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Memorandum

To	George Meservey, Director of Planning & Community Development Michael Domenica, PE, Program Manager
CC	Betsy Shreve, AICP, AECOM Project Director Mark Owen, PG, AECOM
Subject	**Town of Orleans, MA** **Water Quality and Wastewater Planning** **Task Number 8.1 – Preplanning - Treatment and Disposal Site Investigations** **Deliverable 8.1.1.A – Technical Memorandum - Parcels 1/1A Flow Paths - Final**
Project Number	60476644
From	Thomas Parece, P.E., AECOM Project Manager
Date	February 14, 2017

Approvals	Date	Signature / Initials
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1. Background

This Technical Memorandum documents a summary of preliminary groundwater modeling results simulating groundwater flow from Parcels 1/1A, located on Overland Way that might be used for the discharge of treated effluent from the proposed Downtown Area Wastewater Treatment Facility (WWTF).

2. Introduction

Groundwater modeling was proposed as a part of the evaluation of disposal options as modeling can provide feedback on potential designs, such as the size, location, and amount of discharge. Specifically for this project, numerical groundwater modeling is a tool that was used to predict changes in groundwater flow directions based on a groundwater discharge from the proposed Downtown Area wastewater treatment facility.

The objective of the groundwater modeling is to provide a preliminary estimation of where a groundwater discharge from Parcels 1/1A would flow and potentially enter surface waters.

3. Potential Groundwater Discharge Site - Parcels 1/1A

Parcels 1/1A are located on a 26-acre site on Overland Road, in the Town of Orleans (Figure 1). The parcels are located in the northeast corner of the site.

The geology and hydrogeology of the Overland Way site, outside of Sites 1/1A is well known and documented through several studies including several US Geological Survey (USGS) reports. As part of a MassDEP required hydrogeologic evaluation the soils and hydrogeology of Sites 1/1A would have to be confirmed and evaluated. It is expected however, that the soils would be similar to those documented across much of the site. Parcels 1/1A are approximately 6.23 acres and large enough to discharge the projected flow from the Downtown Area Wastewater Treatment Facility. The flow is estimated at 250,000 gpd.

A disposal facility on this site would consist of subsurface leaching trenches, sand beds, or wicks. Subsurface leaching trenches consist of subsurface piping (similar to leaching fields) installed four feet or so below the ground surface for the purpose of distributing and discharging effluent to the underlying soils which infiltrate to the water table. Sand beds are open beds where groundwater is discharged to the ground surface allowing the effluent to infiltrate the underlying soils to the water table. A wick is a vertical subsurface structure constructed for the purpose of transporting highly treated effluent to groundwater. A wick is a large diameter borehole (three feet or so in diameter) filled with pea stone or gravel. The effluent is discharged just over the pea stone allowing the treated effluent to flow over the stone to the underlying water table. The discharge method selected would be based on the results of the hydrogeologic evaluation.

4. Groundwater Modeling Evaluation

Groundwater modeling was conducted as a part of the evaluation of the potential disposal sites. The groundwater modeling can provide feedback on flow directions and where effluent from the Wastewater Treatment Facility may discharge to surface waters downgradient of the WWTF.

For this technical memorandum, Parcels 1/1A were preliminarily evaluated using numerical groundwater modeling techniques. The objective of the modeling was to evaluate what watersheds the effluent from the proposed Downtown Area Wastewater Treatment Facility may discharge. The site and Parcels 1/1A are shown in Figure 1.

