Tracer Study Report
Lockheed Martin Middle River Complex
2323 Eastern Boulevard,
Middle River, Maryland

Prepared for:

Lockheed Martin Corporation

Prepared by:

Tetra Tech, Inc.

October 2014

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ACRONYMS AND ABBREVIATIONS

CB	catch basin
DO	dissolved oxygen
°F	degrees Fahrenheit
gph	gallon(s) per hour
gpm	gallon(s) per minute
in. Hg	inches of mercury
IW	injection well
lbs	pounds
Lockheed Martin	Lockheed Martin Corporation
mg/L	milligram(s) per liter
mL/min	milliliters per minute
MP	metering pump
MRC	Middle River Complex
NMW	new monitoring well
O&M	operations and maintenance
ORP	oxidation-reduction potential
PLC	programmable logic controller
psig	pound(s) per square inch gauge
SDS	safety data sheet
TCE	trichloroethene
Tetra Tech	Tetra Tech, Inc.
USEPA	United States Environmental Protection Agency
UST	underground storage tank

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Section 1
Background

On behalf of Lockheed Martin Corporation (Lockheed Martin), Tetra Tech, Inc. (Tetra Tech) has performed a tracer study at the Lockheed Martin Corporation Middle River Complex (MRC) at 2323 Eastern Boulevard in Middle River, Maryland. This tracer study was performed in accordance with the *Groundwater Remediation System Operations and Maintenance Manual* (O&M manual) for the Lockheed Martin Middle River Complex (Tetra Tech, 2014). Refer to the appropriate sections of the operations and maintenance manual for background information, remediation system process-equipment and controls descriptions, and for specific operation and maintenance procedures.

The groundwater response action at the Middle River Complex implements enhanced anaerobic bioremediation-processes in three areas of the Middle River Complex that have high concentrations of trichloroethene (TCE) in groundwater: the southeastern trichloroethene area (Block E), the southwestern trichloroethene area (Block G), and the northern trichloroethene area (Block I). Amendments will be injected 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 (Appendix C of the operations and maintenance manual, Drawings C-2, C-3, C-4). Field tracer-testing was recommended before system startup because injected fluid pathways are difficult to predict accurately for the low permeability, heterogeneous geology of the Middle River Complex. The main objectives of tracer testing were to:

- evaluate preferential pathways for injected fluid
- determine optimal injection rates
- verify achievable design-injection volumes
- verify the performance and design of injection wells
- determine the effects injection has on the aquifer

- determine if injected material is being transported from the injection areas via flow through utilities or utility bedding, and if such transport is occurring, determine how to prevent it from occurring during the groundwater response action

- test and confirm the full functionality of the injection system, including the process equipment, controls, and communications

This report provides the results of the tracer testing in the following two areas:

- southwestern chlorinated volatile organic compounds area (Block G)

- northern chlorinated volatile organic compounds area (Block I)

Tracer testing was performed using treated pH-adjusted potable water with added sodium-bromide tracer and the same processing equipment and controls as will be used in the enhanced anaerobic bioremediation work. Testing also included process equipment startup, communications testing, and de-bugging.

Section 2
General Approach and Methodology

Tracer testing in each area consisted of the following general components:

a) The injection equipment containers were placed in the Block G and Block I test areas as shown on Figures 2-1 and 2-2. (Tracer testing will be performed in Block E after contamination issues associated with the underground storage tanks (UST) encountered in Block E have been resolved.)

b) The underground injection lines, potable-water line, and power supply were connected to the equipment containers.

c) Baseline performance-monitoring sampling was performed, including bromide sampling.

d) Process equipment, controls, and communications were configured and tested.

e) Test injections were performed using water (with chlorine and dissolved oxygen removed), tracer, and pH buffer (sodium bicarbonate). Specific test configurations for each area are described in Sections 3 and 4 below. The following general procedure was used at each area:

   - The system was configured to simultaneously inject fluid with tracer into several selected injection wells.
   - Injection rates were set as indicated in Sections 3 and 4.
   - Pressure heads in the injection interval were measured, and injection rates were adjusted as necessary.
   - Utilities, outfalls, and channels were visually examined.
   - Samples were collected to determine tracer concentrations in monitoring wells, utilities, and outfalls.

Tracer testing results will be used to determine operational injection rates and wellhead pressures for the full-scale injection events.

2.1 LOGISTICS AND EQUIPMENT

Tracer test equipment and logistics were selected to ensure safety during field procedures, and to minimize risk while achieving the stated test objectives. The following steps summarize general logistics and equipment used for tracer testing:

1) Injection-equipment modules designed to perform full-scale injection events were used for tracer injection. Two equipment modules were used for the tracer tests.

2) Tracer tests were performed simultaneously in Blocks G and I. The equipment modules were positioned as shown on Figures 2-1 and 2-2.

3) For each tracer test, the pH adjustment tank (T-2) in the equipment module was filled with 330 gallons of treated potable water; sodium bromide tracer was then placed in tank T-2. Sodium bromide is a nontoxic tracer commonly used for groundwater studies. Refer to Appendix E of the O&M manual (Tetra Tech, 2014) for the sodium-bromide safety data sheet (SDS).

4) Sodium bicarbonate buffer was also added to tank T-2. Sodium bicarbonate is a common nontoxic chemical often used as a gentle pH-buffering agent. Appendix E of the O&M manual (Tetra Tech, 2014) contains the SDS for sodium bicarbonate. The mixing pump in tank T-2 was activated for approximately 60–120 minutes to dissolve the added chemicals.

5) Operation of the injection system was started using the start-up procedures described in Section 3.1 of the O&M manual (Tetra Tech, 2014). In addition, injection system equipment was configured as described in Section 3.1.3 of the O&M manual (Tetra Tech, 2014). Injection-well configurations for each specific test area are described in Sections 3, 4, and 5 below.

6) Before starting the injection test at each location, data-logging liquid-level transducers were placed in selected wells to automatically record liquid levels. Following each test in each area, the data were downloaded and used to determine the effects the injections had on groundwater levels in the injection area. Two injection events were conducted in Block G, at two sets of seven to eight selected wells. One injection event was conducted in Block I, using all eight Block I injection wells.

7) During injection, site utilities and low laying areas with surface water in the injection areas (including outfalls) were visually inspected to note any change in flow or water characteristics. The active injection wellheads and all wells near the injection wells were also checked for leaks and daylighting of tracer fluid.

8) The presence of bromide tracer was determined by collecting analytical samples from monitoring wells at each injection location, and from various utility locations. Sampling locations specific to each test area are described in Sections 3 and 4 of this document.

9) Injection equipment operated automatically, with little involvement from the system operator. However, field personnel monitored injections at least three times during the first week of operation in each area, and then weekly for the remaining study period.

2.2 BROMIDE SAMPLING PROCEDURE

The results of the bromide tracer analyses will be used to estimate the effects injection has on the aquifer, and to determine if transport via site utilities is occurring. This information will be used to finalize the full-scale injection events. Collecting representative groundwater samples is therefore important for tracer analyses, so a standard low-flow sampling technique was used.

Monitoring wells were purged using a peristaltic pump and disposable polyethylene tubing placed in the middle of the screen. The pumping rate ranged between 100–300 milliliters per minute (mL/min). The purge rate depended on water stabilization and how fast the well recharged without drawdown below the initial static water level.

During groundwater purging, water-level-drawdown measurements and groundwater parameters (such as pH, temperature, specific conductance, dissolved oxygen [DO], and oxidation-reduction potential [ORP]) were collected every five to 10 minutes or after each purge volume, whichever was quicker, until purging was complete. These data were recorded in the appropriate site-specific logbook, and on low-flow-purge data sheets. Water-quality parameters were measured using an inline water-quality meter.

Purging was considered complete when the water quality parameters had stabilized, when the well had been purged dry, when three saturated well casing volumes have been removed or when purging had occurred for 90 minutes. Stabilization was achieved when three consecutive readings, taken at five-minute intervals, were within the following parameters:

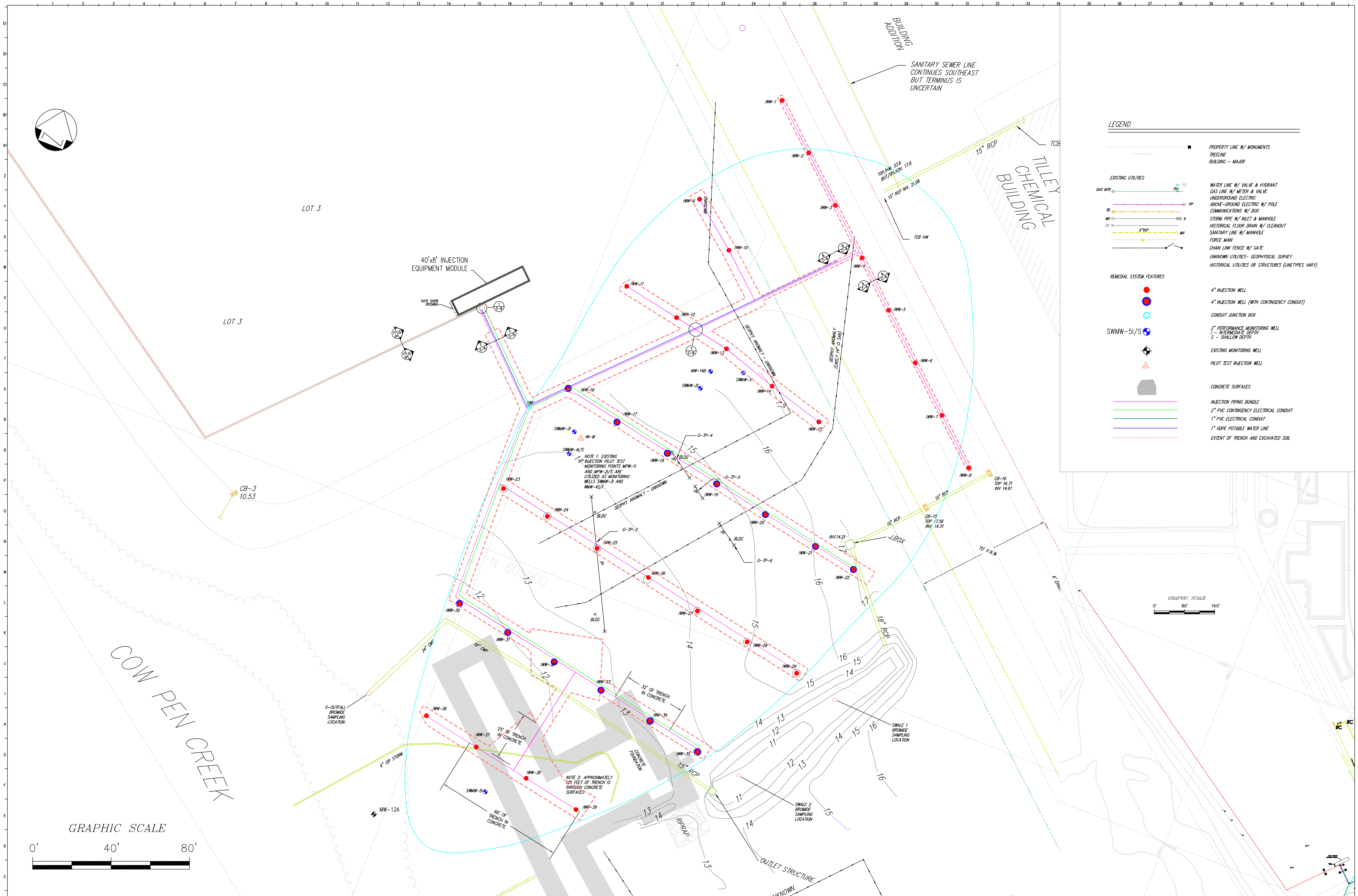
- ±0.1 standard units for pH
- ±3% for specific conductance and temperature
- ±10% for DO and ORP
- less than 10 nephalometric turbidity units for turbidity

  —or—

- for a maximum of one 90 minutes

Samples from utilities were collected by filling the sample bottle directly from the water flowing in the utility; field parameters were not collected for those samples.

The samples were shipped to a fixed-based laboratory (Analytical Laboratory Services, Middletown, Pennsylvania) to be analyzed for bromide using United States Environmental Protection Agency (USEPA) Method 300.0 (“Anions, Ion Chromatography”). The method detection-limit for bromide samples was 0.050 milligrams per liter (mg/L). Samples were collected in 250 milliliter (mL)-unpreserved plastic bottles, and were shipped on ice. Samples were analyzed within method-specific holding time of 28 days.



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.
3. SEWER PIPE CCTV REPORTS PREPARED BY VIDEO PIPE SERVICES, INC. DATED 9/26 & 10/12/2011
4. BLOCK G TOPOGRAPHIC SURVEY UPDATE PREPARED BY TETRA TECH CREW: RAB & AN, DATED: 06/07 & 06/08/2011
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.

TETRA TECH
www.tetratech.com

MARK	DATE	DESCRIPTION	BY

BLOCK G BROMIDE SAMPLING AND INJECTION LOCATIONS

LOCKHEED MARTIN CORPORATION
MIDDLE RIVER COMPLEX, MIDDLE RIVER, MARYLAND

DATE:	8/15/14
PROJECT NO.:	112IC03835
DRAWING SIZE:	ARCH E
DRAWN BY:	DWM
CHECKED BY:	BD

FIGURE 2-1

C:\USERS\BORIS.DYNKIN\DOCUMENTS\LMC MRC\TRACER STUDY REPORT\BLOCK G WITH SWALE.DWG DWM 8/15/14

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.
3. SEWER PIPE CCTV REPORTS PREPARED BY VIDEO PIPE SERVICES, INC. DATED 9/26 & 10/12/2011
4. BLOCK G TOPOGRAPHIC SURVEY UPDATE PREPARED BY TETRA TECH CREW: RAB & AN, DATED: 06/07 & 06/08/2011
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.

TETRA TECH

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MARK	DATE	DESCRIPTION	BY

BLOCK I BROMIDE SAMPLING AND INJECTION LOCATIONS

LOCKHEED MARTIN CORPORATION
MIDDLE RIVER COMPLEX, MIDDLE RIVER, MARYLAND

DATE:	8/15/14
PROJECT NO.:	112IC03835
DRAWING SIZE:	ARCH E
DRAWN BY:	DWM
CHECKED BY:	BD

FIGURE 2-2

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Section 3
Block G Tracer Testing

This section describes the layout field procedures and monitoring performed for the tracer test in Block G.

3.1 FIXED-BASE LABORATORY SAMPLING

Groundwater samples were collected from existing monitoring wells (MW-12A, MW-12B, SWMW-4S, SWMW-4I, and SWMW-1I) in Block G and analyzed for bromide. Samples were also collected at two swale locations within Block G (Swale 1 and Swale 2), and at one stormwater location (G-Outfall). Refer to Figure 2-1 for sampling locations.

Appendix B of the O&M manual (Tetra Tech, Inc. [Tetra Tech], 2014) contains specific parameters and procedures for baseline sampling. Bromide samples were collected before tracer injection began (baseline), several times during the tracer injection event, and after the tracer injection was finished. Bromide sampling procedure and analytical laboratory requirements are described in Section 2-2.

