AECOM
9 Jonathan Bourne Drive
Pocasset, MA 02559
www.aecom.com

508.833.6950 tel
508.833.6951 fax

Memorandum

To	George Meservey, Director of Planning & Community Development
CC	Betsy Shreve, AICP, AECOM Project Director James Begley, LSP, MT Environmental AECOM PRB Team
Subject	**Town of Orleans, MA Water Quality and Wastewater Planning Task Number 11.1.B.2 – NT Demonstration Projects Technical Memorandum for Landfill Groundwater Assessment Update and Nitrogen Response Plan**
Project Number	60476644
From	Thomas Parece, P.E., AECOM Project Manager
Date	July 26, 2018

Approvals	Date	Signature / Initials
George Meservey, Orleans, MA Director of Planning & Community Development		

1. Introduction

This Landfill Nitrogen Response Plan Technical Memorandum provides an updated assessment of groundwater conditions and potential response actions to mitigate sources of groundwater nitrogen and the flux of nitrogen migrating in groundwater from the Orleans Municipal Landfill (the landfill) toward Town Cove in Orleans, Massachusetts. Initial landfill investigations were completed in the spring of 2017 were summarized in the Final Phase 2 Technical Memorandum for Landfill Nitrogen Field Investigation dated September 25, 2017. Additional groundwater investigations including monitoring well installation and sampling and pumping tests (the Phase 3 investigation) were completed in late 2017. Phase 3 analyses were in part undertaken to provide additional information requested by UMass Dartmouth's School for Marine Science & Technology (SMAST) and to further define the nitrogen source and presence in groundwater at the landfill.

2. Orleans Landfill Site Description and Background

A. 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 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 to the north of the capped solid waste area. Landfill cap drainage from the north side of the landfill and transfer station stormwater has been infiltrated along a drainage swale constructed over the former septage disposal area when the landfill was capped in 2005. Part of the area over the lagoons had been paved with asphalt.

B. 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 included in the design of the new Department of Public Works and Natural Resources (DPW) facility currently under construction at the landfill. These modifications include constructing new stormwater infiltration ponds.

3. Landfill Nitrogen Investigation

The landfill nitrogen assessment was completed in three phases of work. Phase 1 was designed to collect initial information through site investigation, monitoring well installation, and soil and groundwater analyses. Additional monitoring wells were installed in Phase 2 as necessary to broadly define the nature and extent of nitrogen in groundwater near the landfill and identify associated sources. Phase 3 work was implemented to collect additional data regarding the extent of nitrogen in groundwater at the landfill necessary for groundwater modeling efforts planned by SMAST, and to complete groundwater pumping tests to confirm hydraulic conductivity values for assessment of the groundwater flow velocity. The groundwater investigation was mainly limited to areas at and immediately downgradient of the landfill except for two monitoring wells installed downgradient in the watershed closer to Town Cove.

Source area and nearfield downgradient monitoring well locations are shown on Figure 2. Downgradient watershed sampling locations are shown on Figure 3. The depth to groundwater in monitoring wells varies depending on location. Surveyed top of casing elevations and well construction details including screen elevations are included in Table 1.

Additional soil samples were also collected from the subsurface near the former septage lagoons during Phase 3 to assess the residual load of organic material and nitrogen from septage in the area. A discussion of test results is included in Section 4.C. Soil test results are included in Table 2.

Monitoring wells were developed by pumping and sampled using the US EPA low flow methodology for field parameters, nitrogen compounds and selected anions, elements and, dissolved organic carbon (DOC). Water table elevations were recorded prior to purging wells for sampling and are shown in Table 3. Monitoring well groundwater sample results from all three phases of the nitrogen investigation are included in Table 4. Pump test groundwater sample results are included in Table 5, and results of stormwater and compost leachate analyses are included in Table 6.

Results of the Phase 1 and Phase 2 investigations were presented in detail in earlier Technical Memorandums (AECOM 2017a and AECOM 2017b). The Phase 3 investigation results are presented below.

A. The landfill groundwater monitoring well network initially included a small network of groundwater monitoring wells that was in place prior to the phased assessment and additional monitoring wells were added in subsequent phases. These pre-existing monitoring wells have been used for semi-annual groundwater monitoring as required by the MassDEP Solid Waste Program and include:

- MW- MW-1S (56-66) and MW-1D (99-109);
- MW- MW-2S (84-94) and MW-2D (124-134);
- MW- MW-3S (50-60) and MW-3D (84-94);
- MW-4S and 4D (upgradient wells); and
- MW-MW-5S (78-88) and MW-5D (124-134).

The range in parentheses refers to the screen depth in feet below ground surface for the monitoring wells downgradient of the landfill.

Monitoring wells installed during the Phase 1 and Phase 2 investigations included monitoring wells at previously existing locations at new deeper screen intervals and monitoring wells at new locations including:

- MW-6A (64-74) and MW-6B (54-64);
- MW-2 (140-150), MW-2 (161-171);
- MW-5 (140-150);
- MW-6 (88-98);
- MW-7S (55-65), MW-7 (90-100), MW-7D (115-125);
- MW-8 (36-46), MW-8 (84-94);
- MW-9 (92-102);
- MW-10 (85-95); and
- MW-13 (74-84).

The two deep screened monitoring wells installed further downgradient in the watershed between the landfill and Town Cove include MW-11 (91-101) and MW-12 (97-97).

Additional monitoring wells installed during the Phase 3 assessment include:

- MW-2 (236-246);
- MW-13 (117-127);
- MW-14 (150-160);
- MW-15 (115-125);
- MW-15 (145-155); and
- MW-16 (110-120), MW-16 (140-150).

Two “point in time” or grab groundwater samples were collected at deep intermediate depths during the soil boring for MW-2 (236-246). The grab groundwater samples were collected at 186-196 and 206-216 feet below ground surface.

Two sets of pumping wells were also installed to conduct pumping tests including:

- MW-PW-1S (95-125), MW-PW-1D (130-160); and
- MW-PW-2S (100-130), MW-PW-2D (130-154).

The depth to groundwater at monitoring wells varies depending on location. All new Phase 3 monitoring wells are 2-inch PVC wells with 10-foot screens. Deep monitoring well MW-2 (236-246) was installed by Sonic drilling, a method that uses a rotating and vibrating the rod, core barrel, and casing at sonic frequencies. All additional monitoring wells and pumping wells were installed with hollow stem auger drilling.

The new and selected previously installed monitoring wells were developed by pumping and sampled using the US EPA low flow methodology in July and August 2017. Data collection included field parameters, nitrogen compounds and selected anions, elements and dissolved organic carbon (DOC).

Water table elevations were recorded prior to purging wells for sampling. 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.

B. A revised nitrogen distribution assessment has been completed based the additional data gathered in the Phase 3 investigation. Groundwater data continues to support the conceptual site model indicating 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 4 indicates that groundwater chemistry on the downgradient (north and northeastern) side of the landfill/transfer station property is stratified with a shallower more aerobic groundwater zone with nitrogen in the form of nitrate, and a deeper anoxic zone with nitrogen in the form of ammonia. The apparent area with elevated nitrate concentrations extends further to the northwest and deeper without underlying ammonia. The extended area of elevated nitrate appears to be related to other sources (commercial properties) cross gradient from the landfill. The assessed area to the southeast, near MW-13, did not show significant concentrations of nitrate or ammonia. The landfill stormwater infiltration pond is in this southeast area and may influence the distribution of nitrate in groundwater by recharging high volumes of lower concentration stormwater.

The groundwater area directly downgradient of the landfill can now we divided into two zones as follows:

- A shallow nitrate contaminated groundwater zone approximately 500 feet wide extending 20 feet in vertical thickness below the water table to approximately elevation -5 MSL. The average nitrate concentration in this upper zone is approximately 9 mg/L based on the latest round of groundwater sampling; and
- A deeper ammonia contaminated groundwater zone approximately 500 feet wide extending 125 feet in vertical thickness, from 20 feet below the water table to approximately 145 feet below the water table (elev. -130 MSL). The average concentration of ammonia in this deep zone is approximately 9 mg/L based on the most recent round of groundwater sampling. This evaluation does not include the results of the grab groundwater samples that were collected at 186-196 and 206-216 feet below ground surface. The low nitrogen concentrations detected in these sample does not appear to be representative based on the significantly higher concentration of ammonia found it the permanent well installed at a deeper depth.

A cross section of the landfill plume is provided in Figure 4.

C. The Phase 3 assessment provided additional information related to groundwater near the landfill. Groundwater elevations have been recorded across the landfill investigation area at approximately 12 to 16 feet above MSL and indicate the groundwater gradient that drives groundwater flow near the landfill. Two monitoring wells showed the presence of perched groundwater above the regional groundwater flow system including MW-1S (56-66), groundwater elevation 23 feet, and MW-8 (36-56), groundwater elevation 24 feet.

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 near monitoring well locations MW-7 and MW-6, close to the capped landfill area 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. V= Ki/n where:

V = Seepage velocity (feet per day);

K = assumed hydraulic conductivity based on the pumping test (feet per day; 100);

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 1.0 feet per day in the downgradient area between the MW-2 location and MW-10, to 1.3 feet per day nearer to the capped landfill near 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 100 feet/day estimated from pump test data. This hydraulic conductivity is similar to that of well sorted sand or sand and gravel and is considered representative of the area.

It is anticipated that the hydraulic conductivity will vary from with depth and across the site depending on aquifer material present. Soil borings completed for monitoring wells showed cuttings that were mainly fine to medium sand with occasional silty clay layers encountered at depth. Silt and clay have lower hydraulic conductivities compared to sand.

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, including both the shallow nitrate and the deeper ammonia, is expected to flow to greater depths as it migrates downgradient toward Town Cove, eventually discharging all or in part vertically up under Town Cove. Figure 5 shows modeled groundwater particle tracks along the expected migration path from the landfill to Town Cove. The vertical extent of migration with groundwater starting near the water table at the top of the landfill plume is expected to reach depths of more than 140 feet below the water table downgradient. Deeper portions of the plume will likely extend significantly deeper unless a low permeability stratum is encountered. A full assessment of the downgradient extent of the landfill nitrogen plume is beyond the scope of this investigation and is not considered feasible or necessary based on the expected depth of migration.

D. A revised nitrogen flux estimate has been prepared based on the additional information gathered in Phase 3. Nitrogen in the form of both nitrate and ammonia have been found in groundwater at the landfill. Ammonia is found in groundwater as the ammonium cation (NH4+). 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 (a 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 the average retardation factor of 4. Published data from 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 plume cross section. Total mass flux or mass discharge is an integrated mass flux estimate (including the sum of all mass flux measures across a plume cross section) and thus represents the total mass of any solute conveyed by groundwater through a defined plane (ITRC, 2010). In this case, because the transport characteristics of nitrate and ammonium are different, the mass flux estimate for the shallow nitrate plume is combined with the mass flux estimated for the ammonium plume to calculate mass discharge referred to here as total flux.

An updated total flux estimate has been developed based on dividing the area downgradient of the landfill into shallow and deep flux zones with differing forms of nitrogen. Both these zones are estimated to be 500 feet wide cross gradient. The nitrate zone used in the flux calculation is 20 feet in vertical thickness and the ammonium zone is 125 feet in vertical thickness. Concentration data indicates the same average of approximately 9 mg/L for nitrate in the 20 feet shallow zone and 9 mg/L for ammonium in the deeper zone (see Figure 4). Ammonium was also detected at a lower concentration deeper with close to 5 mg/L measured in the deepest well MW-2 (236-246). The differing migration rates for nitrate and ammonium in groundwater are included in the flux calculation along with a groundwater velocity of 1.3 feet/day. The estimated nitrate flux in shallow groundwater was calculated at 372 kg/yr and ammonium flux was calculated at 711 kg/yr for a total nitrogen flux 1,083 kg/yr (see calculation in Appendix A).

4. Nitrogen Sources and Response Actions

Primary sources of nitrogen confirmed at the landfill and transfer station include:

- Solid waste: Leachate from the capped solid waste landfill entering groundwater;
- Compost operations: Leachate from compost that either directly infiltrates through soil to groundwater or runs off to the stormwater management system;
- Infiltration through the former septage lagoons: Residual nitrogen in soil in the former septage lagoon area mobilized by the infiltration of precipitation and stormwater; and
- Transfer station and landfill runoff: Runoff from Transfer Station and landfill operations includes nitrogen from multiple sources and is recharged to groundwater.

The nitrogen plume in groundwater (nitrate and ammonia) identified at the landfill is a secondary source of nitrogen migrating to downgradient groundwater.