A. Modeling Method

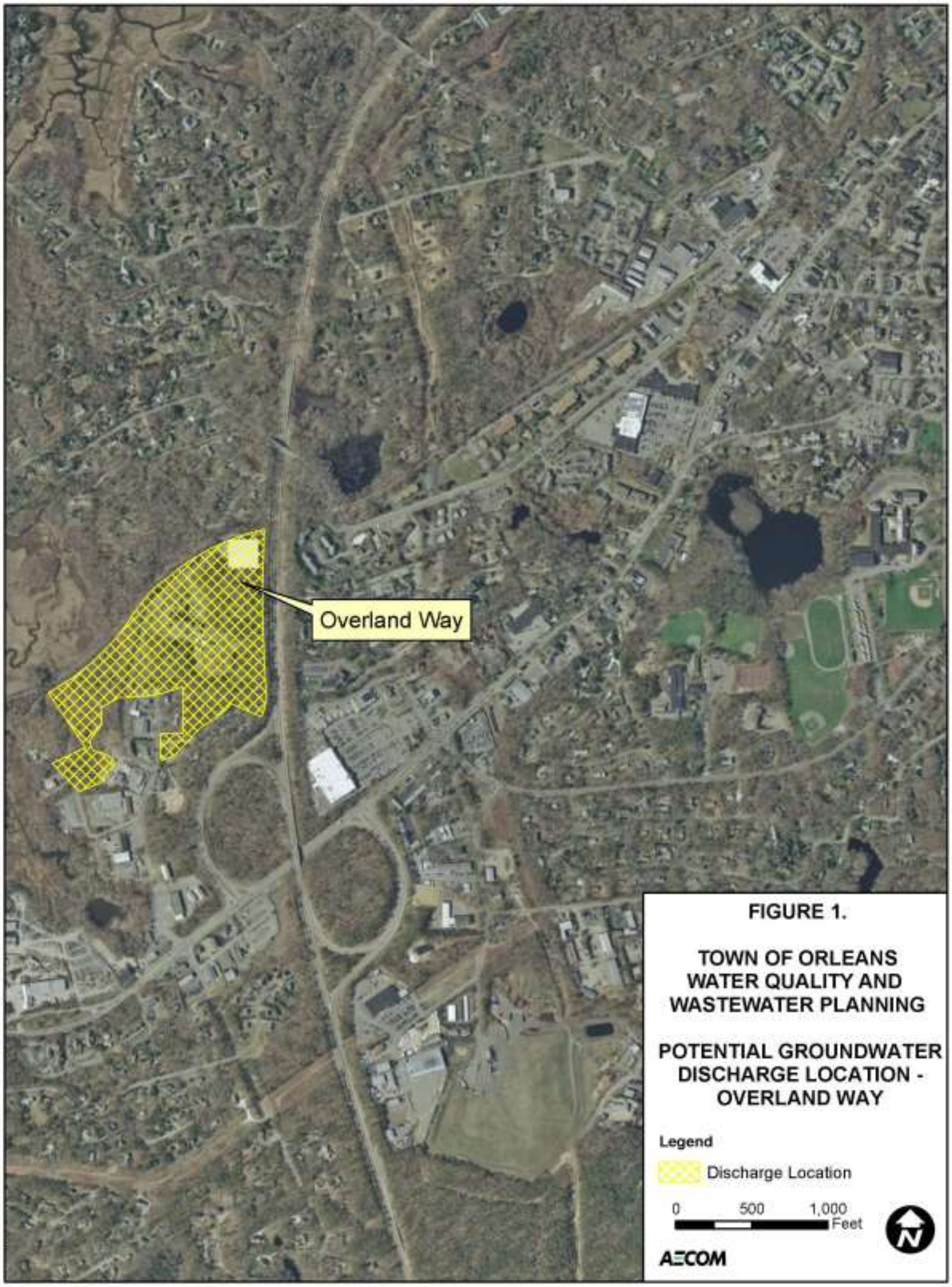
A regional three-dimensional groundwater flow model of the Monomoy Lens was developed by the US Geological Survey as a tool for understanding the groundwater flow system and water budget (USGS, 2004). This regional model formed the basis of a groundwater flow model of the Town of Orleans.

MODFLOW was used for this analysis (MacDonald and Harbaugh, 1988). The three-dimensional groundwater flow model was coupled with a particle tracking model called MODPATH (Pollack, 2004) in order to illustrate the potential movement of groundwater over time. Both of these models were used on the GMS platform, Version 10.0.

B. Conceptual Model of the Aquifer System

A conceptual model of a groundwater flow system is a representation of how an aquifer functions based on available data. Geologic maps and cross-sections, groundwater flow maps, and the generalized water balance (the volume of water entering and leaving the aquifer) are common elements of a conceptual aquifer model. Our understanding of how the Town of Orleans groundwater flow system functions is based on the geological and hydrological data presented in the US Geological Survey reports; additionally the conceptual site model is based on the work done and reported on by the US Geological Survey (2004).

The conceptual site model for hydrogeology and groundwater flow in the Monomoy Lens is well documented in the USGS, 2004 report. Overall, the conceptual site model documented in the US Geological Survey (2004) report is the same as is used for this modeling effort.