3.2 GROUNDWATER TABLE MEASUREMENTS

Groundwater levels were monitored weekly via manual gauging of monitoring wells and via pressure transducers placed within several injection wells (Figures 3-1 through 3-8). Before the transducers were installed, water levels in each well were measured using an electronic water-level meter. Transducers collected data during the entire test. Transducers were installed in each location approximately five to 10 feet below the static water level; recording frequency was set to five minutes. To ensure data quality, wells containing transducers were not sampled or otherwise disturbed. The transducers were removed after tracer testing was finished to allow the groundwater table to recover to static conditions. Data from the transducers were downloaded and assembled as graphs (Figures 3-1 through 3-8).

Groundwater levels in existing monitoring and injection wells near the active injection location were manually measured before tracer testing began. Groundwater levels within these wells were also measured three times during the first week of each injection event, and weekly thereafter.

3.3 INJECTION SOLUTION PREPARATION

The following procedure was used to prepare the injection solution in tank T-2 during Block G tracer testing:

1) Tank T-2 was filled with approximately 330 gallons of treated (dechlorinated and deoxygenated) potable water.
2) Fifty-five pounds (lbs) of sodium bromide were placed into tank T-2.
3) Five 15-lbs bags (75 lbs total) of sodium bicarbonate were added to tank T-2.
4) The mixing pump in tank T-2 was activated for 60–120 minutes to dissolve the chemicals. The tank was checked to verify that mixing was adequate and that no clumping occurred at the bottom of the tank.
5) The tracer-fluid metering-pump (MP-2) dosage was adjusted such that the entire tank volume was injected during the injection event. Pump MP-2 used the signal from electronic flow-meter FMT-1 to automatically maintain a constant tracer concentration in the injected stream, regardless of changes in the injection flow rate.

3.4 INJECTION PROCEDURE

Block G tracer testing consisted of two events:

- *Injection event #1*—injection into seven wells in the central area of Block G (May 6, 2014 through May 27, 2014).
- *Injection event #2*—injection into a second of seven wells in the southern area of Block G, closer to Cow Pen Creek (June 9, /2014 through July 10, 2014).

Equipment for the injection system was prepared and configured for operation as described in Sections 3.1 and 3.1.3 of the O&M manual (Tetra Tech, 2014). Seven injection wells (IWW-4, IWW-13, IWW-17, IWW-26, IWW-29, IWW-32, and IWW-37) in the central area of the site were connected to the injection manifold for the first injection event. The injection system was activated on May 6, 2014, and the injection rate for each connected well was set to approximately 0.15 to 0.2 gallons per minute (gpm), for a total injection rate of approximately

1-1.5 gpm (seven wells connected). Metering pump MP-2 was activated to begin injection of tracer solution from tank T-2 into the injection manifold. Settings for metering pump MP-2 are described above in Section 3.3.

The entire full-scale design volume (6,400 gallons per well, or approximately 44,000 gallons total) was injected during the first injection event. The average flow rate was 0.19 gpm per well, over a 24-day duration. The injection event was finished on May 27, 2014. The entire volume of tank T-2 (approximately 330 gallons) containing 55-lbs of sodium bromide tracer and 75-lbs of sodium bicarbonate was injected by metering pump MP-2 into the treated water stream; the average concentrations of tracer (sodium bromide) and buffer (sodium bicarbonate) were 150 mg/L and 205 mg/L, respectively. The site operator visited the site at least three times during the first week of testing, then weekly thereafter.

Injection event #2 began on June 9, 2014. Injection wells IWW-30, IWW-31, IWW-33, IWW-35, IWW-36, IWW-38, and IWW-39 were connected for this event. A similar (as compared to first injection event) injection solution (sodium bromide and sodium bicarbonate) was prepared in tank T-2. The system was re-activated, and the second injection event was performed. The average flow rate during the second injection event was 0.14 gpm per well, over a duration of 30 days. This injection event was finished on July 10, 2014.

3.5 SUMMARY OF RESULTS – INJECTION EVENT #1

This section summarizes the results of the first injection event. Injection-system process parameters (injection rates, pressures), injection wells parameters, the formation hydraulic response, and bromide tracer results follow.

3.5.1 Process Parameters for Injection Event #1

The Block G injection system operated intermittently between April 23-28, 2014, but was shut down due to problems with programmable logic controller (PLC) software. The PLC software problems were fixed, and the system resumed continuous operation on May 6, 2014 until the end of event on May 27, 2014.

System process parameters for the first injection event are summarized in Table 3-1. The parameters discussed below are presented in the flow direction starting at the upstream parameters.

The potable water pressure was stable during the entire injection event, and ranged from 73 to 76 pound(s) per square inch gauge (psig) [Table 3-1, first data column]. This pressure was in excess of the required injection pressure, and was reduced using pressure regulator PR-1.

The outlet pressure for pressure regulator PR-1 (same as GAC-1 inlet pressure) was adjusted to approximately 10 psig; it remained near this level throughout the injection event (Table 3-1, second data column). The GAC-1 outlet pressure (same as filter PF-1 inlet pressure) varied mostly from 5 to 6.5 psig, indicating that no clogging occurred across the carbon bed (Table 3-1, third data column). Outlet pressure for filter PF-1 varied between 6.5 and 8 psig, indicating that no clogging occurred across the filter (Table 3-1, fourth data column). The filter-outlet pressure was slightly higher than the upstream outlet pressure at GAC-1, because the pressure gauge was mounted lower than at the GAC-1 outlet.

The injection manifold pressure was consistently moderate (mostly between5 and 6 psig) during the injection event [Table 3-1, fifth data column]). The injection pressure was maintained as consistently as possible to ensure that no excessive pressure would be applied to the injection wells.

The total injection rate (measured by electronic flow-meter FMT-1) during the first injection event ranged between 1-1.5 gpm (Table 3-1, sixth data column) or approximately 0.19 gpm (average) per injection well for the duration of the event. This injection rate is lower than what was achieved during the injection test performed in February 2011. Higher injection rates can be obtained by increasing the manifold injection pressure, and thus, injection pressure at the well-head. However, to be conservative, the manifold injection pressure was kept below 6 psig as much as possible to avoid preferential channeling and day-lighting of injection fluid.

The vacuum applied to hollow membrane contactor MC-1 ranged from 23 to 27 inches of mercury (in. Hg). This vacuum is sufficient to remove the bulk of dissolved oxygen from an aqueous stream (Table 3-1, seventh data column).

Based on the reading of the mechanical flow totalizer (Table 3-1, eighth data column), a total volume of 44,765 gallons was injected during the first injection event (6,395 gallons average per injection well). This is very close to the injection volume for the full-scale groundwater treatment in Block G (6,400 gallons per injection well).

The electronic flow-meter FMT-1 indicated a slightly lower total injection volume of 41,865 gallons during the first injection event (Table 3-1, ninth data column). The volume of the tracer solution tank (330 gallons, with 55 lbs sodium bromide and 75 lbs sodium bicarbonate) was injected uniformly over the event (Table 3-1, tenth data column).

3.5.2 Injection Wells Parameters for Injection Event #1

The parameters for individual injection wells include the manifold branch injection pressure (measured downstream of the flow regulating valve), the actual wellhead pressure, and the injected volume, as measured by the flow totalizer at each injection well (Table 3-2).

The manifold branch injection pressures (measured on individual injection lines downstream of the flow-reducing regulating valve) ranged from 0-3.5 psig, and the average value for all wells was 1.8 psig. This parameter is important as it represents the actual line pressure applied to individual injection wells. The injection pressures of the manifold branch were kept at these low levels (0-3.5 psig with an average of 1.8 psig) to limit potential day-lighting and preferential channeling.

Wellhead injection pressures (measured at gauges installed within injection wells manholes) ranged from 1.5 to 6.5 psig, with an average value (all wells) of 3.9 psig. Wellhead injection pressures were slightly higher (typically 2 psig) than the manifold-branch injection pressures, as the wellheads were 4-5 feet lower as compared to the injection manifold; therefore, additional corresponding hydrostatic pressure was added. The highest wellhead pressure (6.0 to 6.5 psig) was measured in well IWW-37, which was in the low spot at the most downstream end of the area.

The total injected volume varied among injection wells, and was dependent upon hydraulic conductivity of the local formation. The wells in the most conductive areas (IWW-13 and IWW-32) received approximately 1.5 times greater volume, as compared to the rest of the wells. The median injected volume was 5,657 gallons, and the average injection volume per well was

6,045 gallons based on totalizer FT-1 reading. The full-design injection-volume per well is 6,400 gallons. Well IWW-37 received the least flow; it operated intermittently due to a plumbing problem which was fixed after the first injection event was finished.

3.5.3 Formation Hydraulic Response for Injection Event #1

As indicated in Section 3-2, the hydraulic response of the formation was monitored via pressure transducers placed within several injection wells, and also via manual gauging of available monitoring and idle injection wells. Transducers were installed in wells SWMW-2I, SWMW-3I, MW-14B, SWMW-5I (Figure 2-1), approximately five to 10 feet below the static water level. The recording frequency of the transducers was set to five minutes. To ensure data quality, wells containing transducers were not sampled or otherwise disturbed.

Measurements recorded by the transducers in wells SWMW-2I, SWMW-3I, MW-14B, SWMW-5I are on Figures 3-1 through 3-4, respectively. Results are shown as the positive changes in hydrostatic pressure relative to the baseline (shown as zero value) before the injection event began. System shutdown and re-start events are also indicated on these graphs.

Transducers measurement results indicate that all four wells responded very quickly to injection. For example, the hydrostatic pressure in well SWMW-2I (Figure 3-1) increased by approximately two feet after only four hours. Similarly, rapid hydraulic response was observed in all wells after the system was turned off; the hydrostatic pressure in all wells decreased by several feet within several hours of system shutdown. The hydrostatic pressure of the formation returned close to pre-injection levels within several days after the injection event ended (Figures 3-1 through 3-4). (System shutdown and restart events occurred several times at the beginning of the first injection event, when the system had to be turned off and re-started because of a problem with PLC software program.) This rapid hydraulic response indicates limited storage in the formation, resulting in limited mounding of the groundwater table.

The overall magnitude of hydraulic response in wells SWMW-2I, SWMW-3I, MW-14B and SWMW-5I was fairly consistent, and ranged between 4 and 6 feet above the static level. The increase in hydrostatic pressure during the injection event indicates that all four wells with transducers were under positive pressure during the tracer test (approximately 1-3 feet). However, day-lighting or preferential channeling into low-laying areas was not observed. This is likely due to the lower permeability of shallow soil, and higher horizontal conductivity of the formation (as compared to a vertical direction in the formation).

Groundwater levels in several existing monitoring and injection wells near the 16 active injection wells were also manually gauged before the event started and while the injection was performed. Manual gauging results for area wells are summarized in Table 3-3. The baseline (pre-injection) measurements in these wells indicate that the depth to the groundwater table becomes shallower in the down-gradient direction (closer to Cow Pen Creek). For example, baseline depths to groundwater in up-gradient injection wells (IWW-3, IWW-5, and IWW-12) were between 6 and 7 feet below ground surface. Static depths to water in the middle portion of Block G were generally between 2 and 3 feet below ground surface, while static depths to water in the down-gradient portion of Block G were generally between 1 and 2 feet below ground surface.

All 16 wells responded when the injection began. The magnitude and character of hydraulic response were similar to that measured by the transducers. As the injection event progressed, most wells were observed under positive hydraulic pressure (i.e., they overflowed when opened). These wells are noted in Table 3-3 with the notation "pressure." No day-lighting or preferential channeling of the injected fluid was observed on the ground surface or in low-lying areas.

3.5.4 Bromide Tracer Results for Injection Event #1

During tracer testing, a sodium bromide tracer was injected into the formation and analytical samples were collected from several monitoring wells (MW-12A, MW-12B, SWMW-1I, SWMW-4S, and SWMW-4I) two surface water locations (Swale-1 and Swale-2), and from a stormwater location (G-Outfall). Figure 2-1 shows sampling locations, while analytical sampling results and pertinent injection parameters (e.g., injected tracer concentrations, quantities, and the injected volumes) are presented on Table 3-4.

The arrival of the bromide tracer was clearly detected in well SWMW-1I, where its concentration increased from 43 µg/L (May 15, 2014) to 2,700 µg/L (May 21, 2014), and further increased to 9,700 µg/L (May 27, 2014) at the end of Injection Event #1. The distance from the nearest injection location (IWW-13) to the point of detection (SWMW-1I) was 15 feet (side-gradient). The arrival of bromide at another monitoring well in the injection area (SWMW-4I) was detected much later (7,500 µg/L on June 10, 2014), because the distance from the nearest injection location (IWW-17) to that location was twice as far (30 feet cross-gradient). Thus, the bromide tracer traveled a maximum distance of 30 feet from injection location, which indicates that adequate distribution of the injected fluid was achieved.

Bromide results from the shallow surface-water location (Swale 1, approximately 20 feet from the nearest active injection well [IWW-29]) show no increase over background levels. The bromide levels in Swale-1 ranged from 120 to 140 µg/L, indicating that no injected fluid traveled to nearby surface water in the low-lying areas. Likewise, the bromide level (20 µg/L) in the sample collected on May 15, 2014 at the stormwater outfall location was also within typical background levels for bromide, again indicating that injection fluid did not travel via the storm drain utilities. A slightly elevated bromide level (390 µg/L) was detected at the beginning of injection event #1 in SWMW-4I, probably due to residual bromide from the injection test conducted in this area in November 2011.

3.6 SUMMARY OF RESULTS – INJECTION EVENT #2

This section summarizes the results of the second injection event conducted in Block G. Injection-system process parameters (injection rates, pressures), injection wells parameters, the formation hydraulic response, and bromide tracer results follow.

3.6.1 Process Parameters for Injection Event #2

The system process parameters for the second injection event are summarized in Table 3-5; parameters discussed below are presented by the flow direction starting with upstream parameters.

Potable water pressure was stable during the entire injection event, with a range of 70-76 psig (Table 3-5, first data column). This pressure was in excess of the required injection pressure, and was reduced using pressure regulator PR-1.

The outlet pressure at pressure regulator PR-1 (same as GAC-1 inlet pressure) was adjusted to approximately 10 psig, and remained close to this level for the majority of the event (Table 3-5, second data column). However, after almost two weeks of injection, signs of activated carbon clogging in GAC-1 were observed, and the outlet pressure at pressure regulator PR-1 was adjusted higher on July 1 and July 7, 2014 to compensate for decreasing pressure at the GAC-1 outlet.

Outlet pressure at GAC-1 (same as filter PF-1 inlet pressure) mostly varied from 4.5 psig at the start of the event to 3.0 psig on July 1, 2014. The pressure differential across the GAC-1 unit increased to 14 psig by the end of injection event, indicating that clogging occurred across the carbon bed (Table 3-5, third data column). The potable water source was very turbid, and likely contained suspended solids that caused GAC-1 clogging. Measures will be taken to address this issue during full-scale groundwater treatment, and will include carbon bed backwash or replacement, and possibly additional filtration at the GAC-1 inlet.

The outlet pressure at filter PF-1 varied from 5 to 7 psig during the injection event, indicating that no clogging occurred across the filter (Table 3-5, fourth data column). The outlet pressure was slightly higher than that of the (upstream) GAC-1 outlet, because the pressure gauge at filter PF-1 was mounted lower than on the gauge at the GAC-1 outlet.

The injection manifold pressure mostly ranged between 2 and 5 psig during the injection event #2 (Table 3-5, fifth data column).

The total injection rate (as measured by electronic flow-meter FMT-1) typically ranged between 0.5 and 1.1 gpm during this injection event (Table 3-5, sixth data column), with an average of approximately 0.14 gpm per injection well. This injection rate is lower than what was achieved during the first injection event due to GAC-1 clogging and correspondingly lower injection pressure.