A. Source: Nitrogen from the Solid Waste Landfill: Solid waste in the capped landfill is a main source of the plume of nitrate and ammonia in groundwater that flows from under the landfill in a northeasterly direction. Elevated nitrogen concentrations associated with the landfill were observed at MW-2, MW-5, and Pumping Wells PW-1 and PW-2 locations. Groundwater downgradient to the southeast of the landfill has lower concentrations of nitrogen, mainly in the form of nitrate. This easterly area is likely affected by recharge of oxygenated water from the stormwater detention basin and receives less flow directly from the capped solid waste landfill area.

Potential Response Actions: The solid waste landfill was capped in 2005 to prevent infiltration of precipitation. The unlined landfill is expected to continue to generate leachate that directly infiltrates to groundwater as the solid waste matures. Leachate generation is affected by landfill settlement, fluid movement, and biodegradation of wastes. No additional direct response actions beyond the completed cap and ongoing groundwater monitoring are considered feasible.

B. Source: Nitrogen from Composting Operations: The landfill composting operation processes yard waste including leaves, brush, garden, and landscape trimmings. Yard waste contains appreciable amounts of nitrogen, phosphorus, and mineral nutrients.

Compost operations have included the maintenance of aerated windrows of yard 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 the compost operations area and porewater collected from within compost piles indicated that compost is a source of high concentrations of nitrogen although leachate volume may be relatively low. Leachate from compost has directly infiltrated to groundwater through sandy soil or is recharged to groundwater through the stormwater management system.

The DPW has recently moved the main composting operation to a location up on the landfill cap. A yard waste material receiving area will be maintained in the area north of the Transfer Station. It is anticipated that the receiving area will be used to store the material for approximately one year prior to moving the material to the composting area on the cap.

Potential Response Actions

1. **Adding impermeable pavement and stormwater controls in the yard waste materials receiving 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. The DPW plans to use this space for receiving and initial storage of yard waste and then periodically transfer materials to a new composting operations area on the landfill cap. The current storage area occupies approximately 10,000 square feet of unpaved ground. Asphalt pavement or another impermeable surface should be installed with a slope of approximately 2 percent to facilitate drainage to the adjoining existing paved surface with catch basins in the stormwater management system.

The impermeable surface is expected to be effective and reliably reduce or eliminate direct infiltration of precipitation through yard waste to groundwater. The benefits of this response action 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 to Town Cove.

2. **Stormwater Treatment:** Depending on the results of further stormwater sampling, stormwater generated from the yard waste storage area could be treated along with transfer station runoff, landfill cap drainage, and drainage from the composting area operations established on the landfill cap as described in Section 4.D.

C. Source: Water Infiltration through the Former Septage Lagoons: The mobilization of nitrogen from the former septage lagoon area has occurred by precipitation infiltrating through unpaved areas and the unlined riprap swale located to the north of the landfill cap.

Additional investigation of the mass of residual septage material in soil was completed in July 2017. Eight soil borings were installed with a direct push Geoprobe rig to collect soil from the subsurface at what used to be the bottom of the septage lagoons. Samples were analyzed for nitrate, nitrite, Total Kjeldahl Nitrogen (TKN), total nitrogen, and total volatile solids and the results are included in Table 2. Previous samples collected from the soil boring at MW-7 had indicated the presence of soil with a high nitrogen and organic content with septage odor at approximately 12-13 feet below ground surface. The concentration of total nitrogen in this residual material at MW-7 was measured at 1,440 mg/kg. Similar observations were made in the eight soil borings completed in July 2017. A 2 to 3-foot layer of residual organic material in sand was encountered across the footprint of the septage lagoon area, with a maximum total nitrogen concentration of 1,160 mg/kg, and an average concentration of 511 mg/kg total nitrogen. Assuming a vertical thickness of 1.5 to 3 feet of residual septage material in sand, the residual total nitrogen in in the layer is approximately 1,500 to 3,000 kilograms based on the average concentration.

There have been several sources of water infiltrating through the former septage lagoons. A portion of footprint of the former septage lagoons was unpaved sandy soil that received direct infiltration of precipitation. An unlined riprap perimeter swale to the north of the landfill cap was located over the septage lagoons and received runoff from the landfill cap drainage layer on the north and west sides of the landfill, as well as stormwater from transfer station catch basins. Stormwater enters the swale through three stormwater drain lines in the concrete headwall on the west end of the swale and through an open channel asphalt perimeter swale on the west side of the landfill cap. Landfill drainage water also enters the swale from an underdrain line or downspout from the north slope of the cap, a downspout from the southwest slope, and from subsurface flow off the 40 mil HDPE liner below the drainage layer on the north slope. The liner ends in or short of the center of the swale.

This section of perimeter 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 limited flow east to the retention basin, except during significant storm events when water flows to the retention basin. This results in recharge to groundwater through the residual organic material in the septage lagoon area. Recharge of aerobic water to this area may also result in nitrification of ammonia in shallow groundwater as the ammonia plume flows north out from under the capped area of the landfill. Nitrification results in a four-fold increase in nitrogen mobility in groundwater. Nitrification of the landfill ammonia plume and mobilization of nitrate from the septage lagoons likely accounts for the significant increase in nitrate observed at the downgradient MW-2S after the landfill was capped in 2005.

Potential Response Actions

Potential response actions were reviewed with the Department of Public Works and Natural Resources and where possible response actions may be implemented by modifications to the DPW facility construction project.

1. **Placement of an impermeable pavement cover over the former septage lagoons area**: The ongoing DPW facility construction project included paving over most of the area of the former septage lagoons, except for the area immediately adjacent to the north side of the capped landfill where a drainage swale is located over the lagoons (Figure 2). The pavement cap is expected to be effective and reliably reduce infiltration through the residual septage material identified in this area. The benefits of paving include preventing further groundwater contamination in the source area.

2. **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 liner under the full extent of the drainage swale forming an impermeable base. Swale reconstruction can be implemented during DPW construction activities to minimize costs. This action presented a higher level of difficulty and cost in comparison to other source control actions due to a higher technical complexity, MassDEP Solid Waste Program permitting requirements, and level of contractor services. AECOM and MT Environmental Restoration prepared technical plans and a Permit Application for ditch maintenance was submitted for MassDEP approval. The action required:

   - 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;
   - Installing a section of HDPE liner forming the impermeable swale; and
   - Repair of any disturbed drainage layer sand and vegetative layer topsoil.

   The extended HDPE liner in the swale will be covered with a sand layer and stone riprap forming a new impermeable rock swale.

   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. Design drawings for swale reconstruction are included in Appendix B.

D. **Source: Transfer Station and Landfill Stormwater Runoff:** Runoff from Transfer Station and Landfill operations includes nitrogen from atmospheric deposition to paved surfaces and diffuse sources including waste bins and compost operations. A grab sample of Transfer Station runoff indicated a total nitrogen concentration of 4.5 mg/L, mainly in the form of organic nitrogen, while a sample of runoff from the composting operations area indicated a total nitrogen concentration of 27 mg/L. The compost area runoff included significant nitrate and organic nitrogen content with a lower concentration of ammonia. Groundwater monitoring data from monitoring wells installed at the MW-13 location adjacent to the current infiltration pond indicated a groundwater concentration of approximately 1.5 mg/L nitrate in the stormwater recharge area. Additional stormwater sampling would be required to fully assess stormwater nitrogen.

   Potential Response Actions

   1. **Collection of additional baseline stormwater quality, runoff rate, and volume data for stormwater treatment feasibility, evaluation, and design**: Preparation of a stormwater sampling plan is recommended to collect data for assessment of treatment feasibility. Water quality and flow data could then be used to model and design a stormwater denitrification biofilter as described in 4.D.2. below.

2. **Adding a stormwater denitrification biofilter system for treatment of transfer station stormwater and runoff:** Sources of nitrogen associated with the stormwater management and landfill cap system include transfer station runoff, runoff from the cap drainage layer, and runoff from composting operations. Two new infiltration ponds are being constructed as part of the DPW redevelopment project. Denitrification biofilters to treat all or a portion of the stormwater could be installed prior to the infiltration ponds. System design will require information regarding the available footprint for treatment cells and data from the baseline stormwater quality assessment.

5. Nitrogen Migration in Groundwater

The estimated nitrate flux in shallow groundwater was calculated at 372 kg/yr and ammonium flux was calculated at 711 kg/yr for a total nitrogen flux 1,083 kg/yr.

Response actions described above to reduce infiltration through the former septage lagoons will serve to mitigate mobilization of residual nitrogen from the septage lagoons and will also reduce the infiltration of aerobic water on top of the landfill plume. This aerobic recharge may be increasing flux by oxidizing ammonium in groundwater from the solid waste source to faster moving nitrate by modifying groundwater geochemistry.

No direct response actions to treat the current mass discharge from the landfill are considered feasible. Groundwater treatment to reduce mass discharge at the landfill would require a significant capital investment and long-term operation and maintenance of treatment facilities. 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 from the landfill may attenuate to some degree through natural processes as it migrates through the deep groundwater system toward Town Cove. The plume from the landfill is expected to flow deeper below the water table as it migrates toward Town Cove. The depth of migration in groundwater likely precludes direct assessment and response actions to intercept the nitrogen load in transit closer to Town Cove.

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.

Given that the mass of nitrogen currently in transit to Town Cove as a result of past landfill and septage lagoon operations beginning in the 1950s is unknown, consideration should be given to offsetting the observed nitrogen mass discharge from the landfill. The offset could be accomplished with management actions to reduce nitrogen loading to Town Cove from other sources such as septic systems located near Town Cove or removing nitrogen in transit to Town Cove in shallow groundwater from other sources. Nitrogen offset by mitigation of sources closer to Town Cove through traditional sewer system installation or non-traditional methods would be beneficial as the groundwater transport times for nitrogen from these sources are short and the benefits would be realized over a short term.

6. Summary and Conclusions

The response actions outlined in Sections 4.A through 4.D above are related to landfill source mitigation and are likely to be feasible. These actions could be implemented in the near term in conjunction with redevelopment of the landfill property for the new Department of Public Works and Natural Resources facility. Nitrogen offset, removing nitrogen sources by extending sewer lines to include areas closer to Town Cove, by mitigating nitrogen in groundwater closer to Town Cove with Permeable Reactive Barriers, or by mitigating nitrogen in Town Cove with expanded shellfish aquaculture are viable alternatives to long term groundwater restoration at the landfill that will result in near- and long-term achievement of water quality goals in Town Cove.

7. References

AECOM, 2017a - Technical Memorandum for Landfill Nitrogen Field Investigation Phase 1 Report – Final. June 30, 2017.

AECOM, 2017b - Technical Memorandum for Landfill Nitrogen Field Investigation Phase 2 Report – Final. September 25, 2017.

Bohlke, J. K., R. L. Smith, and D. N. Miller (2006), Ammonium transport and reaction in contaminated groundwater: Application of isotope tracers and isotope fractionation studies, Water Resource. Res., 42, W05411, doi: 10.1029/2005WR004349.

Chatterjee, N., M. Flury, C. Hinman, C. G. Cogger, 2013, Chemical and Physical Characteristics of Compost Leachates-A Review. Washington State University.

Coastal Engineering Co. Inc, 1992, the Initial Site Assessment Report Orleans Municipal Sanitary Landfill.

Coastal Engineering Co. Inc, 1992, Supporting Documentation for Septage Lagoon Closure.

Coastal Engineering Co., Inc., 1999, Comprehensive Site Assessment Report Orleans Municipal Sanitary Landfill.

Frimpter, M.H., and Gay, F.B., 1979, Chemical quality of ground water on Cape Cod, Massachusetts: U.S. Geological Survey Water-Resources Investigations Report 79-65.

GHD, Inc. and Stearns & Wheler, LLC, 2005 through 2014, Orleans Municipal Landfill Semi-Annual Groundwater Monitoring Reports.

Howes B., S. W. Kelley, J. S. Ramsey, R. Samimy, D. Schlezinger, E. Eichner (2012). Linked Watershed-Embayment Approach to Determine Critical Nitrogen Loading hresholds for the Nauset Harbor Embayment System Towns of Orleans and Eastham, Massachusetts

ITRC (Interstate Technology & Regulatory Council). 2010. Use and Measurement of Mass Flux and Mass Discharge. MASSFLUX-1. Washington, D.C.: Interstate Technology & Regulatory Council, Integrated DNAPL Site Strategy Team. www.itrcweb.org .

