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LOCKHEED MARTIN

June 20, 2018 **VIA PRIVATE CARRIER**

Mr. James R. Carroll
Program Administrator
Land Restoration Program
Land Management Administration
Maryland Department of the Environment
1800 Washington Boulevard, Suite 625
Baltimore, Maryland 21230

Subject: Transmittal of the Groundwater Response Action Plan Addendum Number 4 – Blocks E and F
Lockheed Martin Corporation; Middle River Complex
2323 Eastern Boulevard, Middle River, Baltimore County, Maryland

Dear Mr. Carroll:

For your review please find enclosed two hard copies with a CD of the above-referenced document. This document addresses trichloroethene contamination in Tax Blocks E and F at Lockheed Martin's Middle River Complex in Middle River, Maryland. Groundwater samples collected from injection and monitoring wells in Block E in January and April 2016 indicated that trichloroethene contamination was farther downgradient (south) than previously thought. Downgradient follow-up sampling in Block F in October 2016 and May 2017 indicated that groundwater trichloroethene concentrations extend to nearby surface water in Dark Head Cove. The enclosed Groundwater Response Action Plan (Addendum No. 4) is intended to address the trichloroethene identified in groundwater under Tax Blocks E and F.

If possible, we respectfully request to receive MDE's comments by August 2, 2018.

Please let me know if you have any questions. My office phone is (301) 548-2227.

Sincerely,

*Thomas D. Blackman signed on behalf of*

Lynnette Drake
Remediation Analyst, Environmental Remediation

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# GROUNDWATER RESPONSE ACTION PLAN ADDENDUM NUMBER 4—BLOCKS E AND F LOCKHEED MARTIN MIDDLE RIVER COMPLEX 2323 EASTERN BOULEVARD MIDDLE RIVER, MARYLAND

Prepared for:
Lockheed Martin Corporation

Prepared by:
Tetra Tech, Inc.

June 2018

Approved by:
Lockheed Martin, Inc.

Revision: 0

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Regional Manager

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## APPENDICES

# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| ARARs | applicable or relevant and appropriate requirements |
| ARD | anaerobic reductive dechlorination |
| AWQC | ambient water quality criteria |
| bgs | below ground surface |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act |
| COC | chemical(s) of concern |
| *cis*-1,2-DCE | *cis*-1,2-dichloroethene |
| DHC | *dehalococcoides* |
| DPT | direct-push technology |
| DNAPL | dense nonaqueous-phase liquid |
| ERH | electric resistance heating |
| EW | extraction well |
| GAC | granular activated carbon |
| GC | gas chromatograph |
| gpm | gallon(s) per minute |
| HDPE | high-density polyethylene |
| lbs/day | pounds per day |
| Lockheed Martin | Lockheed Martin Corporation |
| LGAC | liquid-phase granular activated carbon |
| LUCs | land use controls |
| MDE | Maryland Department of the Environment |
| µg/L | microgram(s) per liter |
| µm | micrometer(s) |
| mg/kg | milligram(s) per kilogram |

| | |
|---|---|
| mg/L | milligram(s) per liter |
| MNA | monitored natural attenuation |
| MPE | multi-phase extraction system |
| MRC | Middle River Complex |
| MSL | mean sea level |
| NPDES | National Pollutant Discharge Elimination System |
| NRWQC | national recommended water quality criteria |
| O&M | operation and maintenance |
| PCBs | polychlorinated biphenyls |
| POTW | publicly owned treatment works |
| PRB | permeable reactive barrier |
| RAP | response action plan |
| RAOs | remedial action objectives |
| SEE | steam-enhanced extraction |
| TCE | trichloroethene (also known as trichloroethylene) |
| TCH | thermal conductive heating |
| Tetra Tech | Tetra Tech, Inc. |
| USEPA | United States Environmental Protection Agency |
| UST | underground storage tank |
| VGAC | vapor-phase granular activated carbon |
| VOC | volatile organic compound |
| ZVI | zero-valent iron |

# SECTION 1
# INTRODUCTION

On behalf of Lockheed Martin Corporation (Lockheed Martin), Tetra Tech, Inc. (Tetra Tech) provides this fourth addendum to the *Groundwater Response Action Plan* (Tetra Tech, 2012) to address trichloroethene (TCE) contamination in Blocks E and F at the Lockheed Martin Middle River Complex (MRC) at 2323 Eastern Boulevard in Middle River, Maryland (Figures 1-1 and 1-2). Groundwater samples collected from injection and monitoring wells in Block E in January and April 2016 indicated that trichloroethene contamination was farther downgradient (south) than previously thought. Downgradient follow-up sampling in Block F in October 2016 and May 2017 indicated that groundwater trichloroethene concentrations extend to nearby surface water in Dark Head Cove.

Trichloroethene is the primary chemical of concern in Blocks E and F and is the driver for additional remediation. Trichloroethene's breakdown products, *cis*-1,2-dichloroethene (*cis*-1,2-DCE) and vinyl chloride, have either been detected in the area or are suspected to be present at low concentrations.

The current groundwater response action, as detailed in the *Groundwater Response Action Plan* (Tetra Tech, 2012) and its amendments, was approved by the Maryland Department of the Environment (MDE). The response action includes using enhanced anaerobic bioremediation processes in three areas of elevated trichloroethene concentrations in groundwater:

- the southeastern trichloroethene area (Block E)
- the southwestern trichloroethene area (Block G)
- the northern trichloroethene area (Block I)

The groundwater response action involves injecting amendments into the subsurface using rows of semi-permanent injection wells connected via underground conveyance piping to injection equipment in each of the three trichloroethene areas, and focuses on areas with trichloroethene concentrations exceeding 1 milligram per liter (mg/L). Two injection events have been completed at Block G, and three events have been completed at Block I.

The remedy implementation at Block E was delayed due to the discovery of an underground storage tank (UST) in 2013, and the high-concentration trichloroethene source associated with that location. Following this discovery and the removal of the underground storage tank, a multi-phase extraction system (MPE) was installed and operated to remove trichloroethene mass and reduce trichloroethene concentrations in this area. This system operated in 2014 and 2015, and removed more than 500 pounds of trichloroethene from the subsurface (Tetra Tech, 2016c).

Baseline groundwater sampling was expanded in January and April 2016 to determine volatile organic compound (VOC) concentrations in Block E before implementing tracer testing and subsequent remediation per the groundwater response action. Groundwater sampling results collected from 28 injection wells indicated greater than expected trichloroethene concentrations at the southern (downgradient) side of Block E, prompting an investigation to include sampling of the adjacent southern downgradient area in Block F. Additional investigation in 2016 and 2017 indicated a narrow trichloroethene plume extending from Block E to the edge of Dark Head Cove. Low concentrations of trichloroethene had previously been detected in Block F groundwater, in areas to the southeast that were previously thought to be directly downgradient of the elevated Block E trichloroethene concentrations; concentrations above 1 mg/L had never been measured within this area. The additional investigations in 2016–2017 indicated that the direction of groundwater flow from Block E to Block F is more directly south, rather than to the southeast; thus, the low trichloroethene concentrations detected previously were not directly downgradient of the highest trichloroethene concentrations in Block E.

Because the primary source of the trichloroethene is known to be the underground storage tank discussed above, Lockheed Martin Corporation designates recovered groundwater to be a listed waste until treatment reduces the trichloroethene concentration to 5 micrograms per liter (µg/L) or less. Lockheed Martin will remain in communication with the Maryland Department of the Environment to determine if any changes to this designation are warranted.

The detection of elevated trichloroethene concentrations near Dark Head Cove prompted expansion of the existing surface water sampling program to include locations adjacent to the groundwater plume. Subsequent surface water sampling in this area has indicated that trichloroethene and *cis*-1,2-dichloroethene concentrations in nearby surface water are less than published and calculated risk levels, and vinyl chloride has been nondetect. However, elevated trichloroethene concentrations in Block F groundwater near Dark Head Cove have led Lockheed Martin to consider remedial action within this area.

The trichloroethene contamination in both Blocks E and F is considered when determining the range of possible remedial alternatives and alternative remedies in Block E (in lieu of, or in conjunction with, the remedy detailed in the *Groundwater Response Action Plan* and amendments). These alternatives are presented and analyzed herein. The primary objectives of this document are to:

- briefly discuss the investigations in Blocks E and F
- establish remediation objectives for Blocks E and F
- provide a "long list" of remediation alternatives for Blocks E and F
- provide an analysis of the alternatives, and retain a "short list" of alternatives for further consideration
- provide conceptual design information for the short-listed alternatives
- recommend a remedial alternative for Blocks E and F
- provide a conceptual design and cost estimate for the recommended alternative.

The organization of this report is as follows:

Section 1—Introduction: Presents the background and objectives of this groundwater response action plan addendum, and provides a summary of the content of the subsequent report sections.

Section 2—Previous Investigations: Briefly describes previous Block E and F investigations and describes the conceptual site model.

Section 3—Remedial Alternatives Evaluation: Discusses the chemicals of concern (COC), remedial action objectives (RAOs), screening of technologies, and the long and short lists of alternatives, develops three short-listed alternatives, and selects a proposed response action for Blocks E and F.

Section 4—Proposed Response Action: Provides details for the proposed response action, including the conceptual design, implementation sequence, performance monitoring, and shutdown criteria.

Section 5—References: Lists the references used to compile this report.

# SECTION 2
# PREVIOUS INVESTIGATIONS

This section describes recent (2016 and 2017) investigation results in Blocks E and F. These investigations were performed to guide the implementation of the *in situ* bioremediation injections in Block E, as described in the *Groundwater Response Action Plan* (Tetra Tech, 2012). The results of the 2016–2017 investigations changed the previous depiction of the contaminant location and extent in Blocks E and F, and prompted a revision of the Block E response action that considers implementing a response action in Block F.

## 2.1 2016 BLOCK E SAMPLING RESULTS

During construction of the Block E groundwater remedy in 2013, an underground storage tank (UST) was discovered adjacent to the foundation of former Building D. The UST (shown as former UST 2 on Figure 2-1) contained trichloroethene (TCE) and is considered a source of the southeastern TCE plume in Block E. The planned *in situ* bioremediation in this block was delayed due to the high TCE concentrations remaining in soil and groundwater after tank removal, and a multi-phase extraction (MPE) system was installed near UST 2 to remove the TCE source material. More than 500 pounds of TCE were removed by this system (Tetra Tech, 2016c).

After MPE system operation, groundwater samples were collected from approximately 40 Block E monitoring and injection wells in January and April 2016, to better delineate the TCE plume at locations hydraulically downgradient (south) of UST 2. Sampling results (included in the *Block E Tracer Study Report* [Tetra Tech, 2016a]) indicated that the southeastern TCE plume was farther downgradient than previous known, and extended south of SEMW-6I (located north of Chesapeake Plaza Drive, see Figure 2-1). Groundwater investigation between monitoring well SEMW-6I and Dark Head Cove in Block F was subsequently conducted to delineate the suspected TCE plume in that area.

## 2.2 2016/2017 TCE PLUME DELINEATION IN BLOCK F

Groundwater in Block F was screened for TCE to delineate the suspected plume along four transects perpendicular to the groundwater flow direction, as shown on Figure 2-1:

- Transect A: seven sampling locations (A1 through A7)
- Transect B: six sampling locations (B1 through B6)
- Transect C: eight sampling locations (C1 through C8)
- Transect D: 11 sampling locations (D1 through D11)

Groundwater samples were collected from these 32 sampling locations using a direct-push technology (DPT) drilling rig. Transects A, B, C, and four locations in Transect D (D1 through D4), were screened in October 2016; the remaining seven locations in Transect D (D5 through D11) were screened in May 2017. At each sampling location, groundwater was collected from three depths[1]: 15 to 19 feet (shallow), 20 to 24 feet (intermediate), and 26 to 30 feet (deep). The lateral distance between sampling locations within each transect varied between 12 and 30 feet. TCE concentrations were measured in real time using a field gas chromatograph (GC) model FROG 4000 and/or in a fixed-base laboratory. The results for TCE are shown on Figure 2-1 and listed in Table 2-1, and are summarized below:

- The TCE plume extends approximately 360 feet from UST 2, and 200 feet southeast from the southern edge of Block E, to near Dark Head Cove. The most upgradient portion of this plume is in Block E near the former UST 2 location.
- The bold, dark magenta lines on Figure 2-1 show TCE isoconcentration contour lines, between which TCE has been detected at concentrations of 1,000 micrograms per liter (µg/L) or greater. Once outside of the 1,000 µg/L contour, TCE concentrations rapidly decrease along the sampling transects.
- The downgradient width of the TCE plume varies, from approximately 40 feet wide along Transect A, to approximately 90 feet wide along Transect D near Dark Head Cove (Figure 2-2).

[1]Except for A-6 and A-7 (which were collected at two depths, as the shallowest sample was not collected), and C-8, where only the deepest sample was collected.

- In general, TCE concentrations in Transects A and B are slightly higher with increasing depth. However, this trend is inconsistent, as TCE concentrations in shallow samples in Transects C and D near Dark Head Cove are generally higher.

- The width of the TCE plume increases near Dark Head Cove, and TCE concentrations are generally lower there than in upgradient sampling locations. Groundwater interaction with cove surface water might be responsible for its widening at that location.

The results of the 2016 sampling are in the *Block E Downgradient Trichloroethene Groundwater Investigation* (Tetra Tech, 2017a). Results of the May 2017 sampling are in the *Block E Downgradient Trichloroethene Plume Additional Investigation Report* (Tetra Tech, 2017b).

## 2.3 2016/2017 SURFACE WATER SAMPLING IN BLOCK F

Lockheed Martin collects surface water samples in Dark Head Cove and Cow Pen Creek (located adjacent to the Middle River Complex [MRC] and west of Dark Head Cove) three times per year to monitor for volatile organic compounds (VOCs), polychlorinated biphenyls (PCBs), and 1,4-dioxane. Previous sampling in Dark Head Cove had been primarily associated with MRC stormwater outfall locations, but the discovery of TCE in groundwater near Dark Head Cove in 2016 prompted additional sampling at eight Dark Head Cove locations near Block F. Surface water samples were collected two depths: from one foot below the water line, and from one foot above the water-sediment interface. Additional sampling was conducted in April and June 2017. The same number of samples was collected during these latter events, but sampling locations were adjusted based on the highest TCE concentrations detected during the December 2016 sampling event. Sampling locations were modified again (based on the results of all previous sampling) for sampling that occurred in September 2017.

The sampling locations and results for December 2016, April 2017, June 2017, and September 2017 are shown in Figures 2-3 through 2-6, respectively. Samples labeled with an “S” were collected one foot below the water surface, and samples labeled with a “D” were collected one foot above the sediment layer. The highest TCE concentration detected was 18 micrograms per liter (µg/L) at MRC-SW11A–S in September 2017. The maximum *cis*-1,2-dichloroethene (*cis*-1,2-DCE) concentration was 5.5 µg/L at MRC-SW12B–D in December 2016. In June 2017, all samples were nondetect for TCE, *cis*-1,2-DCE, and vinyl chloride. Vinyl chloride has not been detected in any surface water sample collected. The highest concentrations of TCE and *cis*-1,2-DCE in all samples collected in this area were less than the following screening criteria (Tetra Tech, 2018):

- United States Environmental Protection Agency (USEPA) Region 3 Biological Technical Advisory Group freshwater screening-benchmarks
- USEPA national recommended water quality criteria (NRWQC) for acute and chronic aquatic-organism exposures and NRWQC for human health aquatic-organism consumption
- Maryland ambient water quality criteria (AWQC) for acute and chronic aquatic-organism-exposures, and AWQC for human health aquatic-organism-consumption
- site-specific screening levels for swimming, developed by Lockheed Martin Corporation (Lockheed Martin) to assess primary VOCs, PCBs, and 1,4-dioxane in Dark Head Cove and Cow Pen Creek surface water (Tetra Tech, 2018). The use of these screening values to assess risks posed to recreational users of the cove and creek surface water adjacent to the MRC has been approved by the Maryland Department of the Environment (MDE). These screening levels are calculated using the conservative assumption that recreational users have long-term exposure to surface water (i.e., assumed swimming duration of four hours per day, 70 days per year, for 30 years), and represent a current exposure scenario, as these surface water bodies are used for recreational purposes by nearby residents during warm weather.

These screening levels are used to establish surface water objectives in Section 3.2 (Remedial Action Objectives).

## 2.4 JUNE 2017 PUMPING TESTS IN BLOCK F

Two pumping tests at Block F in 2017 sought to determine whether groundwater extraction is a viable option to hydraulically control the TCE plume near Dark Head Cove. Two pumping wells (EW-1 and EW-2), one monitoring well cluster (SEMW-9S/I), and two piezometers (PZ-1 and PZ-2) were installed at the locations shown on Figure 2-2 in May 2017. Construction details for the new wells and piezometers are summarized in the table below:

| Well designation | Well diameter | Purpose | Screened interval (feet below ground surface) |
|---|---|---|---|
| EW-1 | 4 inches | Groundwater extraction | 15–30 |
| EW-2 | 4 inches | Groundwater extraction | 15–30 |
| SEMW-9S | 2 inches | Groundwater monitoring | 8–18 |
| SEMW-9I | 2 inches | Groundwater monitoring | 20–30 |
| PZ-1 | 1 inch | Temporary piezometer | 20–30 |
| PZ-2 | 1 inch | Temporary piezometer | 20–30 |

Extraction tests were performed separately in EW-1 and EW-2. A step-test was performed at each extraction well using low, intermediate, and high pumping rates, and extended duration (approximately 48-hour) pumping continued at the high extraction rate. Table 2-2 contains a summary of pumping test parameters for wells EW-1 and EW-2, and Table 2-3 contains analytical sampling results from these wells, as well as results collected at four observation wells before, during, and after the pumping tests.

A tidal study performed before the pumping tests began evaluating possible tidal influence on the groundwater table in the tested area. This study shows that the water level in Dark Head Cove fluctuates more than 1.5 feet during each tidal cycle, while the water level in monitoring wells and piezometers fluctuates by more than 0.5 feet. The magnitude of these fluctuations (which vary within each tidal cycle) significantly complicates the analysis of the pumping test data, as separating tidal influence from the changes caused by pumping is difficult. The initial analysis of these results included corrections for these influences; a longer duration measurement and analysis of the tidal cycles is planned for later in 2018, and these data will be used to address this issue in the final remedial design.

Pumping tests indicated that sustained yield at EW-1 is considerably less than at EW-2, likely due to the thin layer (several inches) of gravel near the bottom of the EW-2 well screen. Pumping in EW-2 produced a well-defined hydraulic response in all observation wells in the study area. Pumping in EW-1 produced a weaker hydraulic response as compared to that observed in EW-2. Calculations indicated that EW-2 has a capture zone at least 100 feet wide (i.e., at least a 50-foot radius of influence) that spans the entire 1 milligram per liter (mg/L) TCE plume in that location.

Groundwater modeling performed using the pumping test results (Section 4.2.1) confirmed that the capture zone of EW-2 extends across the 1 mg/L TCE plume, and from EW-2 to the surface water boundary. Appendix A contains information regarding the hydraulic response of monitoring wells due to pumping at EW-1 and EW-2, and to tidal fluctuations in Dark Head Cove. Detailed pumping-test results are in the *Block E Downgradient Trichloroethene Plume Additional Investigation* report (Tetra Tech, 2017b), and conclusions of that report are summarized below:

- Preliminary capture-zone calculations indicate that hydraulic control of the TCE plume in the Block F area can be achieved by a single pumping well (EW-2).
- Sustained pumping rates for EW-1 and EW-2 are 0.65 gallons per minute (gpm) and 4.3 gpm, respectively.
- The combined TCE-mass removal rate for EW-1 and EW-2 is approximately 0.5 pounds per day (lbs/day), two-thirds of which is due to EW-2.
- Sampling results for salinity, bromide, sulfate, total dissolved solids, and alkalinity collected during the pumping tests indicate that surface water from Dark Head Cove is not being pulled into the extraction wells, even after sustained pumping at EW-2 for 40 hours (approximately 11,000 gallons of groundwater pumped).

## 2.5 HYDROGEOLOGY OF BLOCKS E AND F AND CONCEPTUAL SITE MODEL

The soil types present across Blocks E and F generally consist of sands, silts, and clays, with relatively complex layering of lower and higher permeability units to a depth of approximately 30 feet bgs. A lower permeability silt and sand layer is generally present from the grade surface to depths ranging from approximately 7 to 13 feet bgs. A slightly higher permeability silty sand layer with intermittent silt and clay lenses lies below this layer to a depth of 30 feet.

An intermittent coarse sand and gravel layer occurs at a depth of 30 feet, just above the clay layer discussed below. This sand and gravel layer is thin (a maximum of six inches thick) and was detected and recorded at several wells in Blocks E and F. These are the wells where a presence of a thin gravel layer near the top of the clay at 25 to 35 feet bgs was noted on the available boring logs: IWE-13, IWE-22, SEMW-2I, SEMW-7I, SEMW-8I, MW-74C, MW-73B. Although this layer was present in several boring logs from Blocks E and F, we infer that its presence might not have been recorded in some drilling locations due to its thinness.

Indirect evidence of existence of this gravel layer at various locations includes the relatively high pumping rates achieved by one MPE well during the 2014/2015 UST 2 source removal action (Tetra Tech, 2016c), the high pumping rate achieved in well EW-2 (compared to EW-1) during the July 2017 pumping tests in Block F, and the high injection rate achieved in several injection wells during the 2016 tracer test in Block E (Tetra Tech, 2016a). The hydraulic conductivity of the coarse sand and gravel (two to three orders of magnitude higher than the sand and silt layers above it) was confirmed by the 2017 pumping tests in Block F and the groundwater-model calibration results. This highly conductive thin sand and gravel layer, along with interbedded conductive stringers within the lower permeability silty sand layer, is an important pathway for groundwater and contaminant transport from the source area near UST 2 toward Dark Head Cove.

A low-permeability clay layer occurs at approximately 30 feet bgs; it was detected in all observation and injection wells, and appears to be a semi-competent confining layer, as TCE concentrations below this clay in well MW-74C, located near the former 500-gallon UST in Block E, are approximately three orders of magnitude lower than those above the layer. Installation of an additional deeper well in Block F that extends through this clay layer is planned to further characterize TCE concentrations present beneath the clay layer. In addition, a sample of the clay will be evaluated for hydraulic conductivity characteristics to evaluate if the clay layer is acting as a hydraulically confining unit. Sampling results from this well are not expected to affect the alternatives analysis and conceptual design presented in this document, which address the high TCE concentrations in shallower soil and groundwater (above 30 feet bgs).

Concentrations of TCE in soil above 1,000 milligrams per kilogram (mg/kg) and in groundwater above 1,000,000 µg/L were detected at the former UST 2 location during and after tank removal. Operation of the MPE system removed traces of dense nonaqueous-phase liquid (DNAPL) remaining in the area after the UST had been removed (Tetra Tech, 2016c). TCE concentrations immediately up- and side-gradient of the former UST 2 location are low; the maximum upgradient concentration of TCE (in the northern portion of Block E) is 23 µg/L, and all side-gradient concentrations are less than 100 µg/L (see Figure 2-1).

An area of anomalous TCE distribution is present in the central portion of Block E near a former 500-gallon fuel oil UST. This area contains higher groundwater concentrations of TCE in the shallower low-permeability unit, as compared to concentrations in the higher permeability silty sand layer unit below, and no clear mechanism(s) for migration of high TCE concentrations from UST 2 into this unit is apparent. Although this might have resulted from a surface or shallow-subsurface release near the former 500-gallon fuel oil UST, soil sampling conducted in a dense grid to a depth of 12 feet in this area could not locate a residual TCE source. Therefore, some other pathway is responsible for this irregularity in TCE distribution (Tetra Tech, 2017b).

The conclusion that UST 2 is the sole TCE source is supported by the number of data points available for TCE plume delineation. More than 30 Block E injection and monitoring wells were sampled in 2016, and more than 30 new and existing monitoring wells in Block F were sampled in 2017. This is supported by shallow soil and groundwater sampling conducted in the vicinity of UST 2 after it was removed. Results from the nearly 80 sampling locations in this relatively small area (less than 500 feet from the most upgradient sampling locations to Dark Head Cove) delineated the TCE plume (see Figure 2-1). Figure 2-7 is a cross-section location map of the study area, and Figure 2-8 is a cross-section showing general site lithology and TCE concentrations detected in Blocks E and F. The sampling locations in Block F are limited to the portion of the aquifer above the clay unit (generally occurring at 30 feet bgs). Current plans include installing a well screened below this unit; details of the well installation and sampling will be provided under separate cover. As stated above, sampling results from this well are not expected to affect the alternatives analysis and conceptual design presented herein.

The groundwater flow direction, as determined by the wells in Blocks E and F, is south toward Dark Head Cove, with a shallow gradient of 0.01 feet per foot (Figure 2-9). Data from recent groundwater monitoring efforts (to be presented in detail under separate cover) suggest that the hydraulic heads measured in the intermediate (i.e., higher permeability silty sand layer) and shallow (i.e., low-permeability layer) units are similar (within 0.03 feet), and no vertical gradient has been observed. However, the limited number of shallow/intermediate well clusters, the lack of a well below the clay layer in the area, and limited groundwater table measurements collected during tidal cycles, currently preclude accurate assessment of the vertical gradients and tidal influence in Blocks E and F. Long-term (up to one year) groundwater level measurements via transducers is planned for Block E and F wells; this data will be used to more fully develop the conceptual site model and continue development of the focused groundwater model for this area (see Section 4.2.1). The resulting data will then be used to refine the groundwater remedy in this area. Note, however, that this data is viewed as supplemental to that already obtained, and is not expected to change the major conclusions of this document.

TCE concentrations up to 60,000 µg/L have been detected in groundwater near Dark Head Cove, and sporadic low levels of TCE have been detected in cove surface water, indicating that contaminated groundwater is migrating to the cove. Calculations quantifying the mass discharge of TCE in the four Block F transects are discussed in Section 4.2.3, and the hydraulic conductivity for the three major units above the competent clay layer was estimated using results from the groundwater pumping tests (Section 4.2.1). TCE mass-discharge rates for the four transects are relatively consistent, and range from nine to 38 pounds per year, with average and mean rates of approximately 26 and 30 pounds per year, respectively.

Twenty-four groundwater samples are collected from nine multi-port well locations (OF-01 through OF-09) to address potential migration of site chemicals of concern (COC) across Dark Head Cove and Cow Pen Creek; these samples are collected on the other side of these surface water bodies, and across from the MRC. These samples are collected once every three years, most recently in 2016. TCE, *cis*-1,2-DCE, and vinyl chloride were not detected during the 2016 sampling, or in any previous sampling events. Figure 2-10 shows off-site well locations (Tetra Tech, 2016b). The current off-site sampling program is adequate for monitoring the migration of Block F groundwater COC to adjacent properties; however, as additional flow data and deep groundwater data are obtained, this network will continue to be evaluated.

# SECTION 3
# REMEDIAL ALTERNATIVES EVALUATION

This section addresses Blocks E and F groundwater chemicals of concern (COC) and remedial action objectives (RAOs). Possible remedial technologies are screened, long and short lists of alternatives are developed, three short-listed alternatives are evaluated, and a recommended response action is selected.

## 3.1 CHEMICALS OF CONCERN

The primary COC identified in Blocks E and F groundwater at the Middle River Complex (MRC) are trichloroethene (TCE) and its degradation byproducts *cis*-1,2-dichloroethene (*cis*-1,2-DCE) and vinyl chloride. In Blocks E and F, only TCE has been detected at concentrations that exceed Maryland's "Generic Numeric Cleanup Standards" for groundwater. Although "Generic Numeric Cleanup Standards" are not necessarily site cleanup goals, they are expected to trigger land use controls imposed by the Maryland Department of the Environment (MDE). The *Groundwater Response Action Plan* (RAP) (Tetra Tech, 2012) calls for active remediation to be limited to areas exceeding 1,000 micrograms per liter (µg/L) of TCE. Figures 2-1 and 2-2 show the distribution of TCE in groundwater in Blocks E and F. No surface water samples have exceeded the screening levels established for the site (Section 2.3). Metals are not considered COC in groundwater at the MRC (Tetra Tech, 2012).

## 3.2 REMEDIAL ACTION OBJECTIVES

RAOs are contaminant- and medium-specific goals that define the objectives of response actions that will protect human health and the environment. The following RAOs have been established for Blocks E and F:

| Remedial action objective | Description |
|---|---|
| 1 | Conduct active remediation with the objective of reducing the mass of trichloroethene in the subsurface of the active remediation areas and reducing the mass of trichloroethene daughter products, including primarily *cis*-1, 2-dichloroethene and vinyl chloride. |
| 2 | Prevent human exposure (from dermal contact, inhalation, and ingestion) to groundwater containing site-related chemicals of concern at concentrations greater than drinking water standards (MDE "Generic Numeric Standards for Groundwater"). |
| 3 | Prevent discharge of groundwater with chemicals of concern that would cause an exceedance of the MDE ambient water quality criteria or risk-based swimming criteria in Dark Head Cove and Cow Pen Creek. |
| 4 | Prevent off-site migration of site-related groundwater chemicals of concern at concentrations greater than drinking water standards to adjacent properties. |
| 5 | Prevent exposure of industrial workers (via vapor intrusion into buildings) and construction workers (via exposure in trenches) to site-related volatile organic compounds (VOCs) due to groundwater vapors at levels that would pose a carcinogenic risk greater than $1\times10^{-5}$ or a cumulative hazard index greater than 1 for noncarcinogenic VOCs. |

RAOs 1, 2, 3, and 4 are unchanged from those presented in the *Groundwater Response Action Plan Addendum 2: Response Action Objectives and Project Implementation Schedule* (Tetra Tech, 2015). RAO 5 was modified to separate potential risks to construction workers and industrial workers. The risk-based and ambient water quality criteria referenced in RAO 3 are in the MDE-approved *2017 Surface Water Sampling Report* (Tetra Tech, 2018), and are summarized below:

| Parameter | National Recommended Water Quality Criteria (µg/L) | | Ecological surface water screening level (µg/L) | Human health consumption of organism only (µg/L) | Swimming screening levels (µg/L) |
|---|---|---|---|---|---|
| | Freshwater | | | | |
| | Acute | Chronic | | | |
| *cis*-1,2-DCE | Not applicable | Not applicable | Not applicable | Not applicable | 70 |
| TCE | Not applicable | Not applicable | 21 | 300 | 30 |

Vinyl chloride has not been detected in MRC surface water; thus, no site-specific water quality criteria have been established for this parameter. Experience at nearby Martin State Airport suggests that detection of vinyl chloride concentrations approximately one microgram per liter (µg/L) or less might trigger exceedances of risk-based standards.

## 3.3 SCREENING OF TECHNOLOGIES AND PROCESS OPTIONS

This section identifies, evaluates, and screens an appropriate range of technologies and process options applicable for groundwater remediation at Blocks E and F. Various technologies and process options were identified and screened based on the following criteria:

- site-specific information (RAOs, geology, hydrogeology, pumping tests, contaminant distribution, specific risks)
- information and analysis from the *Groundwater Response Action Plan* (Tetra Tech, 2012)
- regulatory guidance documents (e.g., *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* [the Comprehensive Environmental Response, Compensation, and Liability Act] [United States Environmental Protection Agency (USEPA)], 1988)

Table 3-1 summarizes the preliminary screening of technologies and process options applicable to Block E and F groundwater conditions. It presents the general response actions, identifies the technologies and process options, briefly describes the process options, and provides screening comments. The most important screening criteria was an ability to meet the stated RAOs. The relative effectiveness for different technologies and process options to reach remedial objectives is also an important consideration. Associated risk factors for possible negative unintended consequences is also considered while screening remedial technologies and process options. Technologies and process options (to address groundwater contamination at MRC Blocks E and F) that were retained after the screening are listed in Table 3-2.

## 3.4 DEVELOPMENT AND ANALYSES OF ALTERNATIVES

This section discusses the development of the Block E and F groundwater response action alternatives from the retained process options (Table 3-2) and describes the conceptual designs for the selected “short list” of alternatives. Key definitions, assumptions, and design considerations used to develop remedial alternatives for Blocks E and F groundwater follow:

- Reducing migration of TCE and its degradation byproducts to Dark Head Cove is the primary consideration for selecting a remedial alternative for Block F. TCE mass reduction is the primary consideration for selecting an alternative for Block E.
- Areas referred to below are based on the TCE isoconcentration contours from the 2016 and 2017 sampling (see Figures 2-1 and 2-2):

- The "downgradient TCE plume" includes areas in Block F with TCE concentrations greater than 1,000 micrograms per liter (µg/L); this is consistent with the definition for the areas targeted for remediation throughout the groundwater RAP process.

- The "upgradient TCE plume" includes areas in Block E with TCE concentrations greater than 1,000 µg/L.

- The target treatment areas conform to the same areas with TCE concentrations greater than 1,000 µg/L.

- Remaining product from underground storage tank 2 (UST 2) and surrounding soil were removed in 2014. Approximately 500 pounds of TCE were extracted from the former UST 2 source area during operation of the multiphase extraction (MPE) system in 2014 and 2015, and only traces of dense nonaqueous phase liquid (DNAPL) were observed in one extraction well at the beginning of the MPE system operation. Thus, we believe that most of DNAPL associated with the UST 2 source has been removed, and it is unlikely that DNAPL is still present in quantities that would require application of DNAPL-focused technologies.

- TCE mass is adsorbed to silt and clay material in the saturated zone. This TCE mass will likely act as a long-term source of dissolved TCE in groundwater due to matrix diffusion. However, the TCE mass flux associated with matrix diffusion is expected to be considerably lower than the current TCE flux associated with the dissolved TCE phase.

- Hydraulic containment includes groundwater extraction intended to reduce groundwater migration.

- Groundwater extraction rates for containment are based on hydraulic testing in Block F.

- A permeable reactive barrier (PRB) is a treatment intended to reduce COC migration toward Dark Head Cove.

- The preferred method of treated groundwater discharge to surface water is under a National Pollutant Discharge Elimination System (NPDES) permit, to be obtained as part of the system design process. However, discharge to the sanitary sewer could be considered if 1,4-dioxane and/or metals content are too high for NPDES discharge.

### 3.4.1 Assembly of Remedial Alternatives

Based on the assumptions and design considerations listed above, nine remedial alternatives from the retained list in Table 3-2 were assembled and evaluated, comprising the "long list" of alternatives (Table 3-3). These alternatives are as follows:

- ***Alternative 1****:* monitored natural attenuation (MNA) and land use controls (LUCs)

- ***Alternative 2:*** continuing the existing anaerobic reductive dechlorination (ARD) in Block E, MNA/LUCs in Block F
- ***Alternative 3:*** hydraulic containment in Block F; existing ARD in Block E; MNA/LUCs
- ***Alternative 4:*** PRB in Block F, existing ARD in Block E; MNA/LUCs
- ***Alternative 5:*** an air-sparging curtain in Block F, existing ARD in Block E; MNA/LUCs
- ***Alternative 6:*** hydraulic containment and PRB in Block F; continuing the existing ARD in Block E; MNA/LUCs
- ***Alternative 7:*** adding vacuum-enhanced recovery to alternatives featuring groundwater extraction (i.e., Alternatives 3 and 6), MNA/LUCs
- ***Alternative 8:*** thermal treatment in Blocks E and F, MNA/LUCs
- ***Alternative 9:*** ARD in Blocks E and F, MNA/LUCs

These potential remedial alternatives were screened against the CERCLA criteria of effectiveness, implementability, and cost. Several remedial alternatives were eliminated, (a) after the determination that the technologies used in the remedy would be ineffective (i.e., would not mitigate risk), (b) if the risk of unintended consequences posed by the alternative was excessive, (c) if the alternative could not be implemented using a reasonable level of effort, or (d) if the alternative was significantly more expensive than other technologies, with an equal risk-mitigation benefit. This initial screening included consideration of RAOs, area geology and hydrogeology, contaminant type, distribution, and concentrations, the proximity of the site to surface water, and physical characteristics of the affected environmental media.

Installation of the existing ARD system in Block E was completed in 2015. The expected performance of this system was reevaluated, given (a) the more accurate delineation of the Block E TCE plume, (b) the successful ARD activities in Blocks G and I, and (c) expectations that the existing ARD system will effectively reduce COC and meet the RAOs; therefore, remedial alternatives that would be compatible with the existing ARD system in Block E are ranked higher. Table 3-3 includes a brief description of the "long list" of alternatives, and a summary of their advantages and disadvantages based on relative effectiveness, implementability, and cost. Retained alternatives are in bold font in the table. A summary of the criteria follows:

- ***Effectiveness***
    - o the degree to which it protects human health and environment, reduces toxicity, mobility, or volume, and the permanence achieved by the solution
    - o potential for the technology to address the estimated areas or volumes of contaminated media
    - o potential for the technology to meet the cleanup goals identified in the RAOs
    - o technical reliability with respect to contaminants and site conditions
- ***Implementability***
    - o overall technical feasibility for implementation at Blocks E and F
    - o availability of vendors, mobile units, storage and disposal services, etc.
    - o administrative feasibility
    - o special long-term maintenance and operation requirements
- ***Cost (qualitative)***
    - o capital cost
    - o operation and maintenance costs

Retained alternatives (Alternatives 2, 3, and 6) comprise the "short list" of alternatives ultimately established (Section 3.4.2). Based on advantages and disadvantages for each alternative (summarized in Table 3-3), the following alternatives were eliminated:

- ***Alternative 1—Monitored Natural Attenuation and Land Use Controls (MNA/LUCs):*** Although this alternative would currently be protective of human health and the environment by implementing land use controls, it does not remove significant contaminant-mass; therefore, it would not meet RAO 1 in a timely fashion. As such, Alternative 1 was removed from consideration.
- ***Alternative 4—PRB in Block F, existing ARD in Block E, MNA/LUCs):*** This alternative would include a PRB in Block F and continued operation of the existing ARD system in Block E. The reliability of a PRB as the sole mechanism to contain the TCE plume in Block F is unclear, due to a complicated, heterogeneous, low permeability geology, low groundwater flow velocities, and tidal influences on groundwater near Dark Head Cove. This option would provide no treatment of groundwater already downgradient of the PRB, and no backup if the PRB fails or performs poorly. Therefore, Alternative 4 was removed from further consideration.
- ***Alternative 5—an air-sparging curtain in Block F, ARD in Block E, MNA/LUCs):*** Alternative 5 is similar to Alternative 4, but uses an air-sparging curtain as a containment

barrier. Air would be injected into the saturated zone perpendicular to the groundwater flow direction at a depth below the target contamination. The air moves upwards through the contaminated material, and volatile contaminants partition into the air as it moves upward through the water column. The volatile contaminants are removed from water as it passes the air-sparging curtain. The resulting vapor is then collected and treated at the surface. An air-sparging curtain can be installed using a row of injection wells or a trench, with air distribution from the bottom.

