pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION

MEMO

TO	Ragesh R. Patel Regional Manager Environmental Cleanup and Brownfields
FROM	Lisa Strobridge, P.G Professional Geologist
THROUGH	C. David Brown, P.G Professional Geologist Manager
DATE	September 28, 2022
RE	ECB – Land Recycling Program Act 2 Technical Memo Summary Sitewide Fate and Transport Remedial Investigation Report Former Philadelphia Refinery eFACTS PF No. 780190 3144 West Passyunk Avenue City of Philadelphia Philadelphia County

Lisa Strobridge

C. David Brown, P.G. Digitally signed by C. David Brown, P.G.
Date: 2022.09.28 11:57:54 -04'00'

Property Owner:
Hilco Redevelopment Partners (PES R&M)
99 Summer Street, Suite 1110, Boston, MA 02110

Remediator:
Evergreen Resources Management Operations
2 Righter Parkway, Suite 120
Wilmington, DE 19083

Site Address:
3144 West Passyunk Avenue
Philadelphia, PA 19145

Act 2 Standard(s) Sought: non-residential site-specific standard for soil and groundwater

Property Size: ~1300 acres

Project Site History: Petroleum refining began at the Philadelphia Refinery circa 1870. The facility consisted of two refineries, Point Breeze operated by Atlantic Petroleum Corporation (formerly ARCO) and Girard Point operated by Chevron (formerly Gulf). Sunoco purchased these two refineries in 1988 and 1994 and consolidated them into a single facility. In 2012, Sunoco sold the refinery to the Carlyle Group and entered a joint venture to operate it as Philadelphia Energy Solutions (PES). Sunoco, Inc. is now a subsidiary of Energy Transfer Partners, L.P., and Evergreen is a Sunoco affiliate that is responsible for legacy environmental remediation. In 2020, PES was acquired by Hilco Redevelopment Partners (HRP).

The Philadelphia Refinery processed up to 330,000 barrels a day of crude oil. It produced gasoline, diesel, jet fuel, kerosene, home heating oil, and other petroleum liquids. The facility consisted of multiple process units, above-ground storage tanks, pipelines, as well as truck, railcar, and barge transfer equipment. The facility has been divided into eleven areas of interest (AOI 1–11) for purposes of characterizing contamination. The first ten are geographical areas of the facility, and AOI 11 represents the deep groundwater aquifer. From 2012 through 2021 Remedial Investigation Reports have been submitted and approved for AOI-1 through AOI-10 for the site.

Site Findings: The Sitewide Fate and Transport Remedial Investigation Report (RIR) evaluated groundwater characterization data from across the site and assessed the contaminant fate and transport of groundwater and surface water through identified transport pathways. The extent of contaminant transport was predicted and the potential receptors at the plume extents were identified in the report. The objectives of the groundwater flow model (GWF Model) are to 1) demonstrate that the extent of contamination attributable to Sunoco has been delineated, 2) demonstrate that contaminant transport pathways unique to the facility have been reasonably characterized, 3) use of the model output to assess exposure pathways for human health and ecological receptors (including the Ecological Risk Assessment submitted under a separate cover), and 4) evaluate compliance with surface water quality standards from diffuse groundwater discharge.

The GWF model developed for the site used the United States Geological Survey (USGS) groundwater flow model reports (Schreffler, 2001; Sloto, 2012) as a basis for the site specific GWF Model. Updates to the USGS model included modifications to the MODFLOW finite-difference grid, model layer thicknesses and hydraulic properties, changes to boundary conditions, sources, sinks, and flow barriers resulting in changes to the water balance. The GWF Model was then used as the basis for the MT3D transport model to evaluate contaminant transport from onsite sources, as well the potential for offsite source contributions from the following locations: 1) Former Defense Supply Center Philadelphia (DSCP), 2) Philadelphia Gas Works (PGW) Passyunk Facility, 3) South District Work Center of Verizon Pennsylvania, LLC (Verizon SDWC), and 4) Former Enterprise Avenue Superfund Site. The transport model results were then used as mass flux inputs into a Delft3D surface water model that evaluates surface water loading under tidal scenarios.

DEP and EPA discussed the review of this report and this memo reflects DEP comments. EPA comments will be issued in a separate correspondence. DEP subcontracted a groundwater flow model subject matter expert (SME), Dr. William Seaton, P.G. at ARM Group LLC (ARM) to assist with the review of this model. Contracting services were procured under the general technical assistance contract (GTAC). DEP and ARM performed independent reviews of the groundwater flow and transport models and feedback from both DEP and ARM is summarized below. A copy of ARM's technical memo and SME resume is attached for reference.

The Sitewide Fate and Transport Remedial Investigation Report was submitted to DEP and EPA in two parts and included: Part 1- Groundwater Flow Model and Part 2- Contaminant Fate and Transport Assessment. Included in Part 2 of the Fate and Transport RIR are technical memorandums that incorporate additional characterization data, some of which have not been previously reviewed by DEP and EPA. This data was reviewed in the context of model input parameters (source extent) and justification for refining the groundwater flow, and fate and transport modeling in the areas of Belmont Terminal, AOI 8 Ball Field, AOI 2 Case Wharf, and offsite AOI 4 offsite well installation. DEP's review of these memorandums does not include review of these data in the context of revised Remedial Investigations (RI) for those applicable AOIs. Remedial Investigation Report Addendums will need to be submitted for the applicable AOIs in the future.

The groundwater flow model evaluated groundwater elevations observed at the site in 2017 and then predictive groundwater elevations from additional time periods for comparison to observed dataset and then compared to water level observations from 2014, 2015, 2016, 2018, 2019, and 2021. The overall summary statistics of the predicted groundwater elevations is acceptable, however there are select areas of the site that indicate model bias resulting in significant over and under predicting groundwater elevations that could impact the transport model.

The transport model predicted the 30-year extent of the benzene, MTBE, naphthalene, benzo(a)pyrene, and lead dissolved plumes based on conservative (maximum concentrations of contaminants observed onsite that are attributable to Sunoco/Evergreen) assumptions. The projected dissolved plumes migrate to the adjacent surface water in portions of the site where groundwater flows towards the Schuylkill River and Mingo Basin, and offsite in portions of the site where groundwater flows to the east. The projected plume extents were truncated before regional screening levels (RSLs), so additional analysis is needed to assess the extent of the projected plumes with respect to offsite exposure pathways. Where the projected plumes extend to surface water, the maximum projected concentrations meet applicable Chapter 93 surface water criteria for aquatic life. The projected maximum benzo(a)pyrene concentration does not meet applicable Chapter 93 surface water criteria for human health or the reported fish consumption criteria.