LeBlanc, D.R., 1984, Sewage plume in a sand and gravel aquifer, Cape Cod, Massachusetts: U.S. Geological Survey Water-Supply Paper 2218.

MT Environmental Restoration, April 2015, Orleans Landfill Nitrate Data Evaluation Report.

Stearns & Wheeler, LLC, 2006, Construction Certification Report, Town of Orleans Landfill Closure.

Walter, D.A., Masterson, J.P., and Hess, K.M., 2004, Ground-water recharge areas and travel times to pumped wells, ponds, streams, and coastal water bodies, Cape Cod, Massachusetts: U.S. Geological Survey Scientific Investigations Map I-2857, 1 sheet [http://pubs.usgs.gov/sim/2004/2857/].

Weston Inc., 1998, Site Inspection Prioritization Report.

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	Notes
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)	101.4	103.45	94.0	84.00	94.00	17.40	7.40	12.40	10.0	existing	Landfill
MW-2D (124-134)	101.6	103.61	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-2 (186-196)	101.4	NA	196.0	186.00	196.0	-84.60	-94.60	-89.60	10.0	July 2017	Groundwater Sample Only, No Well Installed; Elevation Approximate
MW-2 (206-216)	101.4	NA	216.0	206.00	216.0	-104.60	-114.60	-109.60	10.0	July 2017	Groundwater Sample Only, No Well Installed; Elevation Approximate
MW-2 (236-246)	100.9	102.7	246.0	236.00	246.0	-135.10	-145.10	-140.10	10.0	July 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	103.60	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-7 (90-100)	69.7	71.40	100.0	90.00	100.00	-20.30	-30.30	-25.30	10.0	3/2/2017	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-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	58.80	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	59.30	84.0	74.0	84.0	-17.00	-27.00	-22.00	10.0	March 2017	Landfill
MW-13 (117-127)	57.9	59.73	127.0	117.0	127.0	-59.06	-69.06	-64.06	10.0	July 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
MW-14 (150-160)	105.4	105.15	160.0	150.0	160.0	-44.60	-54.60	-49.60	10.0	July 2017	Landfill
MW-15 (115-125)	107.4	109.17	125.0	115.0	125.0	-7.60	-17.60	-12.60	10.0	July 2017	Landfill
MW-15 (145-155)	107.3	108.87	155.0	145.0	155.0	-37.70	-47.70	-42.70	10.0	July 2017	Landfill
MW-16S (110-120)	101.3	103.38	120.0	110.0	120.0	-8.72	-18.72	-13.72	10.0	July 2017	Landfill
MW-16D (140-150)	101.5	103.36	150.0	140.0	150.0	-38.50	-48.50	-43.50	10.0	July 2017	Landfill
PW-1 (95-125)	102.1	103.66	125.0	95.0	125.0	7.10	-22.90	-7.90	30.0	July 2017	Landfill
PW-1 (130-160)	102.2	104.29	160.0	130.0	160.0	-27.80	-57.80	-42.80	30.0	July 2017	Landfill
PW-2S (100-130)	99.1	100.75	130.0	100.0	130.0	-0.90	-30.90	-15.90	30.0	July 2017	Landfill
PW-2D (130-154)	99.3	101.11	154.0	130.0	154.0	-30.70	-54.70	-42.70	24.0	July 2017	Landfill

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 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 2 Orleans Landfill Soil Analyses

Sample ID	**SLSB-2A**	**SLSB-2B**	**SLSB-3A**	**SLSB-3B**	**SLSB-4A**	**SLSB-4B**	**SLSB-5A**
Sampling Date	**07/13/2017**	**07/13/2017**	**07/13/2017**	**07/13/2017**	**07/13/2017**	**07/13/2017**	**07/13/2017**
Laboratory Analyses							
Nitrogen							
Nitrate as N, mg/kg dry	**0.37**	**0.44**	<0.45	<0.34	<0.34	<0.39	<0.35
Nitrite as N, mg/kg dry	<0.12	<0.11	<0.15	<0.11	<0.11	<0.13	<0.12
Nitrate/Nitrite as N, mg/kg dry	-	-	-	-	-	-	-
Total Kjeldahl Nitrogen as N, mg/kg dry	**162**	**271**	**597**	**246**	**484**	**508**	**661**
Total Nitrogen, mg/kg dry	**162**	**271**	**597**	**246**	**484**	**508**	**661**
Other							
Total Volatile Solids, %	**2**	<1	**3**	**2**	**2**	**4**	**3**

Notes:
Bold - detected above the Minimum Detection Limit

Table 2 Orleans Landfill Soil Analyses

Sample ID	**SLSB-5B**	**MW-7/12-13'**	**MW-7/13.5-14.5**	**MW-7/15-17'**	**MW-7/42-44'**	**MW-7/57-58'**
Sampling Date	**07/13/2017**	**01/18/2017**	**01/18/2017**	**01/19/2017**	**01/19/2017**	**01/19/2017**
Laboratory Analyses						
Nitrogen						
Nitrate as N, mg/kg dry	<0.41	**-**	**-**	**-**	**-**	**-**
Nitrite as N, mg/kg dry	**0.16**	**-**	**-**	**-**	**-**	**-**
Nitrate/Nitrite as N, mg/kg dry	**-**	**0.32**	<0.25	<0.24	**0.76**	<0.23
Total Kjeldahl Nitrogen as N, mg/kg dry	**1160**	**1440**	<93.2	**160**	<78	<86.7
Total Nitrogen, mg/kg dry	**1160**	**1440**	<93.5	**160**	<78.2	<86.9
Other						
Total Volatile Solids, %	**6**	**4**	<1	<1	<1	<1

Notes:
Bold - detected above the Minimum Detection Limit

Table 3 Orleans Landfill Groundwater Elevations

Well ID	Location	TOC Elevation (ft)	Depth to Water (ft)							GW Elevation (August 24/25, 2017) (ft)	Notes
			2/3/2017	2/6/2017	2/28/2017	03/27/2017-03/29/2017	4/25/2017	8/2/2017	08/24/2017-08/25/2017		
MW-1S (56-66)	Landfill	85.18	61.95	62.0	61.88	-	61.65	61.59	60.03	25.15	Perched Water
MW-1D (99-109)	Landfill	85.11	70.60	70.5	70.33	-	69.76	69.90	69.88	15.23	
MW-2S (84-94)	Landfill	101.49	87.90	-	87.63	-	87.08	87.25	89.03	12.46	
MW-2D (124-134)	Landfill	101.42	88.42	88.4	88.20	-	88.37	87.67	89.79	11.63	
MW-2 (140-150) *	Landfill	102.80	89.82	-	89.60	89.38	89.01	89.06	89.00	13.80	
MW-2 (161-171)	Landfill	101.40	NI	NI	NI	89.57	89.09	89.14	89.10	12.30	
MW-2 (186-196)	Landfill	NI	NI	NI	NI	NI	NI	NI	NI	NI	Groundwater Sample Only, No Well Installed
MW-2 (206-216)	Landfill	NI	NI	NI	NI	NI	NI	NI	NI	NI	Groundwater Sample Only, No Well Installed
MW-2 (236-246)	Landfill	102.7	NI	NI	NI	NI	NI	91.28	89.93	12.74	
MW-3S (50-60)	Landfill	70.32	54.20	55.3	54.94	-	54.40	54.62	53.89	16.43	
MW-3D (84-94)	Landfill	69.74	54.90	55.0	54.66	-	55.00	54.35	53.71	16.03	
MW-5S (78-88)	ROW	103.91	90.28	-	89.94	-	89.34	89.43	89.15	14.76	
MW-5D (124-134)	ROW	103.89	89.90	-	89.67	-	89.11	89.24	88.97	14.92	
MW-5 (140-150)	ROW	101.68	NI	NI	NI	89.50	89.11	89.09	88.91	12.77	
MW-6A (64-74)	Landfill	71.22	56.35	56.4	56.41	-	55.90	56.07	55.74	15.48	
MW-6B (54-64)	Landfill	71.40	56.40	56.5	56.33	-	55.77	-	55.49	15.91	
MW-6C (52-62)	Landfill	71.55	NS	NS	NS	-	55.48	55.97	NA	NA	
MW-E6 (88-98)*	Landfill	71.91	57.77	57.8	57.51	-	56.93	-	56.89	15.02	
MW-7S (55-65) *	Landfill	71.64	66.50	56.6	56.22	56.31	55.76	56.01	55.45	16.19	
MW-7D (115-125) *	Landfill	71.66	57.30	57.3	57.03	56.92	56.44	56.60	56.39	15.27	
MW-7 (90-100)	Landfill	69.70	NI	NI	NI	56.66	56.04	55.91	55.45	14.25	
MW-8 (36-46)*	Giddiah Hill Rd	58.80	35.05	34.9	34.62	34.45	33.41	33.31	32.99	25.81	Perched Water
MW-8 (84-94)	Giddiah Hill Rd	58.80	NI	NI	NI	43.07	42.51	42.47	42.38	NA	
MW-9 (92-102)*	Landfill	107.32	93.50	93.3	93.11	-	92.53	92.58	92.56	14.76	
MW-10 (85-95)*	Finlay Rd	93.69	81.12	82.1	80.95	-	80.34	80.35	80.39	13.30	
MW-11 (91-101)	Elementary School	48.97	NI	NI	NI	37.58	NA	NA	NA	NA	
MW-12 (87-97)	Snow Library	NA	NI	NI	NI	35.67	NA	NA	NA	NA	
MW-13 (74-84)	Landfill	57.00	NI	NI	NI	44.07	43.31	44.03	42.82	14.18	
MW-13 (117-127)	Landfill	59.7	NI	NI	NI	NI	NI	43.56	43.33	16.40	
MW-14 (150-160)	Landfill	105.2	NI	NI	NI	NI	NI	90.47	90.51	14.64	
MW-15 (115-125)	Landfill	109.2	NI	NI	NI	NI	NI	-	94.63	14.54	
MW-15 (145-155)	Landfill	108.9	NI	NI	NI	NI	NI	-	94.92	13.95	
MW-16S (110-120)	Landfill	103.4	NI	NI	NI	NI	NI	88.97	88.82	14.56	
MW-16D (140-150)	Landfill	103.4	NI	NI	NI	NI	NI	89.35	89.27	14.09	
PW-1 (95-125)	Landfill	103.7	NI	NI	NI	NI	NI	89.29	89.12	14.54	
PW-1 (130-160)	Landfill	104.3	NI	NI	NI	NI	NI	-	90.46	13.83	
PW-2S (100-130)	Landfill	100.8	NI	NI	NI	NI	NI	-	86.43	14.32	
PW-2D (130-154)	Landfill	101.1	NI	NI	NI	NI	NI	-	87.95	13.16	

NS- no sampled
NI- not installed
NA- not available

Table 4 Orleans Landfill Groundwater Analyses

Sample ID	**MW-2S (84-94)**				**MW-2D (124-134)**				
Top of Screen Elevation (ft)	17.40				-22.40				
Bottom of Screen Elevation (ft)	7.40				-32.40				
Sampling Date	2/26/2016	02/06/2017	3/28/2017[1]	8/9/2017	2/26/2016	02/06/2017	02/06/2017(DUP)	3/28/2017[1]	8/8/2017
Field Measurements									
pH (SU)	4.9	4.8	4.5	4.7	4.7	6.0	6.0	5.6	5.8
Temperature (^{o}C)	13.2	16.0	15.0	16.0	12.4	15.5	15.5	15.1	16.1
Dissolved Oxygen (DO; mg/L)	1.4	1.6	0.8	1.7	0.8	0.1	0.1	0.0	0.3
Dissolved Oxygen (DO; %)	-	16.2	7.5	16.9	-	0.6	0.6	0.2	3.4
Redox Potential (ORP; mV)	193.6	129.8	144.7	331.2	144.9	54.5	54.5	106.0	180.3
Specific Conductivity (µS/cm)[c]	942	751	777	762	886	800	800	828	893
Laboratory Analyses									
Nitrogen									
Nitrate as N (mg/L)	**24.7**	**18.8**	**1.05**	**16.6**	**9.26**	**0.208**	**0.18**	**2.32**	**0.154**
Nitrite as N (mg/L)	<0.01	**0.0**	<0.01	**0.025**	**0.065**	**0.014**	<0.01	<0.01	<0.01
Ammonia (mg/L)	**0.25**	**0.14**	<0.1	**0.11**	**0.34**	**11.5**	**11.2**	**10.9**	**10.9**
Total Kjeldahl Nitrogen (TKN) (mg/L)	-	**2.13**	**2.3**	**2.02**	-	**13.7**	**14.7**	**12.1**	**13.1**
Total Nitrogen (mg/L)	**27.1**	**21.0**	**3.34**	**18.7**	**11.1**	**13.9**	**14.8**	**14.5**	**13.2**
Alkalinity									
Total Alkalinity (mg/L)	-	-	-	-	-	-	-	-	-
Bicarbonate Alkalinity (mg/L)	-	-	-	-	-	-	-	-	-
Anions									
Chloride (mg/L)	**131.0**	**88.8**	**94.8**	-	**152.0**	**97.7**	**99.2**	**134**	-
Sulfate (mg/L)	**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	**0.11**	**0.107**	**0.148**
Dissolved Manganese (mg/L)	**0.60**	**0.55**	**0.528**	**0.514**	**1.10**	**5.12**	**5.10**	**4.48**	**4.62**
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 4/24/17.
E. Data point appears to be in error
(124-134)-Well screen depth below land surface
2. Elevations are approximate. Grab samples were taken and elevations were estimated based on nearby wells.

