holes, all areas explored were the Enfield Silt Loam. Samples were taken of the various layers from B down and bottom of holes. Some of the bottom of hole samples are represented by the C# layer. Samples of pocket materials were taken as well (see logs). After consulting reference materials in the office, I find my assessment of soil horizons conflicted. Horizons labeled as upper C layers with soil textures of Silt Loam could be B layers. The colors led me to C layers but could be the B layer losing color moving towards the substratum. Since sample bags were labeled and draft logs were sent out, I have left the logs as is. Either way these layers are restrictive and likely would be removed.

Location: **Allen Parcel**
Date: **1/7/2021**
Weather: **Sunny, 30s**

Deep Hole #: **2020-Allen-TP01**
Time: **8:20**

Depth from Surface (inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other
0-6	0-A		10 YR 2/1	-	
6-15	B	Silt Loam	10 YR 5/8	-	Massive, firm in place
15-32	C1	Silt Loam	2.5 Y 6/8	-	Massive
32-56	C2	Loamy Sand	2.5 Y 7/6	-	Loose
56-92	C3	Loamy Sand	2.5 Y 7/3	-	Stratified layers, 15-20% gravel, Loose
92-145	C4	Med/Coarse Loamy Sand	2.5 Y 7/4	-	15-20% Gravel mixed, Loose, some silt

Soils went from silt loam to loamy sand, possibly sand with trace silt decreasing in silt content from top down. The underlying C layers were loose and increasing in stratification with layers of gravel and sands mixed in with some silt. No evidence of a perched water table. Hole was difficult to dig deep due to side stability.

Note the break from Silt Loam to Loamy sand around 32” where the soils collapse in.

Note the visible stratification of sands and gravels. The break between Silt Loam and Loamy Sand visible where soils collapse in.

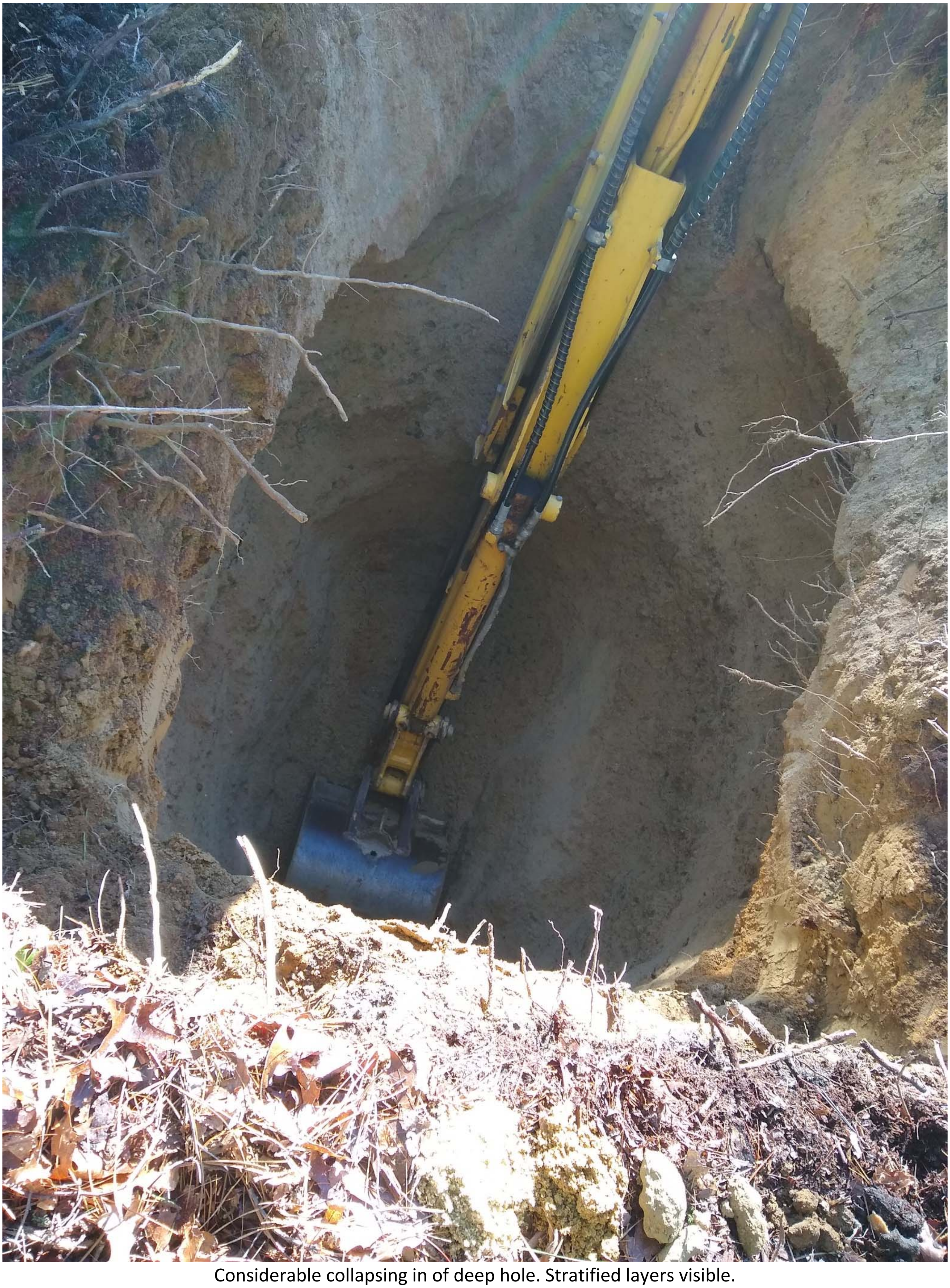
Location: **Allen Parcel**
Date: **1/7/2021**
Weather: **Sunny, 40s**

Deep Hole #: **2020-Allen-TP02**
Time: **10:00**

Depth from Surface (inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other
0-5	A	Silt Loam	10 YR 2/1	-	
5-12	B	Silt Loam	10 YR 6/8	-	Massive, firm in place
12-19	C1	Silt Loam	2.5 Y 7/8	-	Massive, firm in place
19-26	C2	Silt Loam	2.5 Y 7/6	-	Massive, firm in place
26-40	C3	Loamy Sand	10 YR 6/8	**SEE OTHER**	Possible pause in water table - streaks Loose to firm in place mix
40-64	C4	Loamy Sand	10 YR 7/6	-	Loose, 10% gravel
64-156	C5	Med/Coarse Sand	2.5 Y 7/4	-	Trace silt, 20%+ Gravel Loose stratified layers

Soils went from silt loam to loamy sand, possibly sand with trace silt decreasing in silt content from top down. The underlying C layers were loose and increasing in stratification with layers of gravel and sands mixed in with some silt. There were some bright streaks most likely a pause in water moving through siltier pockets of materials. Hole was difficult to dig deep due to side stability.

Note the break in soil around the 32” mark here, collapsing begins in this layer. Streaks and pockets of bright soils visible here. Not enough to make me think a water table is perched this high up.



Considerable collapsing in of deep hole. Stratified layers visible.

Location: **Allen Parcel** Deep Hole #: **2020-Allen-TP03**
Date: **1/7/2021** Time: **11:10**
Weather: **Sunny, 40s**

Depth from Surface (inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other
0-4	A		10 YR 2/1	-	
4-16	B	Silt Loam	10 YR 6/6	-	Massive, firm in place
16-33	C1	Silt Loam	2.5 Y 6/8	-	Pockets of very fine silt loam 2.5 Y 6/2 (samples taken). Massive, firm in place.
33-49	C2	Loamy Sand	10 YR 6/8	-	Semi-firm in place. 20% gravel
49-140	C3	Medium to Coarse Sand	2.5 Y 7/4	-	Very stratified layers of sand and gravel.

Soils went from silt loam to loamy sand to fairly clean medium and coarse sand decreasing in silt content from top down. The underlying C layers were loose and increasing in stratification with layers of gravel and sands mixed in with some silt. There were some pockets of very silty materials void of color. Samples were taken of both the main layer and the pocket material. Hole was difficult to dig deep due to side stability.

Note where soils start collapsing around 36" The pockets of greyish silty material visible.

Close-up of the silty pocket material. The pockets were shovel size but only a few visible in the hole.

Hole was difficult to progress down due to cave ins. Note the stratification.

Location: **Allen Parcel** Deep Hole #: **2020-Allen-TP04**
Date: **1/7/2021** Time: **1:10**
Weather: **Sunny, 40s**

Depth from Surface (inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other
0-7	A		10 YR 2/1	-	
7-16	B	Silt Loam	10 YR 6/8	-	Massive, firm in place.
16-36	C1	Silt Loam	2.5 Y 6/8	-	Massive, firm in place.
36-130	C2	Loamy Sand	2.5 Y 7/6	-	30% gravel. Stratified layers. Loose. Caving in too much to go deeper.

Soils went from silt loam to loamy sand to loamy sand decreasing in silt content from top down. The underlying C layers were loose and increasing in stratification with layers of gravel and sands mixed in with some silt. Hole was too difficult to dig deep due to side stability. A shelf was not dug for safety reasons.

Hole kept collapsing in as we tried to dig deeper. Not stratification of layers.

Location: **Allen Parcel** Deep Hole #: **2020-Allen-TP05**
Date: **1/7/2021** Time: **1:50**
Weather: **Sunny, 40s**

Depth from Surface (inches)	Soil Horizon	Soil Texture (USDA)	Soil Color (Munsell)	Soil Mottling	Other
0-5	A		10 YR 2/1	-	Massive, firm in place.
5-17	B	Silt Loam	10 YR 7/8	-	Massive, firm in place.
17-40	C1	Silt Loam	2.5 Y 6/8	-	Pockets of very fine grey silt loam 2.5 Y 7/2 (sample taken). Massive, firm in place.
40-144	C2	Medium to Coarse Sand	2.5 Y 7/8	**See Other**	Some silt. Possible pause in water flow at 48”. Stratified layers of sands and gravels. Loose.

Soils went from silt loam to medium and coarse sand decreasing in silt content from top down. The underlying C layers were loose and increasing in stratification with layers of gravel and sands mixed in with some silt. Samples were taken of the C1 grey silt loam as well as the main layer material. Hole was difficult to dig due to side stability.


Note pockets of grey silt loam (sample taken).

Note streak. Not throughout hole, only a couple spots at the interface of the B and C1 layers. Not enough evidence to suggest a perched water table. Most likely a siltier pocket holding moisture long enough to oxidize.

Close-up of a streak.

