Final Report
Arsenic Fate, Transport and Stability Study
Groundwater, Surface Water, Soil and Sediment Investigation
Fort Devens Superfund Site
Devens, Massachusetts

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Notice

This document is intended for internal Agency use only. All research projects making conclusions or recommendations based on environmental data and funded by the U.S. Environmental Protection Agency are required to participate in the Agency Quality Assurance Program. This project was conducted under an approved Quality Assurance Project Plan (421-Q10-1). The procedures specified in this plan were used without exception. Information on the plan and documentation of the quality assurance activities and results are available from Kirk Scheckel or Robert Ford.

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1 Introduction

This document presents results from the Fiscal Years 2006-2007 field investigation at the Shepley's Hill Landfill Superfund site to fulfill the research objectives outlined in the proposal, 'Fate and Transport of Arsenic in an Urban, Military Watershed' (Dr. Kirk Scheckel, EPA/ORD) and the Arsenic Fate, Transport and Stability Study QAPP and Work Plan (Draft Version 3, Revised 9 April 2007) prepared by EPA/ORD for the Fort Devens Superfund Site Remedial Project Manager, Ginny Lombardo (EPA/Region I). The purpose of this study is to provide EPA Region 1 with a technical evaluation of the distribution and flux of arsenic in shallow groundwater adjacent to Red Cove and the fate, transport and stability of arsenic in sediments and surface water following groundwater discharge.

The primary role of EPA/ORD was to investigate the migration of mobile forms of arsenic from suspected source areas within the Shepley's Hill Landfill (Fort Devens Superfund Site) into the Red Cove Study Area of Plow Shop Pond (Figure A1). Three goals were addressed as part of this investigation: 1) identification of the mobile form of arsenic in groundwater, 2) identification of the process(es) controlling arsenic uptake onto Red Cove Study Area sediments, and 3) evaluation of the stability of arsenic associated with Red Cove Study Area sediments. Synchrotron speciation techniques were utilized to determine the speciation of arsenic in sediments. This information was used as a basis for determining the flux of arsenic discharging into Red Cove from contaminated groundwater and to provide a preliminary assessment of the influence of the existing groundwater extraction system on groundwater flux into the cove. The information derived from this study was evaluated relative to potential remedial alternative(s) for contaminated groundwater and sediments within and adjacent to the Red Cove Study Area.

1.1 Site Background

Fort Devens was established in 1917 as Camp Devens, a temporary training camp for soldiers from the New England area. In 1931, the camp became a permanent installation and was renamed Fort Devens. Throughout its history, Fort Devens served as a training and induction center for military personnel, and as a unit mobilization and demobilization site. All or portions of this function occurred during World Wars I and II, the Korean and Vietnam conflicts, and operations Desert Shield and Desert Storm. During World War II, more than 614,000 inductees were processed, and Fort Devens reached a peak population of 65,000. The primary mission of Fort Devens was to command, train, and provide logistical support for non-divisional troop units and to support and execute Base Realignment and Closure (BRAC) activities. The installation also supports the Army Readiness Region and National Guard units in the New England area. Fort Devens was selected for cessation of operations and closure under the Department of Defense Base Realignment and Closure Act of 1990 (Public Law 101-510).

Shepley's Hill Landfill encompasses approximately 84 acres in the northeast corner of the former Main Post at Fort Devens (Figure A2). Shepley's Hill Landfill includes three Areas of Contamination (AOCs): AOC 4, the sanitary incinerator; AOC 5, sanitary landfill No. 1; and AOC 18, the asbestos cell. AOCs 4, 5, and 18 are all located within the capped area at Shepley's Hill Landfill. The three AOCs are collectively referred to as Shepley's Hill Landfill (USEPA, 1999). The landfill is situated between the bedrock outcrop of Shepley's Hill on the west and

Plow Shop Pond on the east. Nonacoicus Brook, which drains Plow Shop Pond, flows through a low-lying wooded area to the north of the landfill.

The southern end of the landfill borders the former Defense Reutilization and Marketing Office (DRMO) yard. There was an exposed bedrock knob in this area southwest of the landfill, just north of Market Street, and a second exposed bedrock knob further to the south, just north of the intersection of Antietam and Carey Streets. As part of Devens redevelopment efforts, the southern bedrock knob and a portion of the northern knob were removed to facilitate building construction. In 2001, a 35,000 square foot building and associated paved areas were constructed in the area of the former DRMO yard.

An area east of the landfill and south of Plow Shop Pond is the site of a former railroad roundhouse which was investigated as Study Area 71.

Landfill operations at Shepley's Hill Landfill began at least as early as 1917, and stopped as of July 1, 1992. During its last few years of use, the landfill received about 6,500 tons per year of household refuse and construction debris, and operated using the modified trench method. A portion of the waste was buried below the water table. In an effort to mitigate the potential for off-site contaminant migration, Fort Devens initiated the Fort Devens Sanitary Landfill Closure Plan in 1984 in accordance with Massachusetts regulations entitled "The Disposal of Solid Wastes by Sanitary Landfill" (310 CMR 19.00, April 21, 1971). The Massachusetts Department of Environmental Protection (MADEP) (then the Department of Environmental Quality Engineering) approved the plan in 1985.

The Army performed a Remedial Investigation (RI) (E&E, 1993) and supplemental RI (ABB-ES, 1993) at Shepley's Hill Landfill in accordance with CERCLA between 1991 and 1993. The RI and RI Addendum reports identified potential human exposure to arsenic in groundwater as the primary risk at Shepley's Hill Landfill. The RI Addendum Report also identified potential ecological risks to aquatic and semi-aquatic receptors from exposure to Plow Shop Pond surface water and sediments (USEPA, 1999).

Based on types of contaminants, environmental media of concern, and potential exposure pathways, remedial action objectives were developed in the feasibility study to aid in the development and screening of alternatives (ABB-ES, 1995). These remedial action objectives were developed to mitigate existing and future potential threats to public health and the environment (USEPA, 1999). The remedial objectives for the Shepley's Hill Landfill Operable Unit are:

- Protect potential residential receptors from exposure to contaminated groundwater migrating from the landfill having chemicals in excess of Maximum Contaminant Levels (MCLs).
- Prevent contaminated groundwater from contributing to the contamination of Plow Shop Pond sediments in excess of human-health and ecological risk-based concentrations.

1.2 Scope and Objectives

The field sampling activities and laboratory analyses outlined in the work plan (USEPA ORD, Draft Version 3, Revised 9 April 2007) provide a current assessment of arsenic distribution in groundwater, sediments and surface water within the Red Cove Study Area of Plow Shop Pond adjacent to Shepley's Hill Landfill. Activities were directed towards the collection of sediment and limited soil (aquifer solids) materials for laboratory studies and aqueous samples to assess the chemical speciation of arsenic and chemical conditions in groundwater and surface water. Collection of sediment materials for laboratory characterization facilitated assessment of the chemical speciation and stability of solid phase arsenic. These data provided a means for 1) assessing the long-term assimilative capacity within the unconsolidated aquifer material and the down gradient environment, and 2) the potential for future mobilization of arsenic that is partitioned to sediment solids. In order to provide context for observations of groundwater hydrology and chemistry within the Red Cove Study Area, existing interpretations of site hydrology and reported groundwater chemistry for the aquifer underlying Shepley's Hill Landfill were reviewed (Section 3).

