REPLACING PUMP-AND-TREAT WITH MONITORED NATURAL ATTENUATION USING A REBOUND STUDY AS A PERFORMANCE METRIC

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ABSTRACT

The Test Area North (TAN) Facility of the Idaho National Engineering and Environmental Laboratory (INEEL) is the site of a 3-km-long aerobic trichloroethene (TCE) and tritium plume resulting from past waste injections into the deep fractured basalt aquifer. A pump-and-treat facility has been operating in the plume's medial zone since October 2001, and has significantly reduced influent TCE concentrations. In order to assess the performance of the pump and treat system in reducing contaminant concentrations, a 24-month rebound study will be initiated in early 2005. The rebound study consists of shutting down the pump-and-treat facility and placing it in standby mode, and collecting groundwater samples to monitor contaminant trends. The ultimate goal of the rebound study is to provide data that will be used to determine whether MNA, the approved remedy for the plume's distal zone, can replace pump-and-treat as the medial zone remedy. The study will be dynamic in the sense that periodic monitoring data will be evaluated to determine when the system should resume operations. Rebound to unacceptably high concentrations before the end of the planned 24-month study will result in termination of the rebound study and restart of the pump and treat system. Pump and treat operations will resume at the end of the planned 24 month period, and will continue until a second rebound study is planned and implemented.

INTRODUCTION

Test Area North (TAN) is located in the northern portion of the Idaho National Engineering and Environmental Laboratory (INEEL). It consists of four major facilities that were used to develop a nuclear-powered aircraft and to conduct tests that simulate accidents involving the loss of coolant from nuclear reactors. The key area for this final remedial action is the Technical Support Facility (TSF) area, which is centrally located at TAN (Figure 1). The focus of this remediation activity is Operable Unit 1-07B TAN final groundwater remediation, which includes remediation of the TAN TSF-05 injection well and the surrounding groundwater contamination areas (TSF-23). Industrial activities at the TSF generated wastewater that was introduced into the groundwater via the TSF-05 injection well. Due to the size of the plume and complexity of the site conditions, the remedial action was designed in a phased approach with three distinct technologies:

- enhanced in situ bioremediation for the plume's hotspot, defined as that portion of the plume with TCE concentrations >20,000 μg/L
- pump-and-treat for the plume's medial zone, defined as that portion of the plume with TCE concentrations between 1,000 μg/L and 20,000 μg/L
- monitored natural attenuation (MNA) for the plume's distal zone, defined as that portion of the plume with TCE concentrations less that 1,000 μg/L.

The New Pump and Treat Facility (NPTF) has been operating as the selected remedy for the medial zone of the TAN TCE plume since October 2001 to remove contaminants and to prevent contaminated groundwater from migrating further downgradient. Major components of the pump and treat system include a network of groundwater extraction wells (TAN-38, TAN-39, and TAN-40), an above ground treatment system that uses two air strippers, an injection well (TAN-53A) used to inject the treated water back into the aquifer, and eight monitoring wells to evaluate performance and compliance trends during system operations (refer to Figure 1 for well locations).

Recent sampling results from the NPTF performance and compliance monitoring have shown that NPTF influent TCE concentrations have decreased to approximately 100 μg/L. The net result of concentration reduction resulting from 3 years of operations has resulted in an order of magnitude reduction below the Record of Decision-defined medial zone concentration of 1,000 μg/L. Based on this monitoring data, a rebound study will be conducted to assess the overall impact of NPTF operations on the contaminant plume, and to begin the process of determining whether MNA can become the remedy for the medial zone of the plume.

HISTORICAL DATA REVIEW

NPTF Operations

Figure 1 presents a map of the medial zone illustrating the location of extraction and monitoring wells in relation to the historically defined medial zone. Two transverse wells, TAN-33, and TAN-36, located at the downgradient edge of the medial zone, and four axial monitoring wells TAN-40, TAN-42, TAN-39, and TAN-38, are key locations that will be used to meet the primary objectives for the rebound study. The transverse wells will be used to monitor TCE concentrations near the downgradient edge of the medial zone to determine when NPTF operations should resume, and the three axial wells will be used to monitor TCE concentrations to observe the maximum degree of rebound.

