Lockheed Martin Corporation
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LOCKHEED MARTIN

October 18, 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 Remedial Action Completion Report for Groundwater at Block G
Lockheed Martin Corporation; Middle River Complex
2323 Eastern Boulevard, Middle River, Baltimore County, Maryland

Dear Mr. Carroll:

For your information please find enclosed two hard copies with a CD of the above-referenced document. This report documents the activities and results associated with implementing the response action plan (RAP) to address the groundwater contamination in Block G at Lockheed Martin's Middle River Complex in Middle River, Maryland.

If possible, we respectfully request to receive MDE's document review comments by December 3, 2018.

I am available for your questions; my office phone is (301) 548-2209.

Sincerely,

Thomas D. Blackman
Project Lead, Environmental Remediation

cc: (via email without enclosure)
Gary Schold, MDE
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REMEDIAL ACTION COMPLETION REPORT
FOR GROUNDWATER AT BLOCK G
LOCKHEED MARTIN MIDDLE RIVER COMPLEX
2323 EASTERN BOULEVARD
MIDDLE RIVER, MARYLAND

Prepared for:
Lockheed Martin Corporation

Prepared by:
Contractor

October 2018

Revision: 0

Michael Martin, P.G.
Regional Manager

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ACRONYMS AND ABBREVIATIONS

cis-1,2-DCE	*cis*-1,2-dichloroethene
DHC	*Dehalococcoides ethenogenes*
DO	dissolved oxygen
GAC	granular activated-carbon
g/L	gram(s) per liter
gpm	gallon(s) per minute
Lockheed Martin	Lockheed Martin Corporation
MDE	Maryland Department of the Environment
µg/L	microgram(s) per liter
mg/L	milligram(s) per liter
MRC	Middle River Complex
mV	millivolt(s)
O&M	operation and maintenance
ORP	oxidation-reduction potential
RAP	response action plan
TCE	trichloroethene
Tetra Tech	Tetra Tech, Inc.
TOC	total organic carbon
VOC	volatile organic compound

SECTION 1
INTRODUCTION

On behalf of Lockheed Martin Corporation (Lockheed Martin), Tetra Tech, Inc. (Tetra Tech) has prepared this report describing the activities and results associated with implementing the response action plan (RAP) to address the groundwater contamination in Block G of the Lockheed Martin Middle River Complex (MRC) in Middle River, Maryland. This report also recommends, based on response action results, that a “No Further Action” letter issued by the Maryland Department of the Environment (MDE) is appropriate for Block G groundwater.

1.1 SITE LOCATION AND BACKGROUND

The Middle River Complex is at 2323 Eastern Boulevard in Middle River, Maryland (Figure 1-1). It consists of multiple land parcels designated as tax blocks (referred to as blocks herein, see Figure 1-2), all owned by LMC Properties, Inc., a subsidiary of Lockheed Martin Corporation. Some of these blocks are used by Lockheed Martin Corporation for offices and parking, while others are leased by tenants for parking or operations.

This Middle River Complex groundwater response action is being conducted in accordance with the “Administrative Consent Order and Settlement Agreement” ACO-SAR-MDE0746-2015-1-01 between the Maryland Department of the Environment (MDE) and Lockheed Martin Corporation. The groundwater response action includes enhanced anaerobic-bioremediation in three areas with high groundwater concentrations of trichloroethene (TCE): the southeastern trichloroethene area (Block E), the southwestern trichloroethene area (Block G), and the northern trichloroethene area (Block I). These three areas are shown on Figure 1-3. Note that the trichloroethene plumes and injection locations shown on Figure 1-3 are as they appear in the *Groundwater Response Action Plan* (Tetra Tech, Inc., 2012).

Semi-permanent injection wells were installed at the Middle River Complex to inject biological amendments into the subsurface; these wells are arranged in rows and connected via underground piping to injection equipment in each of the three trichloroethene areas. The injection equipment and controls are housed in two modified shipping containers (i.e., the equipment modules), any one of which can be used for the systems at Blocks G, I, and E. The system allows flexibility in selecting and setting system parameters (e.g., the number of operational injection wells; substrate type and dosage; and injection rates, volumes, and durations). This report documents the injection program performed in Block G. Response actions and results at Blocks E and I are not included in this report.

The first injection event in Block G was performed from February 2015 to June 2015 (Tetra Tech, 2015). The second injection event was performed in Block G from September 2015 to February 2016 (Tetra Tech, 2016). The following relevant documents describe the history and implementation of groundwater response action in Block G:

- *Groundwater Response Action Plan* (Tetra Tech, 2012)
- *Groundwater Response Action 100% Design-Basis Report* (Tetra Tech, 2013)
- *Operation and Maintenance Plan for the Groundwater Remediation System* (Tetra Tech, 2014)
- *Revised Groundwater Response Action Plan Addendum 2: Remedial Action Objectives and Project Implementation Schedule* (Tetra Tech, 2015a)
- *First Injection Completion Report* (Tetra Tech, 2015b)
- *Second Injection Completion Report, Blocks G and I* (Tetra Tech, 2016)

1.2 PURPOSE AND ORGANIZATION

This report describes the response action for groundwater at Block G, presents its results, and provides a request for a "No Further Action" classification for Block G groundwater from the Maryland Department of the Environment (MDE). This report is organized as follows:

Section 2— Implementation of the Remedial Action: Presents a summary of remedial action implementation in Block G.

Section 3—Performance Evaluation: Discusses the results of the injections, performance verification sampling results, and the conclusions that can be drawn from these results.

Section 4—Recommendation for No Further Action: Provides the basis for a "No Further Action" request.

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

SECTION 2
IMPLEMENTATION OF THE REMEDIAL ACTION

The groundwater remediation system at Block G consists of an injection-equipment module connected to injection-well arrays. A low-concentration amendment solution, consisting of sodium lactate (substrate) diluted in treated, pH-adjusted, potable water, was injected into the well array. The amendment solution was prepared as follows:

- The equipment module was connected to potable water via a pressurized water-supply line.
- Potable water was passed through a particulate filter and granular activated-carbon (GAC) vessel to remove suspended solids, residual chlorine disinfectant, and other impurities.
- The water stream was then directed to a semi-permeable, hollow-membrane contactor that removed dissolved oxygen.
- Substrate and pH buffering solution (sodium bicarbonate) were dosed into the treated water and mixed. Additional buffer was added directly to the injection wells, as described in Section 3.
- The injection solution was directed to the injection manifold, where it was injected into individual injection wells via dedicated lines.