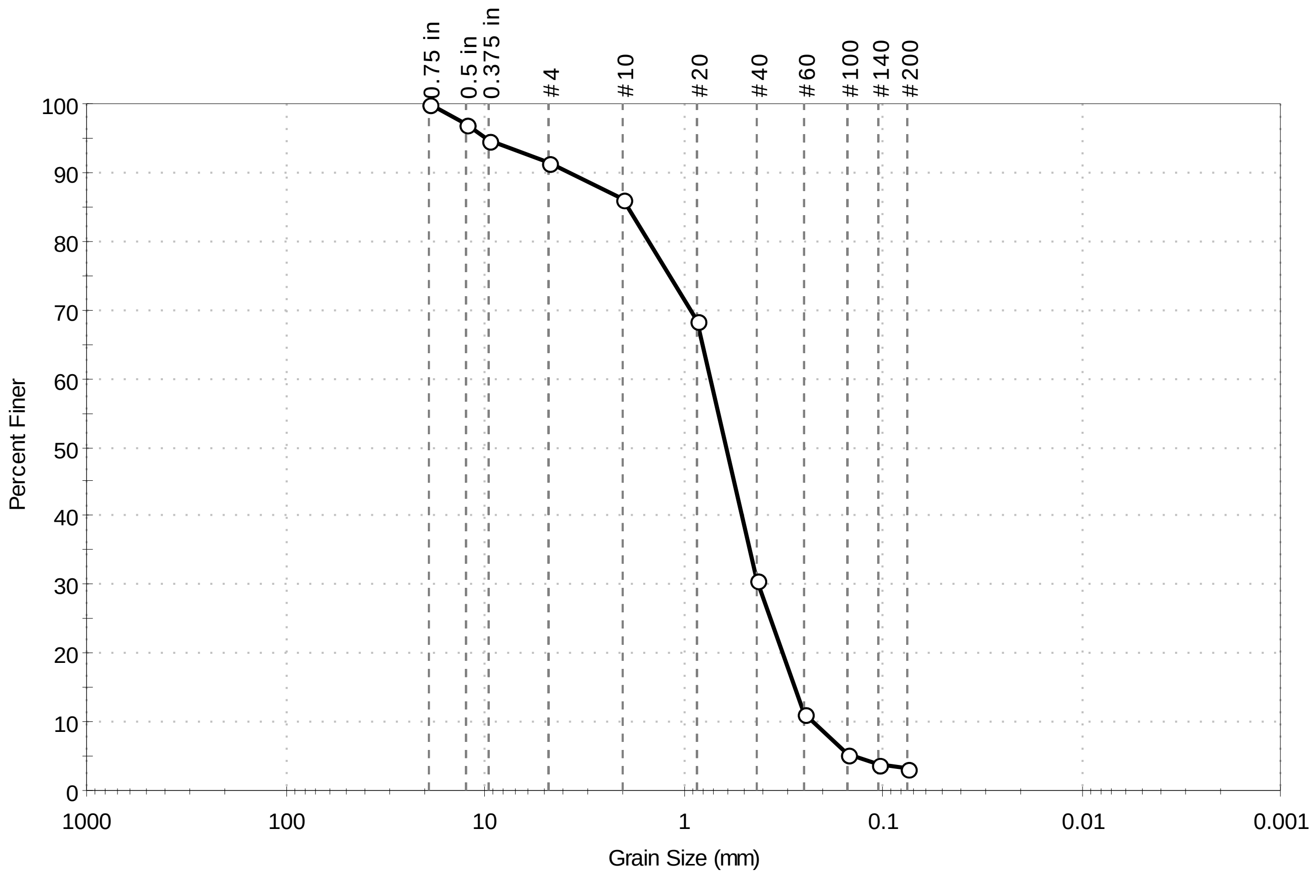
Attachment O.

Allen Parcel Lab Results

GeoTesting EXPRESS

Client:	GHD Engineering		
Project:	Great Pond TWMP Field Invest.		
Location:	Falmouth, MA	Project No:	GTX-313651
Boring ID: B04	Sample Type: bag	Tested By:	ckg
Sample ID: 2020-Allen-B04	Test Date: 05/24/21	Checked By:	bfs
Depth : 6-20 ft	Test Id: 618478		
Test Comment:	---		
Visual Description:	Dry, grayish brown sand		
Sample Comment:	---		

Particle Size Analysis - ASTM D6913/D7928



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	8.7	88.1	3.2

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
0.75 in	19.00	100		
0.5 in	12.50	97		
0.375 in	9.50	95		
#4	4.75	91		
#10	2.00	86		
#20	0.85	69		
#40	0.42	31		
#60	0.25	11		
#100	0.15	5		
#140	0.11	4		
#200	0.075	3.2		

Coefficients

D_{85} = 1.8923 mm | D_{30} = 0.4181 mm

D_{60} = 0.7270 mm | D_{15} = 0.2776 mm

D_{50} = 0.6056 mm | D_{10} = 0.2261 mm

C_u = 3.215 | C_c = 1.063

Classification

ASTM Poorly graded SAND (SP)

AASHTO Stone Fragments, Gravel and Sand (A-1-b (1))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

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Client:	GHD Engineering				
Project:	Great Pond TWMP Field Invest.				
Location:	Falmouth, MA			Project No:	GTX-313651
Boring ID:	B04	Sample Type:	bag	Tested By:	cam
Sample ID:	2020-Allen-B04	Test Date:	05/21/21	Checked By:	bfs
Depth :	6-20 ft	Test Id:	618471		

Test Comment: ---
Visual Description: Dry, grayish brown sand
Sample Comment: ---

Atterberg Limits - ASTM D4318

Sample Determined to be non-plastic

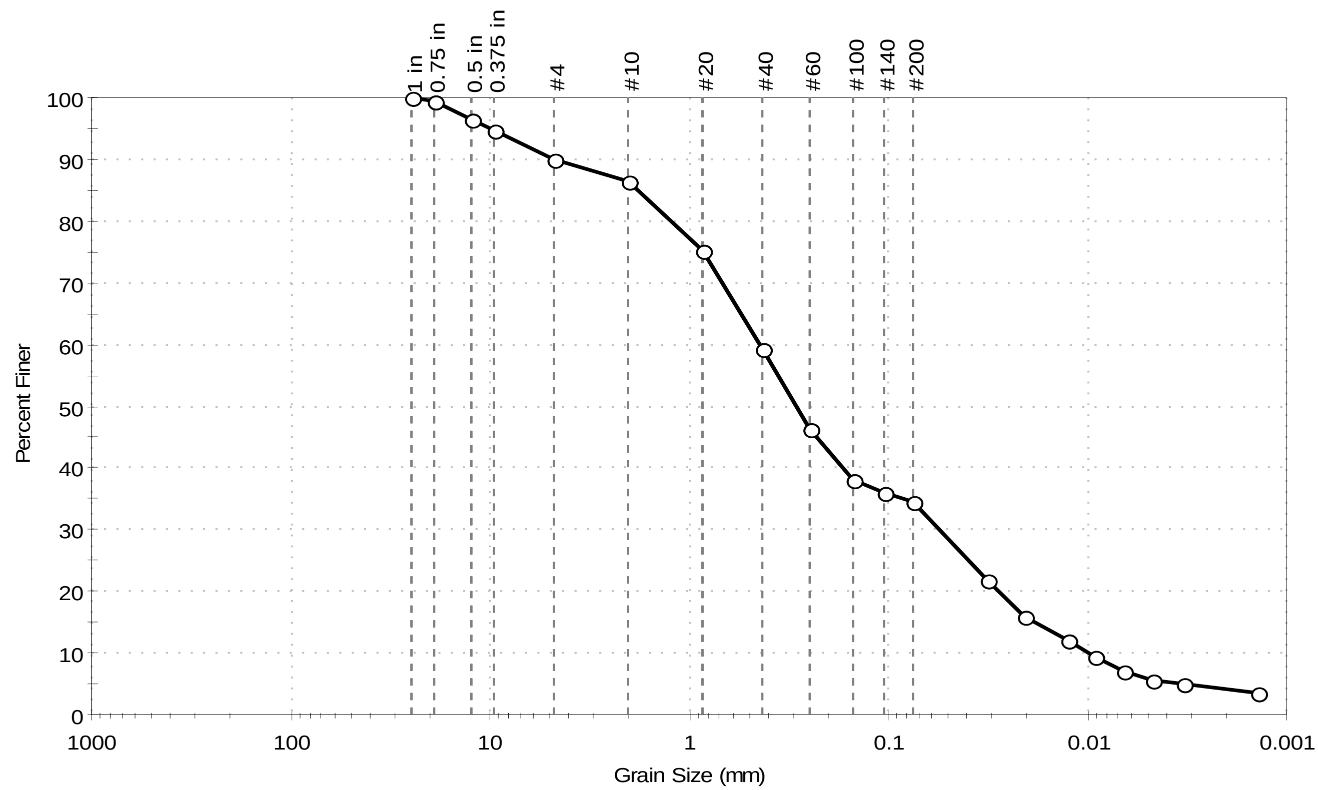
Symbol	Sample ID	Boring	Depth	Natural Moisture Content, %	Liquid Limit	Plastic Limit	Plasticity Index	Liquidity Index	Soil Classification
◆	2020-Allen-B04	B04	6-20 ft	1	n/a	n/a	n/a	n/a	Poorly graded SAND (SP)

69% Retained on #40 Sieve
Dry Strength: LOW
Dilatancy: RAPID
Toughness: n/a
The sample was determined to be Non-Plastic

GeoTesting EXPRESS

Client:	GHD Engineering		
Project:	Great Pond TWMP Field Invest.		
Location:	Falmouth, MA	Project No:	GTX-313651
Boring ID:	TP03	Sample Type: bag	Tested By: ckg
Sample ID:	2020-Allen-TP03	Test Date: 05/27/21	Checked By: bfs
Depth :	1-3 ft	Test Id: 618479	
Test Comment:	---		
Visual Description:	Moist, dark yellowish brown silty sand		
Sample Comment:	---		

Particle Size Analysis - ASTM D6913/D7928



% Cobble	% Gravel	% Sand	% Silt & Clay Size
---	10.2	55.4	34.4

Sieve Name	Sieve Size, mm	Percent Finer	Spec. Percent	Complies
1 in	25.00	100		
0.75 in	19.00	99		
0.5 in	12.50	96		
0.375 in	9.50	95		
#4	4.75	90		
#10	2.00	86		
#20	0.85	75		
#40	0.42	59		
#60	0.25	46		
#100	0.15	38		
#140	0.11	36		
#200	0.075	34		
Hydrometer	Particle Size (mm)	Percent Finer	Spec. Percent	Complies
---	0.0318	22		
---	0.0209	16		
---	0.0125	12		
---	0.0092	10		
---	0.0066	7		
---	0.0047	5		
---	0.0033	5		
---	0.0014	4		

Coefficients

D_{85} = 1.7912 mm	D_{30} = 0.0558 mm
D_{60} = 0.4391 mm	D_{15} = 0.0184 mm
D_{50} = 0.2903 mm	D_{10} = 0.0097 mm
C_u = 45.268	C_c = 0.731

Classification

ASTM Silty SAND (SM)

AASHTO Silty Gravel and Sand (A-2-4 (0))

Sample/Test Description

Sand/Gravel Particle Shape : ANGULAR

Sand/Gravel Hardness : HARD

Dispersion Device : Apparatus A - Mech Mixer

Dispersion Period : 1 minute

Est. Specific Gravity : 2.65

Separation of Sample: #200 Sieve

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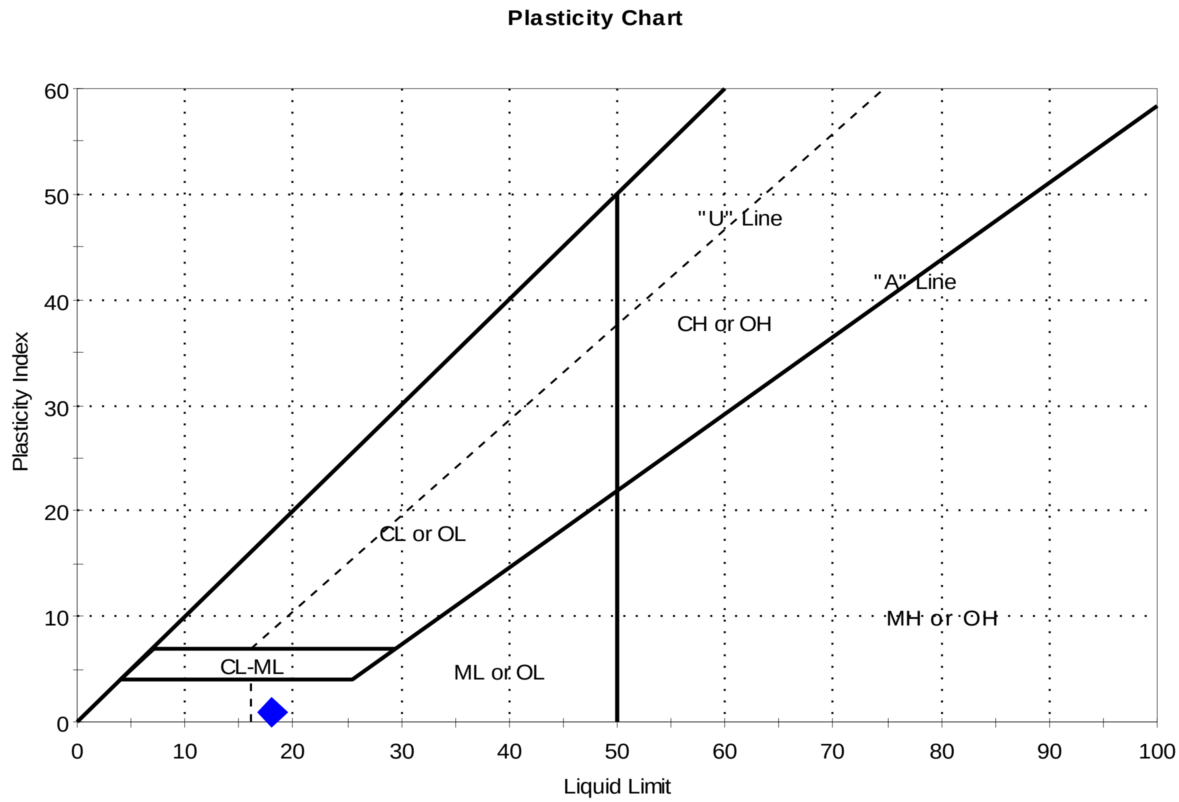
GeoTesting EXPRESS