The research effort was divided between field-based sampling and laboratory-based characterization. Installation of the monitoring network and sampling was conducted during the period September 2005 to November 2007. Reporting and analysis of data resulting from this effort are presented in the following order: 1) Section 2 – hydrologic studies, 2) Section 3 – groundwater chemistry, and 3) Section 4 – sediment and surface water chemistry. Where possible, comparisons are made between data collected from the EPA/ORD monitoring network to historical and concurrent data from the existing site groundwater monitoring network (CH2MHill, 2006) and sediment sampling conducted within Plow Shop Pond (Gannett Fleming, 2006). The result of this analysis is summarized for the Red Cove Study Area in Section 5, which also includes recommendations for alternative remediation strategies for contaminated groundwater and sediments.

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USEPA Office of Research and Development (ORD). Arsenic Fate, Transport and Stability Study QAPP and Work Plan, Groundwater, Surface Water, Soil and Sediment Investigation, Fort Devens Superfund Site, Fort Devens, Massachusetts, Draft Version 3, Revised 9 April 2007 (QAPP ID 421-Q10-1).

2 Hydrologic Studies

The objectives of the hydrologic studies performed at the Fort Devens sediments research site included:

- Determination of groundwater flow rates and directions within the unconsolidated overburden in the Red Cove area of Plow Shop Pond,
- Estimation of groundwater and associated arsenic flux rates in the overburden,
- Evaluation of the spatial and temporal nature of groundwater/surface water interactions within the study area, and
- Preliminary evaluation of the effects of the SHL extraction system on groundwater elevations adjacent to Red Cove and groundwater discharge to the cove.

Investigations included installation of wells and piezometers in the vicinity of Red Cove, the measurement of groundwater and surface water elevations, estimation of the hydraulic conductivities of unconsolidated materials surrounding Red Cove, and the measurement of sediment temperatures within the cove. Data and results from these studies are discussed below.

2.1 Monitoring Network

Forty monitoring wells (Figure 1) were installed in the overburden in the vicinity of Red Cove to estimate groundwater flow rates and directions. Twelve piezometers were installed in Plow Shop Pond to allow comparison of hydraulic head within the sediments with that of the pond. A network of temperature sensors was also installed in the shallow sediments beneath Red Cove to characterize temporal and spatial variability in sediment temperatures as an indicator of the possible distribution of groundwater discharge to the pond. In addition, a sensitive bidirectional advective flux meter (Lien, 2006) was used to measure the magnitude and direction of water movement across the sediment/water interface at four locations in Red Cove.

2.1.1 Groundwater Monitoring Wells

Initially, twenty-one wells were installed in four clusters surrounding Red Cove in September 2005 using a Geoprobe 6600 rig. The clusters were designed to provide complete vertical coverage from the depth of drilling refusal to the water table. The depth of drilling refusal is assumed in this case to be at or very close to the base of the unconsolidated material. In order to validate this assumption, the elevations of the top of bedrock described in geologic logs from existing wells N2, SHL4, and N3 were compared with the elevation of drilling refusal at the locations of the RSK1-7, RSK13-15, and RSK36-43 well clusters, respectively. The difference between the elevation of drilling refusal and the top of bedrock from existing logs was 5.5 ft, 0.3 ft, and 1.7 ft at RSK1-7, RSK13-15, and RSK36-43, respectively. Given that the bedrock topography appears to vary significantly in this area and the well clusters are as much as 50 ft away from the locations where bedrock elevations are known (RSK1-7 cluster to well N2), these relatively small differences between drilling refusal and known bedrock elevations indicate the well clusters likely penetrate the entire thickness of unconsolidated materials at each location.

Following an initial period of characterization, additional wells were installed in April 2007 to better determine the hydraulic conductivity structure and arsenic concentrations along the southern shore of Red Cove as well as hydraulic gradients surrounding the cove.

The majority of the wells are constructed using 1-in Schedule 40 PVC casing and screens 5 ft in length. The slot size for well screens installed in September 2005 was 0.020 in. The slot size for screens used in installation of subsequent wells was 0.010 in. All wells were installed through the Geoprobe rods allowing the formation to collapse around the well as the rods were removed. A bentonite seal was placed from the water table to ground surface and the wells were finished with locking well caps. The wells were surveyed into the existing site-wide network using a Topcon Model CTS-2 Total Station and location data for nearby wells surveyed by CH2M Hill. The surveys were performed using procedure RSKSOP 292.

2.1.2 Surface Water Elevation Monitoring Point

In August 2006, a monitoring point for surface water elevation (Figure 1), equivalent in function to a traditional staff gauge, was established near well cluster RSK16-21 in the northwestern section of Red Cove. The monitoring station was constructed using 2-in Schedule 40 PVC screen anchored in the shallow pond sediments using a steel rod. A reference point at the top of the screen was surveyed into the existing well network using the Topcon Model CTS-2 Total Station and procedure RSKSOP 292.

2.1.3 Cove Piezometers

In April 2007, twelve piezometers (Figure 1) were installed into the sediments beneath Plow Shop Pond. The piezometers are constructed of steel pipe connected to stainless steel screened drive points 0.5 ft in length. The screened points were driven to an average depth of 5 ft below the sediment/water interface using a sliding hammer. Depth of piezometer placement was generally the depth of refusal at each location. It is estimated that the location of the sediment surface may be in error by a maximum of 0.5 ft due to the interference in aquatic plant matter towards positive identification of the sediment surface. A stilling well constructed of 1-in Schedule 40 PVC pipe was attached to each piezometer (Figure 2) such that the top of the piezometer and top of the stilling well are at the same elevation. This construction allows the difference in hydraulic head between the surface water and the groundwater beneath the pond to be measured relative to the same reference point using a standard water level indicator. In this way, the accuracy of each measurement is the same as that of a water level measurement in a conventional well (*i.e.*, 0.01 ft). Therefore, the accuracy of the calculated difference in hydraulic heads is expected to be within 0.02 ft. While the elevation of the piezometer screen may be in error by about 0.5 ft, this does not impact the accuracy of the difference in hydraulic head. Location data for both the monitoring wells and piezometers are provided in Appendix B.

2.1.4 Sediment Temperature Sensors

In October 2006, an array of approximately one hundred small diameter temperature data loggers was deployed in three transects across Red Cove (Figure 3). In addition to the loggers in the transects, several individual loggers were deployed at locations within and adjacent to Red Cove. The temperature loggers, manufactured by Dallas Semiconductor, have a reported precision and accuracy of approximately +/- 0.9 deg F (Johnson *et al.*, 2005). The temperature loggers were placed in waterproof housings and buried at a depth of approximately 1.0 ft below the top of the sediments. The array was used to record sediment temperatures every four hours between October 2006 and September 2007.

2.2 Site Hydrology

Based on the site setting, influences on groundwater flow rates and directions within the overburden in the study area may include precipitation, surface water elevation in Plow Shop Pond, and groundwater extraction from the Shepley's Hill Landfill (SHL) pump-and-treat system. For this investigation, groundwater elevations in wells immediately adjacent to Red Cove and surface water elevations at the staff gauge located in the western portion of Red Cove were monitored at a minimum of every four hours using pressure transducers/data loggers. Since data from an on-site meteorological station were not available, precipitation data for the period of interest were obtained for the station located at the Fitchburg Municipal Airport in Fitchburg, Massachusetts. The Army provided data and information regarding the water flow rates and daily discharge volumes for the SHL extraction system.

2.2.1 Rainfall Data

Daily total rainfall data were obtained for September 2005 through November 2007 (Figure 4) for the meteorological station at the Fitchburg Municipal Airport from the National Climatic Data Center of the National Oceanic and Atmospheric Administration. It is noted that the station is located approximately twelve miles from the study site. Although the magnitude of precipitation at the Fitchburg station may differ from that in the study area, the precipitation patterns should be sufficiently similar to allow identification of the time periods most affected by rainfall and, therefore, the possible influence of precipitation on groundwater and surface-water elevations at the site. For this purpose, an on-site meteorological station was not deemed to be necessary. A more quantitative analysis of the effects of rainfall on hydraulic gradients would require site-specific measurements of rainfall.