The three monitoring wells located near the downgradient edge of the medial zone (TAN-33, TAN-38/44, and TAN-36) have a monitoring history that starts before NPTF operations began with additional data collected during NPTF operations through the present. These wells were located at the downgradient edge of the medial zone to provide an extraction location (TAN-38) and two peripheral monitoring locations (TAN-33 and TAN-36). TAN-44 was installed 20 ft away from TAN-38 as an observation well during the well characterization and evaluation test (INEEL 1998a) and will be used as a surrogate monitoring well for TAN-38. Because of the close location of TAN-38 and TAN-44 (within 20 ft), monitoring data from both wells have been combined for purposes of this evaluation. TCE concentration trends for these three monitoring wells show a period of higher concentrations leading up to the start of NPTF operations, a significant and rapid reduction of TCE concentrations following startup, and a gradual leveling off of TCE concentration to around 100 μg/L after 2 years of operation. Figure 2 shows data from TAN-33 as an example of these trends.

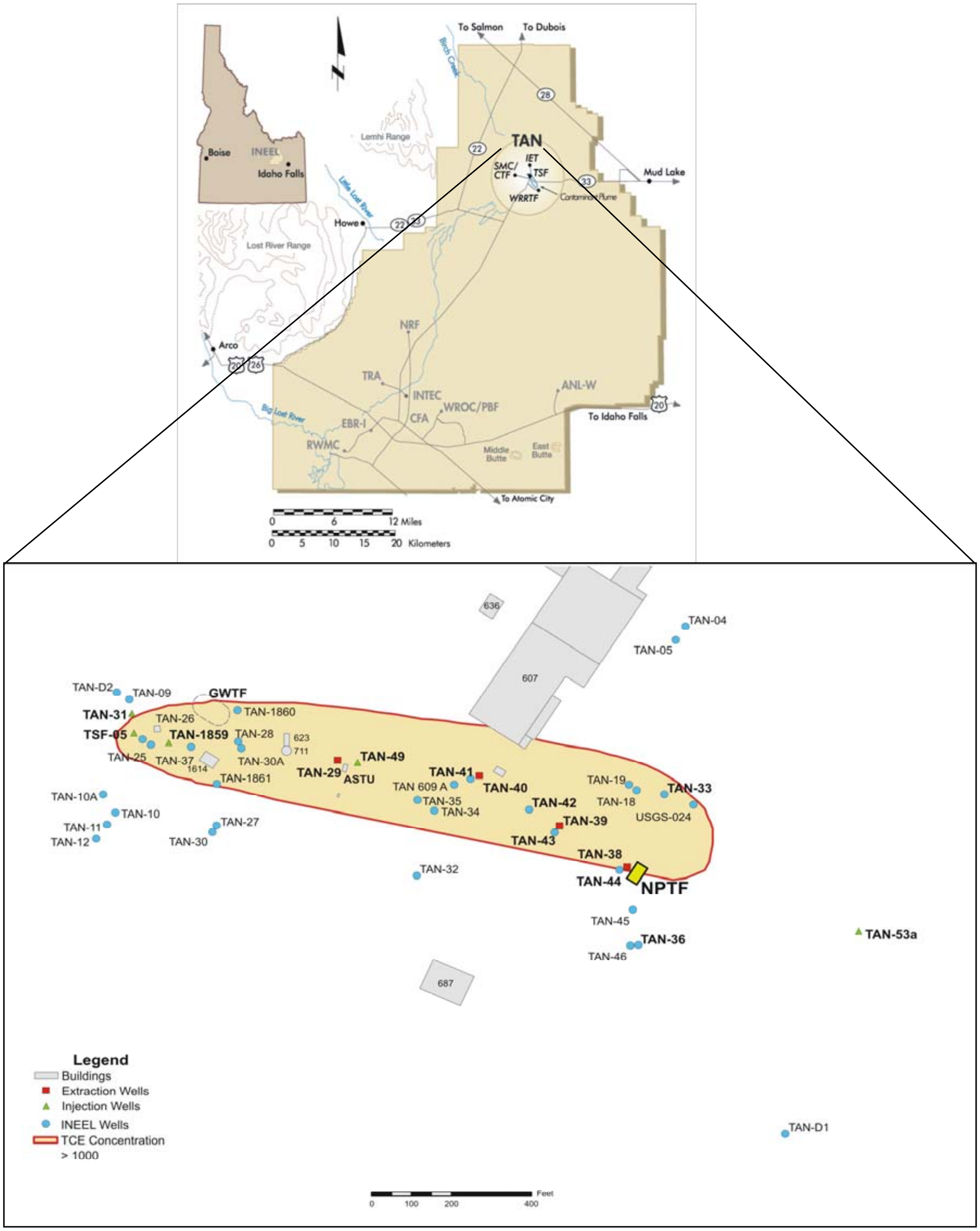

Fig. 1. Site layout of TAN observation wells, extraction wells, and injection wells.

