Air and Ozone Sparging of TCE Using a Directionally Drilled Horizontal Well

Mark Strong and Christopher Bozzini, (mstrong@ch2m.com) (CH2M HILL, Charlotte, North Carolina, USA), Daniel Hood, (NAVFAC ATLANTIC, Jacksonville, North Carolina, USA), and Bob Lowder, (Camp Lejeune EMD, Jacksonville, North Carolina, USA)

ABSTRACT: A one year pilot test was performed at Marine Corps Base, Camp Lejeune to evaluate the performance of air and ozone-enhanced air sparging via a horizontal well. The primary contaminant at the site is trichloroethylene (TCE), with concentrations ranging from 200 to 800 μg/L at a primary target depth of 40 to 45 feet below ground surface (bgs). Site geology consists of silty clay overburden, to a depth of about 35 feet bgs, underlain by partially cemented silty sand and gravel, with thin, discontinuous clay lenses within the transition zone (generally 35 to 40 feet bgs). Horizontal directional drilling (HDD) was selected for subsurface gas delivery because of site constraints, including an active flight line and buried underground utilities; as well as configuration of the plume, which is elongated and relatively deep. The HDD well was constructed of four-inch diameter SDR 11 HDPE, with a slotted section measuring 350 feet in length, positioned at approximately 60 feet bgs. Monitoring wells were installed at select depth intervals on both sides of the well. The objectives of the test were to 1) evaluate the distribution of air using a horizontal well, 2) compare the relative performance of mass transfer (in situ air stripping) to combined in-situ oxidation and air stripping, using ozone enhanced air sparging. Air sparging was conducted for the first three months, at a flow rate of approximately 140 scfm. TCE concentrations were reduced by 90% or more in several wells within this period of time. Based on dissolved oxygen measurements, the distance of influence of air sparging was at least 50 feet on both sides of the well. Subsequent combined air and ozone sparging for approximately five months at a concentration of approximately 7,000 ppm_v produced little change in TCE concentrations, dissolved chloride, or ORP. However, because of various mechanical problems, operation of the ozone generator was intermittent. At the conclusion of the one year pilot study, TCE concentrations were reduced by 99% in all monitoring wells with baseline concentrations exceeding 50 μg/L. The Maximum Contaminant Level for TCE has also been achieved in 14 of 16 wells sampled, with the exception of two deep wells positioned immediately above the slotted portion of the sparge well.

INTRODUCTION

Site 86 is part of Operable Unit (OU) 20, is located within the Marine Corps Air Station (MCAS), New River section of Camp Lejeune is located in Onslow County, North Carolina. The eastern half of the site consists of a grass covered field adjacent to the flight line; the western half consists of several buildings, asphalt roads, and parking lots.

The primary hydrogeologic units of concern at Site 86 are the Undifferentiated Formation and Upper Castle Hayne aquifer. The Undifferentiated Formation consists of relatively low permeability silty clay and fine sand to a depth of approximately 35 ft (10.7 m) bgs. The underlying Upper Castle Hayne aquifer consists of partially cemented silty sand and gravel, with fossil fragments, extending to a depth of approximately 90 ft (27.4 m) bgs. The transition zone between the Undifferentiated Formation and Upper Castle Hayne Aquifer includes discontinuous silty clay lenses. Depth to water ranges from 4 to 8 ft (1.2 to 2.4 m), varying seasonally.

Based on aquifer ("slug") tests and pumping experiments, the average hydraulic conductivity of the Surficial Aquifer (corresponding to the Undifferentiated Formation) is 4.1 x 10^{-4} cm/s. The average hydraulic conductivity of the Upper Castle Hayne aquifer is 1.2 x 10^{-3} cm/s. Groundwater flow is generally east-northeast at approximately 93 ft/year (28.3 m/year). The nearest potential surface water receptor is located approximately 1,400 feet (427 m) downgradient of the plume.