The vacuum applied to the hollow membrane contactor MC-1 ranged from 23.5 to 24.5 in. Hg, and is sufficient to remove the bulk of dissolved oxygen from the aqueous stream (Table 3-5, seventh data column).

Based on the readings from the mechanical flow totalizer (Table 3-5, eighth data column), 41,405 gallons of fluid was injected into seven wells during the second injection event, an average of 5,915 gallons per injection well. This is slightly lower than the injection volume for full-scale groundwater treatment in Block G (6,400 gallons per injection well), and is likely due to an insufficient injection rate at well IWW-35 (see discussion in the following section).

Without well IWW-35, the average injection volume per well is 6,643 gallons which is very close to the design injection volume (6,400 gallons).

Electronic flow-meter FMT-1 indicated a slightly lower total injection volume (39,332 gallons) for the second injection event (Table 3-5, ninth data column). The entire volume of tracer solution (330 gallons, with 55 lbs sodium bromide and 75 lbs sodium bicarbonate) was injected uniformly during the event (Table 3-5, tenth data column).

3.6.2 Injection Wells Parameters for Injection Event #2

The individual injection wells parameters for the second injection event in Block G are summarized in Table 3-6.

Injection pressures for the manifold branch (as measured on individual injection lines downstream of the flow-reducing regulating valve) ranged from negative to 2.0 psig, with the average value for all wells being negative. The manifold branch injection pressures were generally lower during Injection Event #2 due to GAC-1 clogging and therefore reduced manifold pressure.

Wellhead injection pressures (measured at gauges installed within injection wells manholes) ranged from 0 to 6.0 psig, with an average 3.7 psig. These values were slightly lower than those observed in the first injection event #1. Wellhead injection pressures were slightly higher (typically approximately 2 psig higher) than the injection pressures for the manifold branch. The wellheads were 4-5 feet lower than the injection manifold; thus, corresponding hydrostatic pressure was added.

The total injected volume (and therefore the injection rates per well) were more uniform during the second injection event at Block G because more frequent adjustments were made to flow regulating valves at the injection manifold. Well IWW-35 was an outlier (and therefore not used to calculate flow uniformity, median, or average values), and had a lower injection flow rate as compared to other wells. This was likely due to some construction deficiency such as a pinched injection line. The wells with the highest injection rate (IWW-30 and IWW-38) received approximately 19% greater volume compared to the well with the lowest injection rate (IWW-31). Based on the reading at totalizer FT-1, the median injected volume was 5,856 gallons, and the average injection volume per well was 5,875 gallons.

3.6.3 Formation Hydraulic Response for Injection Event #2

As indicated in Section 3-2, the hydraulic response of the formation was monitored via pressure transducers placed within several injection wells, and via manual gauging of idle injection- and available monitoring- wells.

During the second injection event, transducers were installed in wells IWW-32, IWW-34, IWW-37 and SWMW-5I (Figure 2-1) approximately five to 10 feet below the static water level, and recording frequency was set to five minutes. To ensure data quality, wells containing transducers were not sampled or otherwise disturbed.

The measurements recorded by the transducers in wells IWW-32, IWW-34, IWW-37 and SWMW-5I are presented on Figures 3-5 through 3-8, respectively. The results are shown as the positive changes in hydrostatic pressure relative to the baseline (shown as a zero value) before the injection event began. System shutdowns and re-starts are also indicated on these graphs.

Similar to first injection event, transducer measurements in the second event indicated that all four wells responded very quickly to injection. For example, the hydrostatic pressure in well SWMW-5I (Figure 3-8) increased by approximately two feet after only two hours of injection. Similarly, rapid hydraulic response was observed in all wells after the system was turned off; the hydrostatic pressure in all wells decreased by several feet within several hours of the system shutdowns, and the hydrostatic pressure of the formation returned to a level close to its pre-injection level within several days after the end of injections (Figures 3-5 through 3-8). The effects of GAC-1 clogging, and subsequent system adjustment events (pressure and flow decreases, and then an increase after adjustment) can be seen on all graphs. As described earlier, these events occurred at the end of the second injection event. Similar to the first event, this rapid hydraulic response is indicative of a limited storage in the formation, and thus limited mounding of the groundwater table.

The overall magnitude of a hydraulic response in wells IWW-32, IWW-34, IWW-37 and SWMW-5I during the second injection event was similar to the first, and ranged between four and six feet (relative to the static level). A comparison between pre-injection static depths to water and the increase in hydrostatic pressure during the injection in these wells indicate that all four wells with the transducers were under positive pressure during the second injection event (approximately

1-3 feet). However, similar to the first event, day-lighting or preferential channeling into the low-laying areas such as the swale or low-laying spots in Block G was not observed. This is likely due to lower permeability of the overlying shallow soil acting as a vertical hydraulic barrier. I may also be due to a higher formation conductivity in the horizontal direction (as compared to a vertical direction) in the formation.

Groundwater levels in several existing monitoring and injection wells near the active injection locations (four wells) were also manually gauged before the second injection event was started, and while the injection was performed. The most distant well (MW-12A) was 57 feet down-gradient from the nearest active injection well (IWW-36). The rest of the monitoring locations were approximately 25 feet from the nearest active injection well. The manual gauging results are summarized in Table 3-7; baseline (pre-injection) measurements in these wells indicate that depth to groundwater is shallow, ranging from 0.32 to 3.32 feet below ground surface.

All four wells responded when the injection began. As the injection progressed, positive hydraulic pressure was observed in the three wells closest to the active injection locations (i.e., they overflowed when opened). These wells are shown in Table 3-7 with the notation “pressure”. A hydraulic response of 3.32 feet was observed in well MW-12A, which was 57 feet down-gradient from the nearest active injection well (IWW-36). This indicates that there is hydraulic connectivity between this well and the injection wells array.

3.6.4 Bromide Tracer Results for Injection Event #2

Analytical samples for the second injection event were collected from the same locations as were used for the first injection event (Figure 2-1). Sampling results and pertinent injection parameters are on Table 3-4.

The possible arrival of low levels of bromide tracer was detected in down-gradient well MW-12A, at a distance of 57 feet from the nearest active injection well (IWW-36). The bromide concentration in MW-12A increased from 120 µg/L on June 17, 2014 to 280 µg/L on July 24, 2014. However, this increase may not be enough to conclude that the bromide tracer traveled this distance (57 feet) from the injection point. The second monitoring well (MW-12B) was 95 feet from the nearest active injection well, and no increase in bromide concentration over the background level was observed.

Bromide levels above background were not detected in the shallow surface-water sample collected at Swale 2; this location is approximately 20 feet from the nearest active injection well (IWW-35). Bromide levels in Swale 2 ranged from 94 µg/L (June 17, 2014) to 190 µg/L (July 24, 2014) when the injection event was finished. Bromide detected at the end of the second injection event was slightly higher than the rest of the samples from Swale 2; thus, a minor bromide tracer influence cannot be ruled out. However, this value (190 µg/L) is within background bromide levels. Therefore, we conclude it is unlikely that injected fluid traveled to the nearby surface water in the low spot in the swale. However, it cannot be ruled out that a trace quantity of the injected fluid may have entered the swale.

Bromide concentrations slowly increased as the injection progressed to a maximum of 350 µg/L on July 24, 2014. This trend could be attributed to the influence of the injected bromide tracer. Note that this concentration of bromide is close to the typical background levels at the site. However, we conservatively assume that a trace amount of the injection fluid entered stormwater utilities and was subsequently detected at the outfall. The O&M manual contains several recommendations for the full-scale injection event that will reduce the risk of migration of injected fluid into the storm water utilities in Block G.

Table 3-1
Block G Injection-Equipment Process Parameters - Injection Event #1
Lockheed Martin Middle River Complex, Middle River, Maryland

Date	Potable Water Line Pressure (psig)	Pressure Regulator PR-1 outlet Pressure (psig)	GAC-1 Outlet Pressure (psig)	Filter PF-1 Outlet Pressure (psig)	Injection Manifold Pressure (psig)	Total Injection Flow (gpm)	Contactor MC-1 Vacuum (in.Hg)	Total Injected Volume by FT-1 (gallons)	Total Injected Volume by FMT-1 (gallons)	Tracer Solution Tank (T-2) Level (inches)	Comments
4/23/2014	74	9.50	6.50	8.00	6.00	1.3	-23.5	845	579	43	Intermittent system operation due to PLC problems
4/24/2014	76	9.75	6.50	8.00	5.75	1.3	-23.4	2,783	2,500	40.5	
4/25/2014	73	9.50	6.50	8.00	5.50	1.4	-23	3,412	3,124	39.5	
4/28/2014	75	10.00	6.50	8.00	5.50	1.3	-24	8,185	7,821	33.25	System off due to PLC problems
5/6/2014	74	10.00	6.50	7.50	5.25	1.3	-27	10,563	10,179	30	System re-start
5/7/2014	74	10.00	6.00	7.50	5.50	1.4	-25.5	12,316	11,902	27	
5/9/2014	75	10.00	8.00	7.00	5.50	1.4	-25	15,913	15,434	22	
5/12/2014	75	10.00	6.00	7.00	5.00	1.1	-25	21,588	20,995	17.75	
5/19/2014	76	10.00	5.00	6.50	10.75	1	-25	32,682	31,299	10	Injection manifold pressure inconsistent
5/27/2014	--	--	--	--	--	--	-25	44,765	41,865	0	Finish injection event #1

Note:
-- : reading not recorded
PLC - programmable logic controller
psi - pounds per square inch gauge
gpm - gallons per minute
in. Hg - inches of mercury

Table 3-2
Block G Injection-Well Parameters - Injection Event #1
Lockheed Martin Middle River Complex, Middle River, Maryland

Date	IWW-4			IWW-13			IWW-17		
	Manifold Pressure (psig)	Wellhead Pressure (psig)	Injected Volume (gallons)	Manifold Pressure (psig)	Wellhead Pressure (psig)	Injected Volume (gallons)	Manifold Pressure (psig)	Wellhead Pressure (psig)	Injected Volume (gallons)
4/24/14	3	3	332	2	3	432	0	2	451
4/25/14	2	3.5	444	0.5	2.5	375	0	1.5	535
4/28/14	2	3.5	1,234	1.5	2.5	1,648	0.5	2	1,183
5/6/14	3.5	3.5	1,515	2	3	2,128	0	2.25	1,352
5/7/14	3.5	4	1,795	2	2.5	2,485	0	2.5	1,586
5/9/14	3	--	2,247	2.5	--	3,198	0	--	1,993
5/12/14	3	4	2,936	3	3	4,315	0	2.75	2,636
5/19/14	3	4	4,373	3	3	6,736	0	2.75	4,086
5/27/14	--	--	5,657	--	--	9,226	--	--	5,609
Averages	2.9	3.6		2.1	2.8		0.1	2.3	

Date	IWW-26			IWW-32		
	Manifold Pressure (psig)	Wellhead Pressure (psig)	Injected Volume (gallons)	Manifold Pressure (psig)	Wellhead Pressure (psig)	Injected Volume (gallons)
4/24/14	0	2.5	247	2.2	3.3	442
4/25/14	0.5	3	287	1.75	5	580
4/28/14	1	3	755	2	5	1,619
5/6/14	0	4	910	2	5	2,106
5/7/14	0	4.25	1,100	2	5.25	2,516
5/9/14	0.5	--	1,436	2	--	3,206
5/12/14	0	4.5	1,981	2	5.75	4,283
5/19/14	0	4.5	3,209	2	5.75	6,647
5/27/14	--	--	4,486	--	--	9,049
Averages	0.3	3.7		2.0	5.0	

Date	IWW-37			IWW-29		
	Manifold Pressure (psig)	Wellhead Pressure (psig)	Injected Volume (gallons)	Manifold Pressure (psig)	Wellhead Pressure (psig)	Injected Volume (gallons)
4/24/14	Off	Off	112	3	4.5	379
4/25/14	Off	Off	112	2.5	3.5	493
4/28/14	Off	Off	124	2.5	3.5	1,318
5/6/14	Off/On	Off/On	648	2.5	3.75	1,412
5/7/14	3	6.5	691	2.5	4	1,703
5/9/14	2.5	6	1,259	2	--	2,188
5/12/14	Off	Off	--	2.5	4.25	2,937
5/19/14	Off	Off	--	2	4.5	4,535
5/27/14	--	--	2,133	--	--	6,155
Averages	2.8	6.3		2.4	4.0	

Average manifold pressure	1.8 psig
Average wellhead pressure	3.9 psig
Median injection volume	5906 gallons

Note:
-- : reading not recorded

psig - pounds per square inch gauge
gpm - gallons per minute
in. Hg - inches of mercury

Table 3-3

Gauging in Block G Wells - Injection Event #1
Lockheed Martin Middle River Complex, Middle River, Maryland

Date	Depth to groundwater, feet from top of well casing															
	IWW-3	IWW-5	IWW-14	IWW-12	SWMW-2I	IWW-18	IWW-16	SWMW-3I	SWMW-4S	SWMW-4I	IWW-25	IWW-27	IWW-31	IWW-33	IWW-36	IWW-38
4/22/14	6.39	6.5	4.97	6.72	4.38	3.63	2.74	2.72	2.11	2.54	2.03	2.84	1.42	1.76	1.13	2.42
4/25/14	4.46	4.72	1.89	2.26	1.17	1.04	0.75	pressure	1.71	pressure	0.2	0.25	1.04	0.25	0.29	0.3
4/28/14	3.16	3.3	1.8	0.99	--	0.35	0.4	pressure	0.58	pressure	0.25	0.25	0.1	0.4	0.3	pressure
5/7/14	1.8	1.13	0.15	0.18	0.38	0.15	0.22	pressure	1.12	pressure	pressure	0.12	pressure	0.12	0.22	pressure
5/12/14	1.91	0.56	pressure	pressure	pressure	--	pressure	pressure	1.62	pressure	pressure	pressure	pressure	pressure	pressure	pressure
5/19/14	1.89	1.01	pressure	pressure	pressure	--	pressure	pressure	pressure	pressure	pressure	pressure	pressure	pressure	pressure	pressure

Note:
-- : reading not recorded
pressure : Well head under pressure when monitoring took place

Table 3-4
Block G Bromide Tracer Sampling Results Summary
Lockheed Martin Middle River Complex, Middle River , Maryland

Sampling Location	Baseline 2/10/2014[1]		Begin 1st injection event on 5/5/2014[3]. Injecting into wells IWW-4, IWW-13, IWW-17, IWW-26, IWW-29, IWW-32, IWW-37.	5/15/2014[2]		5/21/2014[2]		5/27/2014[2]ug/L		End 1st injection event on 6/2/14.	Begin 2nd injection event on 6/9/14. Injecting into wells IWW-30, IWW-31, IWW-33, IWW-35, IWW-36, IWW-38, IWW-39.	6/10/2014[2] ug/L	6/17/2014[2] ug/L	6/30/2014[2] ug/L	End injection into 2nd set of injection wells on 7/10/14.	7/24/2014[2] ug/L
	Bromide ug/L	pH		Bromide ug/L	pH	Bromide ug/L	pH	Bromide ug/L	pH							
MW-12A	170	5.68		88	5.75								120	200		280
MW-12B	<81	5.34		22	6.01								44	60		49
Swale1				140		130		120				8.7				
Swale2				120									94	110		190
G-OUTFALL	<81	7.74		20									81	120		350
SWMW-4S	200	5.23														
SWMW-4I	820	5.69		390		320	5.76	210	5.73			7500				
SWMW-1I	<81	6.05		43		2700	6.75	9700	5.84			290				

[1]Minimum MDL = 81 ug/L; Minimum RL = 500 ug/L

[2]Minimum MDL = 2.2 ug/L; Minimum RL = 2.5 ug/L

[3]System operated intermittently for 3 days in April of 2014, then shut down due to PLC problems. Continuous injection started in 5/5/2014.