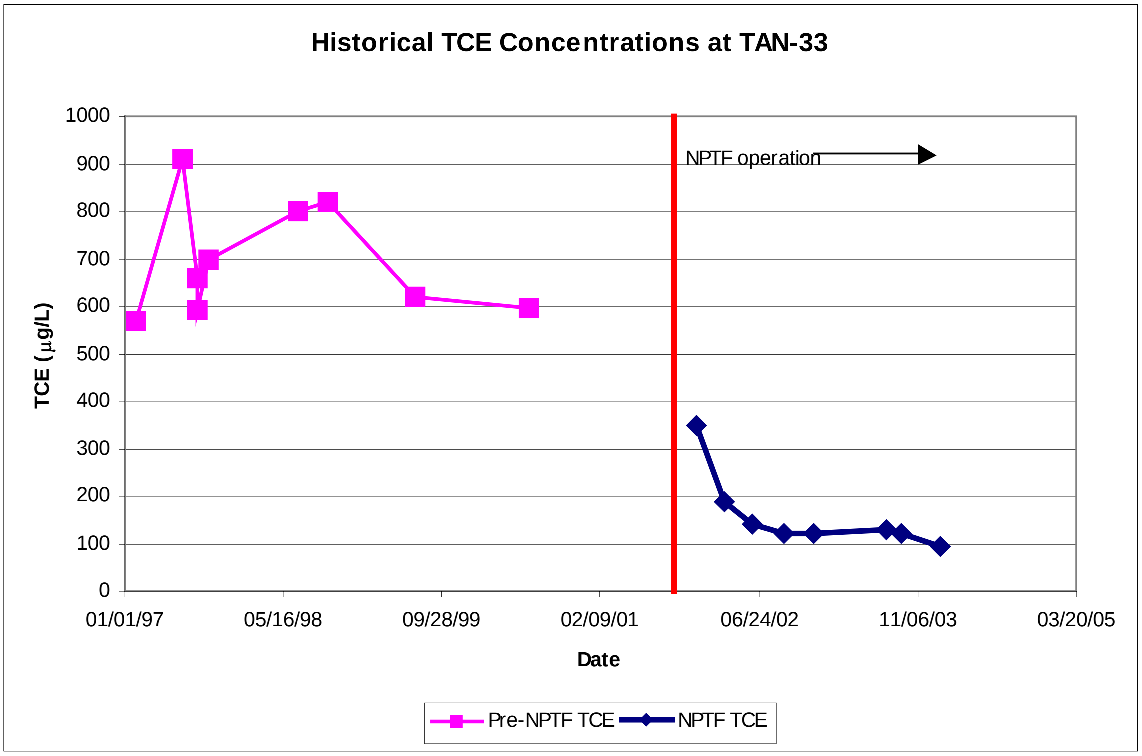

Fig. 2. TAN-33 TCE concentrations.

Air Stripper Treatment Unit Operations

The Air Stripper Treatment Unit (ASTU) is located 500 ft downgradient of the former injection well TSF-05 (Figure 1) and was operated from November 1998 to December 2000. The ASTU extracted groundwater from TAN-29 at 50 gallons per minute (gpm) and reinjected treated water into TAN-49, 50 ft away from TAN-29. The primary objective for the ASTU was to maintain hydraulic containment during the in situ bioremediation (ISB) treatability study field evaluation.