2.2.2 SHL Extraction System Operation

The SHL groundwater remediation system began operation in March 2006. Measurements of the raw water flow to the treatment system and, beginning in August 2006, daily measurements of the total volume of treated water discharged from the system were provided by the Army. For purposes of this analysis, the reported volume of water discharged on a daily basis (Figure 5) was used as a measure of the relative changes in total system extraction rates through time. It is noted that the discharge water volume reportedly includes the volume of chlorine dioxide used during treatment in addition to the volume of water extracted from the wells (Simeone, 2007). The rate of chlorine dioxide addition was reported in May 2007 to typically be 1.3 gal/min. Since these data are only used to identify time periods of particular interest for evaluating the possible influence of the pumping system on groundwater/surface water interactions at Red Cove, the inclusion of a relatively small contribution to flow beyond that of extracted groundwater was considered to have no significant effect on the results. Notable features of the system performance include the reduction in down time beginning in March 2007 and the increase in combined extraction rate to greater than 40 gpm beginning in July 2007.

2.2.3 Groundwater/Surface Water Elevation Data

Groundwater elevations were recorded at a minimum frequency of six times per day in four wells surrounding Red Cove (RSK7, RSK12, RSK15, and RSK19) using pressure transducers/data loggers starting in September 2005 (Figure 1). The staff gauge was added to this network in August 2006 and RSK37 was added in September 2007. The data (Figure 6) indicate significant temporal fluctuations in both groundwater and surface water elevations occur, primarily associated with rainfall events. Groundwater elevations in wells immediately adjacent to the cove respond rapidly to precipitation events and changes in surface water levels which are often, but not always (*e.g.*, October 2007), correlated with precipitation. In general, rainfall events with a magnitude of 0.5 in or more reported at the Fitchburg Municipal Airport resulted in a noticeable increase in both surface water and groundwater elevations. However, the magnitude of the increase is likely related to several factors, including the near-term cumulative rainfall.

The average groundwater elevations (Table 1), as measured in wells screened at the water table in each well cluster, indicate that the net direction of groundwater flow was toward Red Cove in this area between August 2, 2006, and November 7, 2007. Well RSK37, located on the southern shore of Red Cove, was not included in this comparison. The data set for this well (September 13 to November 7, 2007) was too small to support meaningful comparisons.

A comparison of the temporal fluctuations in hydraulic head differences between groundwater elevations measured in water-table wells surrounding Red Cove and surface water elevations (Figure 7) indicates that hydraulic gradients also respond to rainfall and changes in pond stage. Hydraulic gradients toward the pond decrease rapidly in association with rapid increases in pond stage. On several occasions during the fall of 2006, April 2007, and the fall of 2007, surface water elevations were temporarily higher than groundwater elevations at well RSK7. During the fall of 2007, surface water elevations were also higher than groundwater elevations measured at each of the well clusters surrounding the cove for very brief periods of time (Figure 8) corresponding to rapid increases in pond elevation during an extended period of abnormally high pond stage. This indicates that the normal direction of groundwater flow reversed and surface water from Red Cove briefly recharged the aquifer during these periods. These gradient reversals appear to be associated with brief lags in the response of the aquifer to rapid changes in pond stage and are not considered to be significant in the overall interpretation of groundwater flow surrounding the cove.

Examination of the data does not indicate that there is likely to be a simple, direct correlation between pond stage and hydraulic gradient during periods of normal pond stage. However, during the period of abnormally elevated stage between approximately mid-September and the end of October 2007, hydraulic head differences in the immediate vicinity of Red Cove were significantly lower than normal (Figure 7). Pond stage during this period was above an elevation of 218 ft AMSL for approximately 35 days and both pond stage and hydraulic head differences were relatively stable between October 4 and October 19 (15 days) (Figure 9). During this relatively stable period between October 4 and 19, the average groundwater elevations in the wells adjacent to Red Cove (Table 2) were significantly closer to the average elevation of the pond than the average elevations for the period between August 2, 2006, and November 7, 2007 (Table1). This indicates that net groundwater discharge to the pond should also be reduced during this period of elevated pond stage. Further, it indicates that management of pond stage at higher elevations may benefit remedial actions designed to eliminate discharge of contaminated groundwater to Red Cove, assuming that such management was even feasible. A more controlled study of the effects of pond elevation on hydraulic gradient would be required to better quantify the potential benefits of such a strategy.

2.2.4 Effects of SHL Extraction System on Groundwater Elevations at Red Cove

Groundwater elevations in four shallow wells immediately adjacent to Red Cove (RSK7, RSK12, RSK15, and RSK19) do not display obvious correlations with changes in extraction rates of the SHL pump-and-treat system (Figure 10). Possible correlations between groundwater elevations and pumping rates were also examined during the period July 14-29, 2007, when the pumping system was taken off line for four days and restarted at an increased rate (Figure 11). Daily extraction rates, rainfall at the Fitchburg Municipal Airport, and groundwater elevations were plotted against time. These data do not indicate obvious correlations between groundwater extraction and groundwater elevations immediately adjacent to the cove. It is likely that any changes in groundwater elevations due to the ongoing extraction are subtle in this area and are masked by the dominant influences of fluctuations in surface water elevations and precipitation, which are evident in Figure 11. More intensive monitoring of additional wells between Red Cove and the extraction wells would be required to discern the influence of the extraction system in the study area.

It should be noted that an assessment of drawdown to simply demonstrate influence of a pumping system is generally not an effective measure of extraction system performance with respect to groundwater containment objectives. The performance metric of most interest in this regard is the extent and temporal variability of the capture zone as indicated by such lines of evidence as interpretation of potentiometric surfaces, evaluation of downgradient chemical data trends, and, in this case, direct measurements of groundwater discharge to surface water. Additional recommendations concerning evaluations of system performance with respect to groundwater capture can be found in USEPA (2008). In this respect, regardless of whether any observable influence exists in this area, the data clearly demonstrate that groundwater with elevated arsenic concentrations continues to discharge to Red Cove, even at pumping rates greater than 40 gpm.

2.2.5 Potentiometric Surface

At the site-wide scale, shallow groundwater appears to flow in a generally south to north direction as indicated by the site-wide groundwater elevation data provided in the 2006 annual monitoring report (Figure 12) and previous reports. In addition to the influence of the SHL extraction system on groundwater flow in the northern portion of the site, Figure 12 also indicates the potential for groundwater discharge into Red Cove and other areas in the southern portion of Plow Shop Pond. In order to better define hydraulic gradients adjacent to Red Cove, groundwater elevations were measured both in the RSK well network and in surrounding wells on April 26, September 10, and November 7, 2007. In support of this effort, groundwater elevations, surface water elevations, and rainfall were plotted for periods when potentiometric data were obtained to better understand the hydrologic context (Figures 13 and 14).

A potentiometric surface representing the water table was produced from each of these data sets (Figures 15-17). These potentiometric surfaces indicate groundwater flow toward Red Cove, implying discharge of groundwater to the pond in this area. However, differences in the hydraulic gradients indicate the magnitude of the discharge likely varied as well as the portion of Plow Shop Pond that received discharge. Groundwater elevation data used to create the potentiometric surfaces are provided in Appendix C.