1st injection event average injected bromide concentration:	147	mg/L
1st injection event total bromide tracer injected:	55	pounds
1st injection event total volume injected:	44765	gallons
1st injection event volume per well:	6395	gallons
1st injection event average injection rate per welll:	0.15	gallons per minute
1st injection event duration:	29	days
2nd injection event average injected bromide concentration:	161	mg/L
2nd injection event total bromide tracer injected:	55	pounds
2nd injection event total volume injected:	40860	gallons
2nd injection event volume per well:	5837	gallons
2nd injection event average injection rate per welll:	0.14	gallons per minute
2nd injection event duration:	30	days

Table 3-5

Block G Injection-Equipment Process Parameters - Injection Event #2
Lockheed Martin Middle River Complex, Middle River, Maryland

Date	Potable water line pressure (psig)	Pressure regulator (PR-1) outlet pressure (psig)	GAC-1 outlet pressure (psig)	Filter (PF-1) outlet pressure (psig)	Injection manifold pressure (psig)	Total injection flow (gpm)	Contactor (MC-1) vacuum (in.Hg)	Total volume injected by FT-1 (gallons)	Total volume injected by FMT-1 (gallons)	Tracer solution tank (T-2) level (inches)	Comments
6/9/2014	76	10.00	4.50	5.50	4.00	1.00	-24	44,980	42,069	40.00	
6/11/2014	76	10.00	3.75	5.00	10.50	1.10	-24.5	47,601	44,708	38.50	
6/13/2014	76	10.00	3.50	5.00	2.50	0.90	-24.5	50,617	47,683	36.00	
6/16/2014	75	11.50	4.00	5.50	10.50	1.00	-24.5	54,199	51,103	33.50	
6/23/2014	75	11.50	4.00	5.00	3.00	0.90	-24	64,305	60,603	26.50	
7/1/2014	72	14.50	4.00	5.50	3.50	1.10	-24	75,277	70,466	18.50	
7/7/2014	70	19.50	5.50	7.00	4.50	1.40	-23.5	82,719	77,548	8.00	
7/10/2014	--	--	--	--	--	--	--	86,385	81,401	0.00	

Note:
-- : reading not recorded
GAC - granular activated carbon
gpm - gallons per minute
in. Hg - inches of mercury
psig - pounds per square inch gauge

Table 3-6

Block G Injection-Well Parameters - Injection Event #2
Lockheed Martin Middle River Complex, Middle River, Maryland

Date	IWW-30			IWW-31			IWW-33		
	Manifold pressure (psig)	Wellhead pressure (psig)	Injected volume (gallons)	Manifold pressure (psig)	Wellhead pressure (psig)	Injected volume (gallons)	Manifold pressure (psig)	Wellhead pressure (psig)	Injected volume (gallons)
6/11/14	0	3.5	458	2	4	365	1	5.5	324
6/13/14	0	4.25	913	2	4	759	1	6	641
6/16/14	0	4.25	1,432	2	4	1,210	1	6	936
6/23/14	0	4.5	2,992	2	4	2,519	1	6	1,964
7/1/14	0	4.5	4,568	1.5	4	3,830	1	6	3,201
7/7/14	-3	2.5	5,666	0	4	4,794	0	6	4,929
7/10/14	--	--	6,253	--	--	5,216	--	--	6,036
Averages	**-0.5**	**3.9**		**1.6**	**4.0**		**0.8**	**5.9**	

Date	IWW-35			IWW-36		
6/9/14	--	--	4,487	--	--	9,089
6/11/14	-2	1.75	214	-2	3.75	463
6/13/14	0	2.5	437	0	4	1,029
6/16/14	0	3	604	0	4	1,699
6/23/14	0	3	1,263	-2	4	3,277
7/1/14	0	3	1,664	-3	3.5	4,834
7/7/14	-5	0	1,759	-7	1.5	5,533
7/10/14	--	--	1,760	--	--	5,856
Averages	**-1.2**	**2.2**		**-2.3**	**3.5**	

Date	IWW-38			IWW-39		
	Manifold pressure (psig)	Wellhead pressure (psig)	Injected Volume (gallons)	Manifold pressure (psig)	Wellhead pressure (psig)	Injected volume (gallons)
6/9/14	--	--	2,174	--	--	6,174
6/11/14	-5	--	490	0	4	417
6/13/14	0	3	978	0	4	891
6/16/14	0	3	1,562	1	4	1,402
6/23/14	0	3	3,124	1.5	4	2,927
7/1/14	-2	3	4,668	0	4	4,407
7/7/14	-6	0	5,285	0	4	5,642
7/10/14	--	--	5,691	--	--	6,195
Averages	**-2.2**	**2.4**		**0.4**	**4.0**	

Average manifold pressure	-0.5	psig
Average wellhead pressure	3.7	psig
Median injection volume	5,856	gallons

Note:
-- : reading not recorded
psi - pounds per square inch gauge
gpm - gallons per minute
in. Hg - inches of mercury
psig - pressure per square inch gague

Table 3-7

Gauging in Block G Wells - Injection Event #2
Lockheed Martin Middle River Complex, Middle River, Maryland

Date	Depth to groundwater, feet from top of well casing										
	SWMW-2I	SWMW-3I	MW-12A	MW-14B	SWMW-5I	IWW-24	IWW-27	IWW-32	IWW-34	IWW-35	IWW-37
6/2/2014	0.79	2.39	--	1.08	2.05	--	--	--	--	--	--
6/6/2014	--	--	3.32	--	2.98	1.02	0.37	pressure	pressure	1.04	1.78
6/11/2014	--	--	2.34	--	--	0.84	0.35	--	--	pressure	--
6/13/2014	--	--	1.12	--	--	pressure	pressure	--	--	pressure	--
6/16/2014	--	--	0.46	--	--	pressure	pressure	--	--	pressure	--
6/23/2014	--	--	0.32	--	--	pressure	pressure	--	--	pressure	--
7/1/2014	--	--	2.62	--	--	pressure	pressure	--	--	pressure	--
7/7/2014	--	--	1.96	--	--	pressure	pressure	--	--	pressure	--

Note:
-- : reading not recorded
pressure : Well head under pressure when monitoring took place

Figure 3-1 LMC MRC Tracer Study in Block G: Monitoring Well SWMW-2I Hydraulic Response

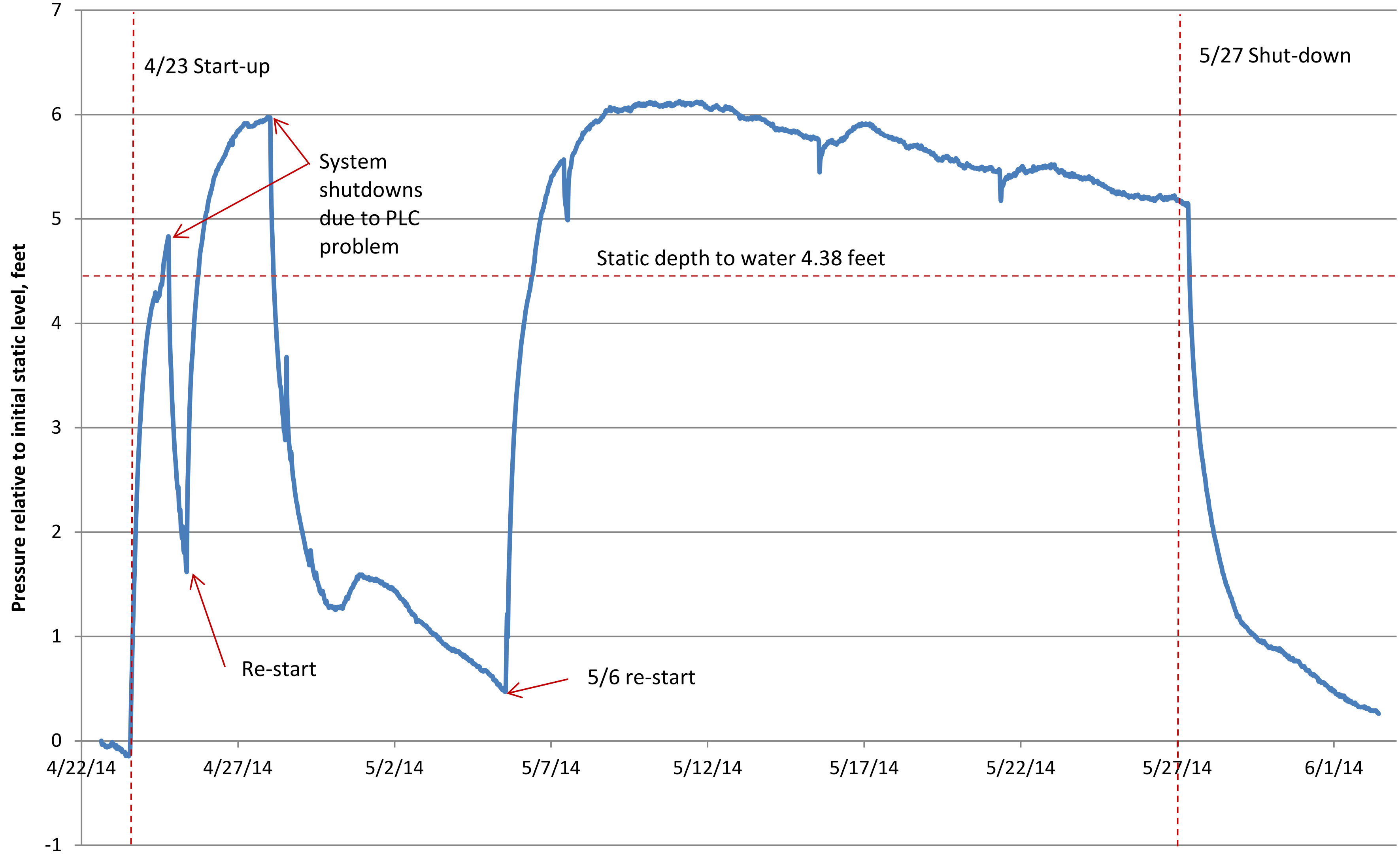
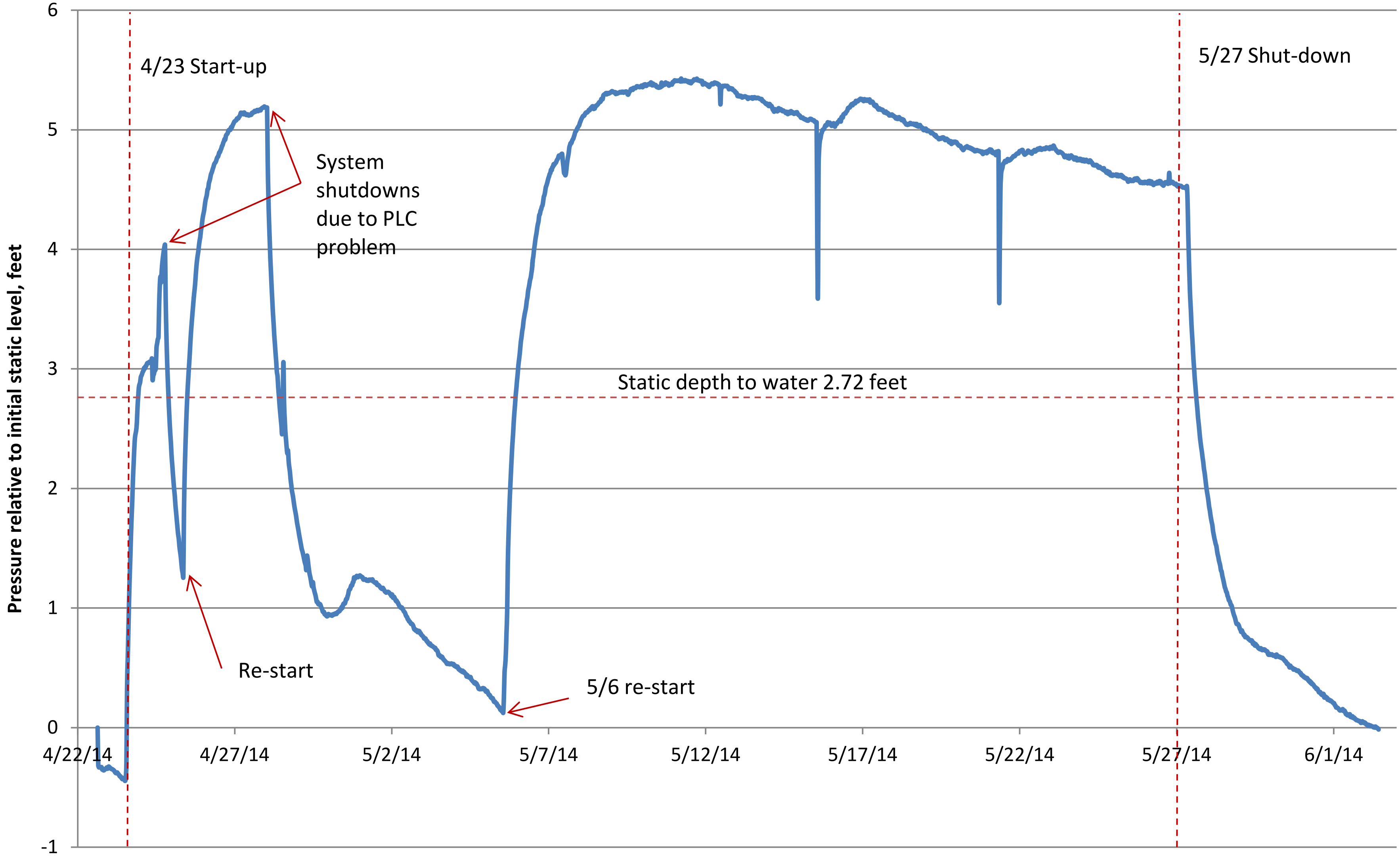


Figure 3-2 LMC MRC Tracer Study in Block G: Monitoring Well SWMW-3I Hydraulic Response



