

Treatment of TBA at Garden Grove Service Stations

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Abstract

GeoHydrologic Consultants, Inc. performed ozone sparging tests at two separate gas station sites in Garden Grove, California to remediate petroleum hydrocarbon impacted groundwater, with tert butyl alcohol (TBA) being the primary target compound.

The first site (Site A) contained pre-ozone sparging TBA groundwater concentrations at a maximum of 5,820 µg/L. Two separate ozone sparging events were performed at this site, with the first taking place for approximately one month in late 2004, followed by a second three month long event in the third quarter of 2005. Concentrations of TBA at the conclusion of the first test were reduced from 2,920 µg/L in well MW-3 to 234 µg/L, reduced from 5,820 µg/L in EW-1 to 1,820 µg/L, and reduced in well MW-5 from 356 µg/L to <10 µg/L. At the conclusion of the second test TBA concentrations were further reduced to 28 µg/L in MW-3, 73 µg/L in EW-1, and remained <10 µg/L in MW-5.

The second site (Site B) had pre-ozone sparging TBA concentrations in groundwater at a maximum of 4,450 µg/L. Ozone injection was performed for approximately 47 days. TBA was reduced in well RS-5R from 337 µg/L to 180 µg/L, in MW-12 from 4,450 µg/L to 3,100 µg/L, and MW-11R from 707 µg/L to <10 µg/L.

Ozone sparging for treatment of TBA in groundwater appeared to be very successful at both Sites.

Key Words

Ozone; ozone sparging; in-situ groundwater remediation; TBA; tert butyl alcohol.

Introduction

GeoHydrologic Consultants, Inc. performed ozone sparging tests at two separate gas station sites in Garden Grove, California to remediate petroleum hydrocarbon impacted groundwater, with tert butyl alcohol (TBA) being the primary target compound. Both of these sites had previously undergone significant remediation using vapor extraction and pump and treat, however TBA groundwater concentrations still persisted above regulatory action levels and therefore closure would not be granted unless the TBA concentrations could be further reduced.

The first site (Site A) contained pre-ozone sparging TBA groundwater concentrations at a maximum of 5,820 µg/L. Ozone sparging at Site A consisted of installation of two ozone sparging points at targeted areas where TBA groundwater concentrations seemed to persist, installation of ozone delivery lines, and installation of a C-Sparge System Model 5030 Ozone Generator Panel. Two separate ozone sparging events were performed at this site, with the first taking place for approximately one month in late 2004, followed by a second three month long event in the third quarter of 2005. The Site is located in the City of Garden Grove, California, at an elevation of approximately 60 feet above mean sea level (msl), and is an operating fuel sales facility. The topography in the vicinity of the Site is relatively flat with a slope to the south/southwest at approximately 20 feet per mile.

The second site (Site B) had pre-ozone sparging TBA concentrations in groundwater at a maximum of 4,450 µg/L. Ozone sparging at Site B consisted of installation of four dual nested ozone sparging points, installation of ozone delivery lines, and installation of a C-Sparge System Model 5030 Ozone Generator Panel. Ozone injection was performed for approximately 47 days. The Site is located in the City of Garden Grove, California, at an elevation of approximately 60 feet above mean sea level (msl). The topography in the vicinity of the Site is relatively flat with a gentle slope to the southwest.

Site Geology/Hydrogeology

Previous subsurface investigations conducted by others at Site A encountered light gray to brown silty fine-grained sands to depths of approximately 10 feet below ground surface (bgs). Beneath the silty sand, a zone of medium brown, slightly plastic, clayey silt occurs to depths of approximately 20 feet bgs. The water-bearing zone was encountered in gray, poorly sorted, fine to medium grained sand and silty sand at an approximate depth of 20 feet bgs. This sand/silty sand zone extends to the maximum depth investigated of 35 feet bgs.

Since site investigation activities commenced in May 1993 at Site A, a total of nine groundwater monitoring wells and two groundwater extraction wells have been installed onsite. Soil boring information from the November 1994 site assessment

indicates that groundwater was encountered within the sandy soils at depths of approximately 20 feet bgs. The groundwater currently present beneath the Site occurs within sediment which consists primarily of sand and silty sand. The static water level gauged in groundwater wells on August 17, 2005 ranged from 11.67 to 14.20 feet bgs in wells MW-1 and K-1, respectively. Groundwater is believed to exist under semi-confined conditions with the finer grained clayey silt sediments from 12 to 17 feet bgs acting as the confining layer. The groundwater flow direction during the August 17, 2005 groundwater sampling event was to the southwest at an approximate gradient of approximately 0.009 feet/foot. Low levels of dissolved petroleum hydrocarbons were detected in seven of the nine wells (MW-2, MW-3, MW-4, EW-1, EW-2, K-1, and K-2) during the quarterly groundwater sampling event conducted on August 17, 2005. TBA is the particular analyte of concern because it was detected in all five monitoring wells mentioned above, as well as both groundwater extraction wells. Detectable levels of TPHg were present only in well EW-1 at a concentration of 51 µg/L (EW-1) for TPHg. Benzene was not detected in the wells above its mdl, and only three wells (EW-1, K-1 and K-2) had detectable levels of MTBE (1.3 µg/L, 1.3 µg/L, and 10 µg/L, respectively). TBA concentrations ranged from non-detect to 391 µg/L (EW-1).

Previous subsurface investigations conducted by others at Site B encountered fine-grained sands to depths of approximately 15 feet below ground surface (bgs). Beneath the sandy sand, a zone of sandy silt and silty sand occurs to depths of approximately 35 feet bgs. At 35 feet below grade, a very fine to fine-grained layer of sand was encountered. At 40 feet below grade, a clay layer was encountered.