Air injection wells would not be effective in Block F due to low soil permeability and heterogeneous geology; thus, the air-sparging curtain would have to be installed using a trench with air distribution piping. Trench installation would require high capital costs, would involve removal and disposal of potentially hazardous-listed soil and groundwater during trench construction, and would require long-term operation and maintenance of the air compressor, a vacuum blower for soil vapor extraction, and air emissions treatment systems (e.g., vapor-phase granular activated carbon vessels). Therefore, Alternative 5 was removed from further consideration.

- ***Alternative 7—adding vacuum-enhanced recovery to alternatives featuring groundwater extraction (i.e., Alternatives 3 and 6):*** This alternative would add vacuum-enhanced multi-phase recovery to alternatives featuring groundwater extraction. The main advantage of this alternative is that it would increase TCE mass removal from groundwater extraction wells. This technology was successfully used in Block E during the 2014/2015 TCE source removal action. However, vacuum-enhanced recovery would require high energy use, and vacuum equipment would have to be maintained, so it would be costly to install and operate. This technology is not needed, based on the site's hydraulic testing and groundwater modeling results. These complications and increased costs outweigh the benefits of increased TCE mass removal rates; thus, Alternative 7 was removed from further consideration.

- ***Alternative 8—thermal treatment in Blocks E and F:*** Thermal treatment in Blocks E and F would partition volatile compounds in soil and groundwater into the vapor phase using heating methods. The partitioned chemicals would move through soil and groundwater toward extraction wells, where they would be collected and treated aboveground using appropriate cleanup methods. The most often-used technologies to deliver heat to the subsurface are electrical resistance heating (ERH), thermal conduction heating (TCH) and steam-enhanced extraction (SEE).

  Thermal treatment would be expected to be effective for the site-specific conditions, such as the COC and geology in Blocks E and F. However, the existing ARD-system subsurface infrastructure in Block E (injection wells, underground piping and power conduits, and the monitoring well network) cannot withstand the higher temperatures associated with thermal treatment, and would have to be dismantled. The existing ARD system in Block E would be expected to be effective in reducing COC mass; therefore, dismantling it before remedy implementation is undesirable.

  Thermal treatment could be applied in Block F in combination with the existing ARD in Block E. However, thermal treatment in Block F might lead to increased surface water temperatures and negative impacts to aquatic life in Dark Head Cove. Also, the clean zone in Block F could be re-contaminated by VOCs migrating from upgradient areas in Block E. Additional negatives of thermal treatment include high capital and implementation costs, uncertain power source if ERH is used, the requirement for large quantities of combustible fuels (e.g., propane) for TCH and SEE, and the requirement for an aboveground treatment system to treat extracted vapors and groundwater.

Alternative 8 was removed from consideration based primarily on its incompatibility with existing ARD in Block E, implementation uncertainties, high costs, and possible undesirable environmental impacts. However, as a contingency, thermal treatment could be used in a treatment train after operation of the ARD system in Block E is finished, or to treat locations where ARD might be deemed ineffective. Another contingency measure that could be potentially applied is a low-temperature thermal treatment to increase effectiveness of ARD, thereby creating more favorable conditions for TCE degradation at increased temperatures.

- ***Alternative 9—ARD in Blocks E and F:*** This alternative would use enhanced ARD technology in Blocks E and F. The existing ARD system in Block E would be expanded. Additional injection wells would be installed in Block F across the TCE plume. The injection lines would be connected to the injection equipment container in Block E. This alternative would be expected to eventually reduce the TCE mass in Blocks E and F. However, it would not contain the TCE plume, and therefore would not prevent the migration of TCE and its degradation byproducts into Dark Head Cove in the short term. ARD would also produce vinyl chloride, a known byproduct of TCE biodegradation, which has a risk-based screening level of less than 1 µg/L in surface water. Using ARD near Dark Head Cove without any containment would potentially cause migration of vinyl chloride and injected amendments into Dark Head Cove, especially in the short term. Alternative 9 was therefore removed from further consideration due to these concerns.

Alternatives 2, 3, and 6 above (renumbered hereinafter as Alternatives 1, 2, and 3 for clarity) were carried forward for further evaluation:

- ***Alternative 1—***existing ARD in Block E, MNA/LUCs in Block F
- ***Alternative 2—***hydraulic containment in Block F, existing ARD in Block E, MNA/LUCs
- ***Alternative 3—***hydraulic containment and PRB in Block F, existing ARD in Block E, MNA/LUCs

### 3.4.2 Description and Analysis of the Retained Alternatives

The retained, short-listed remedial action alternatives are described below, and summarized in Table 3-4. Each retained alternative described in this section includes the following components:

- remedy performance monitoring (specific to each remedial technology)

- MNA in treatment areas for continued mass removal following active remediation
- LUCs necessary to meet the RAOs for Block E and F groundwater

Conceptual designs were developed for the three alternatives. Each was evaluated against the nine CERCLA criteria from 40 *Code of Federal Register* Part 300.430, as well as a tenth criterion we considered: lifecycle impacts. The nine CERCLA and lifecycle evaluation criteria are described below:

- overall protection of human health and the environment
- compliance with applicable or relevant and appropriate requirements (ARARs)
- long-term effectiveness and permanence
- reduction of toxicity, mobility, or volume through treatment
- short-term effectiveness
- implementability
- lifecycle impacts
- cost
- state acceptance
- community acceptance

***Overall protection of human health and the environment*—**Alternatives must be assessed for the degree to which they adequately protect human health and environment (both in the short- and long-term) from regulatory-based unacceptable risks posed by COC in MRC groundwater and adjacent surface water by eliminating, reducing, or controlling exposure to those COC. Evaluation of this criterion includes assessing the other evaluation criteria, especially long-term effectiveness and permanence, short-term effectiveness, and compliance with ARARs.

***Compliance with ARARs*—**Alternatives must be assessed to determine whether they would attain ARARs under federal and state environmental or facility siting laws. ARARs were developed and presented in the initial groundwater RAP (Tetra Tech, 2012). If one or more applicable regulations cannot be complied with, a waiver would have to be invoked. Grounds for invoking a waiver are as follows:

- the alternative would attain a standard of performance equivalent to that required under the otherwise applicable standard, requirement, or limitation through use of another method or approach

- a state requirement has not been consistently applied or the state has not demonstrated the intention to consistently apply the promulgated requirement in similar circumstances at other response actions in the state
- the ability of each alternative to meet the RAOs is also considered in this criterion

***Long-term effectiveness and permanence—***Alternatives must be assessed for the long-term effectiveness and the permanence they offer, along with the degree of certainty that the alternative will succeed. Other considerations include, as appropriate, the magnitude of residual risk (e.g., risks posed by untreated waste or treatment residuals) and the adequacy and reliability of controls (e.g., controls needed to manage untreated waste or treatment residuals).

***Reduction of toxicity, mobility, or volume through treatment—***The degree to which an alternative employs recycling or treatment that would reduce the toxicity, mobility, or volume of the waste must be assessed, including how the treatment and associated reduction would address principal site risks.

***Short-term effectiveness—***The short-term effects of the alternative must be assessed in consideration of the following concerns:

- short-term risks that the community may be exposed to during implementation
- potential effects to workers during the response action and the effectiveness and reliability of protective measures
- potential environmental effects of the response action and the effectiveness and reliability of mitigation measures during implementation
- time until RAOs are achieved

***Implementability—***The ease or difficulty of implementing the alternatives must be assessed by considering technical feasibility, administrative feasibility, and availability of services and materials.

***Lifecycle impacts—***Lifecycle impacts, including energy, water, and material usage and transportation requirements, were evaluated qualitatively, based on the duration and intensity of field construction, duration of operation and maintenance, and waste transportation and disposal quantities. A quantitative analysis of life-cycle impacts was not conducted, because the overall environmental impact of all the remedy alternatives during their respective life cycles would be relatively minor when compared to past and planned remedial actions at the MRC and the minor differences between the alternatives were not great enough to affect the response action recommendation.

***Cost—***Capital and operating cost estimates were developed for each remedial alternative. Cost estimates are in Appendix B. Several assumptions used for the cost estimate are listed below:

- Three injection events are included for Block E ARD based on the ARD operational experience in Blocks G and I.
- The duration of the active remediation associated with Alternative 3, Block F hydraulic containment with PRB, is estimated at 8 years; this was calculated using an exponential decay model for dissolved phase removal and a matrix back diffusion model for the latter portion of the pumping.
- The duration of active remediation associated with Alternative 2 Block F hydraulic containment duration without PRB is estimated at 12 years; this was assumed (for cost estimating purposes) as 50% longer than Alternative 3, due to the reduced VOC removal without the PRB.
- The conceptual design of the Block F groundwater treatment system for Alternatives 2 and 3 is based on pumping from extraction wells EW-1 and EW-2. Sustainable pumping rates and contaminant loading for EW-1 and EW-2 were determined during the July 2017 pump tests.
- PRB curtain longevity in Alternative 3 (5 years) is a conservative value based on discussions with the ZVI material vendors; industry experience reflected in the Interstate Technology & Regulatory Council technology update (*Permeable Reactive Barrier: Technology Update*. June 2011) indicates that the ZVI longevity could be significantly higher.
- A two-year duration of MNA following active remediation for all alternatives is assumed. Bi-annual sampling is assumed for those two years. It is assumed that after those two years, a Response Action Completion Report would be submitted and any groundwater

monitoring in Blocks E and F would be completed under the site-wide groundwater monitoring program.

***State acceptance*—**MDE will review the proposed groundwater RAP addendum and inform Lockheed Martin in writing, on or before the end of a 75-day review period, whether the addendum has been approved or rejected. This criterion is not included in this evaluation because the MDE review has not yet occurred.

***Community acceptance*—**Lockheed Martin is committed to its partnership with the community with regard to environmental activities at the MRC, and currently plans to present the contents of this groundwater RAP addendum to the public. Lockheed Martin will also provide remediation program updates and attend civic association meetings upon request. Input from the community will be an important consideration in selecting and implementing the MRC response action. However, because community review of the groundwater RAP addendum has not yet occurred, this criterion is not included in this evaluation.

***Relative importance of criteria*—**Among the 10 evaluation criteria outlined above, the following are considered *threshold criteria*:

- overall protection of human health and the environment
- compliance with ARARs

*Threshold criteria* must be satisfied for an alternative to be eligible for selection. Among the remaining criteria, the following six are considered the primary *balancing criteria*. *Balancing criteria* weigh the relative merits of alternatives regarding the following:

- long-term effectiveness and permanence
- short-term effectiveness
- lifecycle impacts
- reduction of toxicity, mobility, or volume
- implementability
- cost

The remaining 2 of the 10 criteria (state and community acceptance) are *modifying criteria* that must be considered in selecting a response action. These last two modifying criteria can only be evaluated after MDE and the community have reviewed the proposed RAP addendum. Therefore, this groundwater RAP addendum addresses only 8 of the 10 evaluation criteria. The remaining two will be addressed through the groundwater RAP addendum review, comment, and approval process.

#### 3.4.2.1 Alternative 1: Existing ARD in Block E and MNA/LUCs in Block F

Alternative 1 includes continued operation of the existing ARD system in Block E. However, the ARD system operation would be modified based on the TCE plume delineation resulting from additional investigations in 2016 and 2017 (Section 2.2). The main goal of these modifications would be to achieve more rapid and complete TCE reduction by injecting the biological amendments (substrate, pH buffer, and *dehalococcoides* [DHC] cultures) in the target areas, thus reducing the spread of TCE and its degradation products in the downgradient direction. At the same time, the injection program would be downscaled in the upgradient area of Block E, where TCE concentrations are low (Figures 2-1 and 2-2). Refer to Figure 3-1 for a general layout of the ARD system in Block E.

A primary modification to the ARD system, as originally installed, includes the addition of injection wells near and downgradient of UST 2. This area has the highest TCE concentrations at the site, and is therefore targeted for additional treatment. Four of the multi-phase extraction (MPE) wells have been converted to injection wells (IWE-25 through IWE-28) and piped to the injection system for this purpose (Figure 3-1).

The first full-scale injection would be done in two phases, with a relatively short monitoring phase between them. The modified first injection at Block E is described in the *Block E Tracer Study Report* (Tetra Tech, 2016a), and is summarized below:

- The injection would be performed in a phased approach:
    - *The Phase A injection* would inject the substrate and pH buffer solution to create favorable conditions for bioaugmentation.
    - *The monitoring phase* would determine if conditions favorable for bioaugmentation are achieved.
    - *The Phase B injection* would involve bioaugmentation with DHC cultures. The success of bioaugmentation in Block G leads us to expect that this will significantly accelerate TCE degradation in Block E.

- The sodium-lactate substrate dosage would be increased from the original design values, because current aerobic conditions would have to be overcome quickly to create conditions necessary for bioaugmentation.

- The sodium bicarbonate dosage would be increased from the original design values, because current pH levels are lower than levels favorable for DHC cultures, and our experience at Blocks G and I suggests that the design calculations underestimate the actual buffer values that would be needed.

- A sodium bicarbonate buffer would be delivered directly to the injection wells. Experience at Block G suggests that carbonate-scale precipitate severely affects injection-manifold instrumentation, and prevents increased buffer delivery. Direct placement of sodium bicarbonate was successfully tested at Block G, and no adverse effects were noted.

- Post-injection performance monitoring in Block E would be modified, with more emphasis on the monitoring locations in the center of the TCE plume. Specifically, we propose that additional monitoring wells, including the cluster designated on Figure 3-1 (SEMW-4I [intermediate-zone well] and MPE-1S [shallow zone well]), be included in the performance monitoring program.

Injections would be made on a rotating basis: substrate and buffer would be injected into one group of wells for a specified period, and the injection would then be switched to another group of wells. For more details on the injection quantities, timing, and rationale, see the *Block E Tracer Study Report* (Tetra Tech, 2016a).

This alternative would also include MNA and LUCs in Block F. This would include semiannual sampling of the monitoring wells in the block, and surface water sampling three times per year (April, June, and September). These sampling data would be used to determine the success of the remedy. If data indicate increasing TCE concentrations in Block F groundwater, or if the surface water concentrations exceed screening criteria, an active remedy in Block F might be required.

Alternative 1 is designed to directly reduce the TCE mass in the source area in Block E, and is expected to be effective in reaching this goal. ARD was successfully used to reduce the TCE mass in other MRC areas (in Blocks G and I), and this technique could be applied to Block E. An active remedy in Block F is not included in this alternative, because no surface water screening criteria have been exceeded, and, with the application of LUCs, no current risk to site workers or nearby residents would be posed.

The main advantages of Alternative 1 are that the remedy is already installed, approved by the regulators, and ready for immediate implementation. No additional capital costs would be required to apply the remedy as it has been installed and expanded to address the area immediately downgradient of the former location of UST 2. Reducing the TCE mass in Block E should eventually decrease the mass flux to the downgradient area of concern in Block F, thus reducing migration of TCE into Dark Head Cove. However, the time it takes for this to occur would be lengthy. Alternative 1 does not contain the TCE plume, and does not reduce TCE migration into Dark Head Cove in the short term. Additionally, the anaerobic environment created by ARD could generate vinyl chloride in Block E groundwater, which would create the potential for vinyl chloride migration into the Dark Head Cove.

#### 3.4.2.2 Alternative 2: Hydraulic Containment in Block F, Existing ARD in Block E, MNA/LUCs

Alternative 2 has three major components: (a) groundwater collection, (b) *ex situ* treatment and discharge of treated groundwater and vapors, and (c) operation of existing ARD in Block E. These components are described below.

***Component 1: groundwater collection*—**The groundwater collection component of this option would include two groundwater recovery wells installed in Block F to hydraulically contain the plume. Figure 3-2 shows the groundwater extraction-well locations (EW-1 and EW-2). The number and spacing of the extraction wells are based on the results of the July 2017 pumping test and groundwater modeling for Blocks F and E. Information on expected groundwater recovery rates and containment area is detailed in Section 4.2.2.

***Component 2: ex situ treatment and discharge of treated groundwater and vapors*—**Recovered groundwater would be conveyed via underground piping to a treatment system at Block E (see Figure 3-2). A road crossing would be required to bring existing piping from Block F to Block E. The treatment process will require surface water discharge via an NPDES permit. Treatment system components would be housed in a small, prefabricated enclosure at the location shown on Figure 3-2. The treatment train would consist of the following major components:

- shallow-tray air stripper to remove VOCs from groundwater
- filtration to remove suspended solids after air stripping

- liquid-phase granular activated carbon vessels (LGAC) to provide a final VOC polishing step before discharge to surface water (Dark Head Cove)
- vapor-phase granular activated carbon vessels (VGAC) to treat the air stripper exhaust

Treated groundwater would be discharged under an NPDES permit to Dark Head Cove through a submerged outfall; note that it may be determined, during system design, that discharge to the sanitary sewer (under a permit with Baltimore County) is preferred. In either case, treated groundwater discharge would be metered and routinely sampled to comply with the permit. Treated vapor would be discharged into the atmosphere and included in the general MRC facility air discharge permit. Treated vapors would be routinely sampled (monthly sampling is assumed) to comply with the MRC facility air discharge permit.

***Component 3: continue the existing ARD in Block E—***The existing ARD system in Block E would be operated as described in Alternative 1.

Alternative 2 is expected to be effective in reaching the stated RAOs with a high degree of reliability and at moderate costs. Groundwater extraction would achieve hydraulic containment (and mass reduction) of the TCE plume in Block F. Alternative 2 would rely on extensive and successful experience for treating contaminated groundwater and vapor in Block E, where the MPE system operated in 2014 and 2015 (Tetra Tech, 2016c). ARD technology has been applied successfully in Blocks G and I between 2014 and 2017, thus, implementing ARD in Block E is expected to effectively and efficiently reduce TCE mass.

A drawback of Alternative 2 would be the uncertain pumping duration at Block F that is necessary to maintain hydraulic control and prevent TCE discharge to Dark Head Cove. Even though operation and maintenance costs for a low-flow, relatively uncomplicated, groundwater treatment system are expected to be low, prolonged operation of a groundwater treatment system is generally undesirable. Long-term pumping in Block F might also increase COC migration toward Dark Head Cove as the pumping wells will draw contaminated water from upgradient areas.

#### 3.4.2.3 Alternative 3: Hydraulic Containment and PRB in Block F, Existing ARD in Block E, LUCs/MNA

Alternative 3 is similar to Alternative 2 as it also includes a PRB in the upgradient portion of Block F to enhance TCE plume containment and reduce the duration of groundwater extraction and treatment at Block F. Alternative 3 has four major components: (a) groundwater collection, (b) *ex situ* treatment and discharge of treated groundwater and vapors, (c) operation of existing ARD in Block E, and (d) installation of a PRB in Block F. Components 1, 2, and 3 are essentially the same as Alternative 2, and may be reviewed in the section above.

Several types of reactive media are available for use in PRBs. The selection of the treatment media depends primarily on the type of contaminants to be treated. Block F COC include TCE and its degradation byproducts *cis*-1,2-DCE and potentially vinyl chloride. Zero-valent iron (ZVI) is the reactive medium best suited for these COC. Site COC contacting ZVI will degrade to nontoxic end products (Gillham and O'Hannesin 1994) via an abiotic process that oxidizes (corrodes) the ZVI. This process induces highly reducing conditions that promote substitution of chloride atoms with hydrogen atoms in TCE, *cis*-1,2-DCE, and vinyl chloride molecules. Considerable industry experience applying ZVI to treat TCE exists. Therefore, ZVI would be used as the reactive medium in the PRB.

The PRB in Block F would be approximately 100 feet long by 30 feet deep, and would be installed into the clay layer. The PRB would be installed in the upgradient portion of Block F (see Figure 3-3) and would operate in combination with the Block F hydraulic-containment wells, such that contaminated groundwater would be pulled through the PRB by the downgradient extraction wells, thereby abiotically degrading upgradient COC in groundwater. Two main methods are commonly used to place reactive media within a PRB:

- One method is to excavate a trench and replace native soil with permeable reactive media. The trench for the PRB could be excavated by using a one-pass machine to quickly install a trench without the need for extensive dewatering, or by using trench boxes or sheet piles to stabilize the trench and limit the influx of groundwater during construction.

- Another method is to inject reactive media *in situ*, using a row of several closely placed temporary injection points or wells to create a treatment zone with uniform reactive media. This requires less intensive field work, but may not provide complete treatment due to uncertainties associated with ZVI placement.

PRB installation via a trench would be more expensive and have a higher environmental impact, as compared to installation via a series of injection points; excavated soil from the trench would also have to be transported and disposed of off-site, potentially as a hazardous waste. Additional concerns include fouling of the trench by silt, precipitated metals, and/or biological matter, which could obstruct groundwater pathways. Finally, a trench excavated close to Dark Head Cove could adversely affect surface water quality during construction. An advantage of trench installation is the larger quantity of reactive media that could be used, and potentially its longer treatment duration, as compared to PRBs installed via injection.

A less intensive installation with potentially better flow characteristics, and the ability to more easily develop a pilot approach for this application, make a PRB installed via injection preferable for Block F conditions; therefore, installation of the Alternative 3 PRB would be accomplished by injecting reactive ZVI media in a series of injection points installed via direct-push technology (DPT). The site’s proximity to Dark Head Cove raises special considerations for the injected ZVI medium to be used in Block F, as indicated below:

- The formation of TCE-degradation byproducts *cis*-1,2-DCE and, especially, vinyl chloride, is undesirable. Therefore, an abiotic degradation pathway, where TCE is degraded directly to ethene, would be preferred, and the biotic degradation of TCE to *cis*-1,2-DCE and vinyl chloride should thus be minimized. Accordingly, a ZVI medium that does not contain a carbon substrate (which could enhance biological degradation) should be used.

- The injection of materials capable of migrating into Dark Head Cove and adversely affecting the surface water quality and visual characteristics should be avoided. One example of such materials is the vegetable oil used as an emulsion base in many ZVI formulations. The chosen ZVI material would need to be engineered as a water-based suspension specifically developed for subsurface injection; the use of thickeners or emulsifiers (e.g., guar gum or vegetable oil) to keep the ZVI particles in suspension is not required.

- The migration of dissolved iron from the ZVI PRB to the extraction wells is not desired as it may precipitate and clog the wells, pumps, and/or treatment equipment. Therefore, we recommend implementing and monitoring a small-scale PRB before full-scale implementation. This will also provide information on the most effective installation methods for full-scale implementation.

Alternative 3 is expected to effectively and reliably reach the stated RAOs, and the addition of a PRB to hydraulic containment would enhance both technologies. The ZVI PRB installed upgradient of the Block F extraction wells (see Figure 3-3) would establish a clean zone in Block F relatively quickly, because groundwater flow velocity across the PRB would be increased by pumping, and groundwater COC would be degraded before being pulled into the Block F pumping wells. The creation of this clean zone would allow pumping wells in Block F to be turned off earlier than without this treatment. If ZVI PRB treatment fails or performs poorly, the hydraulic containment wells in Block F would act as backup to prevent migration of TCE and its degradation byproducts into Dark Head Cove.

Alternative 3 would be readily implementable. The proposed location of the ZVI PRB is available, and no underground utilities cross the route. Groundwater COC not addressed by the extraction and ARD system (and migrating from Block E) would be removed by the ZVI PRB and hydraulic containment.

## 3.5 COMPARATIVE ANALYSIS OF ALTERNATIVES AND PROPOSED ALTERNATIVE

Three short-listed groundwater response-action alternatives were compared qualitatively and quantitatively. Both analytical approaches use the same evaluation criteria: the seven CERCLA criteria plus an eighth criterion: the lifecycle impacts of each alternative. As discussed above, this evaluation does not consider state acceptance or community acceptance; these criteria will be evaluated via community input and MDE approval, following submittal of the groundwater RAP addendum to MDE. Table 3-4 summarizes the qualitative analysis per CERCLA; *Criterium® DecisionPlus®* decision-tool software was used for the quantitative analysis (Table 3-5).

*Criterium® DecisionPlus®* allows weighting and ranking of decision-making criteria. The software then processes those data to calculate a score for each alternative. The eight evaluation criteria for the MRC were entered, followed by their assigned sub-criteria. Individual relative weights are then added to each criterion and/or sub-criterion; these weights represent their relative importance. Relative rankings (on a scale of zero–100) are assigned to each criterion and/or sub-criterion, and summed for each alternative. The weights, ranks, and results of this analysis are in Appendix C, and are summarized in Table 3-5. In *Criterium® DecisionPlus®*, higher scores indicate that the alternative is more highly ranked in that category.

A comparison of the selected alternatives based on the seven CERCLA criteria and lifecycle impacts is summarized below:

- ***protection of human health and the environment***—All three alternatives would meet this criterion, but Alternative 1 ranks lower in this category, because it does not contain the TCE plume in Block F, and does not reduce TCE mass flux toward Dark Head Cove in the short term. Although Alternative 1 is currently protective, it would provide the least assurance of continued protection. Alternative 3 is ranked slightly above Alternative 2 due to the additional protection provided via the PRB.

- ***compliance with ARARs and meets RAOs—***All three alternatives would meet these criteria, but Alternative 1 ranks lower in this category, because it does not actively reduce the mass in Block F and does not contain the TCE plume in Block F. Therefore, Alternative 1 does not actively address RAO 3. Alternative 3 is ranked higher than Alternative 2 because the PRB provides more active reductions in Block F TCE mass.

- ***long-term effectiveness and permanence—***The alternative featuring ZVI-based containment (Alternative 3) ranks highest in this category, because it would contain the TCE plume after hydraulic recovery wells have been shut down. Alternative 1 would provide the least long-term effectiveness.

- ***reduction of toxicity, mobility, or volume by treatment—***Alternative 3 ranks higher due to the expected effectiveness and timeliness of the contaminant reductions achieved. ZVI-based remedies would reduce contaminants to innocuous byproducts, rather than transferring contaminants to another medium, as would the *ex situ* treatment of Alternative 2.

- ***short-term effectiveness—***
  - Time to achieve RAOs - Alternatives featuring hydraulic recovery (Alternatives 2 and 3) rank much higher, because TCE plume containment in Block F and TCE mass recovery would be achieved once the system has begun operation.
  - Protect construction workers and minimize environmental impacts - Alternative 1 ranks highest in this category, because the amount of fieldwork (specifically, piping trench installation and system maintenance) would be significantly less than the fieldwork needed for Alternatives 2 and 3. Additionally, due to the simpler implementation, the potential for unintended consequences is reduced.
  - Protect community - Alternatives 2 and 3 would be equally protective of the community, whereas Alternative 1 ranks lower, because it does not prevent short-term migration of TCE into Dark Head Cove.
- ***implementability—***This criterion includes the ability to obtain approvals, constructability, availability of experts and technology, compatibility with existing remediation, and effectiveness in monitoring. Alternative 1 generally ranks highest in these categories, because it is the simplest remedy and the ARD system remedy is already in place and ready for implementation. Alternatives 2 and 3 would be easy to implement, because no major construction would be necessary.

- ***lifecycle impacts—***Alternative 1 has the lowest life cycle environmental impacts, because it lacks construction, operation, and maintenance of a groundwater extraction and treatment system. The life cycle environmental impacts of Alternatives 2 and 3 would be similar. Alternative 2 would have less intensive construction (due to the ZVI PRB included in Alternative 3), but Alternative 2 would have a more prolonged operation and maintenance period. Overall, Alternative 2 is expected to have a slightly lower environmental impact during its life cycle. A quantitative analysis of these impacts was not completed, so a sensitivity analysis was conducted to see if the highest-ranked remedy would change based on adjustment of the rankings for these alternatives. The sensitivity analysis indicates that adjustments in this category would not change the highest ranked alternatives. Therefore, a full impact analysis was not conducted, however is recommended during the pre-design phase to integrate sustainable remediation best management practices to mitigate environmental, community, and economic impacts during remedy implementation.

- ***cost—***Alternative 1 ranks highest (lowest cost) in this category, followed by Alternatives 2 and 3. The costs of Alternatives 2 and 3 are very similar.

The *Criterium*® *DecisionPlus*® scoring is as follows (higher scores indicate that the alternative is more highly ranked):

- Alternative 1—0.277
- Alternative 2—0.341
- Alternative 3—0.382

Alternative 3 was chosen in the qualitative analysis for several reasons. Most importantly, it protects human health and the environment, and complies with RAOs and ARARs. The use of a ZVI PRB in Block F would reduce the required duration of groundwater recovery. In the final comparison of the top two alternatives (Alternatives 2 and 3), the slightly lower cost of Alternative 2 does not outweigh the additional benefits associated with the addition of the PRB in Alternative 3. Thus, Alternative 3 was selected as the proposed groundwater response action at MRC Blocks E and F, based on both the qualitative and quantitative analyses.

# SECTION 4
# PROPOSED RESPONSE ACTION

This section describes the proposed remedial action, its conceptual design and the expected performance of its individual components, monitoring of its performance, implementation details and sequence, and system shut down criteria.

## 4.1 OVERVIEW OF THE CONCEPTUAL DESIGN AND IMPLEMENTATION OF THE PROPOSED RESPONSE ACTION

The conceptual design for the proposed groundwater response action at Blocks E and F at the Middle River Complex (MRC) under Alternative 3 entails hydraulic containment and creation of a zero-valent iron (ZVI) permeable reactive barrier (PRB) in Block F; groundwater collection and operation of the existing anaerobic reductive dechlorination (ARD) system in Block E; and the implementation of monitored natural attenuation (MNA) and the imposition of land use controls (LUCs). Figure 4-1 is a site plan presenting the layout and preliminary design of the proposed response action, and Figure 3-1 in the previous section includes a graphic of the existing ARD system. A summary of the conceptual design for Alternative 3 appears below. This proposed conceptual design might be altered once a more detailed design has been produced, and in response to any additional information and stakeholder comments obtained before implementation.

The final response-action design will be developed following approval of this groundwater response-action plan (RAP) addendum. The design will provide the final design basis for the response actions, details about the areas and volumes to be treated, final locations and designs for the groundwater extraction wells and ZVI PRB, and other details such as flow rates, piping locations, discharge piping, and treatment unit processes. The final design will also include the sampling protocol to be used to evaluate remedial performance in each treatment area, including groundwater and surface water monitoring.

## 4.2 GROUNDWATER COLLECTION

The groundwater collection components of the response action include using two existing groundwater recovery wells in Block F (EW-1 and EW-2); these wells were installed for use in pump testing in this area and have been shown to be adequate for groundwater containment. The number and locations of the extraction wells are based on preliminary groundwater modeling as described below.

### 4.2.1 Groundwater Model Set-Up and Calibration

A fine-grid finite-difference groundwater flow model was built to simulate the effects of pumping in Blocks F and E, and to determine the pumping requirements (number of wells and pumping rates) required to achieve hydraulic capture of the trichloroethene (TCE) plume. Note that this modeling effort was limited in scope, and was performed primarily for planning purposes. The software used for finite-difference groundwater modeling was *Groundwater Vistas* (Version 6.94, Build 10). The modeled area is approximately 500-feet wide by 1000-feet long, and includes both Block F and Block E (see Figure 4-2). The model uses a 46-degree rotation to approximately align with groundwater flow to Dark Head Cove.

Model grid cells vary from 50 feet by 50 feet along the model edges to three feet by six feet within the Block F and E areas. "Constant head" boundaries were set upgradient of the interpreted 1,000 micrograms per liter (µg/L) TCE plume (IWE-7 though IWE-12), and at the shoreline (including stilling well TPZ-1) of Dark Head Cove. A "general head" boundary was placed between the two "constant head" boundaries, approximately 25 feet upgradient of SEMW-7I. The "constant head" boundary condition at Dark Head Cove and the "general head" boundary condition near SEMW-7I are based on synoptic water levels observed during the July 2017 pumping test for EW-2. The upgradient "constant head" boundary condition is based on a projection of the hydraulic gradient observed between SEMW-7I and Dark Head Cove to this upgradient location, assuming the hydraulic gradient across the site is consistent.

A three-layer model was selected, based on a conceptual model of the geology at Blocks E and F (Figure 2-8). The upper two model layers represent silty sand, and the lower model layer represent a thin sand and gravel layer that was encountered in several locations in Block E and F. All model layers are assumed to be flat (consistent with observed site conditions and subsurface soil types).

Estimated hydraulic conductivity values were applied uniformly over the entire area for Layers 1 and 2. Hydraulic conductivity for Layer 3 is uniform over most of the area, except for a small area around PZ-2, where we infer that the gravel layer representing Layer 3 pinches out (this area was assigned the same hydraulic conductivity as Layer 2). A description of each model layer, and the hydraulic conductivity values that resulted in the best model calibration, are summarized below:

- ***Layer 1***
  - geology: upper sand and silt (low permeable)
  - top of Layer 1: 5 feet mean sea level (MSL)
  - bottom of Layer 1: -10 feet MSL
  - Layer 1 thickness: 15 feet
  - hydraulic conductivity: 0.5 feet/day
- ***Layer 2***
  - geology: lower silty sand (more permeable)
  - top of Layer 2: -10 feet MSL
  - bottom of Layer 2: -24 feet MSL
  - Layer 1 thickness: 14 feet
  - hydraulic conductivity: 2.5 feet/day
- ***Layer 3***
  - geology: sand and gravel
  - top of Layer 3: -24 feet MSL
  - bottom of Layer 3: -25 feet MSL
  - Layer 3 thickness: 1 foot
  - hydraulic conductivity: 375 feet/day

Note that the site layering and parameter values are consistent with the site-wide groundwater-modeling effort completed as part of the original groundwater RAP (Tetra Tech, 2012).

The finite-difference groundwater model was calibrated under both stressed (pumping) and non-stressed (non-pumping) conditions. Model calibration was emphasized under stressed conditions (pumping at EW-2), because the goal of creating the finite-difference model is to evaluate the number and extraction rates of site wells that would be required to achieve hydraulic capture of the TCE plume. Groundwater elevations recorded in seven observation wells during the July 2017 pumping tests were used during calibration to evaluate the finite-difference groundwater model. During calibration, hydraulic conductivities were varied (by trial and error) until a strong match between the finite-difference groundwater model and observation well data was observed. A summary of the model calibration results follows:

- EW-2 pumping at 4.3 gallons per minute (gpm)—July 14, 2017 at 7:56 a.m.—stressed (pumping)
  - residual mean close to zero (-0.04), absolute residual mean (0.10), 10% of observed head range (0.99 feet).
  - only one residual outside of the 10% target (SEMW-8S: model Layer 1)

Overall, model calibration is strong, and exhibits a good match between model calculated values and observation well data. Model calibration was verified with an additional stressed (pumping) condition (EW-1 pumping at 0.65 gpm on July 12, 2017 at 1:39 p.m.) and two non-stressed (non-pumping) scenarios (high tide and low tide on July 17, 2017). In general, model calibration in non-stressed conditions is good, though not as strong as under stressed conditions. Most noted variances occur in the Layer 1 observation wells. Overall, model calibration under both stressed and non-stressed conditions is adequate for preliminary well placement and required pumping rate estimates.

### 4.2.2 Recovery Well Configuration and Pumping Rates

We propose extracting groundwater using existing Block F wells EW-1 and EW-2 to capture the TCE plume in Block F. Wells EW-1 and EW-2 were used in the July 2017 pumping test, and sustained pumping rates measured during those tests (4.25 gpm for EW-2, and 0.5 gpm for EW-1) were used to simulate the effect of pumping in Block F in the model.

Groundwater modeling results indicate that wells EW-2 and EW-1 will achieve hydraulic capture of the TCE plume in Block F. Groundwater model particle tracking for Block F in Layers 2 and 3, (shown on Figures 4-3 and 4-4, respectively), indicates that the hydraulic capture associated with extraction well EW-2 would extend to the edge of Dark Head Cove, and would contain the plume's width in that area.

Potentiometric maps produced by the groundwater model Layers 2 and 3 under pumping conditions for Block F are shown on Figures 4-5 and 4-6, respectively. These preliminary results indicate that the proposed extraction wells would achieve hydraulic capture in Block F. However, more detailed groundwater modeling will be performed at the remedial design stage, and the final configuration of the recovery wells might be modified from the preliminary configuration presented in this document.

Existing recovery wells EW-1 and EW-2 are four inches in diameter, are installed to a depth of 30 feet below grade surface (bgs), and are screened between 15 and 30 feet bgs. Groundwater will be recovered using variable-speed electric submersible pumps, in combination with in-well level transducers. The pumps would be set to maintain a constant predetermined liquid level in the wells, thereby reducing groundwater level fluctuations, groundwater aeration, and precipitation of solids.

### 4.2.3 TCE Mass Discharge Evaluation

Calculations of TCE mass discharge rates have been performed across three transects at the site, using TCE concentrations across the plume, the hydraulic gradient measured in the monitoring wells, and the hydraulic conductivity values of different geological units in Block F, as determined by calibrating the groundwater model. The TCE-mass discharge calculations are in Table 4-1. The calculations for the three transects (A, B, and C as shown on Figure 4-7) were performed using the TCE concentrations from the direct-push technology (DPT) investigations completed during the 2017 investigations. The fourth calculation (a calculation based on existing wells, as shown in Table 4-1) was performed using the available monitoring and pumping wells within the TCE plume in Block F (SEMW-8S, -8I, 9S, -9I, EW-1, and EW-2). The purpose of the wells-based calculation is to provide data from reproducible locations to allow TCE mass discharge calculations during the remedy implementation, allowing changes in TCE mass discharge to be tracked.

It should be noted that the wells used for the wells-based calculation are not located on a straight line (Figure 4-7). A line perpendicular to the groundwater flow direction (light-green line on Figure 4-7) was selected as close as possible to the location of the wells used in this calculation. The TCE concentrations in these wells were projected onto this line and the groundwater flow along this 75-foot long line was estimated. Additionally, the TCE concentrations in wells EW-1 and EW-2 were collected during the July 2017 pumping test under pumping conditions. The wells-based calculation in Table 4-1 will be repeated when the TCE concentrations under static conditions become available (sampling planned for July 2018).

The TCE-mass discharge estimates for Transects A and B are the highest, and similar in magnitude (38 and 33 pounds per year, respectively). The wells-based calculated TCE-mass discharge is fairly similar to Transects A and B (approximately 26 pounds per year). The calculated TCE-mass discharge for Transect C (at the edge of Dark Head Cove) is an outlier at approximately nine pounds per year. This low value could be due to interaction of the TCE plume with the nearby surface water in Dark Head Cove. Overall, the TCE-mass discharge rates calculated for transects A and B and the wells-based estimate are within the same order of magnitude and can be used for an approximate quantitative assessment of TCE-mass migrating toward Dark Head Cove.

## 4.3 GROUNDWATER TREATMENT AND DISCHARGE

Recovered groundwater would be conveyed via underground piping to a common treatment system at Block E (Figure 4-1). A road crossing will be required to bring the piping from Block F to Block E. All underground piping carrying contaminated groundwater would be double-walled, high-density polyethylene (HDPE) pipe.