The process equipment used included a GAC vessel, a filter for particulates, a dissolved-oxygen removal contactor, a vacuum pump, metering pumps and storage tanks for substrate and pH buffering solution, mechanical and electronic flow meters and totalizers, control valves, process instrumentation, and controls. Process equipment and electrical components (such as the distribution manifold, flow meter, process piping, hollow-membrane cartridge, and other lightweight instrumentation) are mounted on the container sidewalls. Heavier equipment is secured to the module floor.

Untreated water enters the equipment enclosure from a pressurized domestic-water line. In Block G, the source of this water is the water main beneath Chesapeake Park Plaza. The water stream is first treated by a GAC vessel to remove residual chlorine. Dissolved oxygen is then removed by a membrane contactor and inlet particulate filter.

Amendment solution is introduced directly into the treated stream effluent before it reaches the distribution manifold for the injection wells. A buffering solution of sodium bicarbonate is then used to adjust pH; buffer was added both at the manifold and directly into the injection wells. The amendment solution was then directed to the 10-branch piping manifold, where it was directed to individual injection wells. The startup, shutdown, and operation and maintenance (O&M) procedures followed during the first and second injection event at Block G are detailed in the *Operation and Maintenance Plan for the Groundwater Remediation System at Lockheed Martin Middle River Complex* (Tetra Tech, 2014).

2.1 SUMMARY OF FIRST INJECTION EVENT

The first injection event at Block G began on February 12, 2015 and concluded on June 12, 2015. Amendment was injected into a set of 10 injection wells at a time, and the duration of injection for each set of wells was approximately 30 days. Thirty-nine injection wells were used during the injection sequence. Block G injection wells and piping runs are shown on Figure 2-1.

Two injection wells (IWW-8 and IWW-30) did not accept any measurable flow. The remaining 37 wells received a total amendment volume of 220,681 gallons, with each well receiving an average of approximately 6,000 gallons of amendment solution. The injected volumes of sodium lactate substrate (as 60% syrup) and sodium bicarbonate were 15,600 pounds and 2,230 pounds, respectively. The average sodium lactate concentration (as pure ingredient) was 0.51% by weight, and the average sodium bicarbonate concentration was 1.1 grams per liter (g/L). The average injected sodium lactate and sodium bicarbonate quantities per well were 253 pounds and 52.7 pounds, respectively (see Table 2-1).

Baseline sampling at Block G was conducted in February 2014, and post-injection sampling following the conclusion of the injection event was conducted in June/July 2015. Parameters evaluated in Block G groundwater included total organic carbon (TOC), oxidation reduction potential (ORP), dissolved oxygen (DO), pH, volatile organic compounds (VOCs), and dechlorinating bacteria concentration.

2.2 SUMMARY OF SECOND INJECTION EVENT

The second injection at Block G began on September 4, 2015 and concluded on February 3, 2016. The injected-nutrient substrate was sodium lactate. Bioaugmentation with dechlorinating bacteria cultures was done at the beginning of the second injection. The injection-process parameters are described in the following section.

2.2.1 Bioaugmentation

After the first injection, aquifer conditions became reducing, substrate concentrations were elevated, and pH was within the optimal range for *Dehalococcoides ethenogenes* (DHC) growth. However, the native DHC bacteria population in Block G remained incapable of completely degrading trichloroethene (TCE) to ethene, so bioaugmentation with DHC cultures was used during the second injection to aid TCE degradation. The DHC cultures (KB-1®) used at Block G were produced by SiREM; the volume injected was based upon the manufacturer's recommendation: an approximate ratio of 1:40,000 KB-1® volume to pore volume was used. The pore volume within the 1,000 micrograms per liter (µg/L) TCE contour (Tetra Tech, 2013) at Block G necessitated using 240 liters of KB-1® cultures.

In the last week of August 2015 (before the injection began), all injection wells in Block G were redeveloped using high-pressure jetting and a mobile in-well pump to remove biological fouling and particulate matter (resulting from the first injection) from the well screens. Anaerobic chase water was then prepared and used to push the KB-1® cultures into the injection wells (and subsequently into the formation). Using chase water with the proper parameters to introduce bacterial cultures is essential, because KB-1® cultures require anaerobic conditions and near-neutral pH to proliferate and survive. The goals for the anaerobic chase water produced were as follows: ORP < -100 millivolts (mV); DO <0.25 milligrams per liter (mg/L); and pH >6.8. The anaerobic chase water was prepared as follows:

- Approximately 20,000 gallons of potable water were deoxygenated and treated by activated carbon to remove suspended solids, residual chlorine disinfectant, and other impurities; this volume was placed in a frac tank near the equipment container at Block G.

- Twenty-five gallons of sodium lactate and 50 pounds of sodium bicarbonate were added to the frac tank while the tank was being filled.

- The headspace of the frac tank was filled with argon gas to prevent contact with atmospheric oxygen.

- Frac-tank-water parameters were measured one week later, and results were as follows: pH=6.96, DO=0.03 mg/L, and ORP= −174 mV. These results indicate that chase water with anaerobic properties had been successfully created.

A dedicated injection pump (with associated control valves and temporary lines to convey the anaerobic chase-water from the frac tank to the injection manifold) was installed. The injection pump was wired such that all injection-system safety interlocks were enabled for automatic operation. A dedicated flow totalizer was installed on the pump's discharge to measure the volume and rate of injected chase-water.

KB-1® cultures were transferred from their vendor-supplied vessels to the injection manifold as a side stream. The chase-water injection rate was maintained at approximately 1.5 to 1.8 gallons per minute (gpm) (0.15–0.16 gpm per well) while KB-1® cultures were transferred. The KB-1® transfer procedure was performed according to the vendor's standard operating procedure. Approximately six liters of KB-1® cultures were injected per injection well (a total of 240 liters).

