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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
Mark Mank, MDE
Christine Kline, Lockheed Martin
Norman Varney, Lockheed Martin
Dave Brown, MRAS
Michael Martin, Tetra Tech
Cannon Silver, CDM Smith

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Scott Heinlein, LMCPI
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TABLE OF CONTENTS

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	g9.84 Te(bo)-1079.9r11 0 0 1 r442.0(he)4.0(no)-10.0(ge)4.0(ne)4.0(s)]T

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., 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.

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

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-

- 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: S+ ' 2 PJ/ DQG 253 í P9 7KHVH UHVXOWV LQGLFDWH WKDW FKDHZDMU 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

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.

7HMD7HFK" / RFNKHHG0 DUWQ0 LGG3BI5 LYHU&RP SQB["

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FIGURES

Map Document: (K:\GProject\middle_river\Maps\MiddleRiver_MRC_LocationMap 0114 2010.mxd)
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Middle River Complex

Source: Google Earth Pro, 2008

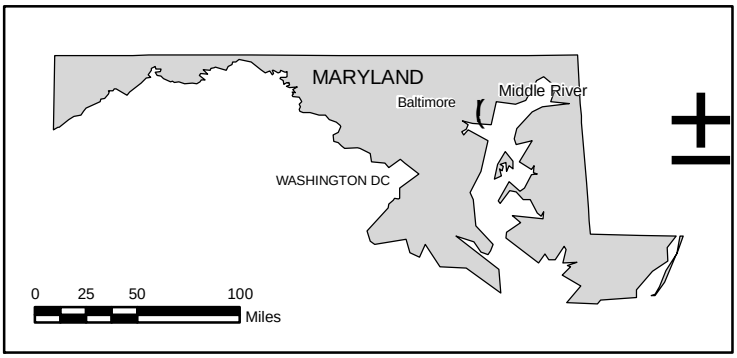

Figure 1-1

Middle River Complex
Location Map

Lockheed Martin Middle River Complex
Middle River, Maryland

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

Tetra Tech, Inc.

COW PEN CREEK

DARK HEAD CREEK

TABLES

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

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 pCa2.70vione6(iec)29.28tined3 0 Td4(in)-3.393(e)1.300tiinwell 7 pi67Sincl90.2ts)i(jec)s,3012 5tion	

	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

Table 3-3 Post Injection pH at Block G
Lockheed (J6 (Jdle River Complex, (Jdle River (J6land

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]Incldes wels (JW-14B(J)2., SW(JW-1I, SW(JW-2I, SW(JW-3I, SW(JW-4I, SW(JW-4S, and SW(JW-5I.
These wels are within the active remediaton areas (defined in the remedial basis report as areas within the
1000 microgram periter µg/L] trichloroetene contour). Wels (JW-12B(-249.2(an)-2.1(d)-254.5((J)7(W)-8.1(-)-2.3(1)-3.0(2)-3.0(A)-254.0(ar)-1.4

	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									

	02/11/14	07/09/15	03/10/16	05/06/16	07/20/16			02/11/14	07/09/15	03/10/16	05/06/16	07/20/16			02/11/14	07/09/15	03/10/16	05/06/16	07/20/16		
	Baseline	Post 1st Injection	Post 2nd Injection	Post 2nd Injection	Post 2nd Injection	Year 1 Verification Monitoring (2017)	Year 2 Verification Monitoring (2018)	Baseline	Post 1st Injection	Post 2nd Injection	Post 2nd Injection	Post 2nd Injection	Year 1 Verification Monitoring (2017)	Year 2 Verification Monitoring (2018)	Baseline	Post 1st Injection	Post 2nd Injection	Post 2nd Injection	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	63	859	0.33	6.9	0	0	0.45	0	0	0.91	3	0	0	0.66
SWMW-1I	1100	1400	4	2.2	0.86	0.83	0	70	680	9.7	1.2	0.33	0	0	0	0	13	27	1.7	2.8	0.68
SWMW-2I	260	0	2	2.8	0.87	0	0.91	8.3	1900	1.9	3.4	1.1	0.44	0.39	0	0	1.2	3.5	0.99	3.7	0.95
SWMW-3I	1300	32	110	22	23	5.1	1.1	220	340	190	260	210	260	1	0	0	11	11	9.7	12	0.37
SWMW-4S	36	0	180	110	49	2.1	4.2	11	6.5	32	41	91	2.3	5.4	0	0	1.9	4.4	2.9	1.4	1.2
SWMW-4I	1300	61	1.2	0	0	0	6.5	180	500	84	22	10	3.3	94.5	0	0	88	43	14	2.5	13.2
SWMW-5I	360	100	0.72	0	0.52	1	1	110	520	63	170	63	0	0.79	0	0	7.7	4.5	9	0	0
Performance monitoring well averages (7 wells																					

ge(geTd [(13)1.9 0 0 1 249.3(ge(geTd d(13)v.T.8 /TT1 9o424O)2.197(e)-251.199(m)6.193(on)1.904(i)4.301(t)4.30T(e)-Od (9)Tj 48.96 0 Td (0)Tj 54.9 0 Td (0)Tj -10.3(ge(g5d (0)Tj 40.02 0 T7 (88)Tj 42.12 0 T5d (0)04(i)4.301(4]TJ 52.8 0 Td [8(W)33f1)1.904(0)]TJ 54.928.964j 4.5 0909(56-4.12.42 TD /)]TJ 54.875.9 4.26 Td (1)Tj /T2 0 Td (41)Tj 4-251.50s)2.902(7)-s6(()27)-s6(.50.90/TT2.16h13-18)1.904(0)]TJ04