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Memorandum

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Subject	**Town of Orleans, MA** **Water Quality and Wastewater Planning** **Task Number 10.1.B.2 – NT Demonstration Projects** **Technical Memorandum for Landfill Nitrogen Field Investigation Phase 2 Report-Draft**
Project Number	60476644
From	Thomas Parece, P.E., AECOM Project Manager
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Approvals	Date	Signature / Initials
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1. Introduction

This Phase 2 Technical Memorandum summarizes information regarding assessment activities implemented January through May 2017 at the Orleans Municipal Landfill and former septage lagoons (the landfill) to investigate nitrogen sources and nitrogen compounds in groundwater. The Phase 2 Technical Memorandum supplements investigation results reported in the Phase 1 Technical Memorandum dated June 30, 2017, by reporting the results of additional investigation and identifying potential corrective actions to address nitrogen sources and transport in groundwater. The landfill is located in the Town Cove/Nauset Marsh Estuarine System watershed. This investigation was implemented in conjunction with an investigation of 1,4-dioxane in groundwater at the landfill, which has been documented in a separate Technical Memorandum.

2. Orleans Landfill Site Description and Background

A. Site Description

The landfill consists of approximately 21 acres of Town-owned land located off Lots Hollow Road (Figure 1). The property includes a natural kettle hole that was used for solid waste disposal from the 1950s until 1991. The unlined solid waste fill area was closed and a 13-acre area was capped with a final cover system at a maximum elevation of approximately 110 feet above mean sea level (MSL) in 2005. The landfill property also includes an active solid waste transfer station and yard waste composting and stockpile area (Figure 2). The yard waste composting area is in part located on a land area formerly used for septage waste disposal to lagoons. Six unlined septage lagoons, used between 1950 and 1989, were located just to the north of the capped solid waste area at an approximate elevation of 50 feet above MSL. Landfill drainage from the north side of the landfill and transfer station stormwater is infiltrated along a drainage swale constructed over the former septage disposal area when the landfill was capped in 2005. The septage lagoons were partially excavated to remove sludge, filled and covered with sand in the 1990s. Part of the area over the lagoons has been paved with asphalt (see Figure 2). The landfill property is downgradient and outside the Zone of Contribution of the Town of Orleans public well located to the south. Adjacent properties include the Charles Moore Ice Arena to the west and commercial/industrial properties to the north and east. Plans have been developed for the construction of a new Department of Public Works and Natural Resources facility on portions of the landfill property starting in the fall of 2017.

The landfill cap and associated drainage system was installed in 2005 to cover the solid waste and prevent continued infiltration of precipitation through the waste. The landfill cap system and transfer station stormwater management system are shown on Figure 3.

The landfill cap includes a subgrade of compacted soil materials on top of waste which is overlain by:

- A gas venting layer consisting of a minimum thickness of six inches of soil with a minimum saturated hydraulic conductivity of 1.2×10^{-3} centimeters per second, overlain by;
- A low permeability layer consisting of a 40 mil textured high-density polyethylene geomembrane, flexible membrane liner, overlain by;
- A drainage layer consisting of soil with a minimum thickness of twelve inches and a minimum saturated hydraulic conductivity of 1.2×10^{-2} cm/sec with a perforated pipe subdrain system constructed within the drainage soil that discharges to the stormwater swales, overlain by; and
- A vegetative support layer comprised of a minimum thickness of twelve inches of soil, with a vegetative cover seed mix.

The cover system was completed with a minimum top slope of 5 percent and side-slopes no greater than 3:1. Stormwater runoff controls were constructed to maintain the integrity of the final cover, prevent ponding of water on areas of the final cover, and to control stormwater runoff to prevent off-site flooding impacts. The current stormwater control system includes a perimeter swale around the entire landfill and a 108,000 cubic foot (808,000 gallon) capacity retention basin located in the northeast corner of the site. The retention basin, also known as the infiltration pond, includes a sediment forebay and was designed to fully control the twenty-five year storm event prior to discharge through an emergency spillway. Stormwater system modifications are planned for implementation during construction of the new DPW facility at the landfill. These modifications include constructing new stormwater infiltration ponds.

B. Background

Nitrogen compounds (total nitrogen, nitrate, and ammonia) have been detected at significant concentrations in groundwater immediately downgradient of the landfill and former septage lagoons. The Barnstable County Health Department (BCHD) conducts semi-annual groundwater sampling events on behalf of the Town of Orleans. Until recently the nitrogen analyses were limited to nitrate. The highest nitrate concentrations in the long term data set have been observed since the landfill was capped in 2005. Long term monitoring of four monitoring wells (MW-1S, MW-2S, MW-2D, and MW-5S) indicates groundwater nitrate concentrations greater than the Massachusetts Maximum Contaminant Limit of 10 mg/L, with a maximum concentration of 40 mg/L observed at monitoring well 2S. Landfill monitoring wells were first tested for total nitrogen in May of 2015. Results of testing indicated that total nitrogen concentrations were significantly higher than nitrate concentrations in some of the deeper wells, while nitrate was approximately equal to total nitrogen in shallow wells (data not shown). The 2015 sampling events did not quantify ammonia. However, the significant difference between the concentration of total nitrogen and nitrate in some of the samples was likely due to the presence of ammonia. Groundwater analyses in 2016 confirmed the presence of ammonia (ammonium ion) in deep groundwater that generally accounts for the difference between total nitrogen and nitrate concentrations.

3. Landfill Groundwater Monitoring Well Network

The following groundwater monitoring wells were in place prior to this assessment:

- MW-1S and 1D on the west side of the landfill property;
- MW-2S and 2D to the north;
- MW-3S and 3D to the east;
- MW-4S and 4D to the south;
- MW-5S and 5D to the northeast; and
- MW-E6B and E6A to the north.

Monitoring well installed prior to this investigation were renamed and identified with a naming convention that included the former name (e.g. MW-2S), and the projected depth interval in feet below ground surface for the screened interval (e.g. MW-2S (84-94). New monitoring wells installed by AECOM used the same naming convention.

Four of the shallow landfill water table monitoring wells originally identified as MW-1S through MW-4S, were installed in 1992 as part of an assessment associated with the septage lagoon closure. Deeper screened monitoring wells originally identified as MW-1D, MW-2D, MW-3D, and MW-4D) were installed as part of the 1994 landfill Comprehensive Site Assessment, completing the well couplets at these locations. One additional couplet (MW-5S and MW-5D) was also installed in 1994. Monitoring well couplet MW-E6B and MW-E6A was installed by AECOM in 2016 for nitrogen assessment.

4. Initial Conceptual Site Model Prior to the Current Assessment

A. Conceptual Site Model

A Conceptual Site Model is a tool used to provide a framework of information to help understand and communicate what is known about a potential problem, visualize available information, identify gaps in data, and prioritize response actions. The following paragraphs provide a narrative version of the CSM for the landfill concerning potential sources of nitrogen and nitrogen in groundwater.

B. Conceptual Site Model - Potential Sources of Nitrogen in Groundwater

Municipal operations at the landfill started in the 1950s. Operations included disposal of septic tank and cesspool waste to septage lagoons until 1989 and solid waste disposal until 1991. Periodically during operations and at closure septage sludge was excavated from the lagoons with material disposed in the solid waste landfill and other unknown areas on and off the landfill property. The remaining mass of nitrogen in the former septage lagoon soil is unknown. Current operations include a transfer station and stockpiling and composting of yard wastes. All these operations may have released nitrogen in the past or may be continuing to release nitrogen compounds to groundwater. The solid waste landfill was capped with an impermeable cover in 2005, reducing the infiltration of water through solid waste material. While the cap minimizes infiltration, the landfill is expected to generate leachate that will infiltrate to groundwater as the landfill settles over time. Drainage structures constructed to manage runoff from the western and northern side of the cap include an unlined rip rap swale that passes directly over part of the former septage lagoon area. This unlined swale allows a portion of the runoff to infiltrate to groundwater along the swale while the remainder drains to the infiltration pond located further to the east beyond the former septage lagoon area. The runoff from the landfill cap infiltrating through the former septage lagoons area may be intensifying the release of nitrogen compounds from residual material in the former septage lagoons. Leachate from compost operations and stormwater runoff from the transfer station is also infiltrated in the vicinity of the former septage lagoons.

C. Conceptual Site Model - Groundwater Flow and Potential Contaminant Transport

Nitrogen compounds are soluble in groundwater and mainly found in the form of nitrate and ammonium cation, the ionized form of ammonia dissolved in groundwater. Nitrate is generally transported with groundwater flow by advection with little retardation. Ammonium however is likely to be transported at less than the rate of groundwater flow due to physical and biogeochemical processes. Studies conducted at the United States Geological Survey (USGS) Cape Cod Tracer Test Site located on a wastewater plume in Falmouth, MA found that ammonium was moving downgradient at a rate about 0.25 times the groundwater velocity (Bohlke, 2006). There is also a potential for natural attenuation of nitrogen compounds under specific conditions. Under aerobic groundwater conditions ammonia may be converted to nitrate. In the presence of sufficient carbon, nitrate may be attenuated to nitrogen gas under anoxic denitrifying conditions.

Regional groundwater contour maps prepared by the USGS with the Cape Cod Commission and previous assessment reports associated with the landfill indicate groundwater flow to the north northwest, north, and northeast toward Town Cove (Walter et. al., 2004 and Coastal Engineering, 1999).

Boring logs for landfill monitoring wells show subsurface sediments that consist of glacial outwash sands and gravel with thin layers of more silty sand, silt and clay. The depth to groundwater varies significantly with location due to land surface elevation differences associated with the topography of the kettle hole.

Groundwater elevation measurements, characterization of the aquifer sediments, and aquifer tests were used by Coastal Engineering to estimate groundwater velocity and flow direction in the vicinity of the landfill (Coastal Engineering, 1999). The hydraulic conductivity of aquifer materials was determined from aquifer testing using slug tests at various locations. The hydraulic conductivity determined at shallow screen locations ranged from 5.6 feet/day at MW-1S to 70.88 feet/day at MW-2S. In general, a higher hydraulic conductivity indicates the potential for faster groundwater flow, depending on the gradient. The hydraulic conductivity determined at deeper screen locations ranged from 14.14 feet/day at MW-3D to 147.74 feet/day at MW-1D (Coastal Engineering, 1999). The method used to test hydraulic conductivity provided information for the immediate vicinity of well screens and may not be representative of the full groundwater flow system.

The slope of the potentiometric surface (the water table) derived from water elevation measurements were used to determine the hydraulic gradient and flow direction. According to the Comprehensive Site Assessment prepared for landfill closure by Coastal Engineering in 1999, there is the potential for divergent flow (groundwater flow in more than one direction) from the landfill area. The shallow screen wells indicated a gradient of 0.012 to the northeast while deeper screen wells showed variation in flow direction including flow to the north and north northwest. Measurements indicated an average gradient of 0.003 to the north and 0.0006 to the northwest respectively. The 1990s data also indicated vertical gradients at all monitoring well couplets (downward at MW-1, MW-2, MW-3, and MW-4 and upward at MW-5). The variation in the vertical gradient and divergent groundwater flow direction could be the due to local mounding effects from stormwater, differences in sediment permeability, and the location of the landfill in a recharge area of the groundwater system. A downward vertical gradient indicates groundwater flow deeper into the aquifer. The porosity was estimated by Coastal Engineering at 0.30 from soil samples collected during soil boring installation. Based on these data, Coastal Engineering calculated the horizontal groundwater velocity at a range of 0.029 feet/day to 2.84 feet/day. Due to heterogeneities in aquifer material, layers with faster and slower groundwater flow are expected throughout the vertical thickness of groundwater affected by the landfill.

The groundwater velocity estimate is also highly variable from point to point horizontally, and can be expected to vary along the long flow path from groundwater recharge to surface water discharge. Slower flow is more likely in low permeability silty sand layers as compared to groundwater in more permeable medium sand layers. Town Cove is located approximately 5,450 feet downgradient on a heading of approximately 40 degrees northeast. The travel time for groundwater from the landfill to Town Cove has been estimated to range up to 50 years (USGS, 2004).

D. Conceptual Site Model Initial Contaminant Assessment - Nitrogen in Groundwater

Landfill monitoring well nitrate data has been collected for more than 20 years between September 1994 and March 2016 (Appendix A). The 1990s data (September 1994 through December 2000) were collected during assessments related to closure of the septage lagoons and solid waste landfill. A gap in data collection occurred during the landfill capping operations and semi-annual monitoring conducted by the Barnstable County Health Department was resumed starting in March 2005. More limited test data are available for MW-1D and MW-3S as they were sampled less frequently.

A reference background nitrate concentration of 0.46 mg/L was previously reported for Cape Cod by the USGS (LeBlanc, 1984). Earlier data from Frimpter and Gay (1979), indicate uncontaminated groundwater may have less than 0.1 mg/L nitrate nitrogen. At the landfill, the lowest nitrate concentrations were observed in the upgradient deep screened monitoring well MW-4D located south of the landfill and was consistent with background Cape Cod groundwater. All other wells tested showed nitrate concentrations above background.

The historical analyses have mainly included testing for nitrate-nitrogen alone. Nitrate-nitrogen analyses provide only a partial assessment of total nitrogen concentrations. Total nitrogen is the sum of total kjeldahl nitrogen (ammonia and organic nitrogen) plus nitrate-nitrogen and nitrite-nitrogen. Recent 2016 BCHD data collection has included groundwater analyses for additional nitrogen compounds. These data show the absence of nitrate but the presence of ammonia in some of the deeper landfill monitoring wells, including MW-2D (124-134) with nitrate at 0.5 mg/L and ammonia at 10 mg/L, MW-3D (84-94) with nitrate at <0.01 mg/L and ammonia at 5.6 mg/L, and MW-5D (124-134) with nitrate at <0.01 mg/L and ammonia at 14 mg/L.

Four of the monitoring wells (MW-1S (56-66), MW-2S (84-94), MW-2D (124-134), and MW-5S (78-88) had nitrate concentrations above the Massachusetts Drinking Water Maximum Contaminant Level (MMCL) of 10 mg/L on one or more sampling dates. MW-5S (78-88) has shown a consistent elevated nitrate concentration over the sampling period (pre- and post-landfill capping), with the nitrate concentration ranging from 6.6 mg/L to 22 mg/L. Other wells including MW-1S (56-66), MW-2S (84-94), MW-2D (124-134), and MW-4S showed a marked increase in nitrate concentration with renewed post-capping groundwater monitoring starting in March 2005 compared to the 1990s data (see Appendix A). One shallow monitoring well, MW-2S (84-94), has shown a generally increasing, but highly variable, trend in nitrate concentration starting when post-capping groundwater sampling was resumed. The concentration of nitrate at MW-2S (84-94) reached a maximum concentration of 40 mg/L in September 2009 and was reported at 34 mg/L in March of 2014 and 22 mg/L in September 2016. MW-5S (78-88) has shown a fairly steady elevated concentration of nitrate.