Initial investigations in 1990 focused on a small area formerly associated with historical petroleum fuel storage activities, designated "Site 86", as shown in **Figure 1**. Petroleum impacts in this area were determined to be insignificant. However, during subsequent investigations in 2002, an associated TCE plume extending approximately 1,500 ft (457 m) downgradient was discovered at a depth of 40 to 45 ft (12.2 to 13.7 m) (**Figure 1**). TCE concentrations over this same area at 50 to 55 ft (15.2 to 16.7 m) bgs were generally less than 100 µg/L, as of January 2002.

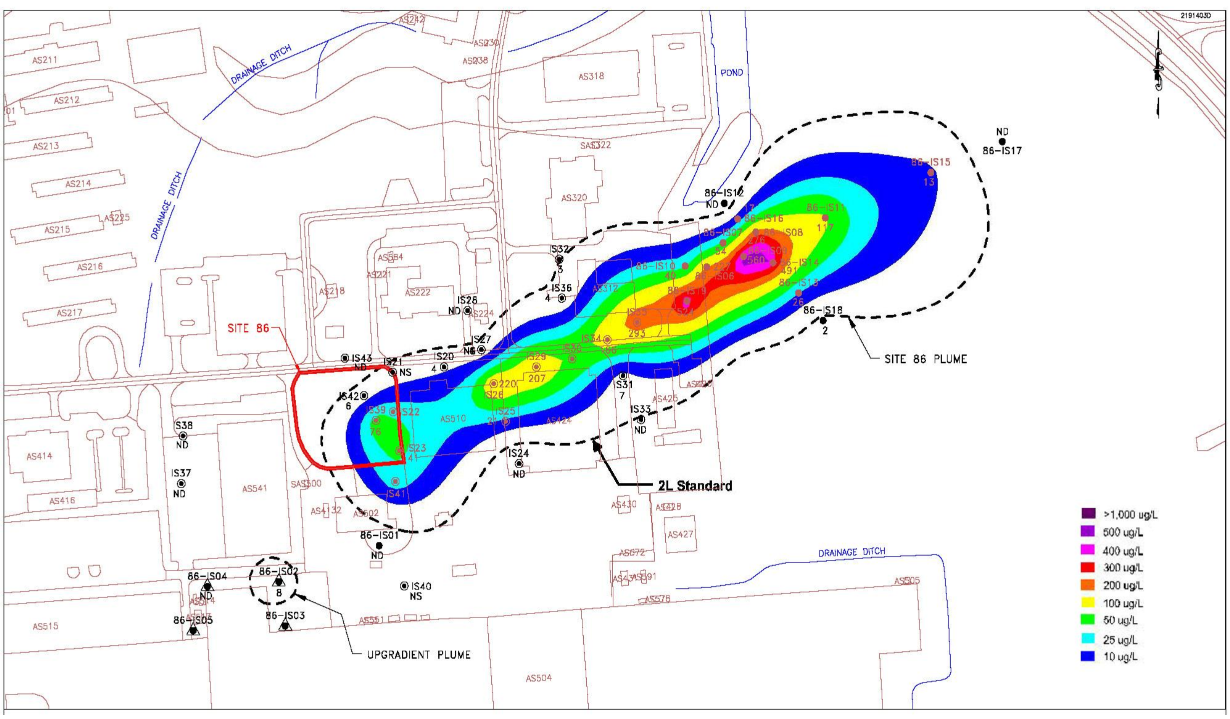

FIGURE 1. Historical TCE Plume Map, 40-45 ft bgs, January, 2002 (reproduced from Michael Baker, Inc. 2003).

As shown in **Figure 1**, TCE concentrations at 40-45 ft (12.2 – 13.7 m) bgs ranged from 200 to 500 µg/L. Concentrations of cis-1.2 DCE were significantly less than TCE levels, and vinyl chloride was negligible, indicating slow reductive dechlorination. Measured total organic carbon in the Upper Castle Hayne aquifer at Site 86 ranged from 4 to 12 mg/L in groundwater, and 1.5 to 3.5 g/kg in soil.