Client:	GHD Engineering				
Project:	Great Pond TWMP Field Invest.				
Location:	Falmouth, MA			Project No:	GTX-313651
Boring ID:	TP03	Sample Type:	bag	Tested By:	cam
Sample ID:	2020-Allen-TP03	Test Date:	05/24/21	Checked By:	bfs
Depth :	1-3 ft	Test Id:	618472		
Test Comment:	---				
Visual Description:	Moist, dark yellowish brown silty sand				
Sample Comment:	---				

Atterberg Limits - ASTM D4318



Symbol	Sample ID	Boring	Depth	Natural Moisture Content,%	Liquid Limit	Plastic Limit	Plasticity Index	Liquidity Index	Soil Classification
◆	2020-Allen-TP03	TP03	1-3 ft	12	18	17	1	-5.5	Silty SAND (SM)

Sample Prepared using the WET method

41% Retained on #40 Sieve

Dry Strength: LOW

Dilatancy: RAPID

Toughness: LOW

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Attachment P.

Potential Migration of Infiltrated Wastewater Phosphorus Downgradient of Allen Parcel; Prepared by EcoLogic

June 2021
Town of Falmouth, MA

Technical Memorandum: Potential Migration of Infiltrated Wastewater Phosphorus Downgradient of Allen Parcel

Prepared by
EcoLogic, LLC
PO Box 39
Cazenovia NY 13035

Prepared for
GHD, Inc.

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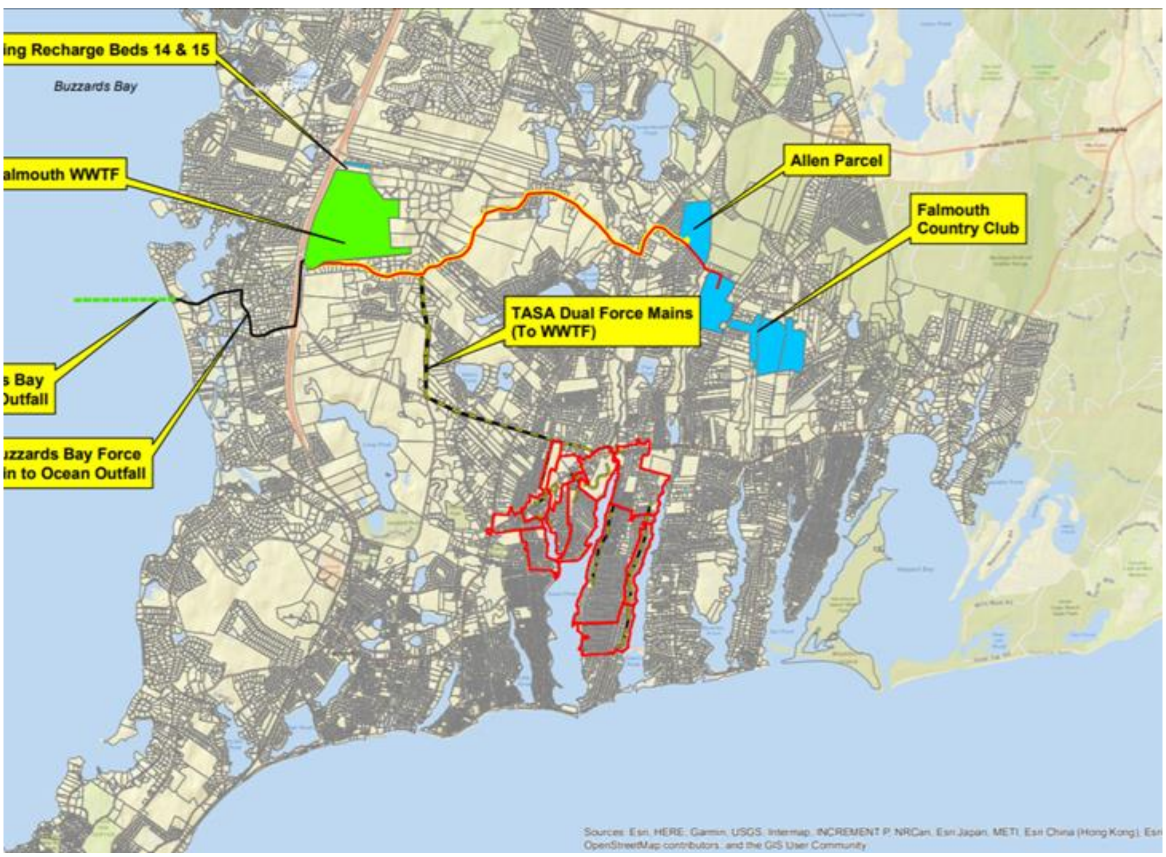
1 Project Objective

As a subconsultant to GHD, EcoLogic was tasked with estimating the downgradient fate and transport of phosphorus from wastewater infiltration beds (current and proposed) at the Falmouth wastewater treatment facility. The issue of concern is the capacity of soils downgradient of infiltration beds to adsorb phosphorus, and the potential water quality impact on local water resources. Environmental scientists from EcoLogic worked closely with the GHD project team to gather relevant data and information regarding wastewater flows and loads, nature and property of soils, downgradient waterbodies, and site hydrogeology (plume behavior).

This technical memorandum summarizes the analyses and estimates capacity of downgradient soils to immobilize wastewater phosphorus. The study area is displayed in Figure 1.

Figure 1
Falmouth, MA Area of Interest



2 Characterization of Waterbodies Downgradient of the Allen Parcel

2.1 Current Conditions of Freshwater Ponds

Most of the 996 inland freshwater ponds of Cape Cod are kettle ponds, formed as depressions left behind by ice blocks as the glacial ice retreated between 14,000 and 17,000 years ago. According to Portnoy et al. (2001), while kettle ponds have a common glacial origin, their subsequent evolution differs based on the depth of the original ice block, landscape position relative to sea level, and the texture (particle size) of the soils in the ponds' watersheds.

Cultural effects must be added to this list; the ponds of Cape Cod are influenced by the amount and type of development in the watershed, invasions of exotic species, application of lime to raise the naturally low pH of the waters, and fisheries management practices.

Unlike most lakes and ponds, kettle ponds do not have prominent tributary streams (inlets) and outlets. Groundwater seepage and direct precipitation, rather than surface water flows, are the source of water to the kettle ponds. The quality of the water in the ponds, therefore, is directly affected by the quality of the groundwater resource.

The lack of defined inlets and outlets for most kettle ponds has some important implications for the cycling of nutrients and organic material. Nitrogen and phosphorus enter the ponds primarily as dissolved nutrients where they are incorporated into biomass. Water leaves the ponds through groundwater seepage and evaporation. Particulate biomass consequently remains in the ponds, and the nutrients continue to cycle through the food web. Through this natural phenomenon, kettle ponds become increasingly enriched over time, as there is little opportunity for particulate material to leave the system. This process is known as eutrophication.

Water resources managers focus on identifying and controlling the sources of nutrients, organic material, and silt to aquatic ecosystems to slow the eutrophication process. Phosphorus is most often the limiting nutrient for primary productivity and algal growth in inland lakes and ponds. While phosphorus is the key to managing eutrophication of inland ponds, nitrogen is usually the limiting nutrient for primary production of coastal ecosystems. Nitrogen enrichment has resulted in degradation of estuarine and marine water quality and habitat conditions, and wastewater is a major source of nitrogen. Scientists and regulators from the EPA, the Massachusetts Department of Environmental Protection (MA DEP), the academic community, and the Cape Cod Commission have supported coastal municipalities in a systematic process to define the need for and extent of reductions in nitrogen loading (MA DEP 2003 "The

Massachusetts Estuaries Project Embayment Restoration and Guidance for Implementation Strategies”). Findings of this analysis have been incorporated into land use and facilities decisions across Cape Cod.

The Town of Falmouth participates in various pond monitoring programs under leadership and guidance of UMass Dartmouth School of Marine Science and Technology (SMAST) and MA DEP, and the Cape Cod Commission. The Coonamessett River has been monitored as part of the Coonamessett River Restoration Project. The freshwater ponds in Falmouth located downgradient of the Allen Parcel are relatively small and currently not monitored as part of these programs, limited data were available from other projects.

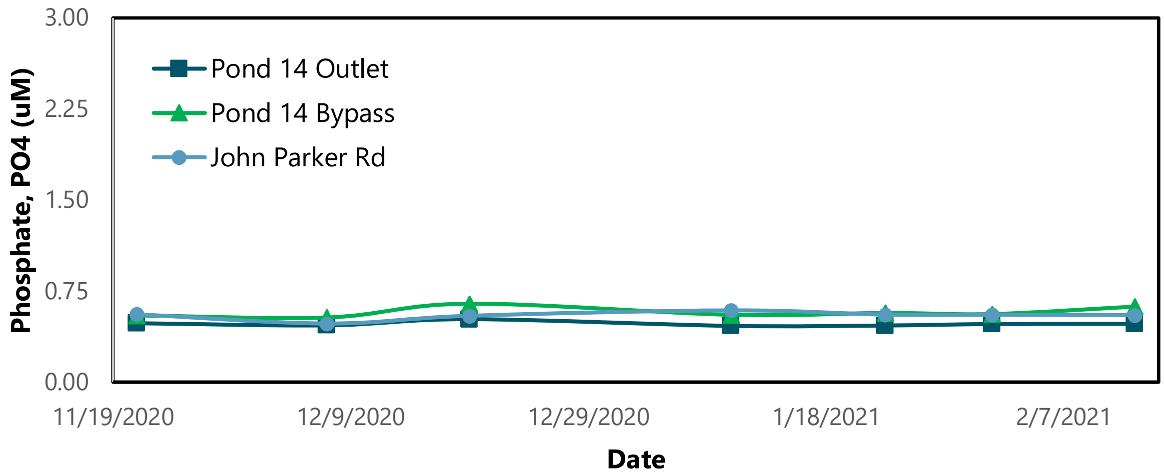
2.1.1 Coonamessett River

The Coonamessett River is a riverine-wetland system extending approximately six miles from Route 151 south through the Coonamessett Pond to the Great Pond estuary. The Coonamessett River is strongly influenced by regional groundwater. The river is underlain by thick deposits of glacial outwash and gravel sediments that are highly porous and permeable to groundwater.