Based on DEP's review of the Sitewide Fate and Transport Remedial Investigation Report, the models do not sufficiently define the present and future extent of contaminants as required by 25 Pa. Code Sections 250.408(a),(b) and (e). The sections of the report, tables, figures, or Appendices where additional required information or explanation, or other deficiencies, were identified are noted below along with an explanation of what is needed.

DEP Comment Number	Report Section	DEP Assessment
1	Part 1, Section 3.2	Provide rationale for omitting surface water/detention ponds in AOI-8 but including the surface water/detention ponds in AOI-3 in cross sections, figures, and modeling efforts.
2	Part 1, Sections 3.2.1.2.2 and 5.3	Provide rationale for using isotropic hydraulic conductivity values for all model layers. See attached ARM Comments #1 and 2.
3	Part 1, Section 3.2.3	Reference is made that well gauging datasets were compiled, reviewed, and interpreted. Historical groundwater elevations and predicted groundwater elevations were tabulated for the water table and lower aquifers for the May 2014, May 2015, May 2016, May 2017, and June 2018 gauging events and presented in Appendix A; hydrographs were included as Appendix B. It was noted that many wells have limited datasets and some wells contain submerged well screens. The report also indicates that efforts were made to remove anomalous data points. Additional explanation is needed to identify locations and the basis for removing well data from the modeling effort. Additional figures and tables depicting the wells used for each model layer are needed (Also see ARM Comment #6)
4	Part 1, Section 3.2.3.1	Additional clarification is needed of the spatial distribution of well hydraulic head residuals for calibration datasets for each model layer. Figures 3-25 through 3-34 depicting color flood groundwater elevation surfaces should include hydraulic head residuals for the well points.
5	Part 1, Sections 3.2.3.2 and 3.2.3.3	The calibration data sets were all from the May and June timeframes from 2014 through 2018. Seasonal variability was reported to be limited as evidenced by continuous data logger monitoring in select wells throughout the facility. Figure 3-35 summarizes the data from dataloggers and Appendix B (hydrographs) depict gauging data per well. A review of the presented information indicates that data loggers were not deployed in AOIs 5 and 6, select wells with datalogger data were not used in the flow model calibration dataset, and layers 3, 4, and 6 did not appear to be evaluated as part of the datalogger data set. Clarification is needed to describe how seasonal variability was evaluated in datasets for AOIs 5 and 6, for wells completed in all model layers, and how calibration points were targeted for well points with more extensive data sets such as datalogger locations.

6	Part 1, Section 3.2.3.2.1	A review of the hydrographs also identified data presentation conditions that require further clarification. LNAPL may not be apparent in select wells due to water levels generally above the screened interval in dozens of wells across the site as indicated in the hydrographs included in Appendix B. There were also some wells where the corrected groundwater elevation was below the screen interval, or no groundwater elevation or apparent NAPL thickness was reported. The wells to re-evaluate include: A-4, A-10, A-11, A-12, A-21, A-23, A-136, A-148, A-152, A-170, A-186, B-39, B-45, B-46, B-47, B-48, B-92, B-94, B-124, B-129, B-130, B-131, B-132, B-136, B-137, B-138, B-144, B-151, B-152, B-157, B-163, B-174, BF-100, BF-101, C-49, C-50, C-51, C-53A, C-54 through C-58, C-60, C-62, C-65, C-95, C-96,C-127, C-131, C-132, C-133, C-136, C-137, C-139, C-140, C-145, C-146, C-147, N-1, N-4, N-9, N-15, N-19, N-20, N-21, N-30, N-33 (no data), N-58, N-61, N-73, N-75, N-77, N-84, N-99, N-103, N-106, N-111, N-114, N-132, N-133, N-150, N-152, N-503, N-504, PGW-MW-4S (no data), PGW-MW-12D (no data), PGW-MW-12S (no data), PGW-MW-13D (no data), PGW-MW-13S (no data), PGW-MW-15S (no data), PGW-MW-21, PZ-132A, PZ-201, PZ-202, PZ-203, PZ-402, PZ-500, PZ-502, PZ-507, RW-6, RW-21, RW-31, RW-32, RW-65, RW-100, RW-101, RW-102, RW-103, RW-105 through RW-108, RW-113, RW-115, RW-116, RW-117, RW-122, RW-123, RW-126, RW-128, RW-200, RW-301, RW-302, RW-304, RW-305, RW-307, RW-308, RW-309, RW-402, RW-404, RW-405, RW-600, RW-702, RW-703, RW-704, S-1, S-5, S-8, S-10, S-12, S-13, S-16, S-20, S-22, S-36, S-39, S-46, S-52, S-76, S-82, S-86, S-153, S-211, S-213, S-225, S-226, S-268, S-308, S-355, S-367, S-370, S-385, S-418, S-871, S-82SRTF, S-83SRTF, S-108SRTF, S-109SRTF, S-137SRTF, S-138SRTF, S-139SRTF, S-141SRTF through S-144SRTF, SW-4, SW-5, URS-3, W-5, W-10, W-12, W-14, W-16, W-19, W-20, W-23, W-25, W-26, W-28, W-30, and WP-8.
7	Part 1, Section 3.3	Further documentation is needed to understand: 1) the numerical inputs used in the model for boundary conditions; 2) how each flow boundary (Fall Line, bulkheads, Mingo Basin, sewers etc.) was treated and assumed flow rates for each layer; 3) if inputs for the drain boundary for the sewers were the same across the site, 4) the rationale for the discontinuous horizontal flow boundary along portions of the Schuylkill River; and 5) the use of a general head boundary across ~75% of the model domain.
8	Part 1, Sections 3.3.2 and 5.2	Provide supporting evidence for treating the bedrock as a no flow boundary in the numerical model.