METHODS AND MATERIALS

The primary goal of the pilot test was to evaluate the performance of a horizontal directionally drilled (HDD) air sparge well, specifically targeting the leading edge of the TCE plume exceeding 200 µg/L, positioned at 40 to 45 ft (12.2 to 13.7 m) bgs. Although HDD had not yet been used for remediation purposes at Camp Lejeune, the technology was selected because of site constraints, including an active flight line and buried underground utilities; as well as configuration of the plume, which was elongated and relatively deep. Air sparging was considered a cost effective method to remove low concentrations of TCE via mass transfer ("stripping"). Soil vapor extraction was not conducted, primarily because of the shallow depth to water and the low permeability of the narrow vadose zone.

An HDD sparge well was designed and installed in September of 2004. The sparge well was constructed of four-inch diameter SDR 11 HDPE, with a 350 ft (107 m) long slotted section, positioned at approximately 60 ft (18.2) bgs. Total lineal distance of drilling was approximately 950 ft (290 m). Slot design included 0.020-inch (0.5 mm) wide openings, oriented parallel to the axis of the pipe, with a total open area of 0.5%. Design flow was 0.5 scfm per foot of slotted pipe. After the HDD well was completed, monitoring wells were installed on either side for the purpose of performance monitoring, as shown in **Figure 2**. In accordance with previous site investigation work, the new monitoring wells were installed at staggered depths: 30-35 ft (9.14 to 10.7 m) ("A" wells), 40-45 ft (12.2 to 13.7 m) ("B" wells), and 50-55 ft bgs (15.2 to 16.7 m) ("C" wells). The new wells were sampled in October of 2004 to establish baseline VOC concentrations; results are shown in **Figure 2**.

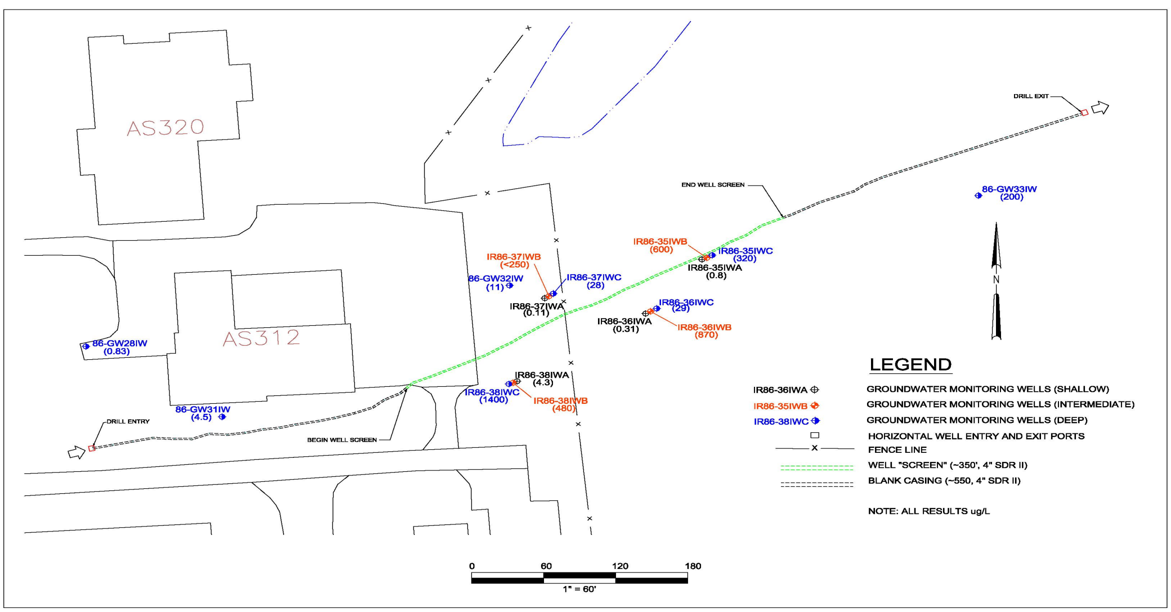

FIGURE 2. HDD Sparge Well and Monitoring Well Layout, Showing Baseline (October, 2004) Data.