Water quality and habitat conditions of the river have been significantly affected by human uses and development. The freshwater (catadromous) fishery declined as development increased and water quality conditions declined. The river became a popular angling destination for anadromous species such as herring and sea-run brook trout that spend most of their lives in the marine environment. Conversion of natural wetland areas along the river into cranberry bogs, coupled with construction of dams to regulate water flow to these bogs, led to further habitat loss.

The Coonamessett River Restoration Project began in October 2017 with a long-term goal of improved water quality of the river and its riparian wetlands. The project began systematic monitoring of biological, chemical, and physical characteristics of the river including nutrient concentrations along the river (phosphate concentrations are displayed in Figure 2). Note that Parker Road Pond (Pond 14), was included as part of the Coonamessett River in the analyses and discussion that follow.

Figure 2
Coonamessett River, Phosphate Concentrations

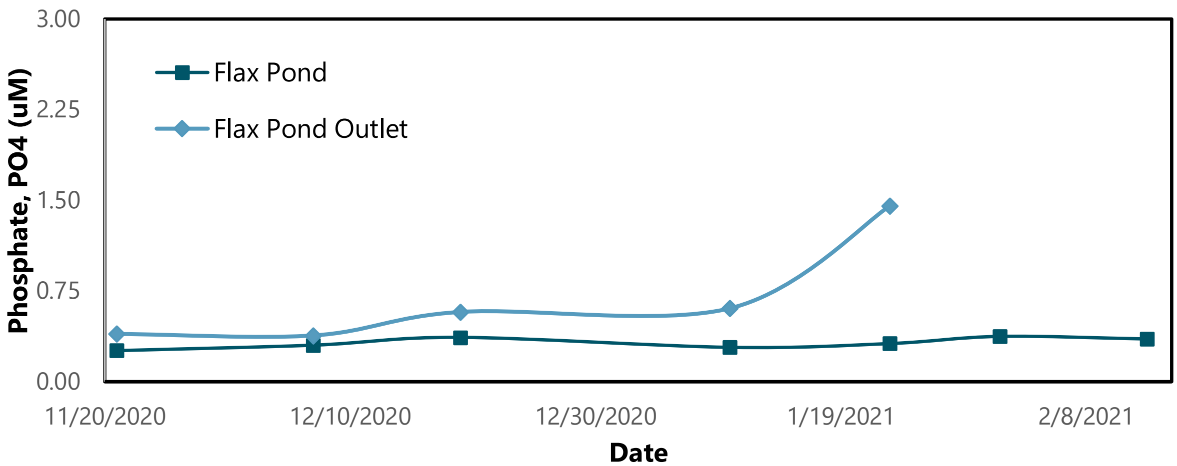


Source: Chris Neill, Coonamessett River Project

2.1.2 Flax Pond

Flax Pond is a small natural kettle pond with a maximum depth of 8.4 m. The 1.1 miles of shoreline are undeveloped and protected by the pond's location within Nickerson State Park. Flax Pond was monitored as part of the Coonamessett River Restoration Project from November 2020 to February 2021. As shown in Figure 3, Flax Pond exhibited an average phosphate concentration of 0.32 µM at its center and a slightly higher concentration at the outlet (note that the outlet was not sampled as part of the two most recent sampling events).

Figure 3
Flax Pond, Phosphate Concentrations



Source: Chris Neill, Coonamessett River Project

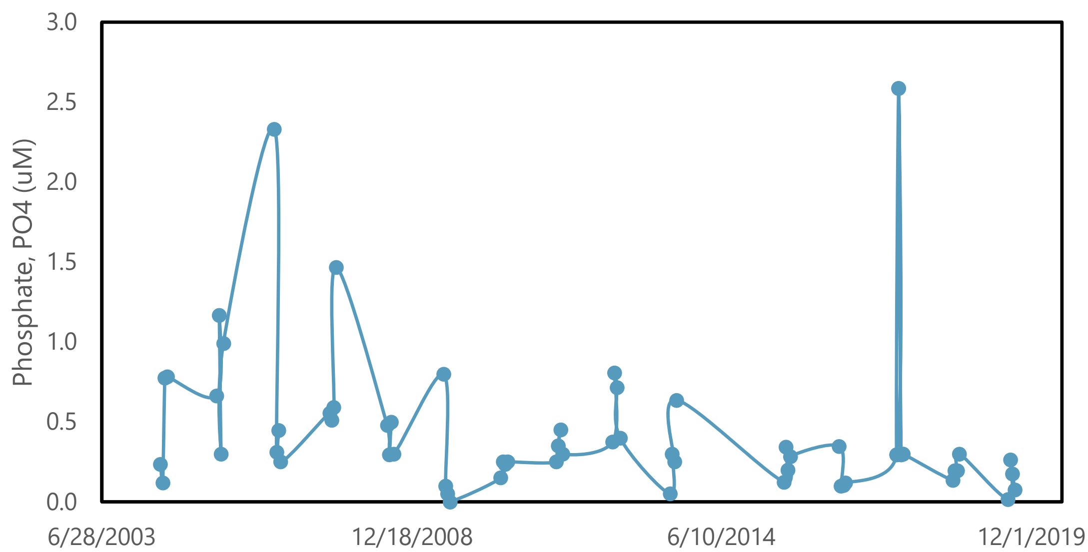
A member of the GHD project team collected a total phosphorus (total P) sample from Flax Pond in May 2021. A surface sample was collected at 0.5 m depth prior to the onset of thermal stratification. The spring total P concentration was reported at 0.015 mg/L.

2.1.3 Backus Brook

Backus Brook flows through 52 acres of cranberry bogs before entering Mill Pond. Backus Brook contributes 90% of Mill Pond's water volume (Unruh *et al.*, 2018). Streamflow varies throughout the year due to cranberry bog flooding practices. The cranberry bogs are a potentially significant source of phosphorus to Backus Brook, particularly during rain events that follow fertilizer application.

Backus Brook was monitored as part of the Pond Watch monitoring program. Phosphate concentrations averaged around 0.5 µM from 2004-2019; the data are variable, as shown in Figure 4.

Figure 4
Backus Brook, Phosphate Concentrations, 2004-2019



Source: Howes, B.L., R. Samimy, D. Goehringer, S. Sampieri. Synthesis of Falmouth Pond Watch Water Quality 2004-2019. UMASS Dartmouth.

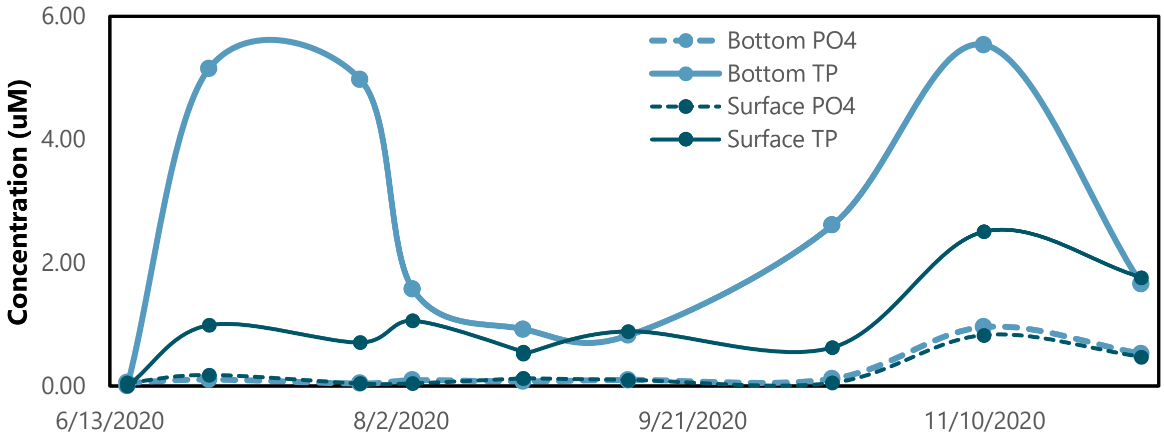
2.1.4 Mill Pond

Mill Pond is a constructed freshwater pond that discharges to the headwaters of the Green Pond estuary. This 16-acre freshwater pond exhibits signs of severe habitat impairment, including over-abundance of aquatic plant growth, periodic oxygen depletion of lower waters, and poor water clarity. These impairments are primarily the result of nutrient loading from watershed sources transported by freshwater tributary inflows. Mill Pond is a phosphorus-limited system, consistent with other freshwater ponds throughout Cape Cod.

In 2018, the nutrient budget and ecosystem health of Mill Pond was examined. This effort was initiated in response to a comprehensive analysis of Green Pond estuary completed as part of the MEP. The Green Pond estuary study identified watershed nutrient loading as a threat to ecosystem integrity.

The focused assessment on Mill Pond's estimated water flux and nutrient loads based on stormwater contribution, land use loading, and inflows from Backus Brook. Average water residence time in Mill Pond is extremely short, estimated to be 7.4 days (Unruh *et al.*, 2018).

Figure 5
Mill Pond, Total Phosphorus and Phosphate Concentrations, 2020



Source: Howes, B.L., 2020. UMASS Dartmouth.

In 2020, UMASS Dartmouth collected samples from both surface water and bottom waters of Mill Pond. The samples were analyzed for total phosphorus and phosphate concentrations. Total P concentrations in surface water samples fluctuated seasonally, increasing during summer months due to increased runoff, decreasing during late summer/early fall as plants and algae grow and assimilate phosphorus, and increasing again as plants and algae approach senescence and phosphorus is released back into the water column. Phosphate concentrations remained stable

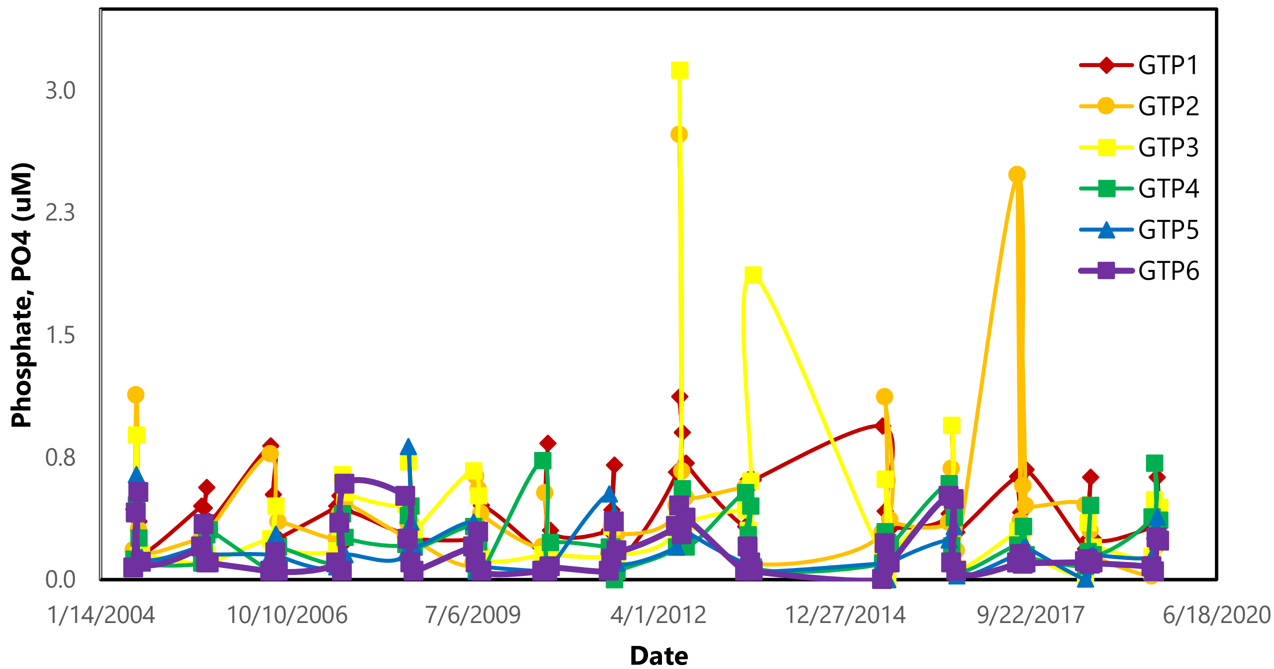
To characterize Mill Pond's ambient Total P concentration, a member of the GHD project team sampled the pond's upper waters in May 2021. The very high Total P result (0.42 mg/L) was likely due to surface vegetation/scum being included in the sample bottle.