The groundwater elevation data from April 26, 2007, were obtained following a significant rainfall event during which the pond level spiked (Figure 13). Groundwater extraction by the SHL pump-and-treat system during the period immediately preceding the measurements appears to have been relatively constant at a combined rate of approximately 25 gpm. Hydraulic gradients near Red Cove (Figure 15) ranged from approximately 0.005 in the vicinity of well RSK7 to approximately 0.013 near RSK15 with the potential direction of groundwater flow toward the cove. The potential direction of groundwater flow was toward Plow Shop Pond from the area of Red Cove as far north as well N1,P3. The groundwater divide separating groundwater with flow directions toward the pond from water moving toward the SHL extraction system was located in the vicinity of wells SHP-05-43, SHP-05-44, and the N1 cluster during the time of these measurements.

The groundwater elevation data from September 10, 2007, were obtained following a period of relatively minimal rainfall (Figure 14). Groundwater extraction by the SHL pump-and-treat system during the period immediately preceding the measurements appears to have been relatively constant at a combined rate of approximately 45 gpm. Hydraulic gradients near Red Cove (Figure 16) ranged from approximately 0.002 in the vicinity of well RSK7 to approximately 0.006 near RSK15 with the potential direction of groundwater flow toward the cove. The groundwater divide separating groundwater with flow directions toward the pond from water moving toward the SHL extraction system was located further south than during the April measurements and was in the vicinity of the N2 well cluster.

The groundwater elevation data from November 7, 2007, were obtained following a period of sporadic rainfall, including a precipitation event on the day preceding the water level measurements (Figure 14). However, the major hydrologic influence on this data set appears to be related to the sustained period of elevated pond stage and the rapid changes in surface water levels during this period. Inspection of this figure indicates that there were even several very brief periods during which surface water elevations at STAFF1 were higher than groundwater elevations in one or more of the monitoring wells, indicating the water in Red Cove temporarily recharged the aquifer. The groundwater elevation measurements used to produce the potentiometric surface were immediately preceded by a rapid decline in pond stage. Therefore, this data set may be significantly affected by hydrologic factors not representative of normal conditions. Groundwater extraction by the SHL pump-and-treat system during the period immediately preceding the measurements appears to have been relatively constant at a combined rate of approximately 40 to 45 gpm. Hydraulic gradients near Red Cove (Figure 17) ranged from approximately 0.002 in the vicinity of well RSK7 to approximately 0.004 near RSK15 with the potential direction of groundwater flow toward the cove. The groundwater divide separating groundwater with flow directions toward the pond from water moving toward the SHL extraction system was located further south than during the measurements made in either April or September and was in the vicinity of wells RSK7 and N2,P2.

Hydraulic gradients measured during September and November in the vicinity of Red Cove were significantly lower in magnitude than in April, implying that flux of groundwater discharging to the cove was also significantly less than in April. The difference in hydraulic gradients may have largely been due to the increased precipitation prior to the measurements in April. More intensive monitoring of a greater portion of the well network between Red Cove and the SHL extraction system would be required to determine whether the extraction system may also have a significant impact on hydraulic gradients in this area of the site.

2.2.6 Vertical Hydraulic Gradients

Vertical hydraulic gradients (i_v) estimated through comparisons of hydraulic head in co-located shallow and deep monitoring points provide information regarding the potential direction for vertical movement of groundwater. In the area of Red Cove, periodic measurements of hydraulic head in wells screened at the water table and at the bottom of the unconsolidated materials were made using a water level indicator at each of the well clusters surrounding the cove (Figure 18). Similar measurements were also made in the piezometers screened in the pond sediments and in the associated stilling wells (Figure 1).

At the locations of the well clusters surrounding Red Cove, vertical hydraulic gradients (Tables 3 and 4), calculated using the measured differences in hydraulic head and the vertical distance between the screen mid-points of wells screened at the water table and at the bottom of the unconsolidated materials, were generally low in magnitude and predominantly either neutral or upward during each monitoring event further indicating the potential for discharge to the cove.

The hydraulic head differences between shallow sediments, as measured in the cove piezometers, and the pond, as measured in the attached stilling wells, were determined at two of the locations (Figure 19) on April 26, 2007, and at the majority of the locations on September 11/12 (Figure 20) and November 6, 2007 (Figure 21). The hydraulic head differences (Table 5) and the potential directions of water flow were calculated using the measured differences in groundwater and surface water elevations at each location. The differences in magnitudes of the hydraulic gradients between different locations may not be significant due to the shallow depth of piezometer placement and the difficulties in accurately estimating the elevation of the top of sediments at each location. Therefore, the magnitude of the hydraulic gradient was not calculated. In general, the potential directions of groundwater flow indicated by the cove piezometers are in good agreement with the detailed potentiometric surfaces produced from April, September, and November groundwater elevation data, generally indicating a potential for upward flow in areas where the potentiometric surface indicates flow toward the pond and vice versa.

2.3 Hydraulic Conductivity Structure

The hydraulic conductivity structure near Red Cove was estimated using pneumatic slug testing techniques in the five well clusters surrounding the cove (Figure 18). The well clusters were designed to provide complete vertical coverage of the saturated overburden from the water table to the bottom of the unconsolidated materials. The tests were conducted using procedure RSKSOP-256. This procedure is based on recommendations derived from Butler (1997). The procedure utilizes air pressure and vacuum to initiate instantaneous changes in head within the well combined with high frequency monitoring of the aquifer response using data loggers and pressure transducers. The aquifer response data were analyzed using the methods of Bouwer and Rice (1976) and Springer and Gelhar (1991).

Results (Figures 22, 23, 24, 25, and 26) indicate that the hydraulic conductivity at each of these locations is generally moderate to high. The average hydraulic conductivity in each profile ranges from approximately 30 ft/d at RSK36-43 to approximately 80 ft/d at RSK8-12. With the exception of well cluster RSK36-43, the horizontal hydraulic conductivity structure was relatively uniform as measured on a 5 ft vertical basis, varying only within a factor 2 to 5 at each location. However, the conductivity structure appears to be more heterogeneous at cluster RSK36-43 varying by more than an order of magnitude within the vertical profile.

The hydraulic conductivity structure estimated at each location was compared with geologic logs from nearby wells at the three locations where such logs (Appendix C) were available (RSK1-7, RSK13-15, and RSK36-43). Detailed comparisons between the lithology logged in borings and the hydraulic conductivity structure were not possible since the borings were logged using a 1.5 ft split spoon sample obtained every five vertical feet and sample recoveries were generally moderate to poor. It should also be noted that relatively small differences in hydraulic conductivity are generally not reliably observable in the geologic logs often obtained at normal sites (Young *et al.*, 1998) due to a variety of factors, including the limited coverage of the vertical profile, poor sample recovery, and the quality/detail of the sample descriptions.

At boring N2, located approximately 50 ft from RSK1-7, the majority of the samples were logged as fine sands (USCS classification SP) with small differences in the percentage of fine-grained materials. In addition, a single thin interval of silty sand (USCS classification SM) was logged within the interval equivalent to the screened zone of the RSK1-7 cluster. However, the elevation of this interval corresponds to an interval for which no reliable estimates of hydraulic conductivity were obtained. Therefore, direct comparison is not possible. With the exception of the silty sand interval, the lithologic log indicates the materials are not highly heterogeneous, which supports the interpretation of the hydraulic conductivity structure at RSK1-7 (Figure 22).

In similar fashion, the geologic log for boring SEA-4, adjacent to well cluster RSK13-15, indicates the materials are relatively homogeneous and are predominantly logged as fine to coarse sands with varying percentage of gravel. A single interval of silty sand with an estimated thickness of approximately 1.5 ft was logged immediately above the bedrock. This again supports the interpretation that the hydraulic conductivity structure is not highly heterogeneous at well cluster RSK13-15 (Figure 24) as measured on a 5 ft vertical interval.