Groundwater monitoring data from TAN-29 are available prior to ASTU operations, during ASTU operations, and throughout the period following cessation of ASTU operations. These data can be used to present one observed effect of rebound following cessation of pump and treat operations. The evaluation of these data is useful in that it provides a basis for design of the NPTF rebound study. Figure 3 illustrates the effect that the ASTU had on contaminant concentration at well TAN-29. The average pre-ASTU TCE concentration at TAN-29 was approximately 1,300 µg/L. At the end of ASTU operations, the TCE concentration was an order of magnitude lower, at 130 µg/L. After shutting off the ASTU, the TCE concentration rebounded at a relatively constant rate over the course of the following 12 to 18 months, until it reached a fairly constant value of approximately 700-800 µg/L. This represents a rebound to approximately one-half to two-thirds of historical values. The maximum TCE concentration measured at TAN-29, post ASTU, was 1,000 µg/L measured on August 18, 2003, which is still below the historical average.

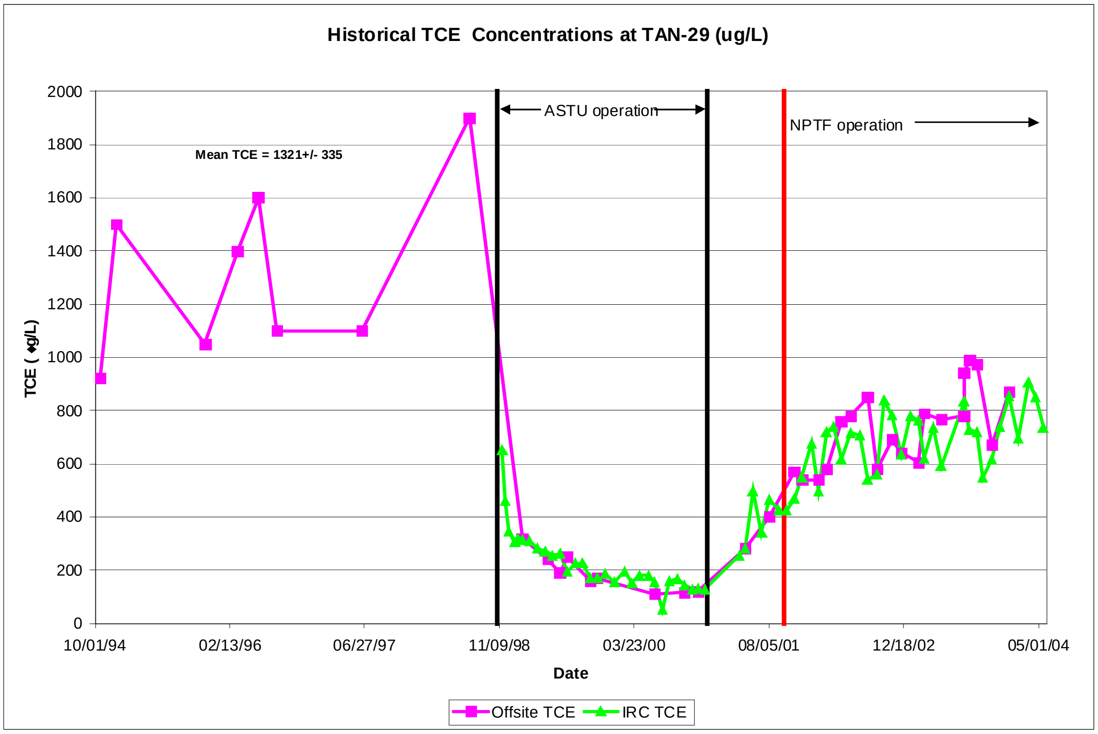

Fig. 3. TAN-29 TCE concentrations; IRC TCE represents onsite TCE analysis.

Because of the proximity of the injection and extraction wells, the ASTU created a small recirculation zone around TAN-29, which contributed to low TCE concentrations. When ASTU operation was terminated, this volume of low concentration water moved downgradient while higher concentration upgradient water moved toward TAN-29 (i.e., from the hotspot). The invasion of this higher concentration water is likely the primary cause of rebound in TAN-29.

Although the ASTU was designed and operated for a different purpose than the NPTF, the contaminant trend data can be used as an example of one response to cessation of a pump and treat system specific to the TAN site conditions. It should be noted that although the less-than-full rebound observed at TAN-29 is indicative of only one potential response trend that might occur during the medial zone rebound study, the TAN-29 data do not preclude a full rebound in the medial zone in response to NPTF shutdown.