Overland Way
FIGURE 1.
TOWN OF ORLEANS
WATER QUALITY AND
WASTEWATER PLANNING
POTENTIAL GROUNDWATER
DISCHARGE LOCATION -
OVERLAND WAY
Legend
Discharge Location
0
500
1,000
Feet
AECOM

In general, the aquifer In the Town of Orleans is a relatively simple water table aquifer composed of relatively homogeneous deposits of sand with trace amounts of gravel and silt. The bottom of the aquifer is assumed to coincide with the bottom of the numerical model, around -350 feet elevation below sea level.

Water enters the aquifer system primarily in the form of rainfall recharge. Rainfall recharge is expected to be around 29 inches per year except in wetlands, lakes, oceans where it may be low or zero. Groundwater leaves the aquifer system through surface water features, such as lakes, streams, wetlands, marshes, and the ocean.

C. Model Design and Updates

The numerical groundwater flow modeling was completed using the US Geological Survey numerical groundwater flow model of the Monomoy Lens as a basis. This model is documented in “Simulated Water Sources and Effects of Pumping on Surface and Ground Water, Sagamore and Monomoy Flow Lenses, Cape Cod, Massachusetts” (USGS, 2005). Modeling files were received from the US Geological Survey and were imported into the GMS 10.0 platform. GMS is a pre and post processor for MODFLOW-2000 that facilitates data input and depiction and interpretation of output.

The model design prepared by the US Geological Survey is structured as follows:

- The model was run as a steady-state model. This run incorporates long-term average conditions and does not include short-term (i.e., transient) changes in storage.;
- The original model domain included the entire Monomoy Lens; a map of this domain is included in Figure 1-1A, Appendix 1 of the US Geological Survey report (USGS, 2004). The updated model domain is bounded primarily by surface water features (streams, marshes, inlets, estuaries, and ocean). The southwestern limit of the model domain was adjusted from the full regional model; a no flow boundary was assigned there to coincide with the groundwater divide;
- The original and current models are 20 layers. In this area of the Monomoy Lens, the groundwater table is low enough such that many of the upper layers go dry. The first fully wet layer is layer 8. The bottom updated model domain ranges from approximately -300 to -400 feet elevation below sea level. With the exception of the lowest model layer, the model layers are uniform thickness across the model domain, see Figure 1-1B, Appendix 1 (USGS, 2004);
- Rainfall recharge was assigned using a variable array for the model domain. The rainfall recharge rate ranges from 0 feet per day to 0.00723 feet per day (0 to 31.67 inches per year). Most of the model area includes rainfall recharge around 29 inches per year. Lesser rates or zero rainfall recharge rates were assigned to wetlands, open water, and/or oceans;
- Surface water features were simulated in a variety of ways:
    - Streams, wetlands, marshes, estuaries and other drainages were simulated using the drain (DRN) package.
    - The Atlantic Ocean and Cape Cod Bay were simulated with a general head boundary (GHB).
    - Lakes were simulated with horizontal flow boundaries (HFB) and high hydraulic conductivity.
    - The original model included using the stream (STR) package for some surface water drainages, but when the model domain was made smaller, those features were excluded. Therefore, the updated model does not use the stream package.

- Hydraulic conductivity values used in the original groundwater model ranged from 10 feet per day for sandy silts to 300 feet per day for sand and gravel deposits. The hydraulic conductivity values for layers 7 and 8 are identical in the area of the proposed discharge. Layer represents the water table aquifer. High hydraulic conductivities (50,000 feet per day) were used for lakes. Recent site investigations completed at the Beach Road Site indicated that the soils were fine to coarse-grained sediments, resulting in hydraulic conductivity values ranging from 62 to 678 feet per day for the sand, and sand and gravel soils underlying the site. These values were consistent with what is currently in the model for these areas; therefore no changes to horizontal or vertical hydraulic conductivity were made in the updated model; and

- The original US Geological Survey model included groundwater extraction consistent with water usage using the well (WEL) package. The updated model made no changes to the well rates for the updated model domain. The WEL package was used to simulate the groundwater discharge at the Beach Road site. This is discussed in the Simulations section, below.