Once conveyed to the treatment system building, treatment via several unit processes will be required before discharging the treated water. The treatment building will be equipped with secondary containment; this is necessary because the recovered water will likely be considered a listed hazardous waste until treatment has reduced the TCE concentration to less than 5 micrograms per liter (µg/L). The treatment system will be designed to treat a maximum continuous flow rate of approximately 15 gpm, to allow for future system expansion if required. The actual expected flow of the treatment system with two extraction wells operating is below 5 gpm. The treatment process includes surface water discharge via a National Pollutant Discharge Elimination System (NPDES) permit. The treatment train will consist of the following major components:

- ***shallow-tray air stripper to remove volatile organic compounds (VOCs)—***Preliminary performance assessment of the air stripping process efficiency was assumed at a 10,000 µg/L maximum influent of TCE, 15 gpm flow, and a Carbonair STAT 80 shallow-tray air-stripper with the following tray dimensions: 48 inches long × 24 inches wide × 10 inches high. Theoretical calculations (55-degrees Fahrenheit groundwater temperature, ideal conditions) indicate a TCE effluent of 0.21 µg/L, when using four air stripper trays. However, 6 trays will be used to be more conservative.

- two bag filters (8.5-inch-diameter housing) to remove suspended solids.

- liquid-phase granular activated carbon vessels (LGAC) for VOC polishing before discharge to surface water (Dark Head Cove). Two vessels, each with 500 pounds of LGAC, are assumed, for cost estimation. The low level of influent VOCs to LGAC should allow the carbon to last several years before replacement is required. Used LGAC would not be listed as a hazardous waste, because concentrations of TCE entering the LGAC are expected to be less than 5 µg/L.

- ***vapor-phase granular activated carbon vessels (VGAC) to treat the air stripper exhaust—***Two vessels, each with 1,000 pounds of VGAC, are assumed, for cost estimation. The VGAC consumption is expected to be approximately 2,100 pounds for the first year of operation, based on the assumed influent groundwater conditions (5,000 µg/L of TCE, on average, for the first year, and 15 gpm), and 15% VGAC loading capacity. Influent VOC concentrations are expected to decrease over time, thus VGAC consumption is expected to decline. Used VGAC would be listed as a hazardous waste, due to contact with TCE associated with recovered site groundwater (which is currently considered to be a listed waste).

Treatment system components would be housed in a pre-fabricated enclosure approximately 12 feet wide by 30 feet long, as shown on Figure 4-1. A process flow diagram for the system is in Figure 4-8. Arrangement of treatment system equipment in the building is shown in Figure 4-9.

Treated groundwater would be discharged under an NPDES permit to Dark Head Cove via a 1.25-inch pipeline (approximately 270 feet from the treatment system) and through a submerged outfall. Discharge would be metered and sampled monthly, or as required, to comply with the NPDES permit. During previous operation of the multi-phase extraction (MPE) system, discharge to the sanitary sewer was permitted and successful; if discharge via NPDES for this remedy is not possible, or would require significant complications to the unit processes and treatment required, discharge to the sanitary sewer could be pursued. Trenching for discharge to the sanitary sewer at MRC would require significant capital, but might be more cost effective than, if the NPDES permit requires metals (for example) to be removed from the extracted groundwater. The final decision on the discharge location will be determined during the project design.

## 4.4 ZVI PRB

The ZVI PRB will be installed by injecting ZVI materials via DPT rig in a line perpendicular to the TCE plume in Block F, and would be constructed upgradient of extraction wells EW-1 and EW-2, as shown on Figure 4-1. The total length of the ZVI PRB will be approximately 100 feet. ZVI materials will be injected from the top of the groundwater table (approximately 5 feet bgs) to the top of the clay layer (approximately 30 feet bgs), as shown on Figure 4-10. The width of the TCE plume at this location is approximately 55 feet, and the ZVI PRB would therefore intercept the plume with a margin of safety. The ZVI PRB would operate in combination with hydraulic containment wells EW-1 and EW-2, such that contaminated groundwater would be pulled through the ZVI PRB by the downgradient extraction wells.

Several different ZVI-based formulations have been developed for direct injection into subsurface via DPT points. Some of these formulations contain emulsified vegetable oil (or other organic substrates) and ZVI particles suspended in the emulsion. Such formulations are intended to combine abiotic degradation of TCE (whereby TCE is transformed directly to innocuous components by ZVI) and ARD (whereby TCE is degraded to *cis*-1,2-DCE, vinyl chloride, and then ethene). The use of this latter approach is not recommended for the ZVI PRB in Block F, because injected oil or other substrates could migrate into Dark Head Cove and adversely affect surface water quality. Moreover, vinyl chloride (a daughter product of TCE biodegradation) might also be formed, and could potentially migrate into Dark Head Cove. Formation of vinyl chloride should be avoided, because its risk-based screening level in surface water is less than 1 µg/L.

We therefore recommend ZVI materials that contain no additional substances that could degrade or migrate into Dark Head Cove and adversely affect water quality. ZVI material with particles engineered specifically for direct injection into the subsurface, with no thickeners (e.g., guar gum) or emulsifiers (e.g., vegetable oil) is recommended. One example of such a ZVI formulation is Z-Loy™ AquaMetal ZVI, developed and distributed by OnMaterials, Inc. This formulation has a ZVI particle size of 2–3 micrometers (µm) that stay in suspension when mixed with water, without the use thickeners. To estimate cost, we assumed that Z-Loy™ AquaMetal ZVI would be used. However, other vendors might have similar ZVI formulations; those materials will be considered at the final design phase. The preliminary ZVI PRB design is based on the following key considerations:

- an estimate of ZVI demand by electron acceptors across the PRB (based on flux)
- injected ZVI material distribution and radius of influence
- manufacturer's dosing recommendations and prior experience

ZVI demand by electron acceptors is calculated in Table 4-2. The main electron acceptors for ZVI are TCE, dissolved oxygen, nitrates, and sulfates. The mass flux of each of these constituents is calculated separately for each geological layer, based on hydraulic conductivities estimated in the groundwater model, ZVI PRB length, hydraulic gradient in Block F, and concentration estimates of electron acceptors for each geological layer. The results of this estimate suggest that ZVI demand would be approximately 130 pounds per year.

This evaluation has many uncertainties, such as accounting for increased groundwater gradient during pumping. One of the main cost factors for a PRB barrier is the performance duration. This PRB application will require a ZVI formulation that stays in suspension in water without the use of any thickeners or emulsifiers due to concerns about releases in the vicinity Dark Head Cove. This requires the use of small iron particles which do not retain their performance as long as larger particles. Assuming that a conservative longevity for this type of ZVI PRB is five years, and applying a safety factor between five and 10, the total ZVI demand (based on electron acceptor flux) ranges from approximately 3,300 to 6,500 pounds (Table 4-2). This estimate (ZVI demand based on flux) was cross-checked using the manufacturer's dosing recommendations (based on a target *in situ* ZVI concentration) and a desired injected ZVI-material distribution based on displaced pore volume. The following parameters were used for this estimation:

- Z-Loy™ AquaMetal *in situ* dosing[2]: 15 grams per liter
- injection-points spacing: 5 feet
- injection overlap: 33% (all pore-volume displaced)
- radius of injected cylinder: 3.3 feet
- ZVI PRB length: 100 feet
- ZVI PRB saturated thickness: 25 feet

[2]The manufacturer recommends six to 15 grams of Z-Loy™ AquaMetal per liter of formation pore -volume (g/L).

- formation effective porosity: 25%

The results of this calculation suggest that approximately 4,300 pounds of Z-Loy™ AquaMetal, and approximately 34,000 gallons of dilution water would be required (see Table 4-3). The quantities of ZVI calculated by both methods (formation demand and target *in situ* concentration, see Tables 4-2 and 4-3, respectively) fall within the same range.

Selective deployment of this material will be considered during the remedy design. For example, higher dosages of ZVI might be needed in the high-permeability gravel layer and in areas of highest TCE contamination.

One unintended consequence of PRB installation could be the introduction of dissolved iron to the aquifer downgradient of the PRB. The migration of the dissolved iron to the extraction wells is not desired as it may precipitate and clog the wells, pumps, and/or treatment equipment. Therefore, we recommended small-scale testing using a 15- to 20-foot-wide PRB cell before full-scale implementation. The effectiveness of TCE removal for the small-scale PRB, and potential production of vinyl chloride, could then be monitored. Collection and analysis of groundwater samples for iron, both upgradient and downgradient of the PRB, and at the extraction wells, will also provide data on potential fouling and precipitation issues before full-scale PRB installation, and will provide information on the most effective installation methods for the full-scale PRB.

## 4.5 EXISTING ARD SYSTEM IN BLOCK E

As described in Sections 3.4.2.1 and 3.4.2.2, operation of the ARD system has been modified from its original design to reflect the more accurate delineation of the TCE plume in Blocks E and F, using data obtained during the additional investigations in 2016 and 2017 (Section 2.2). For example, recent sampling indicates low TCE concentrations (parts per billion levels) at the northernmost row of wells; therefore, the injection volumes in that area will be reduced. The goal of substrate injection into the northernmost row of injection wells is to create reducing conditions upgradient of the TCE source (i.e., former underground storage tank 2 [UST 2]). This would benefit downgradient ARD, as the water flowing into the treatment area would have reducing conditions. Additionally, the injection volumes and substrate concentrations in the most downgradient row of injection wells (wells IWE-22 through IWE-24; see Figure 4-1) would be reduced if the injected substrate is detected at elevated concentrations in hydraulic containment wells EW-1 and EW-2. This would be done because the organic substrate could interfere with the groundwater treatment system operation, and result in the treatment-system effluent negatively affecting groundwater quality.

Injection of higher substrate quantities in the nearby and downgradient (of UST 2) high concentration areas is also planned. Four converted MPE wells have been converted to injection wells (IWE-25 through IWE-28) for this purpose. The planned injection protocol is to provide higher volumes of substrate into these wells, and will be included in the final design.

ARD system operation in Block E will be coordinated with groundwater extraction in Blocks E and F. The ZVI PRB barrier is not expected to be negatively impacted by injected substrate.

Logistically, the first full-scale injection would consist of two injection phases, with a relatively short monitoring phase between them. The first injection at Block E is summarized as follows:

- The injection will proceed in a phased manner:
  - *Phase A injection* will inject the substrate solution and pH buffer, using the entire array of injection wells to enhance reductive dechlorination and create favorable bioaugmentation conditions.
  - *Monitoring phase*—the extent of biodegradation and if conditions favorable for bioaugmentation have been achieved will be determined over two to three months.
  - *Phase B injection*—bioaugmentation with *dehalococcoides* (DHC) cultures will be implemented. We expect that this will significantly accelerate TCE degradation in Block E, based on the success of bioaugmentation in Block G. The bioaugmentation approach developed for Blocks G and I will be used in Block E (Tetra Tech, 2016a).

    The sodium-lactate substrate dosage would be increased as compared to the original design values, as detailed in the *Block E Tracer Study Report* (Tetra Tech, 2016a), because current aerobic conditions must be overcome quickly to create conditions for bioaugmentation. The sodium bicarbonate dosage would also be increased as compared to the original design values detailed in the *Block E Tracer Study Report* Tetra Tech, 2016a), because current pH levels are lower than the levels favorable for DHC cultures. Our experience at Block G suggests that the prior design calculations underestimate the actual buffer values needed.

    Sodium bicarbonate buffer will be delivered directly to the injection wells. Our experience at Block G suggests that carbonate-scale precipitate severely affects injection-manifold instrumentation, and prevents increased buffer delivery. Direct placement of sodium bicarbonate was successfully tested at Block G, and no adverse effects were observed.

Injections will be made on a rotating basis: substrate solution will be injected in one group of wells for a specified period, and then the injection will be switched to another group of wells. More detail on the preliminary injection and performance monitoring protocol is in the *Block E Tracer Test Report* (Tetra Tech, 2016a). The final injection protocol, quantities, and performance monitoring plan will be presented in the remedial design for Blocks E and F, and in the amended operations and maintenance manual.

## 4.6 LAND USE CONTROLS

The Maryland Department of the Environment (MDE) will document land use controls applicable to the MRC property in the applicable No Further Action letter, which will be issued upon successful completion of soil remediation in each tax block. Each No Further Action letter will be filed in the local land use records and will be transmitted to subsequent property owners as part of the deed documentation. MDE regards all land use controls as existing in perpetuity, unless the related environmental covenants are eliminated or modified by mutual consent of the stakeholders. MDE will present certain environmental covenants as part of the No Further Action documentation. The environmental covenants will provide stakeholders with legal standing to enforce the covenants. MDE will determine the final disposition of any land use controls.

Land use controls might include the following:

- prohibiting the use of groundwater beneath the property for any purpose
- requirements to implement sub-slab soil vapor mitigation technology beneath all buildings where and to the extent that the potential for soil vapor intrusion to indoor air exists. For new-footprint buildings, the vapor mitigation system might, for example, consist of slotted polyvinyl chloride tubing arranged in such a manner as to passively exhaust soil vapors from beneath the building slab to the atmosphere. Any passive vent system would be required to be readily convertible to an active remedial system, if necessary. Other acceptable remedial alternatives are also available. Regardless of remedial choice, indoor air would need to be tested before building occupancy, and concentrations of any detected contaminant(s) must not exceed applicable indoor air standards.

These land use controls will apply to the entire tax block where they are applied, and not just to smaller portions of the block, as agreed to by MDE and Lockheed Martin.

## 4.7 SEQUENCE OF REMEDY IMPLEMENTATION

The proposed remedy for Blocks E and F has several active remedial components: groundwater collection to achieve hydraulic control in Block F a ZVI PRB in Block F, and ARD system operation in Block E. These components are interdependent, and will be implemented in the sequence summarized below:

- Groundwater collection, treatment, discharge infrastructure, and additional monitoring points will be installed. This would include installation of well pumps, collection and discharge piping, treatment system components, and other related elements.
- Baseline groundwater monitoring will then be completed.
- Groundwater extraction will begin immediately after the baseline groundwater monitoring, and after all associated permits and approvals have been received. Priority will be given to first establishing hydraulic control in Block F by starting groundwater extraction from EW-1 and EW-2.
- Water will be treated via air stripping and LGAC before being discharged to surface water under an NPDES permit. That water will be considered hazardous waste, and subject to double-containment until the TCE concentration has been reduced to less than 5 μg/L.
- Next, the effects of pumping (e.g., area of the capture zone, mass flux) in Block F will be evaluated and the design and placement of the ZVI PRB in Block F will be refined (if necessary), including sampling extracted groundwater, monitoring wells, and surface water. This step will be used to optimize pumping performance, and to ensure that the ZVI PRB is placed appropriately to maximize TCE mass removal.
- The ZVI PRB test cell will then be installed several months after the hydraulic control system has begun operations; the efficacy of the PRB will be monitored over a period of up to one year.
- The ZVI PRB will then be installed, as was generally described in Section 4.4, and modified based on the data obtained from the installation and monitoring of the test cell. Monitoring of the ZVI PRB performance will be done upgradient of the PRB and in the clean zone created downgradient of the PRB.
- The first ARD injection will then be completed, ARD performance in Block E will be evaluated, and recommendations for follow-up injections will be developed. ARD injections may be completed immediately following the installation of the PRB test cell.
- ZVI PRB performance monitoring will continue, along with monitoring of groundwater concentrations and mass flux in Block F, and surface water concentrations. Operation of the Block F extraction wells will ultimately be discontinued, as described in Section 4.8.

- In both Blocks E and F, performance monitoring/MNA will continue for two years following the completion of active remediation. At that end of that period, if the project goals have been met, a Response Action Completion Report will be submitted. Following approval of that report, groundwater sampling in Blocks E and F will be conducted under the site-wide groundwater monitoring plan.

## 4.8 PERFORMANCE MONITORING AND SHUTDOWN CRITERIA

Monitoring the performance of the response action will be required, including the following:

- Sampling treatment system discharge for parameters required by the permit. Currently, the preferred discharge option is under an NPDES permit; however, sanitary sewer discharge should also be considered during the system design. Additional sampling of the influent from each extraction well, of overall system influent, and after each unit process will also be done monthly during initial system operation, and quarterly thereafter, to determine the effectiveness of the groundwater extraction and treatment.

- Surface water sampling per established protocols will be done three times annually.

- In addition to the groundwater extraction-system influent and extraction well sampling detailed above, semiannual samples will also be collected from Block F monitoring wells SEMW-8S, -8I, 9S, 9I, piezometers PZ-1 and PZ-2, and the new deep well in Block F.

- Groundwater-levels in Block F monitoring wells and piezometers will be periodically measured to confirm groundwater capture and provide additional calibration data for the site groundwater model. If necessary, adjustments to groundwater pumping rates will be made based on these data.

- Two monitoring wells (SEMW-10S and -10I) will be installed downgradient of the ZVI PRB. These wells, and SEMW-7I (installed upgradient of the PRB), will be sampled before PRB installation, quarterly during the first year of operation to monitor for possible TCE degradation byproducts and increases in dissolved iron concentrations, and semiannually thereafter.

- Sampling associated with the Block E ARD will be generally carried out as detailed in the *Block E Tracer Study Report* (Tetra Tech, 2016a), and those data will be analyzed as detailed in that report and in the *Groundwater Response Action Plan* (Tetra Tech, 2012). These documents discuss the sampling, analysis, and responses to such data. As noted in Section 3.4.2.1, additional monitoring of wells SEMW-4I and MPE-1S will be included in the performance monitoring program. The complete performance monitoring plan will be developed during the design phase; ARD shut down criteria are discussed below.

- Following active remediation (ARD and groundwater extraction), sampling of surface water and monitoring wells near Dark Head Cove will be continued for two years. At the end of that period, if the project goals have been met, a Response Action Completion Report will be submitted. Following approval of that report, groundwater and surface water sampling in Blocks E and F will be conducted under the site-wide groundwater/surface water monitoring plan.

For the containment system, sampling of treatment system effluent will be the primary measure of treatment system effectiveness. The system is designed conservatively, to ensure that the expected discharge requirements can be met. However, if requirements are not met (or the results indicate that they might not be met in the future), the system will be shut down and modified to ensure that discharge criteria are met. Similarly, if sampling throughout the system indicates that any individual unit process is not operating properly, troubleshooting of the unit process will begin and appropriate modifications made.

In Blocks E and F, the results of sampling associated with the ARD, ZVI PRB, and groundwater extraction system will be used to determine the effectiveness of the remedy. That data will also be used to determine when the groundwater extraction can be discontinued, as described below.

No quantitative criteria are currently recommended for shutdown of the groundwater extraction system and discontinuation of ARD injections. As data is gathered from the operation of the system and Block F monitoring wells, Block E ARD, and ZVI PRB monitoring, shutdown criteria will be developed. The following outlines the data to be collected and the general approach in the development of the shutdown criteria:

- The groundwater extraction system can be considered for shutdown when discharge of TCE and its degradation products in Block F has been reduced sufficiently such that the concentrations in Dark Head Cove will continue to be in compliance with surface water screening levels; as well as when the plume is determined to be either stable or retracting. The following data will be collected over a one-year period to assist in this evaluation:

    - Performance of continuous water level monitoring to evaluate hydraulic gradients, tidal influence of groundwater levels, and discharge/recharge relationship of the groundwater/surface water system; and

    - Performance of passive flux meter sample collection to measure cumulative groundwater and contaminant fluxes.

  The results will be used, in conjunction with seepage velocity, retardation rates, degradation rates and advective flow, to evaluate the attenuation capacity of the aquifer from the source area throughout the footprint of the plume present in Blocks E and F. Collectively, this mass discharge assessment, including the attenuation capacity assessment, will be used to determine when contaminant mass and mass discharge have been sufficiently reduced such that contaminants are attenuated and pose no risk to receptors, i.e. achievement of RAOs, without active treatment. This will be used to develop the decision criteria for when to commence shutdown of active treatment(s).

- In addition to the actions above, cross-sections and three-dimensional views of the groundwater-surface water interface will be completed to better understand TCE migration and potential discharge to Dark Head Cove., supporting development of a numeric TCE mass discharge criteria for system shutdown.

- The TCE mass removal rate through groundwater extraction will be monitored. We are currently developing a mathematical model to estimate the dissolved phase TCE recovery based on the current groundwater conditions, as well as an estimate of future matrix back-diffusion from the low permeability zones in Block F. These calculations will be presented in the system design and will be modified based on operational data to help determine TCE mass discharge rates and estimate when the extraction system will reach its goals. As the TCE removal rate approaches asymptotic behavior or the TCE mass discharge criteria is reached, the extraction system would be shut down, and groundwater concentrations will be monitored for rebound. Several iterations of shutdown and re-start may be necessary to meet final shutdown criteria.

- Wells in Block F will be monitored to ensure that groundwater capture is occurring and to determine if site concentrations have been sufficiently reduced to meet mass discharge criteria. Trends will also be monitored to determine if the plume is expanding, contracting, or stable; the system will likely have to continue running if the plume is expanding. System shutdown criteria will need to be re-evaluated if vinyl chloride is detected in monitoring wells or in recovered groundwater, because of its presumed low risk-based action level in Dark Head Cove surface water.

- Because the RAO specifies that groundwater discharge containing chemical of concern concentrations that would cause an exceedance of the MDE ambient water quality criteria or risk-based swimming criteria in Dark Head Cove is prevented, surface water sampling results will be a key metric for system shutdown. If exceedances of risk-based criteria exist, system operation will continue and will likely be enhanced. If decreased concentration trends in surface water are observed and the criteria above are met, the system could be shut down.

- For the ARD implementation, the performance monitoring will be the primary mechanism for determining if additional injections are necessary. The general performance monitoring protocol are included above and in previous documents (Tetra Tech, 2012; 2016a). This protocol will be detailed in the system design and operation and maintenance documents. The specific criteria for discontinuing the injections will be detailed in future documents and will be based on allowable mass discharge rates to meet all RAOs as described above.

More site data will be available as the design is completed and operation begins. At that time, the shutdown criteria for groundwater extraction will be developed and submitted to the MDE for approval.

## 4.9 PERMIT REQUIREMENTS

Lockheed Martin will meet federal, state, and local permitting requirements for the proposed groundwater response action. Permitting requirements for the proposed response action relate to installation of infrastructure and *in situ* groundwater treatment, as determined by a review of United States Environmental Protection Agency, MDE, and Baltimore County Department of Environmental Protection and Natural Resources Groundwater Management requirements. Permits that are potentially required to deploy the response action include:

- NPDES permit
- A Baltimore County grading permit for any land disturbance and grading that disturbs more than 5,000 square feet, or more than 100 cubic yards of fill material, will likely not be required. Grading plans will be submitted to Baltimore County for their review and approval. As a condition of receiving a grading permit, a stormwater management plan would be submitted to Baltimore County for review and approval. The stormwater management plan will be prepared to comply with the *Maryland Storm Water Design Manual, Volumes I and II*, including the 2009 revisions and subsequent supplements.
- An erosion and sediment control plan will be submitted, to be reviewed by the Baltimore County Soil Conservation District. Baltimore County will coordinate review of these plans with the Critical Areas Commission.
- If necessary, a joint application will be submitted to MDE, since the project will disturb land within the Chesapeake Bay Critical Area. This information is circulated to various offices within MDE, including tidal and nontidal wetlands divisions, and to the U.S. Army Corp of Engineers.
- MDE and Baltimore County well construction permits.
- Baltimore County building permits for the treatment system enclosure, if required.
- Injecting chemicals into groundwater is regulated by the MDE Underground Injection Control Program. Information on the proposed nature and type of injection well operation to install the ZVI PRB will be submitted to the MDE Groundwater Permits Division for a determination of requirements.
- If adjustments or contingences to the initial system are required, additional permits might be required.
- Permits will be required with Baltimore County to install piping beneath Chesapeake Park Plaza.

## 4.10 CONTINGENCY MEASURES

Several contingency measures will be built into the design and implementation of the response action for Blocks E and F:

- If the Block F hydraulic containment system fails to adequately address migration of the TCE plume, then the following contingency measures could be implemented:
  - Additional extraction wells could be installed in Block F. The final design will include spare piping and conduits to connect the additional wells to the treatment system, to avoid new trenching.
  - The PRB treatment system could be expanded to include more ZVI injection points within Block F.
- In case of inadequate PRB performance and subsequent TCE migration toward Dark Head Cove, the following contingency measures could be implemented:
  - The hydraulic containment system in Block F (extraction wells EW-1 and EW-2) could be re-activated and continue to operate as needed to prevent COC migration into Dark Head Cove.
  - PRB failure analysis would be performed, and the means to restore the PRB effectiveness could be evaluated. For example, the PRB effectiveness could be restored by using additional ZVI injection locations and intervals in the failed locations, by using a different type of ZVI media, by using a different ZVI placement method and/or injecting ZVI media in other locations.
- If the ARD system in Block E and/or the containment system in Block F do not address particularly difficult-to-remedy locations (persistent “hot spots”) deemed necessary to reach RAOs, then thermal treatment technology could be implemented to reach RAOs in such locations. The selection of the thermal technology used would depend on the size and location of the targeted areas. For example, electric resistance heating (ERH) could be more cost-effective if a relatively large area needs to be treated, because the economics of ERH favor application in a larger area due to a significant one-time investment for a new dedicated power line. Thermal conduction heating (TCH) or steam-enhanced extraction (SEE) could be similarly more cost-effective for smaller areas, because fuels such as liquefied propane could be used to generate and deliver heat to the subsurface more economically in a smaller area. Alternatively, lower temperature heating could be implemented in conjunction with the existing infrastructure to enhance the ARD.
- If the ARD system in Block E fails to meet TCE mass reduction criteria, then one or more of the following contingency measures could be implemented (more detail on ARD contingencies is in the groundwater RAP [Tetra Tech, 2012]):

- Adjusting substrate injection rates and volumes, or the mass of substrate injection, or injection of dechlorinating bacteria cultures and/or pH buffering solutions.
- Installing additional injection wells in the recalcitrant locations, including possible additional rows of injection wells.
- Installing extraction wells in Block E to aid in amendments distribution and/or to manage the groundwater flow pattern to aid ARD functionality.
- Varying the type of substrate and other amendments used for ARD.

- If land use controls are not being effectively implemented, the implementation plan could be revised to increase inspections and/or expand the awareness program.

The need for contingency measures will be continuously evaluated using data received, and will be reviewed formally every three years, or when site conditions change significantly.

# SECTION 5
# REFERENCES


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# FIGURES

**Figure 1-1 Middle River Complex Location Map**

**Figure 1-2 Middle River Complex Tax Blocks**

**Figure 2-1 Block E and F Groundwater TCE Plume**

**Figure 2-2 Block F Current Conditions**

**Figure 2-3 Analytes Detected in Surface Water Samples, December 2016**

**Figure 2-4 Analytes Detected in Shallow and Deep Surface Water Samples near the Groundwater Remedy Area, April 2017**

**Figure 2-5 Analytes Detected in Shallow and Deep Surface Water Samples near the Groundwater Remedy Area, June 2017**

**Figure 2-6 Analytes Detected in Shallow and Deep Surface Water Samples near the Groundwater Remedy Area, September 2017**

**Figure 2-7 Block E and F Cross-Section Location**

**Figure 2-8 Cross-Section A–A'**

**Figure 2-9 Potentiometric Map—January 2017**

**Figure 2-10 Off-Site Monitoring Wells Sampled in 2016**

**Figure 3-1 Blocks E and F RAP Addendum, Alternative 1—Existing ARD in Block E**

**Figure 3-2 Blocks E and F RAP Addendum, Alternative 2—Groundwater Extraction, PRB in Block F, and ARD in Block E**

**Figure 3-3 Blocks E and F RAP Addendum, Alternative 3—Groundwater Extraction, PRB in Block F, and Existing ARD in Block E**

**Figure 4-1 Blocks E and F RAP Addendum, Selected Remedy—Groundwater Extraction, ZVI Curtain in Block F, and Existing ARD in Block E**

**Figure 4-2 Groundwater Model Grid**

**Figure 4-3 MRC Blocks E and F Particle Tracking for Model Layer 2**

**Figure 4-4 MRC Blocks E and F Particle Tracking for Model Layer 3**

**Figure 4-5 MRC Blocks E and F Potentiometric Map for Model Layer 2 under Pumping Conditions**

**Figure 4-6 MRC Blocks E and F Potentiometric Map for Model Layer under Pumping Conditions**

**Figure 4-7 Block F Mass Flux Transects Locations**

## Figure 4-8 Groundwater Treatment System Process Flow Diagram

## Figure 4-9 Groundwater Treatment System Equipment Layout

## Figure 4-10 Block F ZVI Curtain Illustration

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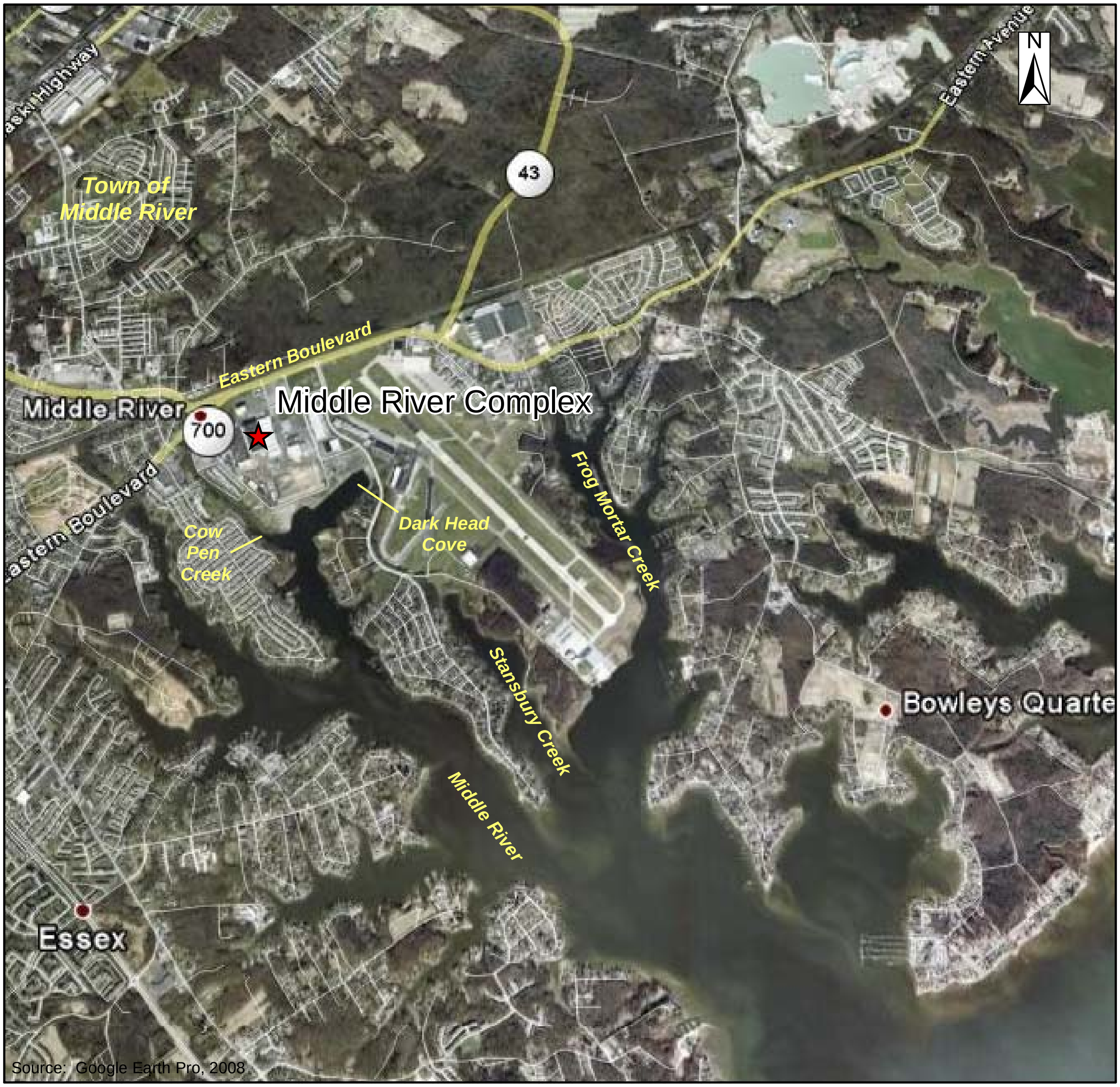


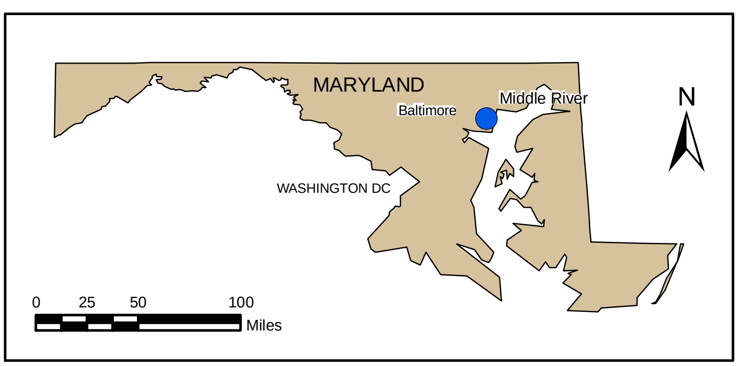


**Figure 1-1**

**Middle River Complex Location Map**

***Lockheed Martin Middle River Complex***
***Middle River, Maryland***

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**Tetra Tech, Inc.**


**FIGURE 1-2**

**MIDDLE RIVER COMPLEX**
**SITE LAYOUT AND TAX BLOCKS**

**LEGEND**

MIDDLE RIVER COMPLEX TAX BLOCK BOUNDARY

STRUCTURE

RAILROAD TRACKS

***Lockheed Martin Middle River Complex***
***Middle River, Maryland***

0 150 300 600 Feet

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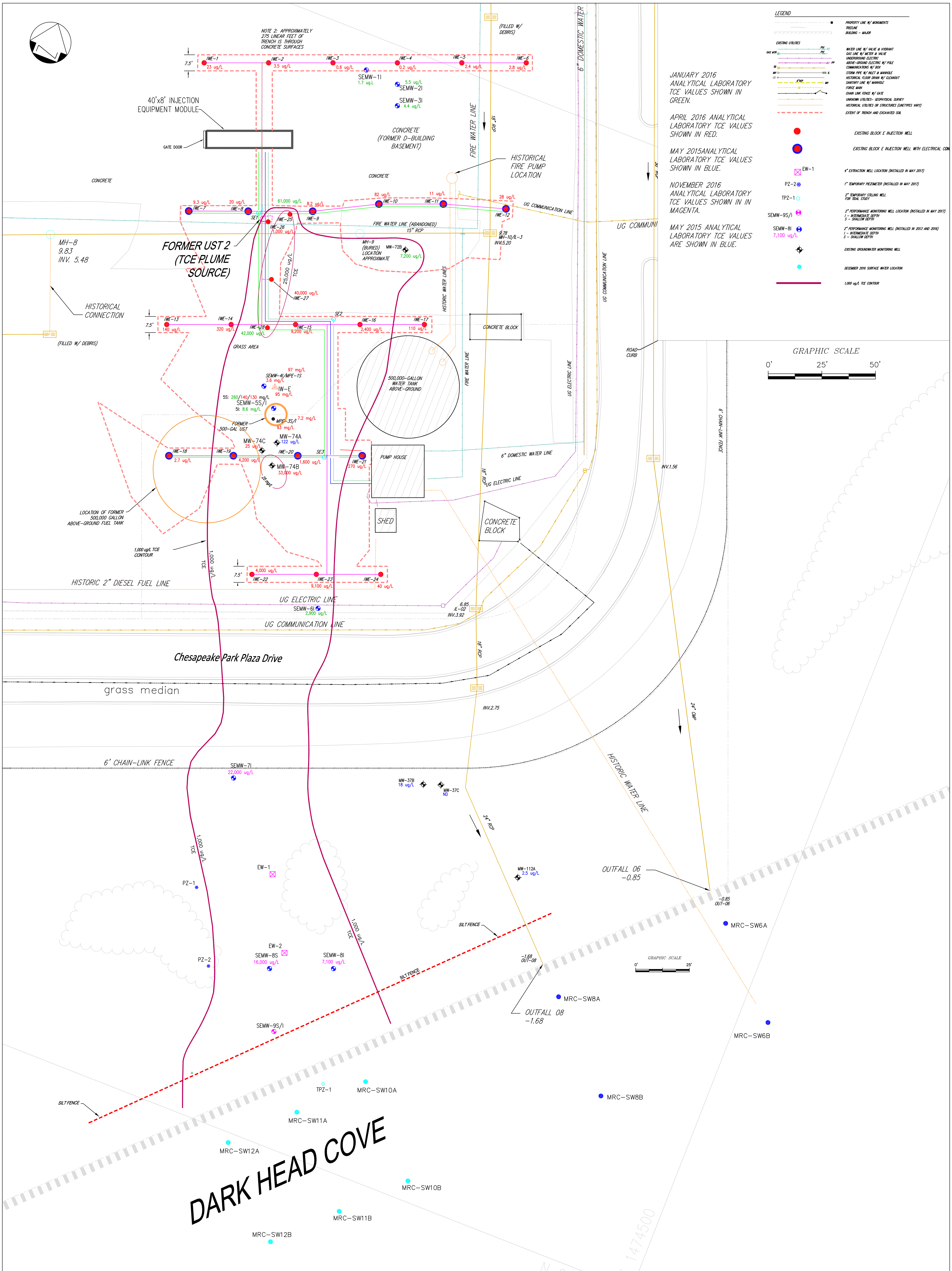


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2. SURVEYED LOCATIONS OF UNDERGROUND ELECTRIC, WATER, COMMUNICATION LINES, ARE BASED ON GEOPHYSICAL SURVEYS CONDUCTED BY ENVIROSCAN, INC. LANCASTER, PA, AND UNKNOWN FEATURES.
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6. BACKGROUND BASEMAP AND PROPERTY LINES ARE FROM CHESAPEAKE PARK SITE PLAN - LMC PROPERTIES, INC PREPARED BY TAI CONSULTING ENGINEERS, DATED 4/15/01. BACKGROUND DATA IS NOT FIELD VERIFIED AND FOR REFERENCE ONLY.