9	Part 1, Sections 3.4 and 5.5	Further documentation is needed to understand: 1) the numerical inputs used in the model for water balance; 2) which model layers accounted for the various recharge and discharge features; 3) clarification of precipitation values and calculated recharge rate (Also see ARM Comments #7 and 8); 4) explanation of how leaking infrastructure was estimated/accounted for as both recharge and discharge features in the water balance; 5) explanation of how groundwater recharge from sewers was addressed in the model; 6) clarification of how surface water discharge was estimated and accounted for in the water balance; and 7) rationale for including some sewers in the water balance and excluding others across the site, including sewers in AOI 9.
10	Part 1, Section 5.2	The model domain was referenced as containing 1,273,230 total cells of which 1,180,578 are active cells. Clarification is needed to identify the location of the active and inactive cells on each layer.
11	Part 1, Sections 5.2 and 5.3.1	Clarification is needed to explain the implications of all layers being classified as constant transmissivity within the groundwater flow model and the impacts of this transmissivity classification to the site-specific hydraulic conductivities that are also referenced as being used.
12	Part 1, Sections 5.3	The groundwater flow model is based on assumptions of steady-state equilibrium conditions for each layer. Additional explanation is needed on how the presence or absence of confining layers impact the steady-state assumption (Also see ARM Comments #3, 4, and 5). Transient modeling should be considered to better reflect site conditions (Also see ARM Comment #10).
13	Part 1, Section 6	Model calibration was performed using the 2017 dataset and then compared to water level observations from 2014, 2015, 2016, 2018, 2019, and 2021. The calibration statistics for each year of data comparison are acceptable, however there are areas across the site (i.e., locations where the horizontal river flow boundary is missing, active remediation is taking place, western side of the river, among others) that have significant residuals for all years modeled. These spatial and layer specific data calibration biases should be evaluated and addressed to improve the overall confidence in the model. Figures depicting calibration target residuals and observed versus simulated water levels should be plotted per layer for each year to better assess data biases. (See ARM Comment #9)

14	Part 2, Section 2.2	Evergreen has identified a list of 21 site COCs that include 10 VOCs, 10 SVOCs and lead. The COCs evaluated in the fate and transport model include benzene, naphthalene, MTBE, benzo(a)pyrene, and lead. Additional site COCs need to be included in the transport model.
15	Part 2, Section 3.1	Statements regarding the results of the electrical resistivity imaging demonstrating that the middle clay minimizes the downward migration of shallow groundwater in the Belmont Terminal need to be re-evaluated, as well as the implications to the flow and transport models in this area. The resistivity dataset suggests preferential flow from the ground surface into bedrock, and a heterogeneous mix of high to low resistivity zones which do not support the conclusions in the text of the middle clay being effective at minimizing the downward migration of shallow impacts into the lower aquifer in the area of Belmont Terminal. In addition, additional evidence is needed to support electrical conductivity interpretations regarding biological activity, presence of gas pockets, and groundwater flow patterns. (Also see ARM Comments #11-18, and 27)
16	Part 2, Section 3.4	Offsite monitoring wells were installed and sampled in 2022, southwest of AOI 4. High dissolved concentrations of target COCs were detected in these wells and were incorporated into the transport model. Additional clarification is needed to explain the findings of the CSIA dataset and implications to the transport model. (Also see ARM Comment #30).
17	Part 2, Section 4.2.1.2	Degradation rates considered for the transport model included site-specific calculated values, literature values, and Chapter 250 values. The text indicates that degradation rates used in the model are consistent with literature values. The degradation rate used for MTBE is 2.5 times higher than literature values. A more detailed explanation of how the attenuation rates were determined is needed, or more conservative values should be used in the model. (Also see ARM Comments #23 and 24).
18	Part 2, Section 4.2.2.2 and throughout remainder of report	The model relies on site-specific data for calculated aquifer properties and model input parameters. The monitoring well locations for layer- and parameter-specific measurements should be clearly described as well as the basis for excluded locations or data. (Also see ARM Comment #26)

19	Part 2, Section 4.2.2.3	The use of a fraction organic carbon (foc) content of 0.05 should be supported by field data from the general areas and layers used in the model. The report indicates foc was analyzed in historical geotechnical assessments at the site, and the values used in the model are consistent with detected values. The geotechnical reports should be included to support the use of foc values used in the model. The high foc values used result in a high calculated retardation value, which needs to be justified and considered in the sensitivity analysis (Also see ARM Comments #20-22, and 35).
20	Part 2, Section 4.2.3.2	Clarification is needed to explain the dataset that was used and the basis for defining the boundary for onsite and offsite contributions in the model for the water-table aquifer impact at AOI 1 near the DSCP site boundary (Also see ARM Comment #25).
21	Part 2, Section 4.3	The initial and predicted concentration figures indicate a variable contaminant trend orientation. Explanation is needed to understand if anisotropic groundwater flow was evaluated as a possible cause of these apparent concentration trends. (See ARM Comment #33)
22	Part 2, Section 4.3	The extent of the projected plumes must extend to the RSLs or calculated SSS (See ARM Comment #32)
23	Part 2, Section 4.4	Model uncertainty was evaluated by adjusting input parameters to evaluate parameter sensitivity. Decreases to degradation and retardation are identified as sensitive parameters that could result in plumes extending beyond the predicted extents. The approach to the overall fate and transport model was stated in the text as using conservative assumptions when possible, and this analysis supports the above comments about the foc and degradation rates used in the model. The figures in Appendix K need to show each uncertainty parameter modeled with plume extents to the RSLs or calculated numerical site specific standard (Also see ARM Comment #34).
24	Part 2, Section 5	Additional clarification is needed for assumptions made in the surface water modeling including: 1) justification for zero groundwater flow into the Schuylkill River during the rising and high tide; 2) how surface water dilution rates were calculated per cell; 3) the mass flux at discharge points for each COC; and 4) how mass from groundwater entering the onsite sewers and presumably discharging to the river was addressed in the model. (Also see ARM Comment #41).
25	Part 2, Section 5	A reference for the fish consumption screening levels presented in the report is needed (Also see ARM Comment #39).

26	Part 2, Section 5	Legends need to be added or clarified on Figures 2.1, 2.6, 2.9, and 4.1 to explain surface water conditions and model assumptions, as identified in ARM Comments #36, 37, 38, and 40.
27	Part 2, Section 6	Climate resiliency should also consider the potential for the redistribution of LNAPL during higher water table conditions (Also see ARM Comment #29).

Site Cleanup History:

NIR Received Dates: October 16, 2006; November 17, 2014; December 14, 2016

RI Approval Dates: Various (2016–2021)

Public Comments:

- On August 29, 2022, DEP received Evergreen's Response to public comments for Ecological Risk Assessment AOI 1 through 9.
  - Evergreen reported receipt of 3 sets of public comments that were technical in nature and related to the submitted report. The 3 sets of technical comments were from Clean Air Council, Brickhouse Environmental, and a set of identical comments from 15 individuals. One additional comment was received from an individual related to the development activities.
  - DEP received, reviewed, and took into consideration the received public comments as part of the review.
  - DEP reviewed the responses to public comments. Some of the comments were consistent with noted report deficiencies.