Landfill groundwater monitoring data also included limited measurements of dissolved oxygen that indicate oxygen levels are low in deeper groundwater. Shallow groundwater is generally aerobic (>1 - 2 mg/L dissolved oxygen). Biological attenuation of nitrate in groundwater by denitrification is inhibited under aerobic conditions in shallow groundwater and significant attenuation is unlikely in shallow groundwater during migration from the landfill to Town Cove. In potential nitrate source areas, the depth to groundwater may be limiting migration of organic carbon from below the former septage lagoons and from composting operations to groundwater while allowing for conversion of infiltrating ammonia in runoff to nitrate under aerobic conditions. Ammonia is generated during composting of high nitrogen materials such as fresh grass clippings. The breakdown of residual organic matter in the unsaturated zone below the former septage lagoons may also be a source of ammonia and nitrate.

It is likely the ammonia in deep groundwater comes from landfill leachate entering groundwater below the unlined landfill. Landfill leachate is a common source of ammonia in groundwater. The deeper groundwater is generally anoxic and therefore would not support the conversion of ammonia to nitrate.

Due to the limited number and location of monitoring wells, the extent of nitrogen compounds in groundwater both vertically and horizontally was not well defined prior to the subject investigation. Assessment of the horizontal and vertical extent of nitrogen compounds in groundwater immediately downgradient of the landfill and septage lagoons was therefore necessary to refine the estimate of nitrogen flux at the landfill. Assessment was also necessary to confirm the sources of nitrogen compounds in groundwater and to facilitate evaluation of necessary response actions.

E. Initial Conceptual Site Model Summary

The CSM indicates that there is the potential for groundwater migrating from the landfill to contribute to the nitrogen load to Town Cove. Transport time from the landfill to Town Cove is long. In this report the mass flux of nitrogen in groundwater at the landfill is defined as the approximate mass that continuously passes through a cross sectional area or plane located on the downgradient side of the landfill and upgradient of Finlay Road to the south. This flux is expected to be persistent given current conditions. Based on information available prior to this investigation, the area with elevated nitrogen concentrations at the landfill appeared to extend up to 800 feet cross-gradient (between MW-1 location to the west and MW-3/MW-5 location to the east). Elevated nitrogen concentrations were also known to extend to at least 40 feet below the water table. Based on recent information, deeper groundwater is contaminated by ammonia rather than nitrate. The full horizontal and vertical extent or nitrogen in groundwater was unknown. The large cross-section area downgradient of the landfill, groundwater flow information, and concentration data indicate there may be a considerable mass flux of nitrate from the landfill. Elevated concentrations of nitrate have been observed in groundwater at the landfill for at least 23 years, a period of time extending at least to the start of regular groundwater monitoring in 1994.

Historical landfill and septage lagoon operations, beginning around 1950 were likely sources of nitrogen to groundwater at one or more locations. The location of septage disposal may have changed over time and septage sludge was excavated and placed at other locations at the landfill. With an estimated groundwater travel time of 50 years to Town Cove, nitrogen from the landfill property may already be contributing nitrogen loading to Town Cove. The mass flux from the landfill actually reaching Town Cove will likely be affected by hydrogeologic and biogeochemical factors including dispersion, retardation, and degradation.

Yard waste composting operations may be a potential source of nitrogen leaching to groundwater. Current infiltration of Transfer Station stormwater and runoff from the top of the capped landfill through the former septage lagoon area may also be adding significant nitrogen to groundwater.

The infiltration of aerobic runoff may have converted a historical ammonia plume to a plume with nitrate as the dominant nitrogen compound in shallow groundwater while ammonia remains present in deeper anaerobic groundwater.

5. Landfill Nitrogen Investigation

The landfill nitrogen assessment was completed in two phases of work. The first phase was designed to collect initial information through site investigation, monitoring well installation, and soil and groundwater analyses. In the second phase of investigation additional monitoring wells were installed as necessary to define the nature and extent of nitrogen in groundwater and identify associated sources. The groundwater investigation was mainly limited to areas at and immediately downgradient of the landfill and septage lagoons with the exception of two monitoring wells installed downgradient in the watershed to Town Cove.

Phase 1 assessment activities were reported in a Technical Memorandum dated June 30, 2017 and included:

- An evaluation of the landfill cap drainage design plans and stormwater management systems in the vicinity of the transfer station and material composting areas to determine if runoff from the landfill surface or transfer station stormwater is recharging groundwater through the former septage lagoons;
- Assessment of the concentration of nitrogen compounds in landfill stormwater and groundwater at recharge locations;
- Groundwater sampling of selected pre-existing groundwater monitoring wells for nitrogen compounds;
- Installation and sampling of new groundwater monitoring wells placed near potential contaminant source areas and adjacent, upgradient, crossgradient, and downgradient of MW-2S (84-94) and MW-2D (124-134) where the highest concentrations of nitrogen had been observed, including monitoring wells with multi-level screen intervals;
- Groundwater monitoring and analyses including measuring groundwater elevations based on surveyed top of well casing elevations and depth to groundwater, collection of groundwater field parameters, and collection of groundwater samples for laboratory analyses of nitrogen compounds and other parameters in groundwater;
- An evaluation of groundwater hydrogeology and groundwater flow in the vicinity of the landfill based on data collected;
- Collection and analyses of sub-surface soil samples from the unsaturated zone at and below the former septage lagoon area for total nitrogen, nitrate and total volatile solids to quantify nutrients and organic material; and
- Installation of new monitoring wells downgradient of the landfill closer to Town Cove as necessary.

Phase 1 monitoring wells were sampled in February 2017 and groundwater samples analyzed for field parameters, nitrogen compounds, and selected anions, elements, and dissolved organic carbon.

Source area and nearfield downgradient monitoring well locations are shown on Figure 2. Downgradient watershed sampling locations are shown on Figure 4.

Monitoring wells installed during Phase 1 included:

- MW-2 (140-150) adjacent to and deeper than MW-2S (84-94) and MW-2D (124-134);
- MW-7S (55-65), MW-7D (115-125) upgradient of MW-2S (84-94) and MW-2D (124-134), adjacent to the north side of the capped landfill and the drainage swale over the septage lagoons;
- MW-8 (36-46) located cross gradient of MW-2S (84-94) and MW-2D (124-134), to the east and downgradient of the east side of the landfill on Giddiah Hill Road;
- MW-9 (92-102), located cross gradient to the west of MW-2S (84-94) and MW-2D (124-134), adjacent to Lots Hollow Road; and
- MW-10 (85-95) located downgradient of MW-2S (84-94) and MW-2D (124-134), on Finlay Road (Figure 2).

Additional data collected during Phase 2 was used to confirm the nearfield nature and extent of groundwater contamination and assess sources of nitrogen in groundwater.

The following Phase 2 monitoring wells were installed and sampled during the Phase 2 assessment to fill data gaps:

- MW-2 (161-171) adjacent to and deeper than MW-2 (140-150);
- MW-5 (140-150) adjacent to and deeper than MW-5D (124-134);
- MW-7 (90-100) adjacent and at an intermediate depth between MW-7S (55-65), MW-7D (115-125);
- MW-8 (84-94) adjacent to and deeper than MW-8 (36-46); and
- MW-13 (74-84) at a new location adjacent to the stormwater infiltration pond.

Locations of both Phase 1 and Phase 2 monitoring wells are shown on Figure 5. Two deep screened monitoring wells MW-11 (91-101) and MW-12 (97-97) were also installed in the watershed between the landfill and Town Cove (see Figure 4).

The depth to groundwater at monitoring wells varies depending on location. Surveyed top of casing elevations and well construction details including screen elevations are included in Table 1. During the field effort landfill MW-1D (99-109) was reconstructed to repair a bent and obstructed well casing. All new monitoring wells are 2-inch PVC wells with 10-foot screens installed with hollow stem auger drilling by Desmond Well Drilling Inc. using a CME-75rig mounted on a GMC 7500.

The new and selected previously installed monitoring wells were developed by pumping and sampled using the US EPA low flow methodology in February and March 2017 for field parameters, nitrogen compounds and selected anions, elements and, dissolved organic carbon (DOC). The results of Phase 1 and Phase 2 groundwater analyses are included in Table 2.

Water table elevations were recorded prior to purging wells for sampling and are recorded in Table 3. Groundwater elevations on the north side of the landfill generally indicate flow to the northeast as indicated on Figure 2. Variations in groundwater elevation at cluster well locations also indicate the potential for steep downward vertical gradients.

6. Investigation Results and Discussion

A. General

Sources of nitrogen confirmed at the landfill and transfer station include:

- The capped solid waste landfill;
- Transfer station runoff;
- Compost operations leachate directly infiltrating through soil and running off to the stormwater management system; and

- Residual nitrogen in soil in the former septage lagoon area, intensified by the infiltration of precipitation, stormwater, and landfill cap drainage through soil and the unlined rock drainage swale located over the former lagoons.

The nitrogen plume identified at the landfill is a secondary source of nitrogen migrating to downgradient groundwater.

B. Evaluation Landfill Cap Drainage Design, Stormwater Management Systems, and Associated Potential Sources of Nitrogen to Groundwater Including the Former Septage Lagoons

Potential sources of nitrogen associated with the stormwater management and landfill cap system include general transfer station runoff and the potential mobilization of nitrogen from the former septage lagoon area by infiltrating stormwater and landfill cover drainage water in the unlined riprap swale located to the north of the landfill cap.

A sample of transfer station runoff was collected from Stormdrain-1 (Figure 2). Stormwater test results are included in Table 4. Laboratory results for the stormwater sample indicated mainly the presence of organic nitrogen with total nitrogen measured at 4.5 mg/L, nitrate-nitrogen at 0.42 mg/L, and ammonia-nitrogen measured at 0.67 mg/L. The result indicates transfer station stormwater is a source of nitrogen infiltration to groundwater although the concentration is generally less than groundwater concentrations in areas affected by additional sources. The stormwater nitrogen concentration is likely to be highly variable depending on the length of time between rain events and the stage of the rain event. The stormwater that initially runs off an area will tend to have higher concentrations than the stormwater that runs off later, after the rainfall has flushed the surface.

The unlined riprap perimeter swale to the north of the landfill cap receives runoff from the landfill cap drainage layer on the north and west sides of the landfill as well as stormwater from the transfer station catch basins. This section of swale is located above southern edge of three of the six the former septage lagoons. Based on landfill drawings and observation, much of the landfill drainage and stormwater infiltrates through the swale with more limited flow east to the retention basin, mainly during significant storm events. This results in a significant recharge to groundwater through the residual organic material with a high concentration of total nitrogen in the septage lagoon area and potentially over time a high mass loading to groundwater.

To investigate the septage lagoons as a residual source of nitrogen, a soil boring was completed at the location of monitoring well MW-7 installed adjacent to the northwest end of the unlined riprap swale in January, 2017. This location was determined to be above one of the former septage lagoons based on historical site plans. Soil sampling results indicated the presence of soil with a high nitrogen and organic content with septage odor at approximately 12 to 13 feet below ground surface. This layer was close to the reported 50 foot elevation of the septage lagoons. Test results for soil samples collected at 12-13 feet, 13.5-14.5 feet, 15-17 feet, 42-44 feet and 57-58 feet below ground surface indicated that high concentrations of nitrogen and organic material were limited to the 12-13 feet range. The concentration of total nitrogen in this residual material was measured at 1,440 mg/kg or 0.14 percent (Table 5). Visual observations at depths less than 12 feet and greater than 13 feet below ground surface indicated the presence of relatively clean sand.

A water table monitoring MW-7S (55-65) was installed in this soil boring with a screen elevation set 14.8 to 4.8 MSL was sampled twice and indicated a variable nitrate concentration of 8.7 mg/L (duplicate 12.8 mg/L) on February 6, 2017 and 4.96 mg/L on March 28, 2017. Trace levels of ammonia were detected at this monitoring well. The deeper intermediate screened well at this location MW-7 (90 -100) (screen elevation -20 to -30) had trace concentrations of both nitrate and ammonia when sampled on March 28, 2017. The deepest well at this location MW-7D (116-126) (screen elevation -45 to -55) was sampled twice, on February 6, 2017 and March 28, 2017. Nitrate was not detected on either date and ammonia was detected at 2.74 mg/L and 2.59 mg/L respectively.

The high concentration of residual nitrogen in the soil 12 to 13 feet below ground surface indicates a relatively thin layer of residual septage material in soil. The elevated nitrate concentration in groundwater at the water table shows that the infiltrating stormwater is likely mobilizing some of this residual material to groundwater with infiltrating stormwater, although significantly higher concentrations of nitrate were observed at the water table well MW-E6-B (54-64) located approximately 100 feet downgradient and at monitoring well MW-2S (84-94) located approximately 430 feet downgradient (see Table 2).

The location of the monitoring well MW-7 cluster is toward the upgradient (south) side of the septage lagoon area. Stormwater and landfill cap drainage has been discharging to the adjacent unlined rip rap swale since the landfill was capped in 2005, likely flushing a significant mass of nitrogen compounds out of soil immediately below the swale over time. The higher concentrations observed in water table monitoring wells at the downgradient monitoring well MW-6 and MW-2 clusters could be indicators of continued mobilization of septage derived nitrogen by slower infiltration of localized precipitation and snowmelt outside the area flushed by large volumes of infiltrating stormwater under the swale. Alternatively this higher concentration of nitrate could come from composting operations in this area as discussed below.

C. Assessment of Nitrogen in Runoff from Composting Operations

The landfill composting operation processes yard waste that includes leaves, brush, garden, and landscape trimmings. Generally yard waste includes green waste and brown waste. Green waste is primarily fresh plant material such as grass clippings and garden waste that contains appreciable amounts of nitrogen, phosphorus, and mineral nutrients. Brown waste includes dry leaves, hay, and brush that contains primarily carbon, with a high carbon/nitrate (C/N) ratio (Chatterjee et. al., 2013).

Compost operations include the maintenance of aerated windrows of yard waste with mixed green and brown waste in an area to the north of the capped landfill on both paved and unpaved surface. An assessment of the concentration of nitrogen compounds in stormwater originating from an area of paved surface that includes yard waste composting operations was completed in the first phase of investigation. Samples of runoff from the paved composting area were collected for nitrogen analyses at Stormdrain-2, located in the paved area near the east end of the riprap swale (Figure 2). The results of analyses were compared to general transfer Station runoff samples that were collected from Stormdrain-1 located adjacent to the Gift Shop. The results of stormwater analyses are included in Table 4.

Significantly higher nitrogen concentrations were detected in the sample from the Stormdrain-2 location, which is more associated with the composting operation than general transfer station runoff. Total nitrogen concentrations from transfer station and composting area stormwater runoff were 4.5 mg/L and 27.1 mg/L respectively. A comparison of the test results is included in Chart 1. These data indicate composting operations are a likely significant source of nitrogen to groundwater. The compost is located on both paved and unpaved surfaces and a portion of the leachate from compost directly infiltrates to groundwater through sandy soil, while a portion is recharged to groundwater through the stormwater management system.