In contrast, the degree of heterogeneity observed in the hydraulic conductivity structure at well cluster RSK36-43 is not readily discernible from the geologic log for well N3, located approximately 50 ft away. All intervals above bedrock at N3 were logged as clean sands with an USCS classification of SP. Two intervals in the lower portion of the section contained significant gravel. The hydraulic conductivity structure obtained from the RSK36-43 well cluster indicates that the hydraulic conductivity in the lower 15 ft of the unconsolidated materials is less than that of the materials near the water table by a factor of approximately 20. Although this degree of heterogeneity is not readily discernible from the geologic log for N3, it is noted that the log does indicate that samples in the lower portion of the unconsolidated aquifer contained some additional fine-grained materials as compared with the samples obtained near the water table. In general, the percentage of fine-grained materials is often a significant control on hydraulic conductivity. An increased percentage of fines can result in a significant reduction in hydraulic conductivity. It is also possible that the geologic materials at RSK36-43 are somewhat different from those logged at N3 which is 50 ft away. It should be noted that two wells in the

RSK36-43 cluster were screened over the interval from approximately 205 ft to 210 ft AMSL. The hydraulic conductivities estimated for materials adjacent to those wells, 3.3 ft/d at RSK39 and 4.6 ft/d at RSK42, were quite similar, indicating that the estimated reduction in hydraulic conductivity with increasing depth at this location is likely representative of actual conditions.

2.4 Groundwater and Arsenic Flux

Based on the differences in hydraulic gradients measured in April, September, and November, it is anticipated that groundwater flux and the associated flux of arsenic through the overburden near Red Cove is temporally variable. Overburden groundwater and arsenic fluxes to Red Cove were estimated for conditions observed on April 26 and November 7, 2007. Groundwater flux to Red Cove was estimated using a flow net approach (Cedergren, 1989) whereby flow lines are constructed using the potentiometric surface for each date for which flux is estimated. Groundwater flux was then calculated between the bounding flow lines ending at Red Cove. In this fashion, the flux of groundwater passing a series of vertical planes immediately upgradient of Red Cove and oriented perpendicular to the direction of flow is estimated. Inputs to the calculations are the saturated overburden thickness, hydraulic gradients in each area, hydraulic conductivity structure, and distance perpendicular to flow over which these inputs are assumed to be representative.

For purposes of this estimation, the potentiometric surface was divided into segments using flow lines indicating flow to Red Cove within the area encompassed by the network of well clusters (Figure 27). The segments were chosen to correspond to the midpoints of the distance between each well cluster and generally correspond with areas of similar hydraulic gradient. The saturated overburden thickness was estimated at each of the well cluster locations as the difference between the elevations of drilling refusal and the water table. Saturated thickness ranged from 15 ft at the RSK13-15 cluster to 32 ft at the RSK1-7 cluster. Since detailed data regarding bedrock topography were not available for the areas immediately west and south of Red Cove and the estimated bedrock topography available from previous investigations varies significantly in this area, the saturated thickness within each segment was assumed equal to the saturated thickness measured at the well cluster within that segment. Additional study would be required to obtain a more rigorous estimate of the bedrock surface in the area where this preliminary estimate of groundwater and arsenic flux was performed.

With the exception of the segment encompassing flow through the vicinity of cluster RSK36-43, hydraulic conductivity within each segment was assumed to be the average measured for the well cluster within that particular segment due to the relatively low degree of heterogeneity observed within each vertical profile. Based on the increased heterogeneity observed at cluster RSK36-43, the hydraulic conductivity structure in this area was represented by a two-layer system. The top layer, which was 8 ft thick, was assigned the average hydraulic conductivity estimated for the upper two wells in the cluster and the bottom layer, which was 15 ft thick, was assigned the average value for the deepest three wells in the cluster.

The hydraulic gradient was calculated near the center of each segment and immediately upgradient of the well cluster representative of that segment. Hydraulic gradients in this area were more stable than in areas immediately adjacent to the pond due, at least in part, to the decreasing significance of the vertical component of flow with increasing distance from the discharge point. Groundwater flux was then calculated (Table 6) as the saturated thickness times the segment width, hydraulic conductivity, and hydraulic gradient.

The flux of arsenic dissolved in groundwater was estimated using the groundwater flux calculated for each segment and the concentration of dissolved arsenic in filtered samples obtained from the well clusters on various dates between October 2006 and November 2007 and analyzed using ICP-MS methodology. Arsenic flux through each segment was then estimated by multiplying the groundwater flux by the average dissolved arsenic concentration.

Assumptions inherent in these calculations include:

- Groundwater flow is horizontal in the area where fluxes are estimated,
- Groundwater from the entire saturated thickness of overburden discharges to the pond,
- Assumed values for saturated thickness, hydraulic conductivity, and dissolved arsenic concentration are representative of relatively large areas surrounding Red Cove, and
- Dissolved arsenic concentrations are constant through time.

In all likelihood, none of these assumptions are fully met in the study area. Significant uncertainty exists with respect to several of these assumptions, particularly the saturated overburden thickness, hydraulic conductivity distribution, and temporal behavior of arsenic concentrations. It is also noted that this analysis does not directly evaluate the potential for discharge to the pond from bedrock. Therefore, these estimates should be considered to be preliminary in nature and useful only in a comparative sense for understanding the factors that may influence flux.

As indicated in Table 6, the flux of groundwater and associated arsenic to Red Cove likely was significantly higher in April 2007 than in November 2007 due to the increased hydraulic gradients at the time of the measurements in April. It is also interesting to note that the contribution of arsenic from each area was not uniform. Groundwater moving to the cove in the vicinity of the RSK1-7, RSK8-12, and RSK16-19 clusters contributed approximately 90% of the calculated arsenic flux on both April 26 and November 7 while representing approximately 40 % of the groundwater flow field toward Red Cove. The difference in arsenic flux appears to be primarily due to the increased arsenic concentrations in these flow paths. Acquisition of sufficient data to constrain the potentiometric surface under a variety of hydrologic conditions representative of the full range of conditions observed at this site would be required to better evaluate the degree to which the current estimates of flux may be representative of “average” conditions.

2.5 Seepage Measurements

A sensitive bidirectional advective flux meter (Lien, 2006) was used to directly measure the magnitude and direction of water movement across the sediment/water interface in Red Cove. The tool was deployed at four locations (Figure 28) to provide direct measurements of water flux in support of conceptual model development for groundwater/surface water interactions within the cove. The meter was used to measure fluxes (Table 7) at each of the four locations in April 2007 and also in August and November 2007 at location SM1B.

Discharge of groundwater into the pond was detected during each measurement. Discharge rates during August and November were lower than in April. The measured rates in November were approximately 40% of the discharge rates measured in April. This reduction is in good agreement with the relative reduction in groundwater flux estimated from the potentiometric surfaces. The flux estimated using the November 7 potentiometric surface was approximately 35% of that estimated from the potentiometric surface produced for April 26.

Assuming that:

- Seepage measurements representative of the area covered by the meter (*i.e.*, approximately 2.47 ft^2) are also representative of the average discharge rate in the cove and
- The area of the cove is approximately 23,000 ft^2, as estimated from Figure 1,

then the total discharge of water during the April 24-26, 2007, measurements would have been approximately 2000 ft^3/d. Using the same assumptions, the groundwater discharge to the cove on November 6 would have been approximately 840 ft^3/d. These values compare relatively well with the estimates of 4300 ft^3/d on April 26 and 1500 ft^3/d on November 7 obtained using the modified flow net approach, given the uncertainties in the distribution of discharge to the cove and the uncertainties in the values of representative parameters for estimation of groundwater flux from the potentiometric surface data.