Discussion of Cleanup Involved and Demonstration of Attainment: Evergreen proposes to attain the site-specific standard for groundwater by demonstrating the absence of complete exposure pathways and eliminating any potential exposures. The Fate and Transport Remedial Investigation Report indicates that maximum projected benzene, MTBE, naphthalene, benzo(a)pyrene, and lead concentrations in the Schuylkill River are <0.1 ug/L, 2 ug/L, <0.01 ug/L, 0.015 ug/L, and 0.0013 ug/L, respectively. The maximum projected concentrations meet applicable Chapter 93 surface water criteria for aquatic life. The projected maximum benzo(a)pyrene concentration does not meet applicable Chapter 93 surface water criteria for human health or the reported fish consumption criteria. Remedies will be described in future cleanup plans.

DEP Final Action Approval/Disapproval Letter: The report is recommended for technical deficiency for the reasons stated in the above table. The technical deficiencies and comments were reviewed with Evergreen on September 26, 2022 and it was communicated during the call that DEP would also meet with Evergreen and Stantec following review of this technical memo which would be provided following the issuance of the decision letter.

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Site Contact:	Tiffani Doerr, P.G., Evergreen	**Phone:**	302-477-1305
Site Consultant:	Jennifer Menges, Stantec	**Phone:**	610-840-2540
EPA Contact:	Kevin Bilash, USEPA Region III	**Phone:**	215-814-2796

ARM Group LLC

Engineers and Scientists

TECHNICAL REVIEW MEMORANDUM

TO: Lisa Strobridge, P.G., DEP SERO Project Officer & James Smathers, DEP Contract Manager

CC: C. David Brown, P.G., DEP SERO Professional Geologist Manager
Wayne Harms, DEP SERO HSCA Project Officer
Scott Wendling, P.G., ARM Program Manager

FROM: David W. Mooney, P.G., ARM Project Manager
William Seaton, Ph.D., P.G., ARM Technical Lead

DATE: 9/26/22

SUBJECT: GTAC-7-1-352 TASK 1010: Philadelphia Refinery Fate & Transport Model Evaluation

ARM Group LLC (ARM) conducted a technical review of the Sitewide Fate and Transport Remedial Investigation Report (F&T RIR) for the Philadelphia Refinery as written by a consultant (Stantec, under contract with the Responsible Party) and dated June 30, 2022. The three-dimensional numerical flow model, MODFLOW, is used to simulate ground water flow through multiple aquifers and builds upon the regional groundwater flow model published in the United States Geological Survey (USGS) Water-Resources Investigation Report 01-4218. The groundwater solute transport modeling was performed using MT3D and groundwater discharge to surface water was evaluated using Delft3D open-source code. A hydrodynamic model for the Schuylkill River was previously created and mass flux information from the transport modeling results are used as input into solute loading of surface water under varying scenarios of mixing and dilution. Lastly, climate change/model resiliency assessment was considered in the models by varying conditions using local climate change predictions from peer-reviewed published resources.

ARM's comments related to its review of Part 1 - Groundwater Flow Model are provided below:

Determination of Modeled Hydraulic Conductivity Parameters

1. Previous modeling investigations and this study generally use isotropic hydraulic conductivity (K) values for all model layers. Previous studies that investigated or illustrated potential anisotropic K behavior in any of the subsurface units via pumping tests or other methods should be reviewed and discussed as they pertain to this site.

2. Figures 5-3A through 5-3C relate the generalized lithologic stratigraphic profiles with the model layers. In some cases, significant variations in stratigraphy within a single layer (implying differences in K of multiple orders of magnitude) have been modeled as a homogeneous, isotropic aquifer. In particular, localized sandy gravel deposits have been logged in borings that correlate with other borings that have muddy sand in the same stratigraphic interval / model layer. Model runs should be conducted for this investigation that utilize anisotropic K zonations that more closely represent actual geologic conditions. If not, the model should justify how variability in observed lithology (having significant spatial extents) can be accurately represented by a single K value in this groundwater flow model.

3. The distribution of the Middle Clay Unit in the site area is in question. Figure 3-23 illustrates significant variations (0' – 30') in Middle Clay thickness over the site area (near the Fall Line boundary), and a large part of AOIs 5, 6 and 7 where it is absent. Site characterization and groundwater modeling by Sloto (2012*) indicate areas where confining layers are not present, and the water-table aquifer is in direct hydraulic contact and communicating with the semi-confined middle and lower sand units of the deep aquifer system. In addition, the geophysical investigation (Appendix B of the F&T Model) provides subsurface electrical resistivity data suggesting vertical hydraulic pathways are present from the ground surface to the bedrock layer. Variations in the presence / absence of confining layers (particularly in the facility area) should be considered for this model.

   *Sloto, R.A. (2012). Migration of Benzene and Simulated Groundwater Flow in the Potomac-Raritan-Magothy Aquifer System of South Philadelphia, Pennsylvania, U.S. Geological Survey Administrative Report.

4. Hydraulic gradients are vertically downward from the water table aquifer to the semi-confined aquifer over much of the site, based on the groundwater elevation contour diagrams included for the various synoptic gauging events (e.g., Figure 3-25 with Figure 3-30). Sloto (2012) identified an area just east of AOI 4 where the aquitard [Middle Clay] was absent and potentiometric heads between the two hydrostratigraphic zones were the same, indicating hydraulic communication existed between the layers. The recent study of the semi-confined aquifer to the southeast (downgradient) of AOI 4 (Technical Memo dated May 26, 2022, by Sanborn Head) found elevated levels of benzene and MTBE (up to 4,650 and 392 ug/l, respectively) in samples collected in May of 2022 from wells installed in the Lower Aquifer. The GW model report should include a review of synoptic water level data for proximate well pairs in the study area to identify other locations where there are similar heads and the model assumptions do not apply.

5. A model with a Middle Clay layer that does not impede downward flow (similar to Sloto, 2012) should be considered with flow lines from the AOIs all the way to the NJ municipal water wells / downgradient model limits. Timing dates should be added to the flow lines to understand the implications of this scenario and the potential of the existing plumes to continue as a source of groundwater contamination.

6. Please provide tables and separate maps for each model layer showing the names and locations of the borings that provide information for characterizing each particular layer. This type of display will assist in the evaluation of the spatial coverage of the control points used for each layer.

