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Treatability Study for Edible Oil Deployment for Enhanced cVOC Attenuation for T-Area, Savannah River Site:

Interim Report – Year One

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INTRODUCTION

Groundwater beneath T-Area, a former laboratory and semiworks operation at the Department of Energy (DOE) Savannah River Site, is contaminated by chlorinated solvents (cVOCs). Since the contamination was detected in the 1980s, the cVOCs at T-Area have been treated by a combination of soil vapor extraction and groundwater pump and treat. The site has received approval to temporarily discontinue the active treatments and implement a treatability study of *enhanced attenuation* – an engineering and regulatory strategy that has recently been developed by DOE and the Interstate Technology and Regulatory Council (ITRC, 2007). Enhanced attenuation uses active engineering solutions to alter the target site in such a way that the contaminant plume will passively stabilize and shrink and to document that the action will be effective, timely, and sustainable.

The paradigm recognizes that attenuation remedies are fundamentally based on a mass balance. Thus, long-term plume dynamics can be altered either by reducing the contaminant loading from the source or by increasing the rate of natural attenuation processes within all, or part of, the plume volume. The combination of technologies that emerged for T-Area included: 1) neat (pure) vegetable oil deployment in the deep vadose zone in the former source area, 2) emulsified vegetable oil deployment within the footprint of the groundwater plume, and 3) identification of attenuation mechanisms and rates for the distal portion of the plume. In the first part, neat oil spreads laterally forming a thin layer on the water table to intercept and reduce future cVOC loading (via partitioning) and reduce oxygen inputs (via biostimulation). In the second and third parts, emulsified oil forms active bioremediation reactor zones within the plume footprint to degrade existing groundwater contamination (via reductive dechlorination and/or cometabolism) and stimulates long-term attenuation capacity in the distal plume (via cometabolism). For T-Area, the enhanced attenuation development process proved to be a powerful tool in developing a strategy that provides a high degree of performance while minimizing adverse collateral impacts of the remediation (e.g., energy use and wetland damage) and minimizing life-cycle costs.

As depicted in Figure 1, Edible oil deployment results in the development of structured geochemical zones and serves to decrease chlorinated compound concentrations in two ways: 1) physical sequestration, which reduces effective aqueous concentration and mobility; and 2) stimulation of anaerobic, abiotic and cometabolic degradation processes. In the central deployment area, contaminant initially partitions into the added oil phase. Biodegradation of the added organic substrate depletes the aquifer of oxygen and other terminal electron acceptors and creates conditions conducive to anaerobic degradation processes. The organic substrate is fermented to produce hydrogen, which is used as an electron donor for anaerobic dechlorination by organisms such as *Dehalococcoides*. Daughter products leaving the central treatment zone are amenable to aerobic oxidation. Further, the organic compounds leaving the central deployment zone (e.g., methane and propane) stimulate and enhance down gradient aerobic cometabolism which degrades both daughter compounds and several parent cVOCs. Figure 1 depicts TCE concentration reduction processes (labeled in green) along with their corresponding breakdown products.

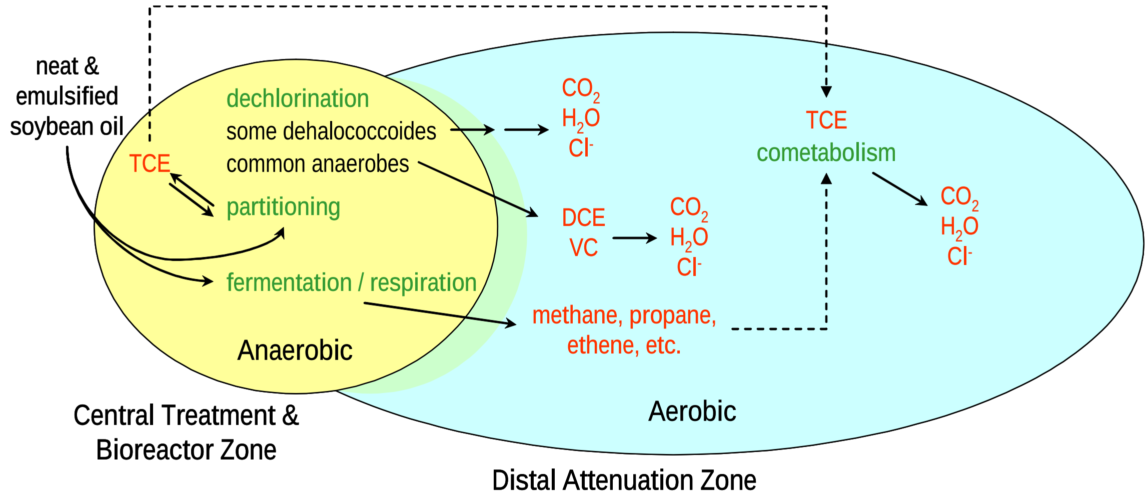

Figure 1 – Schematic of TCE Concentration Reduction Processes

TEST GOALS

Analysis of the conditions in T-Area indicated oil and amendment emplacement along with moderate modifications to the groundwater geochemistry should provide appropriate conditions to change the source area aquifer to anaerobic and initiate reductive dechlorination of trichloroethylene (TCE). Other degradation processes, co-metabolic and abiotic, are also probable in the source area and distal portions of the plume. The overall objective of the testing is to assess the performance of the deployment strategy for long-term attenuation. The specific goals to meet this objective for full scale oil deployment are:

- Evaluate neat and emulsified oil distribution
- Assess the extent and rate of changes from aerobic to anaerobic
- Determine TCE degradation and degradation rates
- Assess degradation daughter products and their subsequent degradation
- Assess degradation pathways (reductive dechlorination, cometabolism, abiotic)
- Assess the recruitment of appropriate bacteria (i.e. fermentative, dechlorinating, and cometabolic) and sufficient amount of biomass
- Determine if additional means are needed to stimulate and/or maintain attenuation (e.g. geochemistry modifications, oil addition, nutrient addition, microbial inoculants, etc.)
- Assess the ability of the oil deployment to stabilize and shrink the groundwater plume and to provide a sustainable treatment to meet the cleanup levels of 5 ppb TCE
- Determine long-term operation, maintenance and monitoring requirements.

DESIGN APPROACH

The design for this combined remedy to transition the remediation of cVOCs in the soil and groundwater of T-Area at the Savannah River Site to passive attenuation based remedy derives from two mechanisms, partitioning and degradation, combined with standard hydrology and engineering calculations. The current configuration of T-Area influenced the assumptions used in developing this design. Notably, the design used existing wells and piezometers for access. This required creative application of treatment reagents to exploit site features and characteristics such as existing well locations, water table and lithology to generate a deployment zone that has the correct geometry to intercept contaminants and effectively treat the groundwater plume.

The result of the design process was a two part deployment: 1) neat (pure) vegetable oil at the water table in the residual source area, and 2) emulsified vegetable oil (EOS™) in the core of the groundwater cVOC plume. The initial estimated distribution of neat and emulsified oil is shown in Figure 2. The full design and implementation plan are provided in the treatabililty study test plan (Riha and Looney, 2007) and underground injection control (UIC) permit (WSRC, 2007). Key deviations from the test plan are provided in the Field Implementation section.

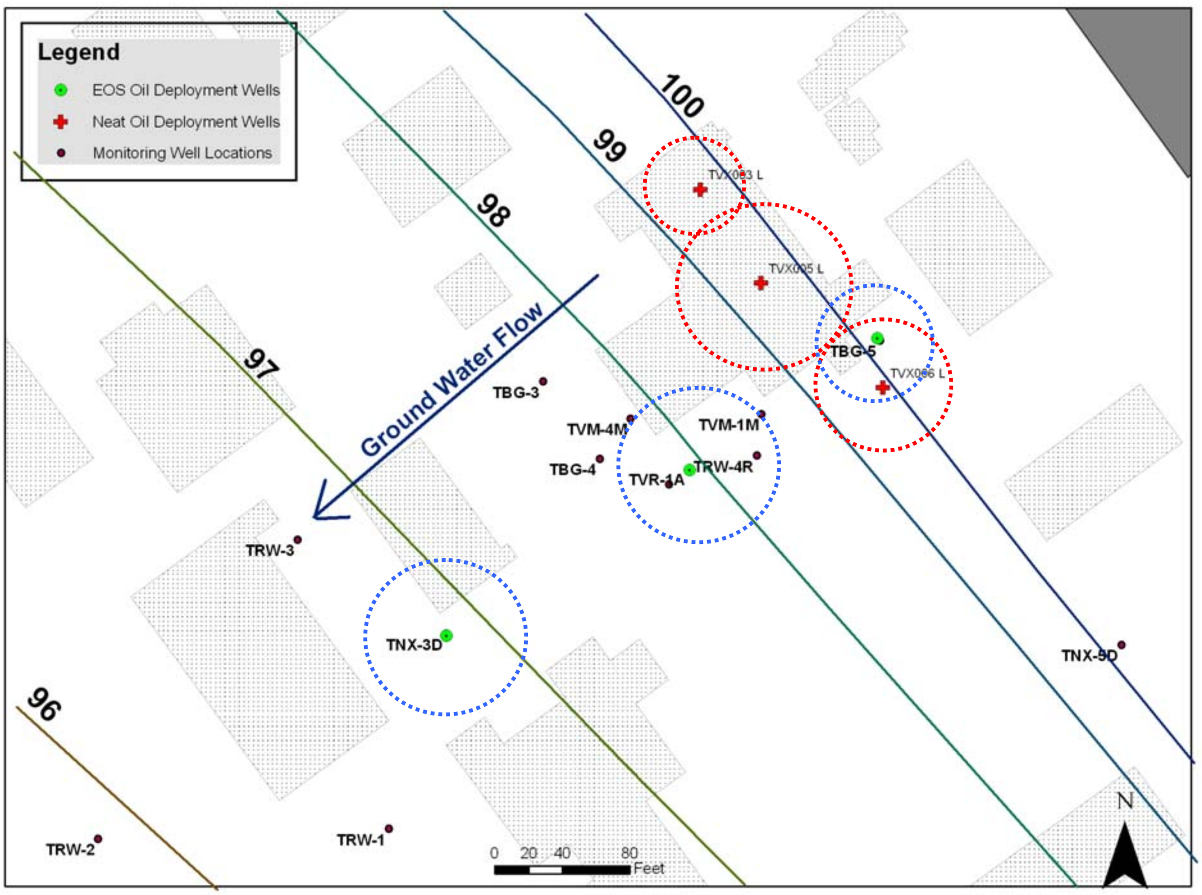

Figure 2 – Plan View Map of Oil Injection Wells and Estimated Initial Distribution

(EOS in blue and neat oil in red. Groundwater elevations as of January 2009)

FIELD IMPLEMENTATION

Emulsified Oil Deployment

The T-Area deployment operated in conjunction with a portable shallow tray air stripper to remove the cVOCs from the groundwater before re-injection. Water was extracted from a down gradient well, treated and re-injected in an up gradient well fitted with EOS and base metering systems. Contaminant mass removed by the air stripper was measured by sampling the air stripper inlet and outlet water stream and analyzing for cVOCs. Total TCE mass removed was 0.016 lbs. The shallow tray air stripper controlled the extraction pump and addition and mixing of reagents. Flexible hoses were used to transfer reagents and water. The air stripper and injection system are shown in Figure 3. In each injection well, the operation continued until the desired EOS was injected along with sufficient water to distribute the EOS throughout the targeted volume. A packer was placed in TRW-4R to maximize the injection or extraction in the upper portion of the screened interval. The progress of the deployment was monitored using periodic samples (contaminants, dissolved oxygen, ORP, total organic carbon (TOC), pH, alkalinity,) from available wells around the injection points.