REBOUND STUDY DESIGN

Objectives

The near-term goal of the rebound study is twofold: (1) to define a performance monitoring strategy that will guide this and future rebound studies; and (2) to provide a thorough initial data set for evaluation of future rebound studies. It is anticipated that additional rebound studies may be necessary and that each will be separated by a period of NPTF operations. The ultimate goal of these rebound studies is to provide data to determine whether MNA can replace pump and treat as the medial zone remedy. The specific technical objectives for this first medial zone rebound study include:

- Monitor TCE concentrations in TAN-40/41, TAN-42, TAN-39/43 to obtain complete rebound curves within the medial zone
- Define a performance monitoring strategy that will result in sufficient data (location, frequency, analytes) to provide a baseline for future rebound studies
- Monitor TCE concentrations in a set of wells along a perpendicular transect near the downgradient edge of the medial zone (TAN-33, -38/44, and –36) to determine when NPTF operations should resume
- Monitor a set of analytes upgradient of the NPTF capture zone to assess the contribution of TCE flux from the hotspot to rebound that occurs during the study
- Quantify the portion of the observed medial zone concentration reduction that is temporary (i.e., the effect of capturing clean water from outside the plume) versus a permanent reduction.

Duration

Two methods of determining the rebound study duration were taken into consideration when designing the study. The first was empirical and based on review of rebound observed after ASTU operations were terminated. Review of Figure 3 concentration trends for TAN 29 shows that rebound to approximately steady state or equilibrium occurred over a period of 24 months. During this period of time, rapid rebound occurred over the first 10 to 12 months and a more gradual rebound occurred over the last 12 months. Thus, to meet the objective of establishing a thorough baseline for comparison to possible future rebound studies, the duration for this first study is set at 24 months.

The second method for determination of study duration is semi-analytical based on estimated groundwater velocity and inferred contaminant transport under natural gradient conditions. Given a conservative groundwater velocity at TAN of 0.5 ft/day (INEEL 1998b, 1998c; INEEL 2000), the maximum distance that a volume of groundwater could move during the 24-month rebound period is approximately 365 ft. Modeling scenarios performed as part of the NPTF design demonstrated that pumping from TAN-38 and TAN-40 at a combined rate of 230 gpm will create a capture zone that extends at least 400 ft downgradient of the pumping wells. Thus, a conservative analysis shows that contaminants originating from the area around TAN-38 near the downgradient edge of the medial zone will be captured even if the study runs the full 24-month duration. Based on these two considerations, the study duration has been conservatively set at a maximum of 24 months. However, the design includes a dynamic decision-making process to ensure that the study will be stopped and NPTF operations resumed if TCE concentrations exceed the established rebound criteria.

Monitoring Locations and Frequencies

The primary field activity during the medial zone rebound study will be the collection of data from groundwater monitoring wells prior to the study, during the study, and following restart of the NPTF at the conclusion of the study. Sampling frequency during the rebound study will be critical from two perspectives. First, a rebound study has never been conducted in the medial zone; therefore, no basis exists to predict the shape or response time of the rebound. This is the primary reason for the need for dynamic decision-making criteria. Secondly, if the data collected indicate that the NPTF should be restarted, it will be necessary to obtain as much data as possible to determine complete breakthrough curves at TAN-40, TAN-42, and TAN-39. This is the primary reason for selection of locations and frequency that will provide adequate data density.

The recommended frequency and duration outlined below takes into consideration both perspectives. Monitoring wells have been selected upgradient of and within the NPTF capture zone to give as complete coverage as possible. Table I identifies the monitoring wells and their monitoring position relative to the NPTF capture zone; both the axial and transverse portions of the medial zone will be adequately covered by the selected monitoring wells. Figure 1 shows the geographical location of the seven monitoring wells included in the monitoring program during the rebound study. The NPTF extraction wells, TAN-40, TAN-39, and TAN-38, are paired with wells TAN-41, TAN-43, and TAN-44 that were installed as observation points during the well characterization and evaluation testing (INEEL 1998). Wells TAN-41, TAN-43, and TAN-44 will be used as surrogates for the extraction wells during the study because piping and other infrastructure precludes ready access to the extraction wells.