Model Recharge Zonation

7. Figure 5-6 illustrates the Model Recharge Zonation utilizing four recharge zones for this project. A single recharge zone (0.0013 feet per day) is used for the entire Former Philadelphia Refinery site area. The report also indicated that "recharge is deemed to be a sensitive parameter and was most sensitive in areas of low hydraulic conductivity assigned in GWF Model layer 1" (page 7.48). Localized recharge variations in the site area should be considered for this project. It is likely that actual recharge varies considerably across the site depending on the degree of impervious ground cover, the location and geometry of grassy or soil covered areas, the location of stormwater outfalls or rooftop downspouts, localized ground surface topography (depressions vs. mounded areas), the location, size, and depth of temporary excavations, etc. Localized spatial and temporal variability in recharge zonation impacts should be evaluated in addition to the single recharge parameter used for the site area in the study. The model should also account for future site conditions with less impermeable surfaces (e.g., lined AST retention dikes and pavement which will likely be removed in the future) and more onsite stormwater infiltration (which will likely be required for future redevelopment).

8. Reese and Risser (2010*) indicate a mean annual groundwater recharge value of 10-12 inches per year. Modeled recharge values used for the site area in this investigation were 0.0013 feet per day (equivalent to 5.7 inches per year). If the Reese and Risser (2010) recharge value was not used for this model, the lower recharge value should be justified.

   *Reese, S. O., and Risser, D. W., 2010, Summary of Groundwater-Recharge Estimates for Pennsylvania: Pennsylvania Geological Survey, 4 ser., Harrisburg, PA.

Model Calibration

9. The combined simulated versus observed target hydraulic head plots for 2017 and 2018 (Figures 6-4 and 6-6) may obscure potential bias in the individual model layers. It would be helpful to create layer-specific plots of simulated versus observed heads to assess the effectiveness of calibration by modeled layer. From a visual examination, it appears that simulated heads in Layer 2 are generally lower than observed heads at higher elevations. Similarly, it appears (from visual inspection of the plots) that simulated heads in Layers 6 and 7 are generally higher than observed heads. Observations from the layer-specific plots may aid in revising/assigning hydraulic conductivity values per zone accordingly.

10. Transient modeling of this site should be considered given the complex interrelationships associated with seasonal changes in precipitation, tidal forces, surface water and groundwater withdrawals, and related factors.

Appendix B of Part 2, Belmont Terminal Technical Memo - Electrical Resistivity Imaging

11. ARM requested the following during its review of the Belmont ERI study referenced above:

    Please provide all field data files in digital form associated with GeoTrax Survey™ images (PHL-01 through PHL-23). These include raw data produced by the resistivity equipment (e.g., for AGI systems: STG, CRS, CMD, etc. files), x,y,z electrode locations, observer notes, and related files.

    Please provide a series of horizontal elevation slices for the entire depth interval covered by the GeoTrax Survey™ profiles (~30' to - 120' elevation) using a 5' spacing between horizontal elevation slices and the same ER color scale used in the report.

    Were the GeoTrax Survey™ images (ER profiles) created using 2D ER data processing methods?

    Were the horizontal elevation slices shown on Inset Graphic 7 & 8 (Appendix A Aestus Technical Memo) created by interpolating the resistivity values from 2D profiles on to a plan view?

    Please list the RMS error associated with each GeoTrax Survey™ image.

    The attached Comment Figures 1 & 2 illustrate two locations at which the GeoTrax Survey™ profile images cross each other. Comment Figure 1 shows the crossing point of PHL14 and PHL-5; Comment Figure 2 shows the crossing point of PHL12 and PHL-6. The resistivity values on the GeoTrax Survey™ images do not match each other at these crossing points.

    The report should explain why the resistivity values do not match each other and potential causes of this issue.

    Do the resistivity values match at other crossing points (we only sampled two crossing points)?

    Explain how this issue impacts the veracity of the ER data set and associated conclusions.?

Responses for the information and questions included above were received from Stantec via email communications dated August 19, 2022 and in an email from Lisa Strobridge dated September 2, 2022.

12. The CD well locations were generally placed over higher resistivity zones on the GeoTrax Survey™ images. Several low resistivity zones extend through the Middle Clay and into the bedrock interval suggesting vertical zones of preferential flow from the ground surface into bedrock.

CD well locations are needed over the vertically-oriented low and very low (< 1 ohm-m) resistivity zones seen on PHL-01 through PHL-17, PHL-18, PHL-20, etc.

13. Correlation between measured resistivity and lithology, degree of pore fluid saturation, fluid conductivity, or other related water chemistry parameters should be included with this type of geophysical investigation.

14. The geophysical report indicates that “The subsurface in Belmont Terminal is biologically active as indicated by the high electrical conductivity measured during the electrical resistivity testing”. The report should describe how high electrical conductivity measured during the electrical resistivity testing supports biological activity.

15. The geophysical report indicates that “Isolated resistive features were present below the middle clay. These features were interpreted to be indicative of gas pockets, likely due to buildup of carbon dioxide resulting from petroleum degradation below the middle clay”. Why are resistive features interpreted as gas pockets? The report should provide evidence for this assertion.

16. The geophysical report indicates that “The ERI combined with soil and groundwater sampling support that the Potomac-Raritan-Magothy (PRM) aquifer series middle clay unit aquitard is spatially contiguous below the Belmont Terminal area and demonstrated to be effective at minimizing the downward migration of shallow groundwater contamination into the lower aquifer in that area. This confirms the middle clay interpretation from the existing 2016 AOI 1 RIR conceptual site model and how the aquitard is represented in the Groundwater Flow (GWF) Model presented in the 2022 Sitewide Fate and Transport RIR to which this memo is an attachment.” Most of the ER profiles do not indicate a horizontally layered set of horizons that would support a spatially contiguous interpretation of this site. On the contrary, the ER data indicate a heterogeneous mix of low-to-high resistivity zones that span the interval from the ground surface to below the top of bedrock (refer to PHL-1-9, 11-18). Only the ER lines located on the northern edge of the site area (PHL-20,21,23) have some indication of horizontal layering of strata however even these lines indicate significant heterogeneities below the Top Middle Clay unit.