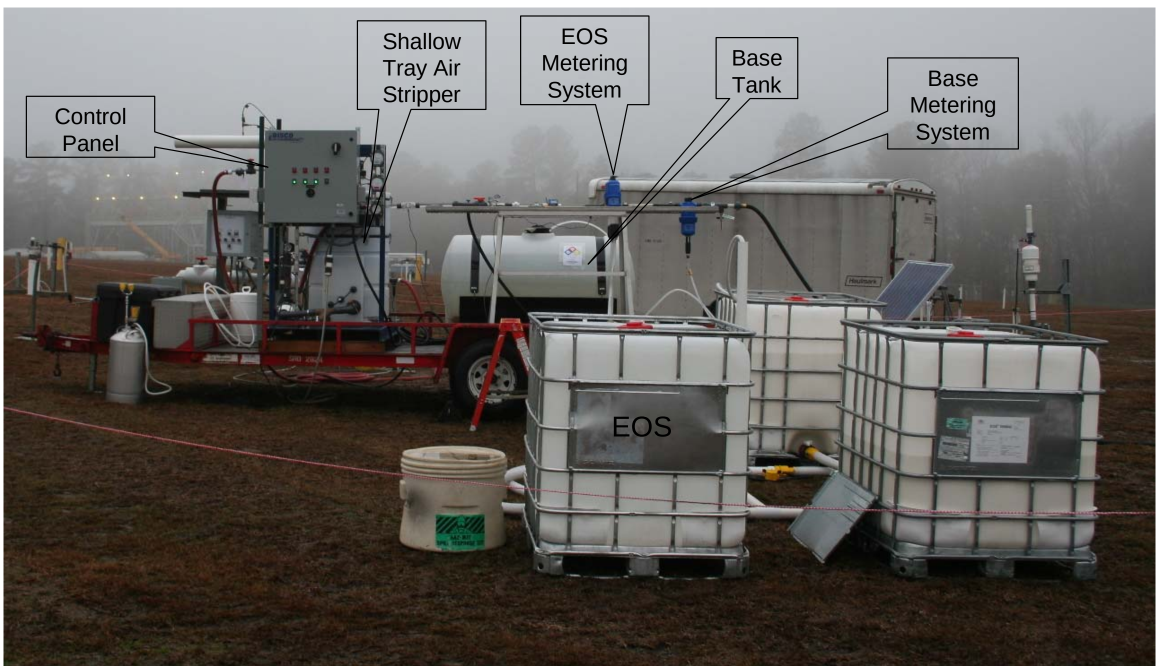

Figure 3 – Air Stripper, EOS and Base Injection System

The original design method of distributing the EOS with injection-extraction well pairs was not feasible in the field due to low well flow rates. The original design involved lowering the water table at the extraction well to guide the EOS from the injection well to the extraction well. For example, well TBG-5 began with an injection flow rate of about 3 gpm (gallon per minute) and dropped to about 1 gpm after the 50,000 gal of EOS and chase water were injected. A minimum of 5 gpm was needed to create the dipole distribution. EOS, water and base were injected by gravity feed. The decrease in flow could be attributed to lowering of permeability due to the oil injection and/or flocculation and clogging by clays from the addition of the base. An interlock sensor was used in each injection well to shut down the system to prevent overflow of the injection well.

As a result of the low flow rates, EOS was distributed radial outward from wells TBG-5, TRW-4R and TNX-3D. See Figure 2. These wells correspond with the flow path of the core of the dissolved plume. TRW-4R (average TCE concentration of 27 µg/l) was used as the extraction well for injection into TBG-5. TRW-3 (average TCE concentration of 3 µg/l) was used as the extraction well for injection into TRW-4R and TNX-3D. After treatment with the air stripper, TCE could not be detected in the injected water. Approximately 0.95 g/gal water of sodium bicarbonate ($NaHCO_3$) and 1.44 g/gal water of hydrous trisodium phosphate ($Na_3PO_4.12H_2O$) were added to the injected water as the pH buffer. The amount of EOS and chase water is provided in Table 1.

Table 1 – Emulsified Oil Injection Volumes

Injection Well ID	Extraction Well ID	Injection Dates	Volume of EOS, gal	Volume of Chase Water, gal	Range of Injection Rates, gpm
TBG-5	TRW-4R	2/20/08-3/10/08	960	50,420	3.3-1.0
TRW-4R	TRW-3	3/17/08-3/26/08	1,250	92,405	7.2 (steady)
TNX-3D	TRW-3	3/27/08-4/19/08	1,250	76,277	6.3-1.8

Neat Oil Deployment

For neat oil deployment, pure soybean oil was used with 0.2% triethyl phosphate (TEP) as a phosphorous source. The oil was emplaced by gravity feed using deep vadose wells TVX-3L, TVX-5L and TVX-6L. The approximate location and dimensions of the neat oil deployment are based on the detailed characterization of the vadose zone to support the SVE operation. In this case, the amount of oil to be deployed was a straightforward geometric calculation (see Figure 1). The key deviation from the test plan was injection in well TVX-6L instead of TBG-5 to allow TBG-5 to be used as a monitoring well. The neat oil injected volumes and approximate flow rates are provided in Table 2 and oil injection into well TVX-5L is shown in Figure 4.

Table 2 – Neat Soybean Oil Injection Volumes

Injection Well ID	Injection Dates	Volume of Neat Soybean Oil, gal	Approximate Injection Rate, gpm
TVX-5L	4/7/08-4/9/08	1,500	1
TVX-3L	4/15/08-4/18/08	300	0.1
TVX-6L	4/24/08-4/25/08	900	0.6

Figure 4 – Neat Soybean Oil Injection in TVX-5L

MONITORING

The goals, metrics and methods for monitoring the performance of the enhanced attenuation remedy are listed in Table 3. The sampling strategy was designed to optimize data collected to meet the study objectives, while minimizing analytical costs. Measurements are being made in a representative set of wells within the treatment zone and outside the treatment zone (for background information) and in representative downgradient wells (to evaluate the aerobic distal treatment zone). Samples were collected prior to injections and monthly after injections.

Table 3 – Strategy for Sampling and Analysis

Test Goal	Metric	Method
Evaluate neat oil distribution	Measure oil presence and thickness in existing wells	oil/water interface probe, bailing
Evaluate emulsified oil distribution	Measure oil presence and approximate concentration in the treated zone using existing wells	Visual identification in water samples. TOC analysis
Assess the extent and rate of change from aerobic to anaerobic	Measure temporal dissolved oxygen (DO) in existing wells	Field sensors and test kits
Determine TCE degradation and degradation rates	Measure temporal TCE and daughter product concentrations	SRNL modified method 5021 headspace analyses
	Measure TCE destruction	Stable C isotope enrichment analyses
Assess daughter products and their subsequent degradation	Measure temporal cVOC concentrations	SRNL modified method 5021 headspace analyses
Assess degradation pathways	dechlorination: measure cVOC daughter products	SRNL modified method 5021 headspace analyses
	cometabolism: measure activity dependent enzymes	Activity-dependent enzyme probes, North Wind Inc.; Stable C isotope ratios
	abiotic: TBD	Stable C isotope ratios
Assess the recruitment of appropriate bacteria and sufficient amount of biomass	Measure temporal type and abundance of the microbial community (fermentative, dechlorinating, and cometabolic)	Quantitative polymerase chain reaction (qPCR) by SRNL and/or commercial laboratory
Determine if additional means are needed to stimulate and/or maintain attenuation	Measure geochemistry and chemistry parameters for maintenance of appropriate attenuation conditions: DO, ORP, TOC, pH, alkalinity, ammonia, sulfate, phosphate, nitrate	Field sensors and test kits
	Measure co-metabolites: methane, propane, butane, ethene, ammonia (breakdown products of soybean oil)	Dissolved gas analysis by commercial lab and SRNL method under development.

STATUS & PRELIMINARY RESULTS

The field deployment of the amendments was initiated in February 2008 and completed in April 2008. Flow rates for diluted emulsion injection and groundwater extraction in the first well pair were below the design assumptions so radial injections were made in three wells along the flow path of the dissolved plume. Data collected from the ten wells indicate that the injected fluids are being distributed in the subsurface as expected and the groundwater plume has decreased in size and concentration. TCE in the treatment zone decreased immediately after injections. This fast decrease in concentration resulted from partitioning and injection of treated (clean air-stripped) water but TCE concentrations have remained near or below 5 µg/l in this area. The data indicate that the buffer added to the injection (trisodium phosphate and bicarbonate) increased the pH from approximately 5 (typical for the Southeastern Coastal Plain) to approximately 6 within the treatment zone.