Since site investigation activities commenced in 1986 at Site B, a total of seventeen groundwater monitoring wells have been installed onsite, of which three have been properly abandoned and two were accidentally destroyed and replaced. Groundwater is generally encountered at depths between 6 and 12 feet below grade. The groundwater currently present beneath the Site occurs within sediment which consists primarily of sandy silt and silty sand. The static water level gauged in groundwater wells on June 6, 2005 ranged from 5.52 to 9.05 feet bgs, under apparently unconfined conditions. The groundwater flow direction during the June 6, 2005 groundwater sampling event was generally to the south at an approximate gradient of 0.011 feet/foot. Dissolved petroleum hydrocarbons were detected in six of the twelve groundwater monitoring wells (MW-2A, MW-3A, RS-5R, MW-11R, MW-12, MW-13) during the quarterly groundwater sampling event conducted on June 6, 2005. In addition, a seventh well (MW-8) had detectable levels of dissolved TPHg in the rebound sampling conducted on July 22, 2005. TBA is the particular analyte of concern because it is detected at elevated levels that range up to 3,100 µg/L (MW-12) on July 22, 2005. Petroleum hydrocarbons detected during the second quarter 2005 sampling event on June 6, 2005 were present at concentrations ranging from non-detect to 192 µg/L (MW-2A) for TPHg, non-detect in the sampled wells for benzene, non-detect to 69 µg/L for MTBE (MW-3A), and non-detect to 3,440 µg/L (MW-12) for TBA.

Previous Site Remediation Activities

Previous remediation activities had been completed at Site A consisting of soil vapor extraction and groundwater pump and treat from 2001 through 2005. Approximately 1,057 pounds of hydrocarbons had been destroyed by the vapor extraction operations and a total of 1,236,566 gallons of groundwater had been treated and discharged into the sewer since the inception of remediation activities at the Site in 2001.

Previous remediation activities had been completed at Site B consisting of soil vapor extraction and groundwater pump and treat from approximately 1989 through 2005. During this time period the vapor extraction system had removed a total of 12,185 pounds of hydrocarbons. The groundwater system had treated a total of 1,125,807 gallons of water since 1989.

Ozone Sparging Well Installation Activities

On October 8, 2004, GeoHydrologic Consultants, Inc. (GHC) oversaw the installation of two ozone sparge wells (SP-1 and SP-2) at Site A. Ozone sparge wells SP-1 and SP-2 were installed to depths of 35 feet bgs and 33 feet bgs, respectively. The well locations are shown in Figure 1. Each ozone sparge well was constructed of 3/4-inch diameter schedule 40 PVC, installed to 35 feet in depth (SP-1) and 33 feet in depth (SP-2). Well SP-1 was screened from 32 to 35 feet below grade, and SP-2 was screened from 30 to 33 feet below grade. A sand pack (#2/16) was placed around the perforated section of each well from the total depth to 30 feet below grade (SP-1) and 28 feet below grade (SP-2). Bentonite pellets were placed on top of the sand pack to 29 feet below grade (SP-1) and 26 feet below grade (SP-2), followed by bentonite chips to two feet below grade. The remaining two feet in each boring was completed with concrete and a flush mounted traffic-rated well box.

On February 10, 2005, GHC oversaw the installation of four dual-nested ozone sparge wells (SP-1s, SP-1d, SP-2s, SP-2d, SP-3s, SP-3d, SP-4s, and SP-4d). Dual-nested ozone sparge wells SP-1(s,d), SP-2(s,d), SP-3(s,d), and SP-4(s,d), were installed to depths of 15 feet bgs (SP-1s and SP-3s), 25 feet bgs (SP-1d, SP-3d, SP-2s, and SP-4s), and 35 feet bgs (SP-2d and SP-4d). The soil borings for the sparge well installation were drilled using a hollow-stem auger-drilling rig. The well locations are shown in Figure 2. Each ozone sparge well was constructed of 3/4-inch diameter schedule 40 PVC connected to a micro-bubble sparge point with approximately three feet of screen. In wells SP-1 and SP-3, a sand pack (#2/16) was placed around the perforated section of the deep sparge point from the total depth to 20 feet below grade, followed by bentonite chips on top of the sand pack to 16 feet below grade, followed by more #2/16 sand on top of the bentonite chips to 10 feet below grade, with bentonite chips from the top of that sand pack to 3 feet below grade. In wells SP-2 and SP-4, a #2/16 sand pack was placed around the perforated section of the deep sparge point from the total depth to 30 feet below grade, followed by bentonite chips on top of the sand pack to 26 feet below grade, followed by more #2/16 sand on top of the bentonite chips to

20 feet below grade, with bentonite chips from the top of that sand pack to 15 feet below grade, and then bentonite grout to 3 feet below grade. The remaining three feet in each boring was completed with concrete and a flush mounted traffic-rated well box.