2.2.2 Injection Process

On September 28, 2015, the injection manifold was changed from the chase-water configuration to the normal configuration (i.e., with connections to the first set of 10 injection wells [IWW-9, -14, -16, -24, -25, -26, -28, -32, -35, and -36]), and treated potable water was used to deliver substrate (sodium lactate) and pH buffer (sodium bicarbonate) to the injection wells. Similar to the first injection, amendment was subsequently injected into the remaining sets of 10 injection wells. Injection duration for each set of 10 wells was approximately 30 days.

Thirty-seven injection wells were used during the entire injection sequence. As in the first injection, two injection wells (IWW-30 and IWW-37) did not take any measurable flow. Block G injection wells and piping runs are shown on Figure 2-1. Injection rates and wellhead pressures during the second injection were similar to the first injection.

The injection wells received a total volume of 178,400 gallons of amendment solution. On average, each well received approximately 4,830 gallons of amendment, a volume slightly above the design goal (4,800 gallons per well). Approximately 7,370 pounds of sodium lactate substrate (as pure ingredient) and 2,635 pounds of sodium bicarbonate were injected, both in the amendment solution, and via direct placement of the sodium bicarbonate in injection wells (see below).

The most difficult maintenance issue encountered during injection was extensive scaling in the injection manifold, which required frequent cleaning of the injection manifold to continue the injection. The precipitated scale was carbonate. Dissolved sodium bicarbonate in the amendment solution likely increased the hardness of the injected solution to a pH that caused scale precipitation.

To decrease the sodium bicarbonate content in the injection (and thus reduce scale formation), approximately 25 pounds of powdered sodium bicarbonate were added directly to each well before the injection began. (Note that the powdered sodium bicarbonate directly added is included in the total quantities described below.) Well-bottom soundings before and after adding sodium bicarbonate indicated that no solids accumulated on the bottom of the wells. This method of sodium bicarbonate delivery proved effective, and pH-buffering results for the second injection were more successful than the first injection.

Direct placement effectively eliminated manifold clogging issues, and the sodium bicarbonate effectively dissolved in the wells. The average sodium lactate concentration (as pure ingredient) was 0.50% by weight, and the average sodium bicarbonate concentration was 1.8 g/L. The average injected sodium lactate and sodium bicarbonate quantities per well were 200 and 72 pounds, respectively. The injection volumes, amendment dosages, and concentrations were close to the design values calculated for Block G (see Table 2-2).

Baseline sampling (before the first injection) was conducted at Block G in February 2014. Three post-injection monitoring events were completed, as described below:

- March 2016—one month after the second injection was complete
- May 2016—three months after the second injection was complete
- July 2016—six months after the second injection was complete

Baseline and post-injection parameters evaluated at Block G include: TOC, ORP, DO, pH, VOCs, and dechlorinating bacteria.

2.3 Verification Monitoring

Per Addendum 2 to the groundwater response action plan (RAP), verification monitoring was conducted annually for two years after active remediation. In April 2017 and April 2018, additional groundwater samples were collected at Block G to determine if VOC rebound had occurred. The April 2017 samples (referred to as year 1 verification monitoring samples) were collected approximately one year and two months after the Block G injections were finished. The April 2018 samples (referred to as year 2 verification monitoring samples) were collected approximately two years and two months after the Block G injections were finished.

Nine wells were sampled during each sampling event, including seven performance-monitoring wells within the treatment area (MW-14B, SWMW-1I, SWMW-2I, SWMW-3I, SWMW-4S, SWMW-4I, SWMW-5I) and two wells (MW-12A and MW-12B) outside the treatment area. Sampling results for April 2017 were formally presented in the *Groundwater Monitoring Report March–April 2017* (Tetra Tech, 2017). Results from April 2018 were provided to Tetra Tech and will be formally presented to MDE in the 2018 groundwater monitoring report that will be generated later this year. Results of both the 2017 and 2018 sampling are in Table 3-5.

SECTION 3
PERFORMANCE EVALUATION

During injections at Block G, substrate was effectively distributed throughout the subsurface, as indicated by the increased total organic carbon (TOC) concentrations at the monitoring wells following the injection (Table 3-1). An anaerobic, reducing environment (favorable for reductive dechlorination) was created, in which the oxidation-reduction potential (ORP) was sufficiently negative (mostly below −100 mV) and dissolved oxygen (DO) concentrations were less than 0.5 mg/L (Table 3-2). Sodium bicarbonate buffering effectively raised groundwater pH to meet the design goal in most locations (Table 3-3). In addition, *Dehalococcoides ethenogenes* (DHC), the bacterial species capable of completely dechlorinating trichloroethene (TCE), was successfully introduced and distributed in quantities sufficient to remediate groundwater in Block G (Table 3-4). Amendment addition resulted in near complete TCE reduction, with only low levels of *cis*-1,2-dichloroethene (*cis*-1,2-DCE) and vinyl chloride remaining (Table 3-5).

The ultimate performance criteria for bioremediation are the reduction of TCE and its biodegradation products *cis*-1,2-DCE and vinyl chloride. After the first injection, volatile organic compound (VOC) sampling results for Block G groundwater (Table 3-5) indicated that much of the TCE mass had been reduced to *cis*-1,2-DCE, but that complete reduction to ethene was not proceeding. The most likely cause of incomplete dehalogenation was an insufficient quantity of DHC microorganisms in Block G groundwater.

Performance monitoring after the second injection (which included DHC bioaugmentation) indicates that significant reductions occurred in both TCE and its daughter products, including *cis*-1,2-dichloroethene and vinyl chloride (Table 3-5). Samples collected during the third monitoring event in July 2016 indicate that average TCE concentrations within the injection area had been reduced by 99% (i.e., from 1,095 micrograms per liter [µg/L] to 9 µg/L), and average VOC concentrations within the injection area had been reduced by 94% (i.e., from 1,192 µg/L to 72 µg/L). The highest vinyl chloride concentration remaining in June 2016 was 15 µg/L. Note that both TCE and VOC concentrations continued to decline during the next six-month performance-monitoring period.