Full anaerobic conditions have not been achieved throughout the treatment zone but elevated levels of methane indicate strongly reducing conditions are present. Sulfate and nitrate have decreased as the anaerobic zones are established. Reductive daughter products and *Dehalococcoides* (dechlorinating bacteria) have not been observed suggesting a limited role for reductive dechlorination throughout the treatment zone. However, there is indication of elevated chloride that is a conservative indicator of TCE destruction (DOD, 2007). Cometabolic degradation may be the dominant destruction mechanism at the writing of this report. Methanotrophic (MOB) bacteria were present prior to deployment. MOB bacteria use methane as their primary food source and are capable of aerobically degrading TCE by cometabolism.

Table 4 provides a general discussion of the results of the metrics used to evaluate the treatment as related to the test goals for this treatability study for long-term attenuation of TCE at T-Area. The initial groundwater TCE concentration plume in January 2008 is shown in Figure 5 and the estimated concentration plume in January 2009 after the amendment injection is shown in Figure 6. Comparison of these plume maps indicates that the primary impact of the treatment was the sharp decline in concentration throughout the former high concentration portion of the plume. The plume maps indicate injection into well TRW-4R displaced dissolved TCE towards TBG-4 resulting in a transient increase in concentration. TCE concentrations in TBG-4 have now begun to decrease. cVOC concentration and selected geochemistry parameter plots for the ten monitored wells follow these figures with discussions for each well. In general, the data indicate significant progress toward the long term objectives for groundwater underlying T-Area. However, the current number and locations of available monitoring wells at this capped site limits the robustness of the data interpretation. Additional monitoring, as recommended below, will aid in developing a more definitive assessment of performance and estimate of timeframe for achieving remedial objectives.

Overall, we estimate the groundwater is moving in the direction indicated in Figure 2 at a rate of 100 to 150 ft/yr. Based on the groundwater elevation contours, the velocity decreases down gradient. TBG-3 and TBG-4 should be impacted by the carbon addition from the neat soybean oil in May or June of 2009 and TRW-2 (the distal plume well) should be influenced by the treatment strategy sometime in the summer of 2009.

Table 4 – Initial Evaluation of T-Area Test Goals

Test Goal	Metric	Results
Evaluate neat oil distribution	Measure oil presence and thickness in existing wells	Neat oil has not been detected in any well except the injection wells at the time of this report. TBG-5 cannot be measured because of the dedicated pump in the well.
Evaluate emulsified oil distribution	Measure oil presence and approximate concentration in the treated zone using existing wells	Elevated TOC has been measured in TVM-1M, TVR-1A, TVM-2M and the three injection wells. The carbon source is being distributed in the treatment zone with the advective groundwater flow. Increases in concentrations in TBG-4 indicate injections in TRW-4R moved contaminated water towards TBG-4 although groundwater mounding was not evident in TBG-4.
Assess the extent and rate of change from aerobic to anaerobic	Measure temporal dissolved oxygen (DO) in existing wells	DO has decreased in the treatment zone but not to full anaerobic conditions. Based on methane production, it is suspected that full anaerobic conditions exist in some areas. Methane is close to solubility limits in some wells.
Determine TCE degradation and degradation rates	Measure temporal TCE and daughter product concentrations	TCE concentrations decreased immediately after injections likely due to partitioning and dilution. Concentrations have remained near or below 5 µg/l (ppb) throughout the treatment zone. Daughter products have not been detected. Degradation rates have not been evaluated at the time of this report and may be difficult to calculate due to the immediate decrease in TCE concentrations.
	Measure TCE destruction	Stable C isotope enrichment analysis is currently inconclusive because of the low TCE concentrations after deployment.
Assess daughter products and their subsequent degradation	Measure temporal cVOC concentrations	Daughter products have not been detected.

Table 4 – Initial Evaluation of T-Area Test Goals (Continued)

Test Goal	**Metric**	**Results**
Assess degradation pathways	dechlorination: measure cVOC daughter products	Daughter products have not been detected. Reductive dechlorination may be taking place in specific zones but the analysis method is not likely sensitive enough to measure the low concentration of daughter products that would be associated with the low TCE concentration.
	cometabolism: measure activity dependent enzymes	Methanogenic (MGN) and methanotrophic (MOB) bacteria were quite abundant prior to deployment (Riha, Looney et al., 2006). Activity dependent enzymes were detected in TRW-2 and show active although slow degradation in microcosm studies. The baseline half life of TCE is measured at 30.8 years. (Lee, 2008).
	abiotic: TBD	Not addressed at the time of this report.
Assess the recruitment of appropriate bacteria and sufficient amount of biomass	Measure temporal type and abundance of the microbial community (fermentative, dechlorinating, and cometabolic)	*Dehalococcoides* were not detected in any well. Other microbial analysis has not been conducted at the time of this report but is planned.
Determine if additional means are needed to stimulate and/or maintain attenuation	Measure geochemistry and chemistry parameters for maintenance of appropriate attenuation conditions: DO, ORP, TOC, pH, alkalinity, ammonia, sulfate, phosphate, nitrate	Geochemistry and chemistry parameters are in a state of flux as the carbon source is distributed by advective groundwater flow. However, the concentration trends indicate the aquifer is moving into conditions to support reductive dechlorination and cometabolism of TCE. It is expected that these parameters will reach some form of equilibrium within the next 6 to 12 months as the nutrient sources are distributed. A determination if additional reagents are needed will be made in this time frame.
	Measure co-metabolites: methane, propane, butane, ethene, ammonia	Co-metabolites are increasing in concentration in the treatment zone. A significant amount of methane is being produced.

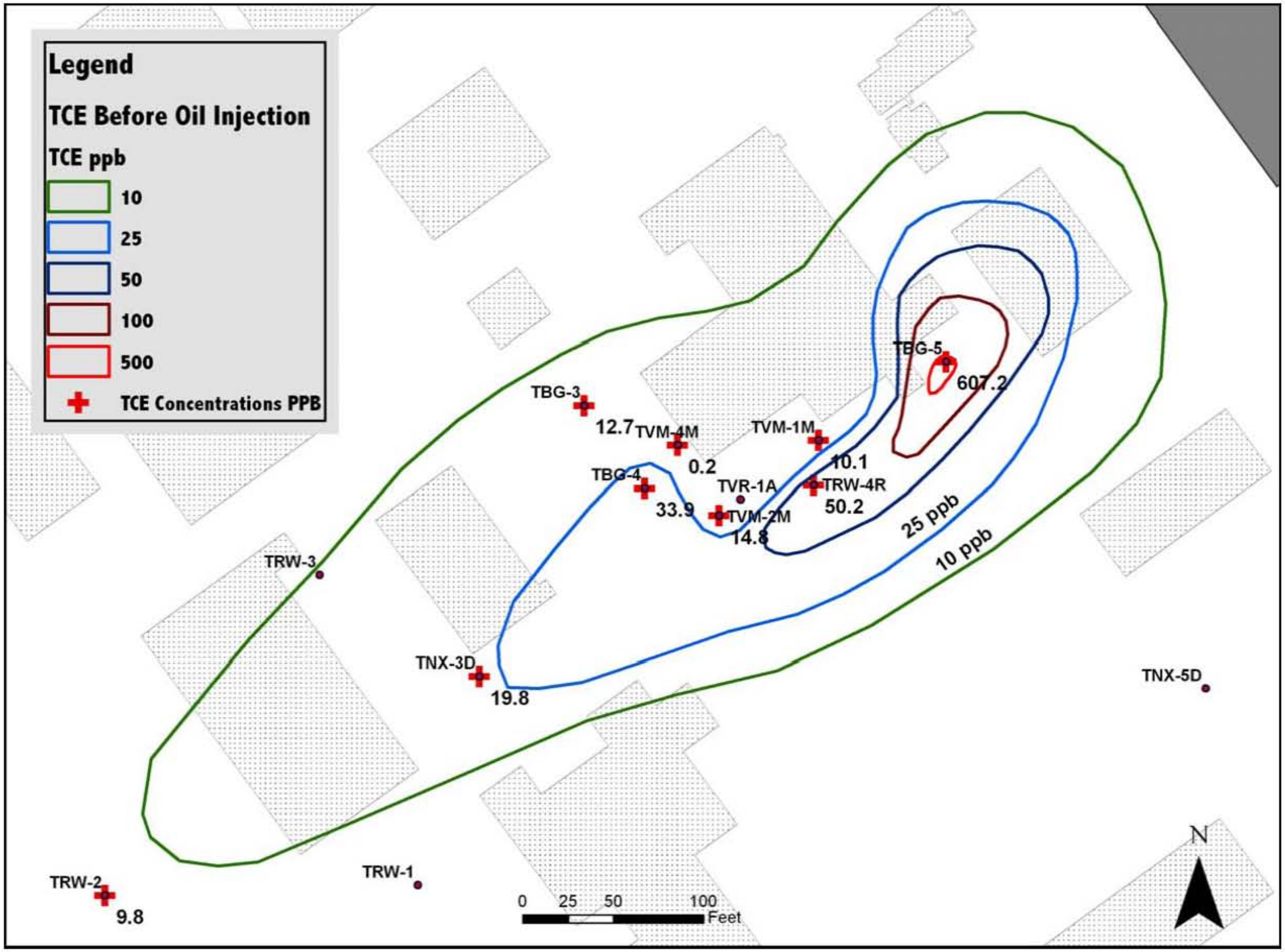

Figure 5 – TCE Concentration Plume Prior to Amendment Injections (January 2008)