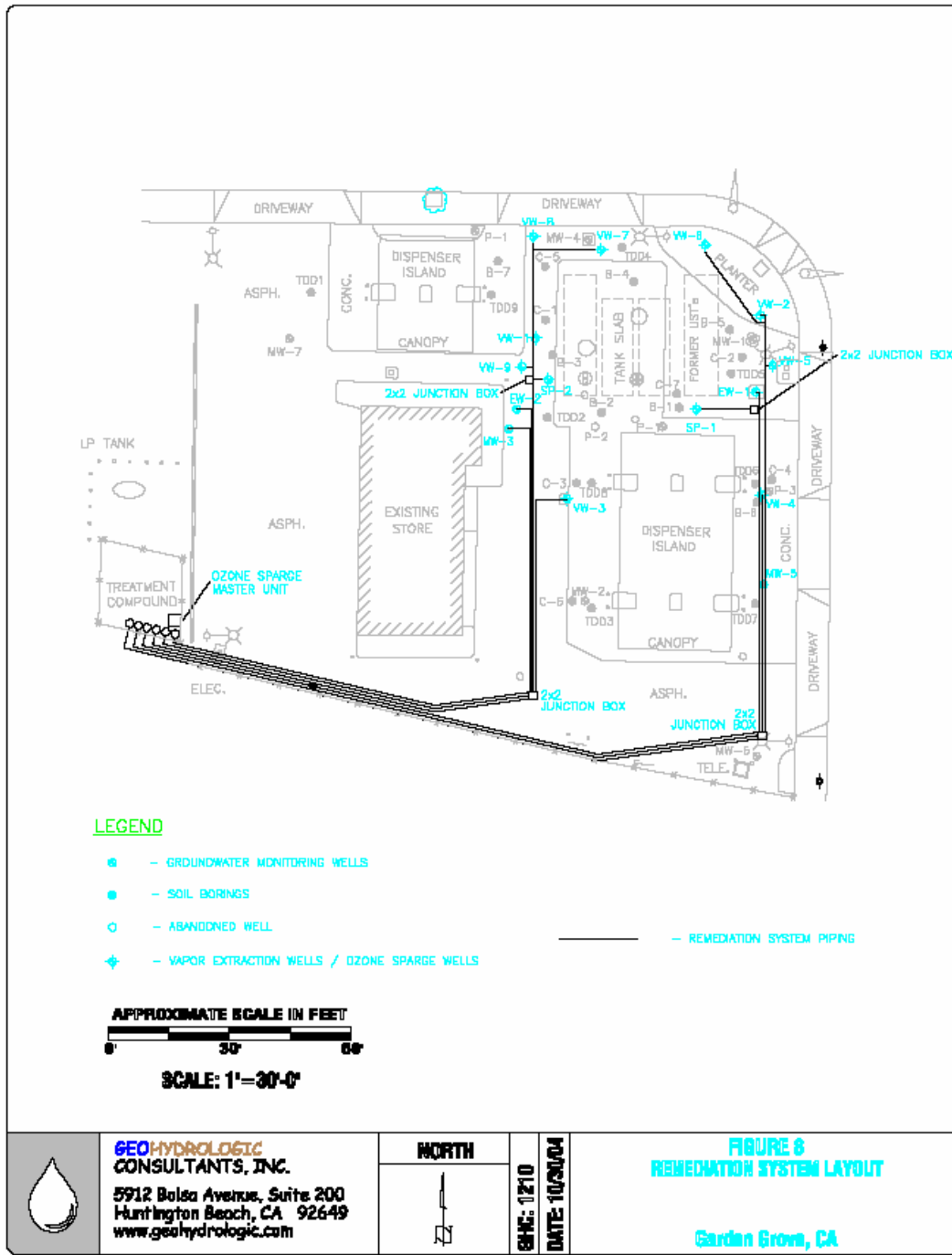


Figure 1. Site A Ozone Sparge Well Locations

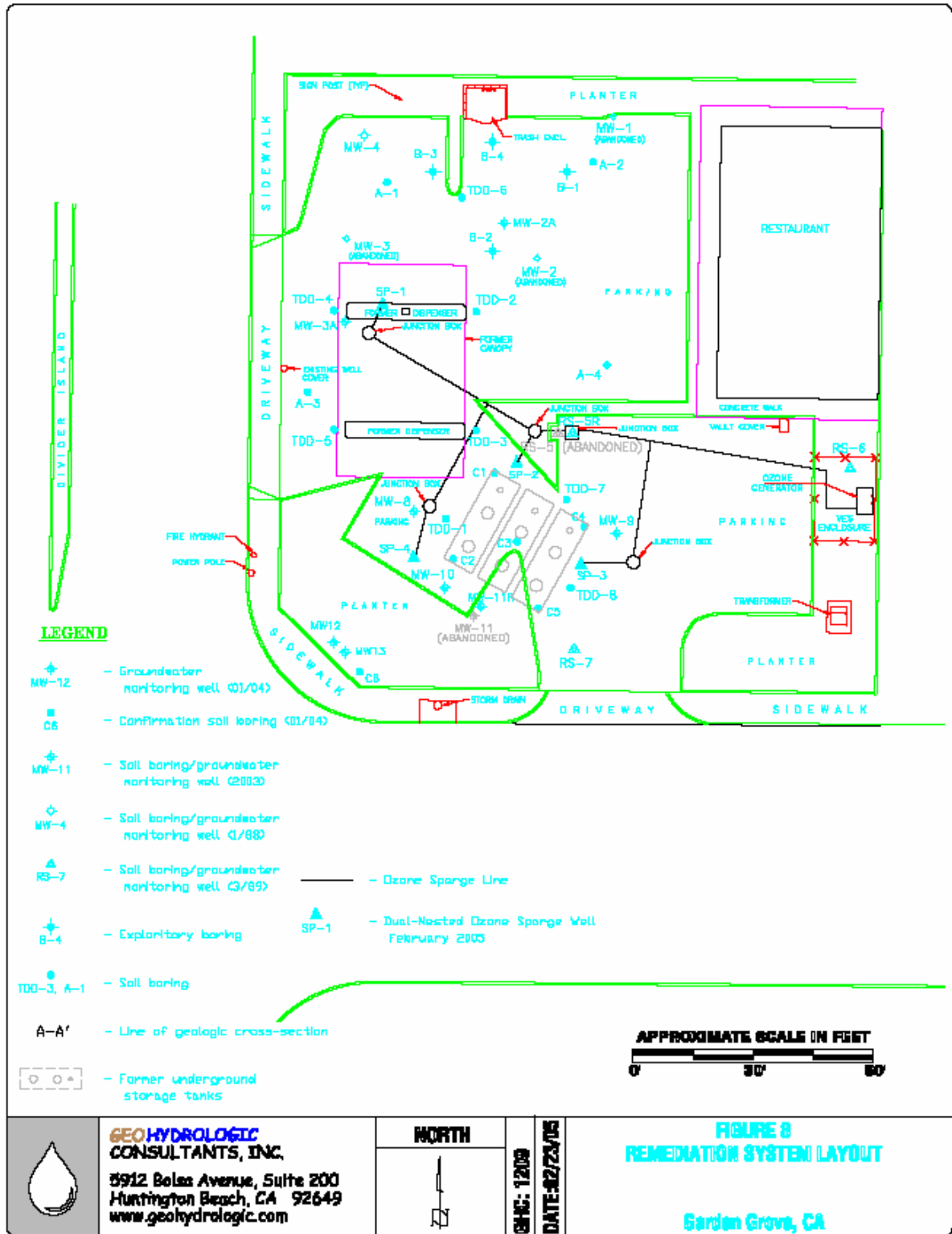


Figure 2. Site B Ozone Sparge Well Locations

Ozone Sparging Activities

Ozone is a highly reactive chemical that has proven to be effective in destroying a wide variety of organic chemicals, including BTEX, MTBE, and TBA. Ozone destroys organic chemicals through the process of chemical oxidation, which breaks the targeted organic chemical down into carbon dioxide and water. Ozone is commonly used in aboveground systems for treatment of wastewater and is widely used to treat extracted groundwater generated from pump-and-treat remediation systems. Generated ozone is injected through tubing to a microporous sparge point designed to generate very small bubbles that are approximately 50 micrometers in diameter. Ozone injected into the formation comes into contact with impacted groundwater and soil, where contaminants are then oxidized on contact.