A follow up investigation was completed in Phase 2 to further evaluate the compost operation as a source of nitrogen. A pan lysimeter (pore water sampler) was installed in an active compost windrow to collect pore water from the compost for analyses. The pan lysimeter was constructed from a 5-gallon bucket with a perforated cover and screen buried in the active compost pile for a period of two weeks. Rain events over the sampling period resulted in the accumulation of drainage pore water in the bucket for analyses of pore water content. The results of compost leachate analyses are included in Table 6. The nitrate concentration in leachate was just over 1 mg/L while the ammonia concentration was 4.94 mg/L and total nitrogen was 98.5 mg/L, indicating a significant organic nitrogen present in leachate that will likely result in groundwater contamination. Nitrogen in leachate will percolate directly to groundwater in unpaved areas and flow with stormwater to the stormwater infiltration pond. Nitrogen in leachate likely contributes to the observed concentration of nitrate in shallow groundwater at the MW-6 and MW-2 locations.

D. Groundwater Investigation and Results

Phase 1 groundwater monitoring wells, including single and multi-screen wells, were installed on the landfill property downgradient of potential source areas and in public roadways immediately downgradient of the landfill property to assess the nearfield horizontal and vertical extent of nitrogen compounds in groundwater. As noted above, monitoring wells were identified with a naming convention that included the location (e.g. MW-2), and the projected depth interval in feet below ground surface (e.g. MW-2 (84-94). Well screen elevations (NAVD 1988) are included in Table 1. Monitoring well locations and screen depth were selected based on previously available assessment data and information regarding the direction of groundwater flow. The objective was to install new monitoring wells:

- In potential source areas (e.g., septage lagoons) to estimate the extent of existing nitrate sources;
- In deeper groundwater at locations of known shallower contamination (nitrogen compounds in groundwater) to assess vertical distribution; and
- Cross gradient from wells with known contamination to determine the lateral extent of nitrogen in groundwater.

Six monitoring wells were installed in Phase 1 at selected locations. An additional five monitoring wells were installed in Phase 2. These new wells were sampled on one or more occasions along with selected pre-existing monitoring wells to collect groundwater concentrations of target nitrogen compounds along with anions and elements that are indictors of geochemistry (Table 2). Water table elevations were recorded during sampling events to provide data for assessment of the direction of groundwater flow (Table 3).

1) Nitrogen Assessment

Groundwater data indicates the presence of a two layer shallow and deep nitrogen plume emanating from the landfill and transfer station property. A review of the groundwater analyses shown in Table 2 indicates that groundwater chemistry on the downgradient (north and northeastern) side of the landfill/transfer station property is not homogeneous and that there are different groundwater zones with nitrogen in the form of nitrate or in the form of ammonia. Concentrations vary at different locations and at some locations concentrations varied between sampling events. Generally nitrate was found in shallow groundwater and ammonia was present in deeper groundwater. There are differences in the vertical thickness of the shallower nitrate zones comparing groundwater in the northwest area downgradient of the landfill to the groundwater in the southeast area downgradient of the landfill. The landfill stormwater infiltration pond is located in the southeast area and may have an effect on the distribution of nitrate in groundwater.

These groundwater areas have been divided into zones, each approximately 800 feet wide, and including shallow and deep areas for characterization and to help refine the estimate of nitrogen flux at the landfill. The estimating flux through each zone can be combined for a total nitrogen flux. These zones are labeled on Figures 6 and 7. The zones defined for the analysis include:

- Zone 1A approximately 800 feet cross gradient on the northwest side of the downgradient area – shallow from the water table to 15 feet below the water table (elevation +15 to 0 ft.);
- Zone 2A approximately 800 feet cross gradient on the northwest side of the downgradient area – deeper with a vertical thickness of 80 feet from 15 feet below the water table to 95 feet+ below the water table (elevation 0 to -95+ ft.);
- Zone 1B approximately 800 feet cross gradient on the southeast side of the downgradient area – shallow from the water table to 60 feet below the water table (approximate elevation +15 ft.to -45 ft.); and

- Zone 2B approximately 800 feet cross gradient on the southeast side of the downgradient area – deep with a vertical thickness of 35 feet from 60 feet below the water table to 95+ feet below the water table (elevation -45 to 95+ft.).

The density of monitoring wells is higher to the northwest (Zones 1A and 2A), which is downgradient of largest number of potential nitrogen sources compared to the southeast area.

Zone 1A: The shallow groundwater in Zone 1A is contaminated with nitrate to a depth of approximately 15 feet below the water table. The maximum concentration of nitrate observed in February/March 2017 groundwater samples was 20.2 mg/L detected in MW-9 (92-102), located cross gradient to the west of MW-2S (84-94) (Figure 2). A concentration of 18.8 mg/L was measured at MW-2S (84-94). An average nitrate concentration in groundwater of 13 mg/L was calculated for Zone 1A with data from February and March 2017 from MW-9 (92-102), MW-2S (84-94), and MW-5S (78-88).

Zone 2A: Nitrogen in the form of ammonia is dominant in the deeper northwest Zone 2A groundwater. The maximum concentration of ammonia observed in February/March 2017 groundwater samples in Zone 2A was 12.7 mg/L, measured at MW-5D (124-134) A concentration of 11.9 mg/L ammonia was measured at MW-2D (124-134). An average ammonia concentration in groundwater of 11 mg/L was calculated for Zone 2A with data from February and March 2017 from MW-2D (124-134), MW-2 (140-150), and MW-2 (161-171).

Zone 1B: Nitrate is also the dominant form of nitrogen in the shallower southeast Zone 1B. The shallow monitoring well MW-8 (36-26) appears to be screened in perched groundwater above the main groundwater flow system and therefore not affected by the upgradient landfill. The maximum nitrate concentration in Zone 1B was 5.14 mg/L measured in groundwater from MW-8 (84-94) with and average concentration of 3 mg/L based on MW-8 (84-94) and MW-13 (74-84) data.

Zone 2B: The deeper zone on the southeast side (Zone 2B) lacks data and conditions are based on the findings to the northwest and the presence of the solid waste area upgradient of Zone 2B. An average ammonia concentration in groundwater of 11 mg/L is assumed for this zone.

A water table monitoring well MW-10 (85-95) was installed downgradient from the landfill investigation area at the corner of Commerce Way and Finlay Road to assess the groundwater gradient. A concentration of 2.4 mg/L or nitrate was measured in a groundwater sample from MW-10 (85-95) that is assumed to represent local conditions unassociated with the landfill. The landfill plume would be expected to have reached deeper depths by this distance downgradient.

2) Groundwater Gradient and Flow Near the Landfill

Groundwater elevations were recorded across the landfill investigation area at approximately 12 to 16 feet above MSL during monitoring event in February and March 2017. Two monitoring wells showed the presence of perched groundwater above the regional groundwater flow system including MW-1S (56-66), groundwater elevation 23 ft., and MW-8 (36-56), groundwater elevation 24 ft.

Water level data from other water table wells indicated that the horizontal groundwater flow direction varied from location to location but was generally toward to the north and northeast toward Town Cove. At most locations with multi-level monitoring wells, water elevation data also showed a potential for downward vertical flow with water elevations higher in shallow screened wells and lower in deeper screened wells.

The groundwater flow direction based on water table wells in Zone 1A in the vicinity of monitoring well locations MW-7 and MW-6 and downgradient to MW-2 was to the north (heading approximately 3 degrees) with a gradient of 0.004. Flow from MW-2 downgradient is generally toward MW-10 on a heading of approximately 30 degrees to the north northeast with a gradient of 0.003.

Darcy's Law can be used to calculate the groundwater seepage velocity through Zone 1:

V= Ki/n where:

V = Seepage velocity (feet per day);

K = assumed hydraulic conductivity (feet per day; 70);

i = groundwater gradient (unitless; 0.003 to 0.004); and

n = effective porosity of sand (unitless; 0.3).

Based on this equation, the estimated the horizontal seepage velocity ranges from approximately 0.7 feet per day in the downgradient area between the MW-2 location and MW-10, to 0.9 feet per day nearer to the capped landfill in the vicinity of monitoring well MW-6 and MW-7. These estimates are based on groundwater elevations observed in water table monitoring wells and a hydraulic conductivity of 70 feet/day found in previous aquifer testing at MW-2S. This hydraulic conductivity is similar to that of fine sand and is considered representative of the area.

It is anticipated that the hydraulic conductivity will vary from location to location depending on aquifer material present. Soil borings completed for monitoring wells showed cutting that were mainly fine to medium sand with occasional silty clay encountered at depth. Silt and clay have lower hydraulic conductivities compared to sand. If a hydraulic conductivity of 5 feet/day characteristic of silt were used in the above equation, the groundwater velocity would be less than 0.1 feet/day.

As expected, multi-level monitoring well water elevation data shows a potential for downward vertical flow with water elevations higher in shallow screened wells and lower in deeper screened wells. The plume of nitrogen is expected to dive to greater depths as it migrates downgradient toward Town Cove, eventually discharging vertically up under Town Cove. Figure 8 shows modeled groundwater particle tracks along the expected migration path from the landfill to Town Cove and the vertical extent of migration with groundwater starting near the water table at the landfill and reaching depths of more than 140 feet below the water table downgradient. Given that current data indicates the nitrogen plume extends at least 85 feet below the water table at MW-2 (161-171) (elevation -59.6 to -69.6), the plume can be expected to reach depths approaching 225 feet or more below the water table unless a low permeability layer is encountered that prevents further downward vertical migration.

3) Characterization of Groundwater Nitrogen Flux at the Landfill

The flux of nitrogen at the landfill is not the same as flux into Town Cove which depends on numerous factors involving the fate and transport of nitrogen over a long period of time (50+ years). At the landfill, nitrogen in the form of both nitrate and ammonia have been found in groundwater. Ammonia is soluble in water and forms the ammonium cation (NH_4^+) in groundwater water. Nitrate is expected to migrate at the same velocity as groundwater while ammonium has a migration rate estimated at 1/4 the groundwater flow velocity (retardation factor of 4). This estimate is based on studies at the USGS tracer test site located on the wastewater plume at Joint Base Cape Cod (JBCC) in Falmouth. Numerous monitoring wells located in the JBCC wastewater plume were sampled on multiple dates in the 1990s and provided data for assessment of ammonium migration that indicated an average retardation factor of 4. This and additional experiments using a variety of methods to estimate ammonium transport at the tracer test site yielded retardation factors that ranged from 3.5 to 6 (Bohlke, 2006).

Nitrogen mass flux estimates can be used to quantify plume strength at the landfill at a given time and location with available data. Mass flux is a rate measurement specific to a defined area, which is usually a subset of a plume cross-section such as the zones described above. A total mass flux or mass discharge is an integrated mass flux estimate (including the sum of all mass flux measures across an entire plume – all zones) and thus represents the total mass of any solute conveyed by groundwater through a defined plane (ITRC, 2010).

An updated total flux estimate has been developed based on dividing the area downgradient of the landfill into flux zones with differing forms of nitrogen at different concentrations. These zones also have different dimensions on the defined flux plane as shown on the cross sections in Figures 6 and 7. This methodology allows for the use of new data to refine the nitrogen flux estimate with both concentration data and the differing migration rates for nitrate and ammonia in groundwater. The nitrate and ammonia flux from these zones can be added to report an estimated total nitrogen flux. Using the average concentrations of nitrate or ammonia in each of the defined zones and considering a range of groundwater velocities from 0.3 to 3.0 feet/day a range of flux can be estimated to account for uncertainties in hydraulic conductivity and groundwater flow. Completing the calculation and adding all zones together indicates a range of total nitrogen flux from 514 kg/yr to 5,144 kg/yr (see Appendix B). The results of a planned pumping test to follow this report will provide additional data to reduce uncertainty with regard to both groundwater velocity and concentration, further refining the flux estimate.

E. Discussion of Results and Management Options

The primary goal of this water quality and wastewater planning and engineering project is to reduce excessive nitrogen loading to the Town's ponds, estuaries and embayments. The Massachusetts Estuaries Project target for the Nauset Harbor system is to reduce the nitrogen load by approximately 8,600 kg N/year, with a 6,700 kg N/year reduction goal for the Town Cove sub-embayment alone (Howes, et.al. 2012). Additional work is planned by the Massachusetts Estuaries Project to update the projected nitrogen load to Town Cove with the results of this landfill groundwater assessment and the results of additional investigations following this report.

Removing nitrogen from groundwater at the landfill will not directly reduce nitrogen loading to Town Cove in the near term because the time for plume migration is estimated at approximately 50 years for nitrogen in the form of nitrate and upwards of 200 years for nitrogen in the form of ammonia. Nitrogen flux from the landfill may attenuate to some degree through natural processes as it migrates through the deep groundwater system toward Town Cove, however, the mass of nitrogen currently in transit to Town Cove as a result of landfill and septage lagoon operations beginning in the 1950s is unknown. Furthermore, the depth of migration likely precludes direct assessment and response actions to intercept the load in transit.

Given these conditions, any actions undertaken at the landfill to address nitrogen would be for the purpose of watershed protection and long term aquifer restoration. These actions would also assist with the currently unquantified reduction of nitrogen load to Town Cove in the distant future. Certain actions related to source mitigation are likely to be feasible and could be implemented in conjunction with planned 2017 redevelopment of the landfill property for a new Department of Public Works and Natural Resources (DPW) facility.

Groundwater restoration at the landfill is likely to be technically feasible but would have to be considered as an investment in aquifer restoration and future nitrogen load reduction to Town Cove, 50 to 200 years from now. Any groundwater response at the landfill should be considered against options to offset the potential nitrogen load in transit or the current nitrogen flux at the landfill with management actions to reduce nitrogen loading from other diffuse sources such as septic systems located closer to Town Cove. Nitrogen offset by mitigation of sources closer to Town Cove through traditional sewer system installation or non-traditional methods may be more beneficial because the groundwater transport times for nitrogen from these sources are shorter and the effects of offset mitigation measures would be realized sooner.

7. Summary of Potential Corrective Actions, Feasibility, and Conceptual Design

The full range of potential nitrogen response actions at the landfill includes short term corrective actions focused on source mitigation and long term corrective actions focused on groundwater restoration. As discussed above, nitrogen offset at other locations is also an option that may be an alternative or supplement to groundwater restoration at the landfill.

The following criteria were considered in evaluating the feasibility of corrective actions.

- **Effectiveness**: The ability of the corrective action to mitigate transport of nitrogen to groundwater or the transport of nitrogen in groundwater.
- **Reliability**: The degree of certainty that the corrective action will be successful over the short- and long-term.
- **Difficulty of Implementation**: Comparative difficulty of implementing each corrective action with respect to the technical complexity, integration with existing facility operations, monitoring requirements, and material and labor availability.
- **Relative Costs**: Costs of remedy design, implementation, operation, removal, and regulatory compliance.
- **Risks**: Comparative risks posed by the remedy to workers, community stakeholders, and the environment during and after remedy implementation.
- **Benefits**: Comparative benefits of restoring natural resources.
- **Timeliness**: The relative timeframe for the corrective action to achieve benefits.

Potentially feasible corrective actions and conceptual designs are evaluated below.