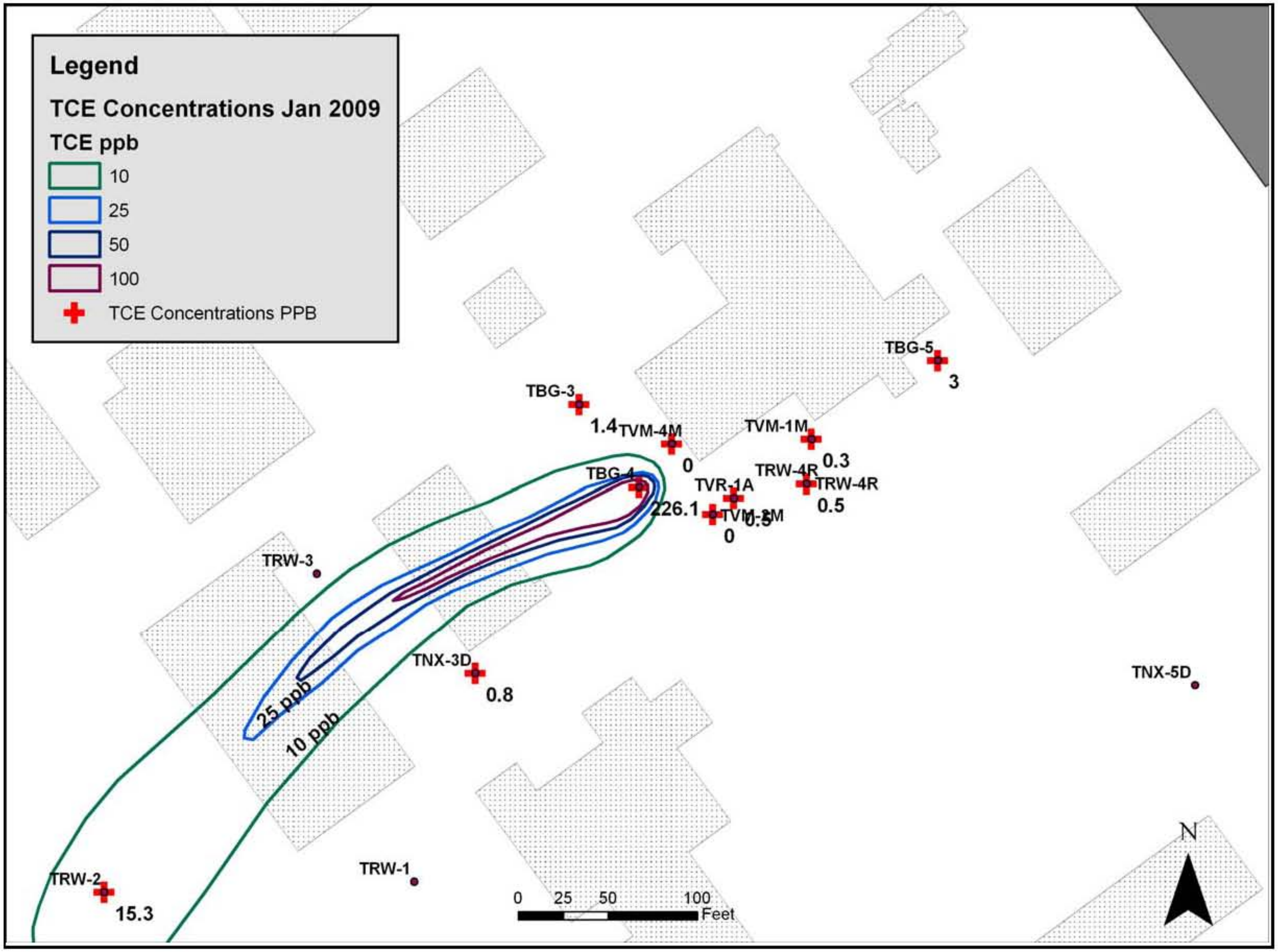

Figure 6 – TCE Concentration Plume after Amendment Injections (January 2009)

Well Concentration Plots

cVOCs and selected geochemical parameters are plotted for each of the ten monitoring wells in Figure 7 through Figure 16. The wells are in order of groundwater flow (up-gradient to down-gradient). Note different scales and broken axes. The injection times are shown on each plot. In general, the black symbols should increase or remain elevated and the red and green symbols should decrease to support reductive dechlorination. Each well is discussed individually in Table 5

Table 5 – Individual Well Discussion

Well	Discussion
TBG-5 Injection Well	TCE has decreased from approximately 600 ppb to around 5 ppb. TOC has remained elevated. pH has increased from near 5 to 6 and is increasing. DO was reduced but is increasing as un-impacted groundwater moves down-gradient. Methane is increasing and is currently near 60% of solubility (methane solubility is 18.2 mg/l). Well production rate has continued to decrease with time likely due to bio-fouling of the screen.
TVM-1M Monitoring Well	This well was impacted briefly during the injection into TRW-4R. TCE concentrations are remaining around 5 ppb and up-gradient injectants are not currently impacting this well.
TRW-4R Injection Well	TCE has decreased from approximately 50 ppb to less then 5 ppb. TOC was elevated and then decreased significantly. pH has increased from near 5 to above 6. DO remains around 0 mg/l and ORP is negative indicating reducing conditions. Methane is increasing and is currently near 40% of solubility. Well production rate has continued to decrease with time likely due to bio-fouling of the screen.
TVR-1A Monitoring Well	TCE remained below 5 ppb until higher concentration groundwater moved past the well from 12/08 to 1/09. This 'slug' is likely from the un-impacted zone between EOS injections in wells TBG-5 and TRW-4R. TOC was elevated and then decreased. pH has increased from near 5 to around 6. DO remains around 0 mg/l and ORP is negative indicating reducing conditions. Methane is decreasing but still around 2 mg/l.
TVM-2M Monitoring Well	TCE has decreased from approximately 15 ppb to around 0 ppb. TOC has remained elevated. pH has increased from near 5 and is approaching 7. DO remains around 0 mg/l and ORP is negative indicating reducing conditions. Methane is increasing and is currently near or above solubility. This zone should provide reductive dechlorination and progression and growth of *Dehalococcoides* however, the TCE (growth substrate) is not present for growth.
TVM-4M Monitoring Well	TCE is near 0 ppb. This well does not appear to have been impacted directly by the oil injections but DO is beginning to decrease and methane is showing a slight increase.
TBG-4 Monitoring Well	TCE has increased from approximately 30 ppb to approximately 350 ppb and is beginning to decrease. Increases in concentrations in TBG-4 indicate injections in TRW-4R moved contaminated water towards TBG-4 although groundwater mounding was not evident in TBG-4. No other impacts from the oil injections are currently evident at the time of this report. It is anticipated that this well will be impacted by the carbon addition from the neat soybean oil in May or June of 2009 and be treated under the distal attenuation zone paradigm.
TBG-3 Monitoring Well	This well was considered a background well and has not been directly impacted by any of the injections. TCE has ranged between 0 and 35 ppb. It is anticipated that this well will be impacted by the carbon addition from the neat soybean oil in May or June of 2009 and be treated under the distal attenuation zone paradigm.

Well	Discussion
TNX-3D Injection Well	TCE has decreased from approximately 20 ppb to less then 5 ppb. TOC has remained elevated. pH has increased from near 5.5 to 6 and is increasing. DO was reduced but increased and then decreased as un-impacted groundwater between wells TRW-4R and TNX-3D moved down-gradient. Methane is increasing and is currently near 70% of solubility. Well production rate has continued to decrease with time likely due to bio-fouling of the screen. Sampling of this well immediately after injections was delayed due to a delay in pump installation.
TRW-2 Distal Monitoring Well	TCE has increased from approximately 10 ppb to 30 ppb. This increase is likely due to rebound after shutting down the pump and treat system. No impacts from the oil injections are currently evident at the time of this report. It is anticipated that this well will be influnced by the oil injections in the summer of 2009 and be treated under the distal attenuation zone paradigm.

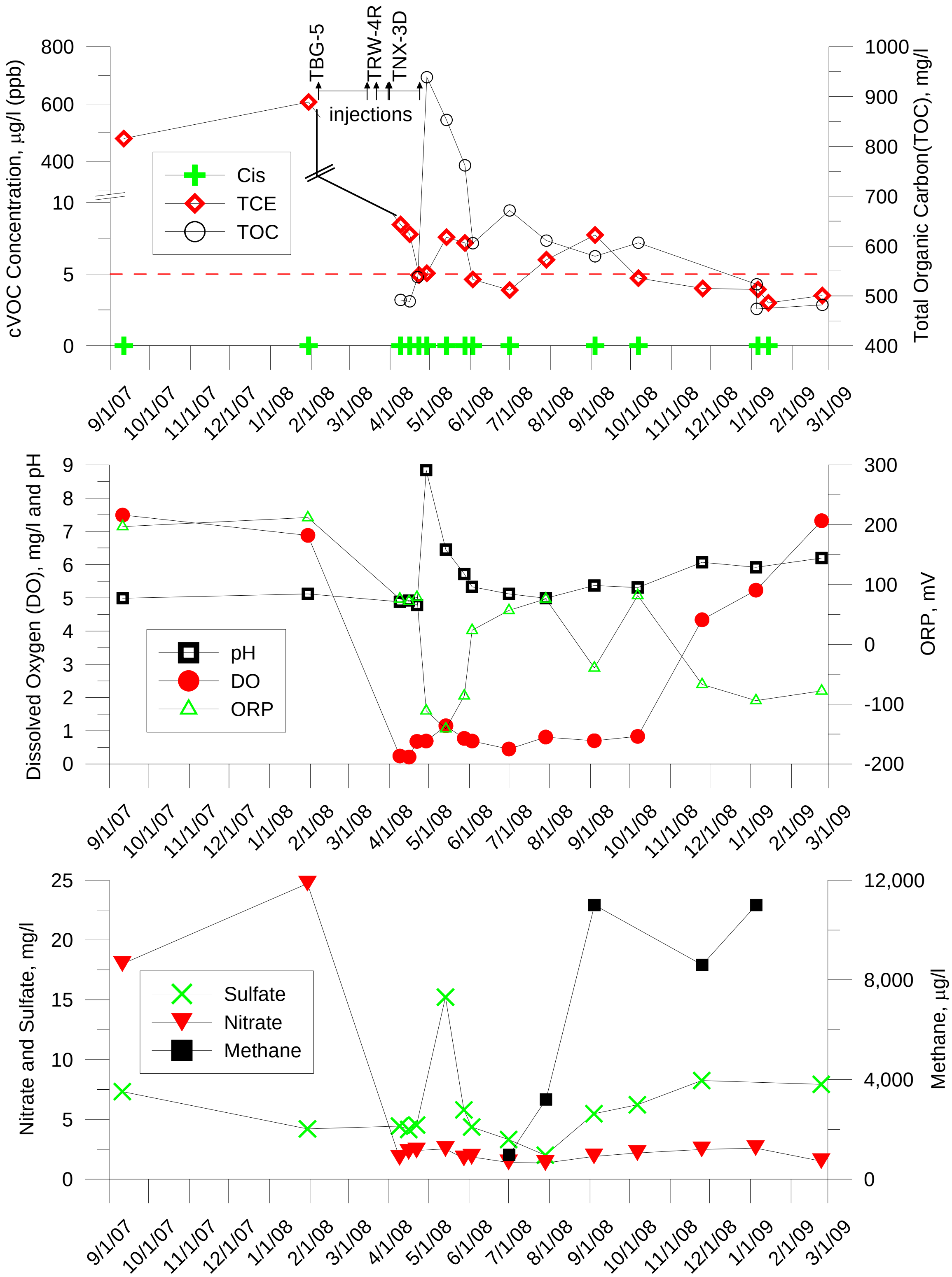

Figure 7 – Analytical Results for TBG-5 (Injection Well)