The initial sampling schedule for the rebound study is presented below in Table II. Baseline sampling of the groundwater monitoring locations will help to establish trends for each of the individual NPTF performance monitoring wells and to establish variability in TCE concentrations observed in these trends. To accomplish this, the medial zone monitoring locations listed in Table I will be sampled once per week for three consecutive weeks before turning off the NPTF.

Initial rebound sampling will be used to monitor aquifer contaminant concentration increases during the first 6 months of the rebound study. It is very important that the sampling frequency during this time be set such that the potential rapid rebound scenario is adequately addressed. To meet this criterion, sampling is planned to start the day after NPTF is placed in standby. Samples will be collected 1 day after shutdown, 2 weeks after shutdown, and monthly for 6 months. The transition sampling will begin 2 months after the last initial rebound sampling event (i.e., in month 8 after shutdown). Samples will be collected every 2 months to monitor the transition to steady state or equilibrium concentrations. Samples will then be collected quarterly during the equilibrium phase to establish steady state concentrations.

At the end of the rebound study, sampling frequency will be set to monitor the reduction of TCE due to the resumed operation of the NPTF. Monitoring the decline in contaminant concentration will assist in evaluating future NPTF performance. If at any time the concentrations of TCE in any of the monitoring locations suggest that the frequency and/or location of monitoring is not sufficient or exceeds sampling required to adequately characterize rebound, the sampling frequency may be changed.

Table I. Medial Zone Rebound Study Monitoring Locations.

Well	Location	Analytes
TAN-29	Upgradient	VOCs and tritium
TAN-41	NPTF Capture Zone – Axial	VOCs and tritium
TAN-42	NPTF Capture Zone - Axial	VOCs and tritium
TAN-43	NPTF Capture Zone – Axial	VOCs and tritium
TAN-44	NPTF Capture Zone – Axial	VOCs and tritium
TAN-33	NPTF Capture Zone – Transverse	VOCs and tritium
TAN-36	NPTF Capture Zone – Transverse	VOCs and tritium

Table II. Medial Zone Rebound Study Monitoring Schedule.

Study Period (months)	Monitoring Phase	Sampling Frequency
3 Samples Prior to NPTF shutdown	Baseline	Weekly
After shutdown: Day 1, Week 2, Month 1, 2, 3, 4, 5, 6	Initial Rebound	Monthly
Month 8, 10, 12	Transition	Bi-monthly
Month 15, 18, 21, 24	Equilibrium	Quarterly
After restart: 2 per week in Weeks 1 and 2; 1 per week in Weeks 3, 4, 5, 6, 7, 8; Month 3, 4, 5, 6, 9, 12, 15, 18, 21, 24	Restart	Weekly, Monthly, Quarterly
Note: Analytical results will be evaluated following each monitoring event to determine whether the rebound threshold criteria is going to be exceeded and the NPTF turned back on, or the study be allowed to continue.		

Analytical Program

Groundwater samples will be analyzed for VOCs and tritium, as shown in Table I. VOC samples will be analyzed using solid phase microextraction-gas chromatography/flame ionization detection (SPME-GC/FID). Tritium samples will be analyzed using liquid scintillation counting. Duplicate samples and field blanks will be collected once for each sampling event listed in Table I. In addition, trip blanks will be included for each shipment of VOC samples.

In addition to VOCs, purge water parameters will be collected as part of the sampling protocol. These parameters include temperature/PH/oxidation reduction potential/dissolved oxygen/conductivity. However, these data will not be quantitatively used in the evaluation of rebound decision criteria but as information to be evaluated after the study is complete.

At least two rounds of bioremediation parameters, including redox and bioactivity indicators, dissolved gases, and nutrients, will be collected optimally during the equilibrium phase of the rebound study; however, if rapid rebound occurs, the parameters will be collected prior to restart of the NPTF. These data will provide additional information in determining whether the TCE concentrations are from the source area or from the medial zone.

Data Evaluation

Data will be collected from seven wells, as described in Table I. Of these, the six NPTF capture zone monitoring wells will be used for groundwater monitoring and characterization of rebound, while well TAN-29 will be used for upgradient monitoring. Characterization of rebound for each of the six individual NPTF capture zone monitoring wells will be presented in comparison to the mean of their individual pre-NPTF concentrations. This will provide the basis for a clear understanding of the shape of the rebound curve and will provide the data for evaluating quantitative restart criteria.