2.2 Saltwater Ponds

2.2.1 Great/Perch Pond

The Great/Perch Pond Embayment System is along the southern shore of the Town of Falmouth, MA. Perch Pond is a drowned kettle pond which connects to Great Pond via a narrow tidal channel. Tidal waters enter Great Pond from the Vineyard Sound inlet; freshwater enters through the Coonamessett River and direct groundwater discharge. The primary ecological threat to this system is degradation from nutrient enrichment. The largest source of controllable nutrients in Great Pond is wastewater from on-site septic systems.

Figure 6
Great Pond, Phosphate Concentrations, 2004-2019



Source: Howes, B.L., R. Samimy, D. Goehringer, S. Sampieri. Synthesis of Falmouth Pond Watch Water Quality 2004-2019. UMASS Dartmouth.

Great Pond was sampled from 2004-2019 as part of the Pond Watch Water Quality Program. Samples were taken from several locations throughout the pond (colored lines are different sites). In 2012, 2013, and 2017 there is a substantial increase in phosphate concentrations within two sites of the lake (GTP2 and GTP3). However, phosphate concentrations are generally similar throughout the length of the waterbody and have been relatively steady from 2004-2019, averaging 0.3 µM phosphate.

Table 1
Water Quality of Great Pond

Parameter (2004-2017 Averages)	Value
Total Phosphorus (mg/L)	0.13
Total Nitrogen (mg/L)	0.93
N:P ratio	7.15
Chlorophyll-a (µg/L)	13.26
Secchi Depth (m)	1.02

Parameter (2004-2017 Averages)	Value
Dissolved Oxygen (mg/L)	5.70

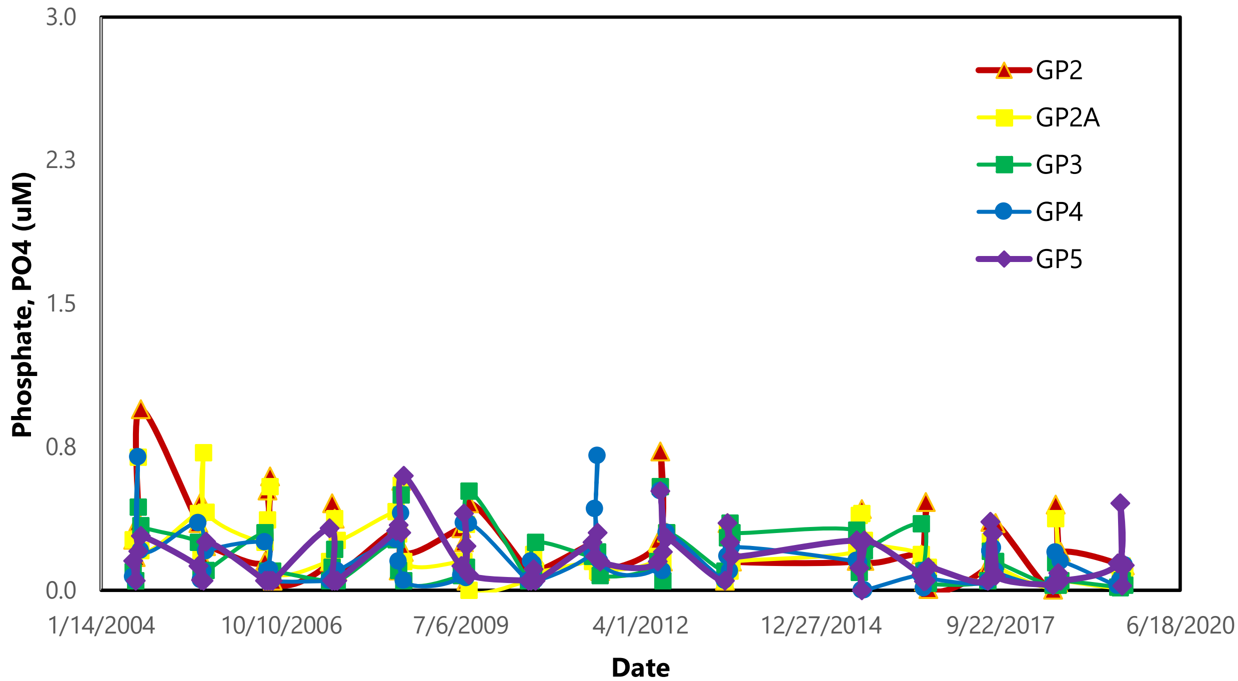
Source: Howes *et al.*, 2019

2.2.2 Green Pond

Green Pond is a coastal embayment that is approximately ¼ mile wide and approximately 2 miles long. The largest source of controllable nutrients in Green Pond is from wastewater from on-site septic systems. From 2015 to 2017, SMAST scientists evaluated nutrient cycling in Mill Pond, which flows into Green Pond. They concluded that Mill Pond attenuates approximately 60% of the upstream nitrogen load and that primary production within this pond is limited by phosphorus, not by nitrogen.

Green Pond was also monitored from 2004-2019 within the Pond Watch Monitoring Program (Figure 6). Samples were taken from several locations throughout the pond (colored lines are different sites). Phosphate concentrations are generally similar throughout the length of the waterbody and have been relatively steady from 2004-2019, averaging 0.2 µM phosphate.

Figure 7
Green Pond, Phosphate Concentrations, 2004-2019



Source: Howes, B.L., R. Samimy, D. Goehringer, S. Sampieri. Synthesis of Falmouth Pond Watch Water Quality 2004-2019. UMASS Dartmouth.

Table 2
Water Quality of Green Pond

Parameter (2004-2020 PALS Averages)	Value
Total Phosphorus (mg/L)	0.10
Total Nitrogen (mg/L)	0.84
N:P ratio	8.4
Chlorophyll-a (µg/L)	14.31
Secchi Depth (m)	1.08
Dissolved Oxygen (mg/L)	6.01

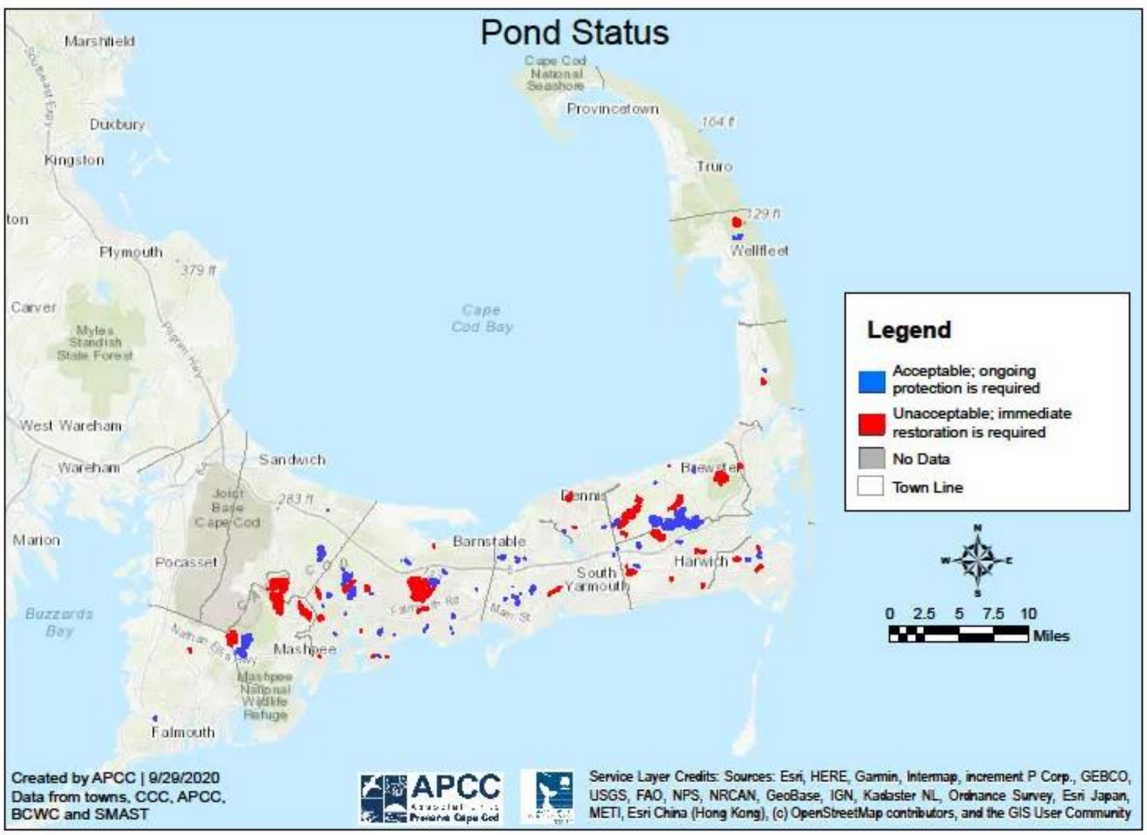
Source: Howes *et al.*, 2019

2.3 Comparison to Ecoregional Ponds

The Association to Preserve Cape Cod (APCC) led an effort to evaluate and report on the 'State of the Waters', designed to help communities understand and interpret pond water quality with respect to trophic state and suitability for recreational uses. The APCC metrics evaluate trophic state using three widely used indicators: total phosphorus, chlorophyll-a, and water transparency normalized on a scale between 0 and 100. Nutrient poor (oligotrophic) ponds score under 40 on this scale, while highly enriched ponds (eutrophic or hypereutrophic) score over 50. Ponds of moderate productivity (mesotrophic) score between 40 and 50. Ponds scoring below 50 are considered “acceptable”; ponds scoring over 50 are considered “unacceptable.” In response to growing concerns regarding public health impacts of cyanobacteria, the APCC modified criteria in 2020 to include this metric, Ponds exhibiting elevated cyanobacterial levels are now considered “unacceptable.” Results of the 2020 assessment are displayed in Figure 7. Note that monitoring data are available for only 15% of ponds on Cape Cod.

In general, ponds in the vicinity of Falmouth exhibited acceptable water quality. Downstream embayments including Great Pond and Green Pond had unacceptable water quality.