Additional verification monitoring in 2017 (year 1 verification monitoring) and in 2018 (year 2 verification monitoring) indicate that no rebound of VOC concentrations had occurred, and that VOC concentrations had reduced further over time (Table 3-5). Verification monitoring within the injection area in year 2 indicate that average TCE concentrations had been reduced by more than 99% from baseline (i.e., from 1,095 µg/L to 2 µg/L), and average VOC concentrations had been reduced by 98% from baseline (i.e., from 1,192 µg/L to 23 µg/L). The changes in the concentrations of TCE and its biodegradation byproducts in the monitoring wells are also summarized on Figure 3-1.

The performance goal for the Middle River Complex (MRC) groundwater response action in Block G, as specified in Addendum #2 to the RAP (Tetra Tech, 2015b), was to 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." Both goals have been met or exceeded at Block G.

SECTION 4
RECOMMENDATION FOR NO FURTHER ACTION

The groundwater remedial action at Block G meets and/or exceeds all performance goals set forth in the *Groundwater Response Action Plan* (Tetra Tech, 2012) and the *Revised Groundwater Response Action Plan Addendum 2: Remedial Action Objectives and Project Implementation Schedule* (Tetra Tech, 2015a).

Substrate was effectively distributed throughout subsurface groundwater at Block G, as indicated by the increased total organic carbon (TOC) concentrations at monitoring wells post injection. An anaerobic, reducing environment was created, in which the oxidation-reduction potential (ORP) was highly negative (mostly below −100 mV) and dissolved oxygen (DO) concentrations were less than 0.5 mg/L. Sodium bicarbonate pH buffering effectively raised groundwater pH to meet the design goal in most locations, and the bacterial species capable of completely dechlorinating trichloroethene (TCE) was successfully introduced and distributed in quantities sufficient to remediate Block G groundwater (Table 3-4).

Groundwater quality in Block G was monitored after each injection event, and for two years (2017 and 2018) after injections were finished. Verification sampling in 2017 and 2018 (Table 3-5) indicates minimal trichloroethene, *cis*-1,2-dichloroethene (*cis*-1,2-DCE), and vinyl chloride concentrations, indicating that no volatile organic compound (VOC) rebound had occurred. Concentrations of volatiles declined throughout the two-year monitoring period and are approximately 98% lower than baseline levels. The most recent (April 2018) average trichloroethene concentration in the treatment area is 2 micrograms per liter [µg/L] (down from a baseline of 1,095 µg/L), and the average of trichloroethene and its degradation products (*cis*-1,2-dichloroethene and vinyl chloride) is 23 µg/L (down from a baseline of 1,192 µg/L).

The remedial action in Block G resulted in near complete trichloroethene reduction, and remaining levels of *cis*-1,2-dichloroethene and vinyl chloride are low, with minimal rebound after injections had been completed. Thus, the performance goal for reducing these compounds was met and exceeded. These results lead Lockheed Martin Corporation (Lockheed Martin) to submit this closure documentation in accordance with Section VI.22 of ACO-SAR-MDE0746-2015-1-01, and to request a "No Further Action" letter (or equivalent) for Block G groundwater from the Maryland Department of the Environment (MDE).

SECTION 5
REFERENCES

Maryland Department of the Environment (MDE), 2006. *Maryland Department of the Environment Voluntary Cleanup Program.* Revision 03/17/06. March.

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FIGURES

Figure 1-1 Middle River Complex Location Map

Figure 1-2 Middle River Complex Site Layout and Tax Blocks

Figure 1-3 MRC Groundwater Remedy Layout

Figure 2-1 Block G Remedy Layout

Figure 3-1 Baseline and Post-Remediation VOCs Concentration

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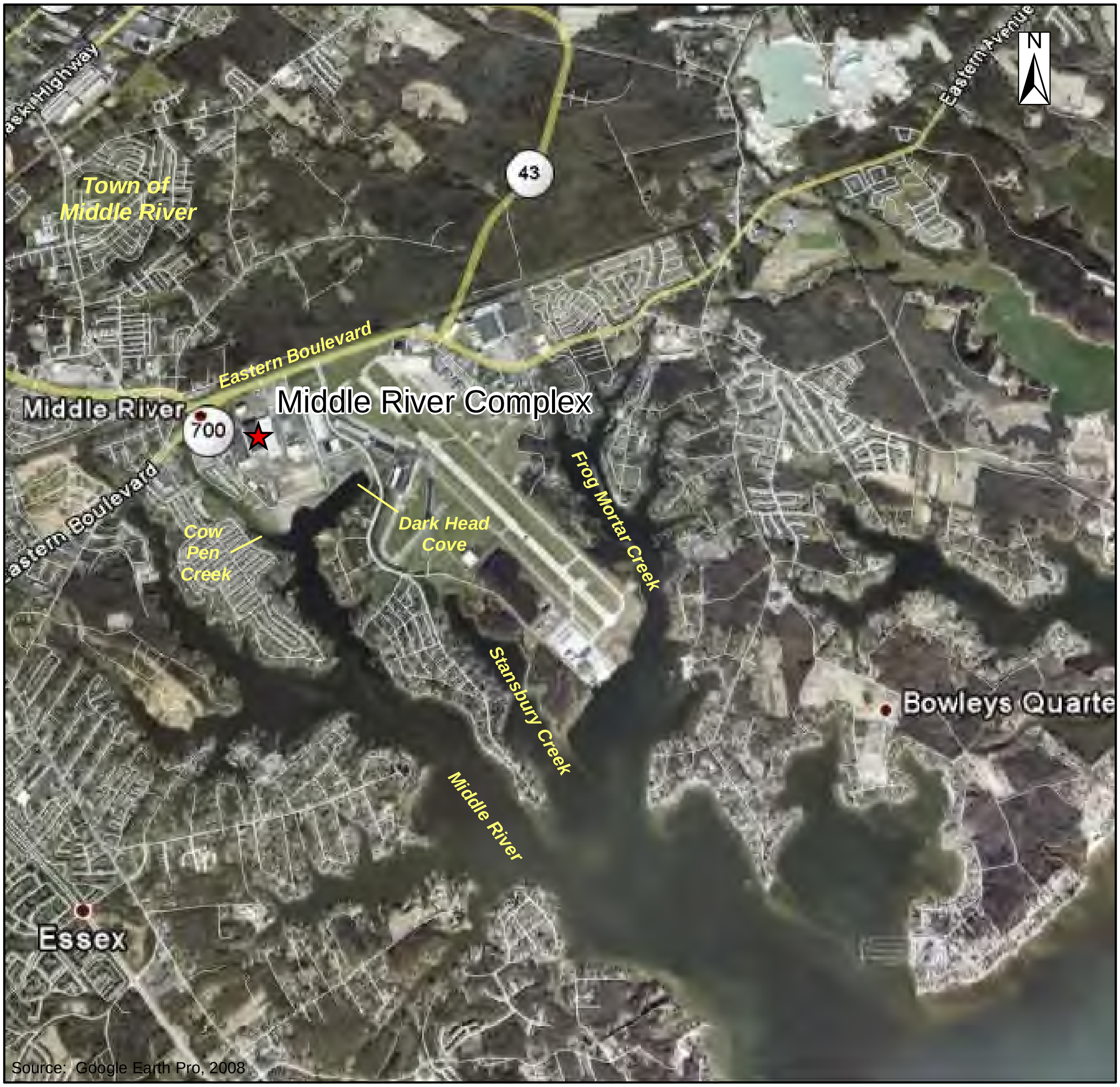