As shown in **Figure 2**, the TCE concentration profile in October 2004 had changed from that associated with the 2002 investigation (**Figure 1**). TCE impacts appeared to have migrated into deeper portions of the Castle Hayne, and concentrations within the target 40 to 45 ft (12.2 to 13.7 m) zone were also higher.

Two phases of sparging operation were planned for the test, for a total duration of1 year. During the first 3 months, air sparging only would be conducted. Subsequently, ozone enhanced air sparging would be conducted for 8 months, with a 1-month period of down-time between phases of operation, to allow for installation of the ozone generator and "rebound" monitoring. An additional 3-month period of "rebound" monitoring was scheduled at the conclusion of the 1-year period. Groundwater sampling events were scheduled for 1, 3, 4, 6, 9, and 12 months after initial (air sparge) start-up.

Compressed air was supplied using a Kaeser™ BSD50 rotary screw compressor, rated for 220 cfm @120 psi. Air flow was measured using an insertion type thermal mass flow sensor, calibrated for 150 scfm @ 30 psi. Ozone was produced on site using an Ozonia™ CFV-03 generator, rated for 60 pounds per day (ppd), dry air feed. Approximately 18 scfm of compressed air was diverted from the main sparge line, through a gas cooler, air filtration system, and twin tower desiccant dryer (necessary to achieve a minimum -100°F dew point), before entering the generator. The ozone generator inlet gas stream was metered using a second mass flow sensor. After exiting the generator, the ozone gas, at a concentration in air of 47 g/m^3 (maximum), was blended back into the sparge air stream. Ozone concentrations were measured before and after the blending tee, using a mid-range concentration monitor. The air compressor and ozone generator were housed in separate 8 x 20 ft (2.4 x 6.1 m) shipping containers.

RESULTS AND DISCUSSION

Air sparging commenced in early February of 2005. Initial air flow rate was 180 scfm; however, the flow rate was decreased to 140 scfm, to mitigate excessive air and groundwater surfacing, particularly within flight line areas. Sparge air distribution within the Upper Castle Hayne Aquifer was effected by the overlying Undifferentiated Formation. A conceptual model of sparge air distribution, showing restricted air channeling within the Undifferentiated Formation, as well as "trapping" of air in the Upper Castle Hayne Aquifer, is illustrated in **Figure 3**. The conceptual model was based on a series of observations at the site, including 1) large volumes of air released from the "A" monitoring wells during groundwater sampling events, after the air compressor was deactivated; 2) irregular, "patchwork" configuration of air bubbling noted at ground surface, immediately above the sparge well slotted section; and, 3) surficial bubbling noted in areas significant distances from the sparge well, including a surface retention pond, positioned approximately 200 feet to the north.

Groundwater analytical data indicated efficient air contact and TCE removal in groundwater monitored by the "B" wells, screened at 40-45 ft (12.2 to 13.7 m), with greater than 90% TCE reduction achieved within three months of continuous air sparging. Example TCE concentration trends for 86-GW35IWA, 86-GW35IWB, 86-GW35IWC, 86-GW36IWA, 86-GW36IWB, and 86-GW36IWC (referred to herein as MW-35A, MW-35B, MW-35C, MW-36A, MW-36B and MW-36C) are shown in **Figures 4 and 5**. In general, the "A" and "C" wells were slower to respond. An initial increase in TCE concentration was noted, particularly the shallow "A" wells. It is inferred that TCE volatilized from the Upper Castle Hayne temporarily accumulated in lower portions of the Undifferentiated Formation, before being removed. The temporary increase of TCE concentration at MW-36C, as shown in **Figure 4,** may be associated with limited horizontal air contact at depths immediately above the sparge well, and/or groundwater movement caused by sparging. In other “C” wells, temporary fluctuations were not noted. For example, TCE at MW-38C (results not shown) decreased from a baseline concentration of 1,200 μg/L to 3 μg/L within 3 months.