Figure 8
Cape Cod Pond Status (APCC, 2020)

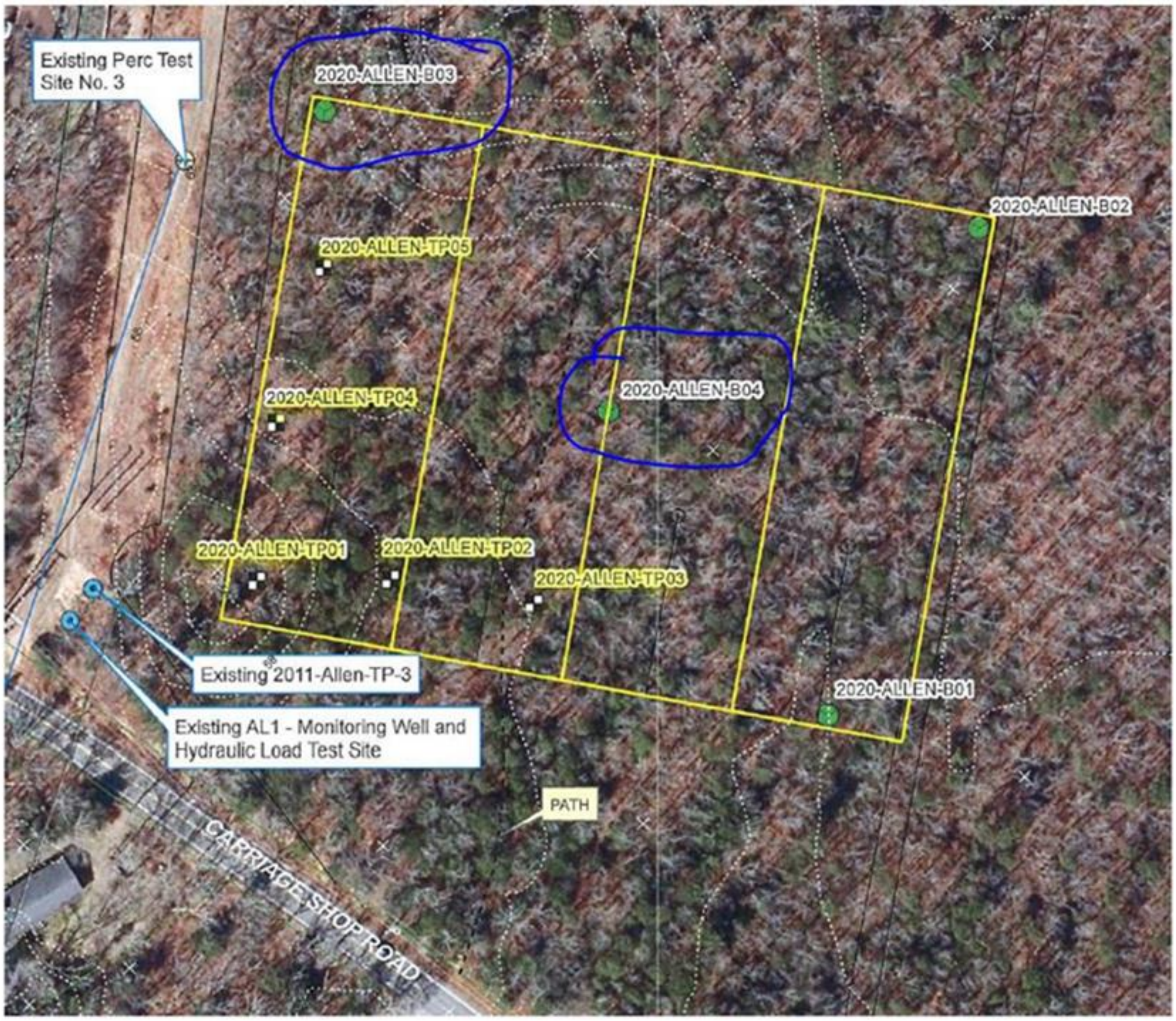


Source: Association to Preserve Cape Cod, 2021.

3 Soil Sampling and Analysis

To characterize the existing physical and chemical characteristics of soils in the vicinity of the Allen Parcel, project team members from GHD obtained soil samples from location B04 at the Allen Parcel and submitted them for laboratory analysis (**Figure 8**).

Figure 9
Allen Parcel, Soil Boring Locations



The yellow outline on **Figure 8** represents the conceptual layout of the open sand beds and groundwater direction is to the south. Three separate composite samples were taken from the boring, one from each soil horizon.

- S1 - Allen B04 (6-8 ft, 8-10 ft, 13-15 ft)
- S2 - Allen B04 (18-20 ft, 23-25 ft, 28-30 ft, 33-35 ft)
- S3 - Allen B04 (38-40 ft, 40-42 ft), from saturated area/groundwater level

The samples were submitted to the Cornell University Nutrient Analysis Laboratory in Ithaca, NY where they were tested for the following parameters:

- Organic matter
- Cation exchange capacity (CEC)
- Elemental analysis: Al, As, Ba, Be, Ca, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, No, Ni, P, Pb, S, Se, Sr, Ti, V, and Zn
- Soil texture (particle size)
- Percent total nitrogen
- Percent total carbon

These parameters were selected following a review of the technical literature regarding factors that affect a soil's capacity to adsorb phosphorus. The results of the soil testing are summarized in **Table 3**. The soils at the Allen Parcel are composed predominantly of sand-sized particles, interspersed with only small amounts of silt and clay-sized particles (less than 4%). The soils are sandy and low in organic matter, consequently resulting in an extremely low cation exchange capacity (CEC). CEC is the total capacity of a soil to exchangeable cations (positively charged ions such as calcium, magnesium, sodium, and potassium); this attraction arises from the presence of negatively charged particles such as clay minerals and organic matter in the soil profile. The CEC influences a soil's ability to hold onto essential nutrients and provides a buffer against soil acidification. Soils with a high CEC tend to be fertile and valued as agronomic resources, allowing for nutrient storage and nutrient availability for plant uptake.

Table 3
Soil Analysis of Boring at Allen Parcel

Parameter	S1	S2	S3
Chemical Characteristics			
Moisture	0.16	0.13	0.13
pH	6.51	6.52	6.17
LOI (%)	0.00	0.10	0.16
Organic matter (%)	0.00	0.00	0.00
CEC (cmolc/kg soil)	0.09	0.09	0.04
Total C (%)	0.21	0.22	0.21
Total N (%)	0.03	0.02	0.03

Parameter	S1	S2	S3
Total Elemental Analysis (extractable in parentheses)			
Aluminum (mg/kg)	513.1 (5.28)	368.2 (5)	425 (4.38)
Arsenic (mg/kg)	0.9	0	0.7
Barium (mg/kg)	2.2	1.7	1.7
Boron (mg/kg)	20.7	12.4	20.2
Cadmium (mg/kg)	0	0	0
Calcium (mg/kg)	23.4 (3.64)	17.6 (4.57)	20.9 (2.33)
Chromium (mg/kg)	1.6	0.8	1.2
Cobalt (mg/kg)	1.1	0.7	0.8
Copper (mg/kg)	1.4 (0.02)	1.1 (0.28)	0.9 (0.19)
Iron (mg/kg)	1940.5 (1.15)	1215.6 (0.88)	2077.6 (0.46)
Lead (mg/kg)	1.7	1.1	1.5
Lithium (mg/kg)	1.4	1.3	1.4
Magnesium (mg/kg)	112.8 (0.78)	82.5 (0.71)	94.7 (0.39)
Manganese (mg/kg)	26 (0.92)	20.3 (0.75)	21.4 (0.34)
Molybdenum (mg/kg)	0.2 (0.00)	0.2 (0.00)	0.2 (0.00)
Nickel (mg/kg)	0.8	0.6	0.7
Phosphorus (mg/kg)	53.5 (0.30)	31.7 (0.32)	50.5 (0.38)
Potassium (mg/kg)	104.1 (0.94)	84.4 (0.75)	91.1 (0.47)
Sodium (mg/kg)	8.7 (6.55)	2.1 (6.08)	2.2 (6.61)
Strontium (mg/kg)	0.9	0.8	0.8
Sulfur (mg/kg)	2.7 (0.58)	1.6 (0.73)	2 (0.66)
Titanium (mg/kg)	27.2	19.2	23
Vanadium (mg/kg)	2.9	1.7	3.6
Zinc (mg/kg)	2.7 (0.01)	1.5 (0.08)	2.1 (0.04)
Particle Size Analysis			
Percent Sand (%)	96.40	96.40	97.40
Very coarse and coarse sands (%)	*61.55*	*60.95*	*62.70*
Medium sands (%)	*23.45*	*24.10*	*24.20*
Fine and very fine sands (%)	*11.85*	*12.25*	*11.35*
Percent Silt (%)	0.60	0.60	0.00
Percent Clay (%)	3.00	2.80	2.60

4 Literature Review

In 2013, EcoLogic completed a literature review to document the processes affecting fate and transport of phosphorus in infiltrated wastewater effluent. The scope of our 2021 assignment included an updated review of any published information and case studies. The overall goal is to inform a semi-quantitative analysis of phosphorus adsorption capacity of soils in the vicinity of the proposed infiltration beds, estimate longevity, and identify downgradient freshwater ponds potentially at risk of eutrophication. Data from Ashumet Pond and other systems document that phosphorus can move with groundwater through the soil matrix and may eventually reach surface water receptors. As discussed above, kettle ponds are uniquely vulnerable due to their hydrology.

4.1 Wastewater Phosphorus

Wastewater phosphorus is present in various forms. Phosphorus chemistry in wastewater treatment and in the subsurface environment is governed by physical, chemical, and (at times) biological processes. Typically, phosphorus is classified as dissolved (soluble) or particulate (organic or inorganic). Dissolved phosphorus may be referred to as soluble phosphorus, while particulate phosphorus is also termed suspended phosphorus. The sum of dissolved and particulate is equal to total phosphorus (Total P).

During wastewater treatment, bacteria break down organic compounds, converting some organic P to inorganic P and releasing orthophosphate (PO_4^{-3}). This dissolved fraction of phosphorus can be transported through the subsurface environment. Orthophosphate contains a negative charge in solution allowing it to bind to positively charged ions in solution and to anion exchange sites on soil particles. Some phosphorus remains associated with very small particles (colloidal), both organic and inorganic, which may also be mobile in the subsurface environment, depending on the nature of the soil porosity, texture, and organic matter content.

Although most phosphorus in treated wastewater is dissolved orthophosphate, regulatory limits on effluent discharges are typically reported as Total P. The Falmouth Wastewater Treatment Facility (WWTF) reported an average effluent Total P concentration for 2016-2020 of 3.14 ± 2.67 mg/L.

4.2 Phosphorus Fate in the Subsurface

The environmental fate of phosphorus from a wastewater infiltration site is a function of the soil's capacity to immobilize the dissolved fraction and retain the particulate fraction of phosphorus. Adsorption mechanisms and mineral precipitation are the dominant chemical processes governing phosphorus migration and retardation in groundwater.

Adsorption is the mechanism by which cations and anions (including phosphate (PO_4^{-3}) are retained by soil particles. This process removes phosphorus from solution, restricts its mobility in the subsurface environment, and decreases its bioavailability. The factors with the greatest effect on soil's adsorption capacity include texture (particle size distribution), mineral content, pH, cation exchange capacity, oxygen availability, and ambient phosphorus concentrations.

However, adsorption may be only a temporary fate of phosphorus due to changes in soil chemistry over time (Schellenger and Hellweger, 2019). Surface adsorption is limited by a fixed availability of sorption sites in a particular soil that will eventually be used up; at that point, the soil has reached its capacity to retain/retard phosphorus migration. Changes in pH, oxygen availability and the passage of time may result in adsorbed phosphorus being rereleased into the groundwater through a process called desorption.

Precipitation occurs when dissolved phosphate (PO_4^{-3}) ions interact with positively charged ions (such as aluminum, iron, calcium, or manganese), precipitate, and settle out of solution. Research suggests that the dominant phosphorus minerals in the subsurface are iron and aluminum precipitates; stability of these minerals is influenced by pH, redox conditions, temperature, and the supply of cations (Lombardo Associates, 2006). Phosphorus precipitated from solution tends to remain held in the soil complex. The only mechanism for dissolution is slow weathering of the minerals. Consequently, precipitation can be considered a permanent phosphorus retention mechanism.

Groundwater movement and chemical processes differ depending on depth in the soil profile. The upper, unsaturated zone is the area where pore space is not completely filled with water and contains some air. The pore space in the deeper, saturated zone is completely filled with water. The unsaturated zone is characterized as aerobic while the saturated zone is typically characterized as anaerobic. These conditions affect the processes that govern phosphorus retardation.

After passing through the infiltration beds, applied wastewater effluent will seep into the unsaturated zone and travel downgradient both horizontally and vertically through the unsaturated zone to the groundwater table. Some phosphorus in the applied wastewater will be adsorbed or precipitated within the unsaturated zone depending on soil texture, pH, content of metal hydroxides, and depth of the aquifer. Once effluent has reached the aquifer (saturated zone), the effluent plume will be advected in the direction of groundwater flow and dispersed in all directions. Depending on the soil properties, phosphorus will be retarded by sorption mechanisms (Schellenger and Hellweger, 2019).