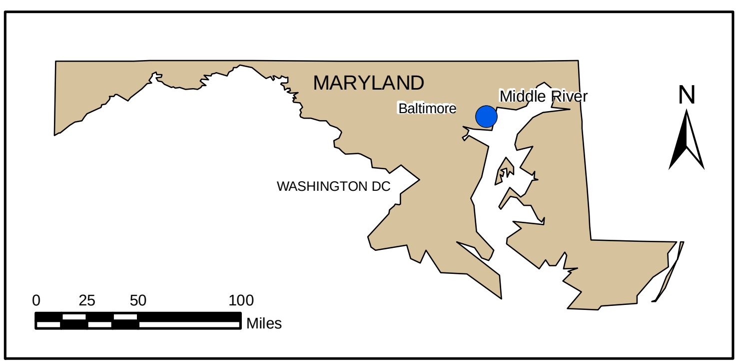

Figure 1-1

Middle River Complex Location Map

Lockheed Martin Middle River Complex
Middle River, Maryland

DATE MODIFIED: 12/15/08	CREATED BY: BJ

Tetra Tech, Inc.

FIGURE 1-2

MIDDLE RIVER COMPLEX SITE LAYOUT AND TAX BLOCKS

Lockheed Martin Middle River Complex
Middle River, Maryland

DATE MODIFIED: 11/30/11
CREATED BY: MP

Map Document: (K:\GProject\middle_river\Maps\Tax Blocks_30Nov11.mxd)
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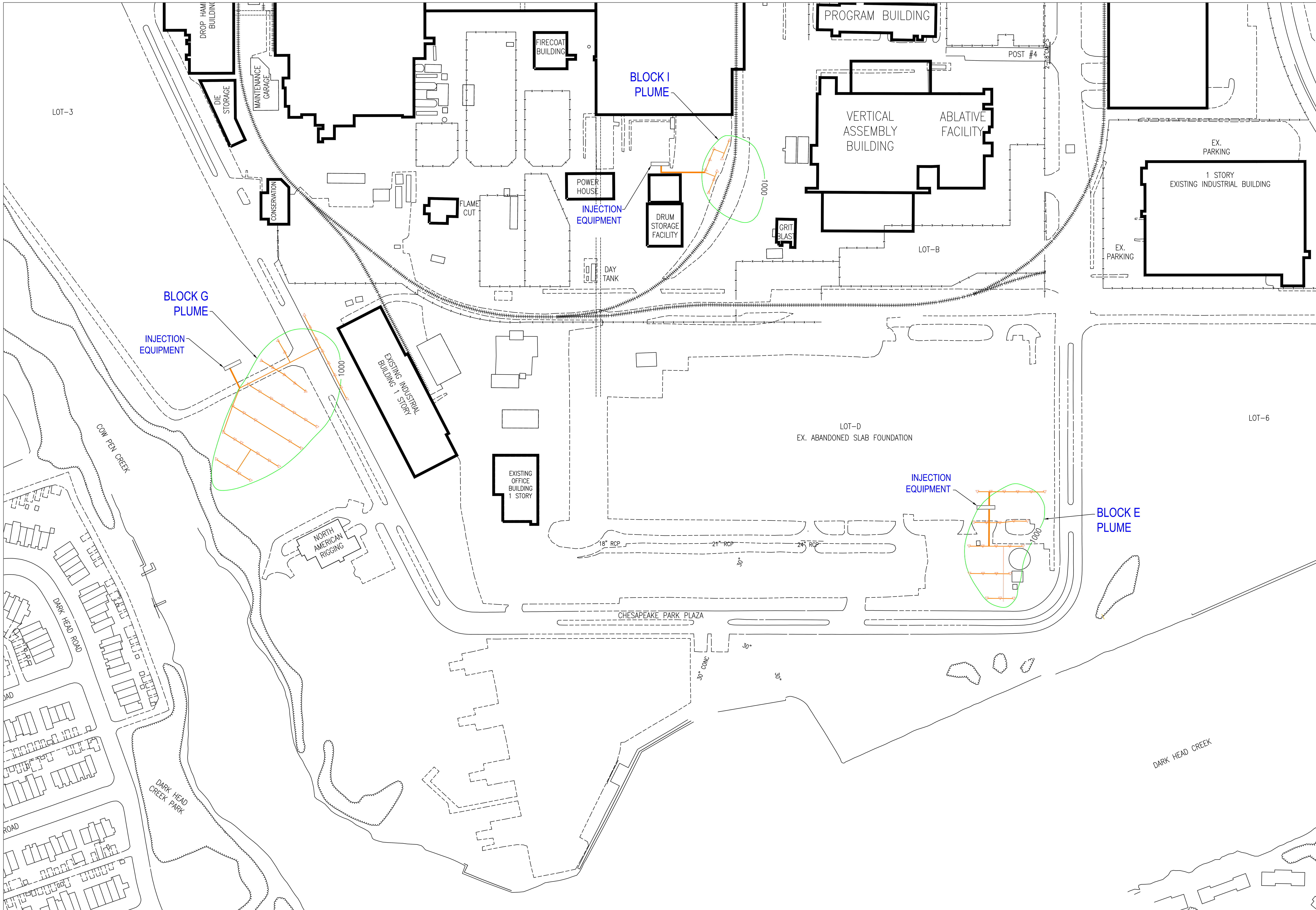

LEGEND

(orange line)	PIPING BUNDLE
△	INJECTION WELL
(thin orange line)	PIPING TO INJECTION WELLS
— 1000 —	1000 ug/L TCE CONTOUR BASED ON 2012 GW RAP

BASE MAP: BASED ON DRAWING PREPARED BY TAI CONSULTING ENGINEERS, INC.