Table 4 Orleans Landfill Groundwater Analyses

Sample ID	**MW-2 (140-150)**			**MW-2 (160-170)**		**MW-5 (140-150)**		**MW-E6-A (64-74)**		
Top of Screen Elevation (ft)	-38.70			-160.00		-38.30		7.60		
Bottom of Screen Elevation (ft)	-48.70			-170.00		-48.30		-2.40		
Sampling Date	02/06/2017	3/28/2017	8/8/2017	3/28/2017	8/9/2017	3/27/2017	8/10/2017	2/10/2016	2/6/2017	3/28/2017
Field Measurements										
pH (SU)	6.0	6.3	5.9	5.7	5.6	6.1	4.4	5.9	5.6	5.8
Temperature (^{o}C)	15.2	16.9	15.5	14.4	15.3	14.6	14.5	13.3	14.9	15.6
Dissolved Oxygen (DO; mg/L)	0.1	0.2	0.3	0.0	0.4	0.17	0.4	0.46	0.15	0.11
Dissolved Oxygen (DO; %)	0.8	2.2	3.3	0.1	4.0	1.6	3.5	-	1.5	1.1
Redox Potential (ORP; mV)	65.1	97.7	187.2	57.5	110.4	195.9	259.8	100.0	56.4	85.5
Specific Conductivity (µS/cm)[c]	637	6341	652	620	685	377	405	672	1069	1186
Laboratory Analyses										
Nitrogen										
Nitrate as N (mg/L)	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	**11.6**	**7.2**	**2.61**
Nitrite as N (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.050	<0.01	<0.01
Ammonia (mg/L)	**11.9**	**11.2**	**11**	**13.7**	**13.2**	**9.34**	**9.4**	**0.10**	<0.1	<0.1
Total Kjeldahl Nitrogen (TKN) (mg/L)	**12.8**	-	**12.5**	NM	**17.1**	NM	**10.4**	-	**1.7**	-
Total Nitrogen (mg/L)	**12.8**	**17.2**	**12.5**	**2.45**	**17.1**	**10.6**	**10.4**	**12.6**	**8.9**	**3.94**
Alkalinity										
Total Alkalinity (mg/L)	-	-	-	-	-	-	-	-	-	-
Bicarbonate Alkalinity (mg/L)	-	-	-	-	-	-	-	-	-	-
Anions										
Chloride (mg/L)	**49.0**	**46.1**	-	**43.6**	-	**39.6**	-	**143.0**	**280.0**	**331**
Sulfate (mg/L)	**62.0**	**63.5**	-	**32.8**	-	**39.5**	-	**55.5**	**34.4**	**27.8**
Elements										
Dissolved Iron (mg/L)	**0.11**	**0.908**	<0.1	**0.647**	**1.15**	**0.113**	**0.12**	**0.05**	**0.15**	**0.107**
Dissolved Manganese (mg/L)	**5.46**	**5.12**	**4.59**	**6.72**	**6.72**	**1.37**	**1.39**	**0.02**	**0.05**	**0.05**
Boron (mg/L)	**0.28**	-	-	-	-	-	-	**0.14**	**0.10**	-
Organic Compounds										
1,4-Dioxane	**2.05**	-	-	-	-	<0.25	-	-	<0.25	-
DOC (mg/L)	**7.0**	-	-	-	-	-	-	**7.6**	**8.1**	-
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

2. Elevations are approximate. Grab samples were taken and elevations were estimated based on nearby wells.

Table 4 Orleans Landfill Groundwater Analyses

Sample ID	**MW-E6-B (54-64)**			**MW-6 (88-98)**			**MW-7S (55-65)**			**MW-7 (90-100)**	
Top of Screen Elevation (ft)	17.80			-15.80			14.80			-20.30	
Bottom of Screen Elevation (ft)	7.80			-25.80			4.80			-30.30	
Sampling Date	2/10/2016	2/6/2017	3/28/2017[1]	02/06/2017	3/28/2017[1]	8/9/2017	02/06/2017	02/06/2017 (DUP)	3/28/2017	3/28/2017	8/9/2017
Field Measurements											
pH (SU)	5.5	5.4	5.2	6.5	6.6	6.6	5.7	5.7	5.2	5.5	5.5
Temperature (^{o}C)	12.5	14.9	15.4	14.0	14.7	15.1	12.7	12.7	13.4	12.5	15.1
Dissolved Oxygen (DO; mg/L)	1.82	1.45	1.06	0.12	0.15	0.34	0.69	0.69	0.04	0.0	0.28
Dissolved Oxygen (DO; %)	-	14.5	10.5	1.2	1.5	3.4	6.5	6.5	0.4	0.1	2.8
Redox Potential (ORP; mV)	72.4	71.2	119.2	-82.1	-36.0	-89.4	39.4	39.4	115.1	-7.2	100.1
Specific Conductivity (µS/cm)[c]	847	743	793	900	991	935	665	665	1229	1534	3926
Laboratory Analyses											
Nitrogen											
Nitrate as N (mg/L)	**20.8**	**16.3**	**8.27**	**0.1**	<0.03	<0.03	**8.7**	**12.8**	**4.96**	**0.154**	**3.04**
Nitrite as N (mg/L)	<0.050	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	**0.012**	**0.015**	**0.032**
Ammonia (mg/L)	**0.10**	**0.11**	<0.1	**0.12**	**22.6**	**24.5**	**0.34**	**0.13**	**0.15**	**0.19**	**0.12**
Total Kjeldahl Nitrogen (TKN) (mg/L)	-	**1.50**	**1.3**	**24.10**	**25.0**	**26**	**1.92**	**2.38**	-	-	**0.93**
Total Nitrogen (mg/L)	**21.2**	**17.8**	**9.60**	**24.2**	**25.0**	**26**	**10.6**	**15.2**	**8.67**	**1.06**	**4**
Alkalinity											
Total Alkalinity (mg/L)	-	-	-	-	-	-	-	-	-	-	-
Bicarbonate Alkalinity (mg/L)	-	-	-	-	-	-	-	-	-	-	-
Anions											
Chloride (mg/L)	**115.0**	**151.0**	**167**	**173.0**	**196**	-	**127.0**	**124.0**	**369**	**428**	-
Sulfate (mg/L)	**52.5**	**41.5**	**43.5**	**22.5**	**21.5**	-	**29.6**	**33.6**	**15.5**	**18.7**	-
Elements											
Dissolved Iron (mg/L)	**0.05**	**0.16**	<0.1	**18.40**	**13.5**	**16.6**	**0.34**	**0.27**	**0.216**	**7.51**	**9.3**
Dissolved Manganese (mg/L)	**0.02**	**0.04**	**0.026**	**2.49**	**2.39**	**1.95**	**0.02**	**0.02**	**0.031**	**0.331**	**0.749**
Boron (mg/L)	**0.14**	**0.11**	-	**0.24**	-	-	**0.08**	**0.08**	-	-	-
Organic Compounds											
1,4-Dioxane	-	<0.25	-	**0.687**	-	-	<0.25	-	-	<0.25	-
DOC (mg/L)	**7.6**	**6.7**	-	8.8	-	-	-	-	-	-	-
Methane	-	-	-	-	-	-	-	-	<2	<2	-

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

2. Elevations are approximate. Grab samples were taken and elevations were estimated based on nearby wells.

Table 4 Orleans Landfill Groundwater Analyses

Sample ID	**MW-7D (115-125)**			**MW-8 (36-46)**		**MW-8 (84-94)**		**MW-9 (92-102)**		
Top of Screen Elevation (ft)	-45.10			23.10		-24.80		13.50		
Bottom of Screen Elevation (ft)	-55.10			13.10		-34.80		9.00		
Sampling Date	02/06/2017	3/28/2017[1]	8/9/2017	2/8/2017	3/27/2017	3/27/2017	8/9/2017	2/8/2017	3/29/2017	8/9/2017
Field Measurements										
pH (SU)	6.2	6.3	6.4	4.5	4.0	5.8	5.2	5.0	4.4	5.0
Temperature (^{o}C)	12.7	12.9	15.2	14.6	13.8	13.4	14.5	15.9	15.5	16.5
Dissolved Oxygen (DO; mg/L)	0.2	0.2	0.20	2.1	2.9	0.4	1.08	7.4	7.8	7.81
Dissolved Oxygen (DO; %)	1.9	2.2	2.0	20.5	28.5	3.7	10.5	-	76.1	80.0
Redox Potential (ORP; mV)	-64.1	2.0	-66.4	175.6	179.8	156.3	178.7	139.1	185.6	209.4
Specific Conductivity (µS/cm)[c]	510	482	514	397	351	297	292	297	327	359
Laboratory Analyses										
Nitrogen										
Nitrate as N (mg/L)	<0.03	<0.03	<0.03	**5.5**	**3.83**	**5.14**	**11.5**	**20.2**	**6.37**	**5.66**
Nitrite as N (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	**0.159**	<0.01	<0.01	<0.01	<0.01
Ammonia (mg/L)	**2.74**	**2.59**	**2.01**	**0.11**	**0.18**	**0.13**	<0.1	**0.34**	<0.1	<0.1
Total Kjeldahl Nitrogen (TKN) (mg/L)	**3.17**	**3.2**	**2.65**	**2.03**	-	-	**1.91**	**2.83**	-	**1.03**
Total Nitrogen (mg/L)	**3.2**	**3.2**	**2.65**	**7.6**	**4.84**	**881**[E]	**13.4**	**23.0**	**6.65**	**6.69**
Alkalinity										
Total Alkalinity (mg/L)	-	-	-	-	-	-	-	-	-	-
Bicarbonate Alkalinity (mg/L)	-	-	-	-	-	-	-	-	-	-
Anions										
Chloride (mg/L)	**55.3**	**57.2**	-	**55.1**	**66.4**	**37.8**	-	**65.5**	**60.8**	-
Sulfate (mg/L)	**36.2**	**34.2**	-	**37.8**	**24.3**	**16.9**	-	**15.5**	**34.6**	-
Elements										
Dissolved Iron (mg/L)	**18.30**	**17.5**	**17**	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Dissolved Manganese (mg/L)	**3.21**	**2.72**	**2.4**	**0.10**	**0.301**	**0.406**	**0.104**	**0.49**	**0.052**	**0.031**
Boron (mg/L)	**0.14**	-	-	**0.09**	-	NM	-	<0.05	-	-
Organic Compounds										
1,4-Dioxane	**1.7**	-	-	<0.25	-	**0.649**	-	<0.25	-	-
DOC (mg/L)	-	-	-	**4.4**	-	-	-	**1.6**	-	-
Methane	-	<2	-	-	-	-	-	-	-	-