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BLOCKS E AND F GROUNDWATER TCE PLUME
BLOCKS E AND F RAP ADDENDUM

LOCKHEED MARTIN CORPORATION
MIDDLE RIVER COMPLEX, MIDDLE RIVER, MARYLAND

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**FIGURE 2-1**

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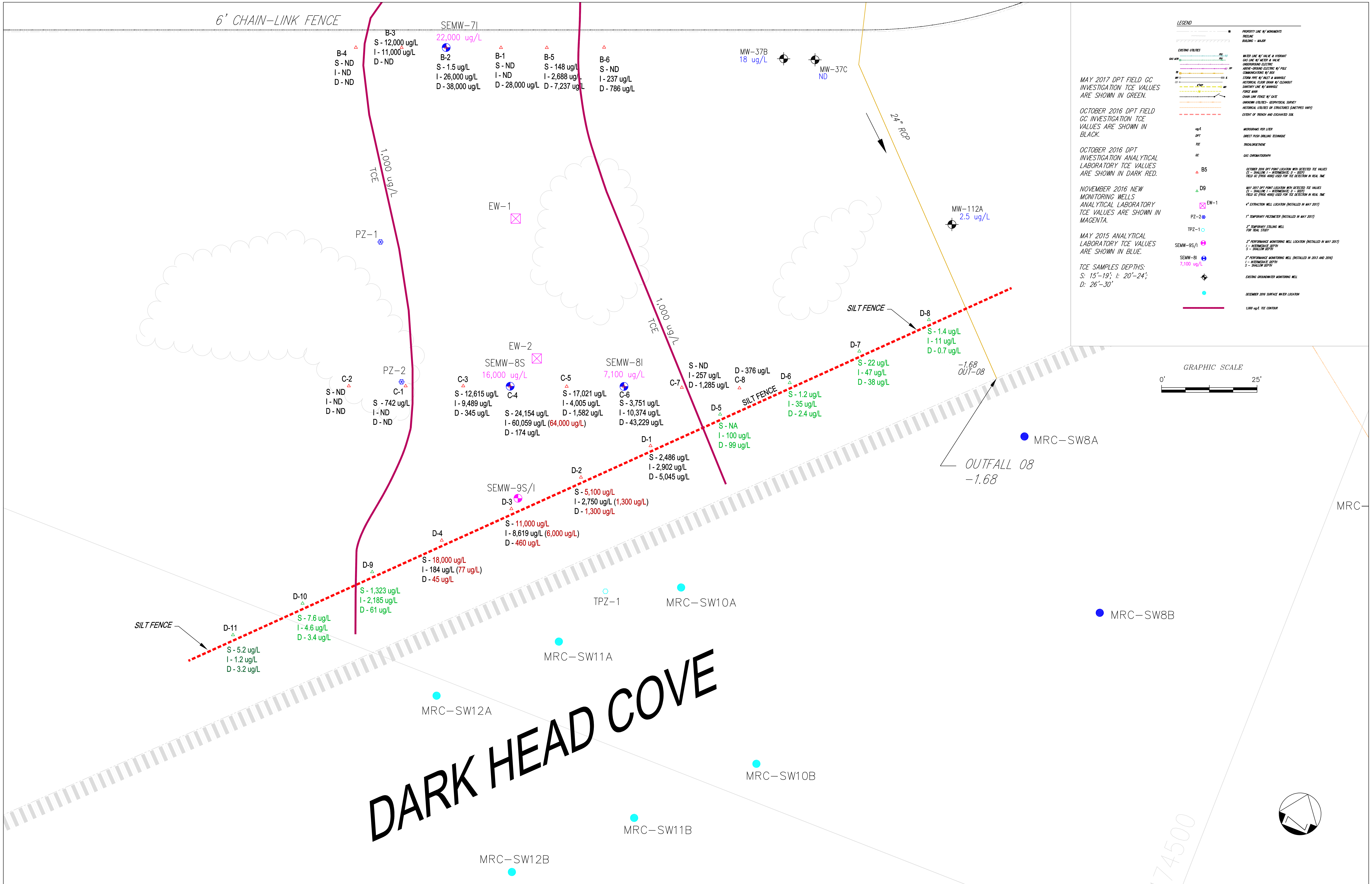


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BLOCK F CURRENT CONDITIONS
BLOCKS E AND F RAP ADDENDUM

LOCKHEED MARTIN CORPORATION
MIDDLE RIVER COMPLEX, MIDDLE RIVER, MARYLAND

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**FIGURE 2-2**

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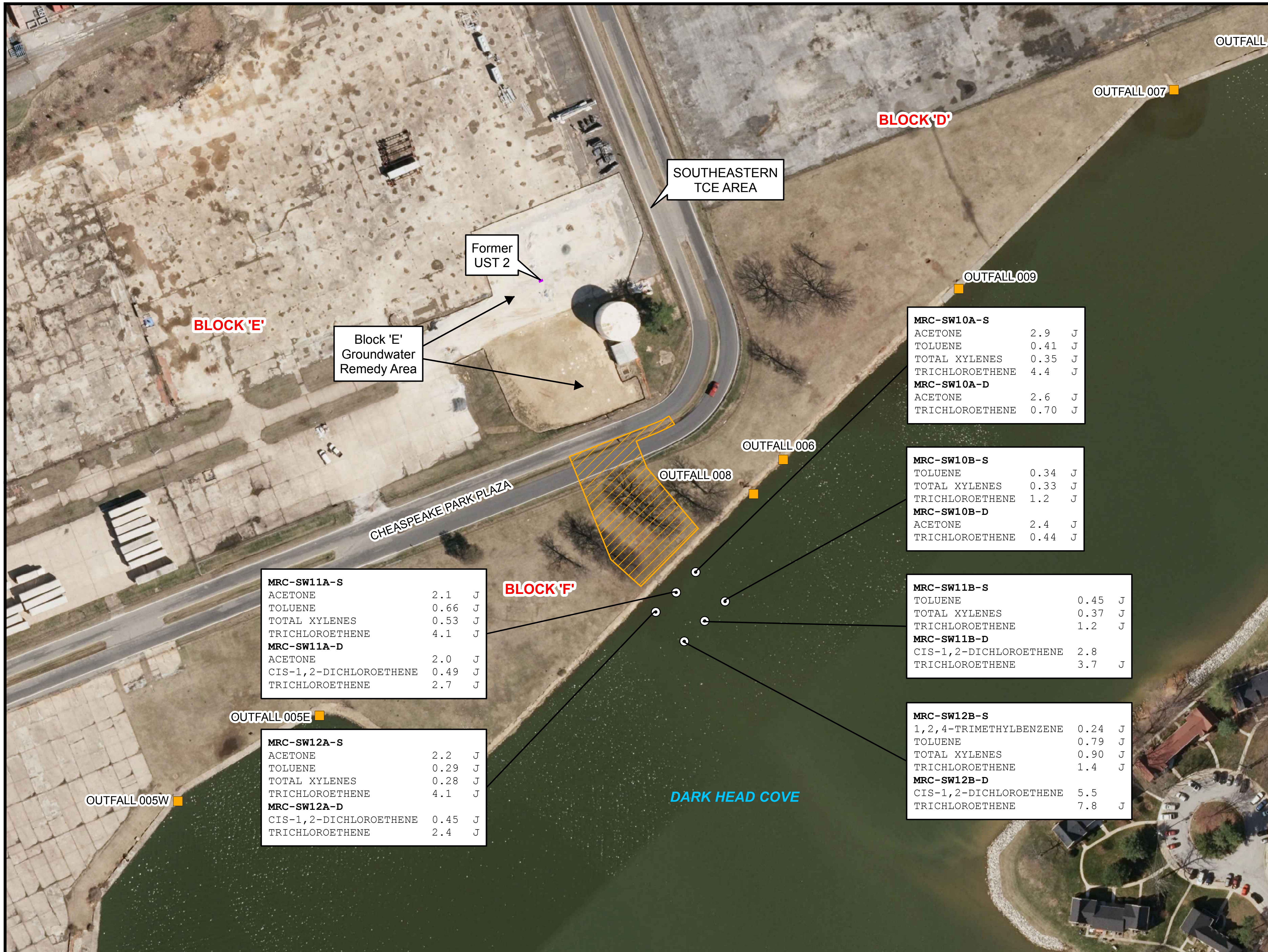


**FIGURE 2-3**

**ANALYTES DETECTED IN SURFACE WATER SAMPLES, DECEMBER 2016 DARK HEAD COVE**

**LEGEND**

- SURFACE WATER SAMPLE LOCATION
- AREA OF PROBE GROUNDWATER SAMPLING, OCTOBER 2016
- STORMWATER OUTFALL LOCATION (UPDATED APRIL 2015)

J = ESTIMATED VALUE.
UST = UNDERGROUND STORAGE TANK.
ALL CONCENTRATIONS SHOWN ARE IN MICROGRAMS PER LITER (µg/L).

SAMPLES COLLECTED DECEMBER 13, 2016.
2014 AERIAL PHOTOGRAPH PROVIDED BY U.S. GEOLOGICAL SURVEY.

***Lockheed Martin Middle River Complex***
***Middle River, Maryland***

0 62.5 125 Feet

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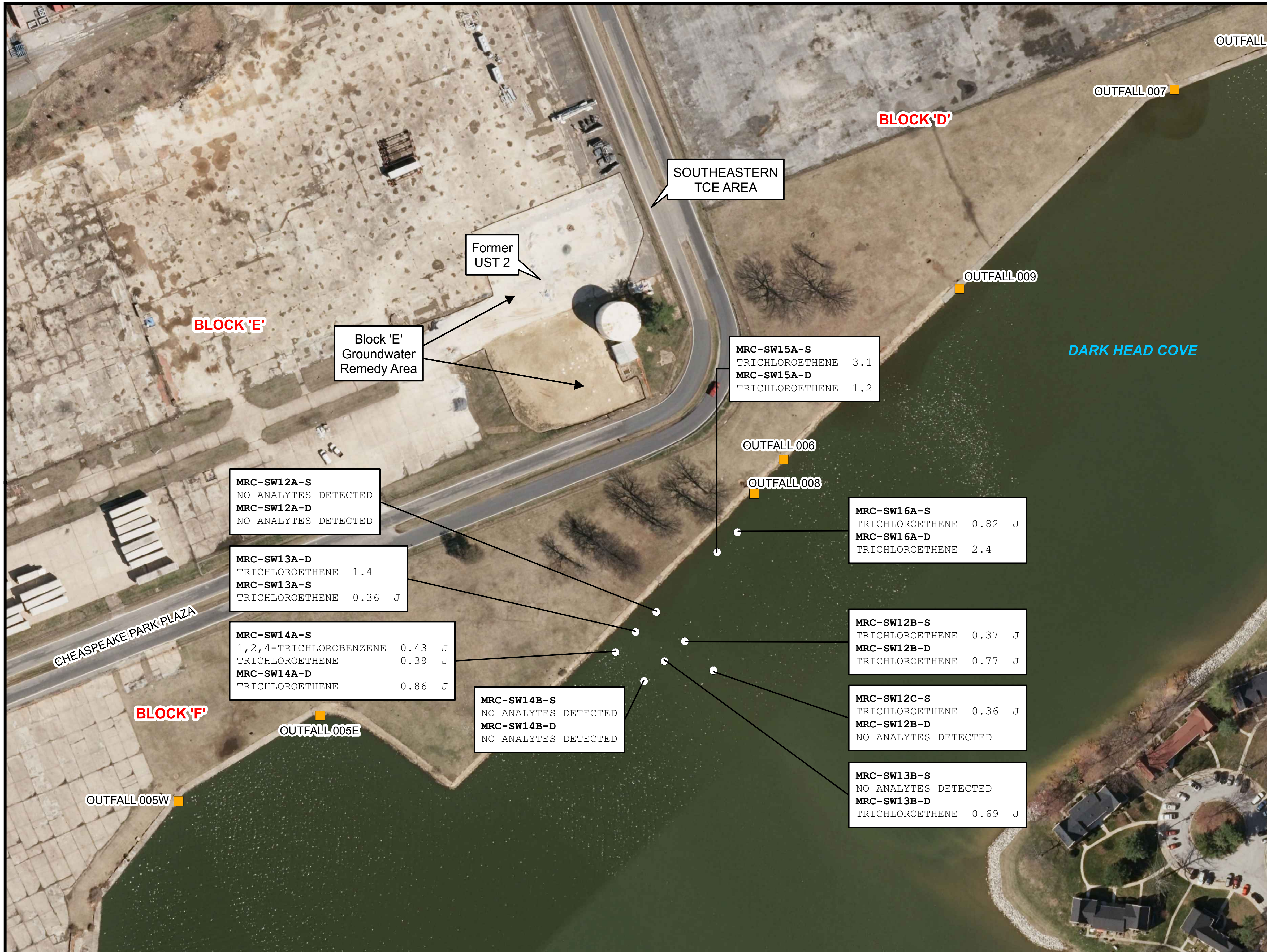


**FIGURE 2-4**

**ANALYTES DETECTED IN SHALLOW AND DEEP SURFACE WATER SAMPLES NEAR GROUNDWATER REMEDY AREA, APRIL 2017 DARK HEAD COVE**

**LEGEND**

○ SHALLOW (S) AND DEEP (D) SURFACE WATER SAMPLE LOCATION, APRIL 2017

■ STORMWATER OUTFALL LOCATION (UPDATED APRIL 2015)

J = ESTIMATED VALUE.
VOCs = VOLATILE ORGANIC COMPOUNDS.
ALL CONCENTRATIONS SHOWN ARE IN MICROGRAMS PER LITER (µg/L).

SAMPLES COLLECTED APRIL 10, 2017.
2014 AERIAL PHOTOGRAPH PROVIDED BY U.S. GEOLOGICAL SURVEY.

*Lockheed Martin Middle River Complex*
*Middle River, Maryland*

0 62.5 125 Feet

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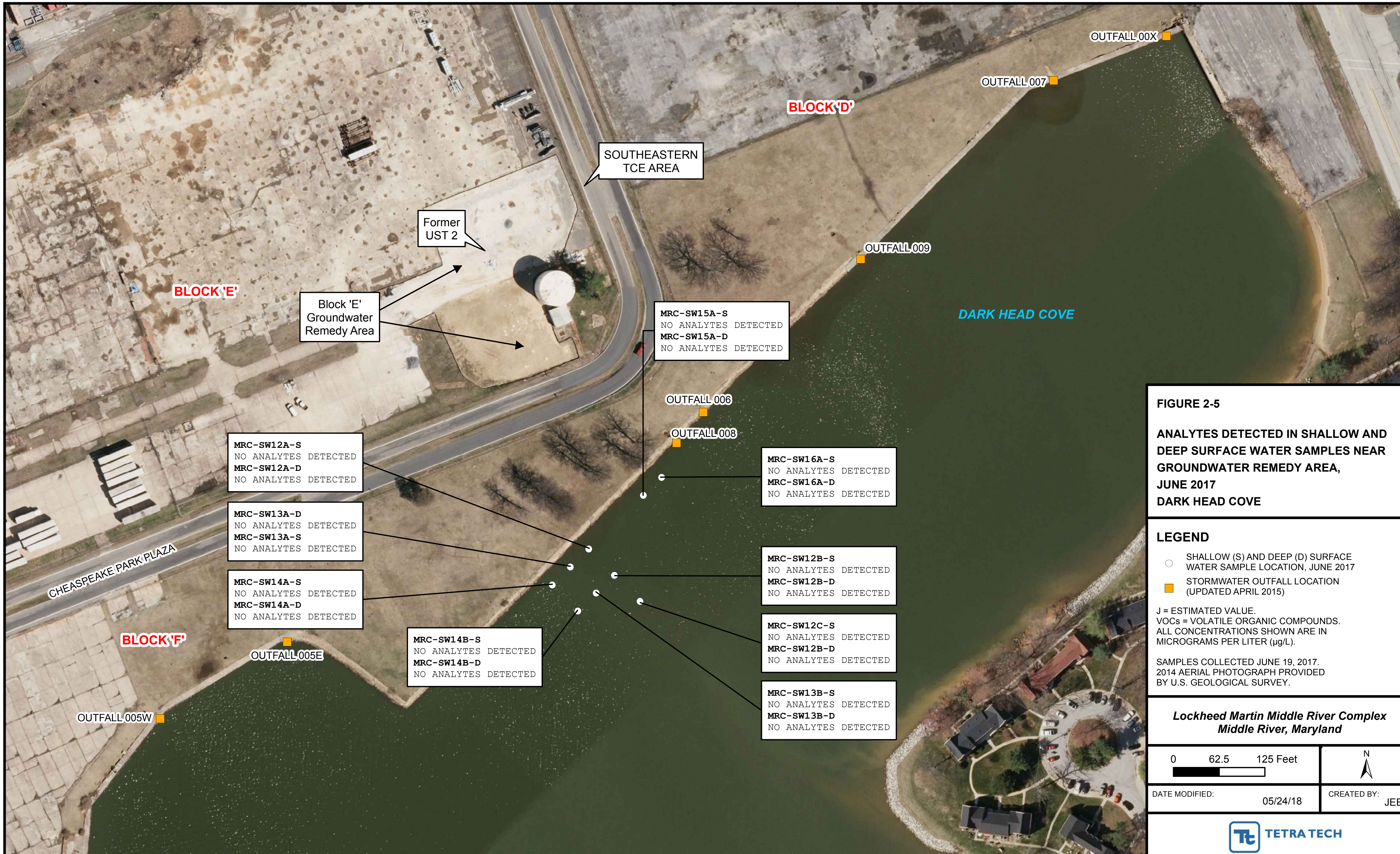


FIGURE 2-5

ANALYTES DETECTED IN SHALLOW AND DEEP SURFACE WATER SAMPLES NEAR GROUNDWATER REMEDY AREA, JUNE 2017 DARK HEAD COVE

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**FIGURE 2-6**

**ANALYTES DETECTED IN SHALLOW SURFACE WATER SAMPLES NEAR GROUNDWATER REMEDY AREA, SEPTEMBER 2017 DARK HEAD COVE**

**LEGEND**

SHALLOW (S) SURFACE WATER SAMPLE LOCATION, SEPTEMBER 2017

STORMWATER OUTFALL LOCATION (UPDATED APRIL 2015)

J = ESTIMATED VALUE.
VOCs = VOLATILE ORGANIC COMPOUNDS.
ALL CONCENTRATIONS SHOWN ARE IN MICROGRAMS PER LITER (µg/L).

SAMPLES COLLECTED SEPTEMBER 12, 2017.
2014 AERIAL PHOTOGRAPH PROVIDED BY U.S. GEOLOGICAL SURVEY.

*Lockheed Martin Middle River Complex*
*Middle River, Maryland*

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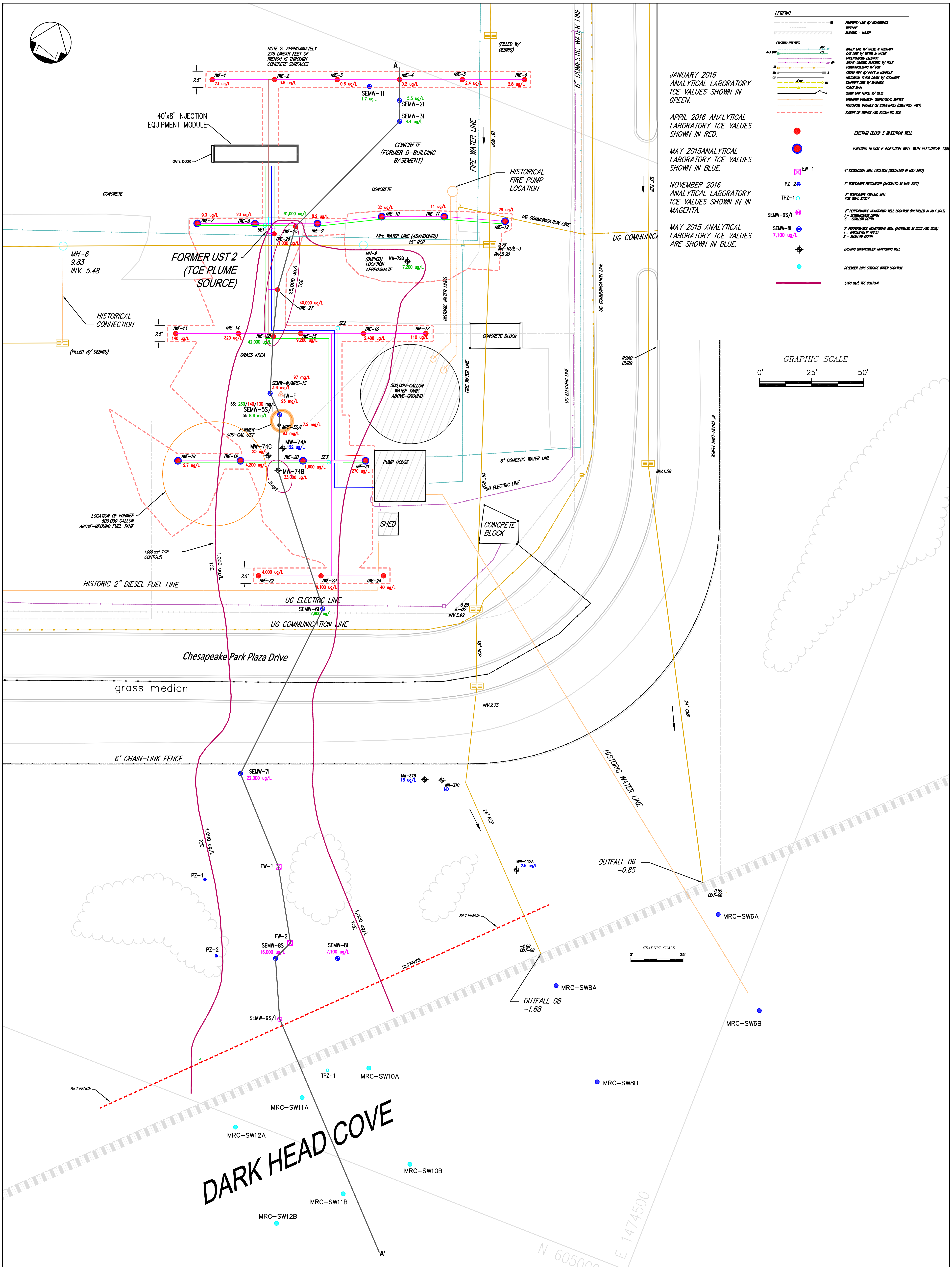


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CROSS-SECTION A-A' LOCATION

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**FIGURE 2-7**

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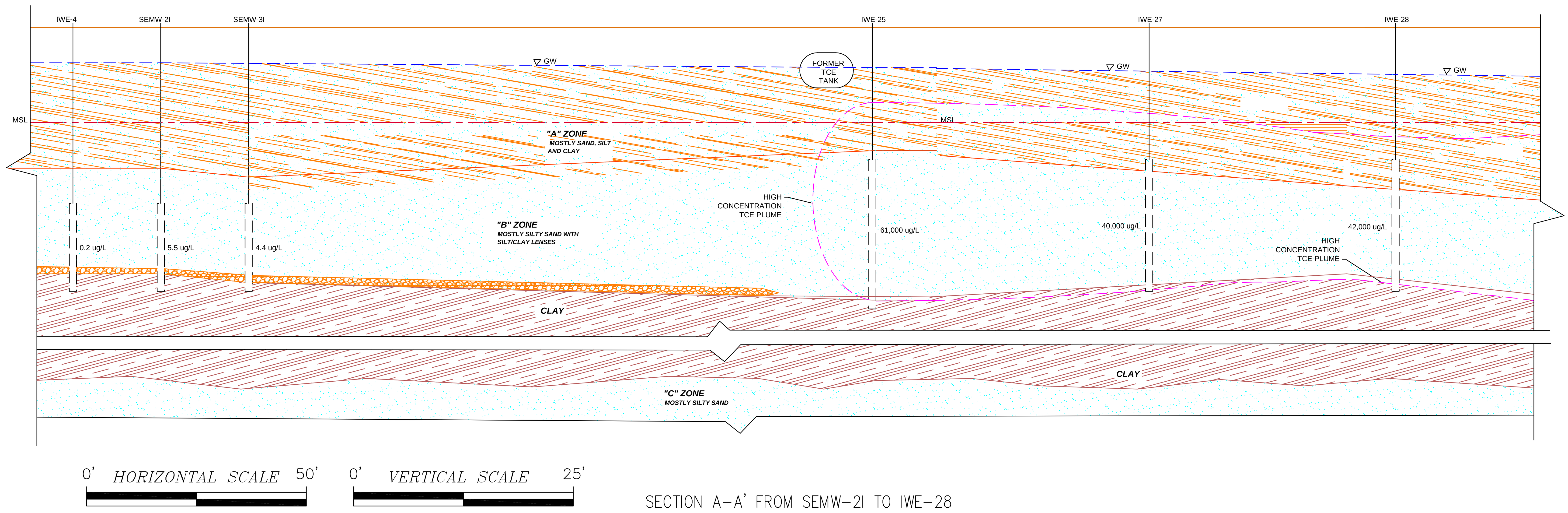
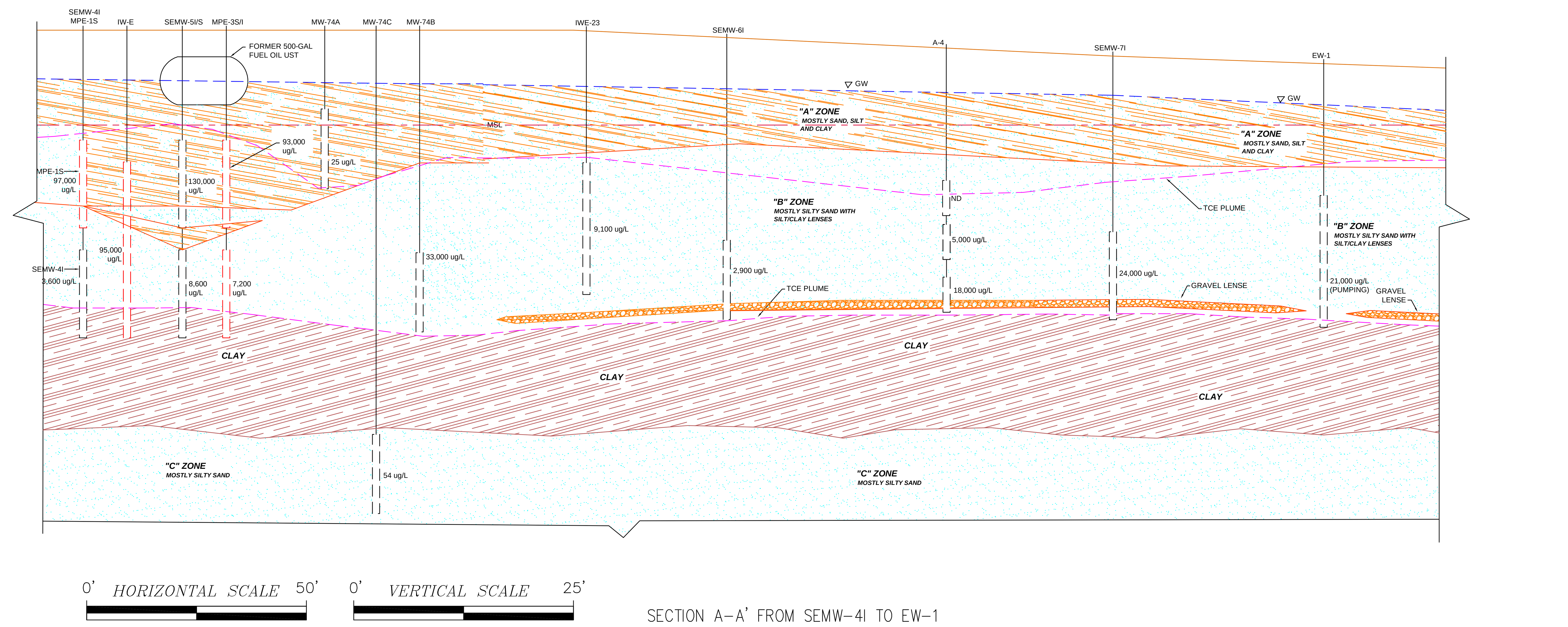
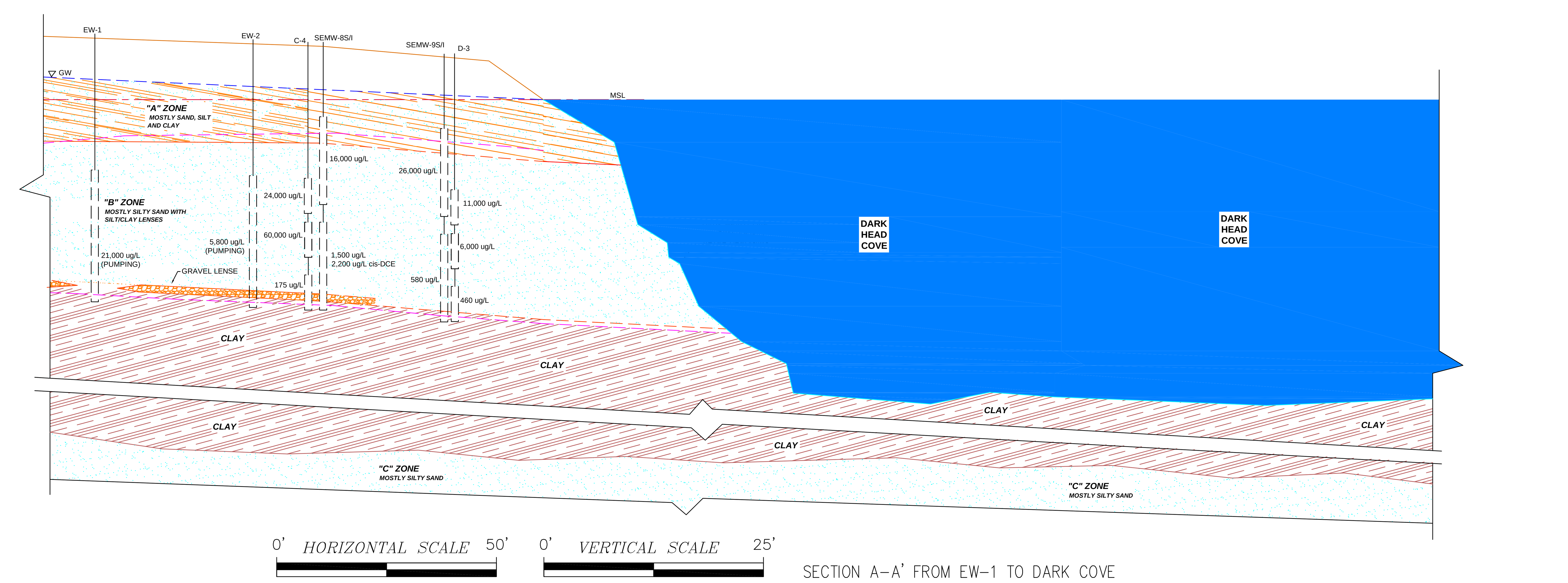



SECTION A-A' FROM SEMW-2I TO IWE-28




SECTION A-A' FROM SEMW-4I TO EW-1




SECTION A-A' FROM EW-1 TO DARK COVE

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CROSS-SECTION A-A'

LOCKHEED MARTIN CORPORATION
MIDDLE RIVER COMPLEX, MIDDLE RIVER, MARYLAND

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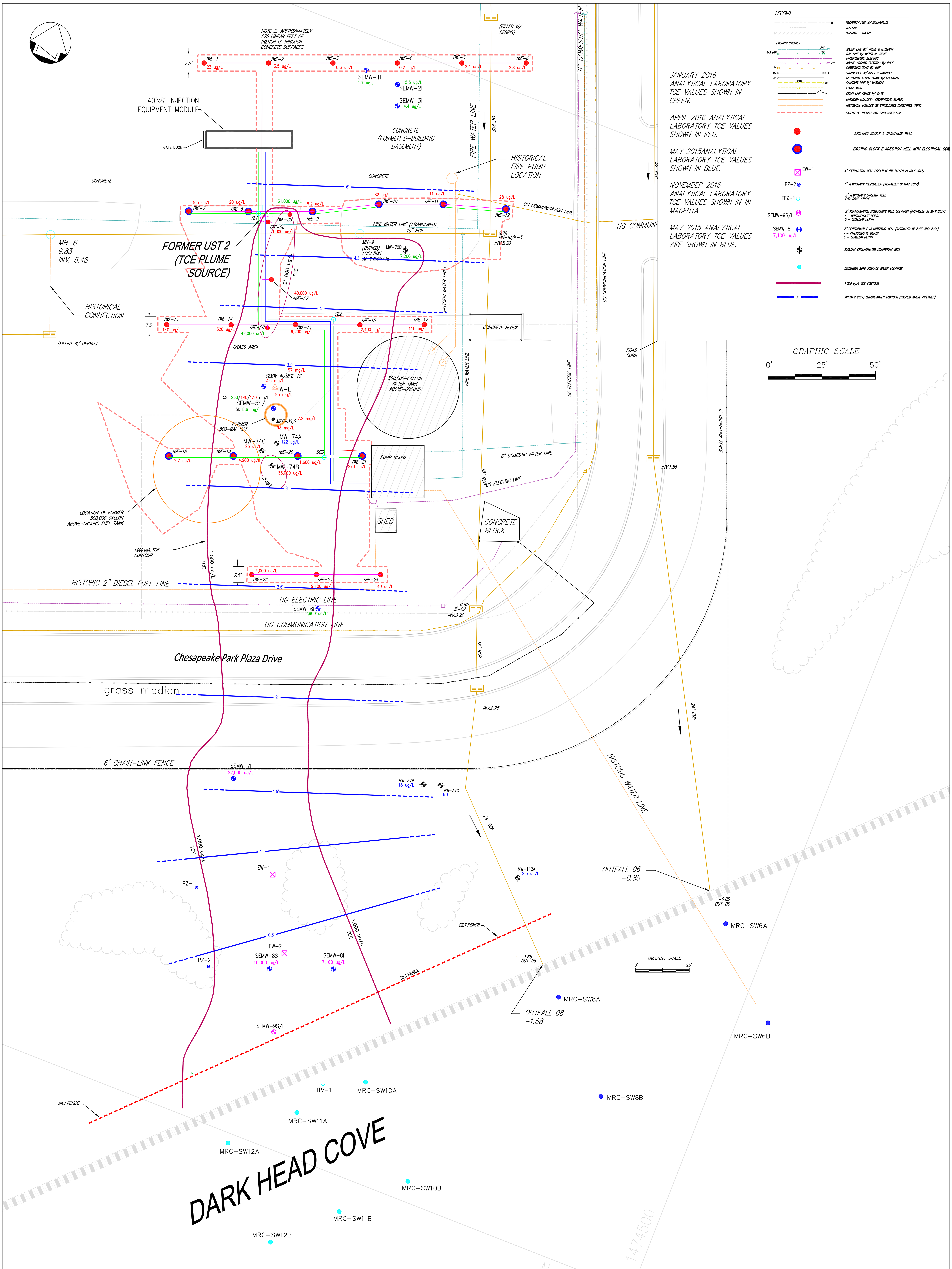
| DATE: | 6/19/18 |
| PROJECT NO.: | 112IC03835 |
| DWG. SIZE: | ARCH A |
| DRAWN BY: | RJD |
| CHECKED BY: | RB |



**FIGURE 2-8**

C:\USERS\BORIS.DYNKIN\DOCUMENTS\LMC MRC\BLOVK F ALTERNATIVES EVALUATION\RAP ADDENDUM\CAD FIGURES\FIGURE 2-8 CCROSS SECTIONS_DHC.DWG DWM 6/19/18

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POTENTIOMETRIC MAP – JANUARY 2017

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MIDDLE RIVER COMPLEX, MIDDLE RIVER, MARYLAND

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| DRAWING SIZE: | ARCH E |
| DRAWN BY: | DWM |
| CHECKED BY: | BD |



**FIGURE 2-9**

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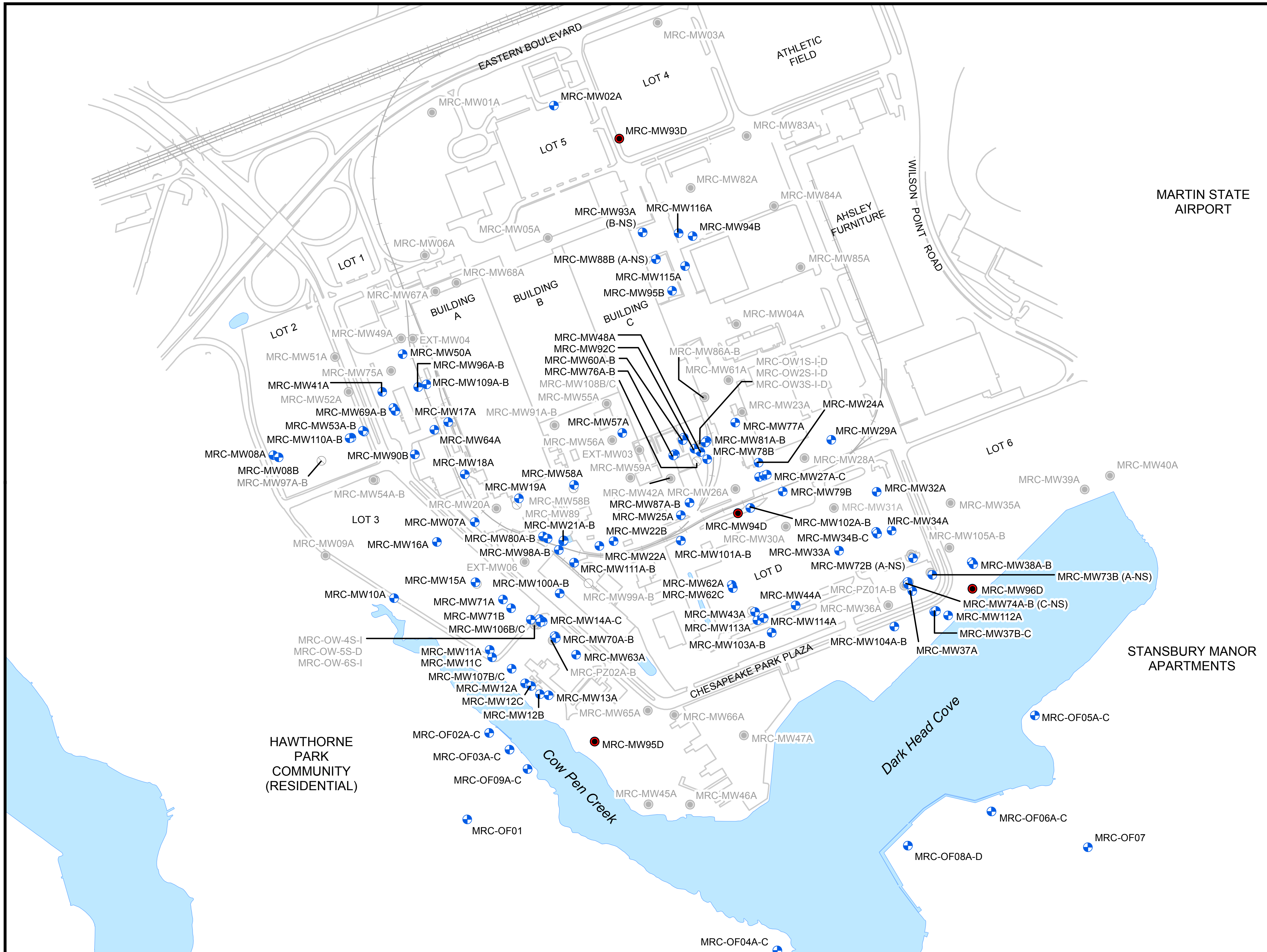


**FIGURE 2-10**

**OFF-SITE MONITORING WELLS SAMPLED IN 2016**

**LEGEND**

- SURFICIAL AQUIFER GROUNDWATER MONITORING WELL (SAMPLED)
- DEEP CONFINED AQUIFER GROUNDWATER MONITORING WELL (SAMPLED)
- WELL NOT TO BE SAMPLED
- ABANDONED WELL BORING
- SURFACE WATER

NS = NOT TO BE SAMPLED
(FOR OBSCURED WELL SYMBOLS)

***Lockheed Martin Middle River Complex***
***Middle River, Maryland***

0 225 450 Feet

N

DATE MODIFIED: 08/01/16

CREATED BY: JEE

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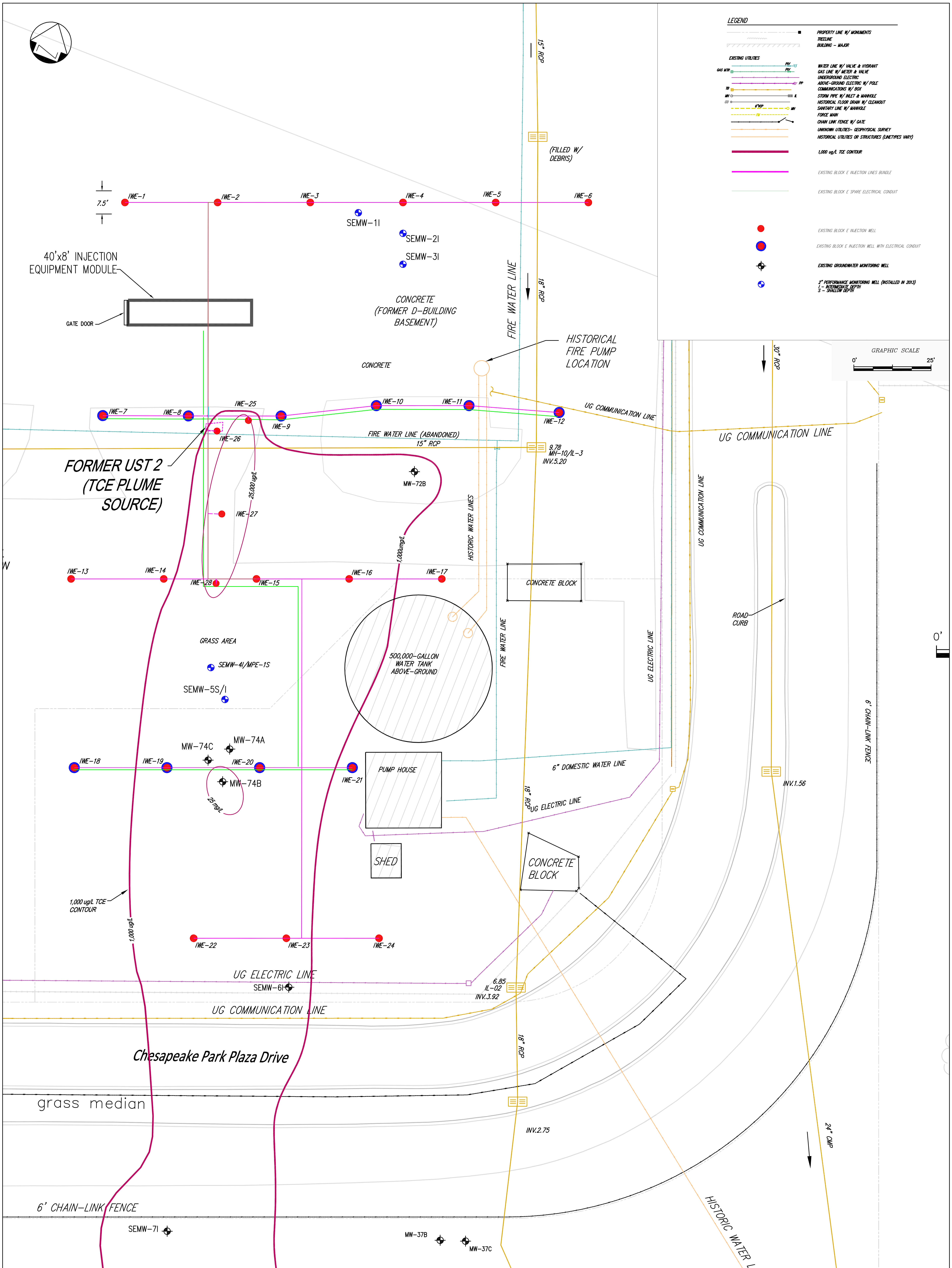
Map Document: (P:\GIS\Middle_River\MapDocs\MXD\middle_river_gw_locs_2016.mxd)
08/01/16 -- JEE




**REFERENCE PLANS & DATA:**

1. UTILITY CROSS CONNECTION SURVEY PERFORMED BY TETRA TECH CREW: RAB & AN, DATED 10/6,10/10 & 10/11/2011
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5. PRE-CONSTRUCTION SURVEY OF STORM DRAIN LINES FOR BLOCK E PREPARED BY TETRA TECH CREW: RAB & AN, DATED 08/15 & 08/16/ 2011.
6. BACKGROUND BASEMAP AND PROPERTY LINES ARE FROM CHESAPEAKE PARK SITE PLAN - LMC PROPERTIES, INC PREPARED BY TAI CONSULTING ENGINEERS, DATED 4/15/01. BACKGROUND DATA IS NOT FIELD VERIFIED AND FOR REFERENCE ONLY.