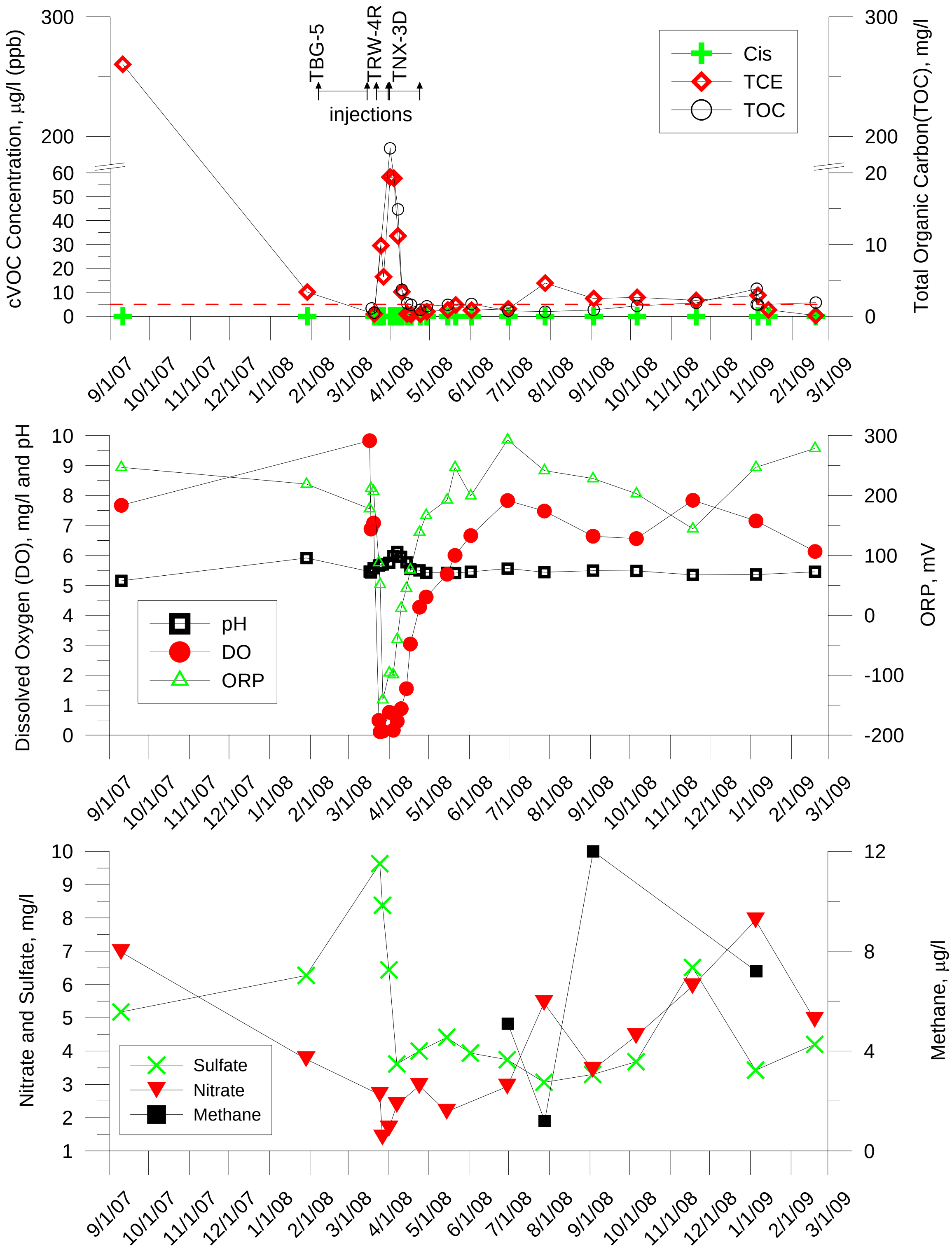

Figure 8 – Analytical Results for TVM-1M (Monitoring Well)

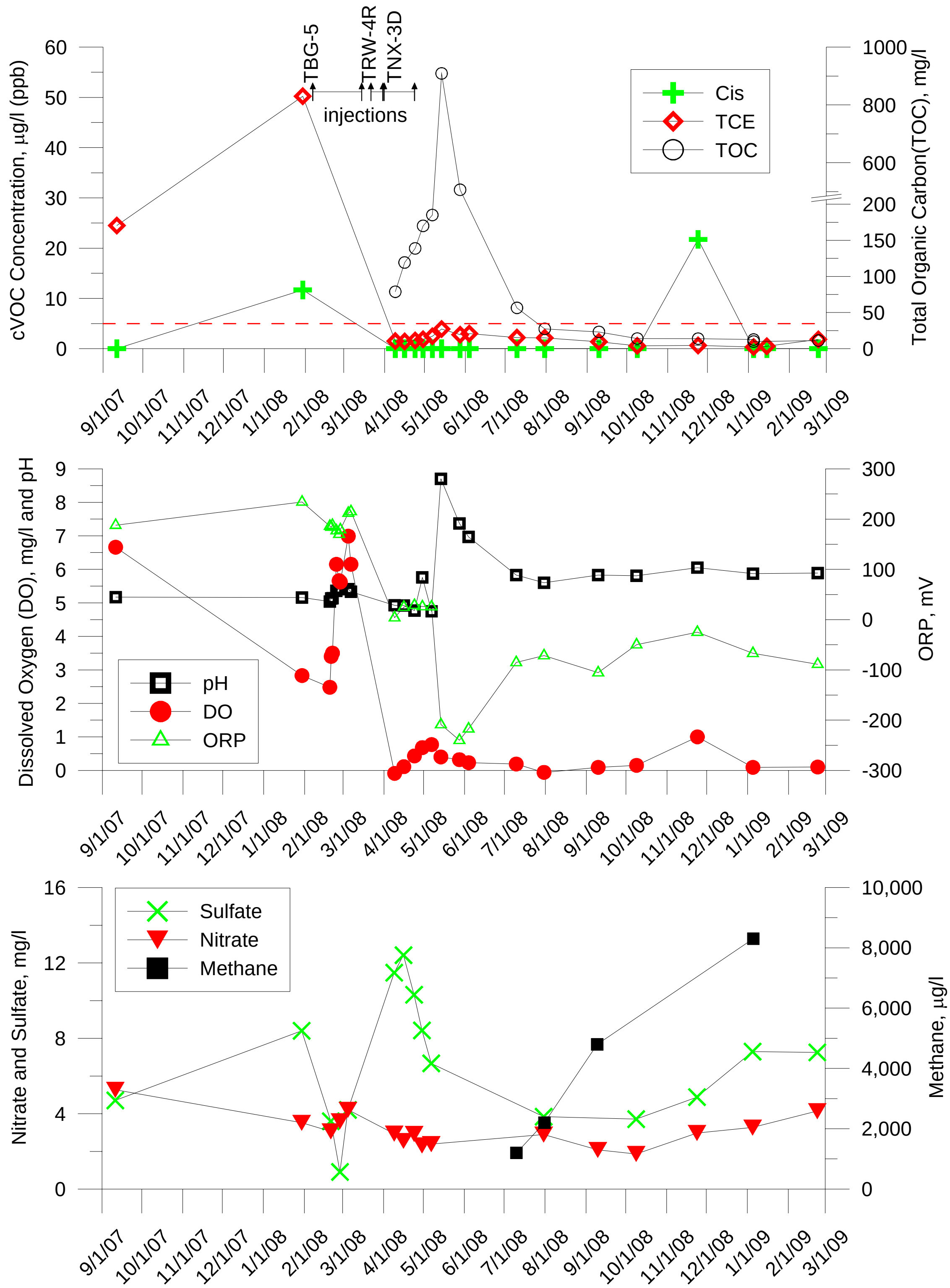

Figure 9 – Analytical Results for TRW-4R (Injection Well)