Between October and December 2004, GHC installed an ozone sparging remediation system at Site A. The system consisted of a C-Sparge System Model 5030, manufactured by Kerfoot Technologies, Inc. of Mashpee, Massachusetts (Kerfoot), which is connected to the sparge points SP-1 and SP-2 with 3/8 inch diameter high density polyethylene (HDPE) tubing to each sparge point (Figure 1). In order to maintain ozone pressure in the tubing at all times during the pilot test, check valves were installed at the connection point between the tubing and the ozone generator, and between the tubing and each sparge point. The tubing was placed in underground 2 inch diameter Schedule 40 PVC piping runs that connected the remediation compound with each sparge point. During the process of connecting the HDPE tubing to each sparge point, the well boxes were broken out of the concrete that was set by driller, modified to allow the HDPE tubing to connect to the well, and then set in 2 feet of concrete.

The ozone generator was programmed to inject ozone into sparge point SP-1 for 30 minutes, then inject ozone into sparge point SP-2 for 30 minutes, and then rest for 20 minutes before repeating this cycle. Each cycle repeated 18 times every day, so that each well had ozone injected into it for 9 hours per day, for a total of 18 hours of ozone injection for every 24 hour period.

The system was started on December 21, 2004, but the system was found to be leaking ozone during the site visit on December 22, 2004 and was shut down. The source of the leak was discovered and repaired on December 23, 2004, and the system was re-started. On each site visit, the system was inspected, the injection pressure in the two sparge lines was recorded, and the elapsed time on the hourly meter was recorded. The injection pressure for SP-1 ranged from 36 pounds per square inch (psi) to 40 psi, and the injection pressure for SP-2 ranged from 22 psi to 38 psi. The site was inspected at least once a week during the pilot test. On January 24, 2005, GHC measured the ozone concentration by using color metric tubes supplied by Kerfoot to be 100 parts per million by volume (ppmV) in both sparge lines. Also on this date, GHC measured the flow rates in the two lines to be 2.0 standard cubic feet per minute (SCFM) in SP-1 and 1.8 SCFM in SP-2.

The system was shut down on January 27, 2005, and the total run time for the first one month ozone sparge test was 615.46 hours.

The second three month long ozone event at Site A was programmed in the same pattern as the one month ozone sparge pilot test, injecting ozone into sparge point SP-1 for 30 minutes, then injecting ozone into sparge point SP-2 for 30 minutes, and then resting for 20 minutes before repeating this cycle. Each cycle repeated 18 times every day, so that each well had ozone injected into it for 9 hours per day, for a total of 18 hours of ozone injection for every 24 hour period.

The ozone injection system was started again on June 23, 2005. The injection pressure for SP-1 ranged from 39 pounds per square inch (psi) to 42 psi, and the injection pressure for SP-2 ranged from 33 psi to 38 psi. The site was inspected at least once a week during this test.

The system was shut down on September 22, 2005, and the total run time for this ozone sparge test at Site A was 1,263.72 hours.

During March 2005, GHC installed an ozone sparging remediation system at Site B. The system consisted of a C-Sparge System Model 5030, manufactured by Kerfoot Technologies, Inc. of Mashpee, Massachusetts (Kerfoot), which was connected to the sparge points SP-1s, SP-1d, SP-2s, SP-2s, SP-2d, SP-3s, SP-3d, SP-4s, and SP-4d with 3/8 inch diameter high density polyethylene (HDPE) tubing to each sparge point (Figure 2). In order to maintain ozone pressure in the tubing at all times during the pilot test, check valves were installed at the connection point between the tubing and the ozone generator, and between the tubing and each sparge point. The tubing was placed in underground 2 inch diameter Schedule 40 PVC piping runs that connected the remediation compound with each sparge point. During the process of connecting the HDPE tubing to each sparge point, the well boxes were broken out of the concrete that was originally set by the driller, and modified to allow the HDPE tubing to connect to the well, and then set in 2 feet of concrete.

The ozone generator was programmed to inject ozone into a specific sparge point for 10 minutes, then inject ozone into the next sparge point for 10 minutes, and so on for each of the eight sparge points before repeating this cycle every 80 minutes. Each cycle repeats 18 times every day, so that each well has ozone injected into it for 3 hours per day, for a total of 24 hours of ozone injection for every 24 hour period of run-time.

The system was started on April 1, 2005, but the system was found to be shut down on the next site visit on April 7, 2005, and the system was re-started. On each site visit, the system was inspected, the injection pressure in the eight sparge lines was recorded, and the elapsed time on the hourly meter was recorded. The injection pressure for SP-1s ranged from 17.0 pounds per square inch (psi) to 35.0 psi, the injection pressure for SP-1d ranged from 21.0 psi to 31.5 psi, the injection pressure for SP-2s ranged from

18.0 psi to 32.5 psi, the injection pressure for SP-2d ranged from 21.0 psi to 29.4 psi, the injection pressure for SP-3s ranged from 14.0 psi to 29.0 psi, the injection pressure for SP-3d ranged from 19.0 psi to 30.0 psi, the injection pressure for SP-4s ranged from 29.0 psi to 33.0 psi, and the injection pressure for SP-4d ranged from 20.0 psi to 34.0 psi. The site was inspected at least once a week during the pilot test. On May 24, 2005, GHC measured the flow rates in the eight lines to be 2.2 standard cubic feet per minute (scfm) in SP-1s, 2.0 scfm in SP-1d, 2.0 scfm in SP-2s, 1.8 scfm in SP-2d, 2.4 scfm in SP-3s, 2.4 scfm in SP-3d, 1.8 scfm in SP-4s, and 1.8 scfm in SP-4d. On June 6, 2005, GHC measured the ozone concentration by using color metric tubes supplied by Kerfoot to be 100 parts per million by volume (ppmV) in all eight sparge lines.

The system was shut down on June 6, 2005, and the total run time for the ozone sparge test was 1,137.41 hours at an average operating efficiency of 70%.