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ALTERNATIVE 1 – EXISTING ARD IN BLOCK E

LOCKHEED MARTIN CORPORATION
MIDDLE RIVER COMPLEX, MIDDLE RIVER, MARYLAND

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|---|---|
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| DRAWING SIZE: | ARCH C |
| DRAWN BY: | DWM |
| CHECKED BY: | BD |



**FIGURE 3-1**

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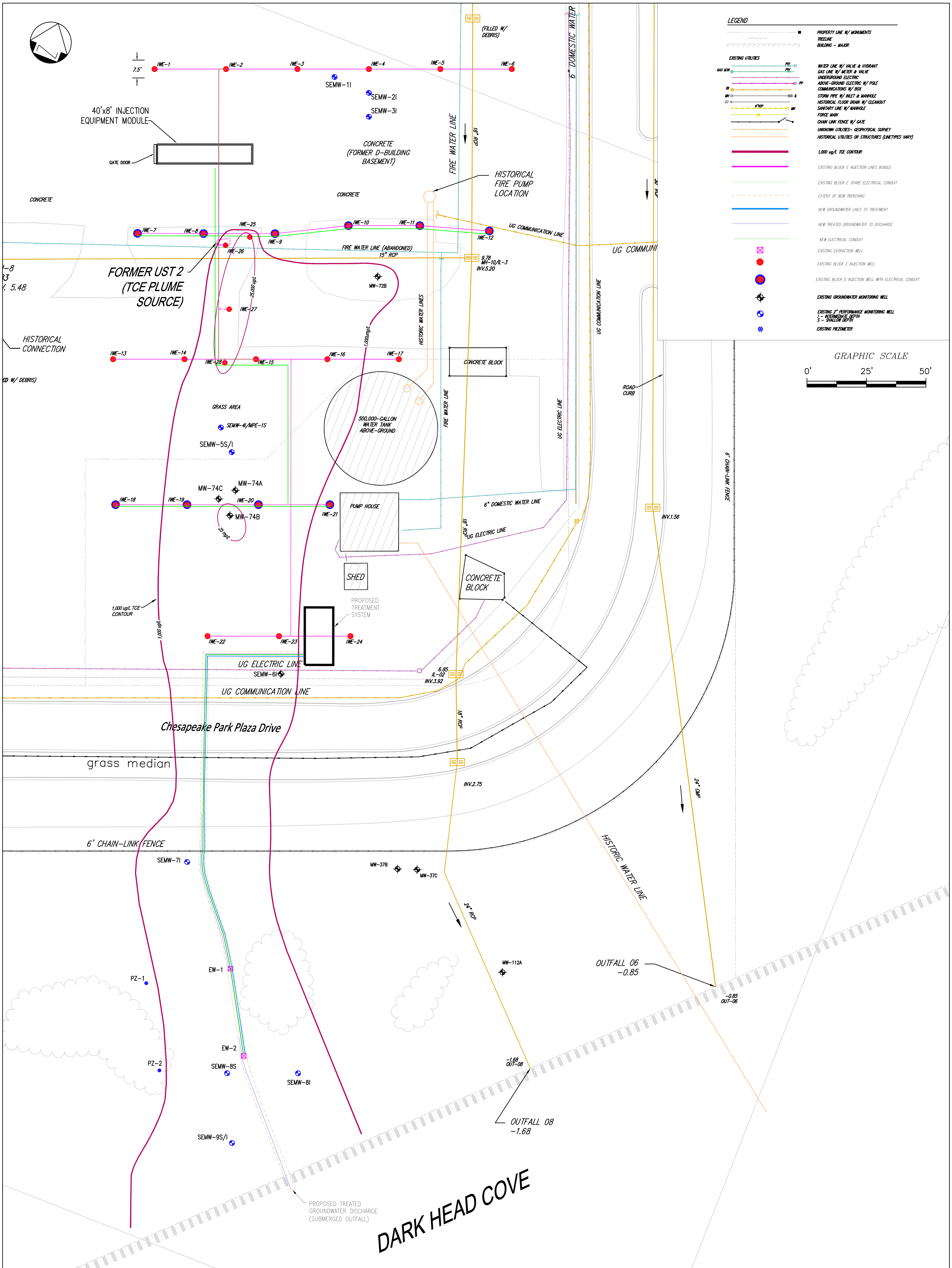


**REFERENCE PLANS & DATA:**

1. UTILITY CROSS CONNECTION SURVEY PERFORMED BY TETRA TECH CREW: RAB & AN, DATED 10/6,10/10 & 10/11/2011
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ALTERNATIVE 2 – HYDRAULIC CONTAINMENT IN BLOCK F, EXISTING ARD IN BLOCK E

LOCKHEED MARTIN CORPORATION
MIDDLE RIVER COMPLEX, MIDDLE RIVER, MARYLAND

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|---|---|
| DATE: | 5/23/18 |
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**FIGURE 3-2**

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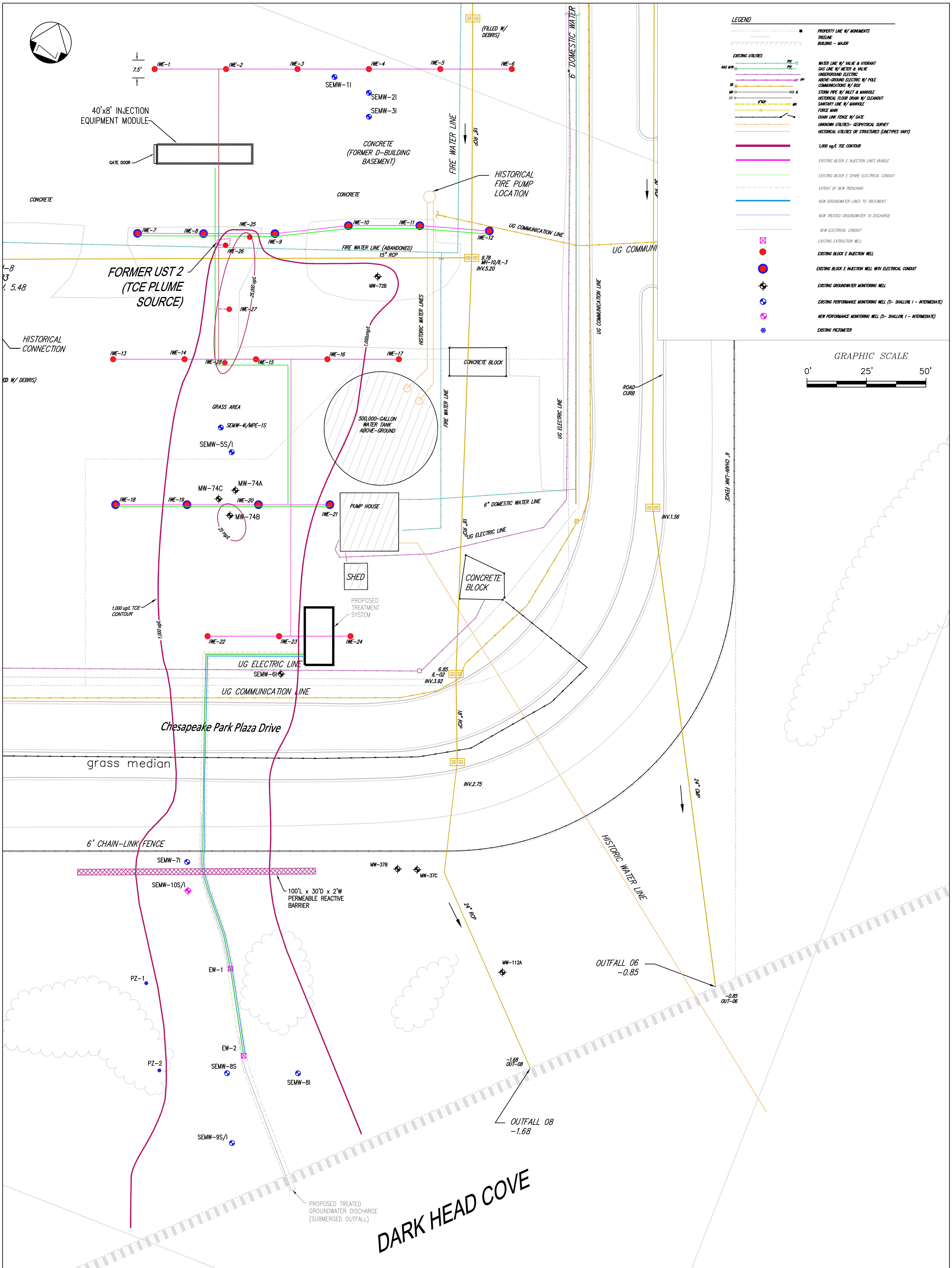


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ALTERNATIVE 3 – HYDRAULIC CONTAINMENT AND PRB IN BLOCK F, EXISTING ARD IN BLOCK E

LOCKHEED MARTIN CORPORATION
MIDDLE RIVER COMPLEX, MIDDLE RIVER, MARYLAND

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| DATE: | 6/10/18 |
| PROJECT NO.: | 112IC03835 |
| DRAWING SIZE: | ARCH C |
| DRAWN BY: | DWM |
| CHECKED BY: | BD |



**FIGURE 3-3**

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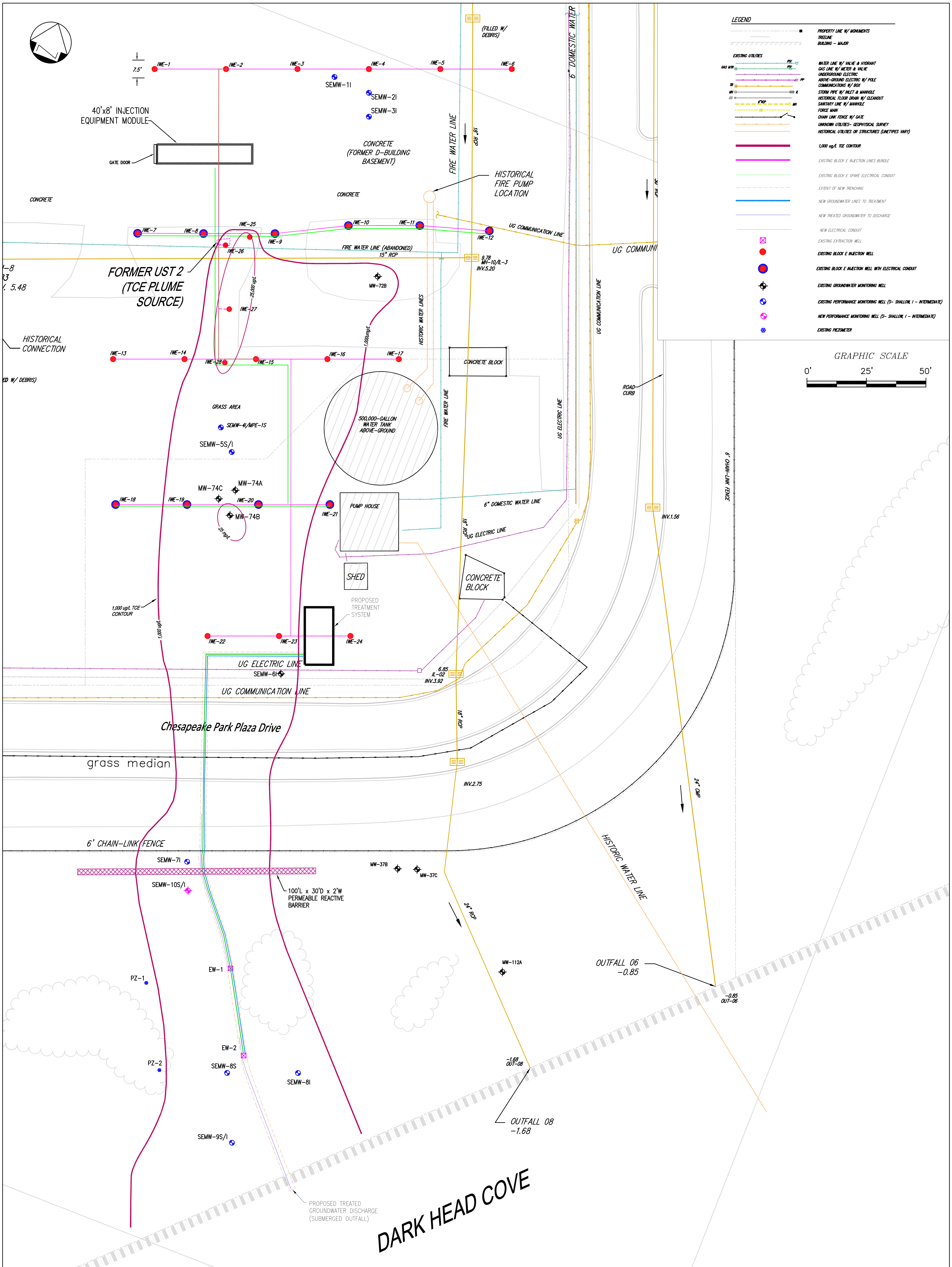


**REFERENCE PLANS & DATA:**

1. UTILITY CROSS CONNECTION SURVEY PERFORMED BY TETRA TECH CREW: RAB & AN, DATED 10/6,10/10 & 10/11/2011
2. SURVEYED LOCATIONS OF UNDERGROUND ELECTRIC, WATER, COMMUNICATION LINES, ARE BASED ON GEOPHYSICAL SURVEYS CONDUCTED BY ENVIROSCAN, INC. LANCASTER, PA, AND UNKNOWN FEATURES.
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SELECTED ALTERNATIVE – HYDRAULIC CONTAINMENT AND PRB IN BLOCK F, EXISTING ARD IN BLOCK E

LOCKHEED MARTIN CORPORATION
MIDDLE RIVER COMPLEX, MIDDLE RIVER, MARYLAND

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|---|---|
| DATE: | 6/10/18 |
| PROJECT NO.: | 112IC03835 |
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| DRAWN BY: | DWM |
| CHECKED BY: | BD |



**FIGURE 4-1**

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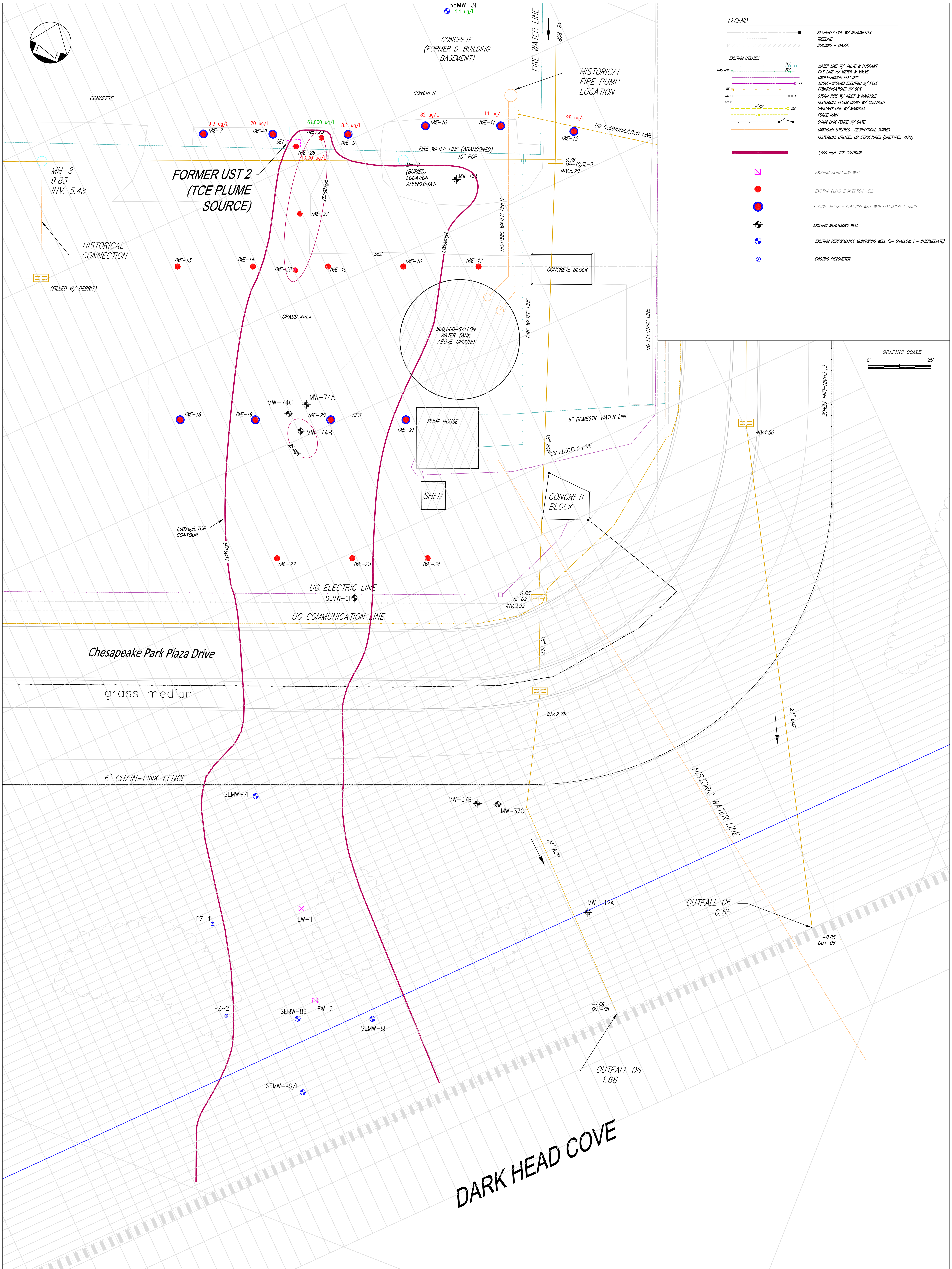


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GROUNDWATER MODEL GRID

LOCKHEED MARTIN CORPORATION
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| PROJECT NO.: | 112IC03835 |
| DRAWING SIZE: | ARCH C |
| DRAWN BY: | DWM |
| CHECKED BY: | BD |



**FIGURE 4-2**

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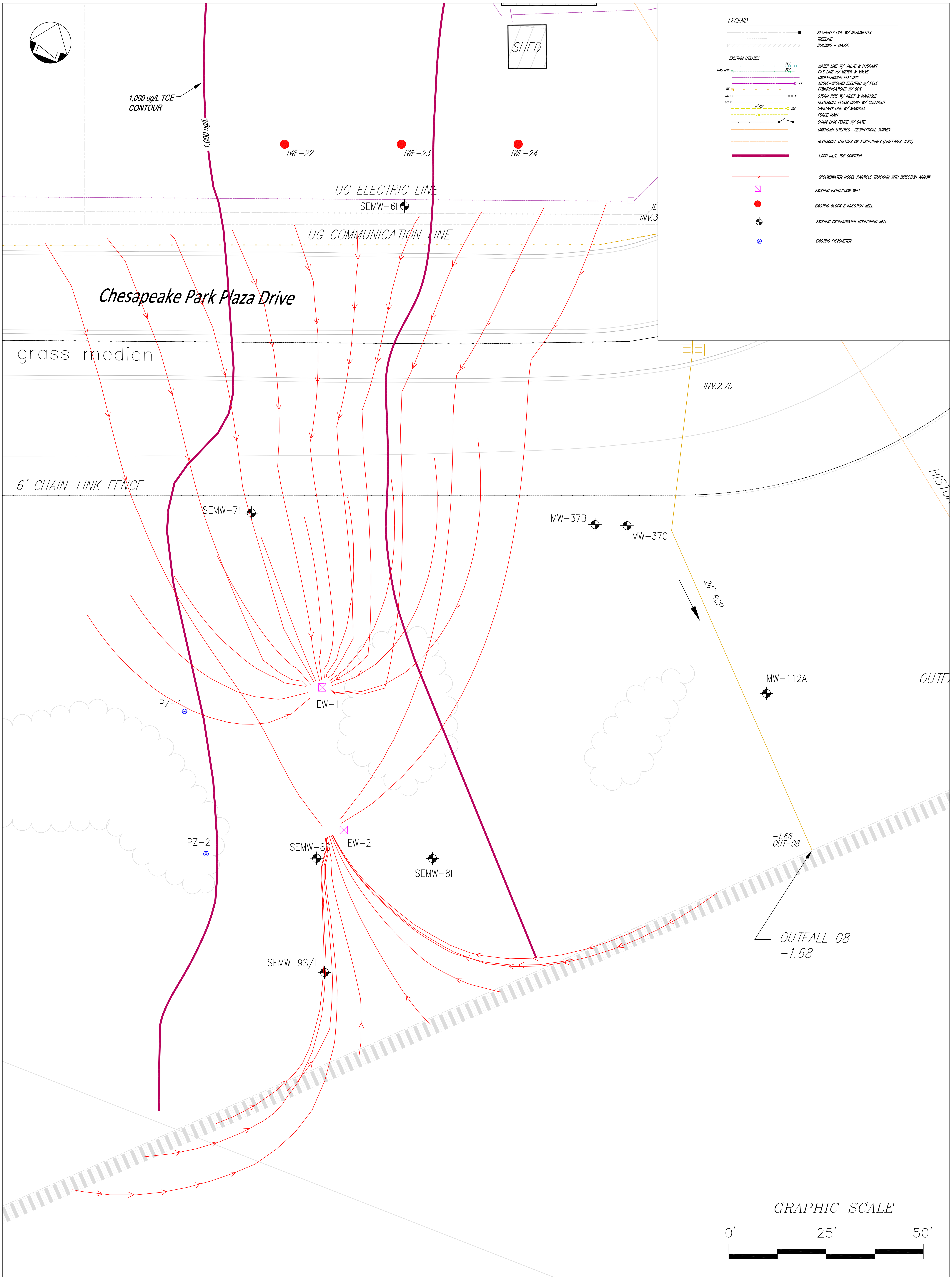


**REFERENCE PLANS & DATA:**

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BLOCK F PARTICLES TRACKING FOR MODEL LAYER 2

LOCKHEED MARTIN CORPORATION
MIDDLE RIVER COMPLEX, MIDDLE RIVER, MARYLAND

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| DATE: | 5/23/18 |
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**FIGURE 4-3**

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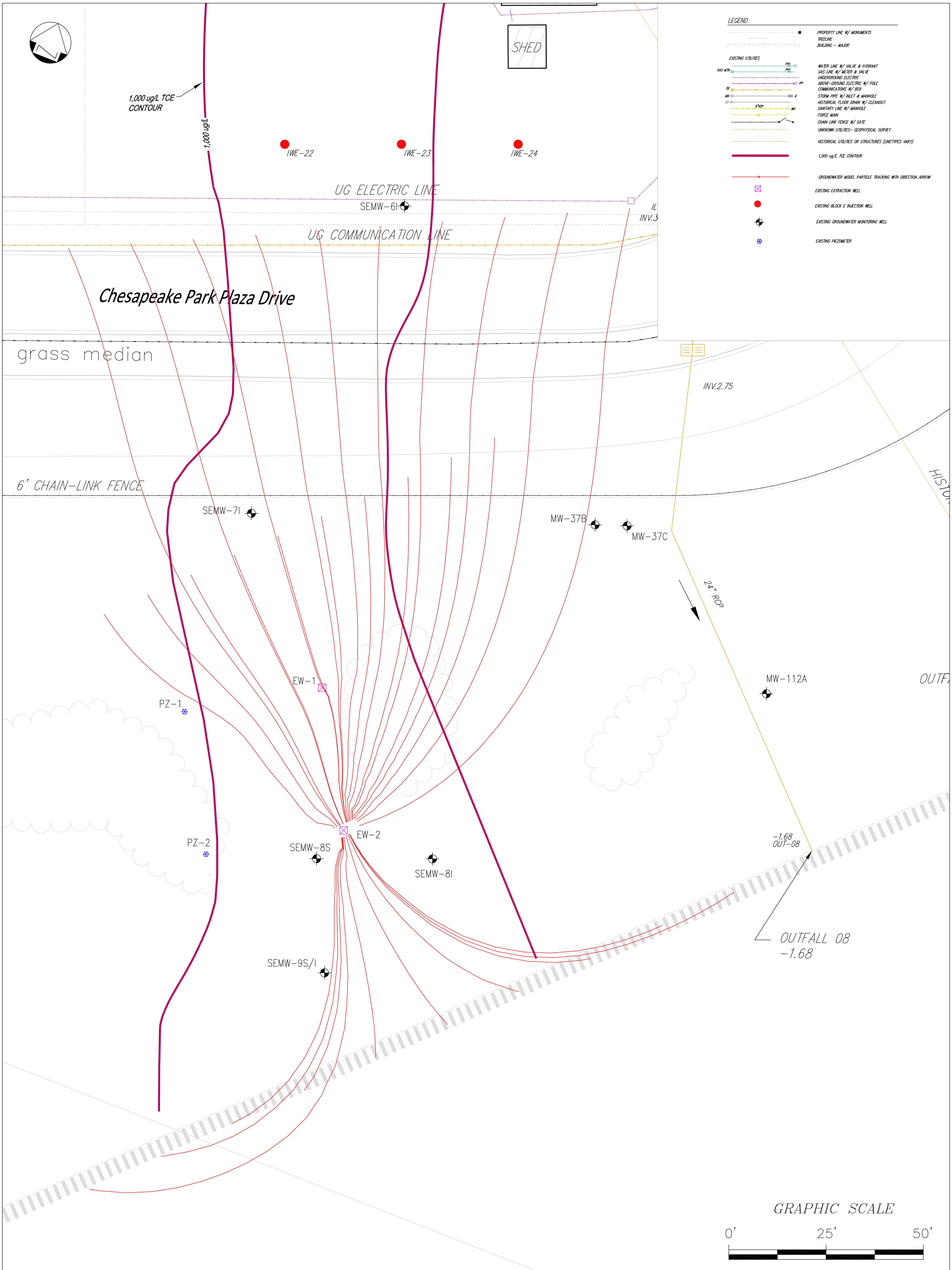


**REFERENCE PLANS & DATA:**

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BLOCK F PARTICLES TRACKING FOR MODEL LAYER 3

LOCKHEED MARTIN CORPORATION
MIDDLE RIVER COMPLEX, MIDDLE RIVER, MARYLAND

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| DATE: | 5/23/18 |
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**FIGURE 4-4**

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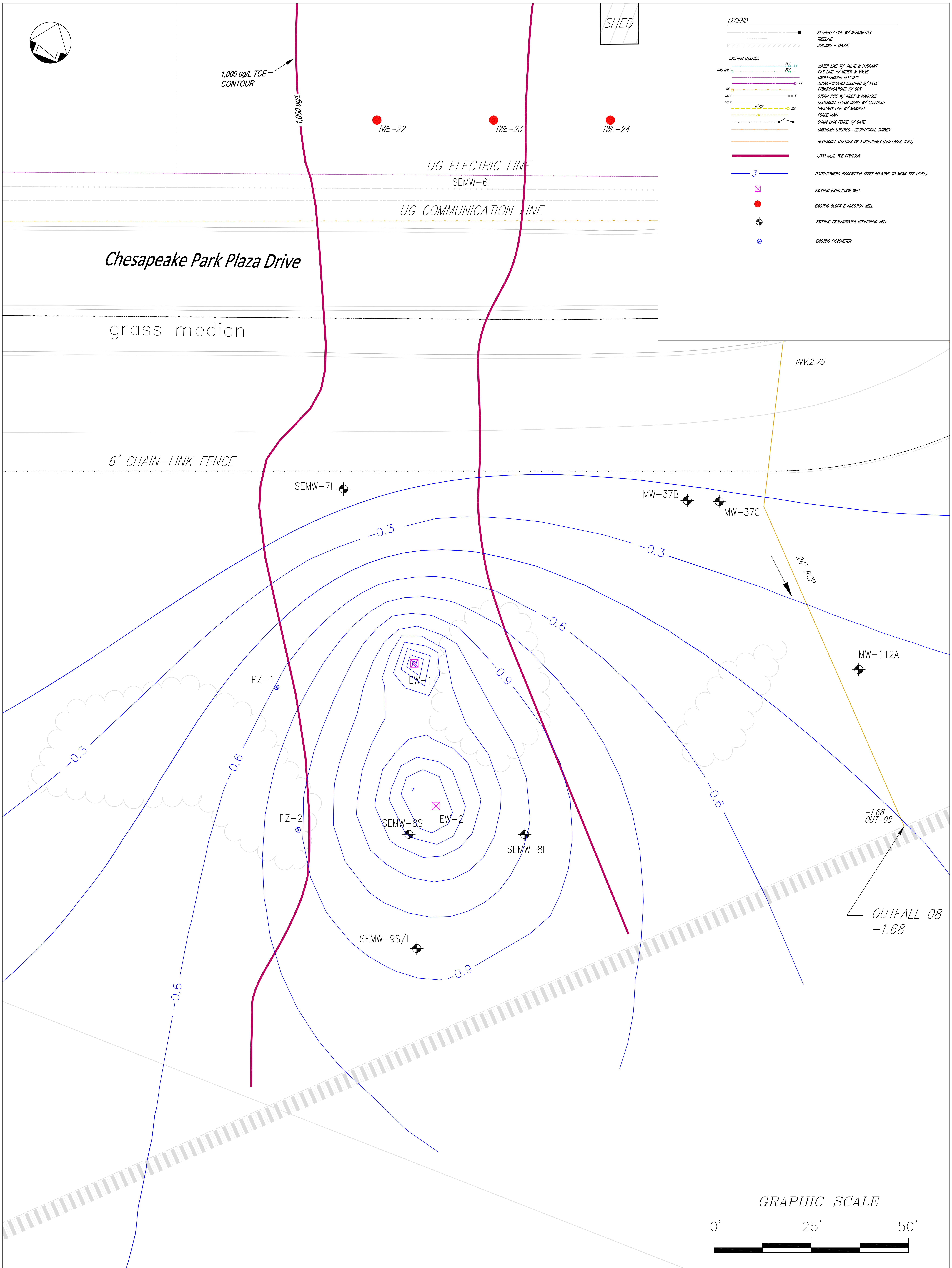


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BLOCK F POTENTIOMETRIC MAP FOR MODEL LAYER 2 UNDER PUMPING CONDITIONS

LOCKHEED MARTIN CORPORATION
MIDDLE RIVER COMPLEX, MIDDLE RIVER, MARYLAND

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| PROJECT NO.: | 112IC03835 |
| DRAWING SIZE: | ARCH C |
| DRAWN BY: | DWM |
| CHECKED BY: | BD |



**FIGURE 4-5**

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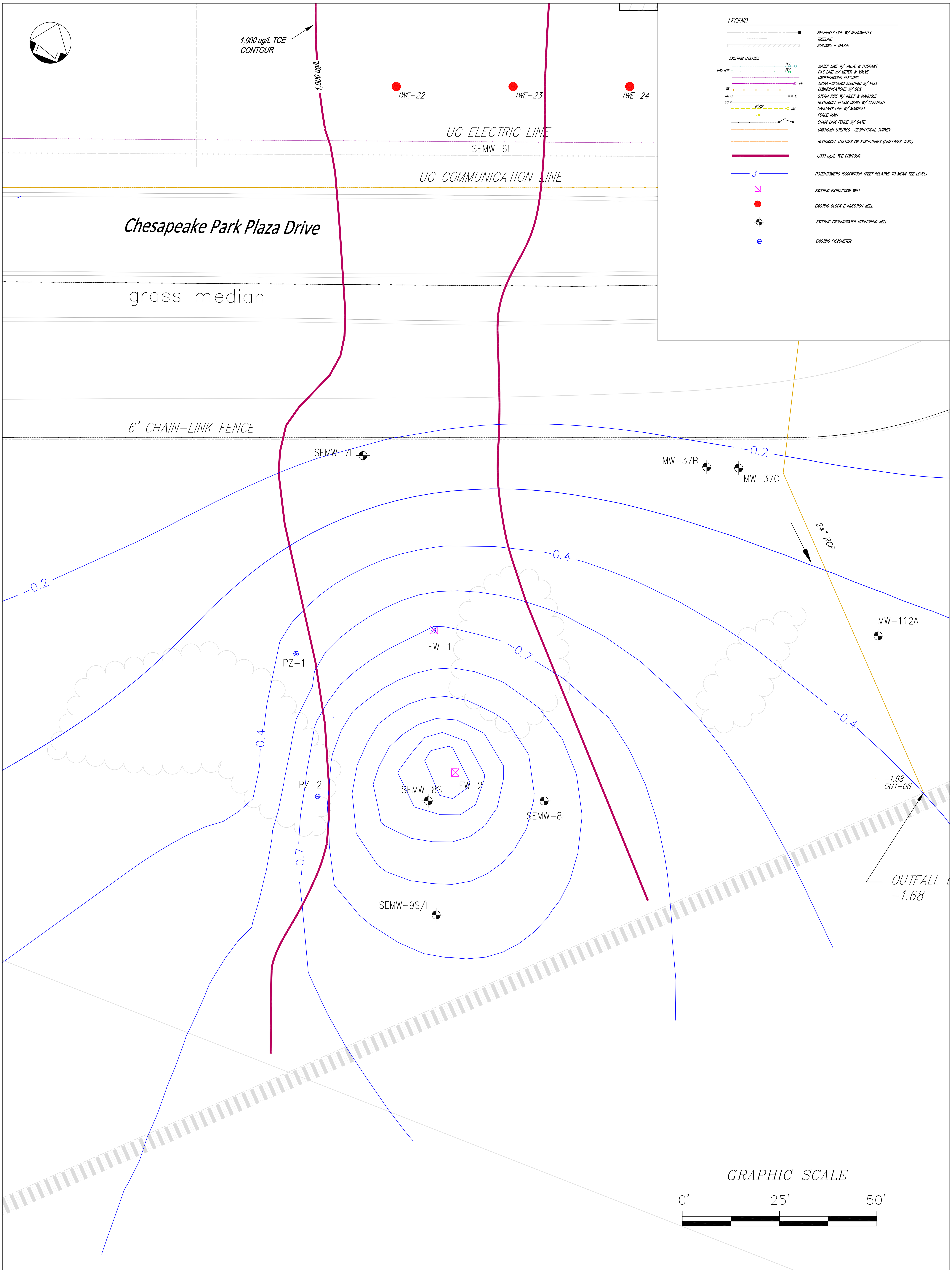