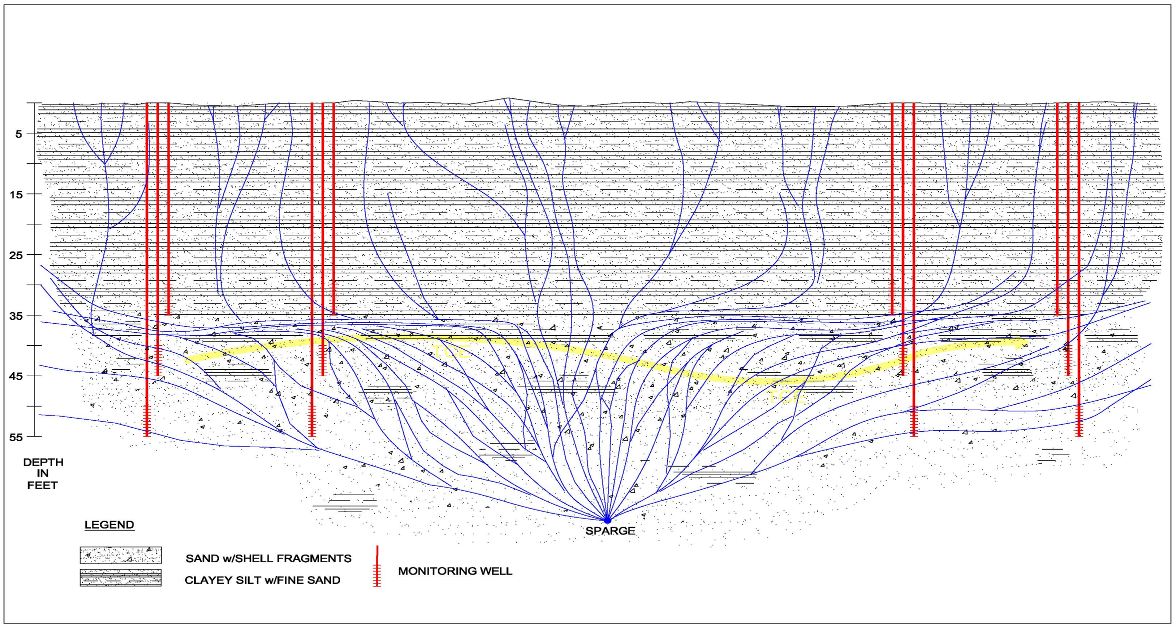

FIGURE 3. Site 86 Air Sparge Conceptual Model.