A number of model updates were made to the model to meet model objectives. They are as follows:

- AECOM converted the solver package to the PCG2 package from the LMG package based on a recommendation from the US Geological Survey in the model documentation that accompanied the model files ("…due to licensing restrictions, the US Geological Survey is no longer able to publicly distribute the Algebraic Multi-Grid (AMG) solver, on which the Link-AMG (LMG) Package relies. There are two possible solutions: (a) use a standard solver publicly available from US Geological Survey, such as SIP or PCG2; or (b) obtain the AMG/LMG solver from Fraunhofer-Institute for Algorithms and Scientific Computing (SCAI).");

- AECOM refined the grid around the some of the discharge sites of interest. The US Geological Survey model used a grid size of 400 feet by 400 feet over the entire model domain. AECOM adjusted the grid to range from 50 feet by 50 feet to 400 feet by 400 feet, with the most refined portions of the model grid located in the areas of interest. This was completed to provide better resolution on the model inputs (i.e., discharge areas) and outputs; and

- In refining the grid, some model features were updated:
  - Drain cell conductances were adjusted to reflect the geometry of the grid cells;
  - General head boundary conductances were adjusted to reflect the geometry of the grid cells; and
  - Horizontal flow barrier segments were added as needed to encompass the ponds/lakes in the model domain.

After the changes above were made, the model was verified to be an adequate representation of the original US Geological Survey model in the following ways:

- A comparison of predicted groundwater elevations were made in select cells/areas to demonstrate that the new version of the model predicted groundwater elevations similar to that predicted by the US Geological Survey model. Generally, the differences were less than 0.5 feet and lower in many instances. There are a handful of cells where the model predictions are greater than 1 foot, but these are far from the areas of interest and so should not impact model predictions;

- A comparison of groundwater flow directions as demonstrated with particle tracking. Particles were seeded in select areas to verify that groundwater flow paths and divides are similar as those mapped by the US Geological Survey (specific reference). Generally speaking the new version of the model was the same or similar to the particle tracking under ambient conditions from the US Geological Survey version of the model;
- A comparison of mass balance generated by the model was completed. More specifically, recharge, well, general head boundary, drain boundary volumes were compared to verify that the water balances were the same or similar to the US Geological Survey model. The percent differences on the water budget components are very small; most differences can be attributed, in part, to the regridding and resulting changes to conductances of the drain and general head boundaries;
- The grid refinement, which doesn't allow a direct comparison of groundwater elevations in places where the grid has been changed significantly, the changes in conductance (in the drain and general head boundary packages) where the grid is refined and groundwater flows into and out of the model differently between the models and therefore results in slightly different elevations; and
- The change in model solver (from LMG to PCG2), which results in a slightly different solution.

In summary, a number of changes to the original US Geological Survey model domain and structure were completed to better meet the project objectives. Despite the changes, the model replicated the US Geological Survey output adequately; differences can be explained and are not expected to impact model predictions. Overall, AECOM considers this model a good tool to complete a preliminary evaluation of effluent disposal scenarios.

D. Changes to Model Input Parameters

There were no changes made to model input parameters such as hydraulic conductivity, effective porosity, and other aquifer parameters.

E. Model Calibration

The full Monomoy Lens model was calibrated and this process is described in Appendix 1 of the US Geological Survey report (2004). In accordance with our scope, AECOM verified that the calibration was maintained after the domain and grid were updated as discussed above. In summary:

- Simulated groundwater elevations from the original model compared favorably to the simulated groundwater elevations generated in the updated model;
- Simulated groundwater flow paths from the original model compared favorably to the simulated groundwater flow paths generated in the updated model;
- The water budget of the original model (for the area of interest) compared favorably with the water budget for the updated model; and
- Simulated groundwater elevations compared favorably to estimates for high groundwater elevation conditions.

Overall the updated model was able to reproduce the results from the original model very closely. Therefore model was considered a good tool for conducting simulations.

F. Predictive Simulation

The calibrated groundwater flow model was used to simulate several groundwater discharge scenarios in order to predict groundwater flow from the discharge sites.

A single discharge scenario was simulated using the groundwater flow model. The scenario simulated a discharge from Parcels 1/1A. The scenario simulated the discharge under the average ambient water table conditions described above. Scenarios simulated an average annual discharge rate of 200,000 gallons per day.

The simulated paths of groundwater flow were illustrated by using the groundwater model particle tracking module. The down gradient extent of the particle traces illustrate where groundwater discharges to a surface water. The simulation results with particle traces are provided in Attachment A.