Option 1 Placement of an Impermeable Pavement Cover Over the Former Septage Lagoons Area

The current DPW facility plan includes paving over most of the footprint of the former septage lagoons, with the exception of the area immediately adjacent to the north side of the capped landfill where the unlined drainage swale is located over the lagoons (Figure 2). This action is not difficult to implement and the pavement cap is expected to be effective and reliably reduce or eliminate infiltration through the residual septage material. Long term maintenance of pavement will be necessary to prevent cracking. The benefits of paving include a near term contribution to aquifer restoration by preventing further groundwater contamination in the source area and long term benefit through reduced nitrogen migration in groundwater. Minimal additional costs are anticipated as pavement of this area is included in current DPW plans.

Option 2 Adding Impermeable Pavement/liner and Stormwater Controls in the Yard Waste Materials Area Located on the North Side of the Transfer Station

The subject area is north of the paved transfer station area and Gift Shop Building (See Figure 2 current Composting Area). This area will be mined for fill material and expanded during DPW construction activities resulting in additional level space. The DPW plans to use this space for receiving and initial storage of yard waste. Periodically this stored yard waste will be moved to the planned composting area on the landfill cap for processing. The current DPW facility plan does not include paving in this area. This material will generate nitrogen rich leachate as precipitation infiltrates the stored piles of yard waste material. The corrective action includes paving the area with an asphalt or concrete liner and constructing stormwater and drainage controls tied to the transfer station storm drain system. Future yard waste storage should be limited to paved surfaces only. This action is considered feasible and could be implemented within the DPW facility project to minimize costs. This action would not be difficult to implement and the pavement liner is expected to be effective and reliably reduce or eliminate infiltration of precipitation through yard waste to groundwater with long term maintenance of pavement to prevent cracking. The benefits of paving include a near term contribution to aquifer restoration by preventing further groundwater contamination in the source area and long term benefit through reduced nitrogen migration in groundwater. Stormwater generated from the area could be treated along with transfer station runoff, cap drainage, and drainage from the composting area operations on the cap as discussed in Number 3 below.

Option 3 Adding a Stormwater Denitrification Biofilter for Treatment of Transfer Station Stormwater and Compost Operation Runoff

In order to treat nitrogen in stormwater efficiently, the infiltration pond can be modified to function as a denitrification biofilter when reconstructed as part of the DPW facility project. The denitrification biofilter concept is similar to the Nitrogen Removing Barriers (NRB) being considered for septic system effluent treatment. The majority of nitrogen in stormwater entering the infiltration pond is expected to be in the form of nitrate. As currently designed, the infiltration pond does not treat nitrate and allows nitrate infiltration to groundwater. The denitrification biofilter design would include constructing the infiltration pond with a layer of sawdust and sand to provide a permeable carbon source to stimulate biological denitrification as the stormwater percolates through. The nitrate would be reduced to nitrogen gas and vented to the atmosphere in the process. The performance of the system could be evaluated with groundwater monitoring wells and sampling devices installed during construction.

Option 4 Replacing the Unlined Drainage Swale on the North Side of the Landfill Cap Area with a Swale or Culvert with an Impermeable Base

This proposed corrective action includes reconstructing the swale with an impermeable base and repositioning the HDPE geomembrane to discharge the cap drainage layer into the swale.

The swale reconstruction could be implemented during DPW construction activities to minimize costs. The benefits of swale reconstruction include a substantial near term contribution to aquifer restoration by preventing further groundwater contamination in the source area and long term benefit through reduced nitrogen migration in groundwater. This action presents a higher level of difficulty and cost in comparison to other source control actions due to a higher technical complexity, permitting requirements, and level of contractor services. The action would require:

- Plan approval by MassDEP;
- Excavation of the current swale for reconstruction of a new impermeable swale;
- Excavation of the vegetative layer and drainage layer along the edge of the cap;
- Welding of a new rectangular section of HDPE liner to extend into or forming the new swale; and
- Reconstruction of the disturbed drainage layer sand and vegetative layer topsoil.

Options include constructing a new asphalt or concrete swale or extending the HDPE liner to the north through the swale and up to the top on the north side to form an impermeable base. All options require welding a new section of HDPE liner from the existing liner into the new swale. With asphalt or concrete construction the liner would be anchored inside the swale. Alternatively, the HDPE liner could be used to form the impermeable surface and be covered with riprap forming a new impermeable rock swale.

Option 5 Capture and Treatment of Nitrogen Flux Zone Groundwater at the Landfill

A groundwater treatment system would include a set of wells for groundwater extraction designed to cut off migration of nitrogen in groundwater with on-site treatment with a nitrification/denitrification biofilter system. Given sufficient flow capacity the denitrification biofilter component could be the stormwater infiltration pond modified to function as a denitrification biofilter. A stormwater infiltration pond biofilter was also considered for treating stormwater as outlined in corrective action Number 3. Additional treatment components for nitrification of extracted ammonia in groundwater would be necessary to convert ammonia to nitrate aerobically prior to denitrification. The nitrification process could be accomplished with an aeration tank or constructed wetland system placed on or adjacent to the landfill cap.

As with all corrective actions at the landfill, the long travel time for nitrogen from the landfill to Town Cove limits the benefit to Town Cove to a time far in the future. The benefit is mainly in the form of long term aquifer restoration. Once the total nitrogen flux in groundwater along the transect north of landfill is confirmed through ongoing work decisions regarding the merit of groundwater treatment can be more fully considered, including comparison to the nitrogen offset option outlined below in Number 6.

Option 6 Nitrogen Offset – Adding Nitrogen Source Reduction and/or Treatment at Alternative Locations Closer to Town Cove to Offset Nitrogen Migrating from the Landfill

The current estimated range of total nitrogen flux in groundwater at the landfill is from 514 kg/yr to 5,144 kg/yr. Given that groundwater treatment at the landfill does not provide timely benefits to Town Cove, a nitrogen offset approach could be undertaken to mitigate the effects of nitrogen in transit and future impacts to Town Cove.

The offset approach includes expanding planned use of traditional wastewater treatment and/or increased use of non-traditional technologies at locations closer to Town Cove to offset these future impacts. A an example, mitigation of the nitrogen flux estimated at the above range could be accomplished through elimination of between 112 and 1,128 Title 5 septic systems at locations closer to Town Cover that were not otherwise planned for by connecting them to the new sewer system.

Additional groundwater assessment is ongoing to collect data for the Massachusetts Estuaries Project to refine the projected nitrogen load to Town Cove. These data will also be used confirm the hydraulic conductivity allowing a more precise estimate of groundwater nitrogen flux.

8. References

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Tables

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Table 1 Orleans Landfill Monitoring Well Construction Details

Location	Surface Elevation (ft)	TOC Elevation (ft)	Total Well Depth (ft bgs)	Screen Beginning Depth (ft bgs)	Screen End Depth (ft bgs)	Top Screen Elevation (ft)	Bottom Screen Elevation (ft)	Mid-Screen Elevation (ft)	Screen Length (ft)	Inst. Date	Address
MW-1S (56-66)	83.3	85.18	66.0	56.00	66.00	27.30	17.30	22.30	10.0	existing	Landfill
MW-1D (99-109)	83.3	85.11	109.0	99.00	109.00	-15.70	-25.70	-20.70	10.0	existing	Landfill
MW-2S (84-94)	101.3	101.49	94.0	84.00	94.00	17.30	7.30	12.30	10.0	existing	Landfill
MW-2D (124-134)	101.6	101.42	134.0	124.00	134.00	-22.40	-32.40	-27.40	10.0	existing	Landfill
MW-2 (140-150) *	101.3	102.80	150.0	140.00	150.00	-38.70	-48.70	-43.70	10.0	1/18/2017	Landfill
MW-2 (161-171)	101.4	102.9	171.0	161.00	171.00	-59.60	-69.60	-64.60	10.0	March 2017	Landfill
MW-3S (50-60)	68.6	70.32	60.0	50.00	60.00	18.60	8.60	13.60	10.0	existing	Landfill
MW-3D (84-94)	68.8	69.74	94.0	84.00	94.00	-15.20	-25.20	-20.20	10.0	existing	Landfill
MW-5S (78-88)	102.1	103.91	88.0	78.00	88.00	24.10	14.10	19.10	10.0	existing	Powerline ROW
MW-5D (124-134)	102.0	103.89	134.0	124.00	134.00	-22.00	-32.00	-27.00	10.0	existing	Powerline ROW
MW-5 (140-150)	101.7	103.6	150.0	140.00	150.00	-38.30	-48.30	-43.30	10.0	March 2017	Powerline ROW
MW-6A (64-74)	71.6	71.22	74.0	64.00	74.00	7.60	-2.40	2.60	10.0	1/21/2016	Landfill
MW-6B (54-64)	71.8	71.40	64.0	54.00	64.00	17.80	7.80	12.80	10.0	1/21/2016	Landfill
MW-6C (52-62)	71.9	71.55	62.0	52.00	62.00	19.90	9.90	14.90	10.0	1/21/2016	Landfill
MW-E6 (88-98) *	72.2	71.91	98.0	88.00	98.00	-15.80	-25.80	-20.80	10.0	1/17/2017	Landfill
MW-7S (55-65) *	69.8	71.64	65.0	55.00	65.00	14.80	4.80	9.80	10.0	1/19/2017	Landfill
MW-7D (115-125) *	69.9	71.66	125.0	115.00	125.00	-45.10	-55.10	-50.10	10.0	1/20/2017	Landfill
MW-7 (90-100)	69.7	71.4	100.0	90.00	100.00	-20.30	-30.30	-25.30	10.0	3/2/2017	Landfill
MW-8 (36-46) *	59.1	58.80	46.0	36.00	46.00	23.10	13.10	18.10	10.0	1/25/2017	Giddiah Hill Road
MW-8 (84-94)	59.2	58.8	94.0	84.00	94.00	-24.80	-34.80	-29.80	10.0	3/1/2017	Giddiah Hill Road
MW-9 (92-102) *	105.5	107.32	102.0	92.00	102.00	13.50	3.50	8.50	10.0	1/25/2017	Landfill
MW-10 (85-95) *	94.0	93.69	95.0	85.00	95.00	9.00	-1.00	4.00	10.0	1/26/2017	Finlay Road
MW-13 (74-84)	57.0	59.3	84.0	74.0	84.0	-17.00	-27.00	-22.00	10.0	March 2017	Landfill
MW-11 (91-101)	49.4	48.97	101.0	91.0	101.0	-41.60	-51.60	-46.60	10.0	March 2017	Elementary School
MW-12 (87-97)	NA	NA	97.0	87.0	97.0	NA	NA	NA	10.0	March 2017	Snow Library

Notes: TOC = Top of Casing
bgs = below ground surface
NA = Not Available

All new wells constructed with 2-inch Schedule 40 PVC threaded flush joint casings, 10 ft screens with Schedule 40 PVC .010" 10 slot well screen

Table 2 Orleans Landfill Groundwater Analyses

Sample ID	**MW-1S (56-66)**		**MW-1D (99-109)**		**MW-2S (84-94)**			**MW-2D (124-134)**			
Top of Screen Elevation (ft)	27.30		-15.70		17.30			-22.40			
Bottom of Screen Elevation (ft)	17.30		-25.70		7.30			-32.40			
Sampling Date	2/8/2017	3/29/2017	2/8/2017	3/29/2017	2/26/2016	02/06/2017	3/28/2017[1]	2/26/2016	02/06/2017	02/06/2017(DUP)	3/28/2017[1]
Field Measurements											
pH (SU)	5.3	4.7	5.6	4.9	4.9	4.8	4.5	4.7	6.0	6.0	5.6
Temperature (°C)	14.1	13.4	13.7	12.6	13.2	16.0	15.0	12.4	15.5	15.5	15.1
Dissolved Oxygen (DO; mg/L)	3.0	1.1	4.2	4.4	1.4	1.6	0.8	0.8	0.1	0.1	0.0
Dissolved Oxygen (DO; %)	-	10.5	-	38.6	-	16.2	7.5	-	0.6	0.6	0.2
Redox Potential (ORP; mV)	120.2	149.8	138.3	143.4	193.6	129.8	144.7	144.9	54.5	54.5	106.0
Specific Conductivity (µS/cm)[c]	137.0	127.0	172.0	173.0	942.0	751.0	777.0	886.0	800.0	800.0	828.0
Laboratory Analyses											
Nitrogen											
Nitrate as N (mg/L)	**3.6**	**2.56**	**3.28**	**4.12**	**24.7**	**18.8**	**1.05**	**9.26**	**0.208**	**0.18**	**2.32**
Nitrite as N (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	**0.0**	<0.01	**0.065**	**0.014**	<0.01	<0.01
Ammonia (mg/L)	<0.1	**0.11**	**0.51**	**0.43**	**0.25**	**0.14**	<0.1	**0.34**	**11.5**	**11.2**	**10.9**
Total Kjeldahl Nitrogen (TKN) (mg/L)	**1.24**	**-**	**1.21**	**-**	**-**	**2.13**	**2.3**	**-**	**13.7**	**14.7**	**12.1**
Total Nitrogen (mg/L)	**4.8**	**4.26**	**4.5**	**4.86**	**27.1**	**21.0**	**3.34**	**11.1**	**13.9**	**14.8**	**14.5**
Alkalinity											
Total Alkalinity (mg/L)	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Bicarbonate Alkalinity (mg/L)	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Anions											
Chloride (mg/L)	**13.2**	**15**	**32.5**	**30.7**	**131.0**	**88.8**	**94.8**	**152.0**	**97.7**	**99.2**	**134**
Sulfate (mg/L)	**6.7**	**5.4**	**8.7**	**8.2**	**66.0**	**77.0**	**81**	**51.6**	**52.5**	**52.0**	**51**
Elements											
Dissolved Iron (mg/L)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	**0.11**	**0.107**
Dissolved Manganese (mg/L)	**0.37**	**0.454**	**0.08**	**0.059**	**0.60**	**0.55**	**0.528**	**1.10**	**5.12**	**5.10**	**4.48**
Boron (mg/L)	**-**	**-**	**-**	**-**	**0.22**	**0.28**	**-**	**0.16**	**0.26**	**0.25**	**-**
Organic Compounds											
1,4-Dioxane	**-**	**-**	**-**	**-**	**-**	<0.25	**-**	**-**	**1.84**	**1.7**	**-**
DOC (mg/L)	**-**	**-**	**-**	**-**	**9.5**	**9.5**	**-**	**4.5**	**7.2**	**8.6**	**-**
Methane	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Notes:
Bold - detected above the Minimum Detection Limit
1. TKN and Total Nitrogen data from re-run analysis reported on
E. Data point appears to be in error
(124-134)-Well screen depth below land surface