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

2. Elevations are approximate. Grab samples were taken and elevations were estimated based on nearby wells.

Table 4 Orleans Landfill Groundwater Analyses

Sample ID	MW-10 (85-95)		MW-11 (91-101)	MW-12 (87-97)	MW-13 (74-84)		MW-13 (117-127)	MW-14 (150-160)	MW-15 (115-125)	MW-15 (145-155)
Top of Screen Elevation (ft)	9.00		-41.60	NA	-17.00		-59.06	-44.60	-7.60	-37.70
Bottom of Screen Elevation (ft)	-1.00		-51.60	NA	-27.00		-69.06	-54.60	-17.60	-47.70
Sampling Date	2/8/2017	3/28/2017	3/29/2017	3/29/2017	3/29/2017	8/9/2017	8/9/2017	8/14/2017	8/4/2017	8/4/2017
Field Measurements										
pH (SU)	5.6	5.4	5.8	5.4	5.3	5.9	5.9	1.9	4.1	4.5
Temperature (^oC)	14.6	15.9	12.2	13.1	13.1	14.6	13.8	14.8	14.5	14.8
Dissolved Oxygen (DO; mg/L)	9.4	8.5	0.8	0.3	0.8	1.00	2.54	3.3	5.3	7.8
Dissolved Oxygen (DO; %)	-	81.5	7.4	2.4	7.9	9.8	24.6	33.0	52.0	77.4
Redox Potential (ORP; mV)	118.9	117.8	112.1	102.5	49.9	14.6	118.8	672.7	517.9	554.9
Specific Conductivity (µS/cm)[c]	175	176	152	179	480	528	247	223	365	430
Laboratory Analyses										
Nitrogen										
Nitrate as N (mg/L)	**2.4**	**2.5**	**0.239**	**0.142**	**1.18**	**1.48**	**1.45**	**8.44**	**2.2**	**0.456**
Nitrite as N (mg/L)	<0.01	<0.01	<0.01	<0.01	**0.013**	<0.01	<0.01	<0.01	<0.01	<0.01
Ammonia (mg/L)	<0.1	<0.1	<0.1	<0.1	**0.11**	<0.1	<0.1	**0.16**	**0.55**	**0.8**
Total Kjeldahl Nitrogen (TKN) (mg/L)	**0.85**	-	-	-	-	**0.56**	**0.45**	**1.11**	**1.38**	**1.49**
Total Nitrogen (mg/L)	**3.3**	**2.83**	**0.54**	**0.46**	**1.58**	**2.04**	**1.9**	**9.56**	**3.58**	**1.95**
Alkalinity										
Total Alkalinity (mg/L)	-	-	-	-	-	-	-	-	-	-
Bicarbonate Alkalinity (mg/L)	-	-	-	-	-	-	-	-	-	-
Anions										
Chloride (mg/L)	**42.9**	**39.1**	**30.9**	**43.2**	**127**	-	-	-	-	-
Sulfate (mg/L)	<5	**6.1**	**12.1**	**8.3**	**22.5**	-	-	-	-	-
Elements										
Dissolved Iron (mg/L)	<0.1	**0.375**	<0.1	<0.1	**6.67**	**4.1**	<0.1	<0.1	-	-
Dissolved Manganese (mg/L)	**0.07**	**0.028**	**0.501**	**0.08**	**0.447**	**0.163**	**0.131**	**0.05**	-	-
Boron (mg/L)	<0.05	-	-	-	-	-	-	-	-	-
Organic Compounds										
1,4-Dioxane	<0.25	-	<0.25	<0.25	<0.25	-	-	-	-	-
DOC (mg/L)	<0.5	-	-	-	-	-	-	-	-	-
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
2. Elevations are approximate. Grab samples were taken and elevations were estimated based on nearby wells.

Table 4 Orleans Landfill Groundwater Analyses

Sample ID	**MW-16S (110-120)**	**MW-16D (140-150)**
Top of Screen Elevation (ft)	-8.72	-38.50
Bottom of Screen Elevation (ft)	-18.72	-48.50
Sampling Date	8/8/2017	8/8/2017
Field Measurements		
pH (SU)	6.1	6.3
Temperature (^{o}C)	15.6	15.5
Dissolved Oxygen (DO; mg/L)	0.2	0.2
Dissolved Oxygen (DO; %)	2.2	2.3
Redox Potential (ORP; mV)	7.5	40.8
Specific Conductivity (µS/cm)[c]	581	503
Laboratory Analyses		
Nitrogen		
Nitrate as N (mg/L)	<0.03	<0.03
Nitrite as N (mg/L)	<0.01	<0.01
Ammonia (mg/L)	**10.3**	**7.39**
Total Kjeldahl Nitrogen (TKN) (mg/L)	**12.3**	**9.09**
Total Nitrogen (mg/L)	**12.3**	**9.09**
Alkalinity		
Total Alkalinity (mg/L)	-	-
Bicarbonate Alkalinity (mg/L)	-	-
Anions		
Chloride (mg/L)	-	-
Sulfate (mg/L)	-	-
Elements		
Dissolved Iron (mg/L)	**2.32**	**4.77**
Dissolved Manganese (mg/L)	**1.72**	**3.26**
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

2. Elevations are approximate. Grab samples were taken and elevations were estimated based on nearby wells.

Table 5 Orleans Landfill Groundwater Analyses - Pump Test

Sample ID	**PW-1 (95-125)**	**PW-1 (95-125)**	**PW-1 (95-125)**	**PW-1 (95-125)**	**PW-1 (95-125)**	**PW-1 (95-125)**	**PW-1 (95-125)**	**PW-1 (95-125)**	**PW-1 (130-160)**
Top of Screen Elevation (ft)									
Bottom of Screen Elevation (ft)									
Sampling Date	7/31/2017	7/31/2017	07/31/2017	08/01/2017	08/01/2017	08/01/2017	08/01/2017	08/01/2017	08/03/2017
Sampling Time	14:45	16:00	20:00	00:15	04:15	08:00	11:00	13:00	12:05
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)	**0.121**	**0.212**	**0.701**	**1.18**	**1.62**	**1.9**	**2.06**	**2.12**	<0.03
Nitrite as N (mg/L)	<0.01	<0.01	**0.012**	**0.012**	**0.013**	**0.012**	**0.013**	**0.012**	<0.01
Ammonia (mg/L)	**9.44**	**8.76**	**8.33**	**8.4**	**7.67**	**7.19**	**7.24**	**7.18**	**12.3**
Total Kjeldahl Nitrogen (TKN) (mg/L)	**10.1**	**9.51**	**10.2**	**10**	**9.95**	**9.69**	**9.52**	**9.71**	**14.7**
Total Nitrogen (mg/L)	**10.2**	**9.72**	**10.9**	**11.2**	**11.6**	**11.6**	**11.6**	**11.8**	**14.7**
Elements									
Dissolved Iron (mg/L)	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**19.6**	**-**
Dissolved Manganese (mg/L)	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**2.59**	**-**

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

Table 5 Orleans Landfill Groundwater Analyses - Pump Test

Sample ID	**PW-1 (130-160)**	**PW-1 (130-160)**	**PW-1 (130-160)**	**PW-1 (130-160)**	**PW-1 (130-160)**	**PW-1 (130-160)**
Top of Screen Elevation (ft)						
Bottom of Screen Elevation (ft)						
Sampling Date	08/03/2017	08/03/2017	08/04/2017	08/04/2017	08/04/2017	08/04/2017
Sampling Time	16:00	20:00	00:00	04:00	07:00	09:55
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)	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Nitrite as N (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ammonia (mg/L)	**11.8**	**11.8**	**12**	**11.3**	**13.3**	**11.1**
Total Kjeldahl Nitrogen (TKN) (mg/L)	**14.8**	**15.4**	**15.3**	**14.9**	**15.1**	**15.2**
Total Nitrogen (mg/L)	**14.8**	**15.4**	**15.3**	**14.9**	**15.1**	**15.2**
Elements						
Dissolved Iron (mg/L)	-	-	-	-	-	**2.46**
Dissolved Manganese (mg/L)	-	-	-	-	-	**3.48**

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

Table 5 Orleans Landfill Groundwater Analyses - Pump Test

Sample ID	**PW-2S (100-130)**	**PW-2S (100-130)**	**PW-2S (100-130)**	**PW-2D (130-154)**	**PW-2D (130-154)**	**PW-2D (130-154)**
Top of Screen Elevation (ft)						
Bottom of Screen Elevation (ft)						
Sampling Date	8/17/2017	8/17/2017	8/17/2017	8/24/2017	8/24/2017	8/24/2017
Sampling Time	10:00	12:00	15:30	10:00	12:00	15:30
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)	**0.412**	**0.519**	**0.626**	**0.167**	**0.188**	**0.186**
Nitrite as N (mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Ammonia (mg/L)	**7.37**	**7.11**	**6.74**	**4.89**	**5.08**	**4.96**
Total Kjeldahl Nitrogen (TKN) (mg/L)	**10.2**	**8.87**	**8.62**	**6.47**	**5.77**	**5.83**
Total Nitrogen (mg/L)	**10.6**	**9.39**	**9.25**	**6.64**	**5.96**	**6.02**
Elements						
Dissolved Iron (mg/L)	<0.1	<0.1	<0.1	**0.306**	**0.369**	**0.35**
Dissolved Manganese (mg/L)	**4.2**	**4.17**	**4**	**4.49**	**4.47**	**4.38**

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

Table 6 Orleans Landfill Stormwater Analyses

Sample ID	**Stormwater 1**	**Stormwater 2**	**LS-1**
Sample Description	Transfer Station Runoff	Compost Runoff	Compost Leachate
Sampling Date	2/8/2017	2/8/2017	3/28/2017
Laboratory Analyses			
Nitrogen			
Nitrate as N (mg/L)	**0.424**	**10.5**	**1.2**
Nitrite as N (mg/L)	**0.026**	**0.15**	**0.428**
Ammonia (mg/L)	**0.67**	**2.92**	**4.94**
Total Kjeldahl Nitrogen (TKN) (mg/L)	**4.05**	**16.4**	**-**
Total Nitrogen (mg/L)	**4.5**	**27.1**	**98.5**
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

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Figures

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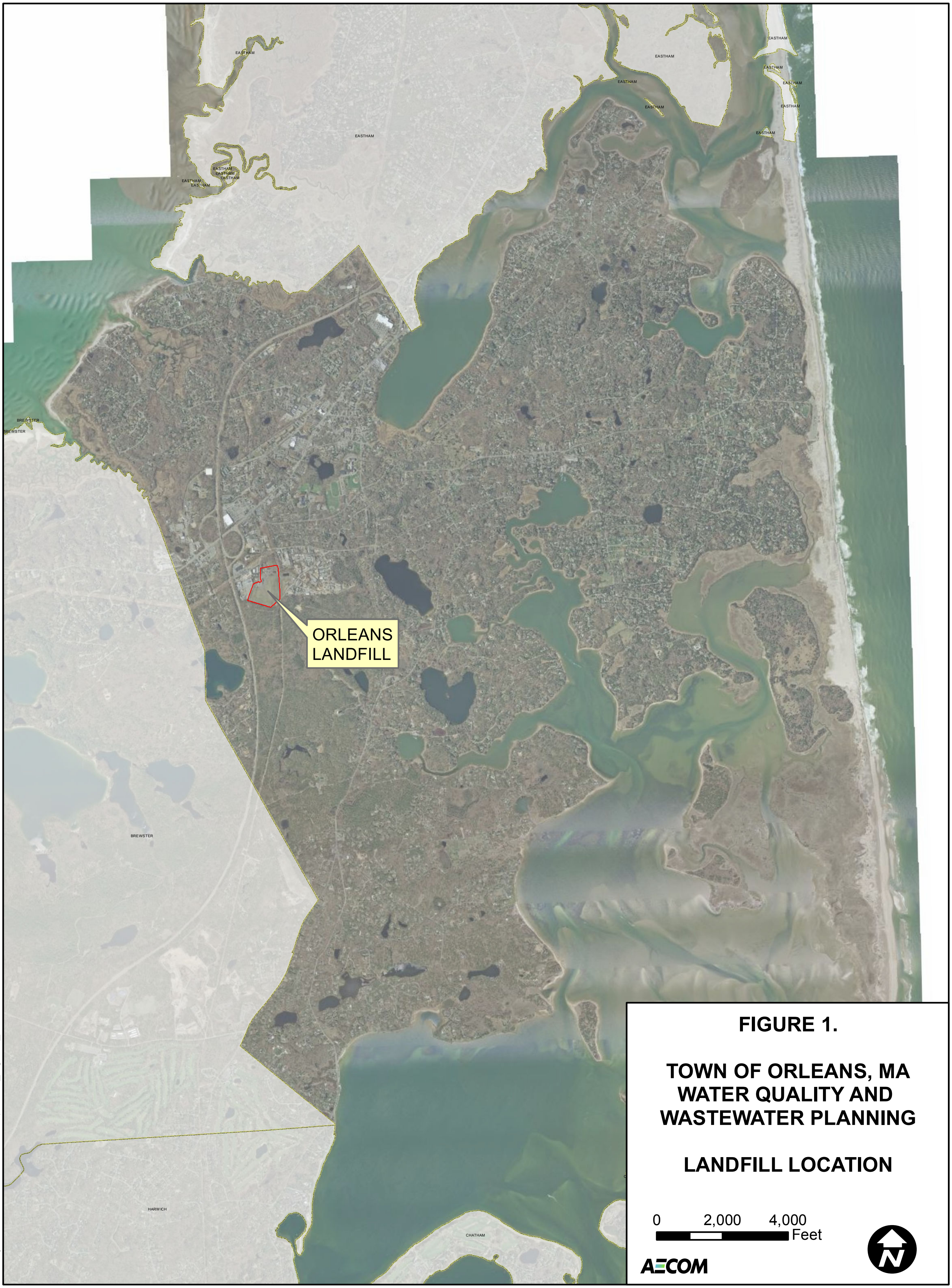

FIGURE 1.