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BLOCK F POTENTIOMETRIC MAP FOR MODEL LAYER 3 UNDER PUMPING CONDITIONS

LOCKHEED MARTIN CORPORATION
MIDDLE RIVER COMPLEX, MIDDLE RIVER, MARYLAND

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| PROJECT NO.: | 112IC03835 |
| DRAWING SIZE: | ARCH C |
| DRAWN BY: | DWM |
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**FIGURE 4-6**

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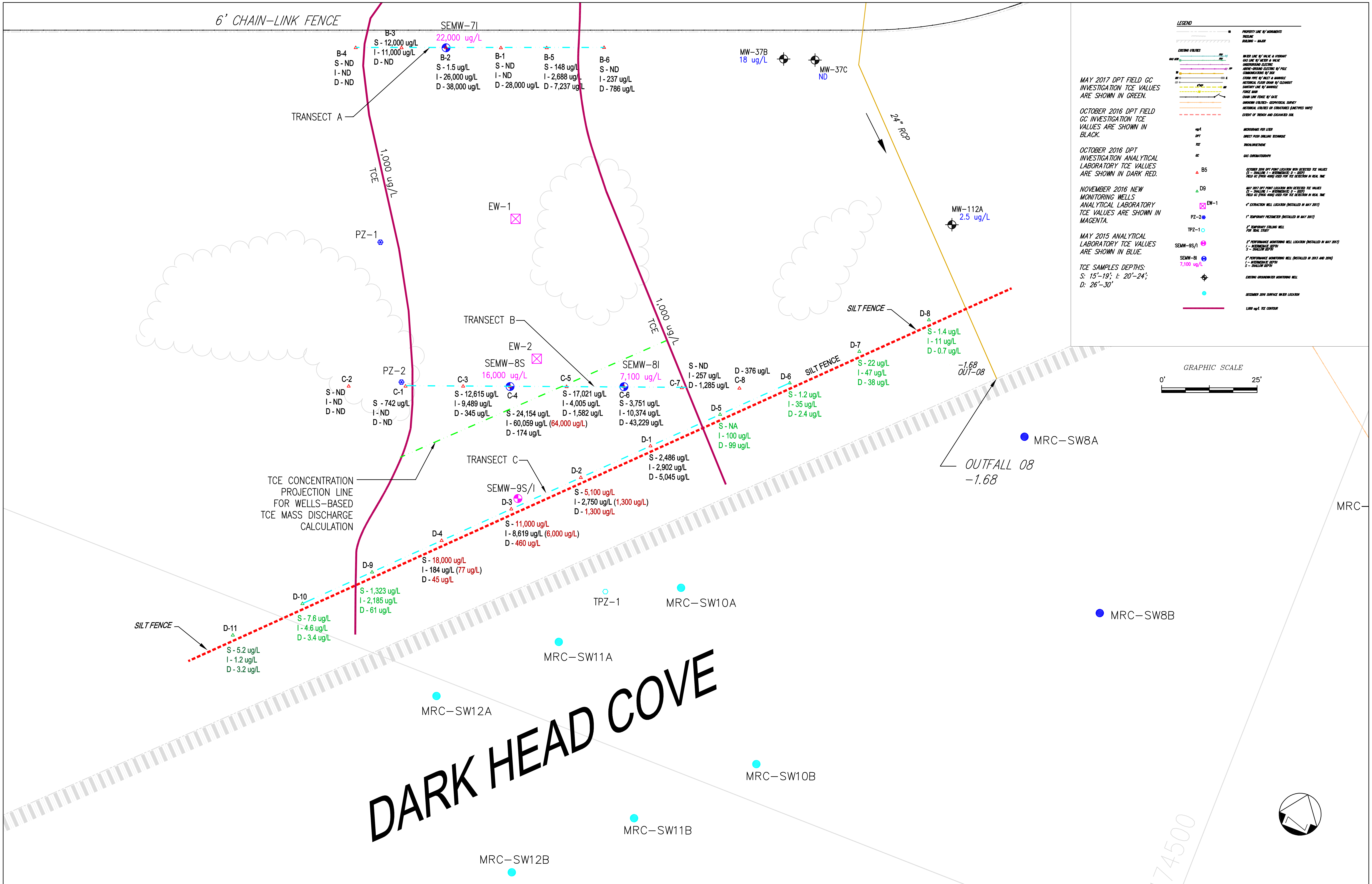


**REFERENCE PLANS & DATA:**

1. UTILITY CROSS CONNECTION SURVEY PERFORMED BY TETRA TECH CREW: RAB & AN, DATED 10/6,10/10 & 10/11/2011
2. SURVEYED LOCATIONS OF UNDERGROUND ELECTRIC, WATER, COMMUNICATION LINES, ARE BASED ON GEOPHYSICAL SURVEYS CONDUCTED BY ENVIROSCAN, INC. LANCASTER, PA, AND UNKNOWN FEATURES.
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BLOCK F TCE MASS DISCHARGE TRANSECT LOCATIONS

LOCKHEED MARTIN CORPORATION
MIDDLE RIVER COMPLEX, MIDDLE RIVER, MARYLAND

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| DATE: | 6/18/18 |
| PROJECT NO.: | 112IC03835 |
| DRAWING SIZE: | ARCH E |
| DRAWN BY: | DWM |
| CHECKED BY: | BD |



FIGURE 4-7

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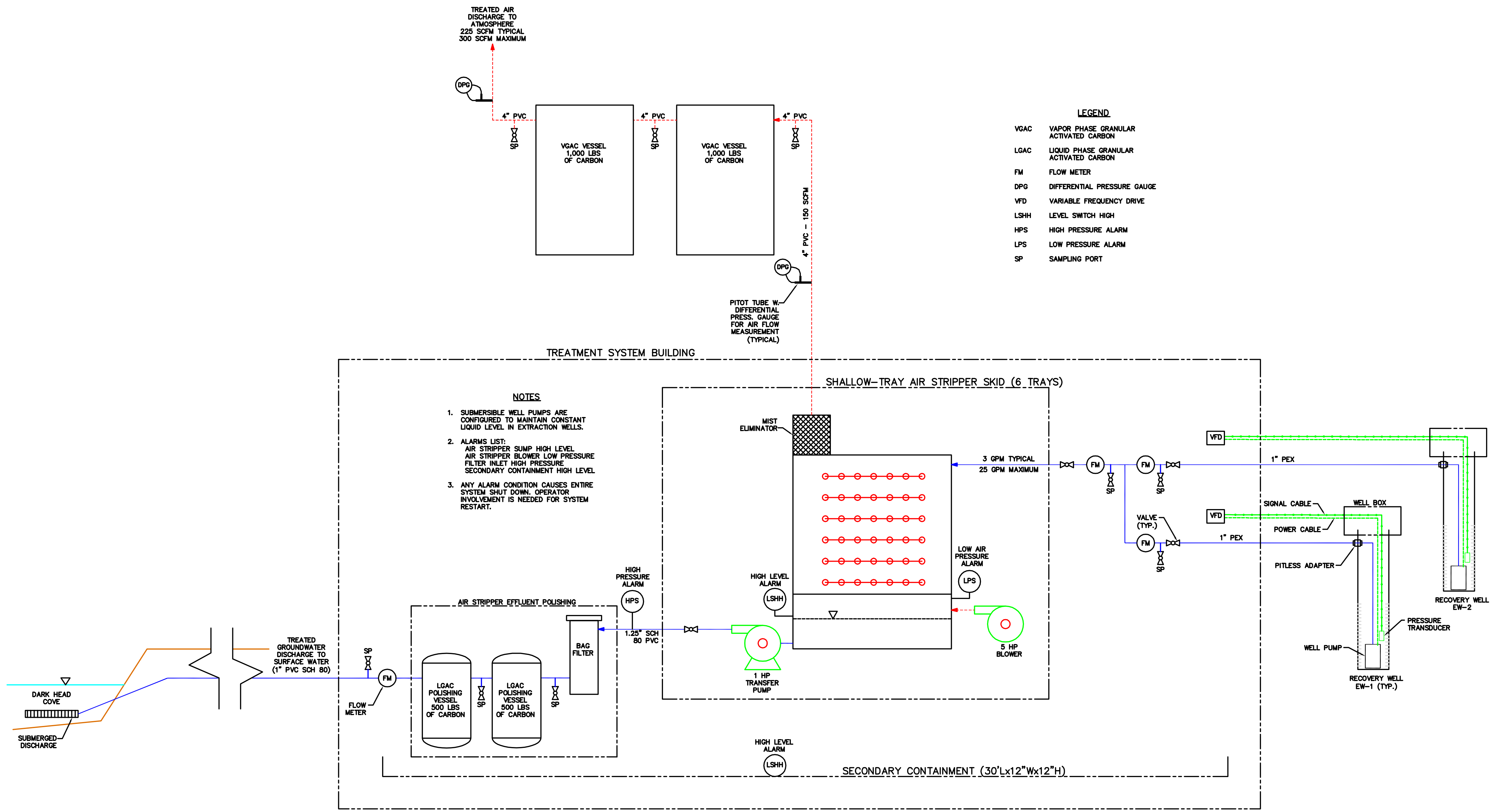


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GROUNDWATER TREATMENT SYSTEM PROCESS FLOW DIAGRAM

LOCKHEED MARTIN CORPORATION
MIDDLE RIVER COMPLEX, MIDDLE RIVER, MARYLAND

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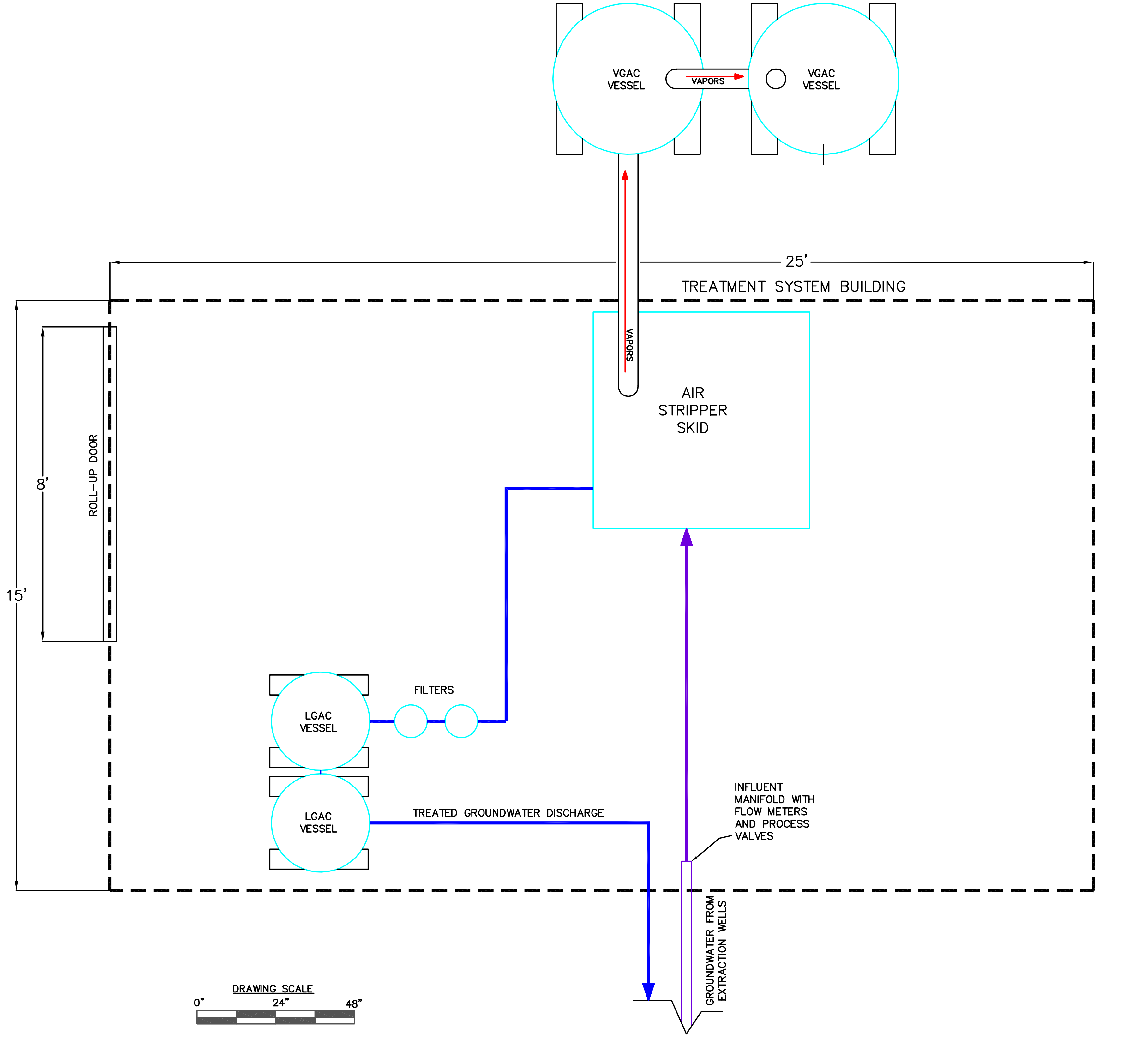
|---|---|
| DATE: | 5/24/18 |
| PROJECT NO.: | 112IC03835 |
| DWG. SIZE: | ARCH B |
| DRAWN BY: | RJD |
| CHECKED BY: | RB |



**FIGURE 4-8**

C:\USERS\BORIS.DYNKIN\DOCUMENTS\LMC MRC\BLOVK F ALTERNATIVES EVALUATION\RAP ADDENDUM\CAD FIGURES\FIGURE 4-8 BLOCK F PFD.DWG DWM 5/24/18




TETRA TECH
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| MARK | DATE | DESCRIPTION | BY |
|---|---|---|---|
| | | | |

GROUNDWATER TREATMENT SYSTEM EQUIPMENT LAYOUT

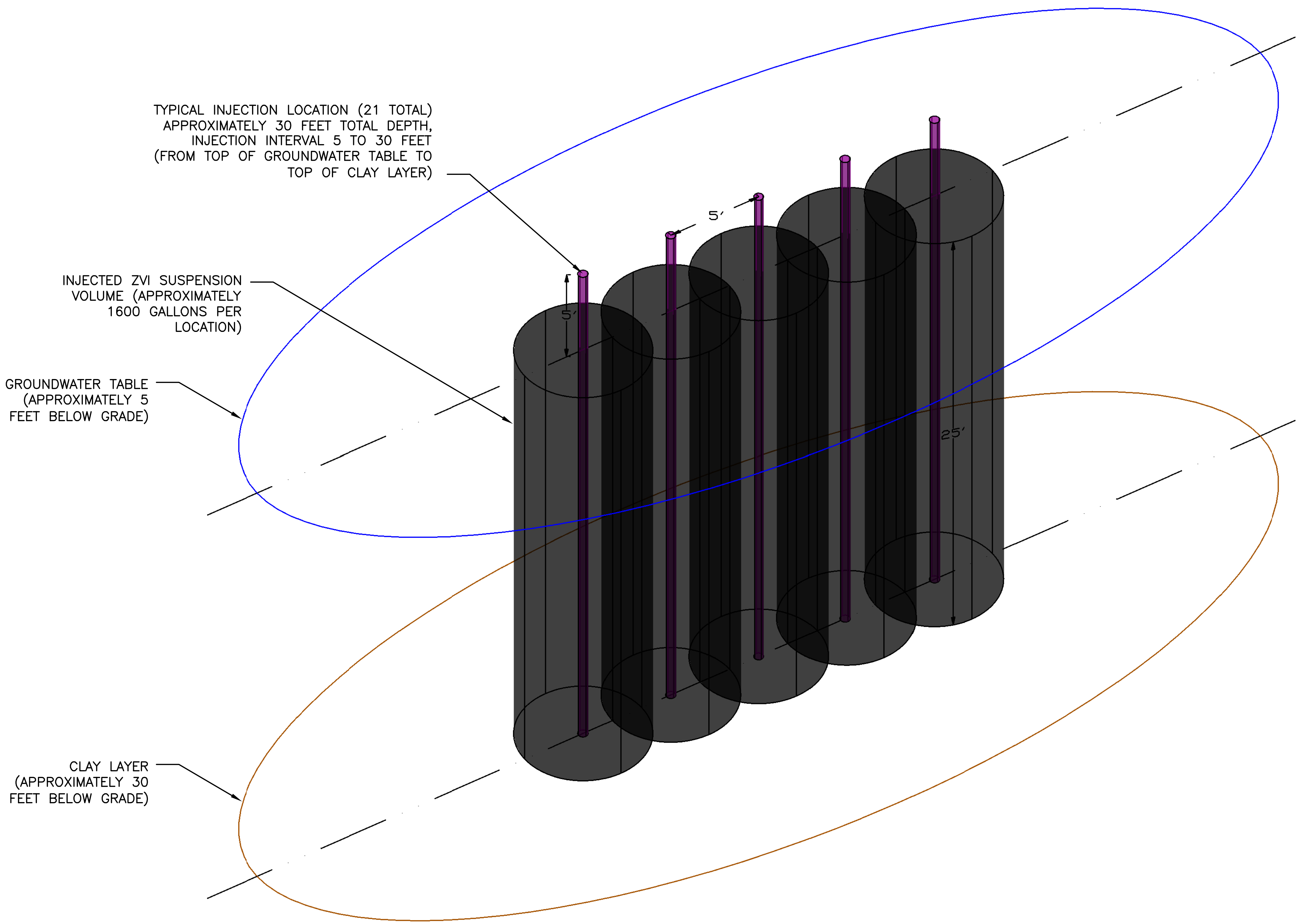
LOCKHEED MARTIN CORPORATION
MIDDLE RIVER COMPLEX, MIDDLE RIVER, MARYLAND

| | |
|---|---|
| DATE: | 5/24/18 |
| PROJECT NO.: | 112IC03835 |
| DRAWING SIZE: | ARCH C |
| DRAWN BY: | DWM |
| CHECKED BY: | BD |



**FIGURE 4-9**

C:\USERS\BORIS.DYNKIN\DOCUMENTS\LMC MRC\BLOVK F ALTERNATIVES EVALUATION\RAP ADDENDUM\CAD FIGURES\FIGURE 4-9 EQUIPMENT LAYOUT PLAN.DWG DWM 5/24/18




## ZVI CURTAIN ILLUSTRATION

INJECTION POINTS SPACED EVERY 5 FEET AND INJECTED ZVI SUSPENSION VOLUME TO ACHIEVE 33% OVERLAP. ASSUMED: 100% PORE VOLUME DISPLACEMENT, 25 FEET SATURATION THICKNESS, AND 25% FORMATION POROSITY. INJECTED VOLUME IS CYLINDER WITH 1600 GALLONS VOLUME, 6 $\frac{2}{3}$ FEET DIAMETER, 25 FEET HEIGHT

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|---|---|---|---|
| | | | |

BLOCK F PRB CURTAIN ILLUSTRATION

LOCKHEED MARTIN CORPORATION
MIDDLE RIVER COMPLEX, MIDDLE RIVER, MARYLAND

| | |
|---|---|
| DATE: | 6/11/18 |
| PROJECT NO.: | 112IC03835 |
| DRAWING SIZE: | ARCH C |
| DRAWN BY: | DWM |
| CHECKED BY: | BD |



**FIGURE 4-10**

# TABLES

**Table 2-1**
**Field GC and Analytical Laboratory TCE Screening Results for Block F**
**Lockheed Martin Middle River Complex, Middle River, Maryland**

| DPT Point ID | TCE by field GC (µg/L) | | | TCE by analytical lab (µg/L) | | |
|---|---|---|---|---|---|---|
| | Shallow 15 to 19 feet | Intermediate 20 to 24 feet | Deep 26 to 30 feet | Shallow 15 to 19 feet | Intermediate 20 to 24 feet | Deep 26 to 30 feet |
| A-6 | NS | 9,039 | 14,918 | | | |
| A-4 | ND | 5,000 | 18,000 | | | |
| A-7 | NS | 223 | 15,442 | | | |
| B-4 | ND | ND | ND | | | |
| B-6 | ND | 237 | 786 | | | |
| B-1 | ND | ND | 28,000 | | | |
| B-2 | 2 | 26,000 | 38,000 | | | |
| B-3 | 12,000 | 11,000 | ND | | | |
| B-5 | 148 | 2,688 | 7,237 | | | |
| C-1 | 742 | ND | ND | | | |
| C-2 | ND | ND | ND | | | |
| C-8 | NS | NS | 376 | | | |
| C-3 | 12,615 | 9,489 | 345 | | | |
| C-4 | 24,154 | 60,059 | 174 | | 64,000 | |
| C-5 | 17,021 | 4,005 | 1,582 | | | |
| C-6 | 3,751 | 10,374 | 43,229 | | | |
| C-7 | ND | 257 | 1,285 | | | |
| D-1 | 2,486 | 2,902 | 5,045 | | | |
| D-2 | NS | 2,750 | NS | 5,100 | 1,300 | 1,300 |
| D-3 | NS | 8,619 | NS | 11,000 | 6,000 | 460 |
| D-4 | NS | 184 | NS | 18,000 | 77 | 45 |
| **Average values**[1] | **7,591** | **9,522** | **10,941** | | | |
| **Median values**[1] | **4,426** | **4,503** | **3,314** | | | |

**For all intervals (shallow, intermediate and deep) within 1000 µg/L TCE contour**

**Average**[1] **9,428 µg/L**

**Median**[1] **4,503 µg/L**

[1]**Average and median values are calculated for the sampling points inside 1,000 µg/L TCE contour (highlighted yellow). Analytical laboratory results were used when available for these calculations. ND (not detected) values for TCE were interpreted as zero values.**

DPT direct push drilling technology
GC gas chromatograph (model FROG 4000)
µg/L micrograms per liter
ND not detected
NS not sampled
TCE trichloroethene

**Table 2-2**
**Block F Pumping Test- Pumping Parameters Summary**
**Lockheed Martin Middle River Complex, Middle River, Maryland**

| EW-1 (low yield well) | Units | Low rate | Medium rate | High rate | Test total |
|---|---|---|---|---|---|
| Total duration | hours | 1.4 | 1.2 | 20.5 | 23 |
| Steady flow | gpm | 0.27 | 0.38 | 0.65 | NA |
| Drawdown | feet | 7.61 | 12.02 | 22.25 | NA |
| Total volume pumped | gallons | 26 | 30 | 788 | 844 |

| EW-2 (high yield well) | Units | Low rate | Medium rate | High rate | Test total |
|---|---|---|---|---|---|
| Total duration | hours | 0.9 | 0.8 | 38.0 | 40 |
| Steady flow | gpm | 1.43 | 2.6 | 4.3 | NA |
| Drawdown | feet | 5.25 | 11.22 | 20.23 | NA |
| Total volume pumped | gallons | 70 | 133 | 10923 | 11126 |
| | | | | | |
| gpm - gallons per minute | | | | | |
| NA - not applicable | | | | | |

**Table 2-3**
**Block F Pumping Test - Analytical Results Summary**
**Lockheed Martin Middle River Complex, Middle River, Maryland**


## Pumping Well Results

***EW-1 pumping test (low yield well)***

| Parameter | EW-1 start | EW-1 mid | EW-1 end | Dark Head Cove | Units |
|---|---|---|---|---|---|
| Trichloroethene | 21000 | 21000 | 21000 | NA | µg/L |
| Bromide | 0.32 | 0.32 | 0.32 | 3.9 | mg/L |
| Sulfate | 14 | 15 | 15 | 130 | mg/L |
| TDS | 190 | 200 | 280 | 1500 | mg/L |
| Iron | 430 | 450 | 1100 | 120 | µg/L |
| Alkalinity | 3.1 | 3.2 | 3.1 | 45 | mg/L |
| SpCond. (field) | 0.286 | | 0.277 | 3.05 | mS/cm |

| | | |
|---|---|---|
| Final pumping rate | 0.65 | gpm |
| Final TCE mass rate | 0.16 | lbs/day |

***EW-2 pumping test (high yield well)***

| Parameter | EW-2 start | EW-2 mid | EW-2 end | Dark Head Cove | Units |
|---|---|---|---|---|---|
| Trichloroethene | 3200 | 3900 | 5800 | NA | µg/L |
| Bromide | 0.76 | 0.79 | 1.00 | 3.9 | mg/L |
| Sulfate | 7 | 7 | 7.2 | 130 | mg/L |
| TDS | 150 | 150 | 130 | 1500 | mg/L |
| Iron | 1300 | 120 | 460 | 120 | µg/L |
| Alkalinity | 4.9 | ND | ND | 45 | mg/L |
| SpCond. (field) | 0.194 | 0.183 | 0.183 | 3.05 | mS/cm |

| | | |
|---|---|---|
| Final pumping rate | 4.3 | gpm |
| Final TCE mass rate | 0.30 | lbs/day |

## Observation Well Results

| Parameter | Units | SEMW-7I | | SEMW-8I | | SEMW-9I | | SEMW-9S | |
|---|---|---|---|---|---|---|---|---|---|
| | | Before Pumping | After Pumping | Before Pumping | After Pumping | Before Pumping | After Pumping | Before Pumping | After Pumping |
| Trichloroethene | µg/L | 26000 | 24000 | 1100 | 1500 | 940 | 580 | 15000 | 26000 |
| cis-1,2-DCE | µg/L | ND | ND | 1500 | 2200 | 15 | 13 | ND | ND |
| Vinyl chloride | µg/L | ND | ND | ND | ND | ND | ND | ND | ND |
| Alkalinity | mg/L | | | | | 15 | 5.8 | 56 | 43 |
| Bromide | mg/L | | | | | 0.24 | 0.19 | 0.20 | 0.21 |
| Sulfate | mg/L | | | | | 8.2 | 7.2 | 88 | 67 |
| Nitrate as nitrogen | mg/L | | | | | 0.18 | 0.40 | 0.12 | 0.065 |
| Iron | µg/L | | | | | 1300 | 380 | 2000 | 140 |
| Manganese | µg/L | | | | | 320 | 250 | 320 | 340 |
| Salinity | NA | | | | | ND | ND | ND | ND |
| TDS | mg/L | | | | | 170 | 150 | 620 | 560 |
| Hardness as $CaCO_3$ | mg/L | | | | | 38 | 33 | 150 | 120 |
| Calcium hardness as $CaCO_3$ | mg/L | | | | | 18 | 12 | 92 | 74 |
| Magnesium hardness as $CaCO_3$ | mg/L | | | | | 21 | 21 | 61 | 48 |
| Ethane | mg/L | | | 0.037 | | 0.0065 | ND | | |
| Acetylene | mg/L | | | 0.0034 | | 0.0034 | | | |
| Butane | mg/L | | | 0.0085 | | 0.010 | | | |
| Ethene | mg/L | | | 0.091 | | 0.0069 | ND | | |
| Methane | mg/L | | | 0.38 | | 0.0079 | 0.18 | | |
| Propane | mg/L | | | 0.0075 | | 0.0090 | | | |
| SpCond. (field) | mS/cm | 0.133 | | 0.329 | | 0.196 | | 0.686 | |
| ORP (field) | mVolts | 399 | | -145 | | -255 | | 135 | |

µg/L - micrograms per liter
$CaCO_3$ - calcium carbonate
cis-1,2-DCE - cis-1,2-dichloroethene
gpm - gallons per minute
lbs/day - pounds per day
mg/L - milligrams per liter
mS/cm - milliSiemens per centimeter
mVolts - millivolts
ORP - oxidation/reduction potential
SpCond. - specific conductivity
TCE - trichloroethene
TDS - total dissolved solids

## Table 3-1

## Screening of Technologies and Process Options for the Groundwater Response Action in Blocks E and F
## Lockheed Martin Middle River Complex, Middle River, Maryland


| General Response Action | Response Action Technology | Process Option | Description | Screening Comment |
|---|---|---|---|---|
| No action | None | Not applicable | No activities conducted at the Middle River Complex (MRC) to address contamination. Biodegradation of contaminants may occur through natural attenuation processes, but would not be verified. | Eliminate. This option does not meet response action objectives (RAOs) and has been eliminated from consideration. |
| Limited action | Land use controls (LUCs) | Institutional controls | Administrative action using property deeds or other land use prohibitions to restrict future site activities. | Retain. Alone, would not meet RAOs; however, would be protective of human health and the environment at this time. |
| | Monitoring and monitored natural attenuation (MNA) | Groundwater sampling | Sampling and analysis of groundwater to evaluate the effectiveness of site treatment and the progress of natural attenuation following active remediation. | Retain. Alone, would not meet RAOs; however, would be protective of human health and the environment at this time and would provide data to confirm protectiveness moving forward. |
| Containment | Hydraulic containment | Groundwater extraction | Extraction wells or trenches to prevent migration of trichloroethene (TCE) toward Dark Head Cove. | Retain. The technology could be used to prevent contaminant migration toward Dark Head Cove. |
| Containment | Barrier | Permeable reactive barrier (PRB) | PRB usesreactive media to prevent migration of TCE toward Dark Head Cove. Reactive media can be placed in a trench or injected *in situ* via a series of injection points or wells. | Retain. The technology could be used to prevent contaminant migration toward Dark Head Cove. |

**Table 3-1**

**Screening of Technologies and Process Options for the Groundwater Response Action in Blocks E and F Lockheed Martin Middle River Complex, Middle River, Maryland**


| General Response Action | Response Action Technology | Process Option | Description | Screening Comment |
|---|---|---|---|---|
| Containment | Barrier | Air sparge curtain | Air sparge curtain utilizes air to remove VOCs from passing groundwater. Air can be injected via horizontal laterals within a trench or via a series of injection wells. | Retain. The technology could be used to prevent contaminant migration toward Dark Head Cove. |
| Collection | Groundwater extraction | Pumping via wells | This option is technologically similar to containment using wells but focuses on contaminant mass removal rather than hydraulic containment. | Retain. Groundwater extraction could be used to reduce contaminant mass. |
| Collection | Multi-phase extraction | Extracting groundwater and vapors via wells | This option is similar to groundwater extraction but utilizes vacuum to increase contaminant removal rates. | Retain. Multi-phase extraction could be used to reduce contaminant mass. |

**Table 3-1**

**Screening of Technologies and Process Options for the Groundwater Response Action in Blocks E and F Lockheed Martin Middle River Complex, Middle River, Maryland**



| General Response Action | Response Action Technology | Process Option | Description | Screening Comment |
|---|---|---|---|---|
| *Ex situ* treatment | Biological | Aerobic/ anaerobic | Natural degradation of organic chemicals of concern (COC) via microorganisms in an aerobic (oxygen-rich) or anaerobic (oxygen-deficient) environment. | Eliminate. Volatile organic compounds (VOCs) are more readily treated by air stripping and/or granular activated carbon (GAC). |
| | Physical | Filtration | Separation of suspended solids from water via entrapment in a bed of granular media or membrane. | Retain. May be useful in combination with other ex-situ treatment options. |
| | | Air stripping | Contact of water with an air stream to remove VOCs. | Retain. Proven treatment method for VOC removal. |
| | | GAC adsorption | Separation of dissolved contaminants from water or air streams via adsorption onto GAC. | Retain. Proven treatment method for VOC removal from contaminated groundwater and air stripper off-gas. |

## Table 3-1

## Screening of Technologies and Process Options for the Groundwater Response Action in Blocks E and F
## Lockheed Martin Middle River Complex, Middle River, Maryland



| General Response Action | Response Action Technology | Process Option | Description | Screening Comment |
|---|---|---|---|---|
| *Ex situ* treatment (Cont.) | Physical | Solvent extraction | Separation of contaminants from a solution by contact with an immiscible liquid with a higher COC affinity. | Eliminate. Not proven to be cost-effective for VOC removal. |
| | | Sedimentation | Separation of solids from water via gravity settling. | Eliminate. Will not be needed based on MPE operational experience. |
| | Chemical | Coagulation/ flocculation | Use of chemicals to neutralize surface charges and promote attraction of colloidal particles to facilitate settling. | Eliminate. Will not be needed based on MPE operational experience. |
| | | Chemical precipitation | Use of reagents to convert soluble compounds into insoluble compounds. | Eliminate. Will not be needed based on MPE operational experience. |
| | | Ion exchange | Removal of dissolved ions through exchange with similarly charged ions held on the active sites of a synthetic resin that is contacted with the liquid to be treated. | Eliminate. Will not be needed based on MPE operational experience. |
| | | Advanced oxidation | Use of oxidizers such as ozone, hydrogen peroxide, or potassium permanganate to break down certain organic compounds. | Eliminate. Low concentrations of 1,4-dioxane do not require treatment. |

## Screening of Technologies and Process Options for the Groundwater Response Action in Blocks E and F Lockheed Martin Middle River Complex, Middle River, Maryland



| General Response Action | Response Action Technology | Process Option | Description | Screening Comment |
|---|---|---|---|---|
| *In situ* treatment | Biological | Enhanced anaerobic reductive dechlorination (ARD) | Injection of substrates and/or bioamendments to create conditions suitable for reductive dechlorination. | Retain. Already installed and ready for use in Block E. |
| | Physical | Air sparging | Injection of air to remove VOCs from groundwater. Vapors are collected for *ex situ* treatment. | Retain. Could be used for TCE plume treatment in Blocks E and F and for containment in Block F. |
| | Chemical | Oxidation via oxidant addition | Destroy contaminants via oxidation using an oxidant injected into the aquifer | Eliminate. Could potentially be effective. However, chemicals and reaction by-products could migrate to Dark Head Cove. |
| | Thermal | Subsurface heating | Volatilization of organic COC through groundwater and soil heating in combination with vacuum extraction of volatilized material. | Retian. Could be effective due to narrow well-defined TCE source area and plume. |

## Table 3-1

## Screening of Technologies and Process Options for the Groundwater Response Action in Blocks E and F
## Lockheed Martin Middle River Complex, Middle River, Maryland



| General Response Action | Response Action Technology | Process Option | Description | Screening Comment |
|---|---|---|---|---|
| Discharge/ disposal | Surface discharge | Direct discharge | Discharge of treated water to surface water. | Retain. Treatment of other constituents, such as other metals, may be required to meet effluent limitation requirements. |
| | | Indirect discharge | Discharge of collected/treated water to local publicly-owned treatment works (POTW). | Retain. POTW may have flow rate and influent limitations. |
| | | Off-site treatment facility | Treatment and disposal of water at an off-site treatment works. | Eliminate. Large volume of water would be too costly to transport by tanker. |
| | Subsurface discharge | Reinjection | Use of injection wells or infiltration for discharge of treated groundwater underground. | Eliminate. Continuous reinjection would be difficult due to the heterogenous, low permeability soil at the site. |

## Table 3-2

## Technologies and Process Options Retained for the Groundwater Response Action in Blocks E and F Lockheed Martin Middle River Complex, Middle River, Maryland

| General Response Action | Response | Process Option |
|---|---|---|
| Limited action | Land use controls | Institutional controls |
| | Monitoring/monitored natural attenuation (MNA) | Groundwater sampling |
| Containment | Barrier | Groundwater extraction via wells |
| | | Permeable reactive barrier (PRB) |
| | | Air sparge curtain |
| Collection | Groundwater extraction | Groundwater extraction via wells |
| | Multi-phase extraction | Groundwater and vapors via wells |
| *Ex situ* treatment | Physical | Filtration |
| | | Air stripping |
| | | Granular activated carbon (GAC) adsorption |
| *In situ* treatment | Biological | Enhanced anaerobic reductive dechlorination (ARD) |
| | Physical | Air sparging |
| | Thermal | VOCs removal via subsurface heating |
| Discharge/disposal | Surface discharge (treated water) | Direct discharge – with National Pollution Discharge Elimination (NPDES) permit |
| | | Indirect discharge – through publicly owned treatment works (POTW) |

**Table 3-3**
**Long List of Remedial Alternatives for the Groundwater Response Action in Blocks E and F**
**Lockheed Martin Middle River Complex, Middle River, Maryland**


| Number | Alternative | Description | Pros | Cons |
|---|---|---|---|---|
| 1 | Monitored natural attenuation (MNA) and land use controls (LUCs) | Institutional controls to prevent certain site uses to ensure acceptable risk to site users. Sampling of groundwater and surface water to confirm acceptable off-site risk, including in Dark Head Cove. | No risk is currently present; will meet RAOs. Low cost. | No active treatment; contingency active remedy may be required if sampling showed unacceptable risk. |
| **2** | **Existing ARD in Block E, MNA/LUCs** | **Utilizes current ARD system in Block E. To the extent possible the ARD system operation will be modified to minimise any adverse impact to Dark Head Cove.** | **Remedy is in place, approved by regulators and ready for implementation. Positive experience at the MRC site based on the results in Blocks G and I. No capital costs are required.** | **Does not provide TCE plume containment and does not prevent TCE migration into Dark Head Cove in the short term. Could generate vinyl chloride at Block E which creates a potential for vinyl chloride migration into Dark Head Cove, especially short term.** |
| **3** | **Hydraulic Containment in Block F, Existing ARD in Block E, MNA/LUCs** | **Use two to three pumping wells in Block F to prevent migration of TCE to Dark Head Cove. Use existing ARD system in Block E to further reduce TCE mass.** | **Hydraulic containment in Block F can be obtained with few pumping wells. Total maximum pumpng rate is expected to be under 5 gallons per minute (gpm) resulting in relatively low treatment system capital and maintenance costs.** | **National Pollutant Discharge Elimination System (NPDES) permit, sanitary sewer (SS) discharge permit or underground injection (UIC) permit will be required. Long-duration operation and maintenance (O&M) may be required for hydraulic containment in Block F.** |
| 4 | Permeable reactive barrier (PRB) in Block F, existing ARD in Block E, MNA/LUCs | PRB in Block F across TCE plume. Use existing ARD system in Block E to further reduce TCE mass. | PRB could be effective in preventing migration of TCE and daughter products. Implementable considering relatively shallow contamination and clay layer and lack of utilities in the area. No long-term O&M required. | Questionable performance under tidal influence and with TCE plume already at Dark Head Cove. High capital and media replacement cost, difficult permitting, potential for creating unforeseen and irreversible hydraulic pathways. No back-up in case of poor performance. |
| 5 | Air sparge curtain in Block F, existing ARD in Block E, MNA/LUCs | Similar to Alternative 4 but utilizes air sparge curtain via horizontal laterals within a trench or via a series of injection wells. | Easy to install and permit if injection well or driven points are used, proven technology. | Questionable performance as a barrier if injection wells or driven points are used due to heterogeneous geology. High capital costs and envoronmental impacts if trench is used. Long duration O&M to maintain air compressor and vapor treatment. |
| **6** | **Adds PRB in Block F to Alternative 3.** | **Similar to Alternative 3 but adds PRB at Block F.** | **Addresses several shortcomings of Alternatives 3 and 4. Potentially reduces pumping duration and O&M cost. Uses pumping component to enhance ZVI curtain performance.** | **PRB will likely need to be re-installed in 5 years after its performance declines. Higher capital costs than some other alternatives.** |
| 7 | Adds vacuum-enhanced recovery to alternatives featuring groundwater extraction | Adds vacuum-enhanced recovery to alternatives with groundwater extraction | Increases TCE mass removal and therefore reduces overall pumping duration | Increased capital and installation costs, more difficult and costly O&M. |

**Table 3-3**
**Long List of Remedial Alternatives for the Groundwater Response Action in Blocks E and F**
**Lockheed Martin Middle River Complex, Middle River, Maryland**


| Number | Alternative | Description | Pros | Cons |
|---|---|---|---|---|
| 8 | Thermal treatment in Blocks E and F, MNA/LUCs | Thermal treatment of the TCE plume in Block E and F. | Effective in low permeability settings. Significant, short-duration mass removal. | Very high implementation cost. Uncertain power source. Uncertain teratment under the road. Dark Head Cove aqueous organsims could be adversely affected by the increased temperatures. |
| 9 | ARD in Blocks E and F, MNA/LUCs | Installation of additional injection wells in Block F similar to Block E. Substrate injection in Blocks E and F using existing ARD injection system in Block E . | Shown to be effective in Block I and especialy at Block G at the Middle River Complex. Could use the exsting injection equipment for both Block E and F. | Same cons as for Alternative 9 but with increased concerns for Dark Head Cove as injections will be much closer to Dark Head Cove. |

Bolded Alternatives are retained.