Table 2 Orleans Landfill Groundwater Analyses

Sample ID	**MW-2 (140-150)**		**MW-2(160-170)**	**MW-3S (50-60)**		**MW-3D (84-94)**		**MW-5S (78-88)**		
Top of Screen Elevation (ft)	-38.70		-160.00	18.60		-15.20		24.10		
Bottom of Screen Elevation (ft)	-48.70		-170.00	8.60		-25.20		14.10		
Sampling Date	02/06/2017	3/28/2017	3/28/2017	2/8/2017	3/29/2017	2/8/2017	3/29/2017	2/26/2016	2/6/2017	3/29/2017
Field Measurements										
pH (SU)	6.0	6.3	5.7	5.25	4.41	6.12	5.63	5.7	5.5	5.1
Temperature (^{o}C)	15.2	16.9	14.4	15.07	13.85	13.99	12.87	13.5	14.0	14.2
Dissolved Oxygen (DO; mg/L)	0.1	0.2	0.0	4.45	4.22	0.11	0.02	5.0	2.4	1.9
Dissolved Oxygen (DO; %)	0.8	2.2	0.1	-	42.1	-	0.2	-	23.2	18.6
Redox Potential (ORP; mV)	65.1	97.7	57.5	100.8	170.8	-56.1	-29.6	169.7	58.3	139.3
Specific Conductivity (µS/cm)[c]	637.0	6341.0	620.0	918	2139	632	709	477.0	523.0	494.0
Laboratory Analyses										
Nitrogen										
Nitrate as N (mg/L)	<0.03	<0.03	<0.03	**0.601**	**0.299**	<0.03	<0.03	**0.03**	**17.3**	**18.6**
Nitrite as N (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	**0.014**	**0.043**	<0.050	<0.01	<0.01
Ammonia (mg/L)	**11.9**	**11.2**	**13.7**	<0.1	<0.1	-	**4.36**	**0.10**	**0.12**	<0.1
Total Kjeldahl Nitrogen (TKN) (mg/L)	**12.8**	-	NM	**0.61**	-	**5.75**	-	-	**2.19**	-
Total Nitrogen (mg/L)	**12.8**	**17.2**	**2.45**	**1.2**	**0.75**	**5.8**	**5.35**	**1.8**	**19.5**	**18.9**
Alkalinity										
Total Alkalinity (mg/L)	-	-	-	-	-	-	-	-	-	-
Bicarbonate Alkalinity (mg/L)	-	-	-	-	-	-	-	-	-	-
Anions										
Chloride (mg/L)	**49.0**	**46.1**	**43.6**	**324.0**	**774**	**159.0**	**147**	**53.1**	**63.5**	**64.4**
Sulfate (mg/L)	**62.0**	**63.5**	**32.8**	5.0	<5	**14.1**	**18.1**	**27.9**	**55.0**	**49**
Elements										
Dissolved Iron (mg/L)	**0.11**	**0.908**	**0.647**	<0.1	**1.27**	**34.6**	**34.5**	-	**0.10**	**0.12**
Dissolved Manganese (mg/L)	**5.46**	**5.12**	**6.72**	**0.18**	**0.669**	**2.66**	**2.78**	-	**0.11**	**0.075**
Boron (mg/L)	**0.28**	-	NM	<0.05	-	<0.05	-	-	**0.11**	-
Organic Compounds				-		-				
1,4-Dioxane	**2.05**	-	-	-	-	-	-	-	-	-
DOC (mg/L)	**7.0**	-	NM	-	-	-	-	-	-	-
Methane	-	-	-	-	-	-	-	-	-	-

Notes:

Bold - detected above the Minimum Detection Limit

1. TKN and Total Nitrogen data from re-run analysis reported on

E. Data point appears to be in error

(124-134)-Well screen depth below land surface

Table 2 Orleans Landfill Groundwater Analyses

Sample ID	**MW-5D (124-134)**			**MW-5 (140-150**	**MW-E6-A (64-74)**			**MW-E6-B (54-64)**		
Top of Screen Elevation (ft)	-22.00			-38.30	7.60			17.80		
Bottom of Screen Elevation (ft)	-32.00			-48.30	-2.40			7.80		
Sampling Date	2/26/2016	2/6/2017	3/29/2017	3/27/2017	2/10/2016	2/6/2017	3/28/2017	2/10/2016	2/6/2017	3/28/2017[1]
Field Measurements										
pH (SU)	6.1	5.9	5.6	6.1	5.9	5.6	5.8	5.5	5.4	5.2
Temperature (^{o}C)	13.5	13.9	13.8	14.6	13.3	14.9	15.6	12.5	14.9	15.4
Dissolved Oxygen (DO; mg/L)	2.4	0.2	0.0	0.17	0.46	0.15	0.11	1.82	1.45	1.06
Dissolved Oxygen (DO; %)	-	1.9	0.0	1.6	-	1.5	1.1	-	14.5	10.5
Redox Potential (ORP; mV)	87.5	29.4	89.8	195.9	100.0	56.4	85.5	72.4	71.2	119.2
Specific Conductivity (µS/cm)[c]	437.0	441.0	445.0	377.0	672.0	1069.0	1186.0	847.0	743.0	793.0
Laboratory Analyses										
Nitrogen										
Nitrate as N (mg/L)	**11.4**	**0.05**	**0.058**	<0.03	**11.6**	**7.2**	**2.61**	**20.8**	**16.3**	**8.27**
Nitrite as N (mg/L)	<0.050	<0.01	<0.01	<0.01	<0.050	<0.01	<0.01	<0.050	<0.01	<0.01
Ammonia (mg/L)	**15.3**	**12.7**	**14**	**9.34**	**0.10**	<0.1	<0.1	**0.10**	**0.11**	<0.1
Total Kjeldahl Nitrogen (TKN) (mg/L)	-	**13.9**	-	NM	-	**1.7**	-	-	**1.50**	**1.3**
Total Nitrogen (mg/L)	**26.8**	**13.9**	**16**	**10.6**	**12.6**	**8.9**	**3.94**	**21.2**	**17.8**	**9.60**
Alkalinity										
Total Alkalinity (mg/L)	-	-	-	-	-	-	-	-	-	-
Bicarbonate Alkalinity (mg/L)	-	-	-	-	-	-	-	-	-	-
Anions										
Chloride (mg/L)	**61.2**	**66.1**	**70.1**	**39.6**	**143.0**	**280.0**	**331**	**115.0**	**151.0**	**167**
Sulfate (mg/L)	**45.2**	**24.0**	**23.8**	**39.5**	**55.5**	**34.4**	**27.8**	**52.5**	**41.5**	**43.5**
Elements										
Dissolved Iron (mg/L)	-	**0.62**	**0.608**	**0.113**	**0.05**	**0.15**	**0.107**	**0.05**	**0.16**	<0.1
Dissolved Manganese (mg/L)	-	**0.52**	**0.584**	**1.37**	**0.02**	**0.05**	**0.05**	**0.02**	**0.04**	**0.026**
Boron (mg/L)	-	**0.06**	-	NM	**0.14**	**0.10**	-	**0.14**	**0.11**	-
Organic Compounds										
1,4-Dioxane	-	-	-	<0.25	-	<0.25	-	-	<0.25	-
DOC (mg/L)	-	-	-	-	**7.6**	**8.1**	-	**7.6**	**6.7**	-
Methane	-	-	-	-	-	-	-	-	-	-

Notes:

Bold - detected above the Minimum Detection Limit

1. TKN and Total Nitrogen data from re-run analysis reported on

E. Data point appears to be in error

(124-134)-Well screen depth below land surface

Table 2 Orleans Landfill Groundwater Analyses

Sample ID	**MW-6 (88-98)**		**MW-7S (55-65)**			**MW-7D (115-125)**		**MW-7(90-100)**	**MW-8 (36-46)**		**MW-8 (84-94)**
Top of Screen Elevation (ft)	-15.80		14.80			-45.10		-20.30	23.10		-24.80
Bottom of Screen Elevation (ft)	-25.80		4.80			-55.10		-30.30	13.10		-34.80
Sampling Date	02/06/2017	3/28/2017[1]	02/06/2017	02/06/2017 (DUP)	3/28/2017	02/06/2017	3/28/2017[1]	3/28/2017	2/8/2017	3/27/2017	3/27/2017
Field Measurements											
pH (SU)	6.5	6.6	5.7	5.7	5.2	6.2	6.3	5.5	4.5	4.0	5.8
Temperature (^{o}C)	14.0	14.7	12.7	12.7	13.4	12.7	12.9	12.5	14.6	13.8	13.4
Dissolved Oxygen (DO; mg/L)	0.12	0.15	0.69	0.69	0.04	0.2	0.2	0.0	2.1	2.9	0.4
Dissolved Oxygen (DO; %)	1.2	1.5	6.5	6.5	0.4	1.9	2.2	0.1	20.5	28.5	3.7
Redox Potential (ORP; mV)	-82.1	-36.0	39.4	39.4	115.1	-64.1	2.0	-7.2	175.6	179.8	156.3
Specific Conductivity (µS/cm)[c]	900.0	991.0	665.0	665.0	1229.0	510.0	482.0	1534.0	397.0	351.0	297.0
Laboratory Analyses											
Nitrogen											
Nitrate as N (mg/L)	**0.1**	<0.03	**8.7**	**12.8**	**4.96**	<0.03	<0.03	**0.154**	**5.5**	**3.83**	**5.14**
Nitrite as N (mg/L)	<0.01	<0.01	<0.01	<0.01	**0.012**	<0.01	<0.01	**0.015**	<0.01	<0.01	**0.159**
Ammonia (mg/L)	**0.12**	**22.6**	**0.34**	**0.13**	**0.15**	**2.74**	**2.59**	**0.19**	**0.11**	**0.18**	**0.13**
Total Kjeldahl Nitrogen (TKN) (mg/L)	**24.10**	**25.0**	**1.92**	**2.38**	**-**	**3.17**	**3.2**	NM	**2.03**	**-**	NM
Total Nitrogen (mg/L)	**24.2**	**25.0**	**10.6**	**15.2**	**8.67**	**3.2**	**3.2**	**1.06**	**7.6**	**4.84**	**881**[E]
Alkalinity											
Total Alkalinity (mg/L)	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Bicarbonate Alkalinity (mg/L)	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Anions											
Chloride (mg/L)	**173.0**	**196**	**127.0**	**124.0**	**369**	**55.3**	**57.2**	**428**	**55.1**	**66.4**	**37.8**
Sulfate (mg/L)	**22.5**	**21.5**	**29.6**	**33.6**	**15.5**	**36.2**	**34.2**	**18.7**	**37.8**	**24.3**	**16.9**
Elements											
Dissolved Iron (mg/L)	**18.40**	**13.5**	**0.34**	**0.27**	**0.216**	**18.30**	**17.5**	**7.51**	<0.1	<0.1	<0.1
Dissolved Manganese (mg/L)	**2.49**	**2.39**	**0.02**	**0.02**	**0.031**	**3.21**	**2.72**	**0.331**	**0.10**	**0.301**	**0.406**
Boron (mg/L)	**0.24**	**-**	**0.08**	**0.08**	**-**	**0.14**	**-**	NM	**0.09**	**-**	NM
Organic Compounds											
1,4-Dioxane	**0.687**	**-**	<0.25	**-**	**-**	**1.7**	**-**	<0.25	<0.25	-	**0.649**
DOC (mg/L)	8.8	**-**	**-**	**-**	**-**	**-**	**-**	NM	**4.4**	**-**	**-**
Methane	**-**	**-**	**-**	**-**	<2	**-**	<2	<2	**-**	**-**	**-**

Notes:
Bold - detected above the Minimum Detection Limit
1. TKN and Total Nitrogen data from re-run analysis reported on
E. Data point appears to be in error
(124-134)-Well screen depth below land surface

Table 2 Orleans Landfill Groundwater Analyses

Sample ID	**MW-9 (92-102)**		**MW-10 (85-95)**		**MW-13 (74-84)**	**MW-11 (91-101)**	**MW-12 (87-97)**
Top of Screen Elevation (ft)	13.50		9.00		-17.00	-41.60	NA
Bottom of Screen Elevation (ft)	9.00		-1.00		-27.00	-51.60	NA
Sampling Date	2/8/2017	3/29/2017	2/8/2017	3/28/2017	3/29/2017	3/29/2017	3/29/2017
Field Measurements							
pH (SU)	5.0	4.4	5.6	5.4	5.3	5.8	5.4
Temperature (^{o}C)	15.9	15.5	14.6	15.9	13.1	12.2	13.1
Dissolved Oxygen (DO; mg/L)	7.4	7.8	9.4	8.5	0.8	0.8	0.3
Dissolved Oxygen (DO; %)	**-**	76.1	**-**	81.5	7.9	7.4	2.4
Redox Potential (ORP; mV)	139.1	185.6	118.9	117.8	49.9	112.1	102.5
Specific Conductivity (µS/cm)[c]	297.0	327.0	175.0	176.0	480.0	152.0	179.0
Laboratory Analyses							
Nitrogen							
Nitrate as N (mg/L)	**20.2**	**6.37**	**2.4**	**2.5**	**1.18**	**0.239**	**0.142**
Nitrite as N (mg/L)	<0.01	<0.01	<0.01	<0.01	**0.013**	<0.01	<0.01
Ammonia (mg/L)	**0.34**	<0.1	<0.1	<0.1	**0.11**	<0.1	<0.1
Total Kjeldahl Nitrogen (TKN) (mg/L)	**2.83**	**-**	**0.85**	**-**	**-**	**-**	**-**
Total Nitrogen (mg/L)	**23.0**	**6.65**	**3.3**	**2.83**	**1.58**	**0.54**	**0.46**
Alkalinity							
Total Alkalinity (mg/L)	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Bicarbonate Alkalinity (mg/L)	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Anions							
Chloride (mg/L)	**65.5**	**60.8**	**42.9**	**39.1**	**127**	**30.9**	**43.2**
Sulfate (mg/L)	**15.5**	**34.6**	<5	**6.1**	**22.5**	**12.1**	**8.3**
Elements							
Dissolved Iron (mg/L)	<0.1	<0.1	<0.1	**0.375**	**6.67**	<0.1	<0.1
Dissolved Manganese (mg/L)	**0.49**	**0.052**	**0.07**	**0.028**	**0.447**	**0.501**	**0.08**
Boron (mg/L)	<0.05	**-**	<0.05	**-**	**-**	**-**	**-**
Organic Compounds							
1,4-Dioxane	<0.25	-	<0.25	**-**	<0.25	<0.25	<0.25
DOC (mg/L)	**1.6**	**-**	<0.5	**-**	**-**	**-**	**-**
Methane	**-**	**-**	**-**	**-**	**-**	**-**	**-**

Notes:

Bold - detected above the Minimum Detection Limit

1. TKN and Total Nitrogen data from re-run analysis reported on

E. Data point appears to be in error

(124-134)-Well screen depth below land surface

Table 3 Orleans Landfill Groundwater Elevations

Well ID	Location	TOC Elevation (ft)	Depth to Water (ft)				GW Elevation (ft)	Notes
			2/3/2017	2/6/2017	2/28/2017	03/27/2017-03/29/2017		
MW-1S (56-66)	Landfill	85.18	61.95	62.0	61.88	-	23	Perched Water
MW-1D (99-109)	Landfill	85.11	70.60	70.5	70.33	-	15	
MW-2S (84-94)	Landfill	101.49	87.90	-	87.63	-	14	
MW-2D (124-134)	Landfill	101.42	88.42	88.4	88.20	-	13	
MW-2 (140-150) *	Landfill	102.80	89.82	-	89.60	89.38	13	
MW-2 (161-171)	Landfill	101.40	NI	NI	NI	89.57	12	
MW-3S (50-60)	Landfill	70.32	54.20	55.3	54.94	-	15	
MW-3D (84-94)	Landfill	69.74	54.90	55.0	54.66	-	15	
MW-5S (78-88)	ROW	103.91	90.28	-	89.94	-	14	
MW-5D (124-134)	ROW	103.89	89.90	-	89.67	-	14	
MW-5 (140-150)	ROW	101.68	NI	NI	NI	89.50	12	
MW-6A (64-74)	Landfill	71.22	56.35	56.4	56.41	-	15	
MW-6B (54-64)	Landfill	71.40	56.40	56.5	56.33	-	15	
MW-6C (52-62)	Landfill	71.55	NS	NS	NS	-	NA	
MW-E6 (88-98)*	Landfill	71.91	57.77	57.8	57.51	-	14	
MW-7S (55-65) *	Landfill	71.64	66.50	56.6	56.22	56.31	15	
MW-7D (115-125) *	Landfill	71.66	57.30	57.3	57.03	56.92	15	
MW-7 (90-100)	Landfill	69.70	NI	NI	NI	56.66	13	
MW-8 (36-46)*	Giddiah Hill Rd	58.80	35.05	34.9	34.62	34.45	24	Perched Water
MW-8 (84-94)	Giddiah Hill Rd	58.80	NI	NI	NI	43.07	NA	
MW-9 (92-102)*	Landfill	107.32	93.50	93.3	93.11	-	14	
MW-10 (85-95)*	Finlay Rd	93.69	81.12	82.1	80.95	-	13	
MW-13 (74-84)	Landfill	57.00	NI	NI	NI	44.07	13	
MW-11 (91-101)	Elementary School	48.97	NI	NI	NI	37.58	11	
MW-12 (87-97)	Snow Library	NA	NI	NI	NI	35.67	NA	

NS- no sampled

NI- not installed

NA- not available

Table 4 Orleans Landfill Stormwater Analyses

Sample ID	**Stormwater 1**	**Stormwater 2**
Sample Description	Transfer Station Runoff	Compost Runoff
Sampling Date	2/8/2017	2/8/2017
Laboratory Analyses		
Nitrogen		
Nitrate as N (mg/L)	**0.424**	**10.5**
Nitrite as N (mg/L)	**0.026**	**0.15**
Ammonia (mg/L)	**0.67**	**2.92**
Total Kjeldahl Nitrogen (TKN) (mg/L)	**4.05**	**16.4**
Total Nitrogen (mg/L)	**4.5**	**27.1**
Anions		
Chloride (mg/L)	**455**	**188**
Sulfate (mg/L)	<5	**5.9**
Organic Compounds		
DOC (mg/L)	**39.6**	**175**

Notes:

Bold - detected above the Minimum Detection Limit

Table 5 Orleans Landfill Septage Lagoon Soil Analyses

Sample ID	**MW-7/12-13'**	**MW-7/13.5-14.5'**	**MW-7/15-17'**	**MW-7/42-44'**	**MW-7/57-58'**
Sampling Date	**01/18/2017**	**01/18/2017**	**01/19/2017**	**01/19/2017**	**01/19/2017**
Laboratory Analyses					
Nitrogen					
Nitrate/Nitrite as N	**0.32**	<0.25	<0.24	**0.76**	<0.23
Total Kjeldahl Nitrogen as N	**1440**	<93.2	**160**	<78	<86.7
Total Nitrogen	**1440**	<93.5	**160**	<78.2	<86.9
Other					
Total Volatile Solids	**4**	<1	<1	<1	<1

Notes:

Bold - detected above the Minimum Detection Limit

Table 6 Orleans Compost Leachate Analyses

Sample ID	LS-1
Top of Screen Elevation (ft)	
Bottom of Screen Elevation (ft)	
Sampling Date	3/28/2017
Field Measurements	
pH (SU)	
Temperature (^{o}C)	
Dissolved Oxygen (DO; mg/L)	
Dissolved Oxygen (DO; %)	
Redox Potential (ORP; mV)	
Specific Conductivity (µS/cm)[c]	
Laboratory Analyses	
Nitrogen	
Nitrate as N (mg/L)	**1.2**
Nitrite as N (mg/L)	**0.428**
Ammonia (mg/L)	**4.94**
Total Kjeldahl Nitrogen (TKN) (mg/L)	-
Total Nitrogen (mg/L)	**98.5**
Alkalinity	
Total Alkalinity (mg/L)	-
Bicarbonate Alkalinity (mg/L)	-
Anions	
Chloride (mg/L)	-
Sulfate (mg/L)	-
Elements	
Dissolved Iron (mg/L)	-
Dissolved Manganese (mg/L)	-
Boron (mg/L)	-
Organic Compounds	
1,4-Dioxane	-
DOC (mg/L)	-
Methane	-

Notes:

Bold - detected above the Minimum Detection Limit

1. TKN and Total Nitrogen data from re-run analysis reported on 4/24/17.

E. Data point appears to be in error

(124-134)-Well screen depth below land surface

Figures

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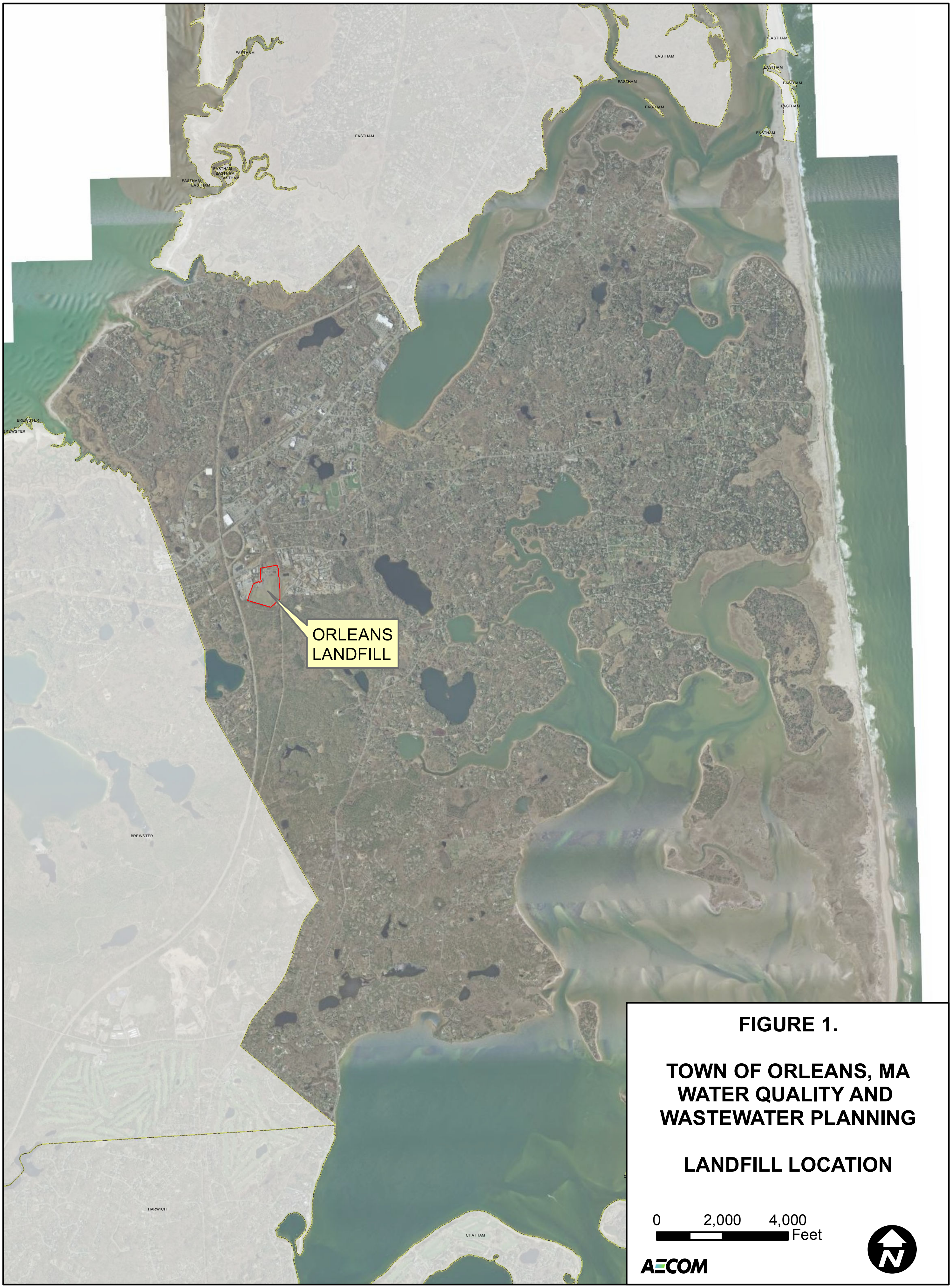

FIGURE 1.

TOWN OF ORLEANS, MA
WATER QUALITY AND WASTEWATER PLANNING

LANDFILL LOCATION

AECOM

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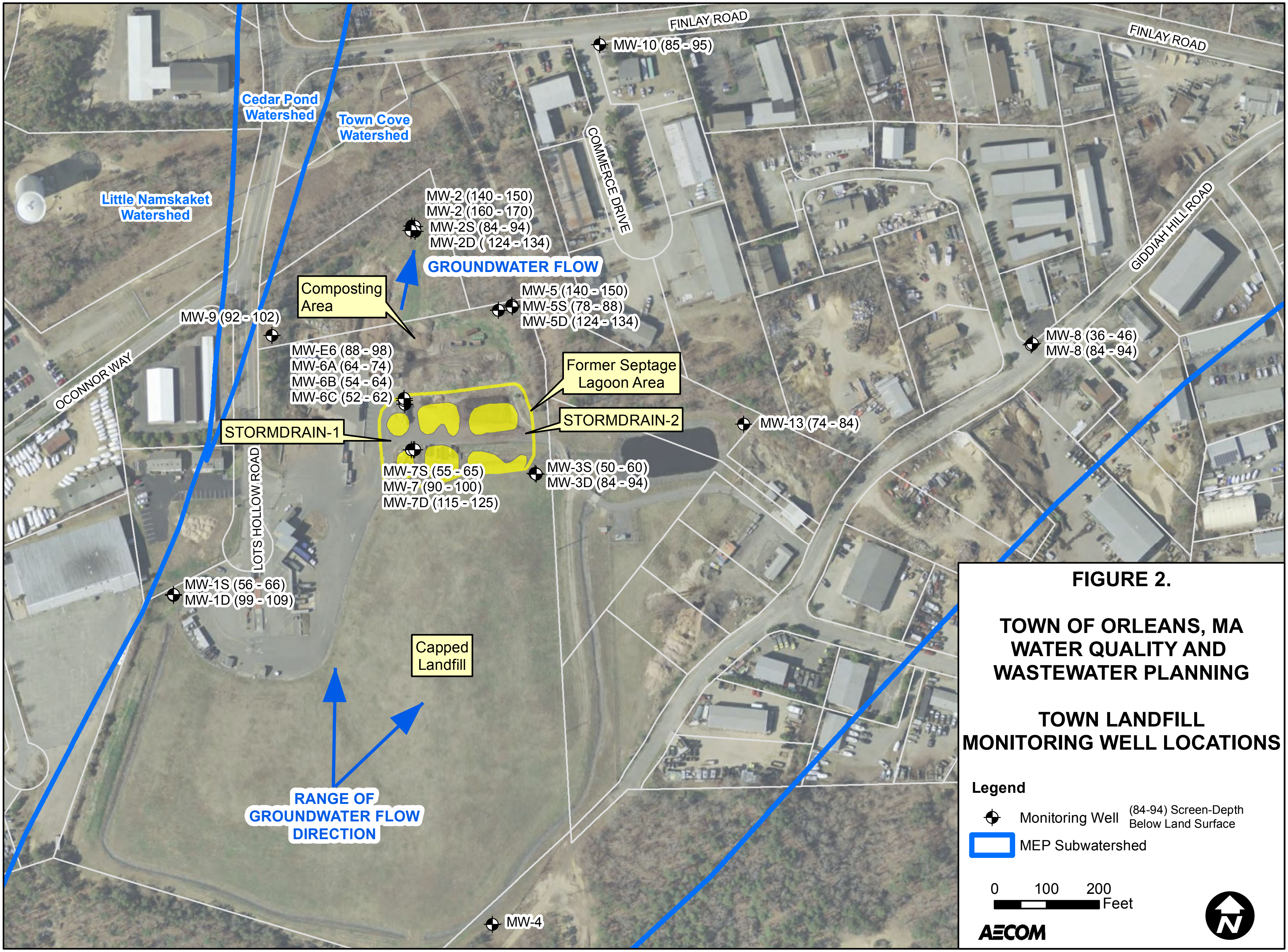

FIGURE 2.