TOPOGRAPHY: TOPOGRAPHY WITHIN AREA OF DISTURBANCE FROM FIELD RUN SURVEY CONDUCTED BY DMW, INC. IN JUNE 1999 FLOATED TO STATE GRID.

HORIZONTAL INFORMATION OUTSIDE OF LIMIT OF DISTURBANCE FROM BALTIMORE COUNTY OFFICE OF INFORMATION TECHNOLOGY GIS SERVICES UNIT. DATE OF CAPTURE: MARCH 1995

EXISTING UTILITIES: FIELD INFORMATION OBTAINED FROM DMW FIELD RUN SURVEY AND LOCKHEED MARTIN ENTITLED "EXHIBIT #6 EXISTING UTILITIES PLAN."

BOUNDARY LINES: BOUNDARY INFORMATION TAKEN FROM RECORDED PLAT E.H.K., JR. 51 FOLIO 43 "1ST AMENDED CHESAPEAKE PARK RE-SUBDIVISION" PREPARED BY MARYLAND SURVEYING AND ENGINEERING CO., INC. 4/24/84. BOUNDARY HAS BEEN ORIENTED TO THE BALTIMORE COUNTY METROPOLITAN DISTRICT GRID, BUT SHOULD NOT BE CONSIDERED A BOUNDARY SURVEY.

SCALE

0' 125' 250' 500'

TETRA TECH

MRC GROUNDWATER REMEDY LAYOUT

LOCKHEED MARTIN MIDDLE RIVER COMPLEX
MIDDLE RIVER, MARYLAND

DATE:	9-29-2015
PROJECT NO.:	
DESIGNED BY:	BD
DRAWN BY:	BD
CHECKED BY:	CP

FIGURE 1-3

TETRA TECH

FIGURE 2-1
BLOCK G REMEDY LAYOUT

Lockheed Martin Middle River Complex
Middle River, Maryland

LEGEND

- INJECTION WELLS
- PERFORMANCE MONITORING WELLS
- OTHER MONITORING WELLS

0 15 30 60 Feet

N

DATE MODIFIED: 8/2/18

CREATED BY: BD

TETRA TECH

FIGURE 3-1
BASELINE AND POST-REMEDIATION VOCs CONCENTRATIONS

Lockheed Martin Middle River Complex
Middle River, Maryland

LEGEND

●	INJECTION WELLS
●	PERFORMANCE MONITORING WELLS
⊕	OTHER MONITORING WELLS
TCE	TRICHLOROETHENE
cis−1,2−DCE	cis−1,2−DICHLOROETHENE
VC	VINYL CHLORIDE

ALL RESULTS ARE REPORTED IN MICROGRAMS PER LITER

0 15 30 60 Feet

N

DATE MODIFIED: 8/2/18

CREATED BY: BD

TABLES

Table 2-1 Block G First Injection Summary

Table 2-2 Block G Second Injection Event Summary

Table 3-1 Post-Injection Total Organic Carbon at Block G

Table 3-2 Post-Injection ORP and DO at Block G

Table 3-3 Post-Injection pH at Block G

Table 3-4 Post-Injection DHC and Ethene at Block G

Table 3-5 Pre- and Post-Injection VOC Concentrations at Block G

Table 2-1
Block G First Injection Summary
Lockheed Martin Middle River Complex, Middle River, Maryland

Parameter	Value	Units
Injection start:	2/12/2015	
Injection end:	6/12/2015	
Total injection wells:	39	
Injection wells that did not accepted flow:	IWW-8, IWW-30	
Injection wells that accepted flow:	37	
Total injected volume:	220,681	gallons
Average injected volume per well:	6,000	gallons
Design injection volume per well:	6,400	gallons
Total injected sodium lactate:	9,356 (100% active ingredients)	pounds
Average sodium lactate per well:	253 (100% active ingredients)	pounds
Average lactate concentration as injected:	0.51%	
Total injected sodium bicarbonate:	1,950	pounds
Total design sodium bicarbonate:	2,230	pounds
Average sodium bicarbonate per well:	52.7	pounds
Design average sodium bicarbonate per well:	60.2	pounds
Average sodium bicarbonate as injected:	1.1	grams per liter

Table 2-2 Block G Second Injection Summary
Lockheed Martin Middle River Complex, Middle River, Maryland

Parameter	Value	Units
Injection start	9/4/2015	
Injection end	2/3/2016	
Total injection wells	39	
Injection wells not used	IWW-30, IWW-37	
Injection wells actually used for injection	37	
Total injected volume	178,400	gallons
Average injected volume per well	4830	gallons
Design injection volume per well	4800	gallons
Total injected sodium lactate	7,370	pounds (as 100% active ingredients)
Total design sodium lactate	7,017	pounds (as 100% active ingredients)
Average sodium lactate per well injected	200	pounds (as 100% active ingredients)
Average lactate concentration as injected	0.50%	
Design lactate concentration	0.50%	
Total injected sodium bicarbonate	2635	pounds
Total design sodium bicarbonate	2790	pounds
Average sodium bicarbonate per well	72	pounds
Design average sodium bicarbonate per well	72	pounds
Average sodium bicarbonate as injected	1.8	grams per liter

Table 3-1 Post-Injection Total Organic Carbon at Block G
Lockheed Martin Middle River Complex, Middle River, Maryland