The results of the model scenario simulated indicate that groundwater flows from Site 1/1A on Overland Way north and west. A majority of the discharge flows under the Namskaket and Little Namskaket Creek marshes directly into Cape Cod Bay. A few particle traces terminate in the creaks and marshes of the Namskaket Creek Watersheds indicating that a portion of the flow discharges into these areas, However, It should be noted that a majority of the flow enters the watersheds relatively close to where the Creeks discharge to Cape Cod Bay where the tidal flux is greatest.

5. Findings

Flow from groundwater discharge from Parcels 1/1A sites was simulated using a modified version of the US Geological Survey Monomoy Lens groundwater Model. Using the groundwater model's particle tracking module, flow paths were used to illustrate the path of the Wastewater Treatment Facility's discharge from the discharge location, through the groundwater, to where it discharges to surface waters. Results of the simulations are included in Attachment A.

Quantifying the flow and nitrate load that discharges into each of the watersheds would require additional groundwater model runs.

If Parcels 1/1A are selected for a discharge location, a detailed hydrogeologic evaluation would be required by MassDEP. The evaluation would require additional subsurface investigations, data analysis, model updates, model calibration, and more detailed model simulations. As part of evaluation, the US Geological Survey groundwater model would be updated to incorporate local and regional hydrogeologic conditions estimated through the hydrogeologic evaluation. At that time, the nitrate load to each subwatershed and quantity of freshwater flow to each watershed could more accurately be estimated.