2.6 Distribution of Groundwater Discharge to Red Cove

In recent years, the use of heat as a tracer for groundwater movement has been applied to characterization of groundwater/surface water interactions. In particular, heat has been identified as a significant tool in characterizing locations and, in some cases, rates of groundwater discharge to surface water (*e.g.*, Stonestrom and Constantz, 2003; Stonestrom and Constantz, 2004). The temperature history in shallow sediments within areas of groundwater discharge is often more stable and less influenced by daily and seasonal temperature fluctuations than in areas without groundwater discharge. Temperature at a depth of 1 ft below the top of sediments was mapped at approximately one hundred locations within Red Cove and several other points in adjacent areas of Plow Shop Pond (Figure 3) between October 2006 and September 2007 to aid in evaluating the potential variability in groundwater discharge within the cove.

In support of this effort, groundwater temperatures in wells screened at the water table were measured using data loggers at four locations (Figure 29) surrounding Red Cove since September 2005. Temperatures in the wells screened at the water table (Figure 30) ranged from approximately 46 deg F to 57 deg F. Groundwater temperatures in wells screened at the bottom of the unconsolidated materials were also monitored between February and October 2006. Temperatures in the deeper wells varied within the same range as the shallow wells. For purposes of this analysis, it is assumed that the temperature range for groundwater discharging to Red Cove was between 46 deg F and 57 deg F during the period of sediment temperature records.

At Red Cove, the greatest contrast between surface water and groundwater temperatures occurs in late winter and, secondarily, again in late summer. For the following analysis, it was assumed that the influence of groundwater discharge would result in warmer sediment temperature for winter and cooler sediment temperature for summer. Sediment temperature on March 20, 2007, was chosen to be representative of cold weather conditions. Observed temperatures at 8:00 a.m. varied from approximately 33 deg F to 52 deg F. The data were plotted (Figure 31) to examine spatial patterns and any correspondence with the range of groundwater temperatures. Examination of the posted data indicates there is significant spatial variability in sediment temperatures. Several areas indicate temperatures were within the range of observed groundwater temperatures while temperature in other areas was much cooler. The areas with the coolest temperatures are less likely to be areas with significant groundwater discharge. It is also noted that the areas with the highest temperature were areas with low seasonal variation in temperature and may represent areas of significant groundwater discharge. In general, the data indicate that the distribution of groundwater discharge within the cove may be spatially variable.

Sediment temperatures during late summer were also examined as an indicator of the possible distribution of groundwater seepage. For this purpose, the temperature at noon on August 22, 2007, was chosen to be representative of late summer conditions. Observed temperatures varied from approximately 49 deg F to 66 deg F. Examination of the posted data (Figure 32) indicates there is a similar pattern to that observed in the March data set. Several areas indicate temperatures were within the range of observed groundwater temperatures (46 deg F to 57 deg F) while temperature in other areas was much warmer. The areas with the warmest temperatures are less likely to be areas with significant groundwater discharge.

Two of the locations where groundwater seepage was measured using the advective flux meter (Figure 33) are within areas of warmer, more stable sediment temperatures measured on March 20, 2007, which are potentially indicative of groundwater discharge areas. The remaining two locations of seepage measurements are adjacent to, but not within, the area where sediment temperatures were measured. Therefore, no direct comparisons with sediment temperature patterns can be made. Additional study, including deployment of temperature sensors in the western portion of Red Cove and expanded use of tools such as the advective flux meter, would be required to better characterize the range and spatial variability of discharge rates within the cove.

2.7 Hydrologic Summary

Multiple lines of evidence, including direct measurements using an advective flux meter, demonstrate that groundwater is currently discharging to Red Cove under most conditions. The dominant influences on groundwater discharge appear to be:

- Precipitation. Periods of increased rainfall may be generally correlated with increased hydraulic gradients toward the cove and, therefore, increased discharge of groundwater to the cove.

- Pond stage. Hydraulic gradients to Red Cove are often briefly decreased and can reverse direction during rapid increases in pond stage. In addition, hydraulic gradients may be significantly reduced during highly elevated stages.

Extraction from the SHL pump-and-treat system does not produce readily discernible influences on hydraulic heads in wells immediately adjacent to Red Cove. Any such effects are likely masked by the more dominant influences of precipitation and changes in pond stage. However, the data clearly demonstrate that the current extraction system does not eliminate discharge to the cove.

Discharge to Red Cove appears to be both spatially and temporally variable in nature. Additional studies would be required to better characterize the range in both discharge rates and locations within the cove.

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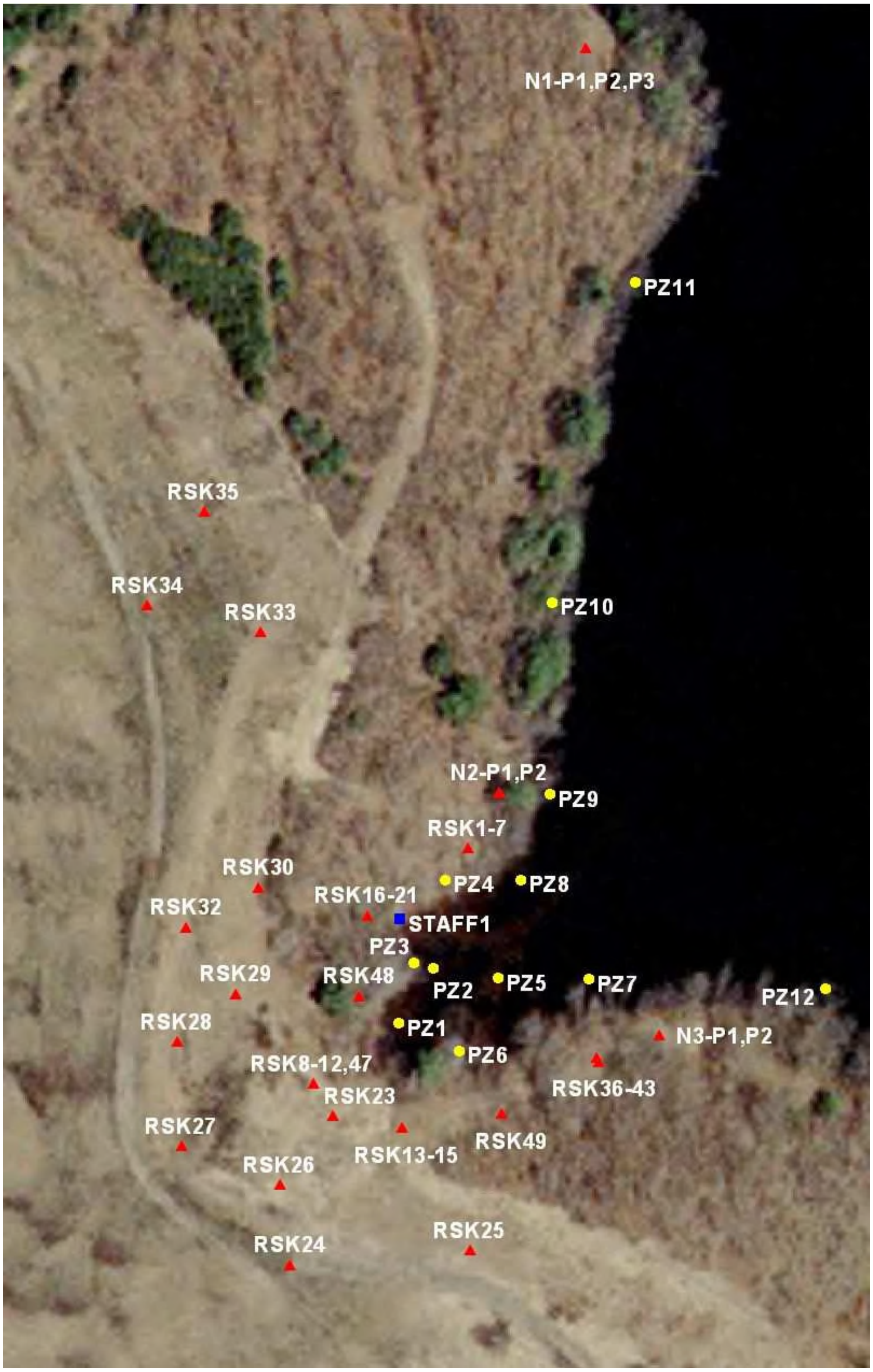

Figure 1. Supplemental monitoring network established near Red Cove. Locations of existing well clusters N1, N2, and N3 are included for reference. Red triangles mark groundwater well locations. Yellow dots are the approximate locations of piezometers within the cove. The blue square marks the location of the Red Cove staff gauge.