There are an infinite number of possible rebound responses following placement of NPTF in standby. The set of possible responses ranges from no measurable response through rapid rebound to concentrations equal to or greater than pre NPTF contaminant concentrations. For this study, NPTF restart criteria have been defined based on a TCE threshold for each of the three wells that form a transect located at the downgradient edge of the medial zone (TAN-33, TAN-44, and TAN-36).

One strategy to compare rebound response in wells with varying TCE concentrations is based on a normalization process using the initial pre-NPTF TCE concentration C_0, which when divided into a rebound concentration C, results in a number between 0 and 1. The initial concentration C_0 can be calculated as the mean of pre-NPTF data, and the standard deviation of this data set can be used to set restart criteria for an individual well. Using the C/C_o concentration ratio allows direct comparison of rebound response between monitoring locations with different initial concentrations. Prior to starting NPTF operations, C/C_o was 1.0, and 3 years of NPTF operations has resulted in C/C_o of approximately 0.1 in all six NPTF capture zone wells. This data evaluation technique will be applied to transverse wells (TAN-33 and TAN-36) and to the axial wells (TAN-41, TAN-42, TAN-43, and TAN-44).

Decision Criteria

Based on the evaluation of simple variance about the mean of pre-NPTF data for individual wells, a set of decision criteria can be developed to provide real time evaluation of rebound and guide continuation of the study or restart of NPTF operations. One of the primary objectives of the rebound study is to accurately define complete rebound curves for TAN-40/41, TAN-42 and TAN-39/43. This, in combination with the conservative study duration defined above, leads to setting decision criteria based on the three monitoring wells located along a transect in the center of the NPTF capture zone; TAN-33, TAN-38/44, and TAN-36. This ensures that contaminants currently at the center of the NPTF capture zone will be captured upon NPTF restart, even if the study runs the full 24-month duration.

Consequently, TAN-33, TAN-44, and TAN-36 will be used to trigger restart of NPTF operations if concentration thresholds are exceeded prior to completion of the planned 24-month study.

Monitoring location TAN-44 is co-located with the extraction well TAN-38 (within 20 ft); TAN-33 is located northeast of TAN-38 on the downgradient edge of the medial zone; and TAN-36 southeast of TAN-38. Together these three wells represent a transect in the center of the NPTF capture zone and at the most downgradient extent of the historical boundary of the medial zone.

Further support for the selection of these three wells for the decision process comes from pumping scenarios presented in INEEL (2002). The modeling illustrates capture zones that were utilized in the design of the NPTF. The report describes the capture zone of a two-well pumping scenario for TAN-38 and TAN-40 as part of the design, and this scenario was found to be able to capture 150% of the plume width, 400 ft (122 m) downgradient of TAN-38. An additional contribution to creation of a larger capture zone is the reverse flow gradient caused by the mounding effect at the injection well TAN-53A (Figure 4). If TCE concentrations at TAN-33, TAN-44, or TAN-36 reveal an increasing trend that exceeds the decision criteria, restart of the NPTF under the modeled pumping conditions will capture all contaminants that may migrate downgradient during the study.

Restart concentration limits for the wells were established using pre-NPTF analytical data for each of the NPTF restart decision wells to set both the initial starting concentration (Co) and twice the standard deviation about the mean. The restart criteria concentration thresholds for the rebound study are shown in Table III. If TCE concentrations shown in column four of Table III for the individual wells are exceeded at any time during the study, the decision criteria will have been met; one additional round of weekly samples will be collected to confirm that concentrations are above the decision criteria. If both samples exceed the decision criteria, the NPTF will resume operations. If, however, the ongoing data evaluation shows that the TCE concentrations stabilize below the restart threshold for each of the three wells, then the rebound study will continue for a maximum of 24 months, as outlined above. For example, if sampling results indicate that TCE concentrations in TAN-44 exceed the level of 440 μg/L and one additional weekly measurement confirms the trend, then the NPTF would resume operation and the rebound study would stop. If the TCE concentration in TAN-44 stabilized below 440 μg/L and both TAN-33 and TAN-36 stabilize below their respective threshold values, the rebound study would continue.