17. The geophysical report states: “Results from the groundwater gauging and sampling indicate that the general groundwater flow pattern is from north to south but with an area of convergence near the Shunk Street sewer where it intersects Frontage Road and Passyunk Avenue (Attachment A, Inset Graphic 4). The pattern supports that the Shunk Street sewer leaks and is removing groundwater from the area”. This assertion assumes that the groundwater flow pattern (flow direction) follows the groundwater gradient. Hydraulic conductivity zones in Coastal Plain aquifers may be anisotropic depending on various factors within each stratigraphic layer thus causing the flow direction to vary from hydraulic gradient. Studies of potential anisotropy in aquifers which have been conducted in the site area should be reviewed and included. In addition, man-made features can divert groundwater flow and should be considered.

18. Reprocessing of the ER data using industry-standard data processing methods (Loke, 2022) suggests relatively complex subsurface geology including an irregular Top of Bedrock surface, potential faulting, localized low resistivity zones, and related features that are not consistent with the simple horizontally stratified subsurface layer model used to represent site conditions in the groundwater model. A subsurface model that is consistent with site conditions as indicated by the ER data and corroborated with boring information should be considered for this study. These factors should be considered when developing Attachment A, Inset Graphic 4 for the report.

    (Loke, M.H., 2022, Tutorial Notes 24th August 2022 Update, https://www.geotomosoft.com/downloads.php)

ARM's comments related to its review of **Part 2 – Contaminant Fate and Transport Assessment** are provided below:

19. The selected indicator parameters are representative of the contaminants at the site and as illustrated in Figure 2-1, are the most common constituents related to the refinery operations found in groundwater samples from the site above MSCs.

20. On page 2.17, it is reported that naphthalene "plume size and composition is predominantly controlled by natural attenuation in the aquifer", yet in the following paragraph it is reported that "naphthalene is expected to exhibit relatively low mobility except in soils with low organic carbon content". Given the high organic carbon contents assumed for the layers, naphthalene retardation is quite high – an R value of approximately 38 is calculated for the Holocene marsh deposits (layers 5-7), suggesting that retardation of naphthalene plays a major role in the transport model.

21. Benzo(a)pyrene (B(a)P) is attributed in Section 2.3.4 to incomplete combustion or as a constituent of coal tar produced at MGPs. While the PGW Passyunk MGP site appears to contribute B(a)P to groundwater at Belmont Terminal and AOI 1 and AOI 2, B(a)P is also present in heavy distillates (e.g., #6/bunker oil) and in distillation bottoms. The F&T report should identify onsite source(s) of B(a)P and attempt to quantify their respective contributions to the B(a)P observed in groundwater beneath the site.

22. The TOC value assumed for the alluvial deposits and fill (layers 1-4) is 5%, while the Holocene-age marsh deposits (layers 5-7; the including the middle and lower sands) is 0.5% (0.005). The Groundwater Flow Model discusses the stratigraphy and describes layers 5-7 as Cretaceous deposits, consisting of fine to coarse sand and gravel. These were deposited in a non-marine fluvial-deltaic environment and are not marsh deposits like the Holocene-age sediments. While the narrative in Section 4.2.1.1 states that f_{oc} values from geotechnical laboratory reports were reviewed and the range of assumed values generally fit those data, no site data were included. A more detailed explanation of how these values were derived is needed, as they are at the upper end or exceed typical assumed values (0.0002 - 0.005, with 0.002 an assumed default value). The TOC values result in high retardation rates and low contaminant travel velocities in the groundwater

model, with resulting smaller plumes. Lower TOC values should be used unless the higher values can be justified.

23. The degradation rates calculated in Appendix J from site data do not include any narrative, tables of analytical results with sampling dates, or isoconcentration diagrams with groundwater contouring to demonstrate the values used in the Buschek and Alcantar plots are from wells on plume centerlines. Site-specific degradation rates are preferable to literature values, as they represent the actual fate of hydrocarbon constituents at the site. As described in Appendix J, electron acceptors at this site may be depleted, given the mass of contaminants and long history of their presence in groundwater, resulting in less efficient oxidation pathways (e.g., sulfate reduction or methanogenesis). A more detailed explanation of how the attenuation rates were determined is needed, or more conservative site-derived values should be used.

24. The first order degradation rate for lead was assumed to be 0.45 $\text{yr}^{-1,}$ however, it is not documented how this value was derived. A value of 0.45 yr^{-1} was calculated for Well A137 in the MES document (Appendix H), however, the data did not fit the regression line well and data from one well are insufficient to establish the attenuation rate of lead through sulfide precipitation throughout the facility. Given the rates and time spans of biodegradation likely vary both horizontally and vertically at the site, levels of sulfate reduction and sulfide production are also likely variable, resulting in varying rates of lead attenuation via sulfide reaction in the subsurface. A more detailed explanation of how the lead attenuation rate was derived and is applicable over the model area is needed.

25. The modeled plumes include contaminant contributions from offsite sources, including the PGW Passyunk MGP facility and city sewers/DSCP (wells on Belmont Terminal, DSCP and PGW are included in Table 4-3 “Unconfined Aquifer Initial Concentration Data Summary” and 4-4 “Lower Aquifer Initial Concentration Data Summary” of Part 2). The model narrative does not discuss these additions quantitatively or attempt to estimate the mass contributions from these sources that are not related to historic petroleum storage and refining. A goal of the model is to demonstrate that the extent of contamination attributable to Sunoco has been delineated and contaminant transport pathways unique to the facility have been reasonably characterized. The PAH plumes (naphthalene and benzo(a)pyrene) appear to be largely originating from offsite facilities. It is not clear if this offsite source has been quantified in order to demonstrate that the extent of contamination attributable to Sunoco has been delineated and contaminant transport pathways unique to the facility have been reasonably characterized.

26. The control points (MW locations) for layer and parameter specific measurements for Figures 4-2 through 4-26 (include null/values - excluded data) should be included.

27. Section 3.1 discusses the Belmont Terminal HRSC, which does not portray continuous horizontal layers. As noted above (see ARM’s Comments related to Appendix B of Part 2, Belmont Terminal Technical Memo - Electrical Resistivity Imaging), the ERI survey does not support the conceptual model of continuous horizontal layers, particularly the middle clay, which is hypothesized in the model to act as an aquitard over the study area.

28. Section 3.2 includes a summary of the AOI 8 Ballfield Area HSCR (Tech Memo in Appendix D). Relatively high levels of benzene and 0.37 feet of LNAPL were found in a well at the northwestern (upgradient) side of the ballfield in N-164. Upgradient and downgradient wells had lower contaminant levels in groundwater, and a source of the hydrocarbons in N-164 was not identified. Sucralose was detected in wells to the south along the Mifflin Street Sewer, although N-164 was not tested for sucralose and is upgradient from the sewer, making the sewer an unlikely source for the product in N-164.