TOWN OF ORLEANS, MA
WATER QUALITY AND WASTEWATER PLANNING

TOWN LANDFILL
MONITORING WELL LOCATIONS

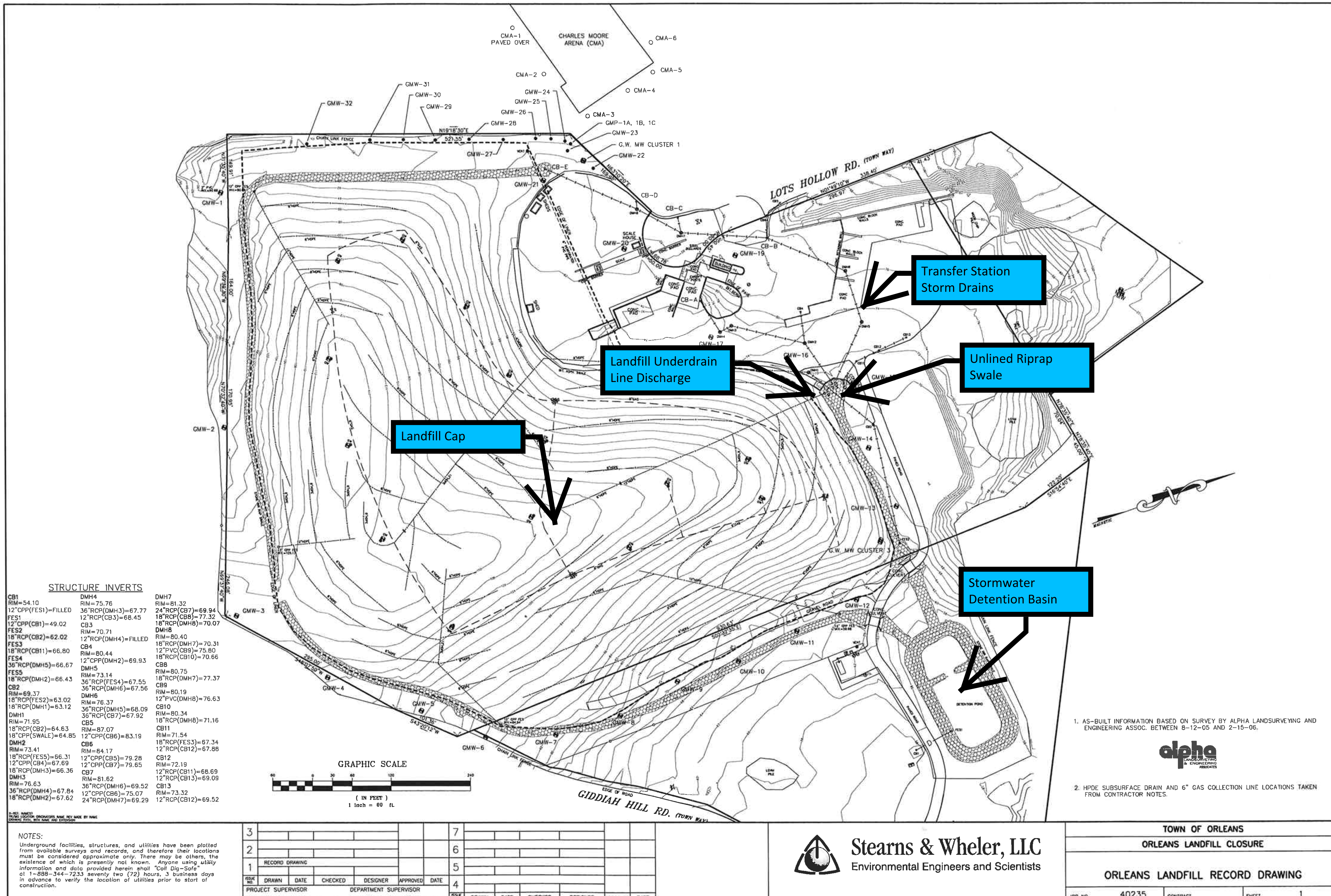

Figure 3 - Landfill Stormwater Management System

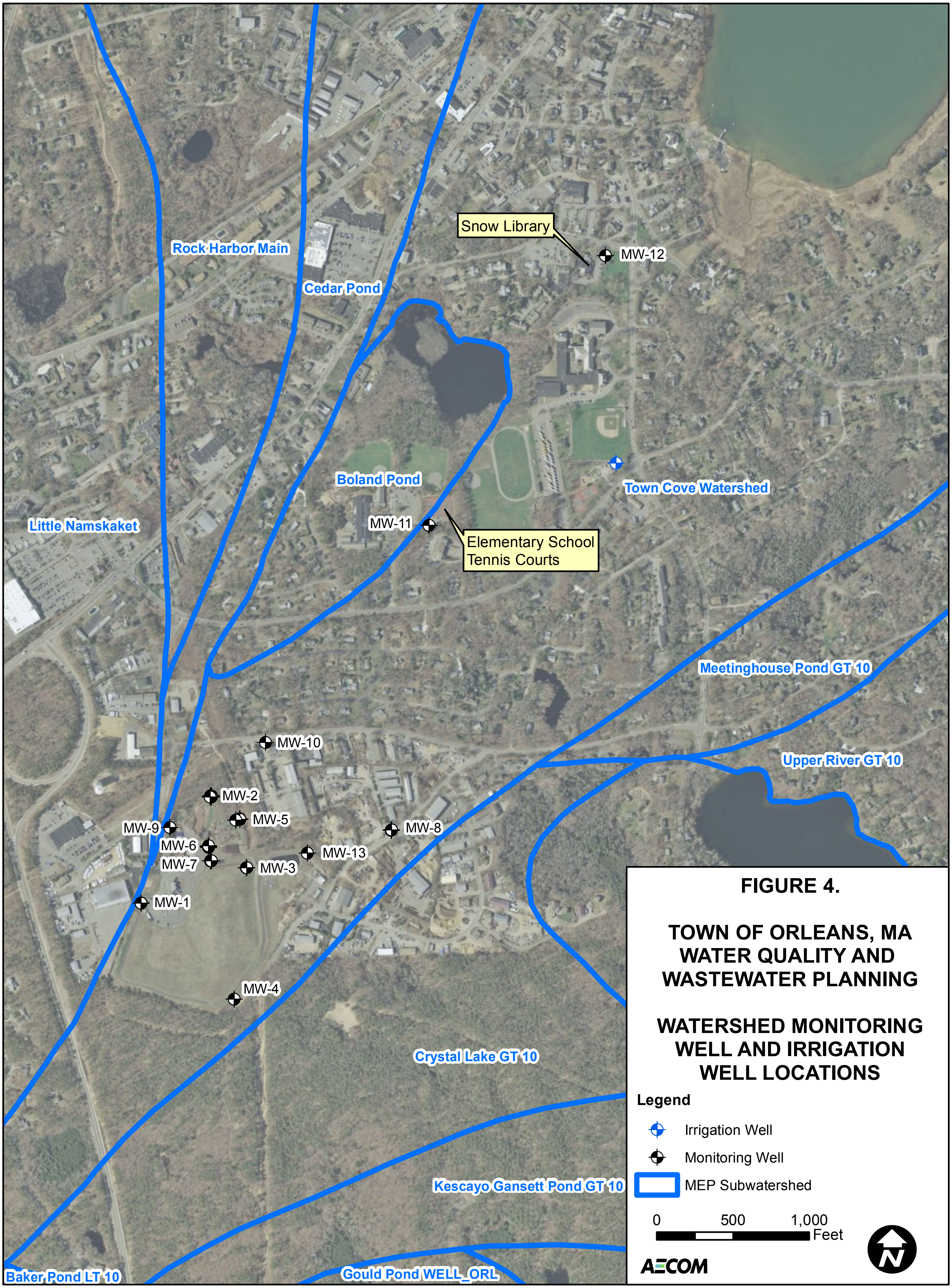

FIGURE 4.

TOWN OF ORLEANS, MA
WATER QUALITY AND WASTEWATER PLANNING

WATERSHED MONITORING WELL AND IRRIGATION WELL LOCATIONS

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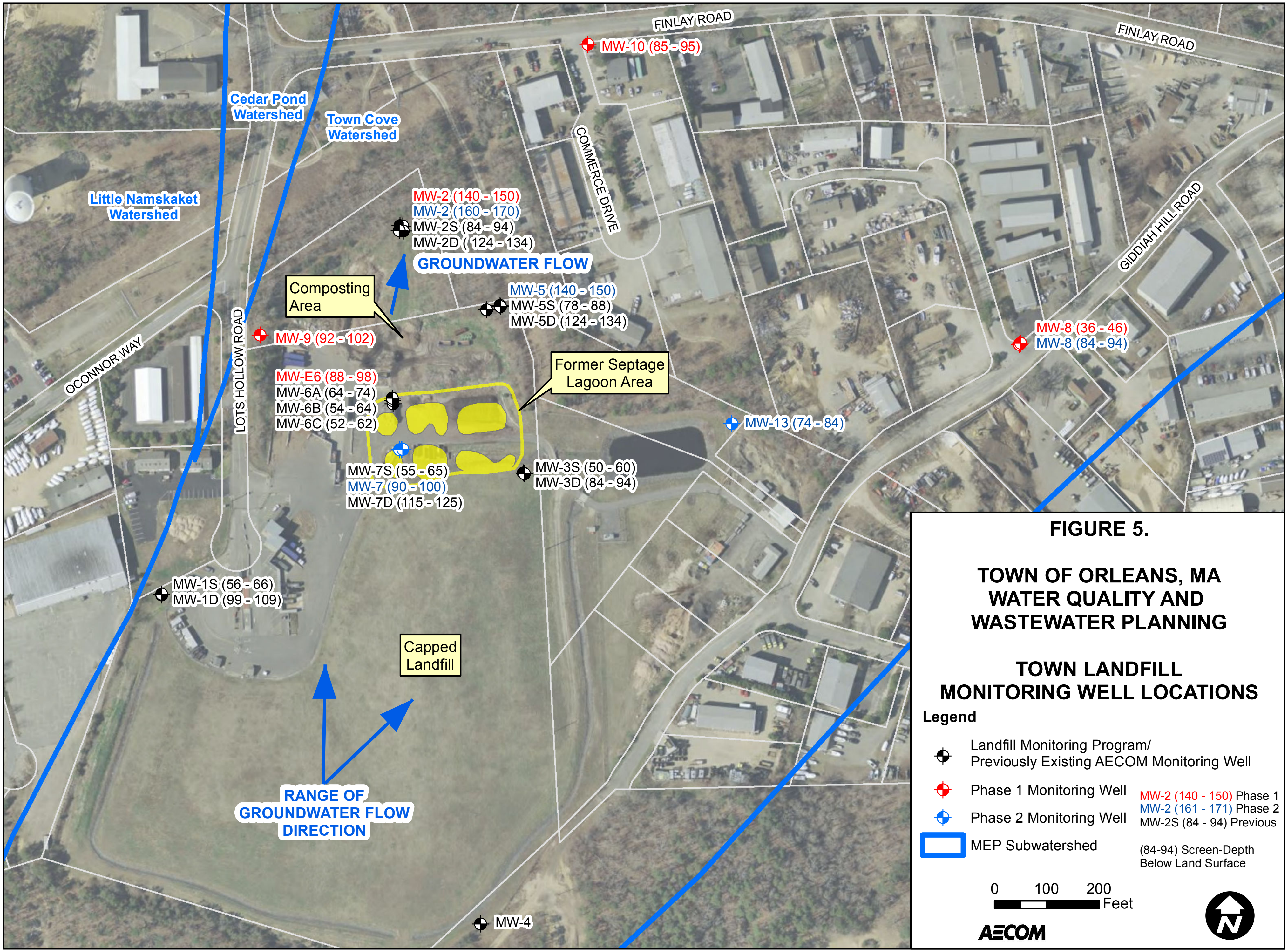

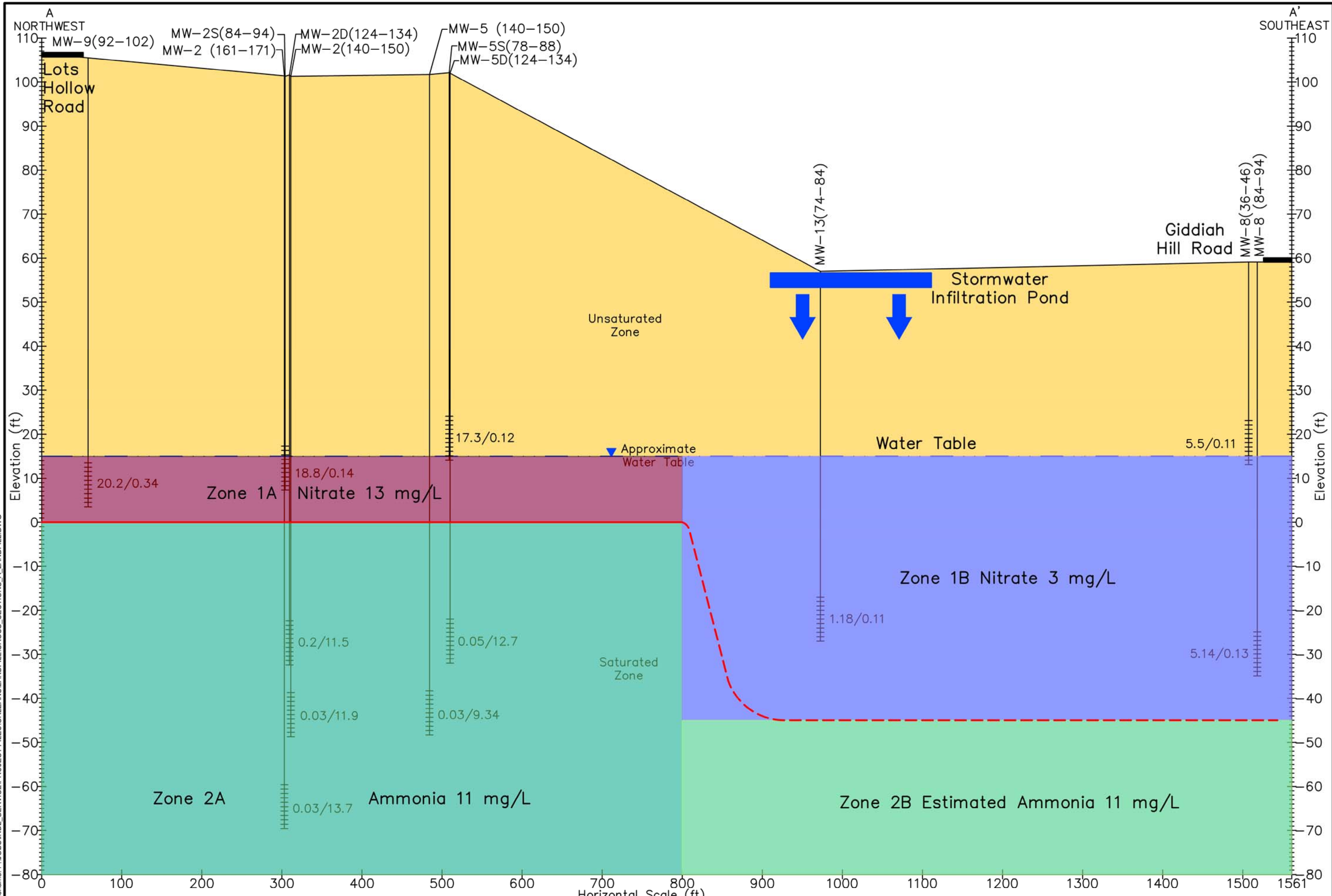

AECOM Figure: 6

LANDFILL CROSS SECTION A-A': NITROGEN DATA
WATER QUALITY AND WASTEWTER PLANNING
TOWN OF ORLEANS, MA
Project No.: 60476644 Date: 2017-07-28