CONCLUSION

The rebound study outlined in this paper represents the first step in determining whether MNA can replace pump and treat as the medial zone remedy for the TAN TCE plume. The rebound study described herein will provide an initial dataset that can be analyzed in the context of making this determination. Since the NPTF will temporarily resume operations at the conclusion of this first rebound study, it is anticipated that additional rebound studies may be conducted in the future. The current rebound study thus provides a defensible basis for the design and implementation of future rebound studies.

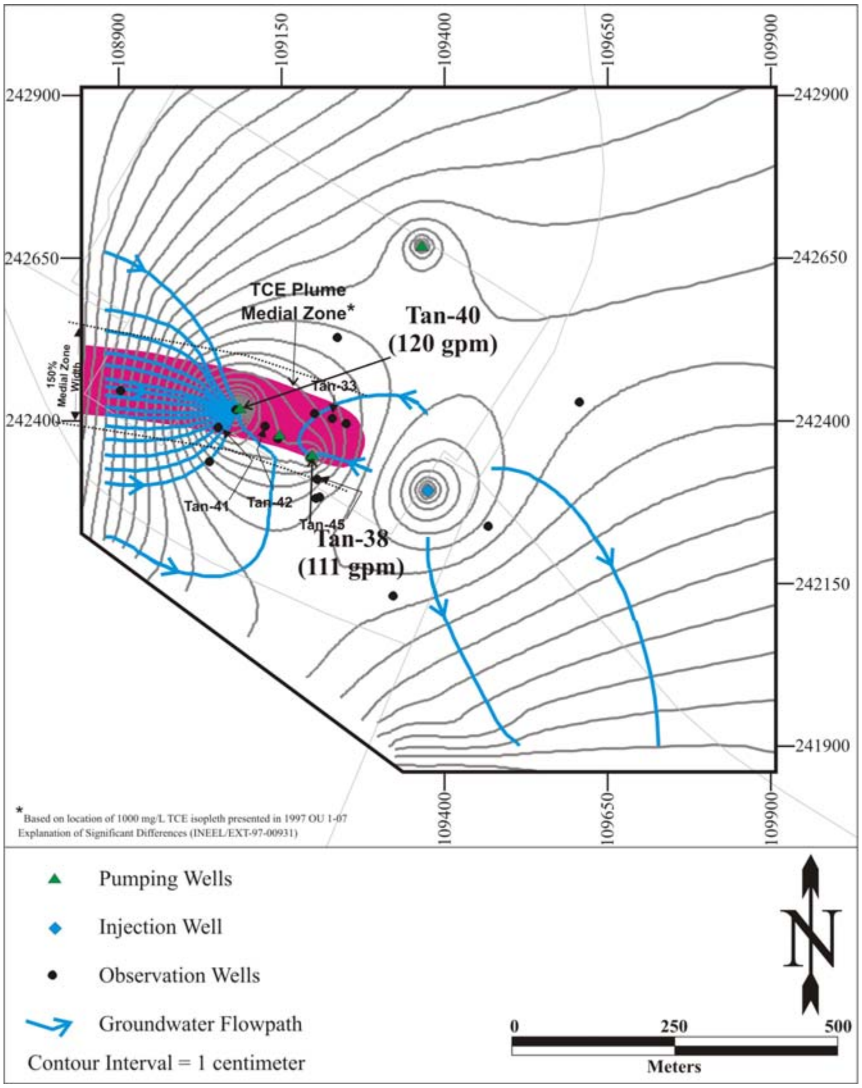

Fig. 4. Particle tracking for extraction from TAN-38 and -40 with injection at TAN-53A.

Table III. Pre-NPTF TCE Mean Concentration Data (μg/L) and Decision Criteria.

Well ID	C_o TCE - Baseline TCE Concentration (μg/L) (number samples)	2*Standard Deviation (2 Sigma)	TCE Threshold Restart Criteria (μg/L) (not to exceed)[1]
TAN-44	702 (11 / 4 years)[2]	262	440
TAN-33	696 (9 / 3 yrs)[2]	240	456
TAN-36	480 (7 / 3 yrs)[2]	152	328

1. Threshold criteria set at (C_0 – 2 sigma), where C_0 is the mean of pre-NPTF TCE concentration data.
2. Number of samples / approximate time interval that samples were collected.

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