29. Section 3.3 discusses the AOI 2 Case Wharf Area HRSC (Tech Memo in Appendix E). Time lapse photography demonstrated there are three discrete areas where product seepage into the Schuylkill River occurs. Well S-473 contained over three feet of LNAPL, while well S-423 contained 1.23 feet. The Tech Memo in Appendix E recommends installing reactive core mats and four recovery wells in the area. It is assumed this area will be addressed in a future Cleanup Plan, but the documented groundwater seepage illustrates that point sources of LNAPL are still emanating into the Schuylkill River. The Fate and Transport Model only considers dissolved phase contaminants, but the site still has seeps of product that will also adversely impact the surface water quality and that should be considered or acknowledged as additional loading sources in the fate & transport assessment report.

30. Section 3.4 addresses the Offsite AOI 4 characterization. Three lower aquifer wells and one shallow aquifer well were installed to the southeast of AOI 4, to the west of the Conrail railroad tracks. Elevated benzene levels were reported in two of the deep wells (3,670 ug/l in S-449 and 4,650 ug/l in S-477) along with MTBE levels that are more than ten times the MSC. The hydraulic gradient in the one new well pair was upward, from the semi-confined zone to the water table aquifer. The text of the F&T report states the CSIA dataset "has provided additional insights into the source of benzene and MTBE in this area of Penrose Avenue near South 26th Street" but fails to include those insights. This technical memorandum does not include the CSIA discussion.

31. Section 3.6 discusses the Environmental Forensics Update, included in Appendix H (MES interpretation of the stable isotope data) and laboratory reports in Appendix I. The forensics identifies up to six sources, with five of the sources from offsite of the facility. The Belmont Refinery (not included in the F&T model) and the PGW Passyunk MGP are listed as off-site sources, along with the ARCO Station and former DSCP. The sewers likely aided transport of the hydrocarbons from different sources, with infiltration and exfiltration occurring at different sewer flows and water table regimes. Sucralose was detected in many monitoring wells along the sewers through or adjacent to the Philadelphia Refinery. The forensic work also points to extensive fractionation of the dissolved constituents due to biodegradation and volatilization (where sewer transport is involved). As noted above in comment #25 above, the report does not describe if the offsite sources were quantified in order to demonstrate that the extent of contamination attributable to Sunoco has been delineated and contaminant transport pathways unique to the facility have been reasonably characterized.

32. The simulated distributions of indicator parameters generally show stable or shrinking plumes over the 30-year period of the model. However, benzene expands in the area of the PGW site and Belmont Terminal, and in the western part of AOI 9 in the lower aquifer. A number of mapped plumes are unusually truncated (Figures 4-3, 4-10 a,c,d, 4-11, 4-13, 4-15, c-e, 4-16). The rationale for the truncated contours should be explicitly cited on each map and explained in the text.

33. Several figures have a distinctive north-south / northwest-southeast trend of contaminant plumes suggesting transport along strike of the unconsolidated layers (e.g., Figures 4-3, 4-4, 4-6, 4-8a-d, 4-9, 4-10b, etc.). In addition, a prominent east-west trend of contaminant plumes on the eastern side of the model is evident on Figures 4-3 – 4-5, 4-10a, 4-10c, 4-11. The potential for anisotropic flow (K) in these aquifers as a cause for these features should be addressed in the narrative.

34. The sensitivity analysis shows that assumptions of no degradation and no retardation extend the plumes beyond the distances shown on the model prediction diagrams for the indicator parameters. If the review of the TOC values and degradation rates results in more conservative values, the results of the predictive model will vary significantly from the results reported in this study.

ARM's comments related to its review of **Part 2 – Surface Water Model in the Contaminant Fate and Transport Assessment,** including the Baird "**Schuylkill River Numerical Modeling of Pollutant Dispersion**" included in Appendix L are provided below:

35. The surface water model uses the constituents of concern flux values from the Groundwater Flow/Fate and Transport Model, which are discussed in comments above. ARM raised questions on the low recharge rate assumed in the flow model, along with high retardation and degradation rates assumed in the contaminant transport section. The COC flux may increase substantially if the recharge rates are increased and if TOC and degradation rates are changed to more conservative values. If so, the new COC flux values would need to be reassessed for impacts to surface water quality.

36. Figure 2.1 does not include a key to identify what colors correspond to presumed ranges of channel depth.

37. Figure 2.6 has three lines on the bottom key, but no green "Verified" water level line is shown – it should be added or the key should be revised.

38. Section 2.4 - Current Speed Data includes Figure 2.9, an example of currents from a River Transect at low flow on October 5, 2013. The figure does not identify what the tidal stage was during the recording of the flow measurements. As discussed in section 3.3, current speeds and directions vary with tidal stage and changes in water level; therefore, the figure would be more useful with information on tidal stage.

39. Table 4.1 lists Human Health Thresholds for COCs (Fish Consumption) but does not include the Chapter 93 Cancer Risk Levels at 1 X 10^{-6}. While there may be no surface

water intakes for water supply in the region of the Schuylkill River impacted by the diffuse flow of groundwater currently, the report should discuss why ingestion was not considered and is not a realistic exposure pathway or they should be included. The Cancer Risk Levels are generally lower than the Fish Consumption listed under Human Health Standards (benzene is 0.58 ug/l compared to 16 ug/l; BaP 0.0001 ug/l compared to 0.00013).

40. Figure 4.1 does not identify the well used to demonstrate the fluctuations in groundwater from the tidal level; the well should be identified, with a reference to the report from which it was sourced.

41. The Schuylkill River numerical model is incomplete as it lacks measured values for COCs in the Schuylkill River (or other surface water bodies). Note the following highlighted text from section 4.7 Sensitivity Testing:

    "The hydrodynamic model was calibrated and validated against measured water levels and currents in the study area and in the Delaware River. However, measurements of Benzene and other COC in the region were not available for calibration of the model. Therefore, confidence in the model was evaluated through a series of sensitivity tests, where selected variables were adjusted through a wide range of values that would encompass typically accepted values".

    While the levels of predicted COCs were quite low and below typical analytical quantitation limits, it is surprising no surface water sample analysis results from the Schuylkill River were referenced or included. Sampling at low-flow conditions along the areas of the river where diffuse flow is predicted would be useful if no data exist.

William J. Seaton, Ph.D., P.G.