Ozone Sparging Results

At Site A at the conclusion of one month ozone sparging, the dissolved TPHg levels in the well with the highest levels of contamination, EW-1, were 1,180 µg/L on December 15, 2004, decreasing to 500 µg/L on January 6, 2005, and then decreasing again to 308 µg/L on January 27, 2005. In well MW-1, the TPHg levels on those three dates were 104 µg/L, 2,230 µg/L, and 499 µg/L, respectively. In well MW-3, the TPHg levels were 467 µg/L on December 15, 2004, and below the mdl of 15 µg/L for the two subsequent sampling events. Well MW-5 was below the mdl on December 15, 2004, then it was measured at 141 µg/L on January 6, 2005, and was below the mdl on January 27, 2005. The other sampled wells had dissolved TPHg levels that were below the mdl on the three sampling dates.

The only well with dissolved benzene was well EW-1, which started with a level of 165 µg/L on December 15, 2004, decreased to 22 µg/L on January 6, 2005, and then decreased again to 15 µg/L on January 27, 2005. The other sampled wells had dissolved benzene levels that were below the mdl on the three sampling dates. A significant decrease in the benzene plume was noted during the testing.

The only well with dissolved MTBE was well EW-1, which started with a level of 11 µg/L on December 15, 2004, increased to 297 µg/L on January 6, 2005, and then decreased to 53 µg/L on January 27, 2005. The other sampled wells had dissolved MTBE levels that were below the mdl on the three sampling dates; an overall slight increase of MTBE concentrations was noted during testing.

The dissolved TBA levels in the well with the highest levels of contamination, EW-1, were 5,820 µg/L on December 15, 2004, increasing slightly to 6,650 µg/L on January 6, 2005, and then decreasing significantly to 1,820 µg/L on January 27, 2005. In well MW-3, the TBA levels on those three dates were 2,920 µg/L, 31 µg/L, and 234 µg/L, respectively. In well EW-2, the TBA levels were below the mdl of 10 µg/L on December 15, 2004, increasing to 49 µg/L on January 6, 2005, and increasing again to

103 µg/L on January 27, 2005. Well MW-5 started at 356 µg/L on December 15, 2004, decreased to 164 µg/L on January 6, 2005, and decreased to below the mdl on January 27, 2005. The other sampled wells had dissolved TBA levels that were below the mdl on the three sampling dates. Results indicated a substantial decrease in the dissolved TBA plume over the course of the pilot test.

Dissolved oxygen levels on December 15, 2004 ranged from 0.15 milligrams per liter (mg/L) in well EW-1 to 7.26 mg/L in well EW-2. On January 6, 2005, the dissolved oxygen levels ranged from 0.64 mg/L in EW-1 to 7.35 in EW-2, and on January 27, 2005, the levels ranged from 1.52 mg/L in MW-1 to 6.60 mg/L in well MW-3. Ozone sparging caused increases in dissolved oxygen in wells EW-1, MW-3, and MW-5, while wells MW-1, MW-4, and EW-2 showed small declines. Levels of methane, which indicate anaerobic conditions, declined from 1.268 mg/L and 0.006 mg/L in wells EW-1 and MW-4, respectively, to less than the mdl of 0.005 mg/L in both wells at the end of the test. This indicates that aerobic microbial activity most likely resumed during the course of the pilot test, and groundwater conditions shifted from anaerobic back to aerobic.

At Site A at the completion of the three month ozone sparging event, the dissolved TPHg levels in the well with the highest levels of contamination, EW-1, were 379 µg/L on June 20, 2005, decreasing to below the mdl of 2.9 µg/L on August 9, 2005, and then increasing to 51 µg/L on September 23, 2005. The other sampled wells had dissolved TPHg levels that were below the mdl on the three sampling dates. Results indicate a significant decrease in the TPHg plume during the course of the testing period.

The only well with dissolved benzene at the completion of the three month ozone sparging event was well EW-1, which started with a level of 15 µg/L on June 20, 2005, decreased to below the mdl of 0.32 µg/L on August 9, 2005, and remained non-detect on September 23, 2005. The other sampled wells had dissolved benzene levels that were below the mdl on the three sampling dates. The benzene plume was eliminated during the testing.

The only well with dissolved MTBE at the completion of the three month ozone sparging event was well EW-1, which started with a level of 3.5 µg/L on June 20, 2005, decreased to 1.5 µg/L on August 9, 2005, and then decreased again to below the mdl of 0.63 µg/L on September 23, 2005. The other sampled wells had dissolved MTBE levels that were below the mdl on the three sampling dates. The MTBE plume was eliminated in the six sampled wells during the testing.

The dissolved TBA levels at the completion of the three month ozone sparging event in the well with the highest levels of contamination, EW-1, were 3,110 µg/L on June 20, 2005, decreasing significantly to 245 µg/L on August 9, 2005, and then decreasing significantly to 73 µg/L on September 23, 2005. In well EW-2, the TBA levels on those three dates were 541 µg/L, 109 µg/L, and 94 µg/L, respectively. In well MW-3,

the TBA levels were 292 µg/L on June 20, 2005, decreasing significantly to 10 µg/L on August 9, 2005, and increasing to 28 µg/L on September 23, 2005. Well MW-4 started at 25 µg/L on June 20, 2005, decreased to 17 µg/L on August 9, 2005, and increased to 57 µg/L on September 23, 2005. The other sampled wells had dissolved TBA levels that were below the mdl on the three sampling dates. The results indicated a substantial decrease in the dissolved TBA plume over the course of this test.

Dissolved oxygen levels during the three month ozone sparging event at Site A on June 20, 2005 ranged from 0.39 milligrams per liter (mg/L) in well EW-1 to 2.14 mg/L in well MW-5. On August 9, 2005, the dissolved oxygen levels ranged from 1.39 mg/L in EW-1 to 3.86 in EW-2, and on September 23, 2005, the levels ranged from 1.38 mg/L in MW-5 to 4.97 mg/L in well EW-2. Ozone sparging caused increases in dissolved oxygen in wells MW-1, MW-3, MW-4, EW-1, and EW-2, while well MW-5 showed a decline. Levels of methane, which indicate anaerobic conditions, were less than the mdl of 0.005 mg/L in well MW-4 during the test, and declined in well EW-1 from 0.012 mg/L on August 9, 2005 to less than the mdl on September 23, 2005. This indicates that aerobic microbial activity most likely increased during the course of this test, and groundwater conditions shifted from anaerobic back to aerobic at the center of the plume.