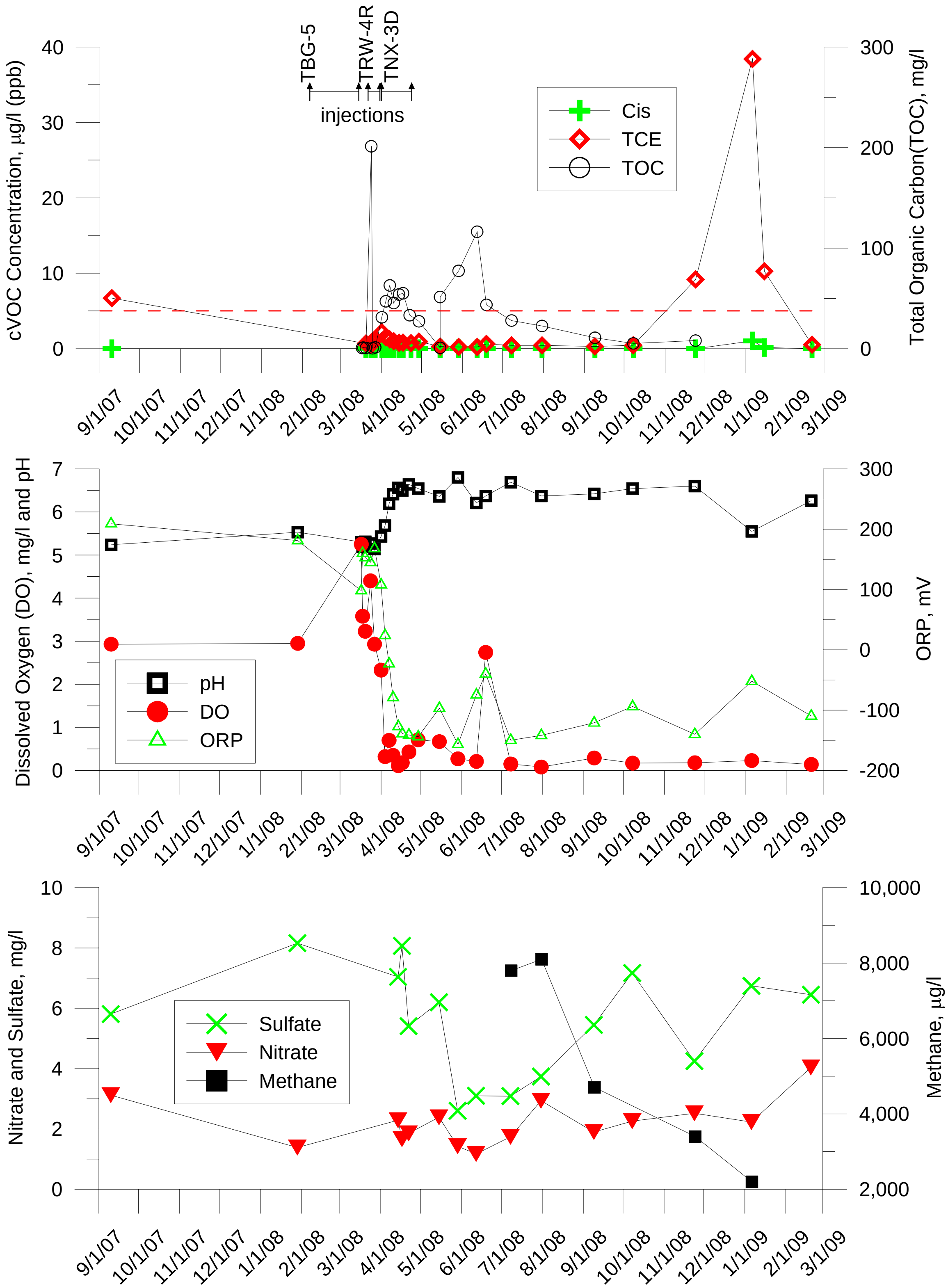

Figure 10 – Analytical Results for TVR-1A (Monitoring Well)

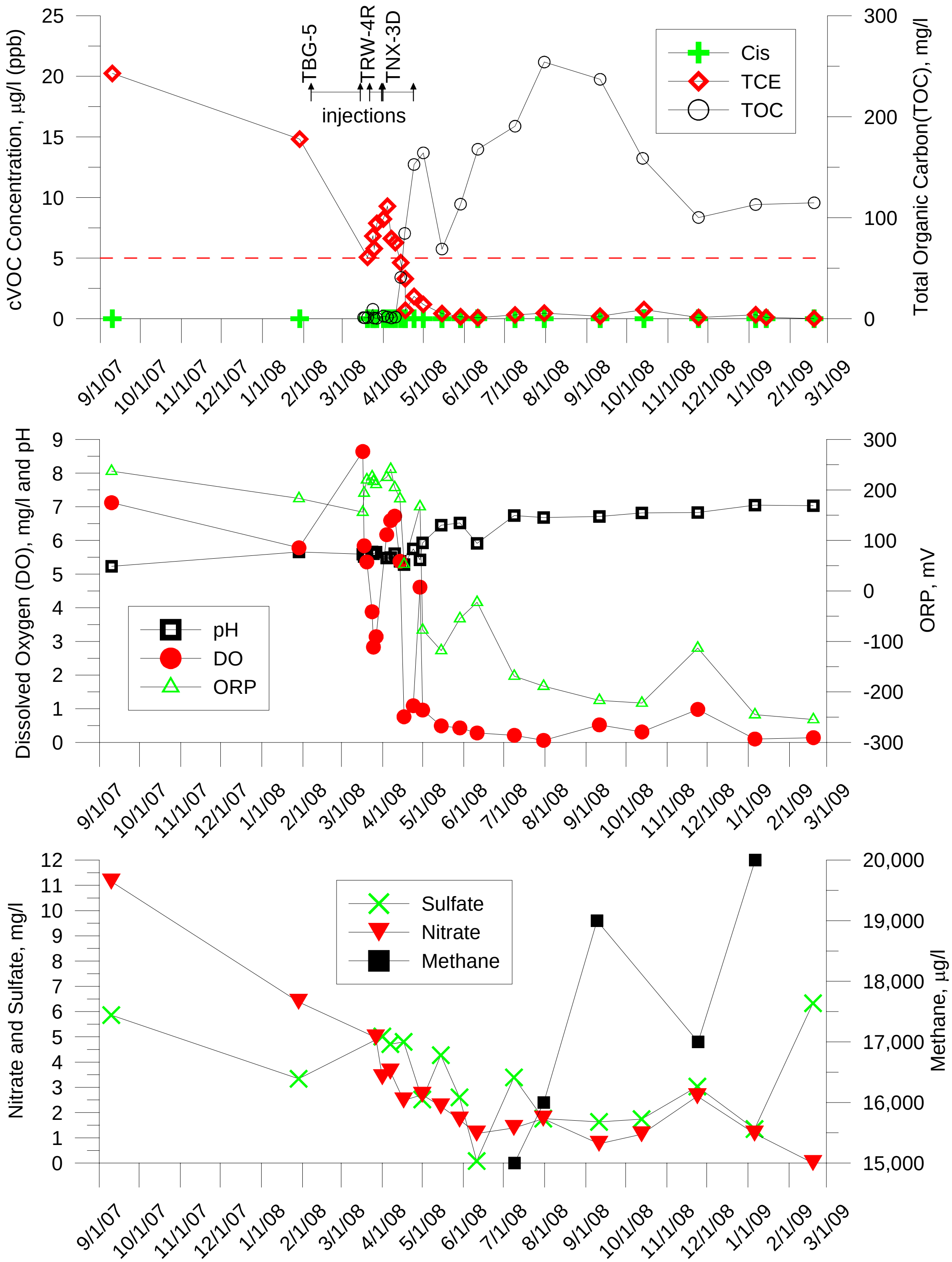

Figure 11 – Analytical Results for TVM-2M (Monitoring Well)

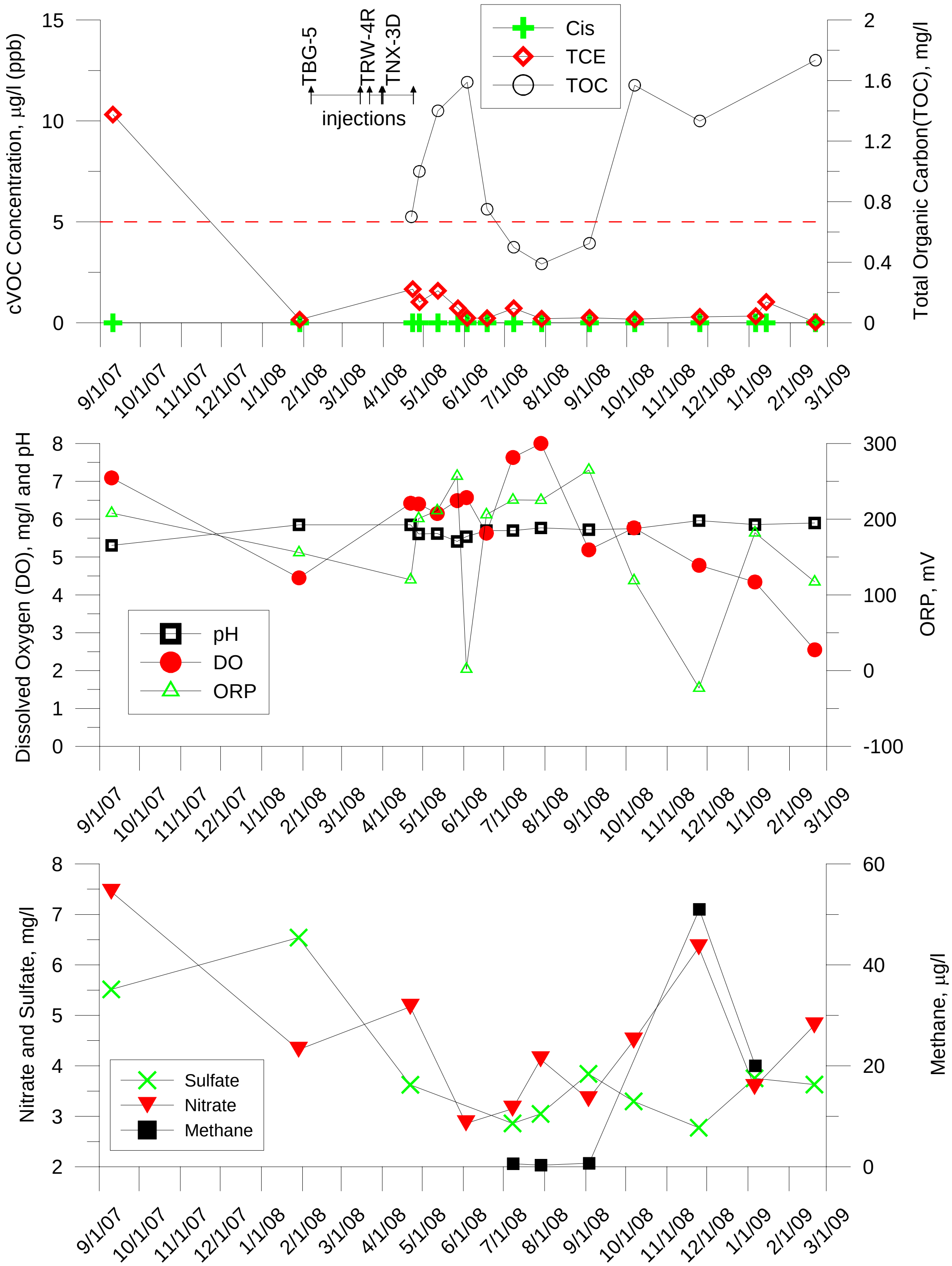

Figure 12 – Analytical Results for TVM-4M (Monitoring Well)