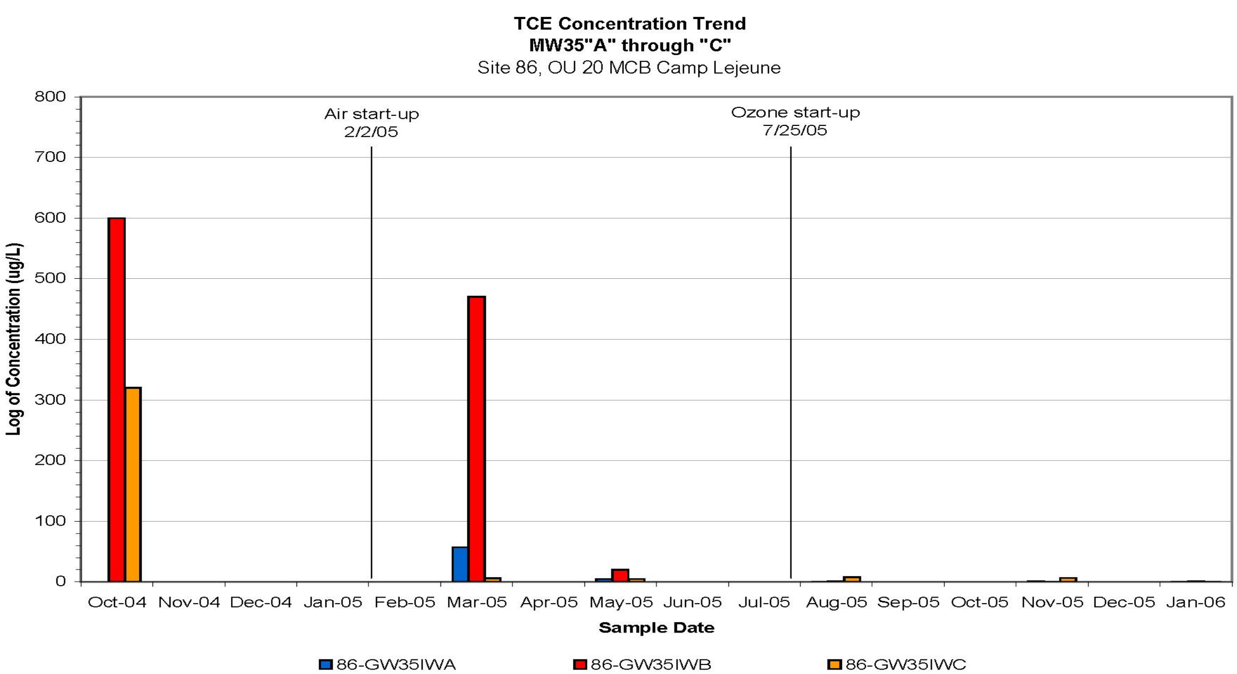

FIGURE 4. TCE Concentrations in MW-35A, -35B, and -35C.