A groundwater dissolved phase TBA iso-concentration map for baseline conditions and the completion of the ozone sparging activities at Site A is included as Figure 3 and Figure 4.

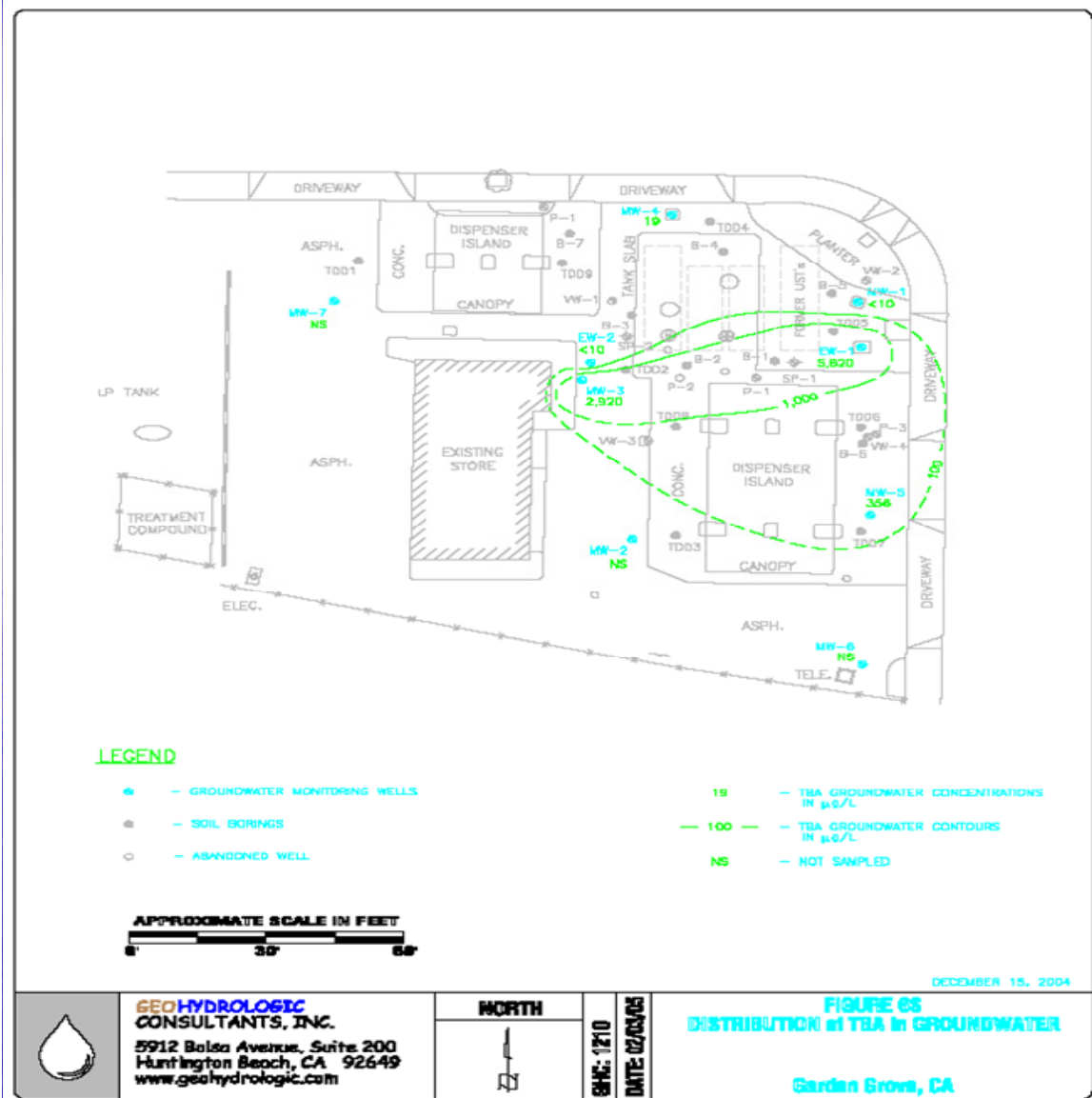


Figure 3. Site A, TBA Iso-Concentrations Before Ozone Sparging

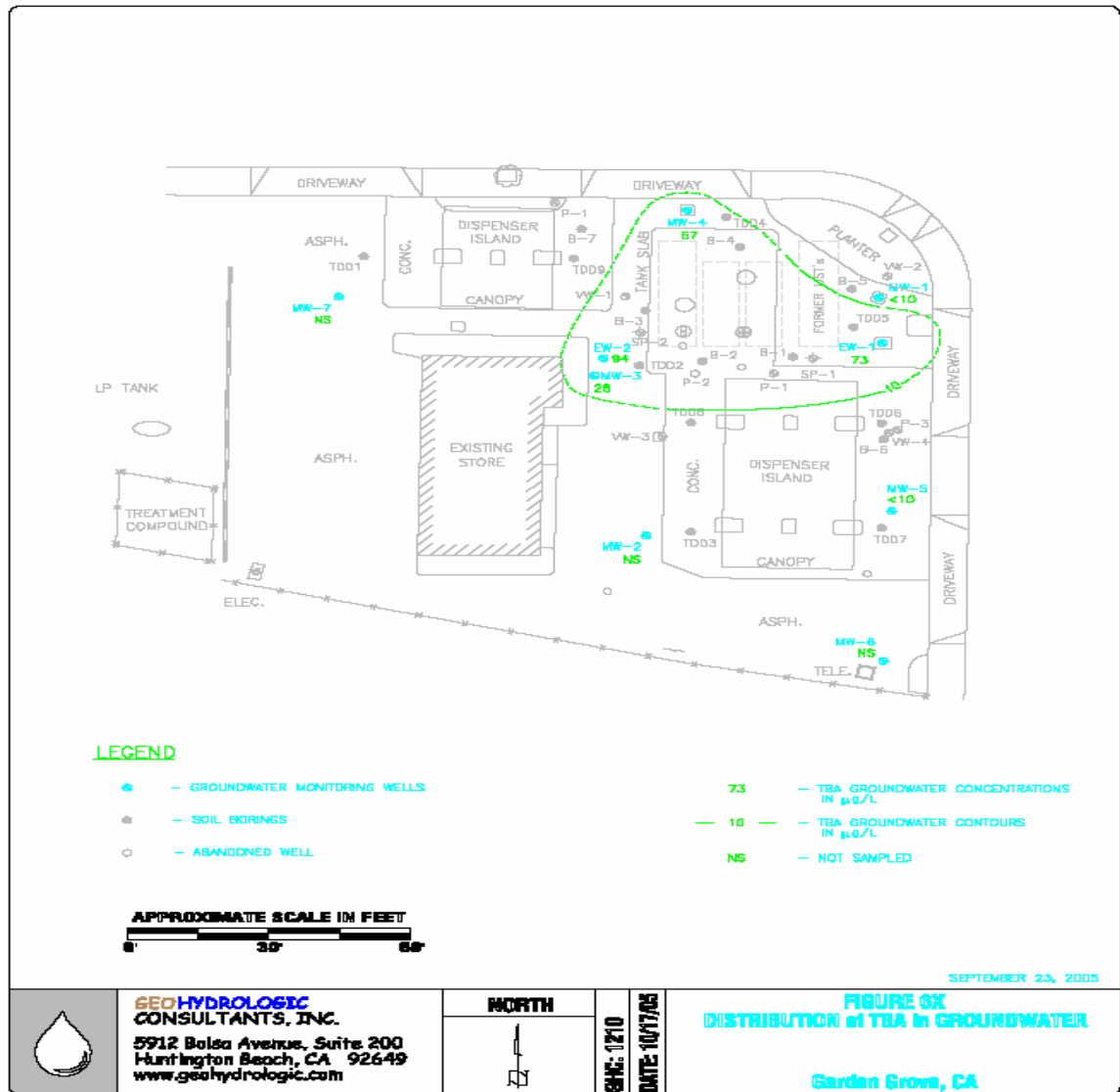


Figure 4. Site A, TBA Iso-Concentrations at Completion of Ozone Sparging

At Site B, the dissolved TPHg levels in the well with the highest levels of contamination, RS-5R, were 929 µg/L on March 29 & 30, 2005, decreasing to less than 15 µg/L on April 21, 2005, then increasing to 496 µg/L on May 5, 2005, dropping to less than 2.9 µg/L on system shutdown on June 6, 2005, and rebounding to 2,280 µg/L on July 22, 2005. In well MW-2A, the TPHg levels on those five dates were 370 µg/L, 199 µg/L, 196 µg/L, 192 µg/L, and 178 µg/L, respectively. In well MW-3A, the TPHg levels were 213 µg/L, 114 µg/L, 699 µg/L, 87 µg/L, and 211 µg/L. Results indicate a significant decrease in the TPHg plume during the testing period, with some rebound in concentrations on July 22, 2005.

At Site B, the only wells with dissolved benzene during this pilot test were wells MW-2A, MW-3A, and RS-5R. MW-2A started with a level of 45 µg/L, decreased to 1.7

µg/L, and decreased again to less than the method detection limit (mdl) for the last three sampling events. In well MW-3A, dissolved benzene was first measured at 4.8 µg/L, decreased to 4.0 µg/L, increased to 100 µg/L, decreased to less than the mdl, and increased slightly to 2.5 µg/L in the last sampling event. In well RS-5R, dissolved benzene was measured to be less than the mdl in four of the sampling events, and was measured at 2.1 µg/L on May 5, 2005. The other sampled wells had dissolved benzene levels that were below the mdl on the five sampling dates. A significant decrease in the benzene plume was noted during the testing, with no dissolved benzene detected on system shutdown, and a small amount of rebound in MW-3A on July 22, 2005.