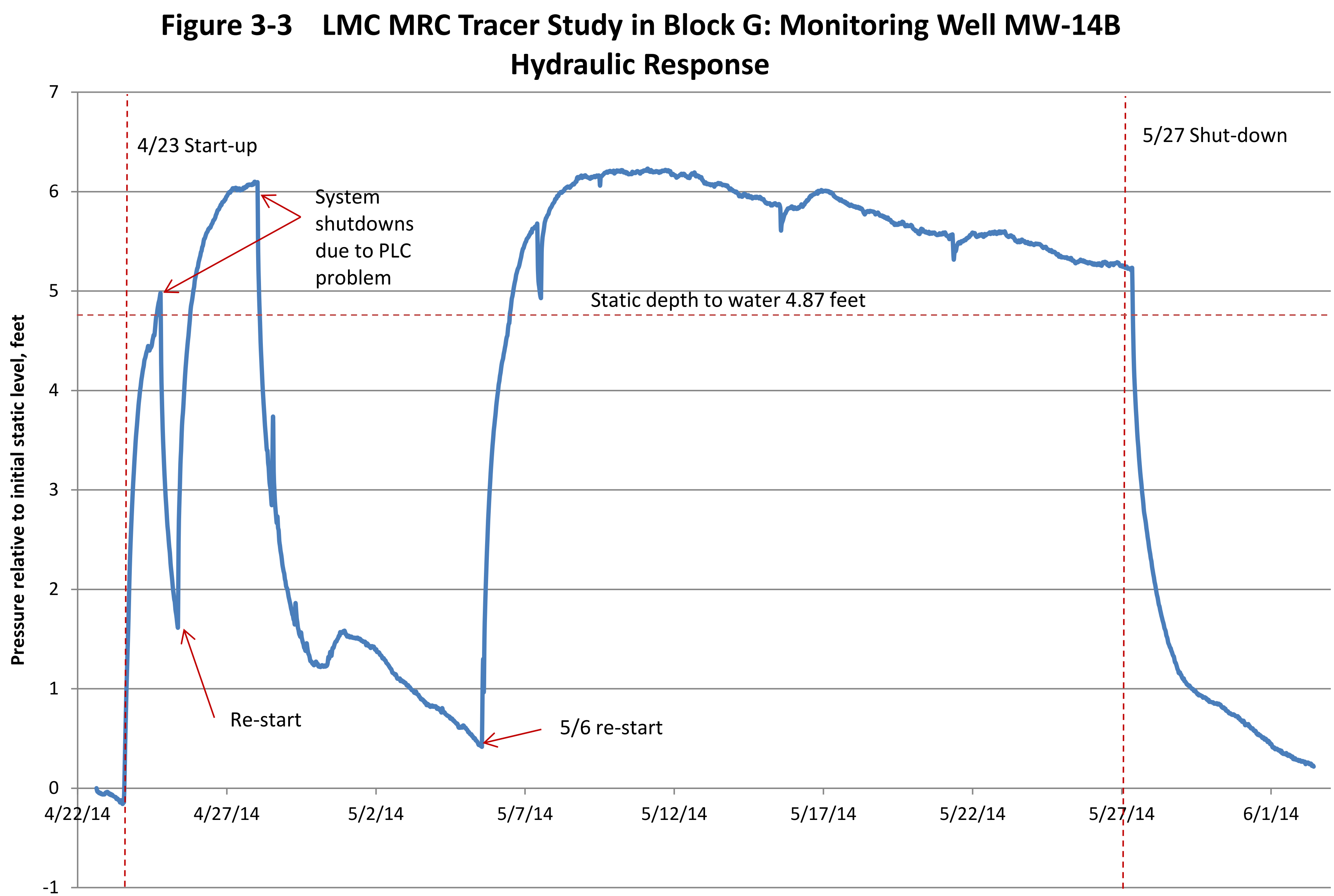


Figure 3-3 LMC MRC Tracer Study in Block G: Monitoring Well MW-14B
Hydraulic Response
Pressure relative to initial static level, feet
7
6
5
4
3
2
1
0
-1
4/22/14
4/27/14
5/2/14
5/7/14
5/12/14
5/17/14
5/22/14
5/27/14
6/1/14
4/23 Start-up
System
shutdowns
due to PLC
problem
Re-start
5/6 re-start
Static depth to water 4.87 feet
5/27 Shut-down

Figure 3-4 LMC MRC Tracer Study in Block G: Monitoring Well SWMW-5I Hydraulic Response (First Injection Event)

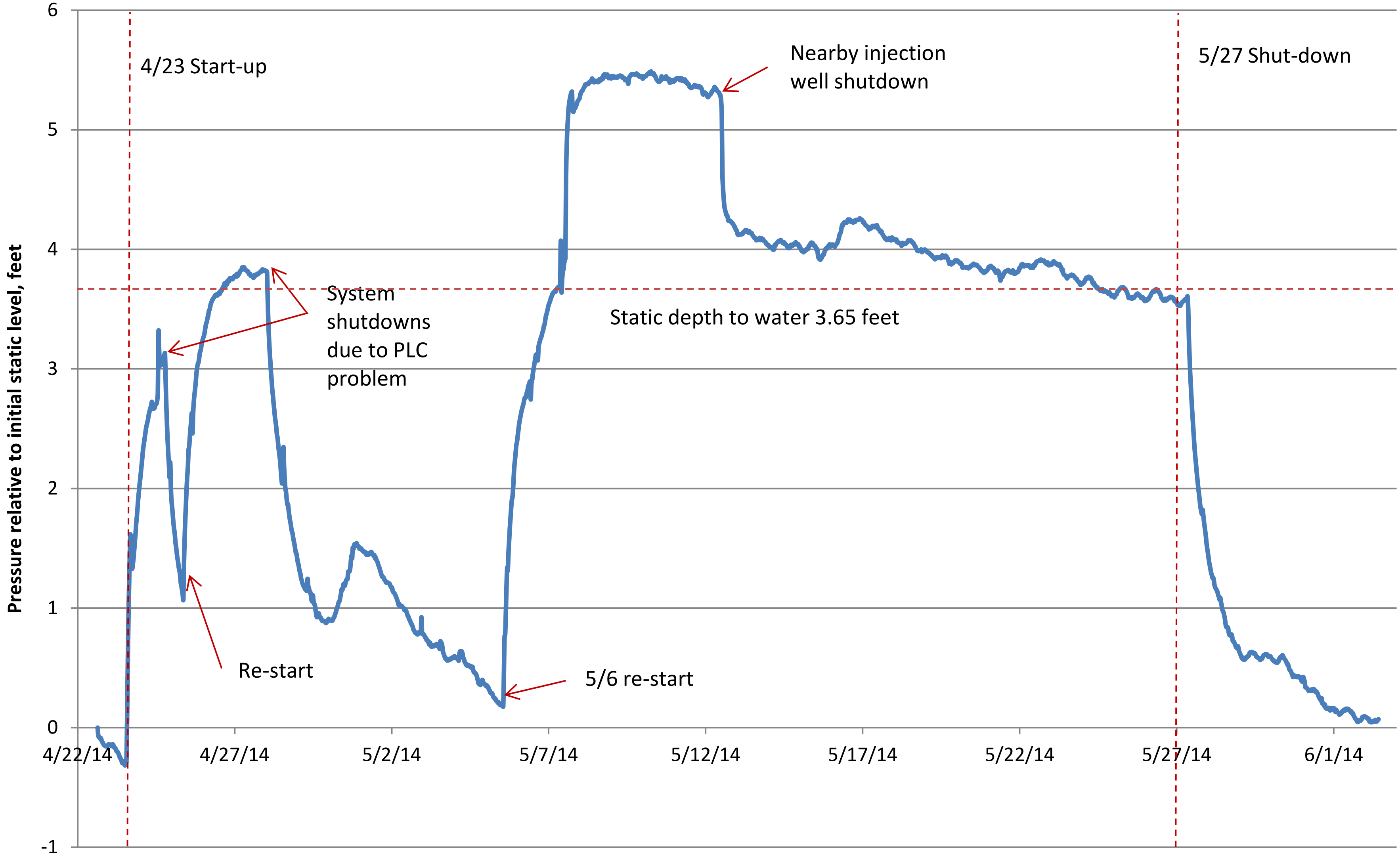


Figure 3-5 LMC MRC Tracer Study in Block G: Monitoring Well IWW-32 Hydraulic Response

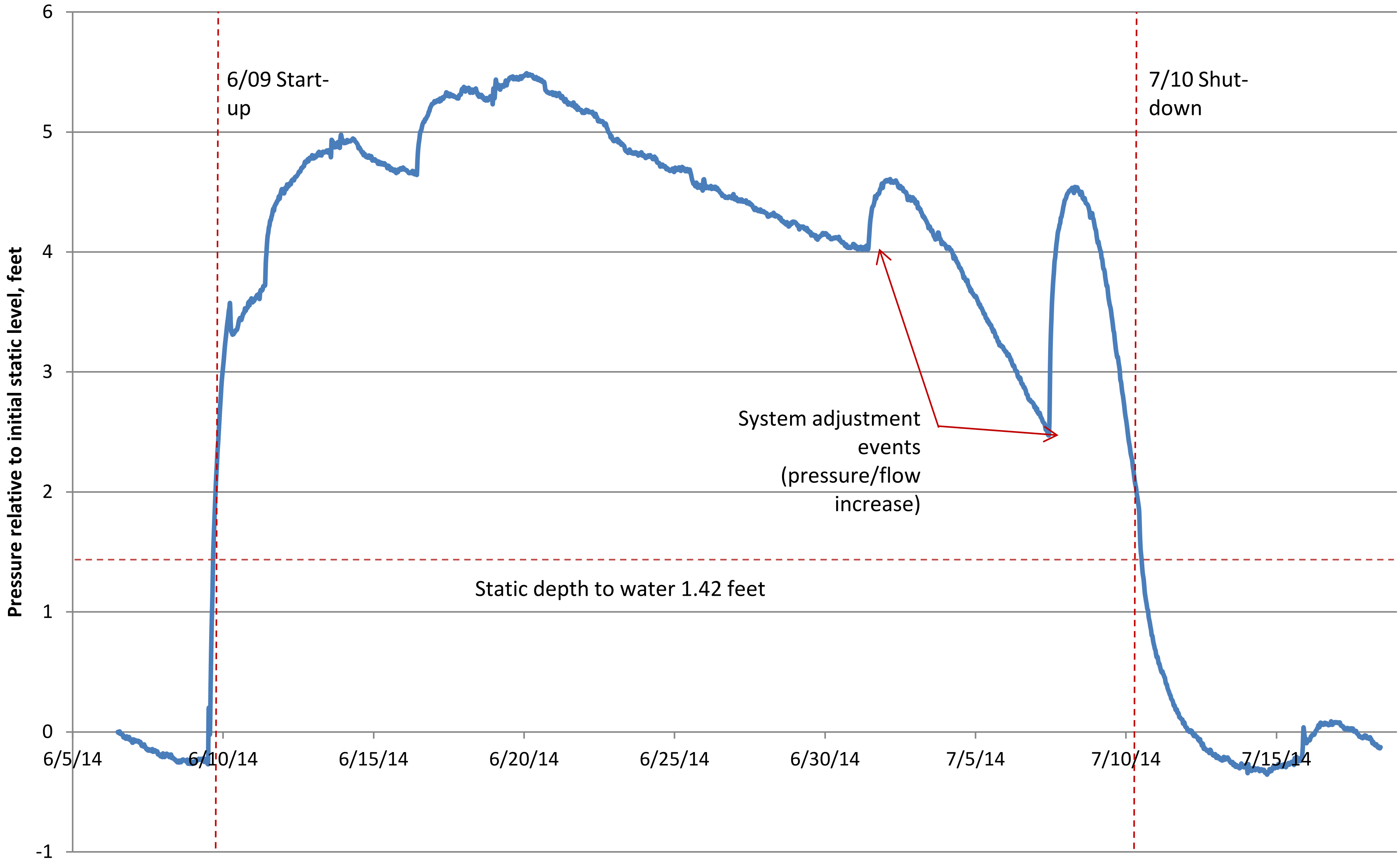


Figure 3-6 LMC MRC Tracer Study in Block G: Monitoring Well IWW-34 Hydraulic Response

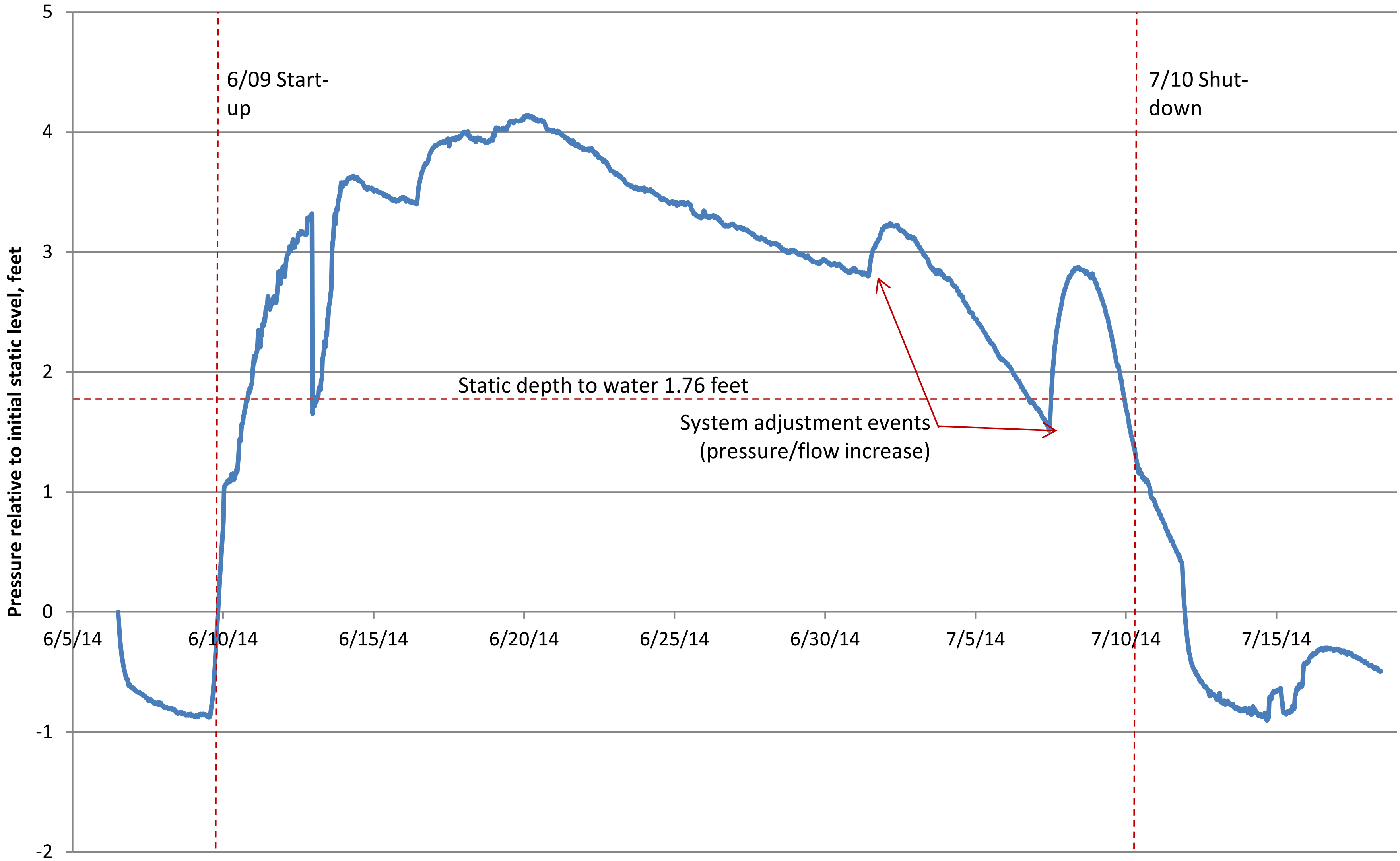


Figure 3-7 LMC MRC Tracer Study in Block G: Monitoring Well IWW-37 Hydraulic Response