Senior Hydrogeologist

Professional Geologist: PA

SUMMARY OF QUALIFICATIONS

Dr. Seaton is a Pennsylvania-licensed Professional Geologist (PG) with over 40 years of experience in the fields of hydrogeology, geology, and geophysics. He has served as principal hydrogeologist for numerous public and private modeling and water supply exploration and development projects throughout the eastern USA. His experience includes management and technical oversight of water supply and geothermal well field projects, developing numerical hydrogeologic models of sites, fracture trace analysis, proposing and implementing detailed geophysical studies with surface and borehole geophysics, supervision of well drilling, aquifer pump and recovery testing, report generation, and water well permitting with local and state authorities. Dr. Seaton has successfully worked through regulatory and permitting issues with the Pennsylvania Department of Environmental Protection, the Virginia Department of Environmental Quality, Susquehanna River Basin Commission, county and township authorities. Dr. Seaton has designed, implemented, and reported on small through large scale geological and geophysical studies with multiple types of analyses in areas with highly complex geology and coastal plain aquifers.

Dr. Seaton has given several presentations dealing with geology, hydrogeology, and geophysics at professional societies, public meetings, and university settings. He has also provided expert witness testimony in litigation cases involving water resources and oil and gas rights.

SELECTED PROJECT EXPERIENCE

Sr Hydrogeologist / Groundwater Flow Modeling - Star Enterprise / Star Terminal / Mantua Community, Fairfax, VA - Geological Site Characterization & Groundwater Flow Modeling in the vicinity of the Mantua community contaminated site. Geological characterization of saprolite and soil layers for numerical flow and transport modeling. Delineated phase separated petroleum hydrocarbon (PSPH) plumes at leak site and in adjacent Mantua subdivision via monitoring wells and surface water sampling. Geological characterization was utilized in numerical groundwater model ARMOS and was utilized to develop groundwater flow and transport models to determine hydrocarbon leak sources, pathways, and accumulation areas and volumes.

Sr Hydrogeologist / Groundwater Flow Modeling – Developed two- and three-dimensional Modflow models to address project-specific goals including: a) evaluate the capacity and long-term sustainability of a high-yield aquifer to receive injected stormwater for a site near Chambersburg, PA, b) investigate the impacts of stormwater retention facilities and impermeable ground cover on groundwater recharge at a landfill site near Bainbridge, PA., c) investigate the potential for stream impacts caused by a nearby high capacity irrigation well (Country Club of Harrisburg, PA), d) develop a groundwater flow model to simulate movement and recirculation of injected fluids for remedial purposes at a closed landfill in northern Virginia.

EMPLOYEE HIGHLIGHTS

EDUCATION

Ph.D. Geological Sciences,
Virginia Polytechnic Institute and State University

M.S. Geological Sciences
Virginia Polytechnic Institute and State University

B.A. Liberal Arts (Geology Physics Majors)
State University College, Potsdam, NY

PROFESSIONAL LICENSING / CERTIFICATION

Professional Geologist - PA

SELECTED PRESENTATIONS & PUBLICATIONS

Seaton, W.J., 2020, Stormwater Injection Wells, PACA Spring Environmental Community Meeting July 14, 2020 Hershey Country Club, Hershey, PA

Seaton, W.J., 2019, 3D Imaging of Aggregate Raw Material Reserves Using 21st Century Geophysical Technology, Pennsylvania Aggregates and Concrete Association (PACA) Annual Meeting, November 17-19, 2019, Hershey, PA

Seaton, W.J., Brandon, R.A., 2018, Groundwater Resource Exploration for Municipal Water Supplies in Pennsylvania, Pennsylvania American Water Works Association's 70th Annual Conference, May 8-10, 2018, Kalahari Resort and Convention Center, Pocono Manor, PA.

Sr Hydrogeologist / Groundwater Flow Modeling - Virginia Department of Environmental Quality (DEQ), Site: Plateau Plaza Exxon, Wirtz, VA – responsible for geological site characterization as input to an in-house groundwater flow and transport model for this contaminated site. Designed and implemented a geophysical survey around existing borings and surface features to produce a hydrogeologic model of the complexly faulted subsurface environment. This information provided the framework for a highly successful flow and transport model using MODFLOW and MT3D.

Sr Hydrogeologist - Alpha Ridge Landfill, Groundwater Recovery System, Howard County, MD – Conducted geophysical surveys to site new recovery wells in fractured bedrock. Conducted packer testing and pump testing to define depth of contamination and capture area. Recommended recovery well locations, depths and pumping rates.

Sr Hydrogeologist - I-95 and I-66 Landfills, Groundwater Contaminant Migration, Fairfax County, VA – Conducted geophysical surveys to define areas of saturation contributing to seeps and to define preferred pathways for contaminant migration in fractured bedrock. Recommended remedy for seep mitigation and locations for groundwater monitoring wells to define the Nature and Extent of contamination.

Sr Hydrogeologist - Energy-from-Waste Facility, Bainbridge, Pennsylvania – Utilized monitoring well data and earth resistivity methods to locate subsurface releases and accumulations of high-chloride fluids associated with a steam generation/cooling tower system at the Covanta Lancaster, Inc. Energy-from-Waste Facility. Data from geophysical surveys was used to locate subsurface areas in shallow unconsolidated materials and faulted bedrock that contained high concentrations of saline fluids that were accumulating due to percolation of ash-prone surface waters and leaks from buried pipes containing high-chloride fluids.

Principal Geophysicist / Hydrogeologist for a community water supply project in southern Pennsylvania. Served as project manager and senior hydrogeologist for the siting, design, aquifer testing and PADEP permitting of the Hess #2 Well for the Washington Township Municipal Authority, Franklin County, PA. This well had a blown yield of 2,400 gpm making this one of the top producing water supply wells in Pennsylvania. The Hess #2 Well was successfully tested at 1,500 gpm, meeting all of the PADEP water quality requirements. Developed wellhead protection zone / ordinance for Hess#2 well using earth resistivity geophysics and aquifer test information.

Principal Geophysicist / Hydrogeologist - served as project manager and senior hydrogeologist for the design and permitting of a high capacity (1,000 gpm) water supply well in a fractured bedrock aquifer in Middlesex, PA. Work included conducting an earth resistivity survey, planning and oversight of a high-yield 48-hour pumping test with an extensive monitoring network, reporting, and meeting PADEP and SRBC regulatory requirements. Conducted water supply well siting and drilling oversight for new exploratory water supply well on adjacent acreage.