Well ID	Total Organic Carbon (TOC) in mg/L				
	Baseline (Feb-14)	Post 1st Injection (Jun-15)	Post 2nd Injection (Mar-16)	Post 2nd Injection (May-16)	Post 2nd Injection (Jul-16)
MW-12B	0	2.9	0.73	0	0.57
MW-12A	3.4	6	51	4.2	37
MW-14B	1.7	471	910	290	0.37
SWMW-1I	2.7	21.5	9	38	11
SWMW-2I	2.3	110	370	230	76
SWMW-3I	1.1	940	770	220	120
SWMW-4S	1.6	2.8	2.9	51	4.9
SWMW-4I	1.1	240	1300	560	330
SWMW-5I	2.9	320	580	550	150
Block G outfall	20	17	6.2	6.9	5.1
Performance goal averages (7 wells[1])	*1.91*	301	563	277	99
All wells averages	*1.87*	*235*	*444*	*216*	*81*

[1]Includes well MW-14B, SWMW-1I, SWMW-2I, SWMW-3I, SWMW-4I, SWMW-4S, and SWMW-5I. These wells are within the active remediation areas (defined in the remedial basis report as areas within 1000 microgram per liter [µg/L] trichloroethene contour). Wells MW-12B and MW-12A are outside the active remediation areas and thus are not included in the performance average values calculation.

mg/L - milligrams per liter

Table 3-2 Post-Injection ORP and DO at Block G
Lockheed Martin Middle River Complex, Middle River, Maryland

Well ID	ORP (mV)					DO (mg/L)				
	Baseline (Feb-14)	Post 1st Injection (Jun-15)	Post 2nd Injection (Mar-16)	Post 2nd Injection (May-16)	Post 2nd Injection (Jul-16)	Baseline (Feb-14)	Post 1st Injection (Jun-15)	Post 2nd Injection (Mar-16)	Post 2nd Injection (May-16)	Post 2nd Injection (Jul-16)
MW-12B	157	-42	-29	-92	-44	0.12	0	0	0	0
MW-12A	117	-17	-118	-83	-114	0	0	0	0	0
MW-14B	184	-132	-189	-164	-103	0	0	0	0	0
SWMW-1I	-4	-163	-135	-106	-127	0	0.49	0.94	0	0
SWMW-2I	-155	-106	-174	-171	-156	0	0	0.94	0	0
SWMW-3I	57	-99	-139	-146	-133	0	0.09	0	0	0
SWMW-4S	106	89	74	-99	-86	2	0	0	0	0
SWMW-4I	81	-124	-145	-151	-148	8.6	0	0	0	0
SWMW-5I	13	-84	-103	-115	-108	5.54	0	0	0	0
Performance goal averages (7 wells[1])	40.29	-88	-116	-136	-123	2.3	0.1	0.3	0.0	0.0
All wells averages	*61.78*	*-75*	*-106*	*-125*	*-113*	*1.8*	*0.1*	*0.2*	*0.0*	*0.0*

[1]Includes wells MW-14B, SWMW-1I, SWMW-2I, SWMW-3I, SWMW-4I, SWMW-4S, and SWMW-5I. These wells are within the active remediation areas (defined in the remedial basis report as areas within 1000 microgram per liter [µg/L] trichloroethene contour). Wells MW-12B and MW-12A are outside the active remediation areas and thus are not included in the performance average values calculation.

DO - dissolved oxygen

mg/L - milligrams per liter

mV - millivolts

ORP - oxidation-reduction potential

Table 3-3 Post Injection pH at Block G
Lockheed Martin Middle River Complex, Middle River, Maryland

Well ID	pH Value				
	Baseline (Feb-14)	Post 1st Injection (Jul-15)	Post 2nd Injection (Mar-16)	Post 2nd Injection (May-16)	Post 2nd Injection (Jul-16)
MW-12B	5.34	6.3	6.01	6.56	6.43
MW-12A	5.68	5.9	6.13	6.34	6.38
MW-14B	6.3	6.3	6.94	6.9	6.31
SWMW-1I	6.05	6.2	7.02	6.6	6.65
SWMW-2I	6.5	6.5	7.07	7.02	6.89
SWMW-3I	5.65	6.1	6.63	6.88	6.86
SWMW-4S	5.23	5.7	6	6.16	6.08
SWMW-4I	5.69	5.9	6.66	6.99	6.93
SWMW-5I	6.52	6.2	6.65	6.49	6.59
Performance goal averages (7 wells[1])	5.99	6.13	6.71	6.72	6.62
All wells averages	*5.88*	*6.12*	*6.57*	*6.66*	*6.57*

[1]Includes wells MW-14B, SWMW-1I, SWMW-2I, SWMW-3I, SWMW-4I, SWMW-4S, and SWMW-5I. These wells are within the active remediation areas (defined in the remedial basis report as areas within the 1000 microgram per liter [µg/L] trichloroethene contour). Wells MW-12B and MW-12A are outside the active remediation areas and thus are not included in the performance average values calculation.

Table 3-4 Post Injection DHC and Ethene at Block G
Lockheed Martin Middle River Complex, Middle River, Maryland

Well ID	DHC (cells/mL)				tceA Reductase (cells/mL)				vcrA Reductase (cells/mL)				Ethene (µg/L)		
	02/11/14 Baseline	03/10/16 Post 2nd Injection	05/06/16 Post 2nd Injection	07/20/16 Post 2nd Injection	02/11/14 Baseline	03/10/16 Post 2nd Injection	05/06/16 Post 2nd Injection	07/20/16 Post 2nd Injection	02/11/14 Baseline	03/10/16 Post 2nd Injection	05/06/16 Post 2nd Injection	07/20/16 Post 2nd Injection	03/10/16 Post 2nd Injection	05/06/16 Post 2nd Injection	07/20/16 Post 2nd Injection
MW-12B	9.00E-01	1.42E+02	NS	NS	7.00E-01	3.00E-01	NS	NS	6.00E-01	1.50E+00	NS	NS	ND	NS	NS
MW-12A	2.19E+01	9.14E+04	1.85E+03	NS	1.97E+01	3.84E+02	5.80E+00	NS	1.22E+01	1.21E+04	4.63E+01	NS	7.7	9.7	NS
MW-14B	NS	NS	7.46E+03	7.00E-01	NS	NS	7.20E+00	5.00E-01	NS	NS	1.72E+03	5.00E-01	NS	54	ND
SWMW-1I	<5.00E-01	1.72E+05	3.12E+05	3.47E+04	<5.00E-01	7.52E+02	1.26E+03	2.74E+02	<5.00E-01	4.59E+04	6.21E+04	NS	24	140	73
SWMW-2I	<5.00E-01	1.50E+04	4.84E+04	1.66E+05	<5.00E-01	2.15E+01	1.25E+02	2.80E+02	<5.00E-01	2.51E+03	7.77E+03	2.75E+04	75	91	50
SWMW-3I	NS	NS	NS	1.14E+04	NS	NS	NS	3.66E+01	NS	NS	NS	2.23E+03	NS	11	NS
SWMW-4I	NS	NS	2.50E+04	2.80E+05	NS	NS	8.10E+00	2.90E+02	NS	NS	3.44E+03	3.49E+04	NS	12	18
SWMW-5I	NS	NS	NS	6.13E+04	NS	NS	NS	2.10E+00	NS	NS	NS	5.02E+03	NS	NS	7.9