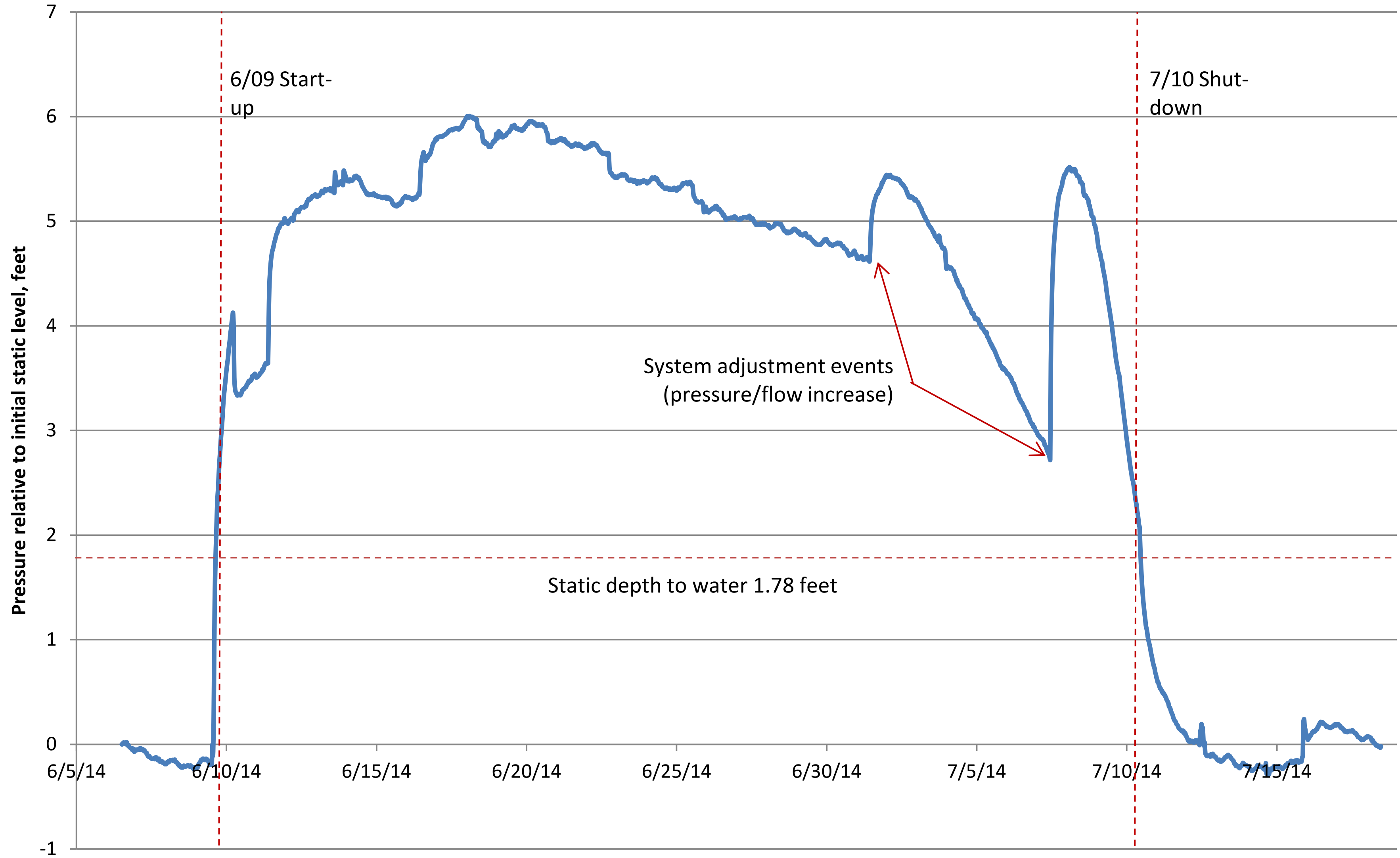
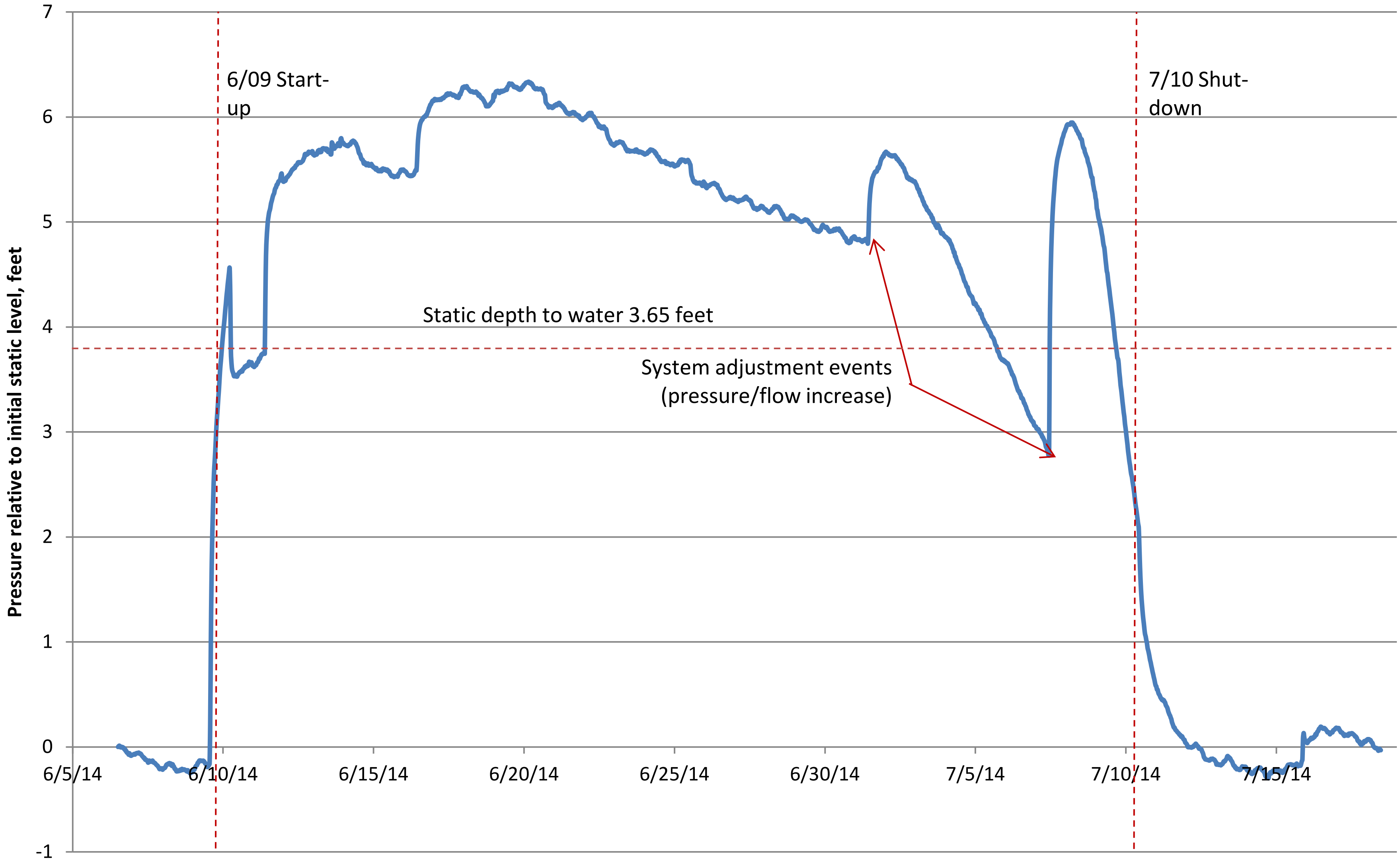


Figure 3-8 LMC MRC Tracer Study in Block G: Monitoring Well SWMW-5I Hydraulic Response (Second Injection Event)



Section 4
Block I Tracer Testing

This section describes the layout, field procedures, and monitoring performed for the Block I tracer test.

4.1 FIXED-BASE LABORATORY SAMPLING

Bromide groundwater samples were collected from five existing monitoring wells (MW-81B, NMW-1I, NMW-2I, NMW-2S and NMW-3I) in Block I. Bromide samples were also collected from two stormwater utilities locations (MH-10 and CB-10A) and from one surface water location at Outfall-009 (Figure 2-2).

Appendix B of the operations and maintenance (O&M) manual (Tetra Tech, Inc. [Tetra Tech], 2014) contains specific parameters and procedures for baseline sampling. Samples were collected from all locations above before tracer injection began to establish baseline bromide levels. In addition, samples were collected several times during the injection event, and two weeks after the injection was finished. Bromide sampling procedure and analytical laboratory requirements are described in Section 2-2.

4.2 GROUNDWATER TABLE MEASUREMENTS

Groundwater levels were monitored periodically by manual gauging of monitoring wells and via pressure transducers placed within several injection wells (Figure 2-2). Before the transducers were installed, water levels in each well were measured using an electronic water-level meter. Transducers collected data for the duration of the tracer test. Transducers were installed in each location approximately five to 10 feet below the static water level; recording frequency was set to five minutes. To ensure data quality, wells containing transducers were not sampled or otherwise disturbed. Data from the transducers were downloaded and assembled as graphs for analysis (Figures 4-1 through 4-4).

Groundwater levels in existing monitoring and injection wells near the active injection location were manually measured before tracer testing began. Groundwater levels within these wells were also measured three times during the first week of the injection event and weekly thereafter.

4.3 INJECTION SOLUTION PREPARATION

The following procedure was used to prepare the injection solution in tank T-2 during Block I tracer testing:

1) Tank T-2 was filled with approximately 330 gallons of treated (dechlorinated and deoxygenated) potable water.
2) Three 55- lb bags (165 lbs total) of sodium bromide were placed into tank T-2. Greater quantities of bromide tracer were used for Block I as compared to Block G because high baseline bromide concentrations were detected in two Block I wells; details follow in Section 4.6.4. These high bromide concentrations were likely caused by (residual) bromide tracer injected during the November 2011 injection test.
3) Five 15-lbs bags (75 lbs total) of sodium bicarbonate were added to tank T-2.
4) The mixing pump in tank T-2 as activated for 60–120 minutes to dissolve the chemicals.
5) The dosage of tracer fluid was injected via metering pump (MP-2) such that the entire tank volume was injected during the event. Electronic flow-meter FMT-1 signaled pump MP-2, and automatically maintained a constant tracer concentration in the injected stream, regardless of the changes in the injection flow rate.

4.4 INJECTION PROCEDURE

Block I tracer testing consisted of one event; tracer was injected into all eight injection wells in Block I (May 6, 2014 through June 7, 2014).

The injection solution (450 mg/L sodium bromide and 200 mg/L sodium bicarbonate) in tank T-2 was prepared per procedures described above. Injection system equipment was prepared for operation and configured as described in Sections 3.1 and 3.1.3 of the O&M manual (Tetra Tech, 2014). Eight injection wells (IWN-1 through IWN-8) were connected to the injection manifold. The injection system was activated on May 6, 2014, and the injection rate for each connected well was be set to approximately 0.13 gallons per minute (gpm), for a total injection rate of approximately one gpm (with eight wells connected). Metering pump MP-2 was activated to begin injection of bromide tracer/sodium bicarbonate solution from tank T-2 into the injection manifold, using settings described in the O&M manual.

The total volume injected was slightly above the volume for the full-scale design Approximately 45,000 gallons of tracer fluid were injected (equivalent to approximately 5,600 gallons per injection well); the injection volume for the full-scale design is 5,000 gallons per well (or 40,000 gallons total). The average flow rate during injection was 0.13 gpm per well. The injection duration was 31 days (from May 6, 2014 through June 7, 2014). The site operator visited the site at least three times during the first week of testing, then weekly thereafter.

4.5 INJECTION EVENT RESULTS SUMMARY

This section presents a summary of the results for the Block I injection event, including process parameters for the injection system (injection rates, pressures), parameters for injection wells, the hydraulic response of the underlying formation, and results of bromide tracer testing.

4.5.1 Process Parameters

System-process parameters for the entire injection event are summarized in Table 4-1. The parameters discussed below are presented in the flow direction starting at the upstream parameters.

The potable water pressure was stable during the entire injection event, and ranged from 64 to 66 pounds per square-inch gauge (psig) [Table 4-1, first data column]. Pressure was in excess of the required injection pressure, and was reduced using the pressure regulator PR-1. Outlet pressure for pressure regulator PR-1 (same as GAC-1 inlet pressure) was adjusted to approximately 8 psig; it remained close to this level for the entire injection event (Table 4-1, second data column). GAC-1 outlet pressure (same as filter PF-1 inlet pressure) was adjusted to 5 psig; it also remained relatively constant for most of the injection event. However, approximately three weeks after injection began, clogging of activated carbon in GAC-1 was indicated: the outlet pressure at GAC-1 began to decline, decreasing to 3 psig by the end of injection. The pressure differential across the GAC-1 unit increased from 3 psig to 5 psig from beginning to the end of injection, indicating clogging occurred across the carbon bed (Table 4-1, third data column). Note that the potable water source was very turbid, and likely contained suspended solids that caused GAC-1 clogging. Preventative measures that will be taken to address this issue, including carbon bed backwash or replacement, and possibly additional filtration at the inlet to GAC-1.

The outlet pressure at filter PF-1 varied from 4 to 6 psig during the injection event. The pressure differential across the filter did not increase, indicating that the clog was not at the filter (Table 4-1, fourth data column). The outlet pressure at PF-1 was slightly higher than the pressure upstream at the GAC-1 outlet because the pressure gauge on the filter outlet was mounted lower than one on the outlet for GAC-1.

Pressure in the injection manifold ranged between 4 psig at the beginning of the injection event, declining to 2.5 psig at the end of the event due to GAC-1 clogging (Table 4-1, fifth data column).

The total injection rate (as measured by electronic flow-meter FMT-1) ranged between 0.9 and 1.2 gpm (Table 4-1, sixth data column) or an average of approximately 0.13 gpm per injection well for the injection duration.

The vacuum applied to the hollow membrane contactor MC-1 ranged between 27.5 and 28.5 inches of mercury. This vacuum is sufficient to remove the bulk of dissolved oxygen from an aqueous stream (Table 4-1, seventh data column).

Electronic flow-meter FMT-1 readings (Table 4-1, 8^{th} data column) indicate that 44,897 gallons of fluid were injected during the injection event (an average of 5,612 gallons per injection well). This is slightly above the full-design injection volume for Block I (5,000 gallons per injection well). The mechanical flow totalizer (FT-1) malfunctioned and the readings could not be obtained. This instrument will be replaced before the full-scale injection event.

The entire tracer solution tank volume (330 gallons, 165 lbs of sodium bromide, 75 lbs of sodium bicarbonate) was injected uniformly during the injection event at Block I (Table 4-1, 9^{th} data column).

The impact of sodium bicarbonate solution injection on the groundwater pH buffering in the vicinity of the injection wells was generally inconclusive. Values of pH in several monitoring wells slightly increased during the tracer test while other wells demonstrated no clear trend or had pH values actually decreasing during the test (Tables 3-4 and 4-4). It is believed that the amount of sodium bicarbonate injected during the tracer test was insufficient for groundwater pH buffering. The design quantities of sodium bicarbonate to be injected during the full scale injection event will be much greater that the amounts used during the tracer tests.

4.5.2 Injection Wells Parameters

Table 4-2 summarizes parameters for individual injection wells, including the injection pressure at manifold-branch (measured downstream of the flow regulating valve), pressure of the actual wellhead, and the injected volume (measured by the flow totalizer) at each injection well. Injection-pressures at the manifold branch (measured on individual injection lines downstream of the flow-reducing regulating valve) ranged from negative to 5 psig, with a negative average value of -0.7 psig for the entire injection event.