**Table 3-4**
**Analysis of Short-List Alternatives using CERCLA Criteria**
**Lockheed Martin Middle River Complex, Middle River, Maryland**

| Evaluation Criterion | Alternative 1<br>Existing anerobic reductive dechlorination (ARD) in Block E with monitored natural attenuation (MNA) / land use controls (LUCs) in Block F | Alternative 2<br>Hydraulic containment in Block F; existing ARD in Block E; MNA/LUCs | Alternative 3<br>Hydraulic containment and zero valent iron (ZVI) permeable reactive barrier (PRB) in Block F; existing ARD in Block E; MNA/LUCs |
|---|---|---|---|
| Overall Protection of Human Health and Environment | Protective of human health and the environment based on currect site conditions; but, does not provide containment of contaminated groundwater migrated toward Dark Head Cove. Does not provide a contingency if conditions change and risk is present. | Protective. Provides mass reduction and containment of groundwater. | Protective. Provides mass reduction and containment of groundwater. Additional containment provided by ZVI PRB. |
| Compliance with Applicable or Relevant and Appropriate Requirements (ARARs)/Meets Remdial Action Alternatives (RAOs): | Compliant with ARARs but does not meet RAO 1. | Compliant with ARARs and will meet RAOs. | Compliant with ARARs and will meet RAOs. |
| Long-Term Effectiveness and Permanence | Does not provide long-term effectiveness in the prevention of migration of contaminated groundwater toward Dark Head Cove. | Provides for long-term effectiveness in meeting RAOs, but does not provide residual treatment following the shut down of groundwater extraction (as is the case for Alternative 3). | Provides for long-term effectiveness in meeting RAOs. |
| Short-Term Effectiveness | Provides the most protection to workers and the community during implementation because there are no associated construction activities. However, does not reduce the migration of the contaminated groundwater toward Dark Head Cove in the short term. | Least intensive construction activities. Provides reductions in migration toward Dark Head Cove as soon as the groundwater extraction is initiated. | Relatively non-intensive construction activities. Provides reductions in migration toward Dark Head Cove as soon as the groundwater extraction is initiated. |
| Reduction of Contaminant Toxicity, Mobility, or Volume through Treatment | Provides reductions in toxicity and volume through treatment in Block E, but does not provide any treatment is Block F. | In Block E, provides reductions in toxicity and volume through ARD. In Block F, provides reductions in mobility through containment, but all treatment transfers the contaminants to activated carbon, it does not destroy them (until off-site regeneration). | In Block E, provides reductions in toxicity and volume through ARD. In Block F, provides reductions in mobility through containment, and reductions in toxicity and volume through treatment in the ZVI PRB. |
| Implementability | Readily implementable; all infrastructure currently on site and permits obtained. Can use experience from injections in other areas of the site. Monitoring of the remedy is straightforward. | Readily implementable; fairly minor construction activities. Permitting may be time-consuming, but similar permits have been obtained at the site. Monitoring of the remedy is straightforward. | Readily implementable; multiple subcontractors available to complete ZVI curtain installation. Permitting may be time-consuming, but similar permits have been obtained at the site. Monitoring of the remedy is straightforward. |
| Life Cycle Impacts | Lowest life cycle impacts; provides least protection. | Less intensive installation, but longer operation and maintenance (O&M) period that Alternative 3. | Moderate installation impacts, but shorter O&M period. |
| <u>Costs</u>:<br>Capital<br>O&M/LTM (10 Years)<br>Total | <br>$0<br>$785,000<br>$785,000 | <br>$350,000<br>$1,630,000<br>$1,980,000 | <br>$660,000<br>$1,560,000<br>$2,220,000 |

**Table 3-5**
***Criterium® DecisionPlus®* Weights and Rankings**
**Lockheed Martin Middle River Complex, Middle River, Maryland**

| Weighting | | | | | | Rankings | | |
|---|---|---|---|---|---|---|---|---|
| ***Weights*** | ***Criteria*** | ***Weights*** | ***Sub-Criteria 1*** | ***Weights*** | ***Sub-Criteria 2*** | **Alternative 1** | **Alternative 2** | **Alternative 3** |
| 90 | Overall protection of human health and environment | | | | | 40 | 70 | 80 |
| 90 | Compliance with ARARs/meets RAOs | | | | | 20 | 80 | 85 |
| 80 | Long-term effectiveness and permanence | 90 | Technical reliability | | | 40 | 70 | 90 |
| | | 40 | Residual potential risk | | | 40 | 70 | 90 |
| 75 | Reduction of toxicity, mobility and volume through treatment | 50 | Destruction of hazardous constituents | | | 60 | 60 | 90 |
| | | 40 | Irreversibility of treatment | | | 80 | 85 | 90 |
| 70 | Short-term effectiveness | 50 | Time to achieve remedial action objectives (RAOs) | | | 40 | 85 | 90 |
| | | 50 | Un-mitigatable adverse impacts | 90 | Minimize environmental impacts | 80 | 75 | 75 |
| | | | | 90 | Protect construction workers | 90 | 80 | 70 |
| | | | | 100 | Protect community | 60 | 80 | 90 |
| 90 | Implementabilty | 75 | Obtaining other approvals | | | 90 | 80 | 70 |
| | | 100 | Constructability | | | 100 | 90 | 85 |
| | | 25 | Availability of experts and technology | | | 100 | 95 | 95 |
| | | 35 | Compatibility with existing remediation | | | 100 | 90 | 90 |
| | | 60 | Effectiveness of monitoring | | | 100 | 100 | 100 |
| 40 | Life-cycle impacts | 50 | | | | 80 | 60 | 70 |
| 75 | Cost | 50 | Capital | | | 100 | 60 | 50 |
| | | 50 | Operation, maintenance, and monitoring (OMM) | | | 100 | 40 | 60 |
| | | | | | | **0.277** | **0.341** | **0.382** |

**Table 4-1**
**Block F TCE Mass Discharge Estimate**
**Lockheed Martin Middle River Complex, Middle River, Maryland**

***Hydraulic Properties***

| | Layer 1 | Layer 2 | Layer 3 |
|---|---|---|---|
| Hydraulic gradient | 0.01 | | |
| Saturated thickness (ft) | 15 | 14 | 0.5 |
| Hydraulic conductivity (ft/day) | 0.50 | 2.50 | 375 |

| TCE mass discharge section description | Transect A: between DPT points B-4 and B-6 | | | Transect B: between DPT points C-1 and C-7 | | | Transect C: between DPT points D-10 and D-6 | | | Wells-based calculation: 8I/S, 9I/S, EW-1 and EW-2 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Section length (ft)** | 65 | | | 72 | | | 140 | | | 75 | | |
| | **Layer 1** | **Layer 2** | **Layer 3** | **Layer 1** | **Layer 2** | **Layer 3** | **Layer 1** | **Layer 2** | **Layer 3** | **Layer 1** | **Layer 2** | **Layer 3** |
| Average layer TCE (mg/L) | 2.27 | 6.65 | 12 | 9.71 | 14.03 | 7.77 | 4.77 | 2.10 | 0.87 | 21.00 | 7.69 | 5.80 |
| Layer flow (gpd) | 36 | 170 | 912 | 40 | 188 | 1010 | 79 | 367 | 1964 | 40 | 188 | 1010 |
| Section combined flow (gpd) | 1118 | | | 1239 | | | 2409 | | | 1239 | | |
| Layer TCE mass discharge (lbs/year) | 0.25 | 3.45 | 34.24 | 1.19 | 8.05 | 23.88 | 1.14 | 2.34 | 5.17 | 2.58 | 4.41 | 17.83 |
| Section combined TCE mass discharge (lbs/year) | **37.9** | | | **33.1** | | | **8.7** | | | **24.8** | | |
| Average TCE mass discharge (lbs/year) | 26 | | | | | | | | | | | |
| Median TCE mass discharge (lbs/year) | 29 | | | | | | | | | | | |

ft - feet
ft/day - feet per day
gpd - gallons per day
lbs/year - pounds per year
mg/L - milligrams per liter
TCE - trichloroethene

TCE mass discharge Transect A: TCE values for layers are the average between six DPT points (B-4 though B-6). The average value for shallow DPTs are used for Layer 1; intermediate DPTs for Layer 2: and deep DPTs for Layer 3.

TCE mass discharge Transect B: TCE values for layers are the average between six DPT points (C-1 though C-7). Same approach as for Section A.

TCE mass discharge Transect C: TCE values for layers are the average between eoght DPT points (D-10 though D-6). Same approach as for Sections A and C.

**Table 4-2**
**Block F ZVI Formation Demand Estimate**
**Lockheed Martin Middle River Complex, Middle River, Maryland**

**ZVI PRB length (feet)** **100**
**Hydraulic gradient** **0.01**

| | Layer 1 | Layer 2 | Layer 3 |
|---|---|---|---|
| Saturated thickness (feet) | 15 | 14 | 0.5 |
| Hydraulic conductivity (feet/day) | 0.50 | 2.50 | 375 |
| Flow (gallons/day) | 56 | 262 | 1403 |
| Trichloroethene (mg/L) | 22 | 22 | 5.8 |
| Sulfate (mg/L) | 7.9 | 7.9 | 7.0 |
| Nitrates (mg/L) | 1.1 | 1.1 | 1.0 |
| Dissolved oxygen (mg/L) | 2.0 | 2.0 | 2.0 |

**Combined flow across ZVI PRB (gallons/day)** **1720**
**Formation porosity (%)** **25%**

| | Acceptor flux* (pounds/year) | Molar mass (grams/mole) | Stoichiometric iron demand (mole iron required per mole of acceptor) | Stoichiometric iron demand (pounds ZVI/ yr) | Stoichiometric iron demand (pounds ZVI /5 yr) |
|---|---|---|---|---|---|
| Trichloroethene | 46 | 131 | 6 | 39 | |
| Sulfate | 38 | 96 | 8 | 58 | |
| Dissolved oxygen | 10 | 32 | 4 | 24 | |
| Nitrate | 5 | 62 | 5 | 8 | |
| | 99 | | **Total ZVI:** | **130** | |
| | | **ZVI demand with safety factor of 5 =** | | **651** | **3256** |
| | | **ZVI demand with safety factor of 10 =** | | **1302** | **6511** |

* Used analytical data for EW-1 under pumping conditions (assumed the same for all layers)

| Electron donors | Molar mass (grams/mole) | Electrons per mole |
|---|---|---|
| ZVI | 56 | 3 |

mg/L - milligrams per liter
ZVI - zero valent iron

**Table 4-3**
**Block F ZVI Estimate Based on Target In Situ Concentration**
**Lockheed Martin Middle River Complex, Middle River, Maryland**

| | | |
|---|---|---|
| Length of ZVI PRB | 100 | feet |
| Injection points spacing | 5 | feet |
| No of injection locations | 21 | |
| Saturated thickness (feet) | 25 | |
| Injection cylinder overlap | 33% | |
| Injection cylinder radius | 3.33 | feet |
| Formation porosity (%) | 25% | |
| Total pore volume | 34270 | gallons |
| Pore volume replacement (%) | 100% | |
| Total injection volume | 34270 | gallons |
| *In-situ* ZVI dose | 15 | grams/Liter |
| Total ZVI (pounds) | 4303 | pounds |
| Injection volume per five-foot interval | 326 | gallons |
| ZVI per five-foot interval | 41 | pounds |

ZVI - zero-valent iron

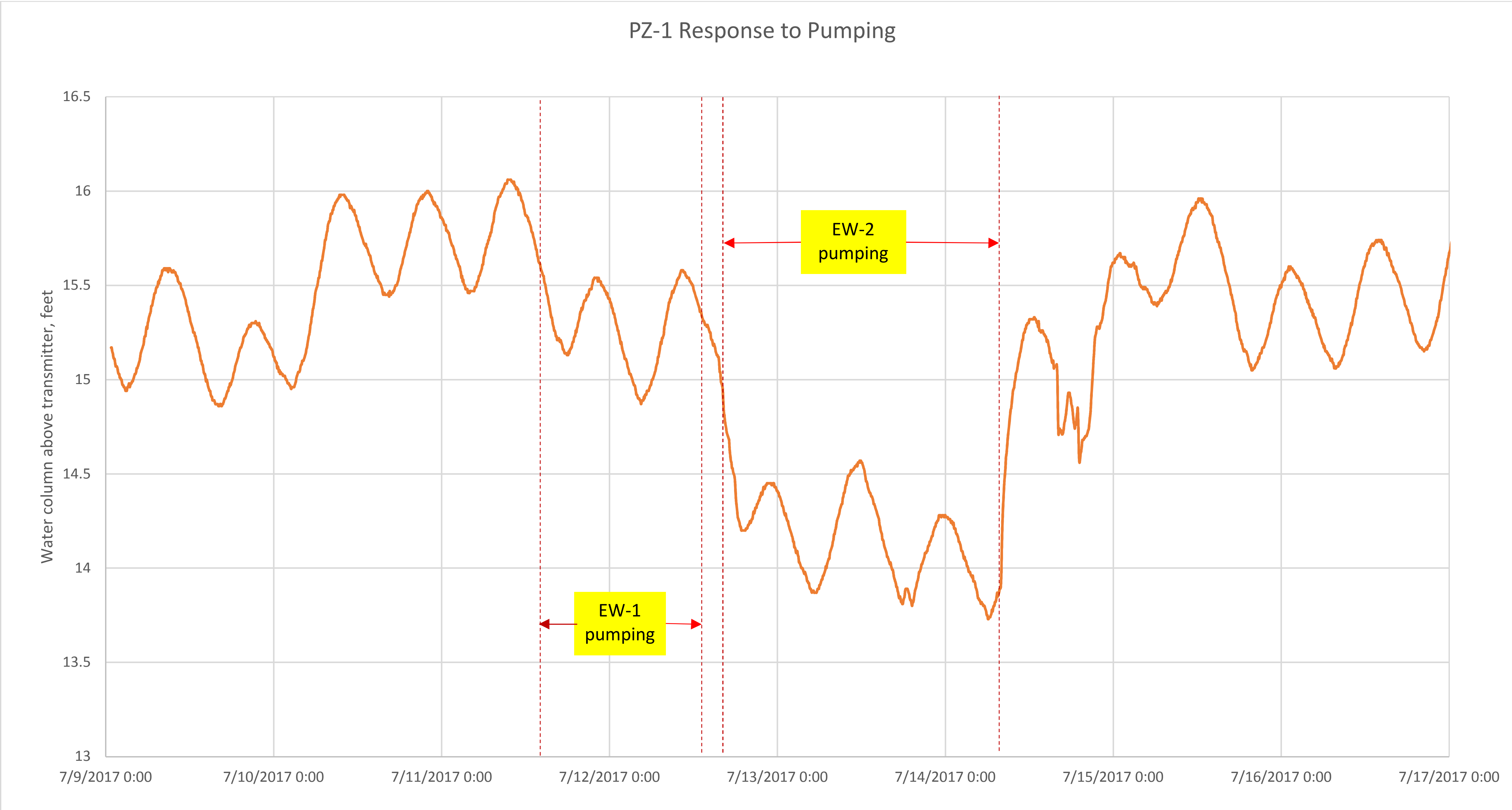
# APPENDICES

## Appendix A—Monitoring-Well Hydraulic Response and Dark Head Cove Tidal Measurements

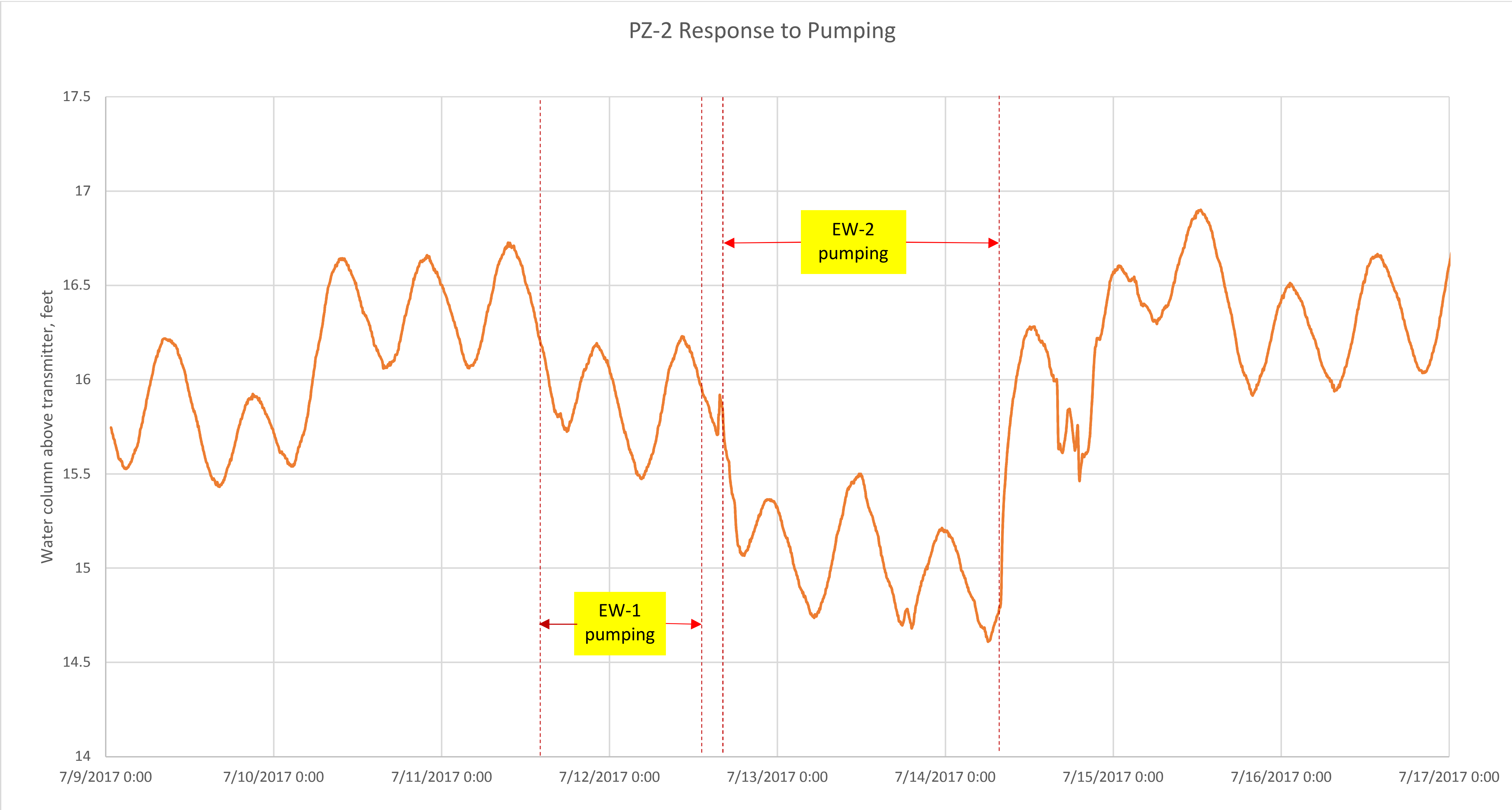
## Appendix B—Remedial Alternative Cost Estimates

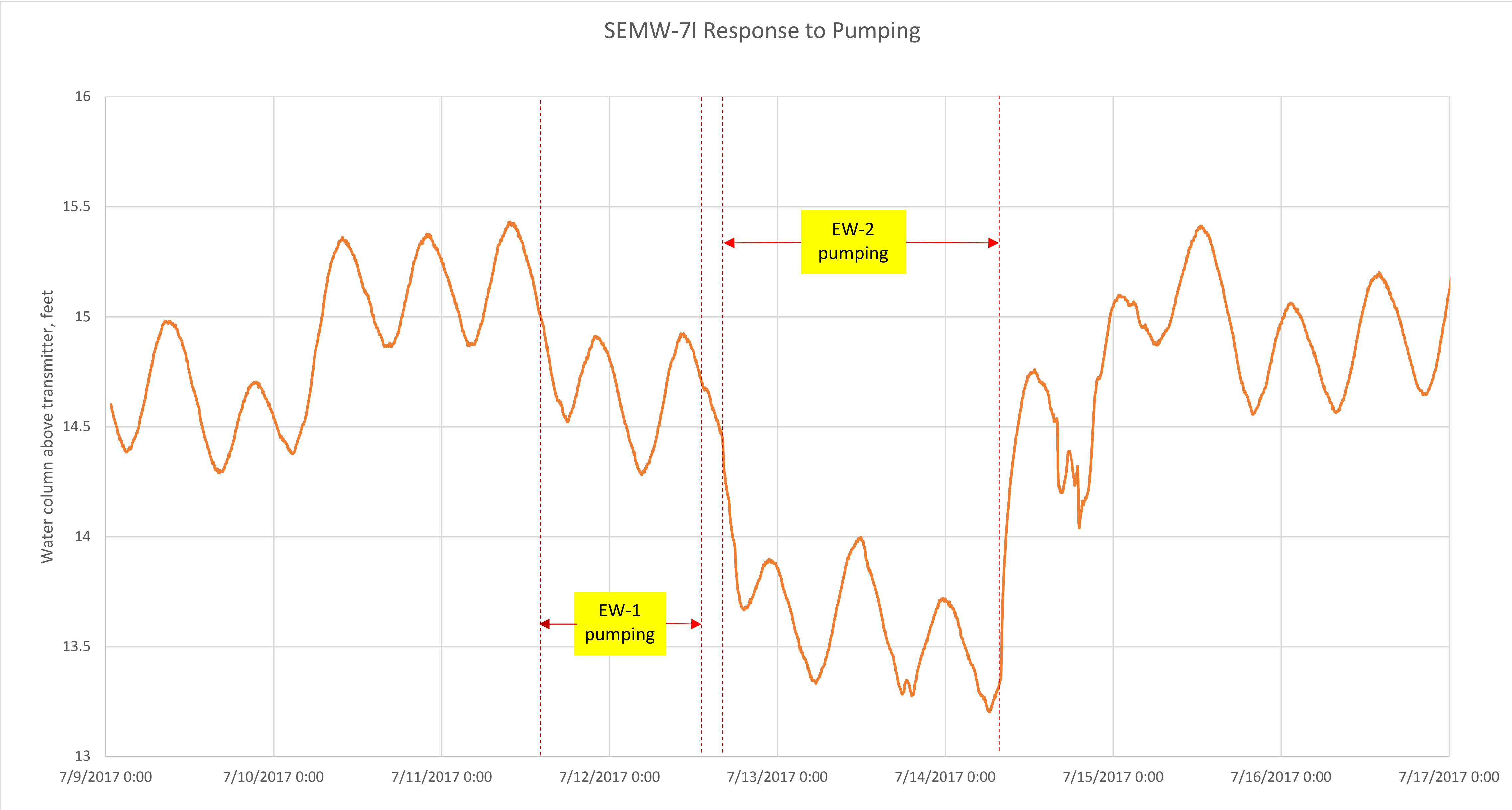
## Appendix C—*Criterium® DecisionPlus®* Alternative Analysis Results

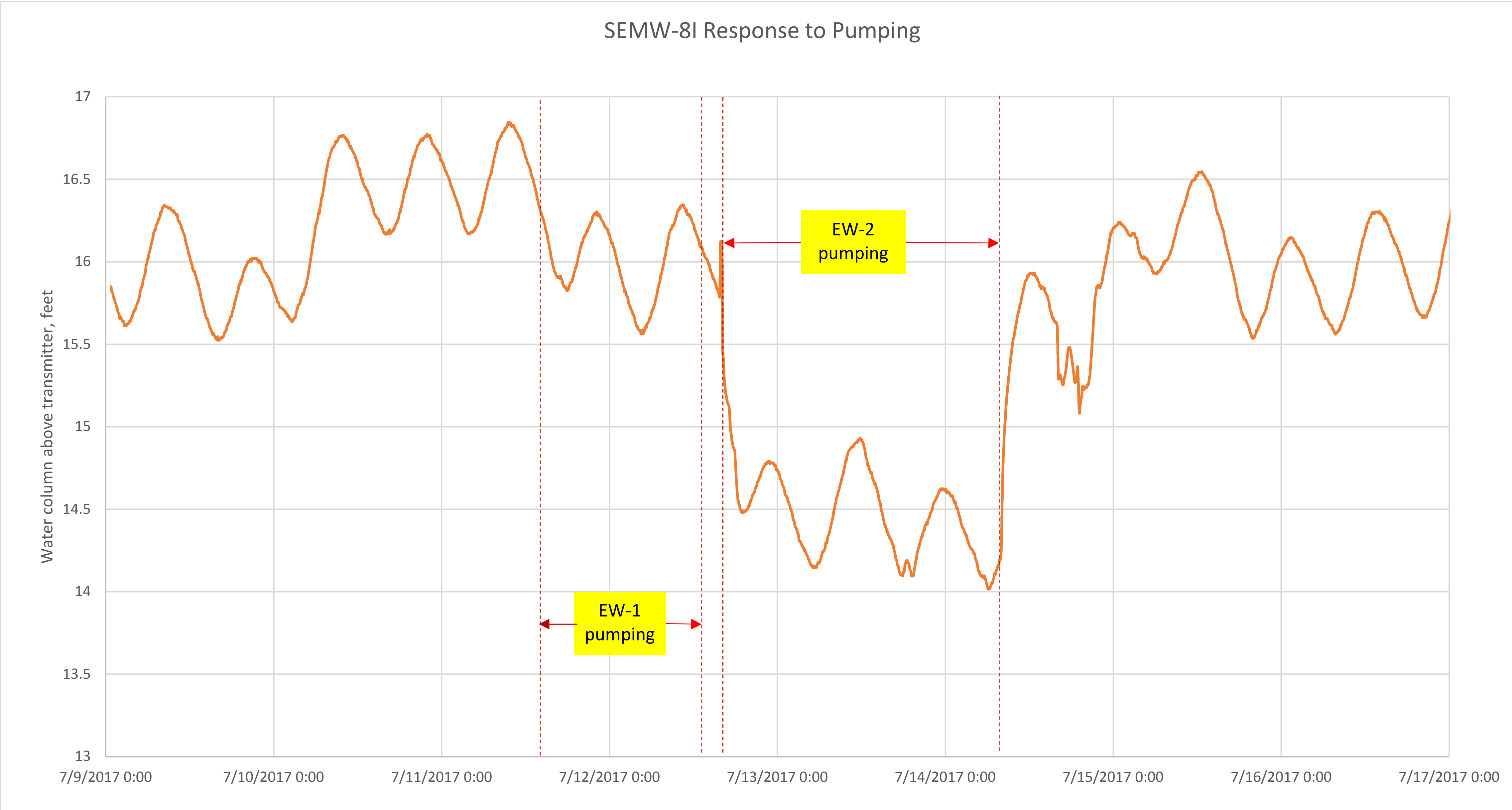
# Appendix A—Monitoring-Well Hydraulic Response and Dark Head Cove Tidal Measurements



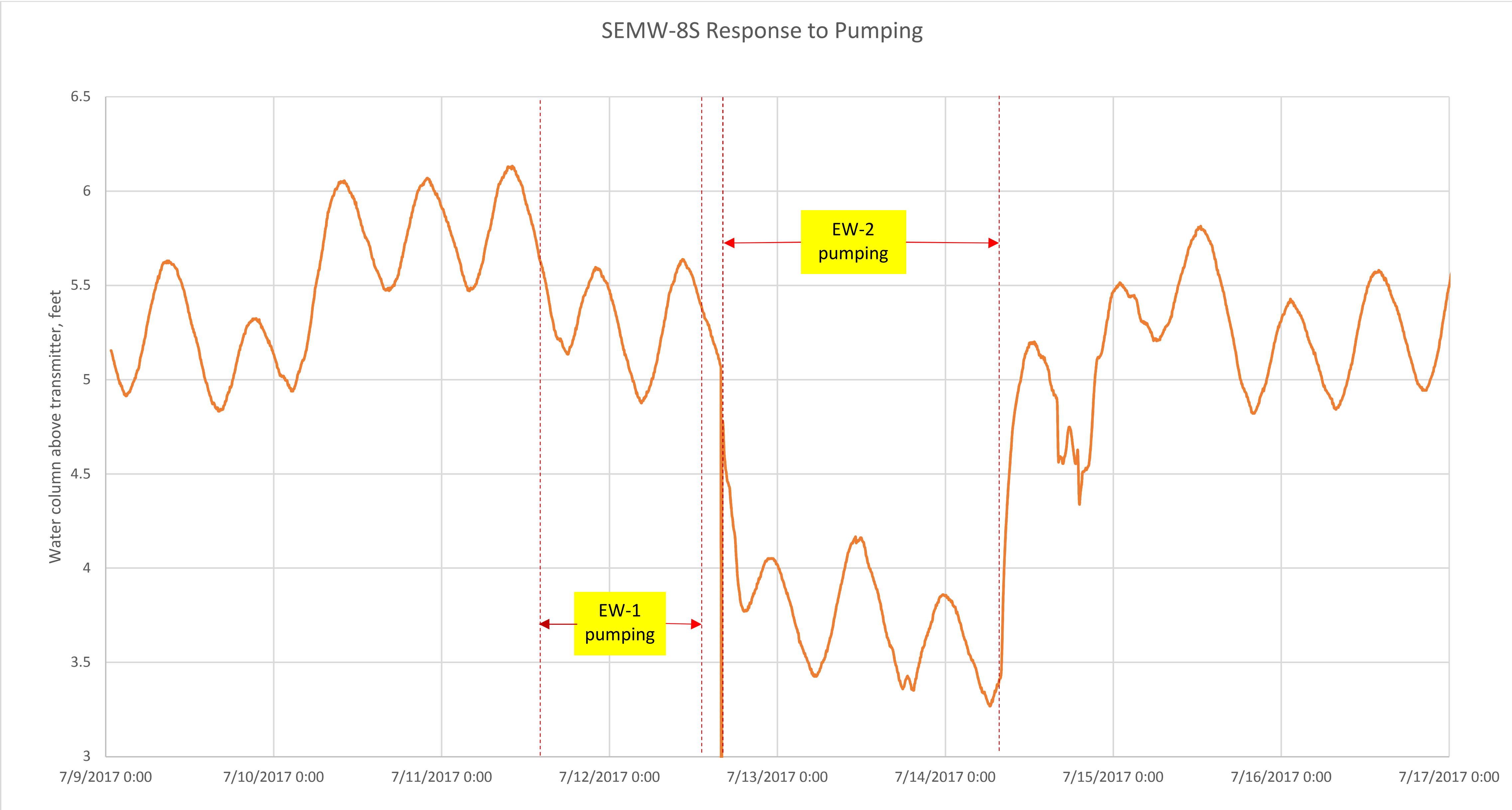
PZ-1 Response to Pumping
Water column above transmitter, feet
16.5
16
15.5
15
14.5
14
13.5
13
7/9/2017 0:00
7/10/2017 0:00
7/11/2017 0:00
7/12/2017 0:00
7/13/2017 0:00
7/14/2017 0:00
7/15/2017 0:00
7/16/2017 0:00
7/17/2017 0:00
EW-2 pumping
EW-1 pumping

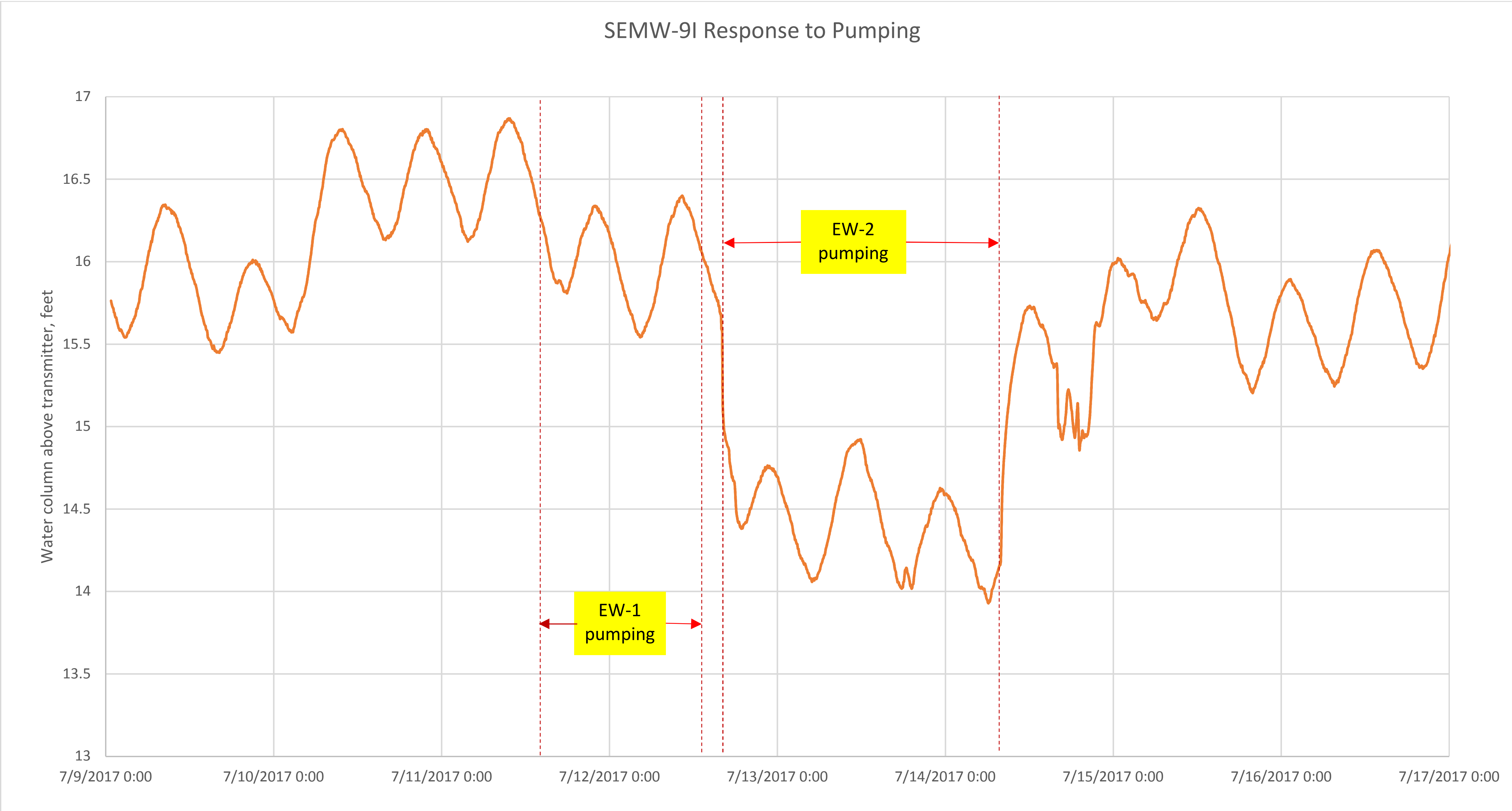

PZ-2 Response to Pumping
Water column above transmitter, feet
17.5
17
16.5
16
15.5
15
14.5
14
7/9/2017 0:00
7/10/2017 0:00
7/11/2017 0:00
7/12/2017 0:00
7/13/2017 0:00
7/14/2017 0:00
7/15/2017 0:00
7/16/2017 0:00
7/17/2017 0:00
EW-2 pumping
EW-1 pumping


SEMW-7I Response to Pumping
Water column above transmitter, feet
16
15.5
15
14.5
14
13.5
13
7/9/2017 0:00
7/10/2017 0:00
7/11/2017 0:00
7/12/2017 0:00
7/13/2017 0:00
7/14/2017 0:00
7/15/2017 0:00
7/16/2017 0:00
7/17/2017 0:00
EW-1 pumping
EW-2 pumping