At Site B, the only wells with dissolved MTBE during the pilot test were wells MW-2A, MW-3A, and RS-5R. MW-3A started with a level of 33 µg/L, increased to 97 µg/L, increased again to 160 µg/L, decreased to 69 µg/L, and decreased again to 12 µg/L. Well MW-2A started with a level of 12 µg/L, decreased to 8.2 µg/L, remained the same at 8.2 µg/L, decreased to 6.4 µg/L, and decreased again to 3.9 µg/L. Well RS-5R started below the mdl for the first two sampling events, then increased to 2.9 µg/L on May 5, 2005, decreased to 2.6 µg/L on June 6, 2005, and decreased to below the mdl on the final sampling event. The other sampled wells had dissolved MTBE levels that were below the mdl on the five sampling dates; an overall decrease of MTBE concentrations was noted during testing.

At Site B, the dissolved TBA levels in the well with the highest levels of contamination, MW-12, started at 4,450 µg/L, decreased slightly to 4,060 µg/L, decreased again to 2,790 µg/L, increased to 3,440 µg/L, and then decreased to 3,100 µg/L. In well MW-11R, the TBA levels on those five dates were 707 µg/L, 1,500 µg/L, 3,560 µg/L, 2,920 µg/L, and less than 10 µg/L, respectively. In well MW-13, the TBA levels started at 958 µg/L, decreased to 868 µg/L, increased to 1,020 µg/L, decreased to 910 µg/L, and decreased to 810 µg/L. Well RS-5R started at 337 µg/L, decreased to 203 µg/L, decreased again to 49 µg/L, decreased to 10 µg/L, and then rebounded to 180 µg/L. The results indicate a substantial decrease in the dissolved TBA plume over the course of the pilot test.