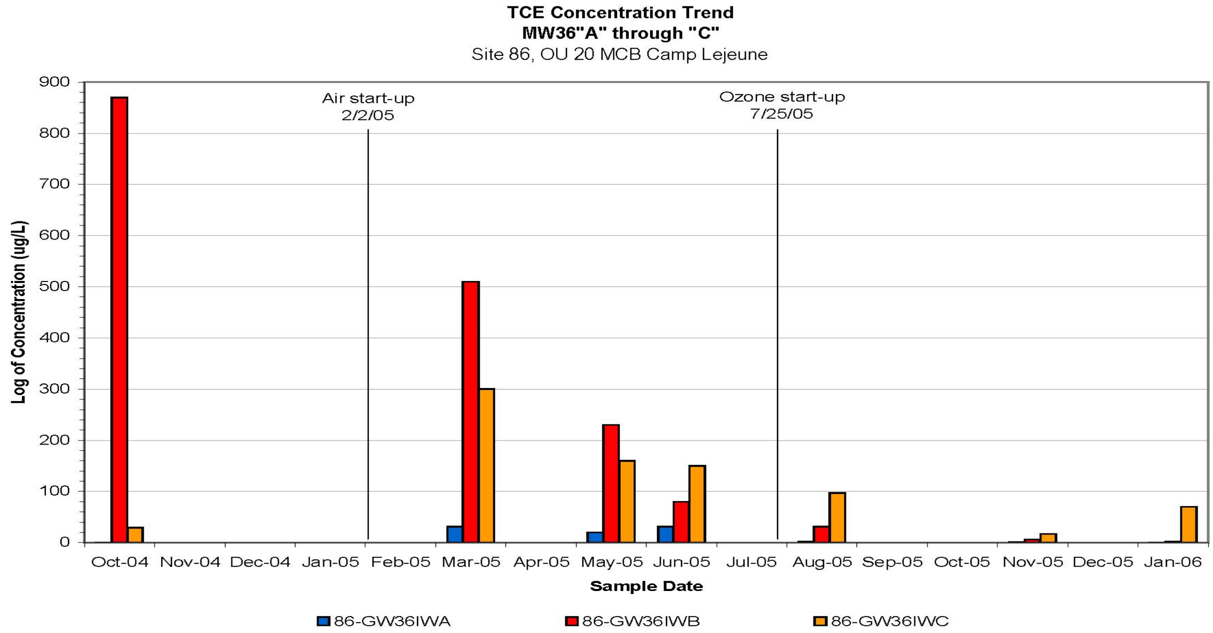

FIGURE 5. TCE Concentrations in MW-36A, -36B, and -36C.

Air sparging "distance of influence", based on dissolved oxygen and ORP measurements, was determined to be at least 50 feet on either side of the well. However, as previously mentioned, air bubbling in a pond was observed as far as 200 feet away. Baseline and 3-month (May, 2005) DO and ORP data are summarized in **Table 1** below.

TABLE 1. Baseline and Three Month DO/ORP Measurements.

MW (30-35')	DO/ORP (10/2004)	DO/ORP (05/2005)	MW (40-45')	DO/ORP (10/2004)	DO/ORP (05/2005)	MW (50-55')	DO/ORP (10/2004)	DO/ORP (05/2005)
						MW-28C	0/-101	3.3/286
						MW-31C	1.9/-120	1.2/152
						MW-32C	0/-128	2.4/8.3
						MW-33C	0.5/-6	1.0/118
MW-35A	1.2/-46	3.7/271	MW35B	1.6/-86	2.6/253	MW-35C	1.4/-104	1.6/125
MW-36A	0.8/2.0	2.3/179	MW-36B	0.8/-93	3.6/117	MW-36C	1.2/-160	2.1/187
MW-37A	1.5/-77	2.5/250	MW-37B	1.3/-89	3.6/146	MW-37C	2.1/-8	2.8/226
MW-38A	1.2/-66	2.2/224	MW-38B	1.9/-99	2.5/269	MW-38C	1.92/-110	2.8/251

During the month of May, 2005, air sparging was not conducted, and "rebound" of TCE concentrations was not observed. In early June 2005, following the 4-month groundwater sampling event, air sparging was re-started. Ozone production began in late July 2005, after an 8-week delay, due to equipment problems (primarily associated with the air dryer system). After several weeks of operation at 25-50% capacity, to evaluate potential surfacing of ozone gas (which was not detected), the generator was operated at maximum capacity. At 100% capacity, production exceeded 60 pounds of ozone per day, and ozone concentrations in the sparge air, measured after the blending tee, averaged 7,000 ppm_v. However, generator operation was interrupted on several occasions by various mechanical problems. The total mass of ozone injected from July 22, 2005, to December 29, 2005, was approximately 3,900 pounds. The generator was deactivated on December 29, 2005, because of chiller failure, and was not restarted. Air sparge operations continued until January 24, 2006, at which time the air compressor was also deactivated.

Because ozone is short-lived in the environment (generally 15 to 20 minutes or less in cool water), concentrations in groundwater are difficult to quantify, especially during a sparge application involving high pressures, with potentially hazardous sampling of ozonated water. For this reason, ORP and (to a lesser extent) DO trends in groundwater, 24 to 48 hours after ozonation, were evaluated. An example of ORP and DO trends for MW-36B is shown in **Figure 6.** As shown in **Figure 6**, ORP and dissolved oxygen progressively increased in the Upper Castle Hayne aquifer, although a more erratic trend was noted in the Undifferentiated Formation ("A" wells). It is not apparent from this data set whether increasing ORP and DO is the result of ongoing air sparging, or contribution from ozone.