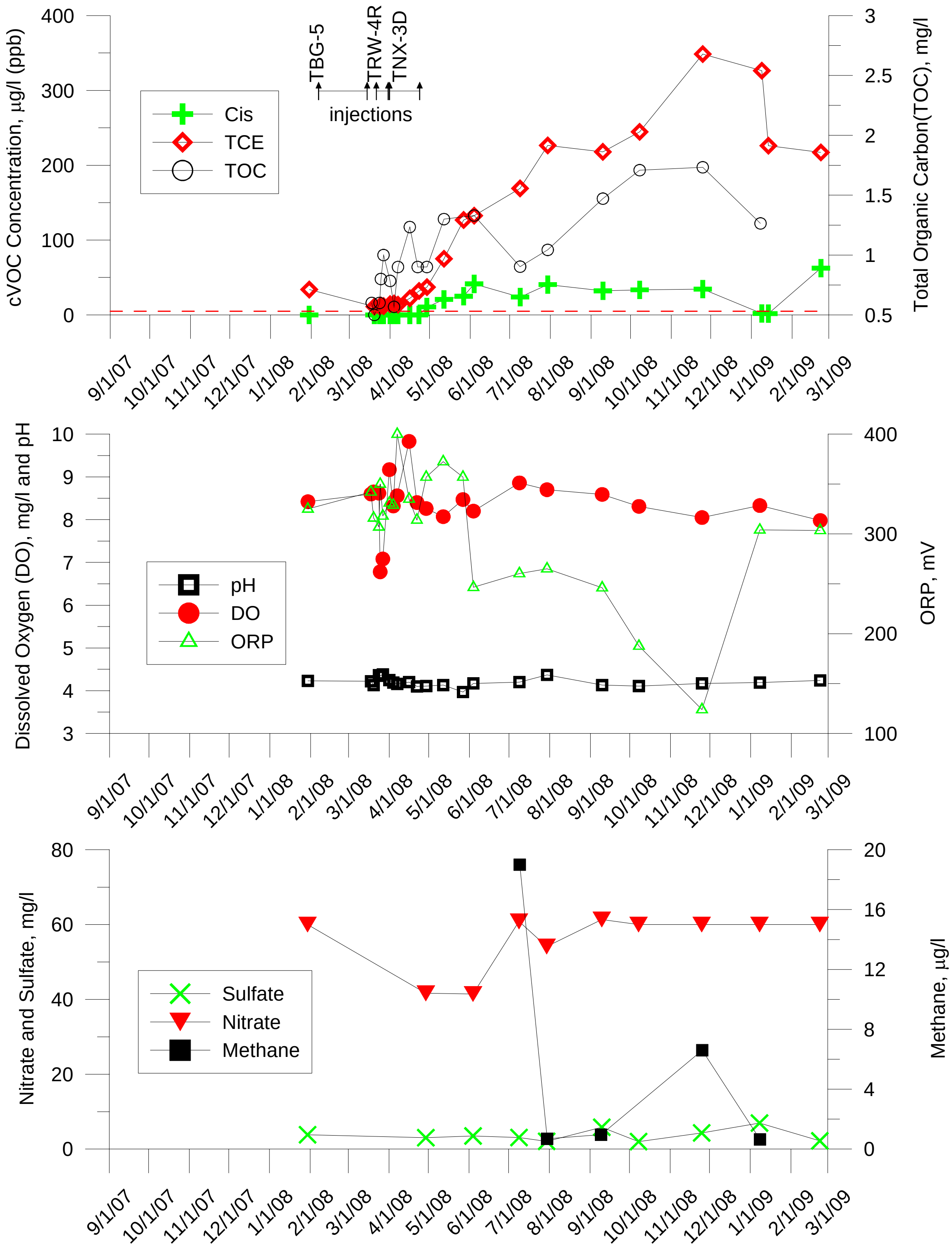

Figure 13 – Analytical Results for TBG-4 (Monitoring Well)

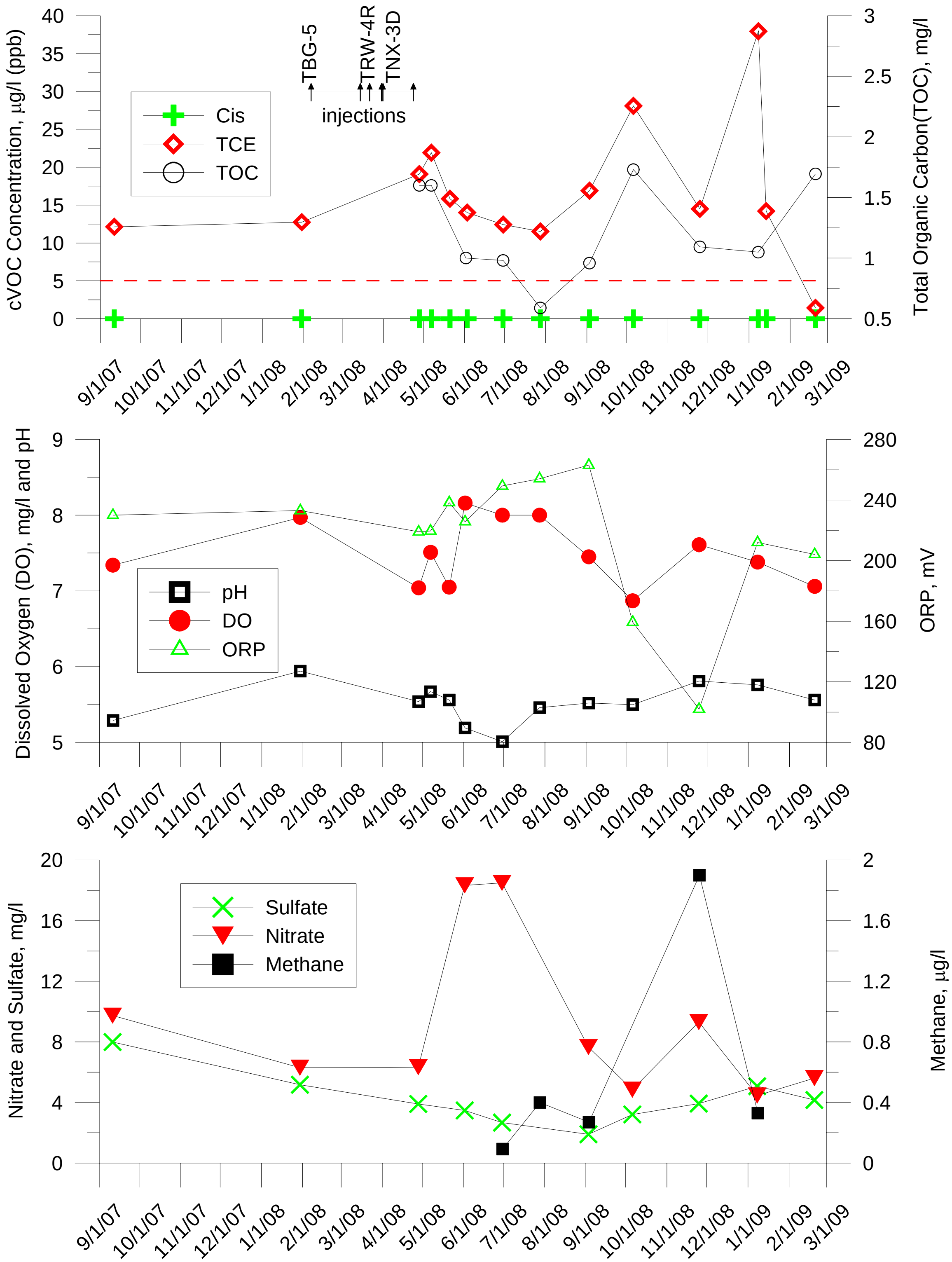

Figure 14 – Analytical Results for TBG-3 (Monitoring Well - Background)