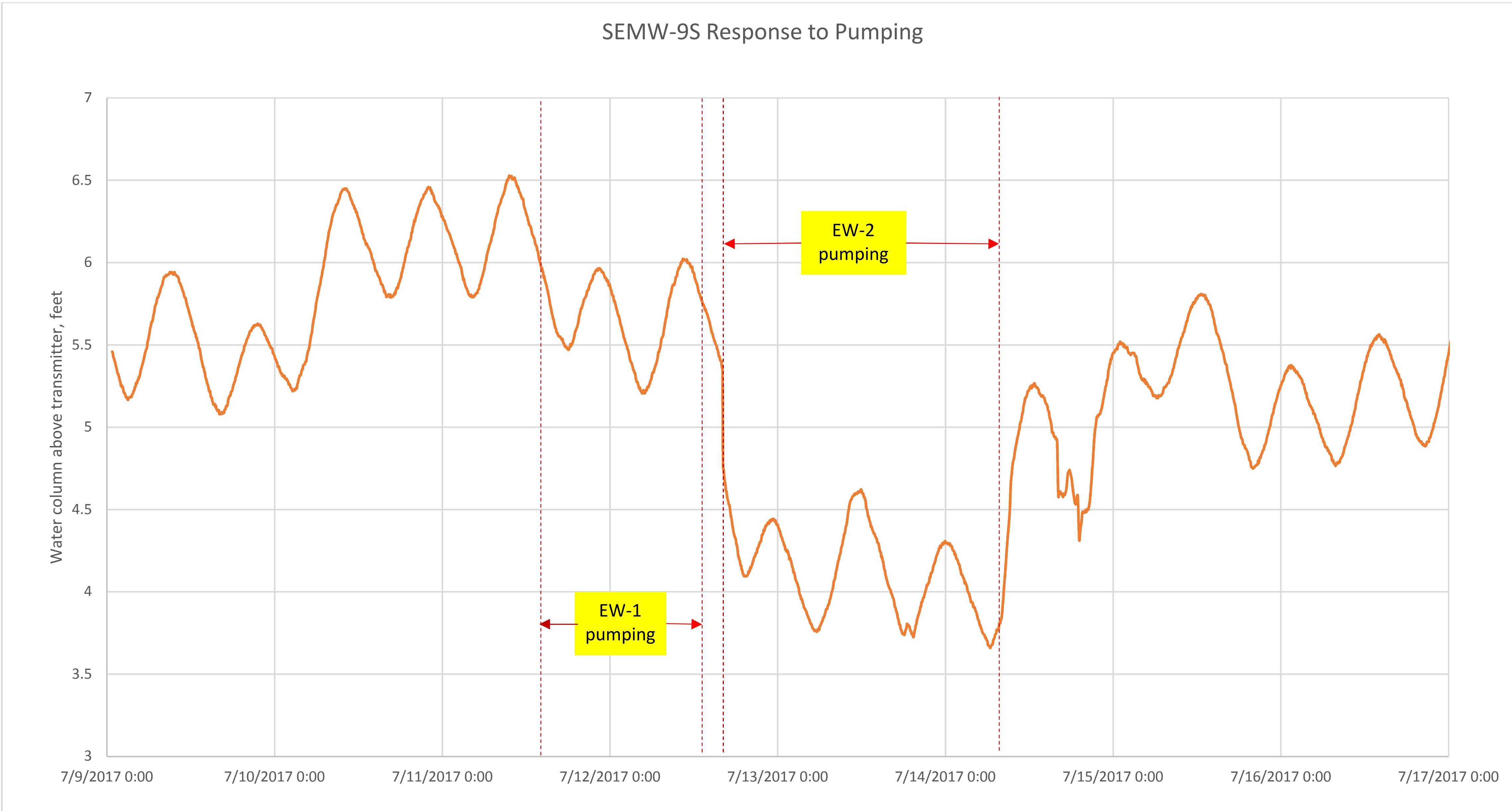


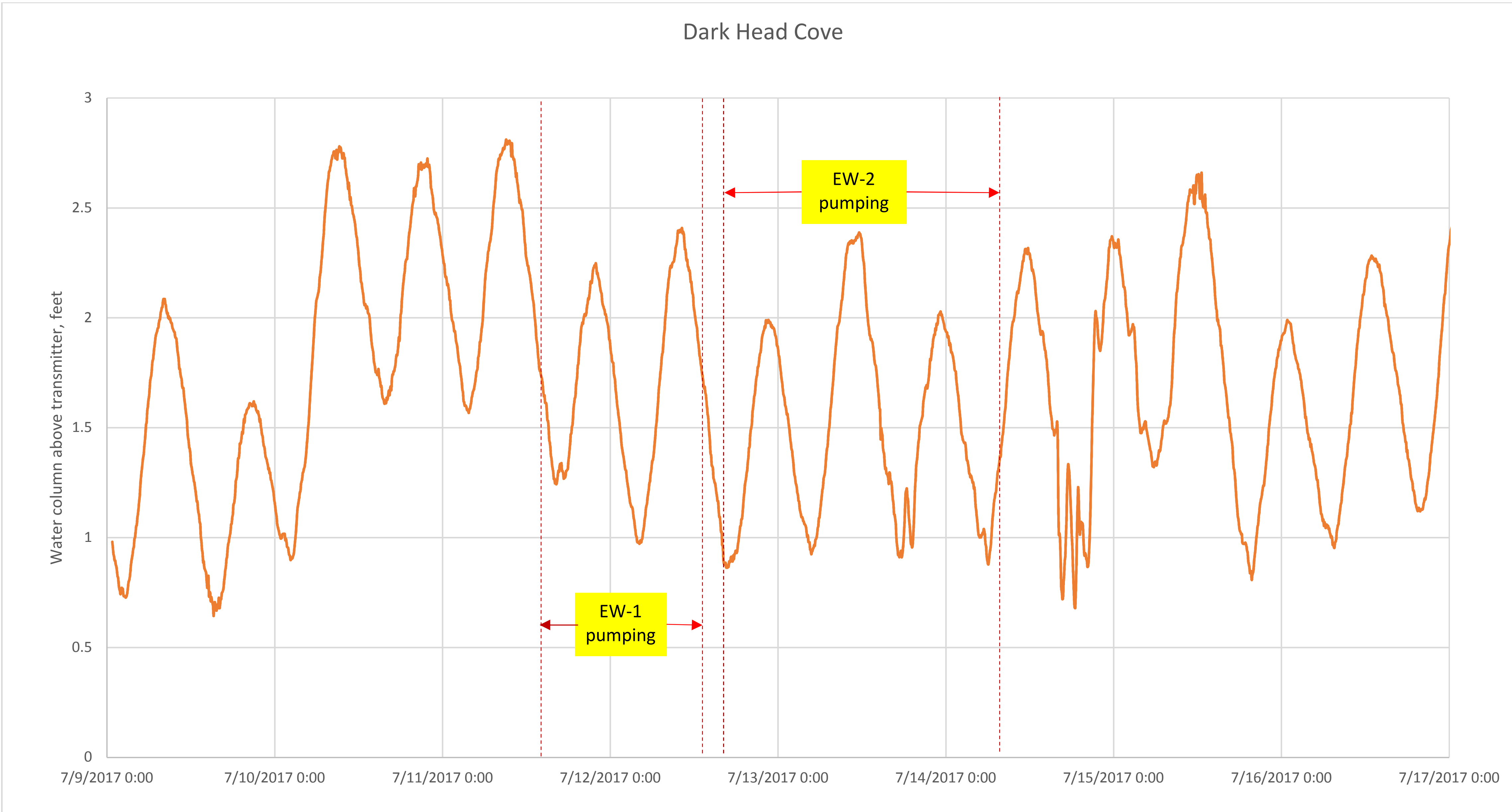
SEMW-8I Response to Pumping
Water column above transmitter, feet
17
16.5
16
15.5
15
14.5
14
13.5
13
7/9/2017 0:00
7/10/2017 0:00
7/11/2017 0:00
7/12/2017 0:00
7/13/2017 0:00
7/14/2017 0:00
7/15/2017 0:00
7/16/2017 0:00
7/17/2017 0:00
EW-2 pumping
EW-1 pumping


SEMW-8S Response to Pumping
Water column above transmitter, feet
6.5
6
5.5
5
4.5
4
3.5
3
7/9/2017 0:00
7/10/2017 0:00
7/11/2017 0:00
7/12/2017 0:00
7/13/2017 0:00
7/14/2017 0:00
7/15/2017 0:00
7/16/2017 0:00
7/17/2017 0:00
EW-2 pumping
EW-1 pumping



SEMW-9I Response to Pumping
Water column above transmitter, feet
17
16.5
16
15.5
15
14.5
14
13.5
13
7/9/2017 0:00
7/10/2017 0:00
7/11/2017 0:00
7/12/2017 0:00
7/13/2017 0:00
7/14/2017 0:00
7/15/2017 0:00
7/16/2017 0:00
7/17/2017 0:00
EW-2 pumping
EW-1 pumping


SEMW-9S Response to Pumping
Water column above transmitter, feet
7
6.5
6
5.5
5
4.5
4
3.5
3
7/9/2017 0:00
7/10/2017 0:00
7/11/2017 0:00
7/12/2017 0:00
7/13/2017 0:00
7/14/2017 0:00
7/15/2017 0:00
7/16/2017 0:00
7/17/2017 0:00
EW-2
pumping
EW-1
pumping


Dark Head Cove
Water column above transmitter, feet
3
2.5
2
1.5
1
0.5
0
7/9/2017 0:00
7/10/2017 0:00
7/11/2017 0:00
7/12/2017 0:00
7/13/2017 0:00
7/14/2017 0:00
7/15/2017 0:00
7/16/2017 0:00
7/17/2017 0:00
EW-2 pumping
EW-1 pumping

# Appendix B—Remedial Alternative Cost Estimates

**MRC Block F Groundwater Remediation Alternatives Cost Summary**
**MRC Blocks E and F RAP Addendum**

| Alternative | Capital Cost | ARD 1st Injection[1] | ARD 2nd Injection[1] | ARD 3rd Injection[1] | Years 1 to 4 O&M Cost | Years 5 to 8 O&M Cost | Years 9 to 12 O&M Cost | 5th year PRB Curtain re-installation[1] | O&M Duration years | Total O&M Cost | Bi-annual MNA (Year 1) | Bi-annual MNA (Year 2) | Total MNA Duration years | Total MNA Cost | Total Cost |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Alternative 1: ARD, MNA, LUCs** | | $260,000 | $161,000 | $280,000 | | | | | | $701,000 | $32,000 | $52,000 | 2 | $84,000 | $785,000 |
| **Alternative 2: Hydraulic Containment in Block F, existing ARD in Block E, MNA, LUCs** | $350,000 | $260,000 | $161,000 | $280,000 | $356,000 | $272,000 | $216,000 | | 12 | $1,545,000 | $32,000 | $52,000 | 2 | $84,000 | $1,979,000 |
| **Alternative 3: Hydraulic Containment and PRB in Block F, existing ARD in Block E, MNA, LUCs** | $659,000 | $260,000 | $161,000 | $280,000 | $356,000 | $272,000 | | $142,000 | 8 | $1,471,000 | $32,000 | $52,000 | 2 | $84,000 | $2,214,000 |

[1]Costs for ARD injection events in Block E and PRB curtain re-installation (year 5) are considered as part of O&M

**Cost Estimate for Alternative 1 - Existing ARD in Block E, MNA/LUCs**
**MRC Blocks E and F RAP Addendum**

**ARD 1st Injection Event**

| Item | Description | Qty | Units | $/Unit | Cost |
|---|---|---|---|---|---|
| System start-up | Equipment repair and preparation | 1 | ls | $10,000 | $10,000 |
| System O&M | Phase A and B injection | 1 | ls | $75,000 | $75,000 |
| Bioaugmentation | 1 field week, 2 people | 1 | ls | $20,000 | $20,000 |
| Performance Monitoring | Between phases and post injection | 6 | days | $1,500 | $9,000 |
| Substrate | Sodium lactate | 14300 | lbs | 1.25 | $17,875 |
| pH buffer | Sodium bicarbonate | 2400 | lbs | 0.60 | $1,440 |
| DHC cultures | *Dehalococcoides* | 160 | L | $250 | $40,000 |
| PM/coordination/oversight | | 120 | hours | $170 | $20,400 |
| Reporting | Post injection | 1 | ls | $20,000 | $20,000 |
| Analytical sampling | Performance monitoring (2 events) | 2 | ls | $6,000 | $12,000 |
| Frac tank for bioaugmentation | Includes cleaning | 1 | ls | $5,000 | $5,000 |
| Electric power | 3 KW load for 3 months | 6552 | kwh | $0.12 | $786 |
| Equipment maintenance | | 1 | unit | $2,500 | $2,500 |
| Expenses | Travel, meals, hotels, fuel | 1 | ls | $25,000 | $25,000 |
| **ARD 1st injection event total** | | | | | **$259,001** |

**ARD 2nd Injection Event**

| Item | Description | Qty | Units | $/Unit | Cost |
|---|---|---|---|---|---|
| System start-up | Equipment repair and preparation | 1 | ls | $2,000 | $2,000 |
| System O&M | One injection event | 1 | ls | $40,000 | $40,000 |
| Performance Monitoring | 2 events | 6 | days | $1,500 | $9,000 |
| Substrate | Sodium lactate | 10725 | lbs | 1.25 | $13,406 |
| pH buffer | Sodium bicarbonate | 1800 | lbs | 0.60 | $1,080 |
| PM/coordination/oversight | | 120 | hours | $170 | $20,400 |
| Reporting | Post injection | 1 | ls | $20,000 | $20,000 |
| RA completion report | Block E | 1 | ls | $25,000 | $25,000 |
| Analytical sampling | Performance monitoring (2 events) | 2 | ls | $6,000 | $12,000 |
| Equipment maintenance | | 1 | unit | $2,500 | $2,500 |
| Expenses | Travel, meals, hotels, fuel | 1 | ls | $15,000 | $15,000 |
| **Annual O&M cost** | | | | | **$160,386** |

## Cost Estimate for Alternative 1 - Existing ARD in Block E, MNA/LUCs
## MRC Blocks E and F RAP Addendum

**ARD 3rd Injection Event**

| Item | Description | Qty | Units | $/Unit | Cost |
|---|---|---|---|---|---|
| System start-up | Equipment repair and preparation | 1 | ls | $10,000 | $10,000 |
| System O&M | Phase A and B injection | 1 | ls | $75,000 | $75,000 |
| Bioaugmentation | 1 field week, 2 people | 1 | ls | $20,000 | $20,000 |
| Performance Monitoring | 3 events | 9 | days | $1,500 | $13,500 |
| Substrate | Sodium lactate | 14300 | lbs | 1.25 | $17,875 |
| pH buffer | Sodium bicarbonate | 2400 | lbs | 0.60 | $1,440 |
| DHC cultures | *Dehalococcoides* | 160 | L | $250 | $40,000 |
| PM/coordination/oversight | | 120 | hours | $170 | $20,400 |
| Reporting | Post injection | 1 | ls | $30,000 | $30,000 |
| Analytical sampling | Performance monitoring (3 events) | 3 | ls | $6,000 | $18,000 |
| Frac tank for bioaugmentation | Includes cleaning | 1 | ls | $5,000 | $5,000 |
| Electric power | 3 KW load for 3 months | 6552 | kwh | $0.12 | $786 |
| Equipment maintenance | | 1 | unit | $2,500 | $2,500 |
| Expenses | Travel, meals, hotels, fuel | 1 | ls | $25,000 | $25,000 |
| **ARD 1st injection event total** | | | | | **$279,501** |

**ARD system total** **$698,889**

**Alternative 1 Long Term Monitoring (year 1)**

| Item | Description | Qty | Units | $/Unit | Cost |
|---|---|---|---|---|---|
| Sampling (labor and analytical) | Bi-annual | 2 | ea | $10,000 | $20,000 |
| Management/coordination | Bi-annual | 2 | ea | $1,000 | $2,000 |
| Reporting | Bi-annual | 2 | ea | $5,000 | $10,000 |
| **Annual LTM cost** | | | | | **$32,000** |

**Alternative 1 Long Term Monitoring (year 2)**

| Item | Description | Qty | Units | $/Unit | Cost |
|---|---|---|---|---|---|
| Sampling (labor and analytical) | Bi-annual | 2 | ea | $10,000 | $20,000 |
| Management/coordination | Bi-annual | 2 | ea | $1,000 | $2,000 |
| Reporting | Bi-annual | 2 | ea | $5,000 | $10,000 |
| Remedial Action Completion Report | | 1 | ea | $20,000 | $20,000 |
| **Annual LTM cost** | | | | | **$52,000** |

## Cost Estimate for Alternative 2 - Hydraulic Containment in Block F, existing ARD in Block E, MNA/LUCs MRC Blocks E and F RAP Addendum

### 1. Groundwater Extraction System Capital Cost

**Groundwater extraction subsurface components**

| Item | Description | Qty | Units | $/Unit | Cost |
|---|---|---|---|---|---|
| Conveyance piping to treatment system installation | | | | | |
| Trenching subcontractor, materials | 1" PEX lines to treatment plant, 1 1/4" HDPE line to discharge | 400 | feet | $60 | $24,000 |
| Road crossing | Traffic control, permitting | 1 | ls | $10,000 | $10,000 |
| Debris disposal for trenching | Asphalt and concrete (10% of trench volume assumed) | 100 | c.y | $25 | $2,500 |
| Trench installation oversight (engineer) | 50' of conveyance piping per day | 8 | days | $1,500 | $12,000 |
| Extraction wells and pumps installation | | | | | |
| Vaults for extraction wells (labor, materials) | 2'x2' vaults, 5'x5' concrete pads | 2 | ls | $1,500 | $3,000 |
| Pumps and level sensors for extraction wells (equipment, installation) | 0.5 hp pumps, pressure transmitters | 2 | ls | $2,500 | $5,000 |
| Management/planning | Documentation, planning, management, permitting | 5 | days | $2,500 | $12,500 |
| Contingency (20% of total) | | 20% | ls | | $11,300 |
| Design/Engineering (15% of total) | | 15% | ls | | $10,350 |
| **Groundwater extraction subsurface components subtotal** | | | | | **$90,650** |

**Aboveground treatment plant components**

| Item | Description | Qty | Units | $/Unit | Cost |
|---|---|---|---|---|---|
| Equipment building | 15' x 25', pre-fabricated, bay doors, insulated | 375 | sf | $50 | $18,750 |
| Equipment building foundation | 17' x 27' concrete slab, includes grading | 459 | sf | $20 | $9,180 |
| Air stripper | Shallow tray, 50 gpm,350 scfm | 1 | unit | $25,000 | $25,000 |
| LGAC vessels | 500 lbs GAC each, 30" dia, steel, TIGG CL500 | 2 | unit | $6,600 | $13,200 |
| VGAC vessels | 1,000 lbs GAC each, 46" dia, steel, TIGG N1200 PDB | 2 | unit | $10,800 | $21,600 |
| Bag filters | Aluminum housing | 2 | unit | $1,000 | $2,000 |
| Electric Service | Panels/Motor Controls | 1 | unit | $10,000 | $10,000 |
| Control Panel/Programming | SCADA, touch-screen panel, remote access via cellular network | 1 | unit | $10,000 | $10,000 |
| Piping and instrumentation | Various | 1 | unit | $10,000 | $10,000 |
| Oversight cost (engineer) | 10 field days assumed for construction | 10 | days | $2,000 | $20,000 |
| Management/planning | Documentation, planning, management | 5 | days | $2,500 | $12,500 |
| Dishargce permit | NPDES permit (or sewer or injection) | 10 | days | $2,500 | $25,000 |
| Other permitting | Road crossing, grading, etc. | 10 | days | $2,500 | $25,000 |
| Contingency (20% of total) | | 20% | ls | | $30,446 |
| Design/Engineering (15% of total) | | 15% | ls | | $22,835 |
| **Aboveground treatment plant components subtotal** | | | | | **$255,511** |

**Groundwater Extraction System total capital cost** **$346,161**

**Cost Estimate for Alternative 2 - Hydraulic Containment in Block F, existing ARD in Block E, MNA/LUCs MRC Blocks E and F RAP Addendum**

## 2. Groundwater Treatment System O&M cost

**Years 1 to 4 Treatment System Annual O&M**

| Item | Description | Qty | Units | $/Unit | Cost |
|---|---|---|---|---|---|
| Periodic system O&M | Every 2 weeks | 26 | visits | $1,500 | $39,000 |
| Management/coordination | 4 hours/month | 48 | hours | $150 | $7,200 |
| Reporting | NPDES, system status | 1 | ls | $15,000 | $15,000 |
| Analytical sampling | Monthly sampling | 12 | mo | $500 | $6,000 |
| VGAC changeout costs | 15% VGAC loading capacity, 3 mg/L inlet VOCs at 3 gpm | 270 | lbs | $5 | $1,350 |
| Electric power | 4 KW constant load | 35040 | kwh | $0.12 | $4,205 |
| Equipment maintenance | | 1 | unit | $5,000 | $5,000 |
| Spare parts | | 1 | unit | $2,000 | $2,000 |
| IDW transport and disposal | Filter bags, etc | 500 | lbs | $1.00 | $500 |
| Contingency (10% of total) | | 10% | ls | | $7,975 |
| **Annual O&M cost** | | | | | **$88,230** |

**Years 5 to 8 Treatment System Annual O&M**

| Item | Description | Qty | Units | $/Unit | Cost |
|---|---|---|---|---|---|
| Periodic system O&M | Every 3 weeks | 18 | visits | $1,500 | $27,000 |
| Management/coordination | 3 hours/month | 36 | hours | $150 | $5,400 |
| Reporting | NPDES, system status | 1 | ls | $10,000 | $10,000 |
| Analytical sampling | Monthly sampling | 12 | mo | $500 | $6,000 |
| VGAC changeout costs | 15% VGAC loading capacity, 1 mg/L inlet VOCs at 3 gpm | 270 | lbs | $5 | $1,350 |
| Electric power | 4 KW constant load | 35040 | kwh | $0.12 | $4,205 |
| Equipment maintenance | | 1 | unit | $5,000 | $5,000 |
| Spare parts | | 1 | unit | $2,000 | $2,000 |
| IDW transport and disposal | Filter bags, etc | 500 | lbs | $1.00 | $500 |
| Contingency (10% of total) | | 10% | ls | | $6,095 |
| **Annual O&M cost** | | | | | **$67,550** |

**Years 9 to 12 Treatment System Annual O&M** (intermittent operation assumed - 50%)

| Item | Description | Qty | Units | $/Unit | Cost |
|---|---|---|---|---|---|
| Periodic system O&M | Every 4 weeks | 13 | visits | $1,500 | $19,500 |
| Management/coordination | 2 hours/month | 24 | hours | $150 | $3,600 |
| Reporting | NPDES, system status | 1 | ls | $10,000 | $10,000 |
| Analytical sampling | Monthly sampling | 6 | mo | $500 | $3,000 |
| VGAC changeout costs | 15% VGAC loading capacity, 1 mg/L inlet VOCs at 1.5 gpm | 140 | lbs | $5 | $700 |
| Electric power | 2 KW constant load | 35040 | kwh | $0.12 | $4,205 |
| Equipment maintenance | | 1 | unit | $5,000 | $5,000 |
| Spare parts | | 1 | unit | $2,000 | $2,000 |
| IDW transport and disposal | Filter bags, etc | 500 | lbs | $1.00 | $500 |
| Contingency (10% of total) | | 10% | ls | | $4,800 |
| **Annual O&M cost** | | | | | **$53,305** |

## 3. ARD cost

| | | | | | |
|---|---|---|---|---|---|
| 1st injection event | from Alternative 1 (year 1) | 1 | ls | $259,001 | $259,001 |
| 2nd injection event | from Alternative 1 (year 2) | 1 | ls | $160,386 | $160,386 |
| **Total ARD cost** | | | | | **$419,387** |

**Cost Estimate for Alternative 2 - Hydraulic Containment in Block F, existing ARD in Block E, MNA/LUCs MRC Blocks E and F RAP Addendum**

## 4. LTM

**Alternative 2 Long Term Monitoring (year 1)**

| Item | Description | Qty | Units | $/Unit | Cost |
|---|---|---|---|---|---|
| Sampling (labor and analytical) | Bi-annual | 2 | ea | $10,000 | $20,000 |
| Management/coordination | Bi-annual | 2 | ea | $1,000 | $2,000 |
| Reporting | Bi-annual | 2 | ea | $5,000 | $10,000 |
| **Annual LTM cost** | | | | | **$32,000** |

**Alternative 2 Long Term Monitoring (year 2)**

| Item | Description | Qty | Units | $/Unit | Cost |
|---|---|---|---|---|---|
| Sampling (labor and analytical) | Bi-annual | 2 | ea | $10,000 | $20,000 |
| Management/coordination | Bi-annual | 2 | ea | $1,000 | $2,000 |
| Reporting | Bi-annual | 2 | ea | $5,000 | $10,000 |
| Remedial Action Completion Report | | 1 | ea | $20,000 | $20,000 |
| **Annual LTM cost** | | | | | **$52,000** |

## Cost Estimate for Alternative 3 - Hydraulic Containment and PRB in Block F, existing ARD in MRC Blocks E and F RAP Addendum

### 1. PRB Curtain Installation

**ZVI Installation (initial)**

| Item | Description | Qty | Units | $/Unit | Cost |
|---|---|---|---|---|---|
| Pre-design investigation | Determine depth to clay layer | 3 | days | $5,000 | $15,000 |
| Permitting | Injection permit | 1 | ls | $10,000 | $10,000 |
| Management/planning/coordination | Documentation, planning, management | 5 | days | $2,500 | $12,500 |
| DPT drilling sub | DPT rig, injection/mixing, | 10 | days | $5,000 | $50,000 |
| Frac tanks, potable water | 1 tank, 3 weeks rental, 35,000 gallons of potable water | 1 | ls | $5,000 | $5,000 |
| ZVI materials | Z-LoyTM AquaMetal ZVI | 4500 | lbs | $6.00 | $27,000 |
| Oversight cost (engineer) | 10 field days total assumed for installation | 10 | days | $2,000 | $20,000 |
| PRB pilot test | Assumed as 10% of PRB | | | | $139,500 |
| Contingency (20% of total) | | 0 | ls | | $13,950 |
| Design/Engineering (15% of total) | | 15% | ls | | $15,300 |
| **PRB curtain installation subtotal** | | | | | **$308,250** |

**PRB Curtain Installation (replacement at year 5)**

| Item | Description | Qty | Units | $/Unit | Cost |
|---|---|---|---|---|---|
| Permitting | Injection permit | 1 | ls | $5,000 | $5,000 |
| Management/planning/coordination | Documentation, planning, management | 2 | days | $2,500 | $5,000 |
| DPT drilling sub | DPT rig, injection/mixing, assumed injecting into 4 location at the same time, 2 gpm at each location | 5 | days | $5,000 | $25,000 |
| Frac tanks, potable water | 1 tank, 2 weeks rental, 20,000 gallons of potable water | 1 | ls | $3,000 | $3,000 |
| ZVI materials | Z-LoyTM AquaMetal ZVI | 2250 | lbs | $6.00 | $13,500 |
| Oversight cost (engineer) | 10 field days total assumed for installation | 5 | days | $2,000 | $10,000 |
| Contingency (20% of total) | | 20% | ls | | $71,950 |
| Design/Engineering (15% of total) | | 15% | ls | | $7,725 |
| **ZVI curtain installation subtotal** | | | | | **$141,175** |

### 2. Groundwater Extraction System Installation (same as for Alternative 2) **$346,161**

### 3. Groundwater Treatment System O&M cost

**Years 1 to 4 Treatment System Annual O&M (same as for Alternative 2)** **$88,230**
**Years 5 to 8 Treatment System Annual O&M (same as for Alternative 2)** **$67,550**

### 4. ARD cost

| | | | | | |
|---|---|---|---|---|---|
| 1st injection event | from Alternative 1 (year 1) | 1 | ls | $259,001 | $259,001 |

## Cost Estimate for Alternative 3 - Hydraulic Containment and PRB in Block F, existing ARD in MRC Blocks E and F RAP Addendum

| | | | | | |
|---|---|---|---|---|---|
| 2nd injection event | from Alternative 1 (year 2) | 1 | ls | $160,386 | $160,386 |
| **Total ARD cost** | | | | | **$419,387** |

## 5. LTM

**Alternative 3 Long Term Monitoring (year 1)**

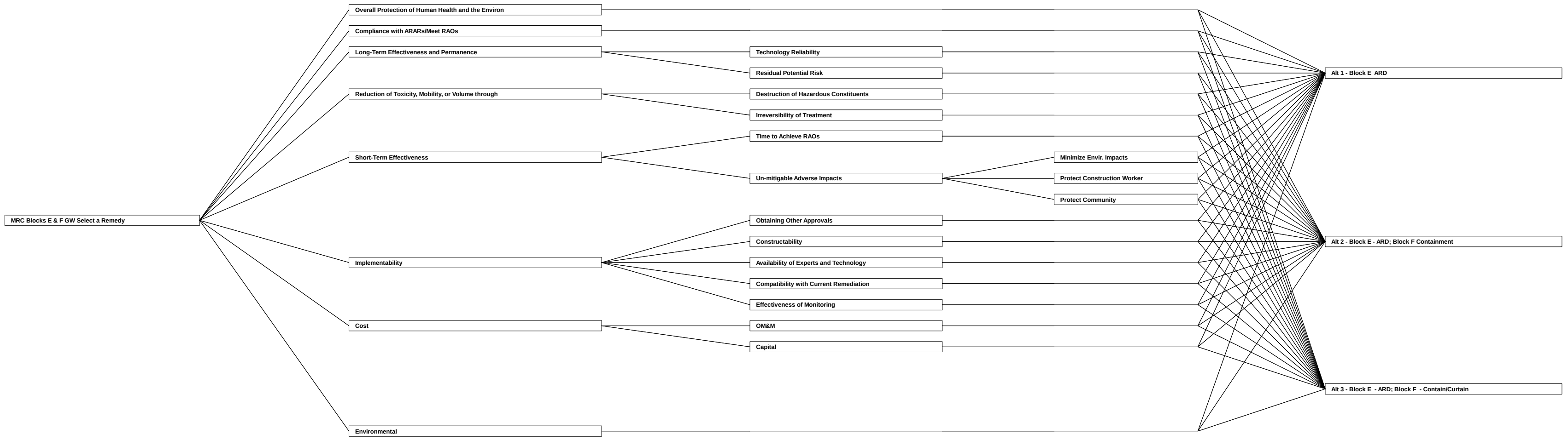
| Item | Description | Qty | Units | $/Unit | Cost |
|---|---|---|---|---|---|
| Sampling (labor and analytical) | Bi-annual | 2 | ea | $10,000 | $20,000 |
| Management/coordination | Bi-annual | 2 | ea | $1,000 | $2,000 |
| Reporting | Bi-annual | 2 | ea | $5,000 | $10,000 |
| **Annual LTM cost** | | | | | **$32,000** |

**Alternative 3 Long Term Monitoring (year 2)**

| Item | Description | Qty | Units | $/Unit | Cost |
|---|---|---|---|---|---|
| Sampling (labor and analytical) | Bi-annual | 2 | ea | $10,000 | $20,000 |
| Management/coordination | Bi-annual | 2 | ea | $1,000 | $2,000 |
| Reporting | Bi-annual | 2 | ea | $5,000 | $10,000 |
| Remedial Action Completion Report | | 1 | ea | $20,000 | $20,000 |
| **Annual LTM cost** | | | | | **$52,000** |

# Appendix C—*Criterium*® *DecisionPlus*® Alternative Analysis Results

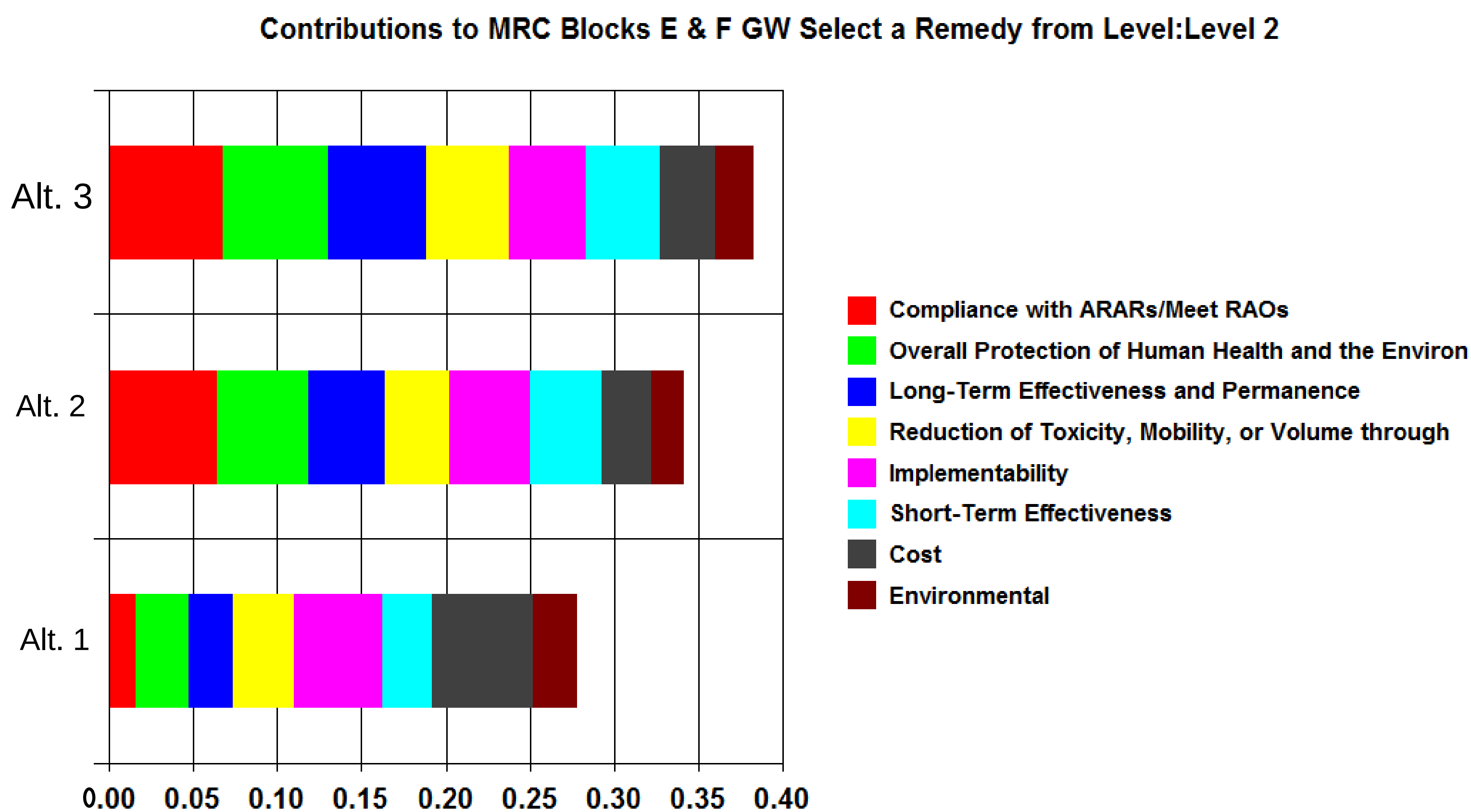
# CDP MRC Blocks E & F Groundwater Remedy LMC



| *Weights* | *Priorities* | *Rating Set* | *Weights* | *Priorities* | *Rating Set* | *Level 3* | *Weights* | *Priorities* | *Rating Set* |
|---|---|---|---|---|---|---|---|---|---|
| 90 | 0.148 | Overall Protection of Human Health and the Environ | | | | Technology Reliability | | | |
| 90 | 0.148 | Compliance with ARARs/Meet RAOs | | | | Residual Potential Risk | | | |
| 80 | 0.131 | Long-Term Effectiveness and Permanence | 90 | 0.692 | Technology Reliability | Destruction of Hazardous Constituents | | | |
| 75 | 0.123 | Reduction of Toxicity, Mobility, or Volume through | 40 | 0.308 | Residual Potential Risk | Irreversibility of Treatment | | | |
| 70 | 0.115 | Short-Term Effectiveness | 50 | 0.556 | Destruction of Hazardous Constituents | Time to Achieve RAOs | | | |
| 90 | 0.148 | Implementability | 40 | 0.444 | Irreversibility of Treatment | Un-mitigable Adverse Impacts | 90 | 0.321 | Minimize Envir. Impacts |
| 75 | 0.123 | Cost | 50 | 0.5 | Time to Achieve RAOs | | 90 | 0.321 | Protect Construction Worker |
| 40 | 0.066 | Environmental | 50 | 0.5 | Un-mitigable Adverse Impacts | | 100 | 0.357 | Protect Community |
| | | | 75 | 0.254 | Obtaining Other Approvals | Obtaining Other Approvals | | | |
| | | | 100 | 0.339 | Constructability | Constructability | | | |
| | | | 25 | 0.085 | Availability of Experts and Technology | Availability of Experts and Technology | | | |
| | | | 35 | 0.119 | Compatibility with Current Remediation | Compatibility with Current Remediation | | | |
| | | | 60 | 0.203 | Effectiveness of Monitoring | Effectiveness of Monitoring | | | |
| | | | 50 | 0.5 | OM&M | OM&M | | | |
| | | | 50 | 0.5 | Capital | Capital | | | |

| *Lowest Criteria* | *Alt 1 - Rating* | *Alt 1 - Priority* | *Alt 2 - Rating* | *Alt 2 - Priority* | *Alt 3 - Rating* | *Alt 3 - Priority* |
|---|---|---|---|---|---|---|
| Overall Protection of Human Health and the Environ | 40 | 0.211 | 70 | 0.368 | 80 | 0.421 |
| Compliance with ARARs/Meet RAOs | 20 | 0.108 | 80 | 0.432 | 85 | 0.459 |
| Technology Reliability | 40 | 0.2 | 70 | 0.35 | 90 | 0.45 |
| Residual Potential Risk | 40 | 0.2 | 70 | 0.35 | 90 | 0.45 |
| Destruction of Hazardous Constituents | 60 | 0.286 | 60 | 0.286 | 90 | 0.429 |
| Irreversibility of Treatment | 80 | 0.314 | 85 | 0.333 | 90 | 0.353 |
| Time to Achieve RAOs | 40 | 0.186 | 85 | 0.395 | 90 | 0.419 |
| Minimize Envir. Impacts | 80 | 0.348 | 75 | 0.326 | 75 | 0.326 |
| Protect Construction Worker | 90 | 0.375 | 80 | 0.333 | 70 | 0.292 |
| Protect Community | 60 | 0.261 | 80 | 0.348 | 90 | 0.391 |
| Obtaining Other Approvals | 90 | 0.375 | 80 | 0.333 | 70 | 0.292 |
| Constructability | 100 | 0.364 | 90 | 0.327 | 85 | 0.309 |
| Availability of Experts and Technology | 100 | 0.345 | 95 | 0.328 | 95 | 0.328 |
| Compatibility with Current Remediation | 100 | 0.357 | 90 | 0.321 | 90 | 0.321 |
| Effectiveness of Monitoring | 100 | 0.333 | 100 | 0.333 | 100 | 0.333 |
| OM&M | 100 | 0.5 | 40 | 0.2 | 60 | 0.3 |
| Capital | 100 | 0.476 | 60 | 0.286 | 50 | 0.238 |
| Environmental | 80 | 0.381 | 60 | 0.286 | 70 | 0.333 |

| Alternatives | Value | Decision Scores |
|---|---|---|
| Alt 3 - Block E - | 0.382 | |
| Alt 2 - Block E - | 0.341 | |
| Alt 1 - Block E | 0.277 | |


Contributions to MRC Blocks E & F GW Select a Remedy from Level:Level 2
Alt. 3
Alt. 2
Alt. 1
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
Compliance with ARARs/Meet RAOs
Overall Protection of Human Health and the Environ
Long-Term Effectiveness and Permanence
Reduction of Toxicity, Mobility, or Volume through
Implementability
Short-Term Effectiveness
Cost
Environmental