Injection pressure at the wellhead (measured at gauges installed within injection wells manholes) ranged from negative to 5.5 psig, with an average value of 2 psig for the entire injection event. Wellhead injection pressures were slightly higher (typically 2 psig higher) than the pressures at the manifold branch because the wellheads were 4-5 feet lower than the injection manifold; therefore, corresponding hydrostatic pressure was added.

The total volume injected at each injection well varied, depending on the hydraulic conductivity of the local formation. The well in the most conductive area (IWN-6) received a volume approximately 1.7 times greater as compared to wells in the least conductive areas (IWN-5 and IWN-8). The injection volume for the rest of the wells was fairly uniform, and close to the design injection volume of 5000 gallons per well. The average injection volume per well was 4,994 gallons based on the totalizer readings for individual wells, and 5612 gallons based on the main electronic totalizer reading.

4.5.3 Formation Hydraulic Response

During the Block I injection event, transducers were installed in wells MPN-2I, IWN, MPN-2S and OW-1B (Figure 2-2), approximately five to 10 feet below the static water level; recording frequency was set to five minutes. To ensure data quality, wells containing transducers were not sampled or otherwise disturbed.

Transducer measurements in wells MPN-2I, IWN, MPN-2S and OW-1B are graphically depicted on Figures 4-1 through 4-4, respectively. Results are shown as the positive changes in hydrostatic pressure relative to baseline (shown as zero value) before the injection event began System shutdown and re-start events are also indicated on these graphs.

Transducers measurements indicate that all four wells responded to injection. For example, the hydrostatic pressure in well IWN (Figure 4-2) increased by approximately two feet after approximately six hours of injection. Well MPN-2S was screened in the shallow zone, and responded to the injection more slowly (Figure 4-3). After the system was turned off, the hydrostatic pressure in all wells returned close to pre-injection levels within several days (Figures 4-1 through 4-4). System shutdown events of short duration (several hours) occurred twice at the beginning of injection; these events are clearly seen on all graphs.

The hydraulic response in wells MPN-2I, IWN, MPN-2S and OW-1B ranged between four and five feet relative to the static level. Pre-injection static depths to water in these wells, and an increase in hydrostatic pressure during the injection, indicate that water levels in these wells were approximately five feet below the ground surface; therefore, potential day-lighting was limited.

Groundwater levels in five nearby existing monitoring- and injection-wells were also manually gauged before the injection started and while the injection was performed. These manual gauging results are summarized in Table 4-3. The baseline (pre-injection) measurements in these wells indicate that groundwater table was approximately 8-10 feet below the ground surface

All five wells responded when the injection began. Hydraulic response was similar to that measured by the transducers: depth to water decreased by approximately four feet by the end of injection. However, water levels in all five wells remained well under ground surface levels, thus limiting potential day-lighting. Visual observations of the ground surface and the underground structures (e.g., catch basins) did not indicate day-lighting or preferential channeling of injected fluid.

4.5.4 Bromide Tracer Results

Analytical samples were collected from five monitoring wells (MW-81B, NMW-1I, NMW-2I, NMW-2S and NMW-3I), from two stormwater utility locations (catch basins MH-10 and CB-10A), and from one surface-water location (Outfall-009). Figure 2-2 shows the sampling locations. Sampling results and pertinent injection parameters (e.g., injected tracer concentrations, quantities, and volumes injected volumes) are summarized on Table 4-4.

Baseline bromide sampling indicated high bromide levels at one Block I location, in the shallow and intermediate depths: NMW-2S and NMW-2I, respectively (both at 18,000 micrograms per liter [µg/L]). The presence of bromide at these levels was likely due to residual bromide from tracer injected during the November 2011 injection test. It was unclear if these wells would provide valuable data, but the arrival of injected tracer was clearly observed, even over these high background levels. In fact, the injected tracer was clearly detected in five wells sampled within Block I, at concentrations up to several orders of magnitude higher than the background levels (Table 4-4), indicating a good distribution of the injected fluid was achieved.

The bromide samples collected from the surface water location at Outfall-009 indicated relatively high background bromide levels (1,300µg/L median value). These results are expected as Outfall-009 samples were collected near the outfall directly from the surface water of Dark Head Cove. Thus, these bromide levels are indicative of brackish seawater, and are expected to be influenced by tidal fluctuations, winds, and other factors.

Analytical results from the stormwater utility location (MH-10 on Figure 2-2) indicated a clear increase of the bromide tracer (from <81 µg/L at baseline to a maximum of 3,700 µg/L on June 4, 2014). Tracer levels detected in MH-10 remained elevated in the two sampling events (on June 20, 2014 and July 24, 2014) conducted after the injection was finished on June 7, 2014.

An elevated level of the bromide tracer was also detected at the second stormwater utility location (CB-10A on Figure 2-2), ranging from less than 81 µg/L (baseline) to 4,700 µg/L (maximum) on June 4, 2014. However, this was the only high level detection in CB-10A. Bromide concentrations in the remaining samples were close to background levels.

The detection of bromide tracer in Block I stormwater utilities (MH-10 and CB-10A) is a direct indication that injected fluid entered the storm water utilities (pipes and/or underground structures such as catch basins or manholes. Note, however, that the highest bromide tracer concentrations detected at these utility locations were significantly lower than the concentrations detected in monitoring wells. For example, on June 4, 2014, the average bromide tracer concentration in the five Block I monitoring wells used for the tracer test was 51,608 µg/L, while compared to 4,200 µg/L was detected in the stormwater system (value is an average of the two highest detections at MH-10 and CB-10A). This indicates that although injected fluid entered the stormwater system, its inflow was relatively low.

Based on the presence of tracer in the storm sewer system, the injection event for the full-scale bioremediation will be modified to address this. These modifications will be reflected in the updated O&M manual for the bio-remediation system.

Table 4-1

Block I Injection-Equipment Process Parameters
Lockheed Martin Middle River Complex, Middle River, Maryland

Date	Potable Water Line Pressure (psig)	Pressure Regulator PR-1 outlet Pressure (psig)	GAC-1 Outlet Pressure (psig)	Filter PF-1 Outlet Pressure (psig)	Injection Manifold Pressure (psig)	Total Injection Flow (gpm)	Contactor MC-1 Vacuum (in.Hg)	Total Injected Volume by FMT-1 (gallons)	Tracer Solution Tank (T-2) Level (inches)	Comments
5/6/2014	64	8.00	5.00	6.00	4.00	0.90	-28.5	355.7	40	Injection event begins
5/7/2014	64	7.50	5.00	5.75	3.75	1.10	-28	2,085.0	37	
5/9/2014	64	7.75	5.00	5.75	3.50	1.20	-28	3,382.0	35.5	
5/12/2014	64	7.50	5.00	5.75	3.75	1.10	-28	8,233.0	29	
5/16/2014	64	7.50	5.00	5.75	1.50	1.10	-27.5	14,232.0	20.5	
5/19/2014	66	7.50	4.50	5.00	3.00	1.10	-28	19,141.0	40.5	
5/27/2014	64	8.00	4.00	4.50	2.50	1.00	-28	31,165.0	23	
6/2/2014	66	8.00	3.00	4.00	7.50	0.90	27.5	39,007.6	13	
6/7/2014	_	_	_	_	_	_	_	44,897.0	0	Injection event ends

Total injection volume per well (average)	5612 gallons	-- : reading not recorded
Injection event duration	31 days	psig - pounds per square inch gauge
Average injection rate per well	0.13 gpm	gpm - gallons per minute
		in. Hg - inches of mercury

Table 4-2
Block I Injection-Well Parameters
Lockheed Martin Middle River Complex, Middle River, Maryland

Date	IWN-1			IWN-2			IWN-3		
	Manifold Pressure (psig)	Wellhead Pressure (psig)	Injected Volume (gallons)	Manifold Pressure (psig)	Wellhead Pressure (psig)	Injected Volume (gallons)	Manifold Pressure (psig)	Wellhead Pressure (psig)	Injected Volume (gallons)
5/6/2014	4.5	1.25	163	2.5	0	86	0	0	99
5/7/2014	-2	0	286	-2	0	223	off	off	305
5/9/2014	-3	0	517	0	0.5	405	--	--	305
5/12/2014	0	0	1302	0	0	1027	--	--	--
5/16/2014	0	0.5	2299	1	3	1803	--	--	--
5/19/2014	0	0.5	3105	0	0.5	2418	-3	1.5	348
5/27/2014	0	1	4743	0	0	3605	-4	1.75	2350
6/2/2014	-4	0	5160	1	0	4789	-3	2.25	4885
Averages	**-0.6**	**0.4**		**0.3**	**0.5**		**-2.5**	**1.4**	

Date	IWN-4			IWN-5			IWN-6		
	Manifold Pressure (psig)	Wellhead Pressure (psig)	Injected Volume (gallons)	Manifold Pressure (psig)	Wellhead Pressure (psig)	Injected Volume (gallons)	Manifold Pressure (psig)	Wellhead Pressure (psig)	Injected Volume (gallons)
5/6/2014	3.5	1	84	5	2.5	73	0	0	86
5/7/2014	-2	1.75	364	2.5	5	168	-6	--	441
5/9/2014	-4	1.5	614	1	4.5	327	-7	0	758
5/12/2014	0	1	1433	2	4	843	0	0	1867
5/16/2014	0	1.25	2435	2	4	1473	0	0	3285
5/19/2014	0	1.5	3258	2	4	1950	-4	0	4452
5/27/2014	0	1	4945	2	3.75	2803	-5	0	6915
6/2/2014	-6	0	5073	2.5	4.5	3994	-9	0	6928
Averages	**-1.1**	**1.1**		**2.4**	**4.0**		**-3.9**	**0.0**	

Date	IWN-7			IWN-8		
	Manifold Pressure (psig)	Wellhead Pressure (psig)	Injected Volume (gallons)	Manifold Pressure (psig)	Wellhead Pressure (psig)	Injected Volume (gallons)
5/6/2014	1.25	4	71	2.5	3.25	92
5/7/2014	0	--	321	0	3.25	133
5/9/2014	0	4.5	559	-2	3	249
5/12/2014	0	5.5	1342	0	3	691
5/16/2014	0	--	3242	0	--	1252
5/19/2014	0	5.5	3153	0	3.5	1686
5/27/2014	0	5.25	4842	0	3.5	2479
6/2/2014	-6	4	5128	1	5	3991
Averages	**-0.6**	**4.8**		**0.2**	**3.5**	

Average manifold pressure	-0.7	psig
Average wellhead pressure	2.0	psig
Median total injection volume	4,979	gallons
Average total injection volume	4994	gallons

Note:
-- : reading not recorded
psi - pounds per square inch gauge
gpm - gallons per minute
in. Hg - inches of mercury
psig - pound(s) per square inch gauge

Table 4-3

Gauging in Block I Wells
Lockheed Martin Middle River Complex, Middle River, Maryland

Date	Depth to Groundwater, feet from top of well casing				
	NMW-1I	NMW-2I	NMW-2S	NMW-3I	MW-81B
4/23/2014[1]	9.66	9.74	9.65	8.02	9.48
5/7/14	6.67	7.61	7.38	6.46	5.68
5/9/14	6.92	6.99	7.23	5.98	5.46
5/12/14	6.3	6.51	6.4	5.24	4.93
5/16/14	5.81	5.82	5.23	--	3.94
5/19/14	5.24	5.92	6.08	3.62	4.09
5/27/14	5.02	5.42	5.56	3.61	3.45
6/2/14	5.35	5.12	5.84	3.38	3.92

Note:
-- : reading not recorded
[1]Static conditions before injection

Table 4-4
Block I Brominde Tracer Results Sammary
Lockheed Martin Middle River Complex, Middle River, Maryland

Sampling Location	Baseline 2/10/2014[1]			5/16/2014[2]		5/27/2014[2]		6/04/2014[2]			6/20/2014[2]		7/24/2014[2] ug/L
	Bromide ug/L	pH	Begin injection event on 5/6/2014. Injecting into wells IWN-1 through IWN-8	Bromide ug/L	pH	Bromide ug/L	pH	Bromide ug/L	pH	End injection event on 6/7/14.	Bromide ug/L	pH	
MW-81B	360	8.51		250	6.81	290	6.01	6800	5.83		10000	6.27	
NMW-2I	18000	5.47		35000	5.5	72000	5.5	68000			36000		
NMW-3I	570	6.21		7500	5.81	77000	5.24	120000	5.38		50000	6.02	
NMW-1I	330	5.15		230	5.14	220	5.42	240	4.58		19000		
NMW-2S	18000	6.24		27000	5.47	61000	5.58	63000	5.74		28000		
OUTFALL-9	280	8.05		1400		1500		1300			1000		
MH-10	<81			9.7		110		3700			2100		3200
CB-10A	<81			200		220		4700			430		51

[1]Minimum MDL = 81 ug/L; Minimum RL = 500 ug/L

[2]Minimum MDL = 2.2 ug/L; Minimum RL = 2.5 ug/L

Injection event average injected bromide concentration:	434	mg/L
Injection event total bromide tracer injected:	165	pounds
Injection event total volume injected:	45488	gallons
Injection event volume per well:	5686	gallons
Injection event average injection rate per welll:	0.13	gallons per minute
Injection event duration:	31	days

Figure 4-1 LMC MRC Tracer Study in Block I: Monitoring Well MPN-2I Hydraulic Response

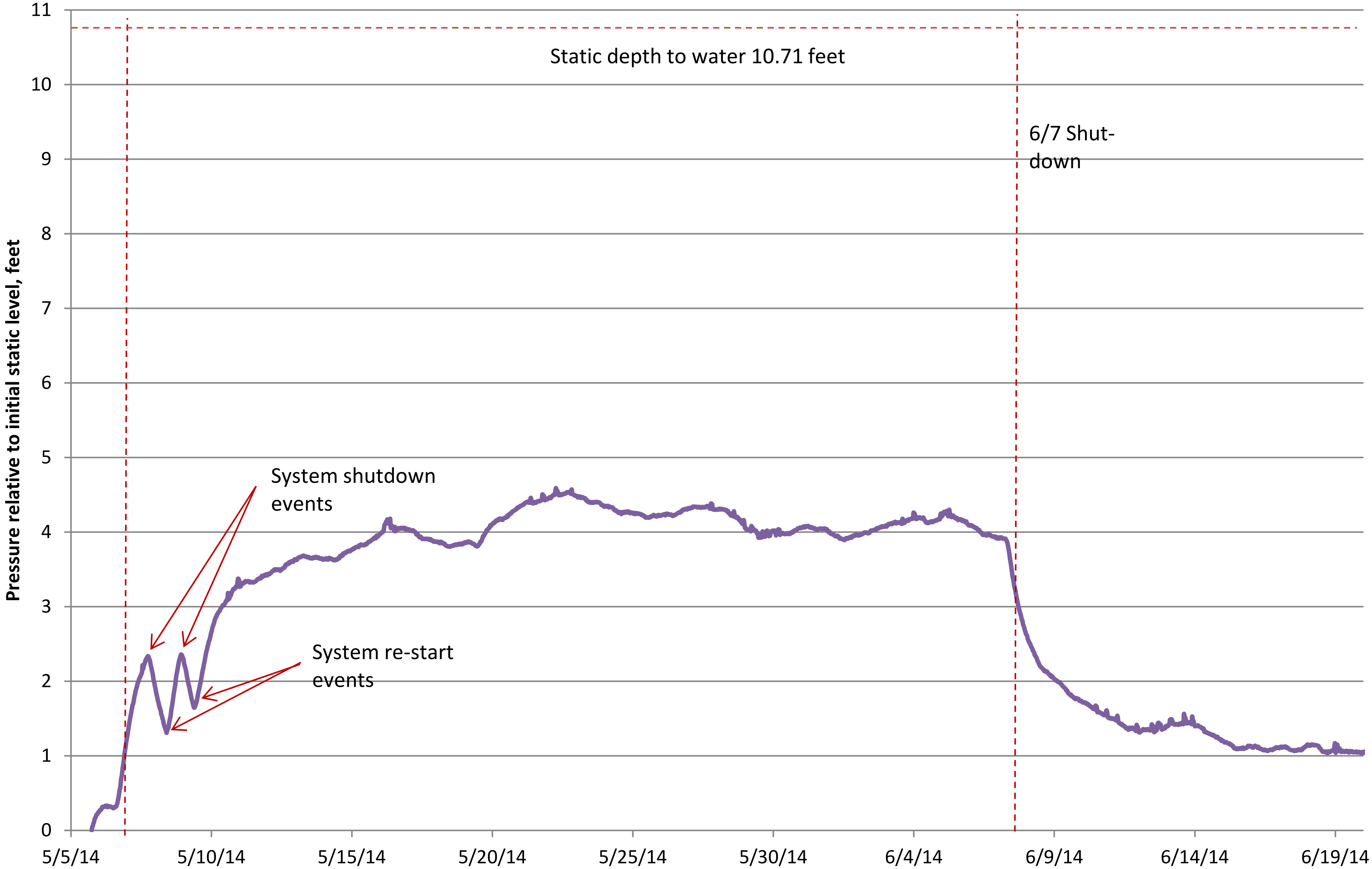


Figure 4-2 LMC MRC Tracer Study in Block I: Monitoring Well IWN Hydraulic Response