As described above, the objective of this assignment is to characterize soil properties at the Allen Parcel and estimate the phosphorus binding capacity of downgradient soils, in both the saturated and unsaturated zones.

4.3 Favorable Conditions for Phosphorus Retention/Retardation

Organic matter in the soil matrix may compete with orthophosphate for binding sites on mineral and soil surfaces, thereby decreasing phosphate adsorption. The Allen Parcel soil sample measured 0% organic matter, indicating that this process is not likely to be significant. The site soils are also oxic (in the unsaturated zone) and slightly acidic. Once sorbed, phosphate ions are retained (i.e., phosphorus desorption rates are slow) under these oxic and slightly acidic conditions. This slow desorption process may extend over decades. Taken together, the conditions of site soils are highly favorable for phosphorus adsorption.

pH influences the solubility of phosphate minerals, the adsorption of phosphate onto mineral surfaces, as well as speciation of the aluminum, calcium, and iron commonly contained in phosphate minerals. Under more acidic conditions, there is an increase in the positive surface charge of iron and aluminum (hydr)oxides, and therefore an increased affinity for phosphate adsorption (Goldberg and Sposito, 1984). In addition, under acidic and oxic conditions, cations (Al^{3+}, Ca^{2+}, and Fe^{3+}) are weathered from the soil. Higher concentration of cations in solution is associated with greater phosphorus retention capacity due to precipitation reactions that establish equilibrium between aluminum-phosphate and iron-phosphate minerals (Lombardo Associates, 2006).

Under oxic conditions in soils with a pH greater than five, aluminum hydroxides (e.g., gibbsite) govern Al^{3+} concentrations, calcite usually controls Ca^{2+} concentrations in solution, and ferrihydrite and goethite control the concentration of Fe^{3+} (Lombardo Associates, 2006). Relevant factors affecting phosphorus retardation in the subsurface environment downgradient of the Allen Parcel are summarized in Table 4.

Table 4
Factors Affecting P Retardation in the Subsurface Environment

Factor	Effect	Implication for Allen Parcel Soils
Soil texture	Silts and clays provide greater surface area for particle adsorption	Sandy soils, less surface area for adsorption
Mineral Content	Soil minerals (e.g., aluminum, iron, calcium, manganese) will form complexes with P and remove it from solution	Soils are moderate in aluminum, calcium, and manganese providing capacity to immobilize P
pH	Slightly acidic conditions enhance adsorption capacity	Soils were slightly acidic (6.17-6.52), regional groundwater pH is slightly acidic, will enhance removal mechanisms

Factor	Effect	Implication for Allen Parcel Soils
CEC	Soils with higher CEC typically have more clay-sized particle which enhance P adsorption	Very low CEC
P Concentration	Higher ambient P concentrations improve adsorption	Treated wastewater P is higher than ambient groundwater concentrations
Thickness of the unsaturated zone and oxygen availability	Greater opportunity for phosphorus immobilization through adsorption and precipitation reactions	Deep unsaturated zone (greater than 20 m), large, oxygenated soil prism available for reactions that immobilize P

5 Testing Scenarios

The retention of phosphorus downgradient of the wastewater infiltration system is a function of the volume of soil to which the infiltrating treated wastewater effluent is exposed (the soil prism), the mass and concentration of phosphorus present in the wastewater, the rate of infiltration and groundwater flux, and the adsorptive capacity of the soil prism.

5.1 Retention Capacity Calculations

An empirical model was used to estimate the phosphorus retention capacity of the soil. The model projections are primarily driven by the amount of reactive aluminum present in the soils and the downgradient prisms through which the applied effluent will migrate. GHD identified two effluent flow rates to use in the empirical groundwater modeling scenarios: 0.5 million of gallons per day (MGD), and 1.03 MGD. Other model input parameters are summarized in Table 5.

Table 5
Model Input Parameters and Results

Input	Scenario 0.5	Scenario 1.03	Source or Calculation
P Loading Characteristics			
Proposed volume of infiltrated wastewater at Allen Parcel (MGD)	0.5	1.03	GHD Scenario Proposal
Proposed volume of infiltrated wastewater at Allen Parcel (L/d)	1,892,705.892	3,898,974.138	GHD Scenario Proposal (unit conversion)
Current effluent concentration (mg/L)	3.14	3.14	Falmouth WWTF (WWTF eff flow N-P.xlsx)

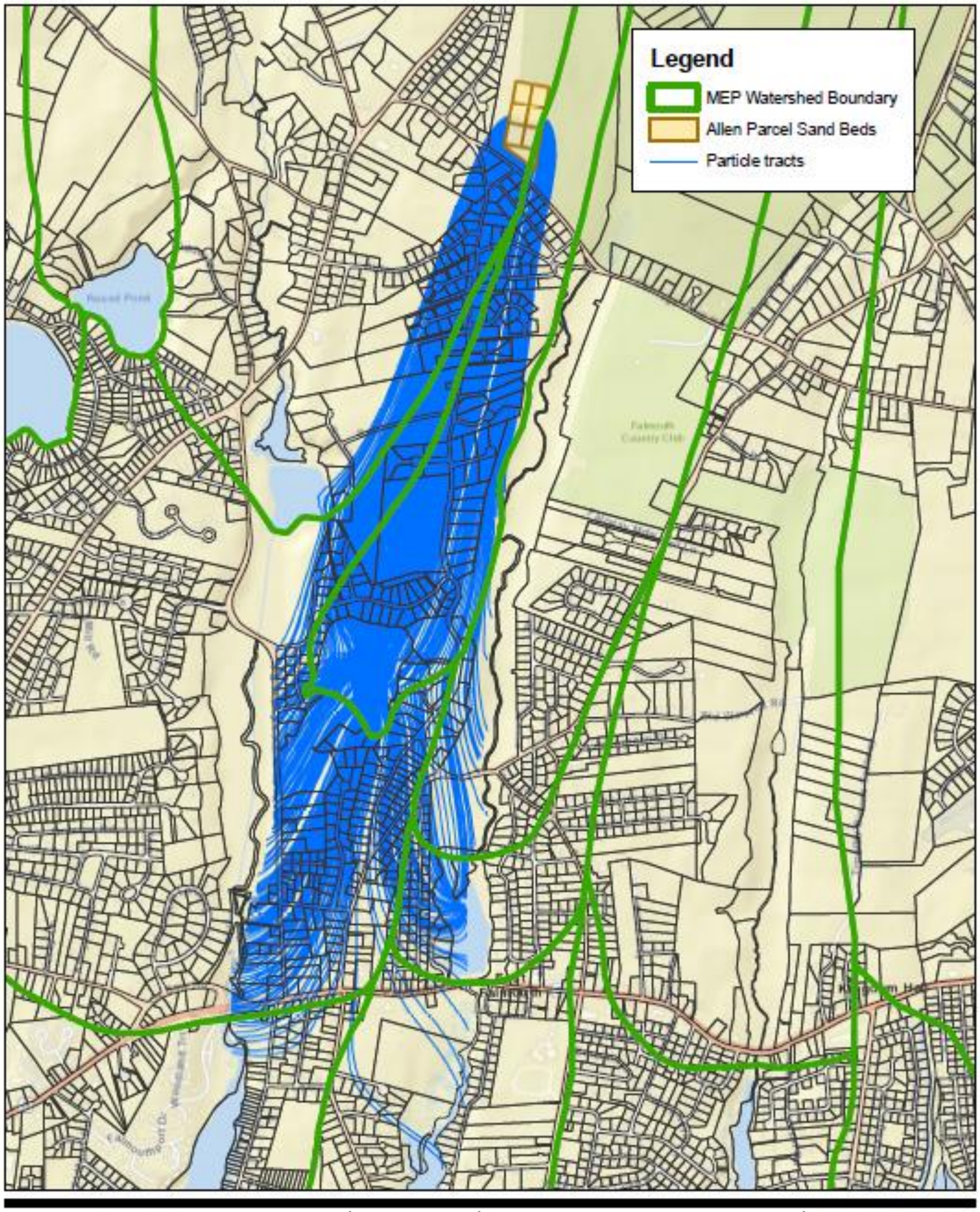
Input	Scenario 0.5	Scenario 1.03	Source or Calculation
Estimated TP load at 3.14 mg/L (kg/yr)	2,169	4,467	Proposed volume of infiltrated wastewater at Allen Parcel * Projected Effluent concentration * 365 d
Soil Characteristics			
Soil Porosity (g/cm^3)	1.6	1.6	Average bulk density based on soil texture data
Al content of unsaturated soils (mg/kg)	513	513	Allen Parcel soil boring
Al content of saturated soils (mg/kg)	425	425	Allen Parcel soil boring
% of reactive Al in unsaturated soils (%)	10	10	2013 EcoLogic Report, Crocker Pond
% of reactive Al in saturated soils (%)	5	5	2013 EcoLogic Report, Crocker Pond
Molar ratio of reactive Al to P binding sites (kg P/kg Al)	0.3	0.3	2013 EcoLogic Report, Crocker Pond
Coonamessett River			
% of Plume intercepting CR	57.2	58.3	GHD particle track analysis
Unsaturated prism (m^3)	7,020	44,337	GHD calculation
Saturated prism (m^3)	5,147,762	13,095,228	GHD calculation
Capacity of unsaturated zone to sequester P (years)	0.14	0.42	Bound P to Al in unsaturated soil / Estimated TP load
Capacity of saturated zone to sequester P (years)	42.32	51.27	Bound P to Al in saturated soil / Estimated TP load
Flax Pond			
% of Plume intercepting FP	68.2	41.4	GHD particle track analysis
Unsaturated prism (m^3)	110,898	171,287	GHD calculation
Saturated prism (m^3)	17,281,187	17,487,400	GHD calculation

Input	Scenario 0.5	Scenario 1.03	Source or Calculation
Capacity of unsaturated zone to sequester P (years)	1.85	2.28	Bound P to Al in unsaturated soil / Estimated TP load
Capacity of saturated zone to sequester P (years)	119.15	96.42	Bound P to Al in saturated soil / Estimated TP load
Mill Pond			
% of Plume intercepting MP	23.5	16.4	GHD particle track analysis
Unsaturated prism (m^3)	18,000	25,045	GHD calculation
Saturated prism (m^3)	13,215,550	12,760,865	GHD calculation
Capacity of unsaturated zone to sequester P (years)	0.87	0.84	Bound P to Al in unsaturated soil / Estimated TP load
Capacity of saturated zone to sequester P (years)	264.43	177.61	Bound P to Al in saturated soil / Estimated TP load
Backus Brook			
% of Plume intercepting BB	8.3	18.2	GHD particle track analysis
Unsaturated prism (m^3)	13,445	51,943	GHD calculation
Saturated prism (m^3)	7,209,548	11,881,309	GHD calculation
Capacity of unsaturated zone to sequester P (years)	1.84	1.57	Bound P to Al in unsaturated soil / Estimated TP load
Capacity of saturated zone to sequester P (years)	408.44	149.01	Bound P to Al in saturated soil / Estimated TP load