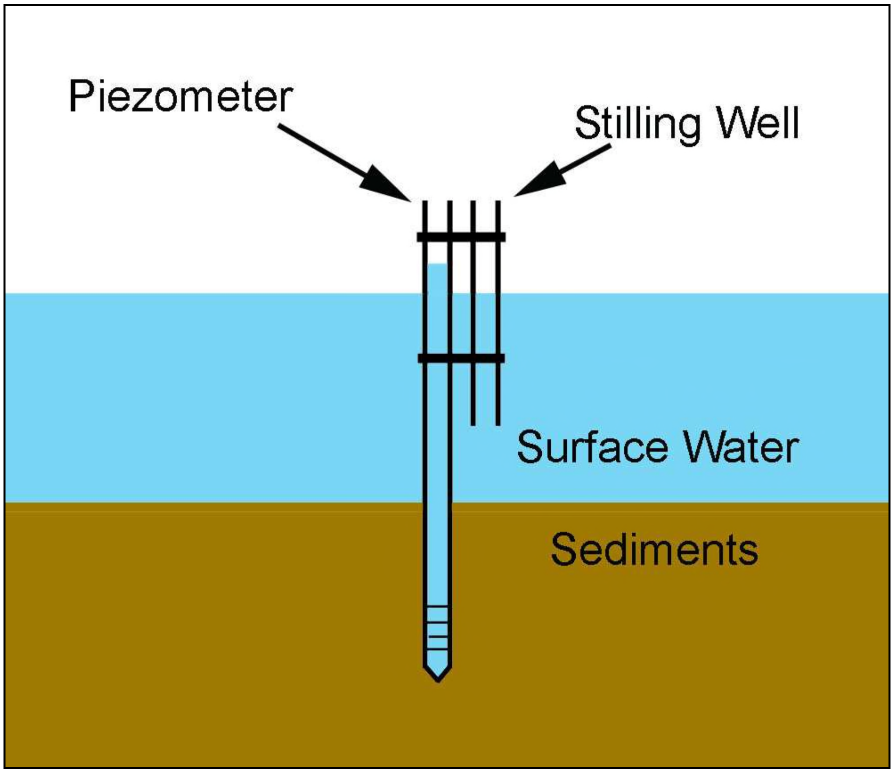

Figure 2. Schematic diagram of piezometers constructed within Red Cove. Stilling well is attached only to the piezometer riser.

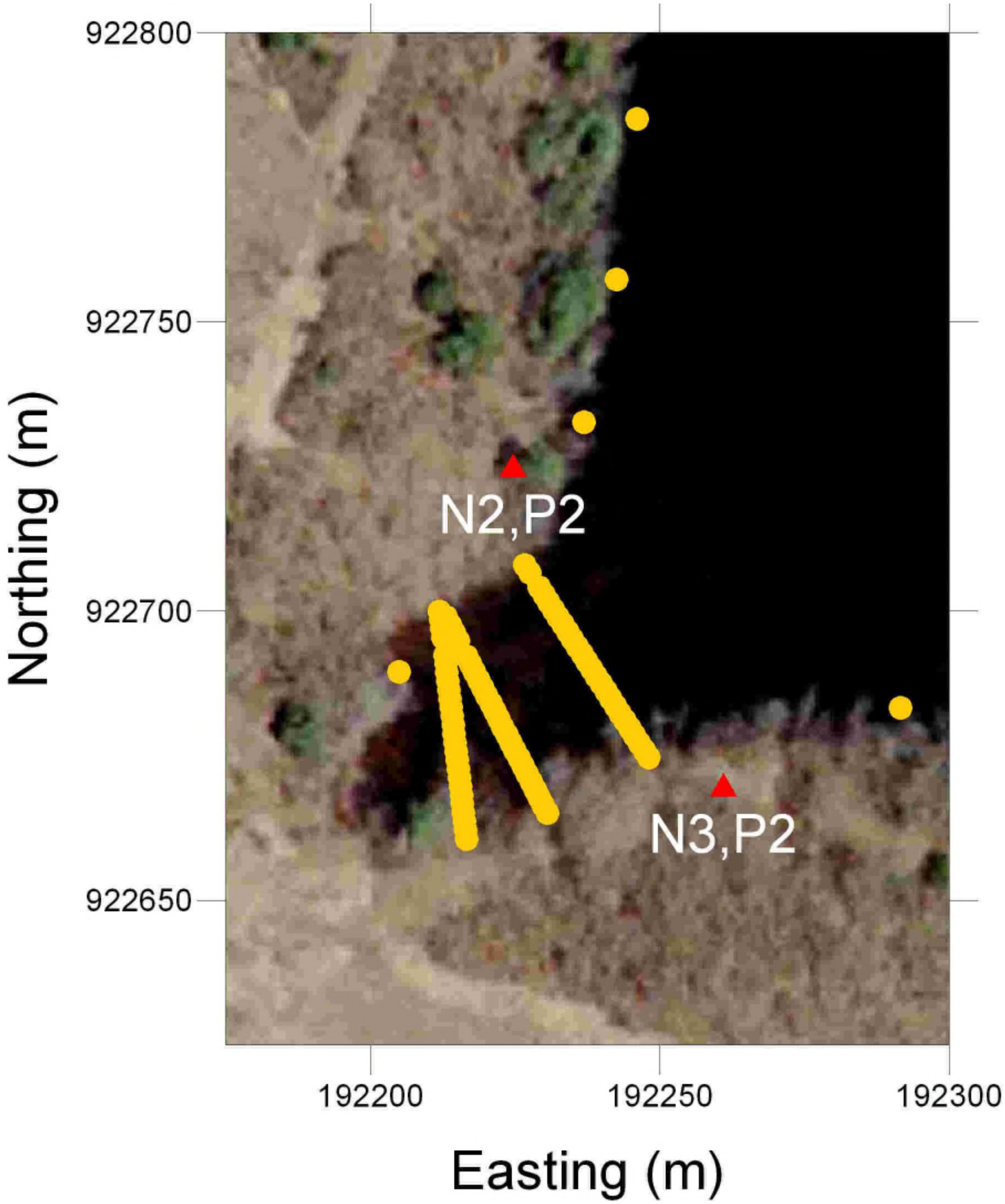

Figure 3. Locations of the sediment temperature data loggers deployed within Plow Shop Pond.