**TOWN OF ORLEANS, MA
WATER QUALITY AND
WASTEWATER PLANNING**

LANDFILL LOCATION

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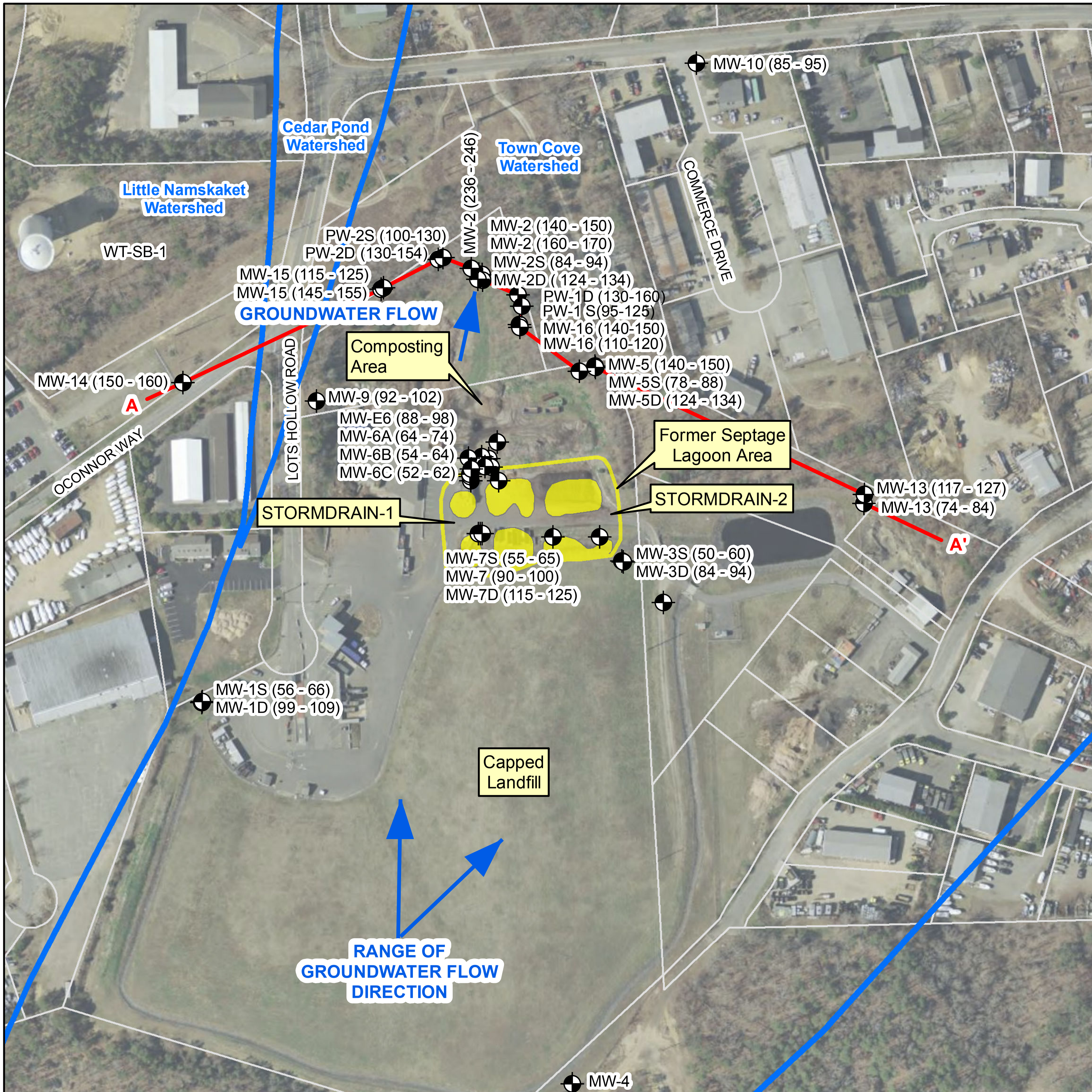

FIGURE 2.

TOWN OF ORLEANS, MA
WATER QUALITY AND
WASTEWATER PLANNING

TOWN LANDFILL
MONITORING WELL LOCATIONS

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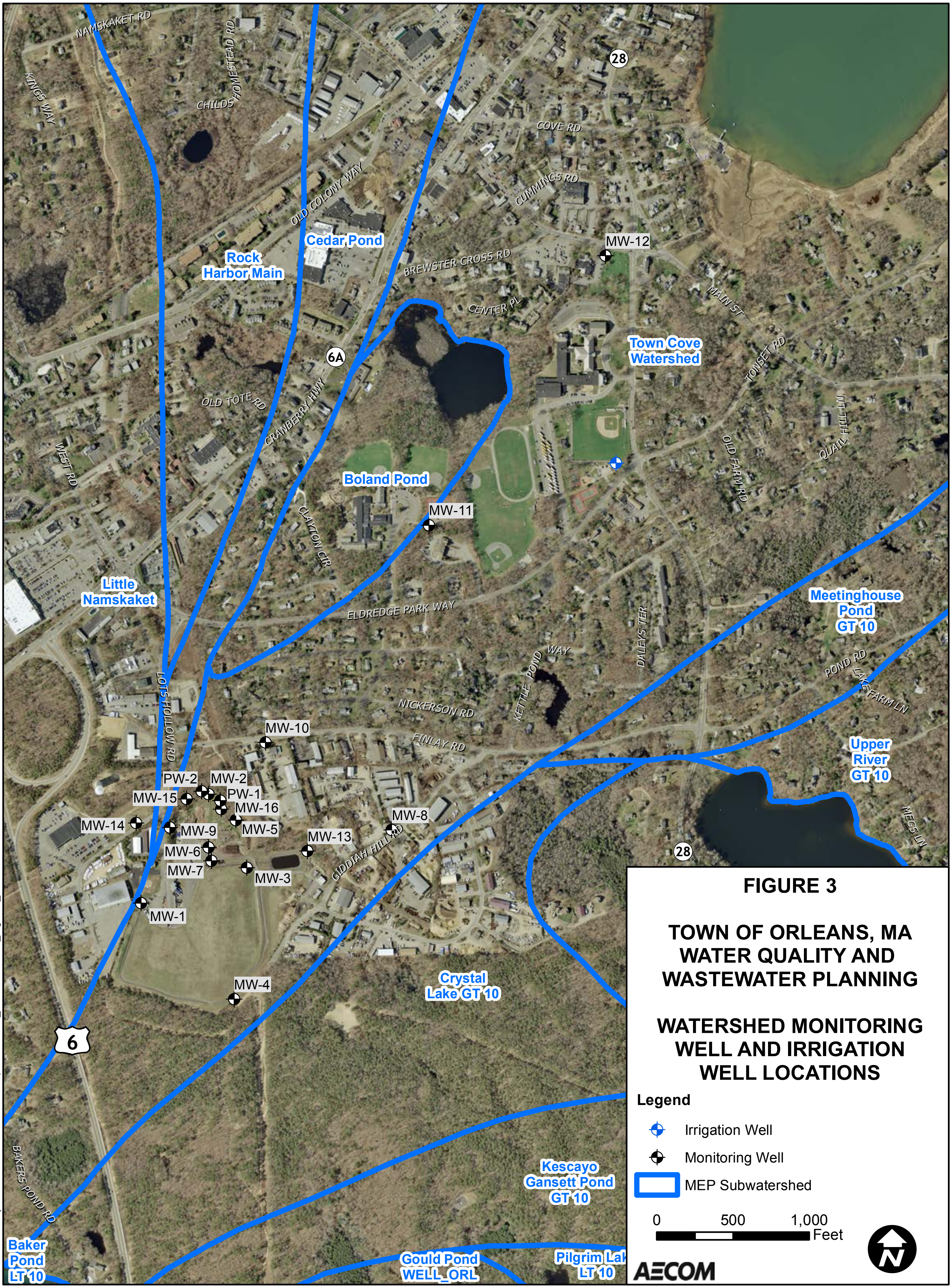

FIGURE 3

TOWN OF ORLEANS, MA WATER QUALITY AND WASTEWATER PLANNING

WATERSHED MONITORING WELL AND IRRIGATION WELL LOCATIONS

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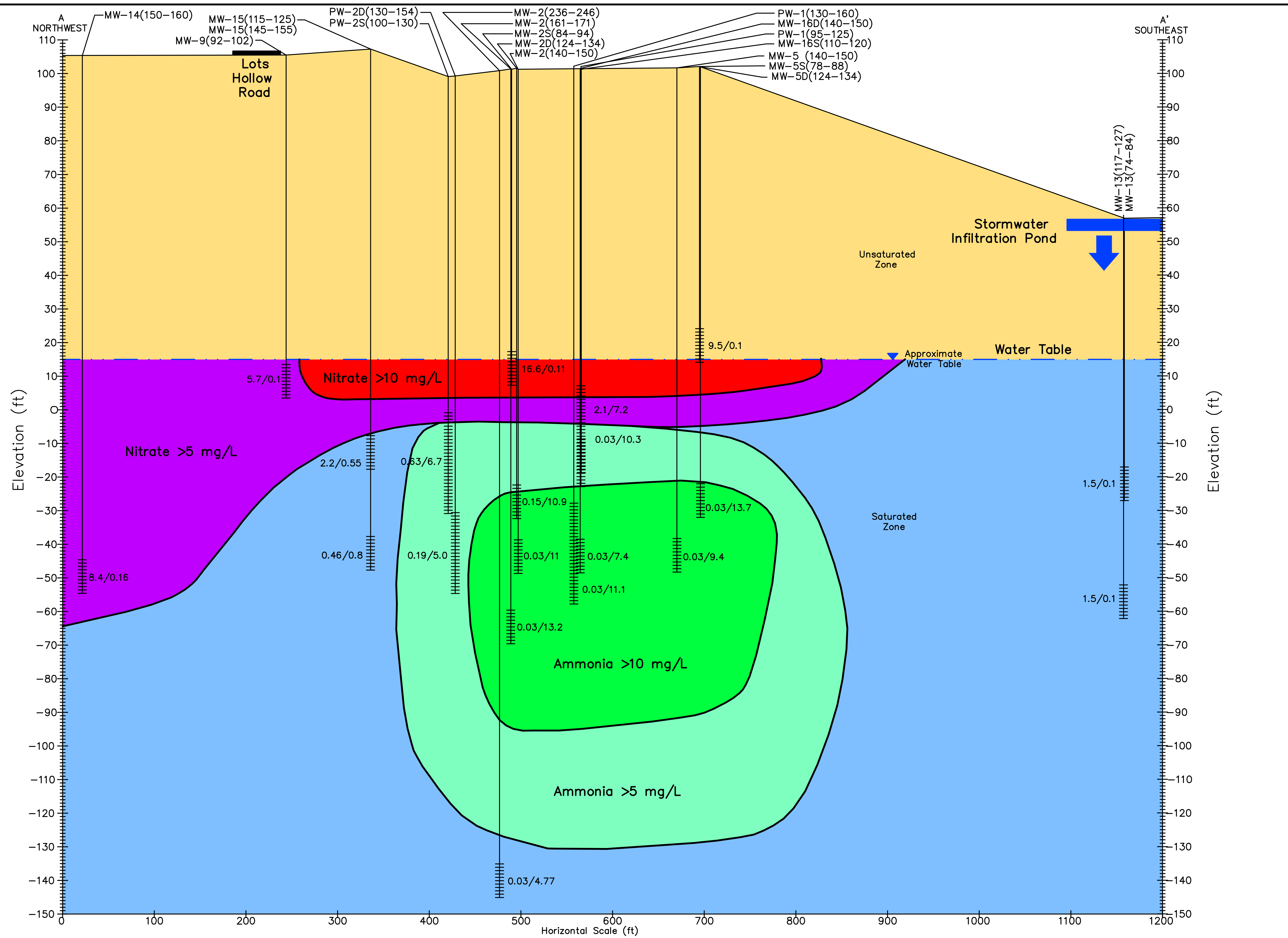