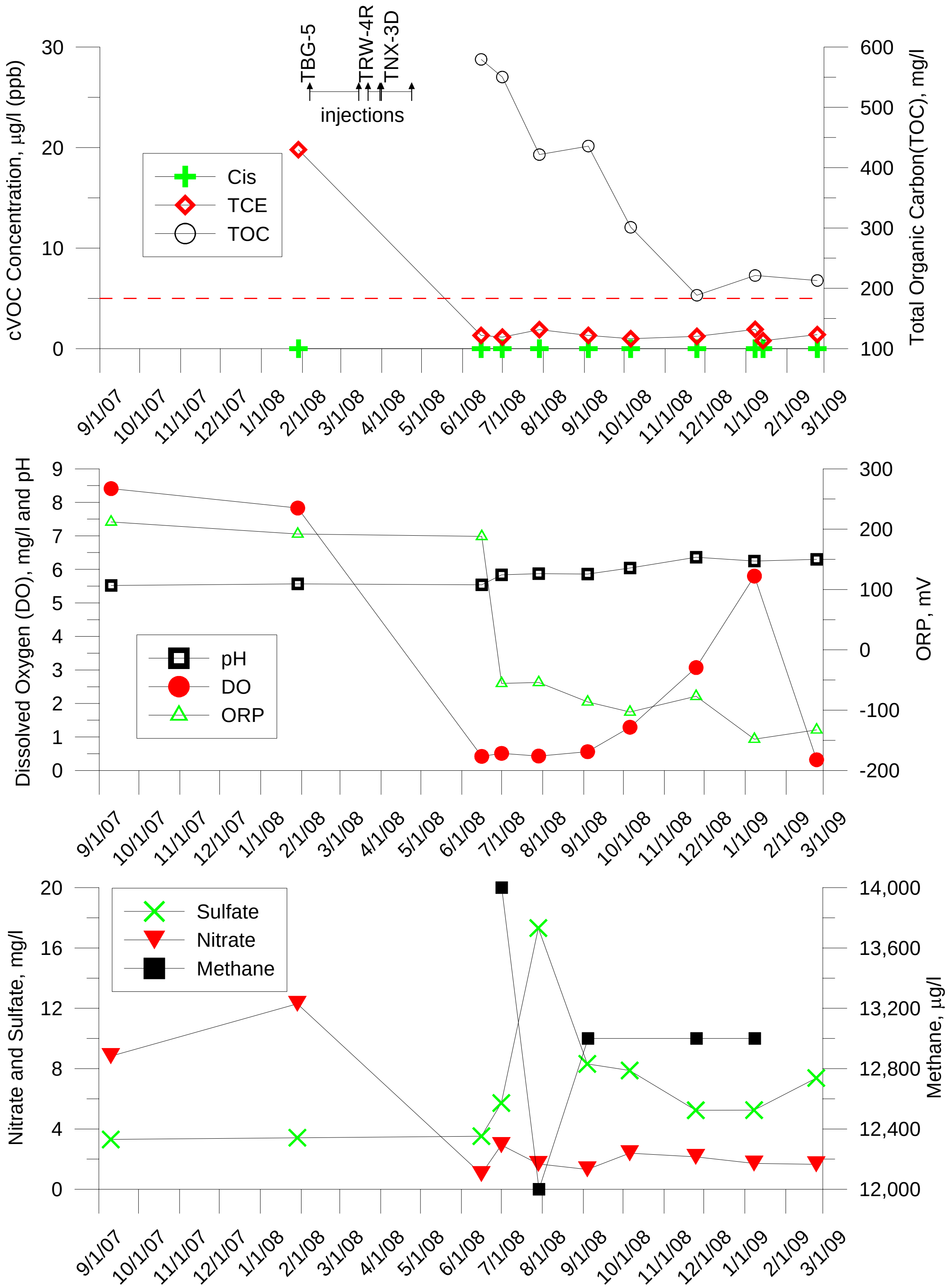

Figure 15 – Analytical Results for TNX-3D (Injection Well)

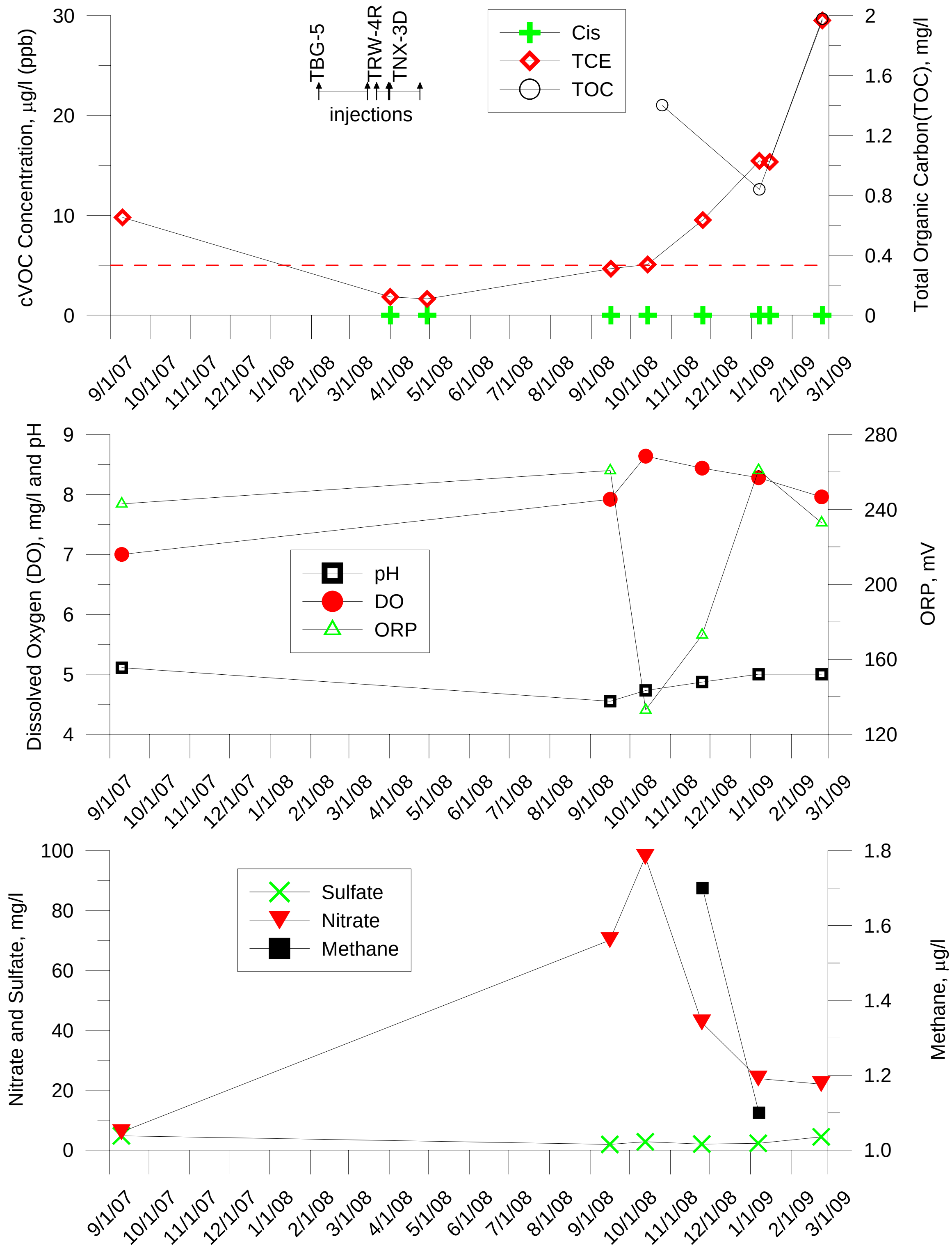

Figure 16 – Analytical Results for TRW-2 (Distal Monitoring Well)

COSTS TO DATE

Costs through March 2009 are being provided although the Treatability Study is planned for a three year duration. Material costs and man hours are provided in this interim document and are broken down by fiscal year in Table 6. Material costs include off-site laboratory analyses, $12K for purchase of the air stripper, $61K for the EOS and $18K for the neat soybean oil. Total man hours include professional and technician hours for all aspects of the project including permitting, reporting, field deployment, field sampling and analyses, and SRNL laboratory analyses.

Table 6 – Cost and Man Hours through March 2009

Year	Total Materials	Total Man Hours
FY08	$120,300	3,047
FY09	$7,400	1,158

SUMMARY

The basis of the enhanced attenuation paradigm is to implement up-front active engineering solutions that alter the target site in such a way that the contaminant plume will passively stabilize and shrink and to document that the action will be effective, timely, and sustainable. The paradigm encourages combining remedial technologies so that each is matched to the target conditions and contaminant concentrations throughout the life of the site (until achieving regulatory goals). The combination of technologies that emerged for the treatability study for the remediation of T-Area included: 1) neat (pure) vegetable oil deployment in the deep vadose zone in the former source area, 2) emulsified vegetable oil deployment within the footprint of the groundwater plume, and 3) stimulation and documentation of aerobic attenuation for the distal portion of the plume. The following list summarizes the results from the first year of the T-Area treatability study:

1. The dissolved TCE plume has decreased in size and concentration – a measure of success in the enhanced attenuation and monitored natural attenuation paradigms,
2. The amendments are spreading in the central plume area,
3. The central zone biogeochemistry is developing to support reductive dechlorination and cometabolism of TCE,
4. Cometabolites (e.g. methane) are being generated and distributed to stimulate aerobic attenuation in the distal plume zone,
5. EOS injection into well TRW-4R displaced the dissolved groundwater plume towards well TBG-4 resulting in a transient concentration impact that is currently dissipating, and
6. The limited number and locations of available monitoring wells likely bias interpretations of the data. Additional monitoring wells are needed to document the attenuation processes.

PATH FORWARD

The proposed path forward for the second year of the treatability study is to continue monitoring to focus on amendment distribution and the development of the central treatment zone and distal attenuation zone (refer to Figure 1). The authors believe the treatment zones will continue to develop and additional degradation of cVOCs will occur. However additional treatment at TBG-4 as part of this Treatability Study may be appropriate since the dissolved contaminants appear to have been moved to this location by the water injection used in the study. The dissolved contaminants are easily treated at this time, and would demonstrate the near complete degradation of the plume as part of the study. The following tasks are proposed.

1. Continue T-1 Air Stripper Outage,
2. Continue monthly sampling and analysis,
3. Install additional monitoring wells in the distal attenuation zone,
4. Perform microbial analysis using Microbial Insights Bio-Trap samplers for cometabolism of TCE. The analysis will include methanotrophs, methanogens, soluble methane monooxygenase, propane monooxygenase, toluene dioxygenase, and ring hydroxylating toluene monooxygenase,
5. Add EOS/base in TBG-4 to treat this part of the plume if concentration trends warrant. If this action is taken, use extracted water from TBG-4 for amendment addition and re-injection to avoid displacement of the dissolved plume in this area.
6. Perform microbial analysis for *Dehalococcoides* if full reducing conditions develop and TCE daughter products are present,
7. Determine or develop and perform methods to redevelop low production monitoring wells that will not impact sample quality,
8. After conditions stabilize, repeat enzyme activity probes for cometabolic organisms and perform a rate study to quantify enhancement.

REFERENCES

DOD (2007). Protocol for In Situ Bioremediation of Chlorinated Solvents Using Edible Oils. San Antonio, TX, U. S. Department of Defense, Air Force Center for Environmental Excellence.

ITRC (2007). A Decision Flowchart for the Use of Monitored Natural Attenuation and Enhanced Attenuation at Sites with Chlorinated Organic Plumes, Interstate Technology and Regulatory Council, Enhanced Attenuation Chlorinated Organics Team.

Lee, M. H. (2008). Enzyme Activity Probe Microcosm Study: T-Area. Idaho Falls, ID, North Wind, Inc.

Riha, B. D. and B. B. Looney (2007). Treatability Study Work Plan for Edible Oil Deployment for Enhanced cVOC Attenuation for T-Area, Savannah River Site. Aiken, SC, Savannah River National Laboratory.

Riha, B. D., B. B. Looney, et al. (2006). Studies to Support Deployment of Edible Oils as the Final cVOC Remediation in T-Area: Summary Report. Aiken, SC, Savannah River National Laboratory.

WSRC (2007). Underground Injection Control Permit Application for Edible Oil Deployment for Enhanced cVOC Attenuation at the SRS T-Area OU (U). Aiken, SC, Westinghouse Savannah River Company.