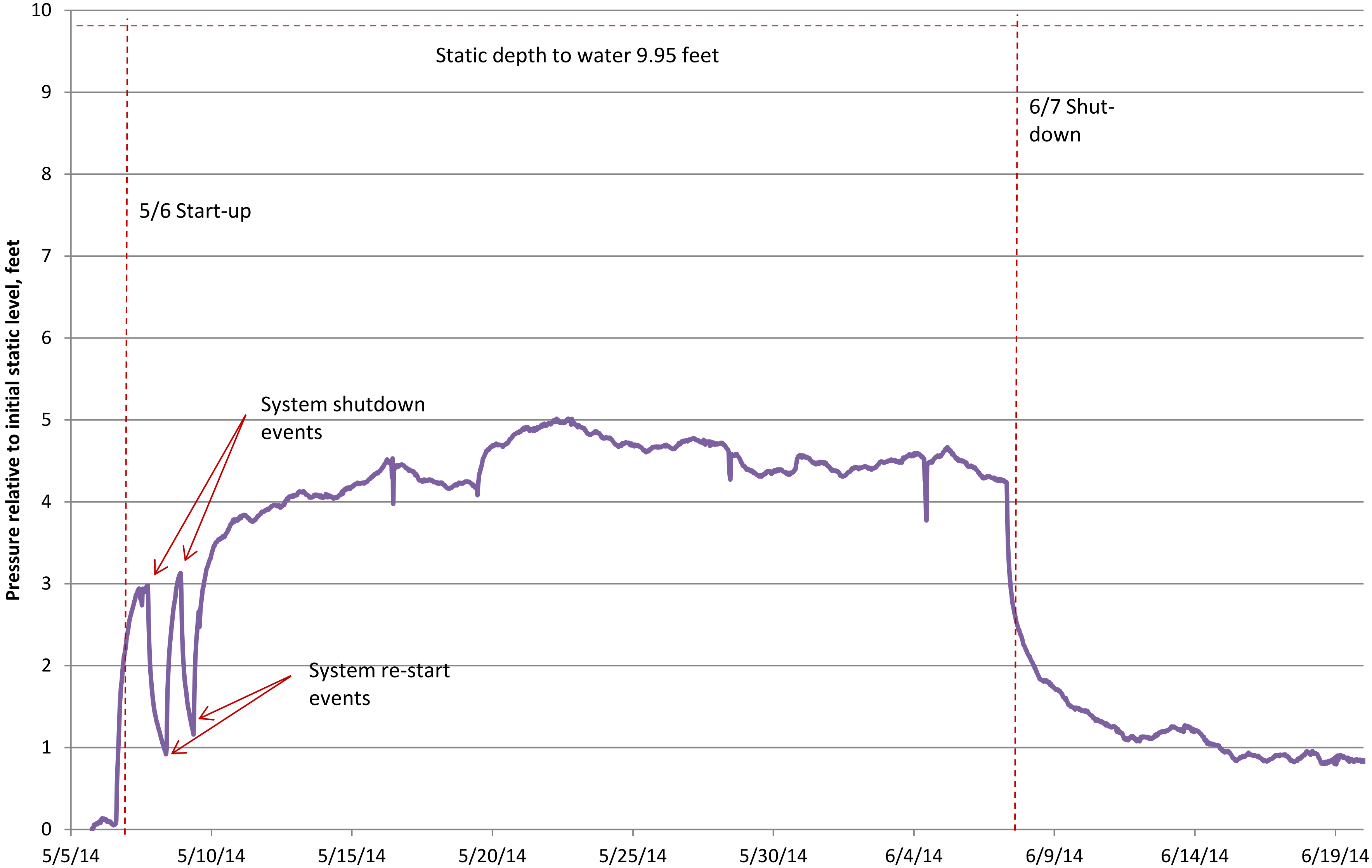


Figure 4-3 LMC MRC Tracer Study in Block I: Monitoring Well MPN-2S Hydraulic Response

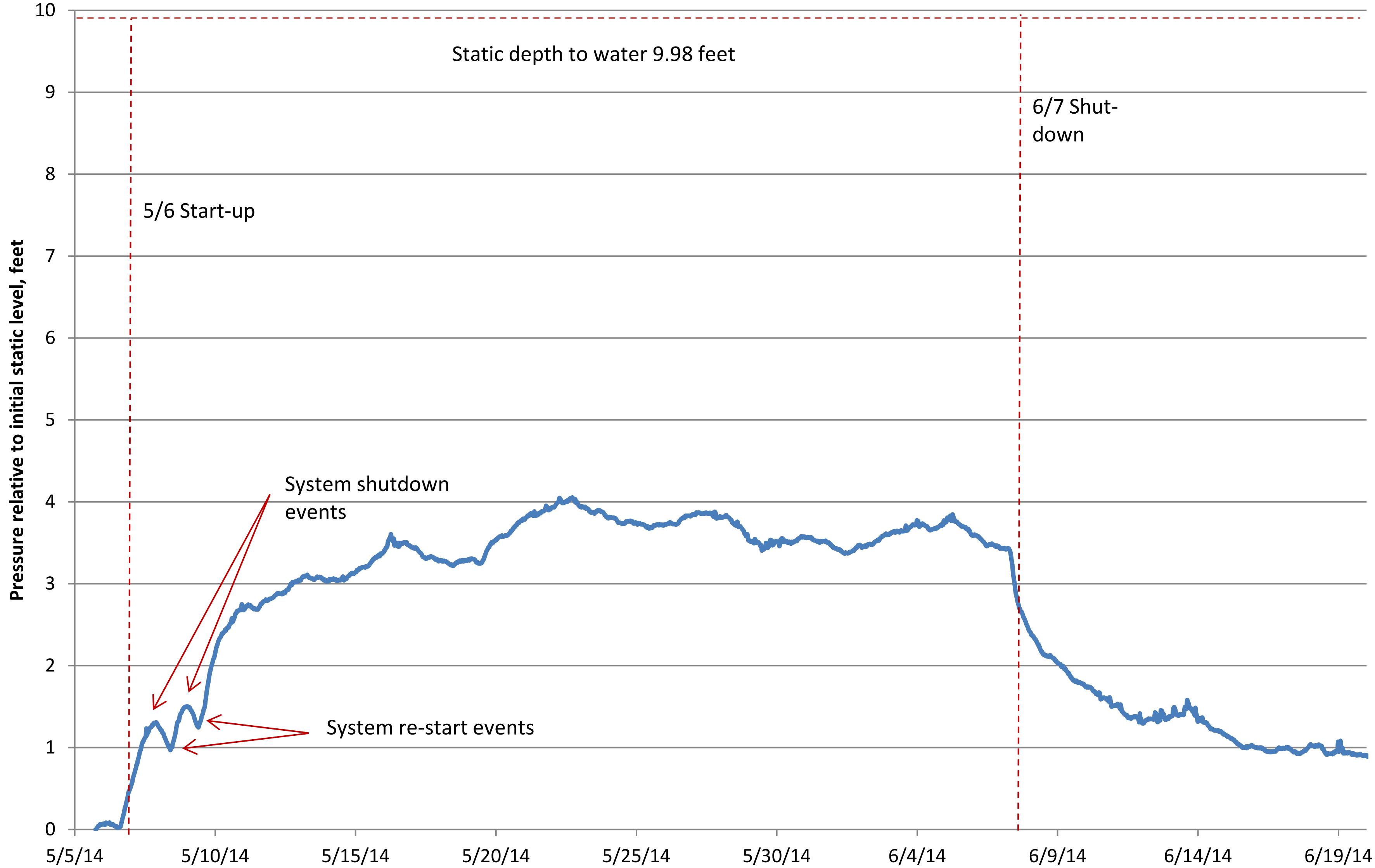
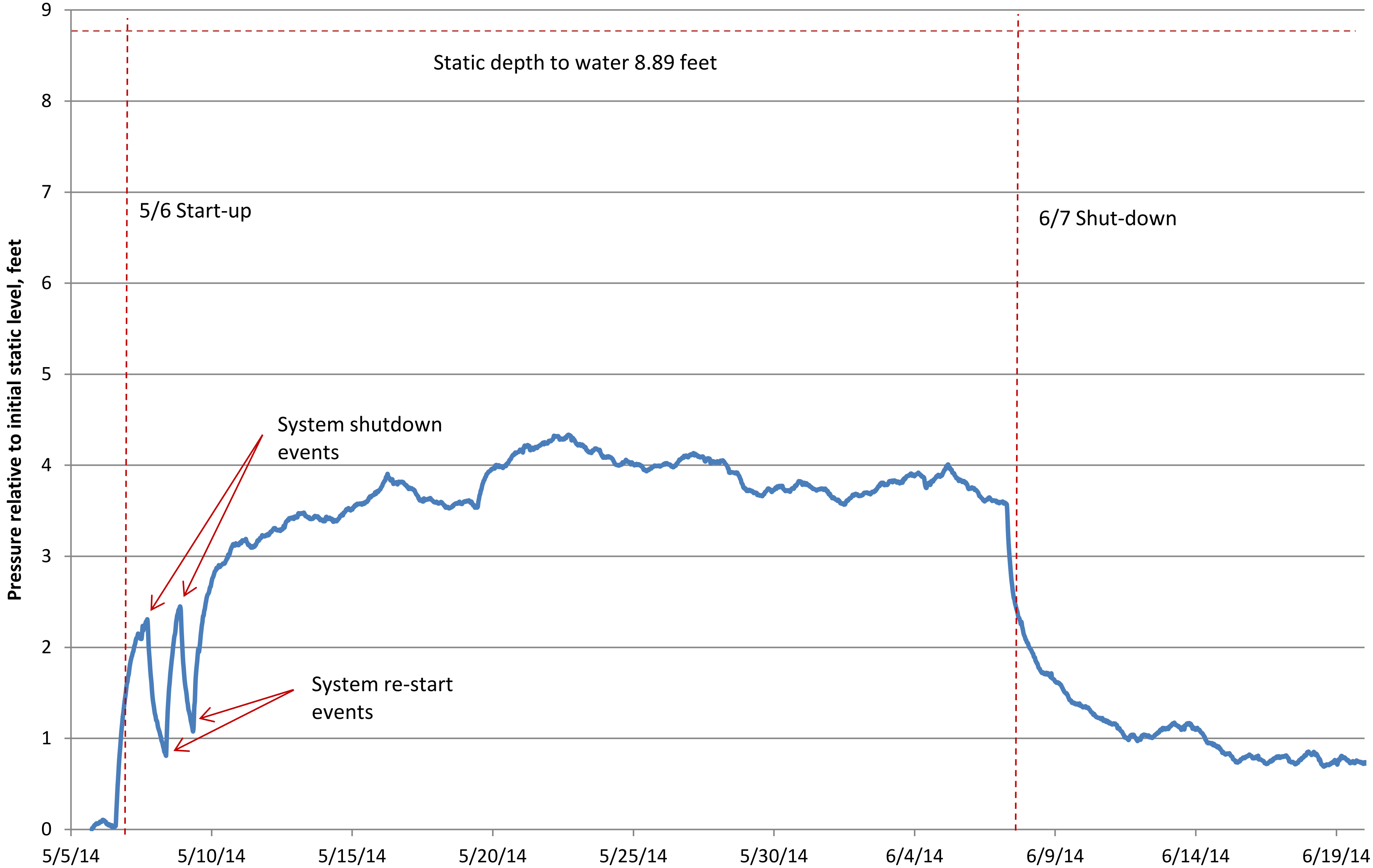


Figure 4-4   LMC MRC Tracer Study in Block I: Monitoring Well OW-1B Hydraulic Response



Section 5
Summary and Conclusions

A summary of the tracer study results and conclusions follow:

1. The system design was fully validated and the injection process equipment and controls were tested under actual operating conditions similar to future full-scale operation requirements.

2. A full design injection volume was injected into each set of injection wells. Some individual injection wells received higher or lower volume, but most wells received the approximate full-design injection volume of bromide-tracer and sodium bicarbonate buffered water.

3. No day-lighting was observed during the tracer study.

4. The injected fluid entered storm drain utilities in Block I. Specific recommendations to address this issue for the full-scale Block I injection event are in the updated operations and maintenance (O&M) manual.

5. Tracer tests indicated that injection fluid may have entered the storm drain utilities in Block G. Specific recommendations to address this potential issue for the full-scale Block G injection event are in the updated operations and maintenance manual

6. The injection rates for individual wells were lower than the values achieved during the November 2011 injection test, which could increase the overall duration of the future full-scale bio-remediation injection event. Modifications to avoid an increased duration are made in the updated operations and maintenance manual, and consist of altering the number of wells used for simultaneously injecting amendment.

7. Bromide tracer was clearly detected in multiple monitoring wells in Blocks G and I. Therefore, we conclude that an adequate injected-fluid distribution was achieved, and that adequate distribution of amendments can be achieved using the design injection volumes.

8. Strong hydraulic response to injection was detected in all monitoring locations at distances up to 57 feet from the point of injection. Thus, we conclude that the existing hydraulic conditions are favorable for achieving adequate distribution of amendments using the design injection volumes.

9. Untreated potable water used for injection in Blocks G and I was very turbid and contained suspended solids. At the end of injection in both areas, suspended solids began to clog the granular carbon vessels. Measures to address this issue include replacing the activated carbon bed and additional filtration (as detailed in the updated operations and maintenance manual).

Section 6
References

1. Tetra Tech, Inc. (Tetra Tech), 2012. *Injection Pilot-Test Report.* March.

2. Tetra Tech Inc. (Tetra Tech), 2014. *Draft Operation and Maintenance Plan for Groundwater Remediation System at Lockheed Martin Middle River Complex, 2323 Eastern Boulevard, Middle River, Maryland.* January.

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