LANDFILL CROSS SECTION A-A': NITROGEN/AMMONIA DATA
WATER QUALITY AND WASTEWTER PLANNING
TOWN OF ORLEANS, MA
Project No.: 60476644 Date: 2018-04-19

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Figure: 4

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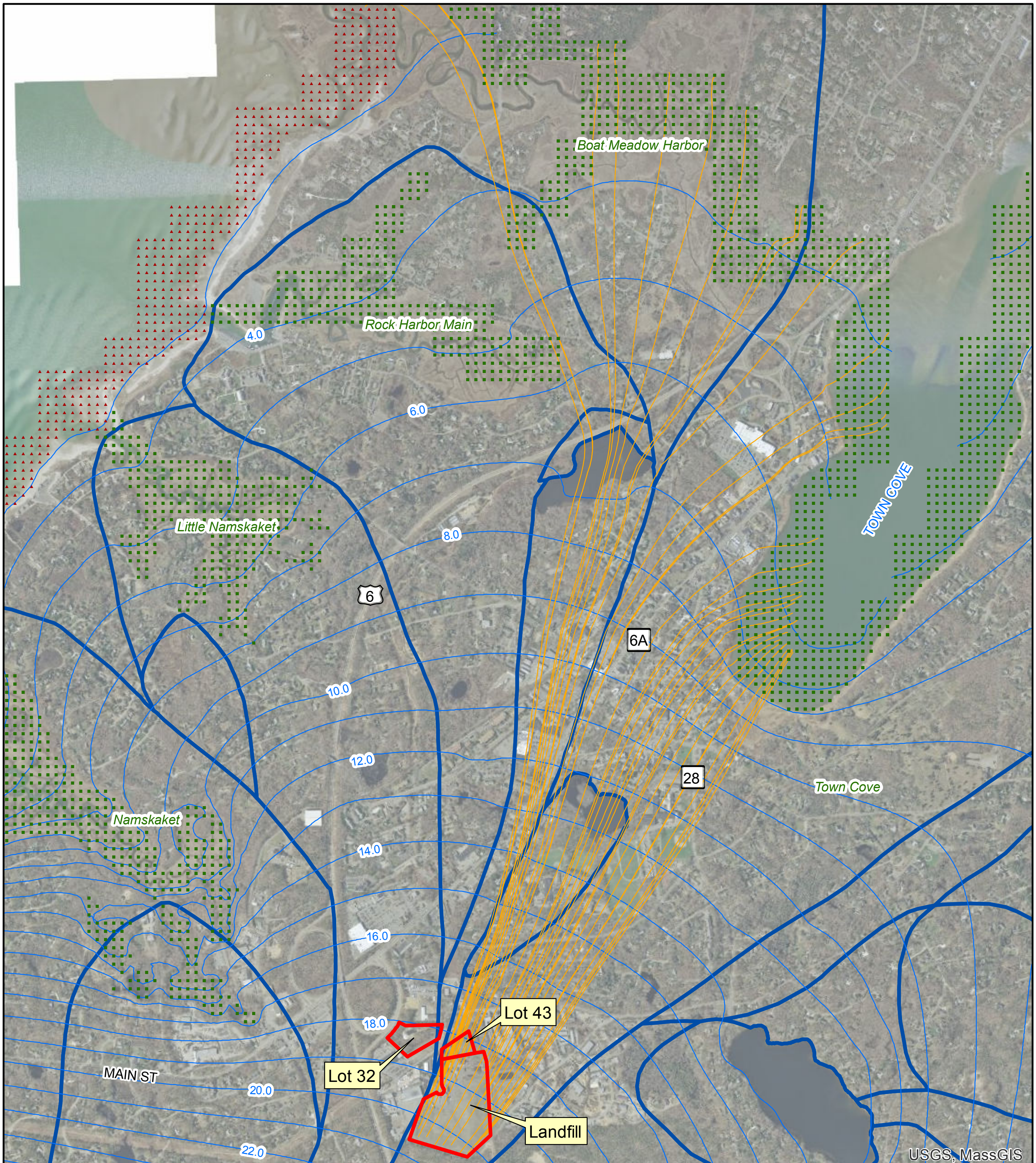

Legend

- Particle Trace Landfill
- MEP Subwatershed
- Estuary
- Ocean/Cape Cod Bay

FIGURE 5
TOWN OF ORLEANS
WATER QUALITY AND WASTEWATER PLANNING
STEADY STATE MODEL -
PARTICLES ORIGINATING FROM LANDFILL

N

0 1,250 2,500 5,000 Feet

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Appendix A – Orleans Landfill Nitrogen Groundwater Flux Calculations

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

Shallow Nitrate

Parameter	Units		Total Nitrogen Flux
Hydraulic Gradient	ft/ft	0.004	
Conductivity	ft/day	100.00	
Porosity	unitless	0.30	
Darcy Velocity	ft/d	0.40	
Average Linear Groundwater Velocity	ft/d	1.33	
Vertical Extent	feet	20.00	
Length of Affected Aquifer[1]	feet	500.00	
Groundwater Flux	ft3 / d-ft length	8.00	
Groundwater Flux	ft3 / day	4,000.00	
Groundwater Flux	L/day	113,267.20	
Groundwater Flux	Gallons/min	20.78	
Nitrate Concentration	mg/L	9.00	
Nitrate Flux	kg /yr-ft length	0.74	
Nitrogen Flux	kg/year	372.08	372

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

Deep Ammonia

Parameter	Units		
Hydraulic Gradient	ft/ft	0.004	
Conductivity	ft/day	100.00	
Porosity	unitless	0.30	
Darcy Velocity	ft/d	0.40	
Average Linear Groundwater Velocity	ft/d	1.33	
Vertical Extent	feet	125	
Length of Affected Aquifer[1]	feet	500	
Groundwater Flux	ft3 / d-ft length	50	
Groundwater Flux	ft3 / day	25000	
Groundwater Flux	L/day	707920	
Groundwater Flux	Gallons/min	130	
Ammonia Concentration	mg/L	11.00	
Ammonia Flux (adjusted by ammonium retardation factor of 4)	kg /yr-ft length	1.42	
Nitrogen Flux (adjusted by ammonium retardation factor of 4)	kg/year	711	711

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

Total Nitrogen Flux	1,083

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Appendix B – Orleans Landfill Drainage Swale Reconstruction Drawings

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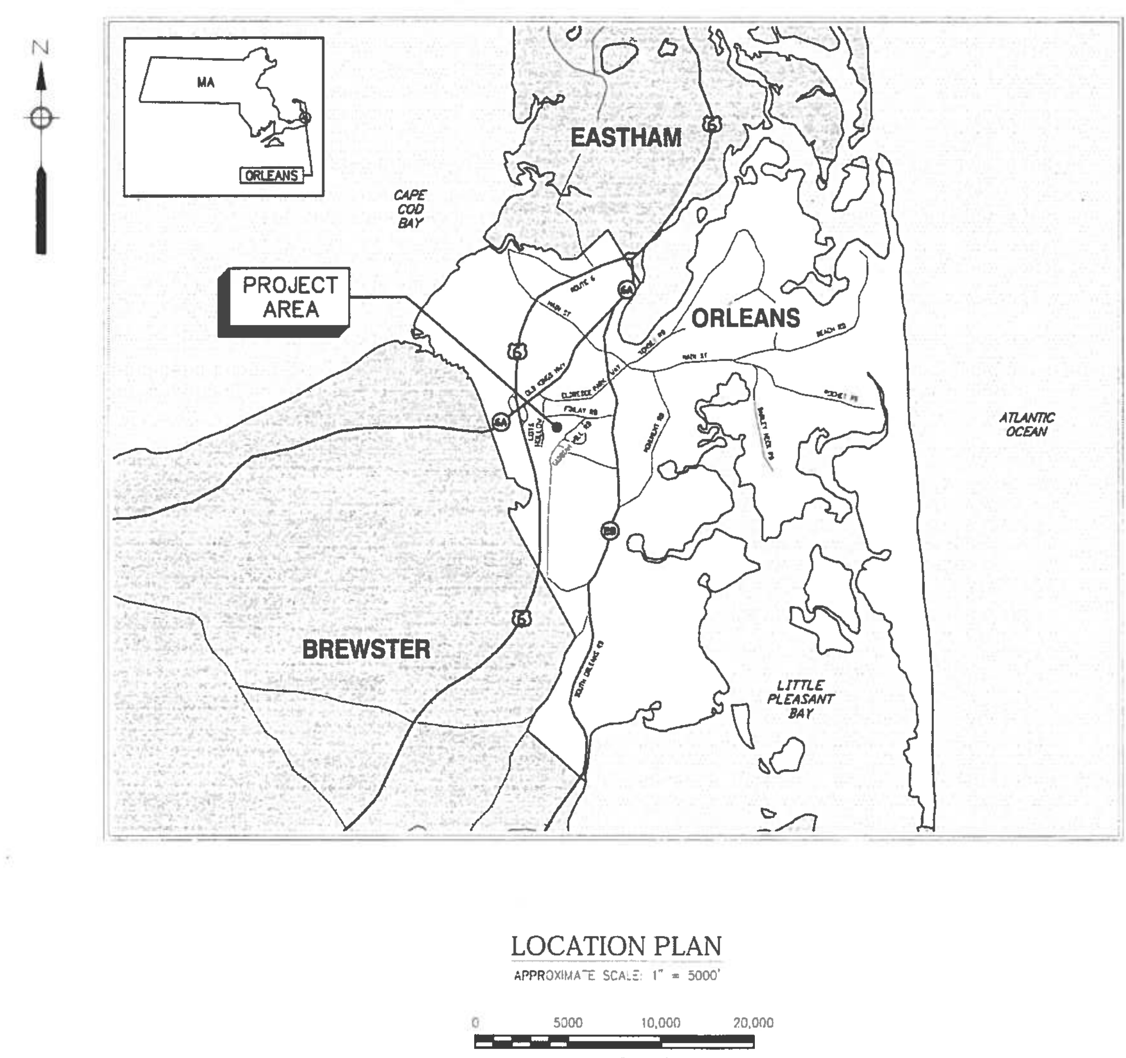
TOWN OF ORLEANS
DPW FACILITY
DRAINAGE SWALE RECONSTRUCTION

ORLEANS, MA
MARCH 2018



LOCATION PLAN

APPROXIMATE SCALE: 1" = 5000'

INDEX OF DRAWINGS

SHEET NO.	TITLE
G-001	COVER SHEET AND INDEX OF DRAWINGS
C-101	EXISTING CONDITIONS PLAN
C-102	SITE PLAN
C-301	PROFILE AND DETAILS

DRAWING REFERENCE:

1. BASE MAPPING FROM THE TOWN OF ORLEANS DPW FACILITY WAS PROVIDED BY WESTON AND SAMPSON ON 06/15/2017 FOR THE DEVELOPMENT OF THE LANDFILL ACTION PLAN.
2. CONTOUR ELEVATIONS REFERENCE THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD 88).