5.2 Phosphorus Sequestration Capacity

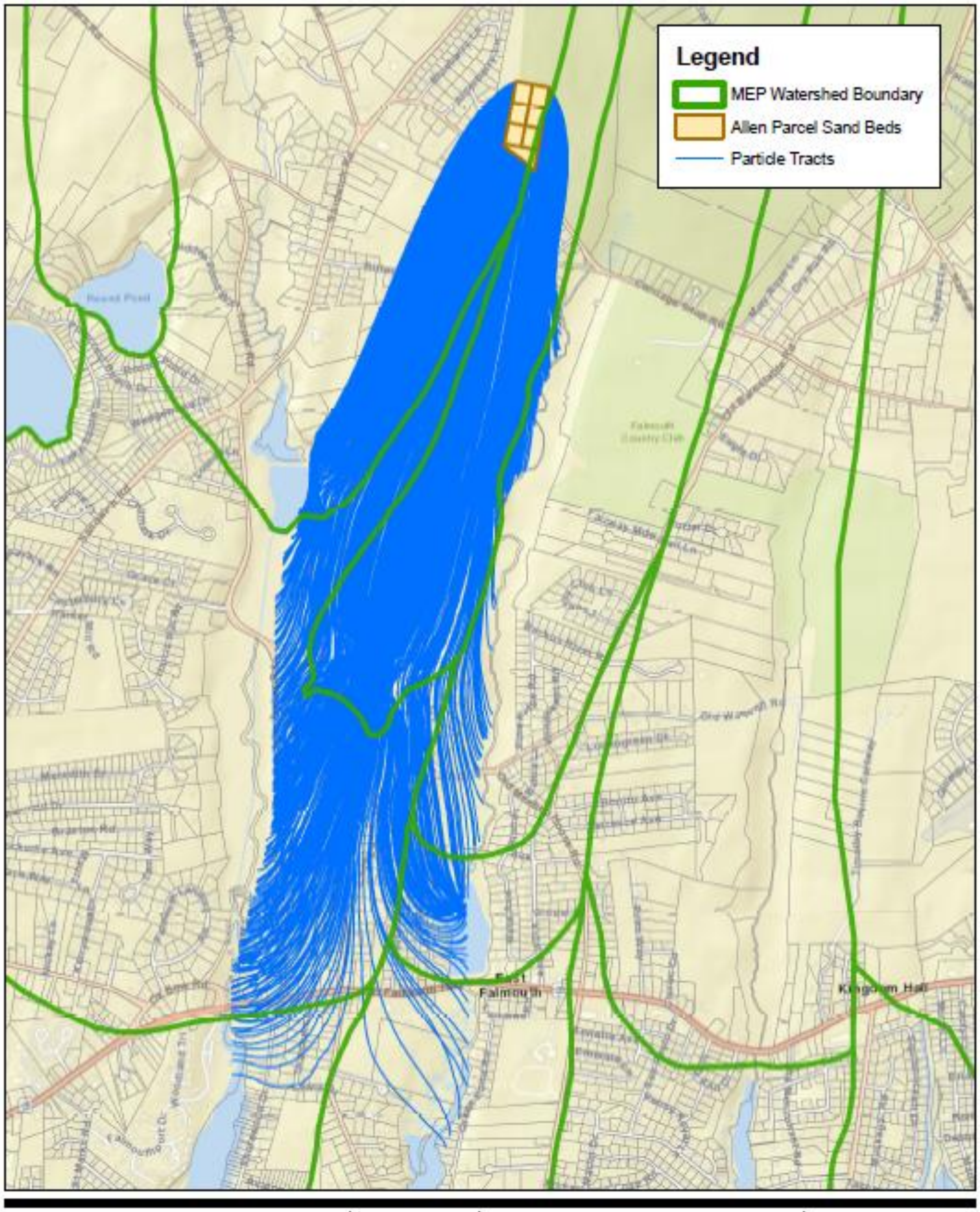
The volume of soil interacting with the infiltrating wastewater plume (the soil prism) can be estimated using various assumptions. For this assignment, the volume of the soil prism was estimated based on the groundwater model's projected flow path of treated wastewater toward each waterbody using a particle track analysis. The results of each particle track analysis are shown in **Figures 9** and **10**.

Figure 10
Particle Track Analysis, Scenario 0.5 MGD



Source: GHD

Figure 11
Particle Track Analysis, Scenario 1.03 MGD



Source: GHD

A soil prism volume was estimated for each scenario. The soil prism calculation incorporates the three dimensions (depth of vertical penetration, lateral plume width and horizontal distance to each waterbody). The soil prism was multiplied by the soil's bulk density (1.6 x 106 g/cm3) to estimate the mass of soil within the flow path of the infiltrating wastewater plume. We estimated the phosphorus sequestration capacity using site-specific data (aluminum content), aluminum reactivity, and the mass of soil to calculate potential phosphate binding sites. The soil prism was divided into its saturated and unsaturated zones which gives recognition to the different processes that govern phosphorus sequestration. The results of this calculation for each waterbody are provided in **Table 5**.

The potential contributions of other reactive minerals that play a role in phosphorous sequestration (notably iron and manganese) are not included in the model calculations. Inclusion of these other minerals would increase capacity even further.

5.3 Sensitivity Analysis

There are numerous assumptions that affect the calculated phosphorus binding capacity downgradient of the Allen Parcel. Because the model is largely dependent on soil aluminum content, the analysis was performed by altering the aluminum content. To ensure that the sensitivity analysis is based on relevant environmental conditions, the lowest aluminum content from soil borings at the Allen Parcel was used (368.2 mg/kg). Results of the sensitivity analysis for each waterbody are provided in **Table 6**.

Table 6
Sensitivity Analysis Results

Input	Scenario 0.5	Scenario 1.03
Soil Characteristics		
Al content of unsaturated soils (mg/kg)	368.2	368.2
Al content of saturated soils (mg/kg)	368.2	368.2
Coonamessett River		
Capacity of unsaturated zone to sequester P (years)	0.10	0.30
Capacity of saturated zone to sequester P (years)	36.66	44.42
Flax Pond		
Capacity of unsaturated zone to sequester P (years)	1.32	1.64
Capacity of saturated zone to sequester P (years)	103.22	83.53

Mill Pond		
Capacity of unsaturated zone to sequester P (years)	0.62	0.60
Capacity of saturated zone to sequester P (years)	229.09	153.87
Backus Brook		
Capacity of unsaturated zone to sequester P (years)	1.32	1.13
Capacity of saturated zone to sequester P (years)	353.85	129.10

6 Discussion: Other Factors

In addition to the assumptions embedded in the calculations of phosphorus binding capacity, there are several additional factors that affect the precision of the model predictions related to the magnitude, time scale, and ecological significance of phosphorus migration from the proposed infiltration beds at the Allen Parcel to each waterbody.

6.1 Soil Prism Volume Estimations

The soil prism volume (the volume of soil that the infiltrated wastewater flows through) is used in the model to estimate the mass of soil and phosphorus binding sites present. The soil prism volume may vary in depth or horizontal spread which can alter the percentage of the plume that flows to and through each waterbody. This affects the estimation of the total phosphorous sequestration capacity.

It is possible that the infiltrated wastewater may migrate deeper through the subsurface and reach an elevation below the depth of the waterbodies. Some waterbodies, particularly Mill Pond (1.25 m deep) and Flax Pond (8.4 m deep) are shallow. Because the ponds downgradient of the Allen Parcel are kettle ponds with no defined inlet streams, groundwater is the primary source of water along with limited direct precipitation onto the pond surface.

The depth to groundwater at the Allen Parcel boring was estimated at 36 ft (11 m). The proposed infiltration beds at the Allen Parcel may raise the groundwater table downgradient of the Allen Parcel. Wastewater typically has a higher density than natural groundwater due to the presence of dissolved salts. Therefore, once the infiltrated wastewater seeps to the depth of groundwater flow, the wastewater is expected to flow at a greater depth and may not affect the surface water quality of some ponds.

6.2 Wastewater Effluent Loading

Treated wastewater from the Falmouth WWTP varies seasonally in both volume and phosphorus concentration. The calculations of phosphorus retention capacity assumed constant application of average TP effluent concentrations as reported from 2016-2020. The combination of seasonal changes in loading and pulsed application to the various infiltration beds likely represents another 'margin of safety' in terms of phosphorus sequestration capacity of downgradient soils. Intermittent applications enable the groundwater table to experience fluctuations in water level, which can affect redox status and adsorption.

6.3 Critical Loading to Downgradient Waterbodies

Phosphorus is the nutrient of greatest concern for managing eutrophication of the inland freshwater kettle ponds of Cape Cod. Because groundwater is the primary water supply to to kettle ponds, groundwater phosphorus concentration directly affects water quality and aquatic habitat. Each pond has a loading rate threshold that will maintain water quality conditions at an acceptable baseline. Quantification of the loading rate that will allow maintenance of acceptable water quality and habitat conditions is the focus of research and management. Aquatic systems are often monitored to develop a relationship between watershed activities and nutrient loading, and the relationship between loading and resulting water quality conditions. Water quality models are a tool to help quantify this relationship and provide a framework for testing the efficacy of control measures

Planning and water quality management is a systematic process that involves several aspects, as outlined below.

- Characterization of existing water quality and habitat conditions
- Pollutant and pollutant source identification
- Identification of water quality goals
- Quantification of acceptable nutrient loads and source contribution
- Strategy development for source reductions to meet water quality goals

On Cape Cod, nutrient management planning has focused on reducing nitrogen export to coastal estuaries and meeting limits of nitrogen Total Maximum Daily Load (TMDL) allocations. Currently, Massachusetts has no promulgated numerical standards for phosphorus concentrations in freshwater ponds. This limits a quantitative analysis of potential water quality impacts of infiltrating wastewater on downgradient waterbodies. However, a qualitative analysis can be drawn from current conditions, estimated phosphorus loading, the capacity of the aquifer to sequester phosphorus, and the estimated time for phosphorus to reach downgradient waterbodies.

If the phosphorus sequestration capacity of the upper unsaturated zone becomes depleted over time, the saturated zone will provide additional binding sites to retard phosphorus transport through the groundwater. Water recharging the aquifer dilutes the wastewater plume which affects phosphorus equilibration The depth of the wastewater plume affects the risk of intercepting downgradient kettle ponds as well. Finally, alum treatment programs have been demonstrated to be an effective remedial strategy for kettle ponds affected by excessive phosphorus loading (Wagner et al. 2017).

Based on conservative calculations of phosphorus sequestration, it is estimated that the proposed expanded use of the infiltration beds at the Allen Parcel will not cause or contribute to water quality degradation of downgradient waterbodies. The soils have a large capacity to retard migration and sequester phosphorus. Conservative estimates indicate that the soils between the Allen Parcel sand beds and the closest waterbody, the Coonamessett River, have adsorptive capacity of at least of 36 years. The kettle ponds are estimated to have an adsorptive capacity of over 100 years. Note that these estimates do not reflect any impact of future treatment technologies to further reduce effluent phosphorus concentrations.

7 Recommended Monitoring Program

It is recommended that a baseline water quality and aquatic habitat assessment of each downgradient waterbody be completed before use of the proposed infiltration sand beds at the Allen Parcel. Annual monitoring will characterize current water quality conditions and be used to document year-to-year variability that will help differentiate trends from natural variations. Further, it is recommended that the Town document land use and land cover changes, including impervious surfaces within the watershed to help identify potential pollutant sources.

Table 7
Recommended Long-Term Monitoring Program

Parameter	Rationale	Sampling Protocol
Water temperature and dissolved oxygen profile	Aquatic habitat, evidence of DO depletion	Sample at 1 m intervals at deepest point in pond in summer months (June-Sept)
Nearshore (littoral zone) habitat plant community, algal abundance, sediment types	Establish baseline, consider whether recreational access is impaired	Single survey, July

Parameter	Rationale	Sampling Protocol
Trophic state parameters: total P, total N, chlorophyll-a, secchi disk transparency	Baseline productivity level	Two depths: surface and deep. Sample in summer months (June-September)
Current recreational access points and protected lands	Document how the resource is used	Field observations and mapping
Septic systems within 300 ft. of waterbodies	Estimate potential for phosphorus contribution from septic systems	Field observations and mapping
Land use and impervious surfaces in watershed	Estimate potential for phosphorus contribution from stormwater	Field observations and mapping

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