At Site B, dissolved oxygen levels on March 29 & 30, 2005 ranged from 0.55 milligrams per liter (mg/L) in well MW-2A to 6.77 mg/L in well MW-11R. On April 21, 2005, the dissolved oxygen levels ranged from 0.66 mg/L in MW-2A to 7.66 in MW-8. On May 5, 2005, the levels ranged from 0.03 mg/L in MW-2A to 2.37 mg/L in well MW-11R. On June 6, 2005, the levels ranged from 2.98 mg/L in MW-2A to 7.75 mg/L in well MW-8. On July 22, 2005, approximately 7 weeks after ozone sparging stopped, the oxygen levels had dropped to a range from 0.18 mg/L in MW-8 to 3.93 mg/L in well MW-13. Ozone sparging generally caused increases in dissolved oxygen in the sampled wells during the course of the sparge pilot test, and then showed large declines in the July 22 rebound samples. Levels of methane, which indicate anaerobic conditions, declined from 0.504 mg/L in well MW-3A on March 30 to 0.025 mg/L on July 22. This indicates that aerobic microbial activity most likely resumed during the course of the pilot test around that well, and groundwater conditions shifted from

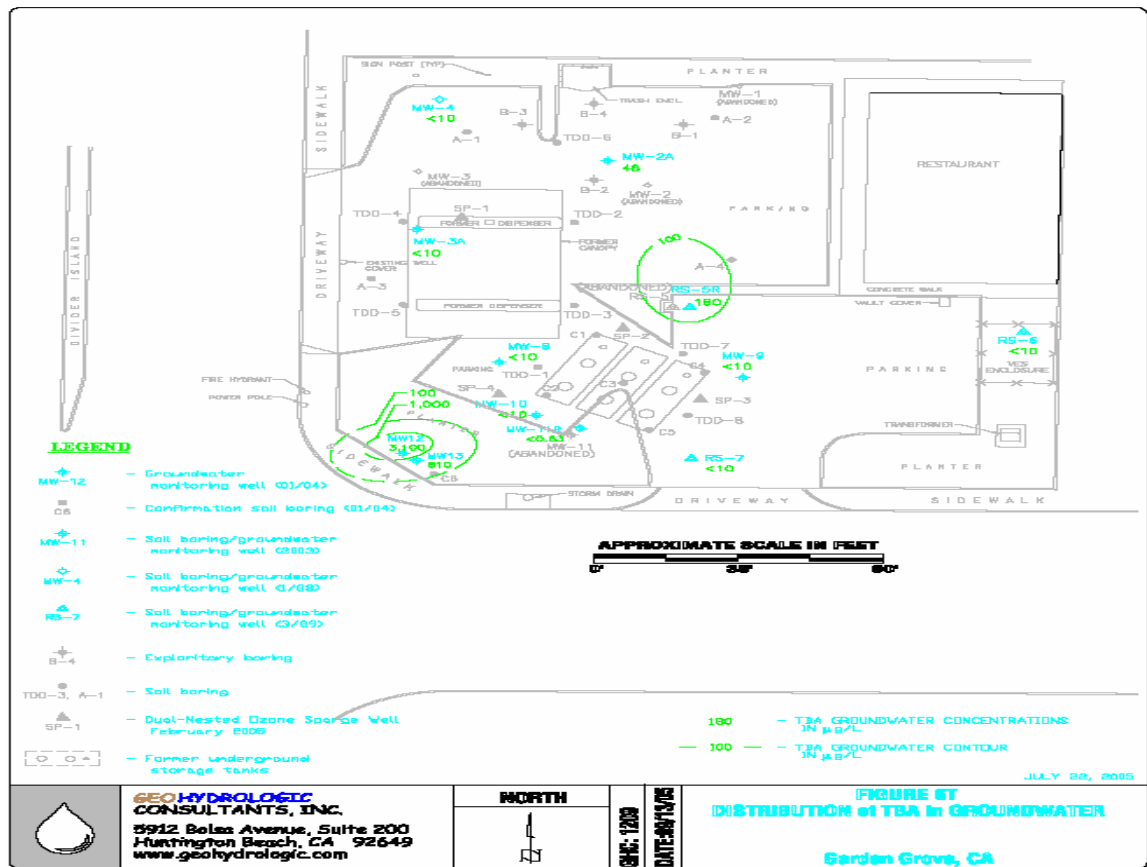


Figure 6. Site B, TBA Iso-Concentrations at Completion of Ozone Sparging

Conclusions

At Site A, the project was completed for under \$25,000 including installation, rental, operation and maintenance, and groundwater monitoring. Two separate ozone sparging events were completed at the Site, with the first event for one month in 2004, and the second event for three months in third quarter of 2005. Maximum TBA starting concentrations of 5,820 µg/L with TBA concentrations in MW-3 being reduced from 2,920 µg/L to 234 µg/L at conclusion of first one month test, TBA concentrations in EW-1 being reduced from 5,820 µg/L to 1,820 µg/L at conclusion of first one month test, and TBA concentrations in MW-5 being reduced from 356 µg/L to <10 µg/L at conclusion of first one month test. The TBA concentrations in MW-3 were further reduced from 234 µg/L to 28 µg/L at conclusion of second three month test, TBA concentrations in EW-1 were further reduced from 1,820 µg/L to 73 µg/L at conclusion of second three month test, and TBA concentrations in MW-5 remained <10 µg/L at conclusion of second three month test. Ozone sparging for approximately four months combined time demonstrated significant reductions in dissolved phase groundwater hydrocarbon concentrations, including MTBE and TBA, and closure for Site A was requested and is currently pending.

At Site B, the project was completed for under \$15,000 including installation, rental, operation and maintenance, and groundwater monitoring. Dissolved TBA levels in the well with the highest levels of contamination, MW-12, started at 4,450 µg/L, decreased slightly to 4,060 µg/L, decreased again to 2,790 µg/L, increased to 3,440 µg/L, and then decreased to 3,100 µg/L. In well MW-11R, the TBA levels on those five dates were 707 µg/L, 1,500 µg/L, 3,560 µg/L, 2,920 µg/L, and less than 10 µg/L, respectively. In well MW-13, the TBA levels started at 958 µg/L, decreased to 868 µg/L, increased to 1,020 µg/L, decreased to 910 µg/L, and decreased to 810 µg/L. Well RS-5R started at 337 µg/L, decreased to 203 µg/L, decreased again to 49 µg/L, decreased to 10 µg/L, and then rebounded to 180 µg/L. Ozone sparging for approximately one month demonstrated significant reductions in dissolved phase groundwater hydrocarbon concentrations, however TBA concentrations appeared to persist in the area of MW-12 since no sparging points were in this immediate area and the area may have some finer grained soil horizons beneath the water table. Based on these results, installation of an additional sparge point was recommended in this area and it was also recommended to connect this well to the system and operate the ozone sparging system for another three months in order to further reduce dissolved phase hydrocarbon concentration, including TBA, to acceptable concentrations that would not rebound.