ANSI B 11" x 17"
Project Management Initials: Designer: Checked: Approved:
Last saved by: BOURDEAUJ(2017-07-28) Last Plotted: 2017-07-28
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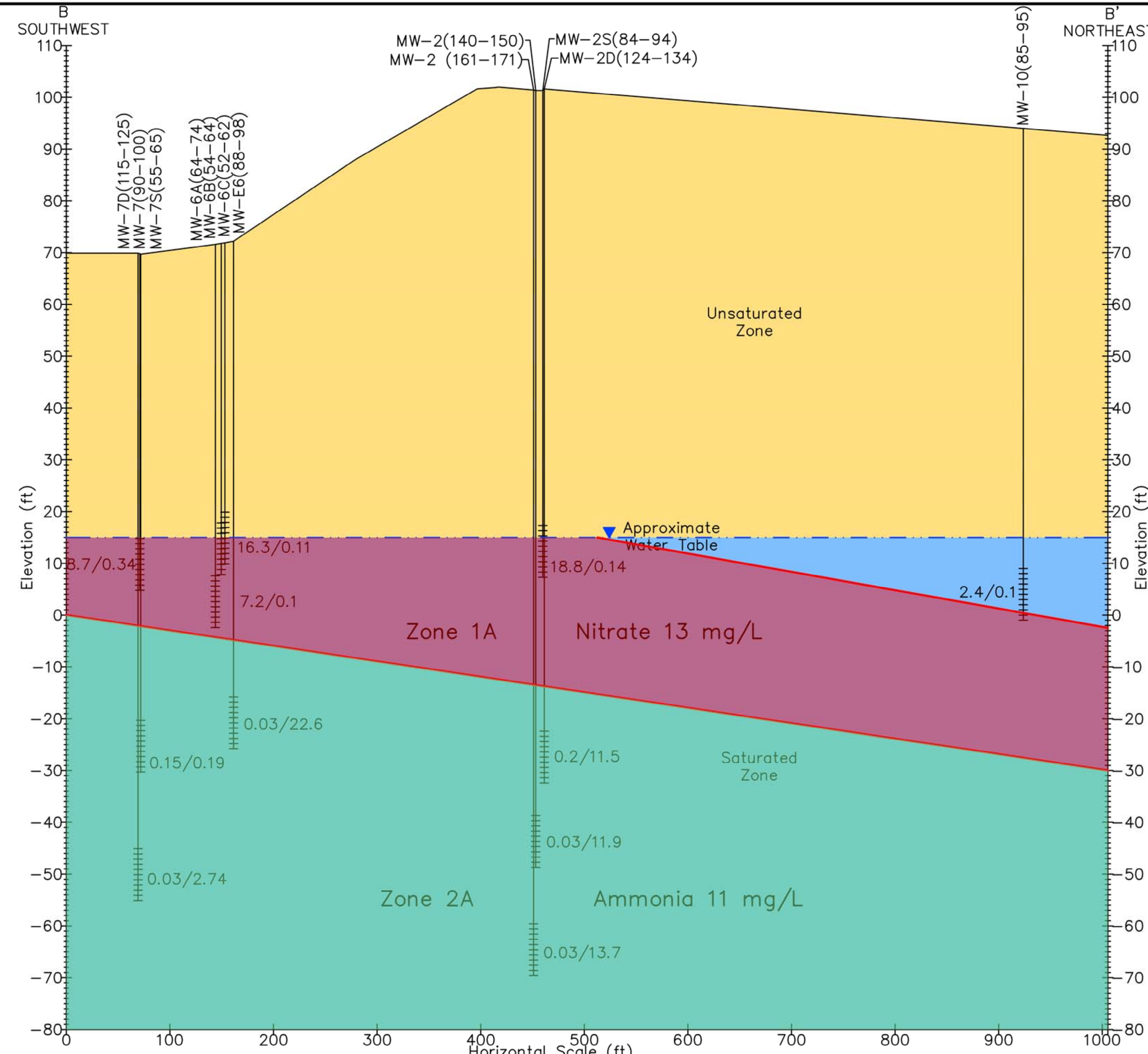

NITRATE-N/AMMONIA-N

NOTE:
DATA REPRESENTATIVE BASED ON SAMPLING EVENTS CONDUCTED IN FEBRUARY AND MARCH 2017.

LANDFILL CROSS SECTION B-B': NITROGEN DATA
WATER QUALITY AND WASTEWTER PLANNING
TOWN OF ORLEANS, MA
Project No.: 60476644 Date: 2017-07-28

AECOM
Figure: 7

Project Management Initials: Designer: Checked: Approved: ANSI B 11" x 17"

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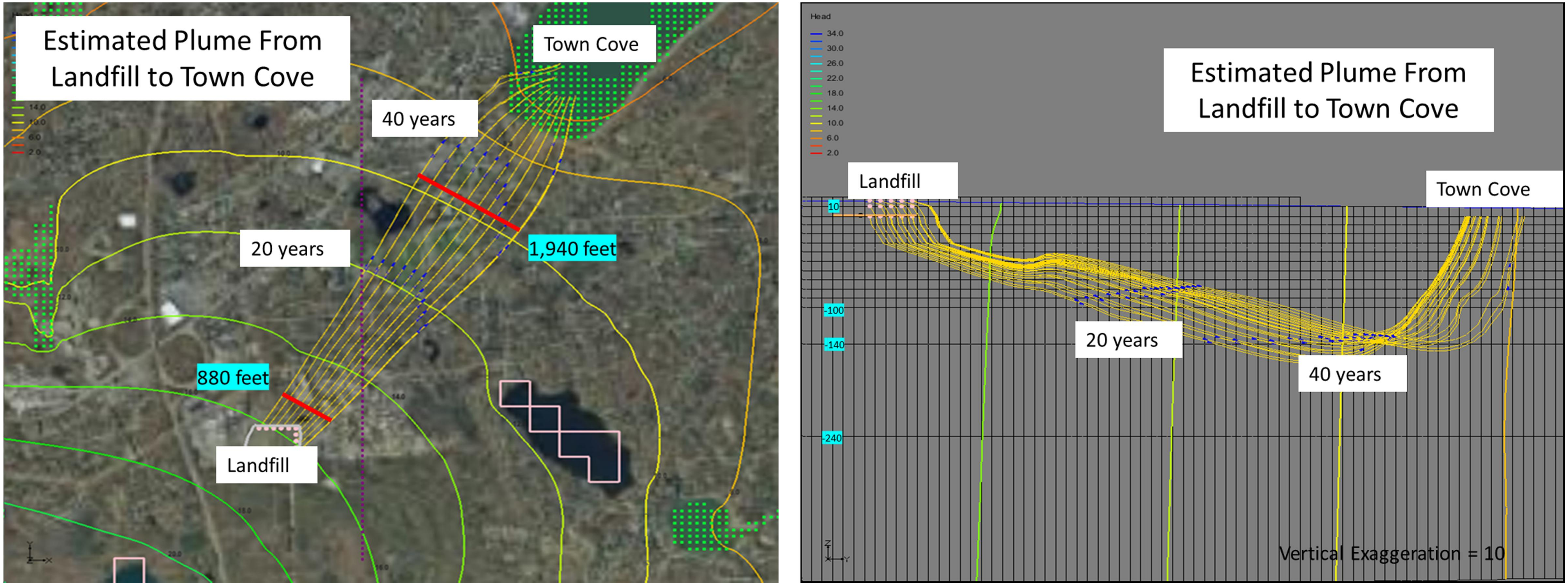

FIGURE 8

TOWN OF ORLEANS, MA
WATER QUALITY AND WASTEWATER PLANNING

LANDFILL GROUNDWATER FLOW –
PARTICLE TRACKING

AECOM

Appendix A – Barnstable County Health Department Historical Nitrate Data

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Appendix A - Summary of Landfill Monitoring Wells Nitrate Data (BCHD)

	MW-1S	MW-1D	MW-2S	MW-2D	MW-3S	MW-3D	MW-4S	MW-4D	MW-5S	MW-5D
Date	Nitrate	Nitrate	Nitrate	Nitrate	Nitrate	Nitrate	Nitrate	Nitrate	Nitrate	Nitrate
	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
Sep-94	5.15	NS	2.40	2.10	0.15	0.10	NS	0.03	6.60	0.1
Jan-95	<.1	NS	5.40	3.20	0.13	0.13	NS	0.02	**10.30**	0.22
May-95	0.20	NS	9.50	4.60	0.19	0.20	<.02	<.02	9.30	0.3
Aug-95	<.1	NS	0.90	1.70	0.30	<.02	<.02	<.02	**12.90**	0.40
Jul-98	<.02	NS	4.60	1.50	<.02	<.02	<.02	<.02	**17.00**	<.02
Aug-99	<.02	NS	4.80	1.50	0.09	<.02	0.09	0.02	**15.00**	<.02
Apr-00	0.07	NS	3.90	0.20	0.06	0.05	<.01	<.01	9.60	<.02
Dec-00	NS	NS	3.70	0.40	1.00	<.01	<.01	<.01	**10.00**	<.01
Mar-05	0.03	NS	1.90	**11.00**	7.70	NS	0.05	NS	9.80	<.01
Jul-05	4.50	NS	**18.00**	1.00	NS	0.98	<.01	<.01	**10.00**	7.90
Feb-06	0.22	NS	**11.00**	**11.00**	NS	0.67	<.01	0.11	**18.00**	1.00
Sep-06	0.46	2.10	**19.00**	**15.00**	NS	0.32	0.93	<.01	**14.00**	0.21
Mar-07	0.25	3.00	**16.00**	7.30	NS	ND	5.60	<.01	**12.00**	<.01
Oct-07	1.90	NS	**31.00**	4.30	NS	ND	2.70	<.01	**12.00**	<.01
Apr-08	2.20	NS	**32.00**	8.90	NS	ND	5.50	0.1	**15.00**	<.01
Sep-08	**16.00**	NS	8.90	9.00	NS	ND	2.80	<.01	**13.00**	<.01
May-09	1.80	NS	**30.00**	2.00	NS	ND	3.60	<.01	**21.00**	<.01
Sep-09	**13.00**	NS	**40.00**	1.20	NS	0.53	2.50	<.01	**12.00**	0.30
Apr-10	2.60	NS	**17.00**	5.60	NS	0.20	4.20	<.01	**10.00**	0.10
Sep-10	**13.00**	NS	**28.00**	0.66	NS	0.25	2.40	<.01	**22.00**	0.15
Mar-11	1.80	NS	**28.00**	0.73	NS	0.39	4.00	<.01	**12.00**	0.19
Jun-11	1.50	NS	**26.00**	0.71	NS	0.26	1.40	0.15	8.40	0.51
Mar-12	0.54	NS	**27.00**	1.30	0.9	0.44	1.60	<.01	9.70	0.28
Sep-12	10.00	NS	**27.00**	<.02	<.01	<.01	1.40	<.01	**12.00**	<.01
Apr-13	3.30	NS	**38.00**	4.10	0.67	0.60	6.60	0.18	**17.00**	0.38
Sep-13	1.60	NS	**37.00**	**12.00**	<.01	0.01	2.90	<.01	8.70	0.73
Mar-14	1.80	NS	**34.00**	8.10	1.70	1.20	1.00	0.12	**14.00**	3.80
Oct-14	5.70	NS	**23.00**	1.80	2.70	1.40	2.00	<.01	**12.00**	<.01
May-15	2.20	NS	**20.00**	4.20	<.01	0.94	2.70	<.01	9.50	<.01
Oct-15	5.00	NS	**25.00**	0.94	0.36	0.27	1.10	<.01	**11.00**	0.14
Mar-16	1.70	NS	**22.00**	3.80	7.3	<.01	1.40	<.01	**12.00**	<.01

Notes: Concentration Greater than Groundwater Standard of 10 mg/L in Bold
NS = Not Sampled

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Appendix B – Nitrogen Groundwater Flux

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Town of Orleans, Massachusetts
Water Quality and Wastewater Planning
Non-Traditional Technologies - Landfill Nitrogen Flux (DRAFT)
Estimated Nitrogen flux (mass per time) at the Orleans Landfill.

Zone 1A Nitrate

Parameter	Units	Low Range Flux	High Range Flux	Mid Range Flux
Groundwater Seepage Velocity (Variable)	ft/d	0.30	3.00	1.00
Porosity	unitless	0.30	0.30	0.30
Darcy Velocity	ft/d	0.09	0.90	0.30
Vertical Extent	feet	15.00	15.00	15.00
Length of Affected Aquifer[1]	feet	800	800	800
Groundwater Flux	ft3 / d-ft length	1.35	13.50	4.50
Groundwater Flux	ft3 / day	1080	10800	3600
Groundwater Flux	L/day	30582	305821	101940
Groundwater Flux	Gallons/min	5.61	56.10	18.70
Nitrate Concentration	mg/L	13.00	13.00	13.00
Nitrate Flux	kg /yr-ft length	0.18	1.81	0.60
Nitrogen Flux	kg/year	145	1451	484

1. Affected Aquifer length - cross-gradient line across watershed at landfill

Town of Orleans, Massachusetts
Water Quality and Wastewater Planning
Non-Traditional Technologies - Landfill Nitrogen Flux (DRAFT)
Estimated Nitrogen flux (mass per time) at the Orleans Landfill.

Zone 1B Nitrate

Parameter	Units	Low Range Flux	High Range Flux	Mid Range Flux
Groundwater Seepage Velocity (Variable)	ft/d	0.30	3.00	1.00
Porosity	unitless	0.30	0.30	0.30
Darcy Velocity	ft/d	0.09	0.90	0.30
Vertical Extent	feet	60	60	60
Length of Affected Aquifer[1]	feet	800	800	800
Groundwater Flux	ft3 / d-ft length	5.40	54.00	18.00
Groundwater Flux	ft3 / day	4320	43200	14400
Groundwater Flux	L/day	122329	1223286	407762
Groundwater Flux	Gallons/min	22	224	75
Nitrate Concentration	mg/L	3.00	3.00	3.00
Nitrate Flux	kg /yr-ft length	0.17	1.67	0.56
Nitrogen Flux	kg/year	134	1339	446

1. Affected Aquifer length - cross-gradient line across watershed at landfill

Town of Orleans, Massachusetts
Water Quality and Wastewater Planning
Non-Traditional Technologies - Landfill Nitrogen Flux (DRAFT)
Estimated Nitrogen flux (mass per time) at the Orleans Landfill.

Zone 2A Ammonia

Parameter	Units	Low Range Flux	High Range Flux	Mid Range Flux
Groundwater Seepage Velocity (Variable)	ft/d	0.30	3.00	1.00
Porosity	unitless	0.30	0.30	0.30
Darcy Velocity	ft/d	0.09	0.90	0.30
Vertical Extent	feet	80	80	80
Length of Affected Aquifer[1]	feet	800	800	800
Groundwater Flux	ft3 / d-ft length	7	72	24
Groundwater Flux	ft3 / day	5760	57600	19200
Groundwater Flux	L/day	163105	1631048	543683
Groundwater Flux	Gallons/min	30	299	100
Ammonia Concentration	mg/L	11.00	11.00	11.00
Ammonia Flux (adjusted by ammonia retardation factor of 4)	kg /yr-ft length	0.20	2.05	0.68
Nitrogen Flux (adjusted by ammonia retardation factor of 4)	kg/year	164	1637	546

1. Affected Aquifer length - cross-gradient line across watershed at landfill

Town of Orleans, Massachusetts
Water Quality and Wastewater Planning
Non-Traditional Technologies - Landfill Nitrogen Flux (DRAFT)
Estimated Nitrogen flux (mass per time) from the Orleans Landfill.

Zone 2B Ammonia

Parameter	Units	Low Range Flux	High Range Flux	Mid Range Flux
Groundwater Seepage Velocity (Variable)	ft/d	0.30	3.00	1.00
Porosity	unitless	0.30	0.30	0.30
Darcy Velocity	ft/d	0.09	0.90	0.30
Vertical Extent	feet	35.00	35.00	35.00
Length of Affected Aquifer[1]	feet	800	800	800
Groundwater Flux	ft3 / d-ft length	3.15	31.50	10.50
Groundwater Flux	ft3 / day	2520	25200	8400
Groundwater Flux	L/day	71358	713583	237861
Groundwater Flux	Gallons/min	13.09	130.91	43.64
Ammonia Concentration	mg/L	11.00	11.00	11.00
Ammonia Flux (adjusted by ammonia retardation factor of 4)	kg /yr-ft length	0.09	0.90	0.30
Nitrogen Flux (adjusted by ammonia retardation factor of 4)	kg/year	72	716	239

1. Affected Aquifer length - cross-gradient line across watershed at landfill