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PROJECT
Town of Orleans
DPW Facility
Drainage Swale
Reconstruction

CLIENT
Town of Orleans, MA
19 SCHOOL ROAD
ORLEANS, MA 02653
(508) 240-3700

CONSULTANT
AECOM TECHNICAL SERVICES, INC
9 JONATHAN BOURNE DRIVE
POCASSET, MA 02559
PHONE: (508) 833-6950
www.aecom.com

CONSULTANTS

REGISTRATION

COMMONWEALTH OF MASSACHUSETTS
THOMAS E. PARECE
CIVIL
No. 34483
REGISTERED PROFESSIONAL ENGINEER

ISSUE/REVISION

I/R	DATE	DESCRIPTION
C	2018-04-27	CHANGE IN LINER MATERIAL
	2018-03-22	ISSUED FOR DEP PERMIT
A	2018-02-21	DRAFT PLANS FOR REVIEW

PROJECT NUMBER
60476644

Designed By:	M. CURRAN
Drawn By:	M. CURRAN
Dept Check:	T. PARECE
Proj Check:	M. DONOGHUE
Date:	MARCH 2018
Scale:	AS NOTED

DISCIPLINE
GENERAL

SHEET TITLE
COVER SHEET AND INDEX OF DRAWINGS

SHEET NUMBER
G-001

Project Management Initials: Designer: ____ Checked: ____ Approved: ____

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EXISTING CONDITIONS SITE PLAN

SCALE: 1"=40'

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Town of Orleans, MA
19 SCHOOL ROAD
ORLEANS, MA 02653
(508) 240-3700

CONSULTANT

AECOM TECHNICAL SERVICES, INC.
9 JONATHAN BOURNE DRIVE
POCASSET, MA 02559
PHONE: (508) 833-6950
www.aecom.com

CONSULTANTS

REGISTRATION

COMMONWEALTH OF MASSACHUSETTS
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A	2018-02-21	DRAFT PLANS FOR REVIEW

PROJECT NUMBER

60476644

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Drawn By:	M. CURRAN
Dept Check:	T. PARECE
Proj Check:	M. DONOGHUE
Date:	MARCH 2018
Scale:	AS NOTED

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SHEET TITLE

EXISTING CONDITIONS SITE PLAN

SHEET NUMBER

C-101

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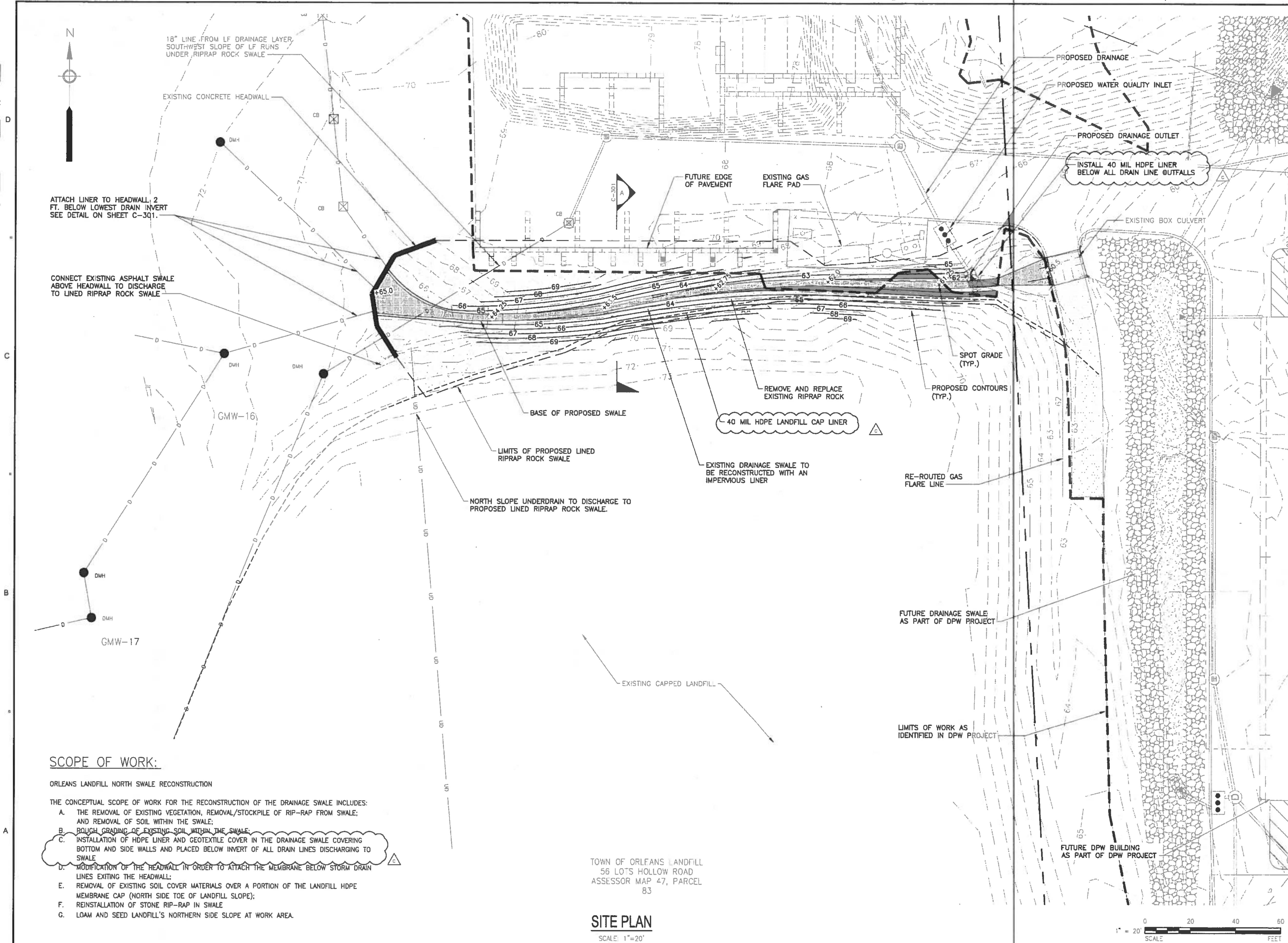

SCOPE OF WORK:

ORLEANS LANDFILL NORTH SWALE RECONSTRUCTION

THE CONCEPTUAL SCOPE OF WORK FOR THE RECONSTRUCTION OF THE DRAINAGE SWALE INCLUDES:

A. THE REMOVAL OF EXISTING VEGETATION, REMOVAL/STOCKPILE OF RIP-RAP FROM SWALE; AND REMOVAL OF SOIL WITHIN THE SWALE;
B. ROUGH GRADING OF EXISTING SOIL WITHIN THE SWALE;
C. INSTALLATION OF HDPE LINER AND GEOTEXTILE COVER IN THE DRAINAGE SWALE COVERING BOTTOM AND SIDE WALLS AND PLACED BELOW INVERT OF ALL DRAIN LINES DISCHARGING TO SWALE
D. MODIFICATION OF THE HEADWALL IN ORDER TO ATTACH THE MEMBRANE BELOW STORM DRAIN LINES EXITING THE HEADWALL;
E. REMOVAL OF EXISTING SOIL COVER MATERIALS OVER A PORTION OF THE LANDFILL HDPE MEMBRANE CAP (NORTH SIDE TOE OF LANDFILL SLOPE);
F. REINSTALLATION OF STONE RIP-RAP IN SWALE
G. LOAM AND SEED LANDFILL'S NORTHERN SIDE SLOPE AT WORK AREA.

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Town of Orleans DPW Facility Drainage Swale Reconstruction

CLIENT

Town of Orleans, MA
19 SCHOOL ROAD
ORLEANS, MA 02653
(508) 240-3700

CONSULTANT

AECOM TECHNICAL SERVICES, INC
9 JONATHAN BOURNE DRIVE
POCASSET, MA 02559
PHONE: (508) 833-6950
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Proj Check:	M. DONOGHUE
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Scale:	AS NOTED

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SHEET TITLE

SITE PLAN

SHEET NUMBER

C-102

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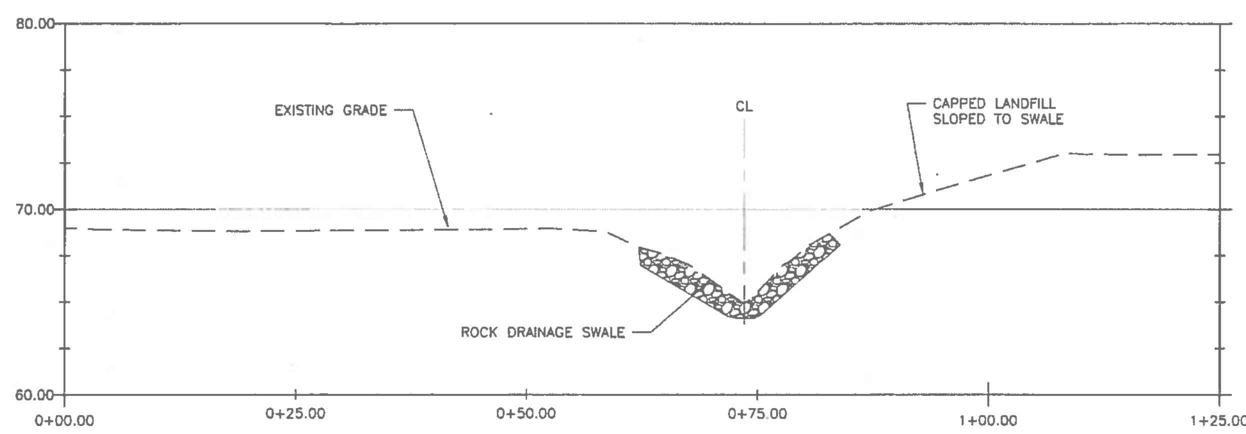
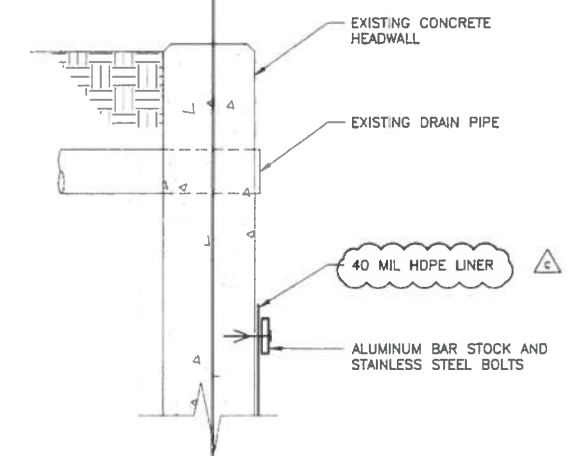


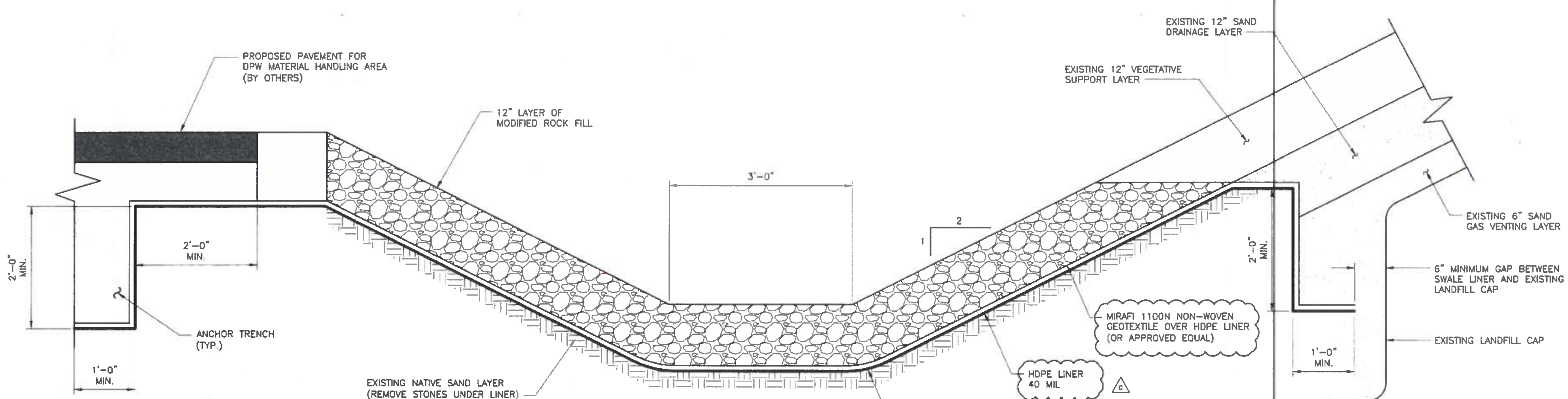
PROFILE A THROUGH EXISTING DRAINAGE SWALE

SCALE: 1"=10'



LINER CONNECTION DETAIL

NOT TO SCALE



NOTES:

THE INTENT OF THE PROPOSED SWALE MODIFICATION IS TO PREVENT THE INFILTRATION OF STORMWATER BELOW THE AREA OF THE EXISTING SWALE.

1. OVERLAP GEOTEXTILE PANELS A MINIMUM OF 12".
2. GEOTEXTILE AND HDPE LINER SHALL BE INSTALLED IN ACCORDANCE WITH MANUFACTURER'S SPECIFICATIONS.
3. HDPE LINER SHALL BE INSTALLED WITH A MINIMUM WIDTH OF 12' CENTERED ON THE MIDDLE OF THE SWALE. ADDITIONAL LINER SHALL BE INSTALLED AS NEEDED WITH OVERLAPS AND JOINT SEALING AS SPECIFIED BY THE MANUFACTURER.
4. EDGES OF GEOTEXTILE AND LINER SHALL EXTEND FROM BOTTOM OF ANCHOR TRENCH TO BOTTOM OF ANCHOR TRENCH.

C

IMPERVIOUS SWALE DETAIL

SCALE: 1"=1'-0"

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PROFILE AND DETAILS

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C-301