< - result not detected
µg/L - micrograms per liter
cells/mL - cells per milliliter
DHC - *dehalococcoides ethenogenes*
NS - not sampled

Table 3-5 Pre- and Post-Injection VOC Concentrations at Block G
Lockheed Martin Middle River Complex, Middle River, Maryland

Well ID	Trichloroethene (µg/L)						
	02/11/14 Baseline	07/09/15 Post 1st Injection	03/10/16 Post 2nd Injection	05/06/16 Post 2nd Injection	07/20/16 Post 2nd Injection	Year 1 Verification Monitoring (2017)	Year 2 Verification Monitoring (2018)
MW-14B	2900	2	0.33	0	0	0.78	0.67
SWMW-1I	1100	1400	4	2.2	0.86	0.83	0
SWMW-2I	260	0	2	2.8	0.87	0	0.91
SWMW-3I	1300	32	110	22	23	5.1	1.1
SWMW-4S	36	0	180	110	49	2.1	4.2
SWMW-4I	1300	61	1.2	0	0	0	6.5
SWMW-5I	360	100	0.72	0	0.52	1	1
Performance monitoring well averages (7 wells[1])	1037	228	43	20	11	1	2
All wells averages	*1004*	*357*	*97*	*71*	*59*	*31*	*6*

Well ID	*cis*-1,2-Dichloroethene (µg/L)				*cis*-1,2-Dichloroethene (µg/L)		
	02/11/14 Baseline	07/09/15 Post 1st Injection	03/10/16 Post 2nd Injection	05/06/16 Post 2nd Injection	07/20/16 Post 2nd Injection	Year 1 Verification Monitoring (2017)	Year 2 Verification Monitoring (2018)
MW-14B	63	859	0.33	6.9	0	0	0.45
SWMW-1I	70	680	9.7	1.2	0.33	0	0
SWMW-2I	8.3	1900	1.9	3.4	1.1	0.44	0.39
SWMW-3I	220	340	190	260	210	260	1
SWMW-4S	11	6.5	32	41	91	2.3	5.4
SWMW-4I	180	500	84	22	10	3.3	94.5
SWMW-5I	110	520	63	170	63	0	0.79
Performance monitoring well averages (7 wells[1])	95	687	54	72	54	38	15
All wells averages	*89*	*554*	*118*	*143*	*71*	*49*	*13*

Well ID	Vinyl chloride (µg/L)						
	02/11/14 Baseline	07/09/15 Post 1st Injection	03/10/16 Post 2nd Injection	05/06/16 Post 2nd Injection	07/20/16 Post 2nd Injection	Year 1 Verification Monitoring (2017)	Year 2 Verification Monitoring (2018)
MW-14B	0	0	0.91	3	0	0	0.66
SWMW-1I	0	0	13	27	1.7	2.8	0.68
SWMW-2I	0	0	1.2	3.5	0.99	3.7	0.95
SWMW-3I	0	0	11	11	9.7	12	0.37
SWMW-4S	0	0	1.9	4.4	2.9	1.4	1.2
SWMW-4I	0	0	88	43	14	2.5	13.2
SWMW-5I	0	0	7.7	4.5	9	0	0
Performance monitoring well averages (7 wells[1])	0	0	18	14	5	3	2
All wells averages	*0*	*0*	*22*	*14*	*6*	*3*	*4*

Note: Total VOCs include trichloroethene, cis-1,2-dichloroethene, and vinyl chloride

[1]Includes wells MW-14B, SWMW-1I, SWMW-2I, SWMW-3I, SWMW-4I, SWMW-4S, and SWMW-5I. These wells are within the active remediation areas (defined in the remedial basis report as within 1000 microgram per liter [µg/L] trichloroethene contour). Wells MW-12B and MW-12A are outside the active remediation areas and thus are not included in the performance average values calculation.

TCE - trichloroethene

VOCs - volatile organic compounds

µg/L - micrograms per liter

Note: Total VOCs include trichloroethene, cis-1,2-dichloroethene, and vinyl chloride

[1]Includes wells W-14B, SWMW-1I, SWMW-2I, SWMW-3I, SWMW-4I, SWMW-4S, and SWMW-5I. These wells are within the active remediation areas (defined in the remedial basis report as within 1000 microgram per liter [µg/L] trichloroethene contour). Wells MW-12B and MW-12A are outside the active remediation areas and thus are not included in the performance average values calculation.

TCE - trichloroethene

VOCs - volatile organic compounds

µg/L - micrograms per liter

		Changes from baseline	
		VOCs	*TCE*
Average VOCs baseline	1093 µg/L	0.0%	0.0%
Average VOCs post 1st injection	911 µg/L	-16.7%	-64.5%
Average VOCs 1 month after 2nd injection	237 µg/L	-78.3%	-90.3%
Average VOCs 3 months after 2nd injection	228 µg/L	-79.2%	-93.0%
Average VOCs after Year 1	83 µg/L	-92.4%	-96.9%
Average VOCs after Year 2	23 µg/L	-97.9%	-99.4%
Average VOCs after Year 2 (including 12B)			-99.4%