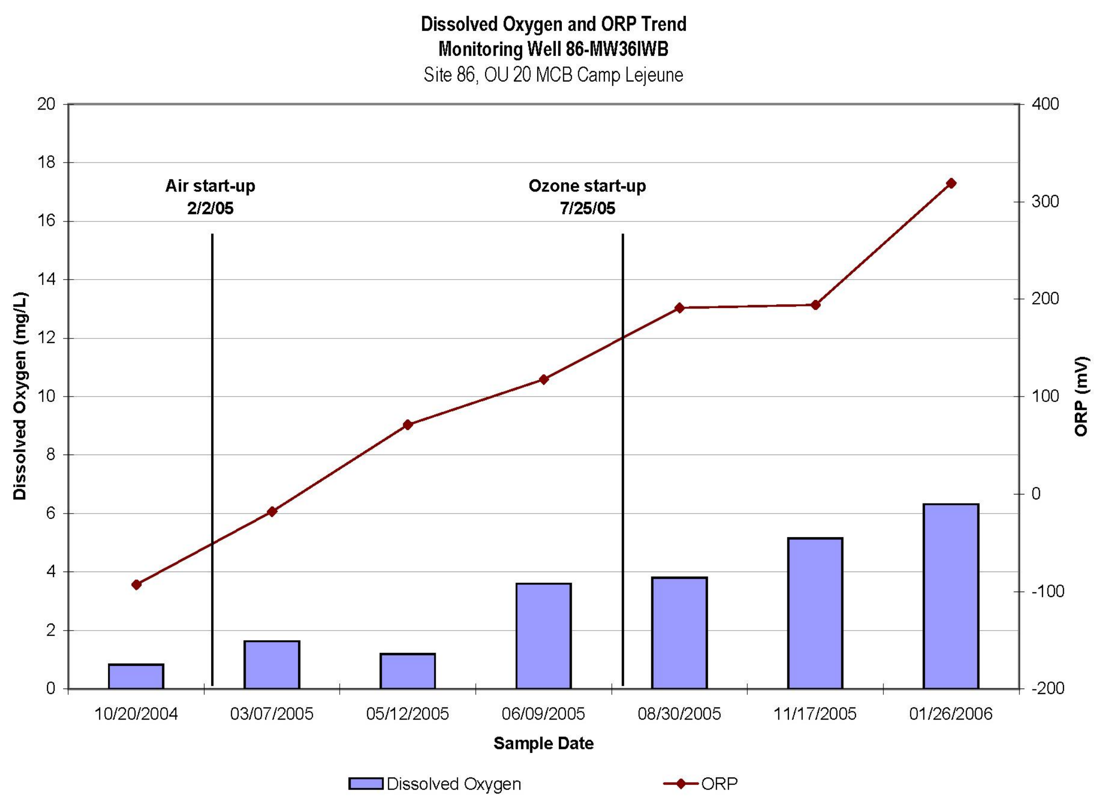

FIGURE 6. Oxidation-Reduction Potential and Dissolved Oxygen Data Trend.

CONCLUSIONS

Air sparging below a low permeability layer, using an HDD well, resulted in extensive lateral distribution of air, and rapid reduction of dissolved TCE and associated cVOC compounds. Within one year, TCE removal exceeded 99% in all monitoring wells with baseline concentrations exceeding 50 µg/L. Of the 16 monitoring wells sampled during the pilot test period, TCE in all but two wells was reduced to less than the MCL (5 μg/L). The highest concentration of TCE detected at the conclusion of the test period was 70 μg/L, in MW-36C. A final groundwater sampling event is scheduled for May of 2006.

Assessment of combined air and ozone sparging proved inconclusive, because of the short duration of the pilot test, low concentrations of TCE after air sparging, and inconsistent ozone generator operation.

REFERENCES

CH2M HILL, 2002, *Site 86 Technology Evaluation*

Michael Baker, Inc. 2003. *Amended Remedial Investigation, Operable Unit 20, Site 86*