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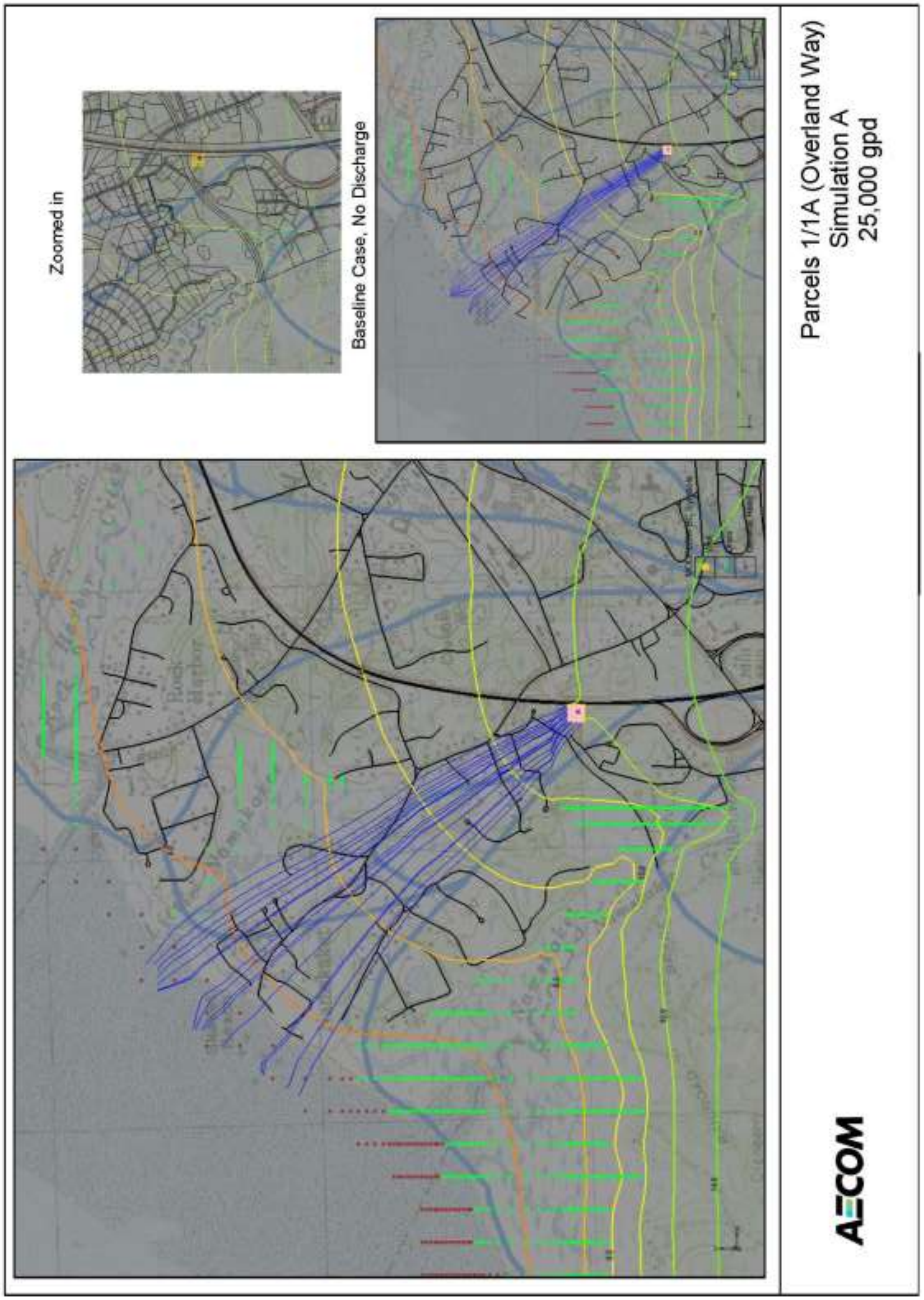
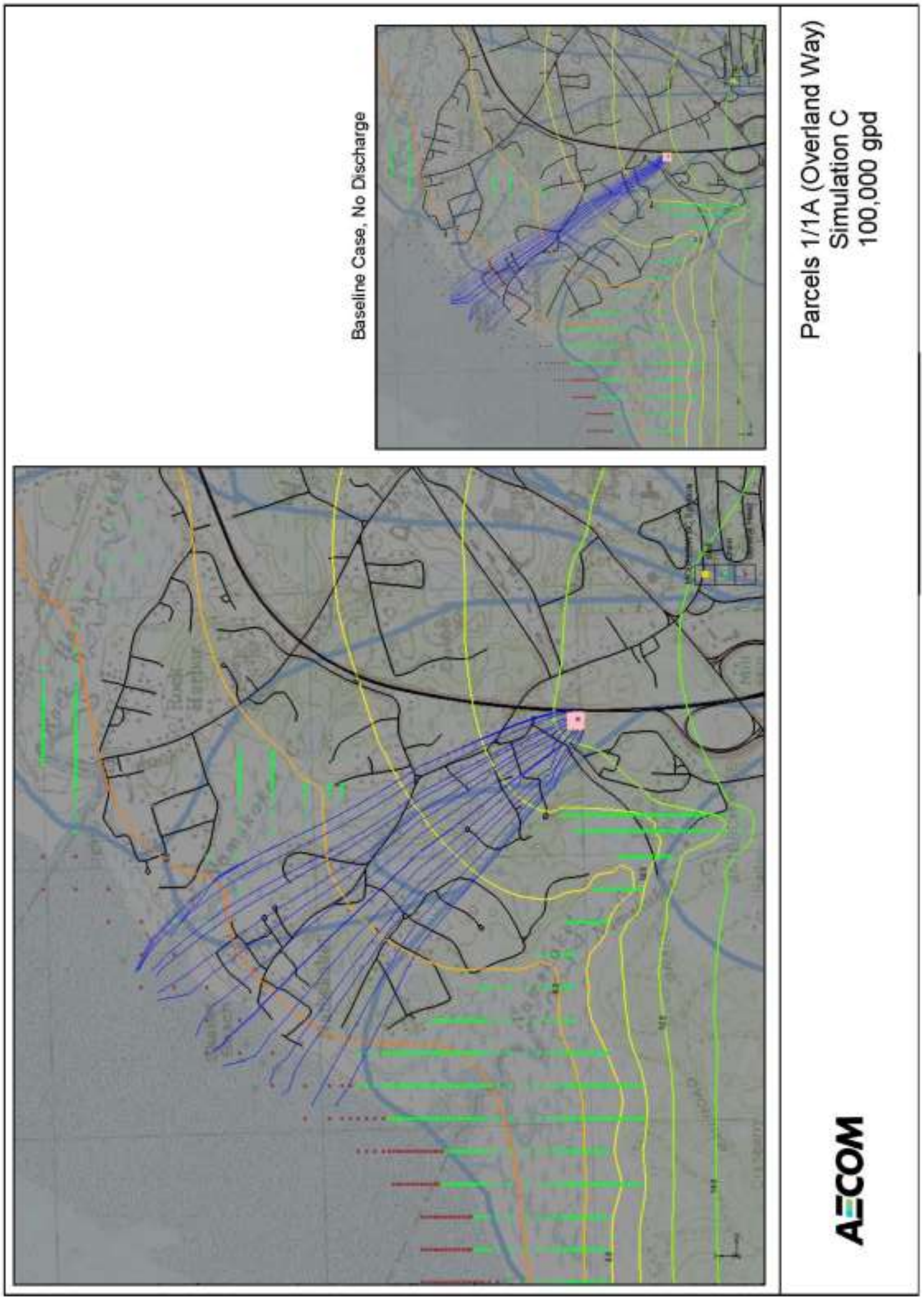
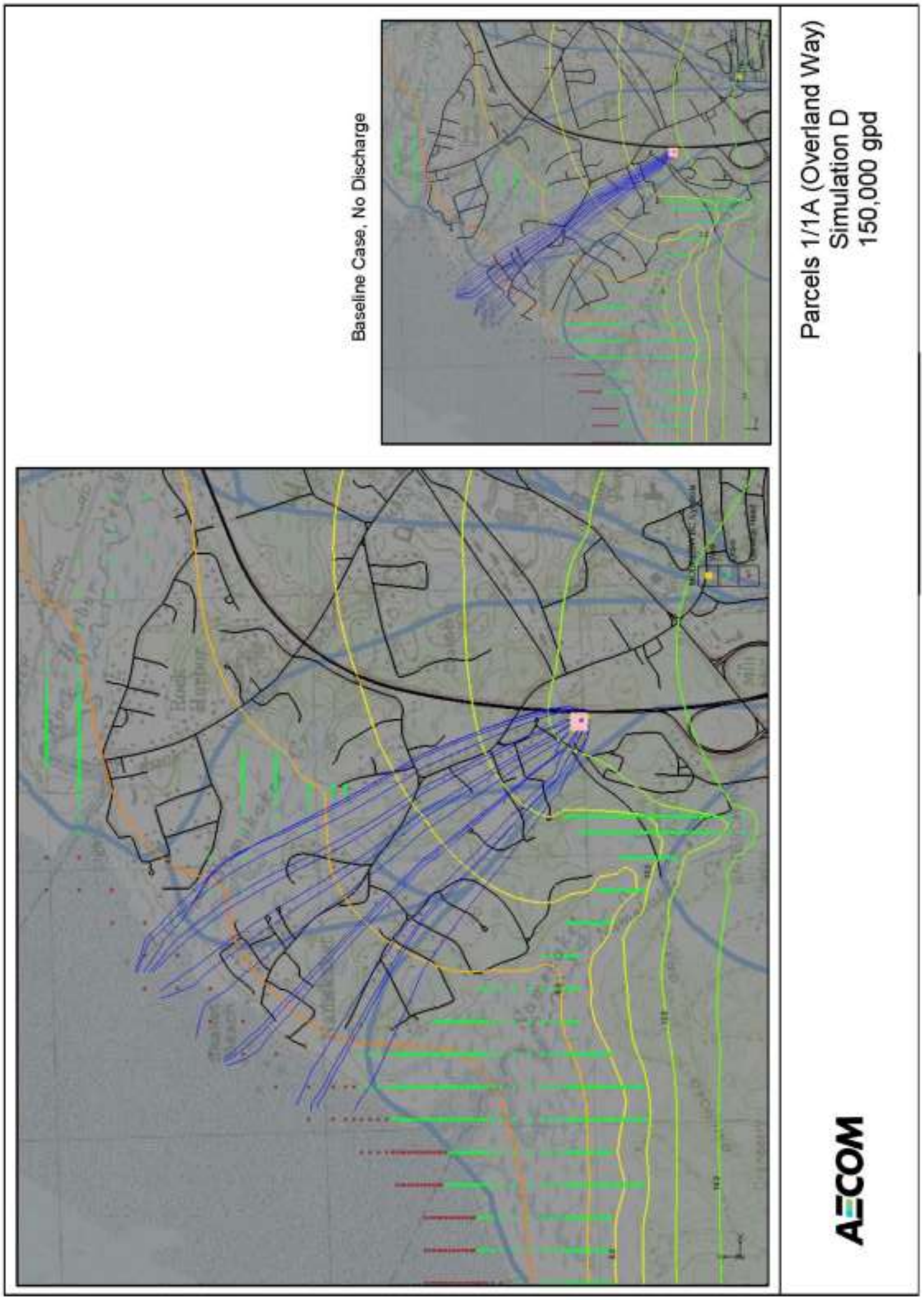
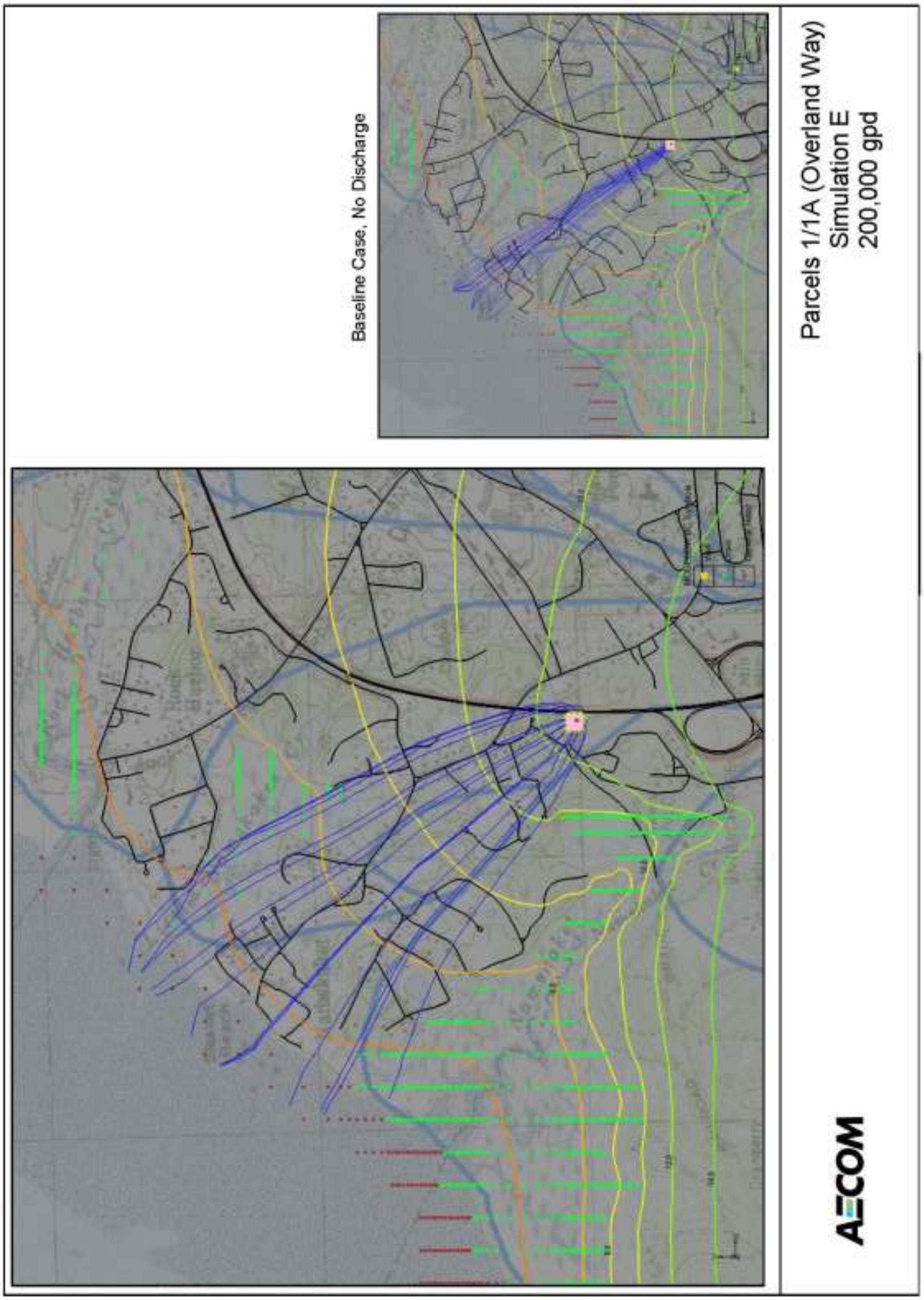
ATTACHMENT A


Zoomed in
Baseline Case, No Discharge
Parcels 1/1A (Overland Way)
Simulation A
25,000 gpd
AECOM


Baseline Case, No Discharge
Parcels 1/1A (Overland Way)
Simulation B
50,000 gpd


Baseline Case, No Discharge
Parcels 1/1A (Overland Way)
Simulation C
100,000 gpd


Baseline Case, No Discharge
Parcels 1/1A (Overland Way)
Simulation D
150,000 gpd
AECOM


Baseline Case, No Discharge
Parcels 1/1A (Overland Way)
Simulation E
200,000 gpd
AECOM