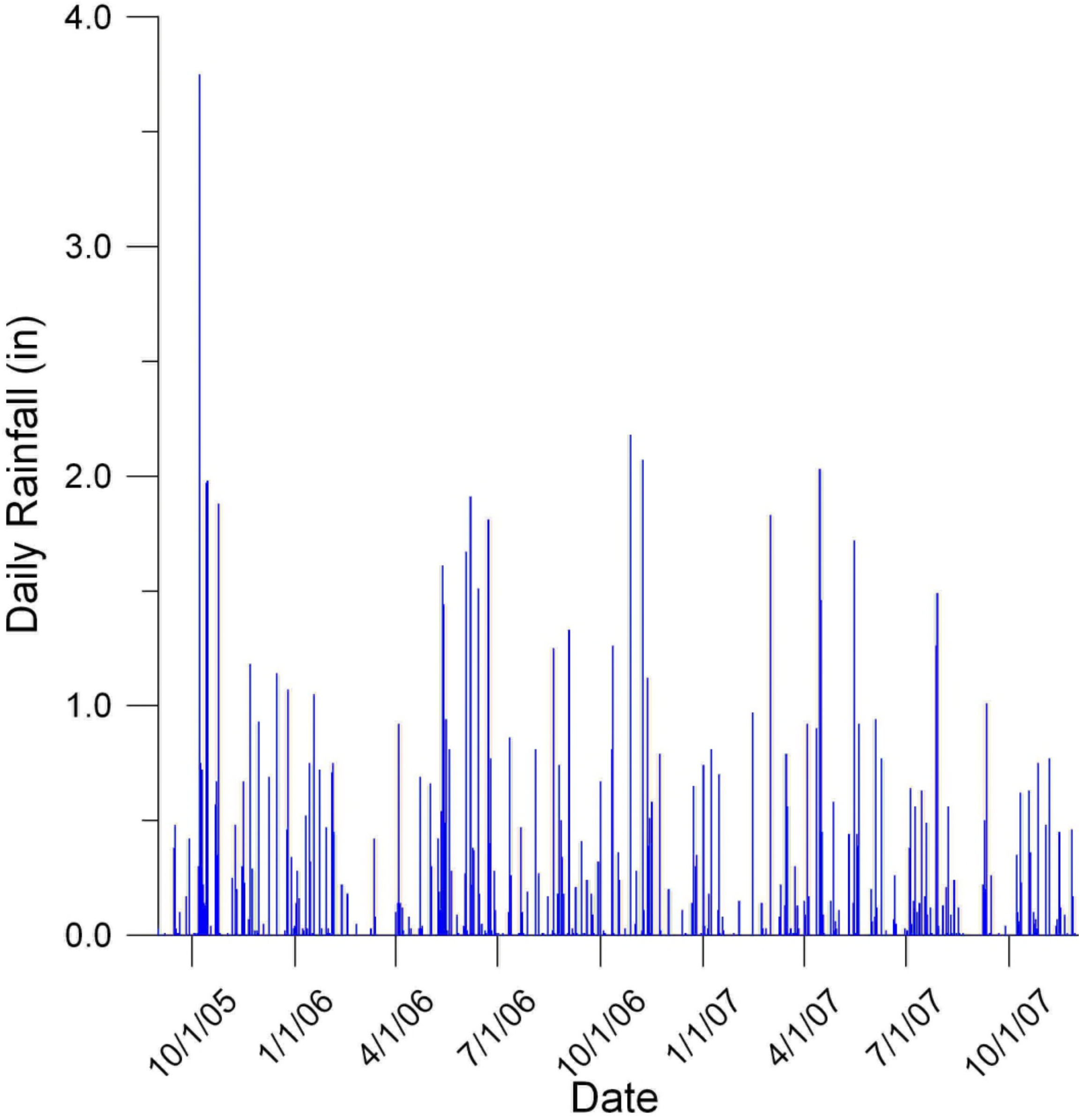

Figure 4. Daily rainfall at Fitchburg Municipal Airport during Red Cove study period.

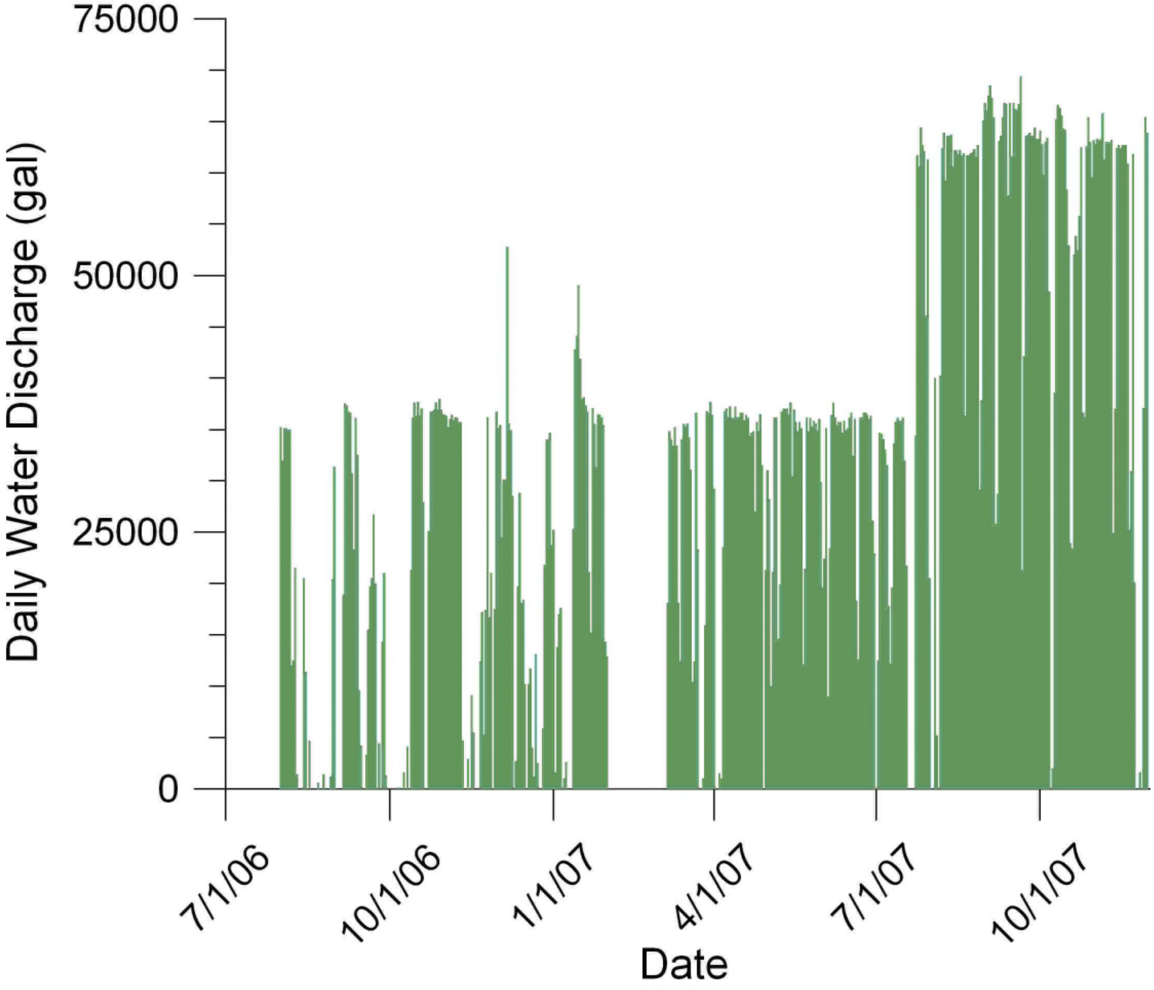

Figure 5. Daily water discharge from SHL treatment system between August 1, 2006 and November 30, 2007.

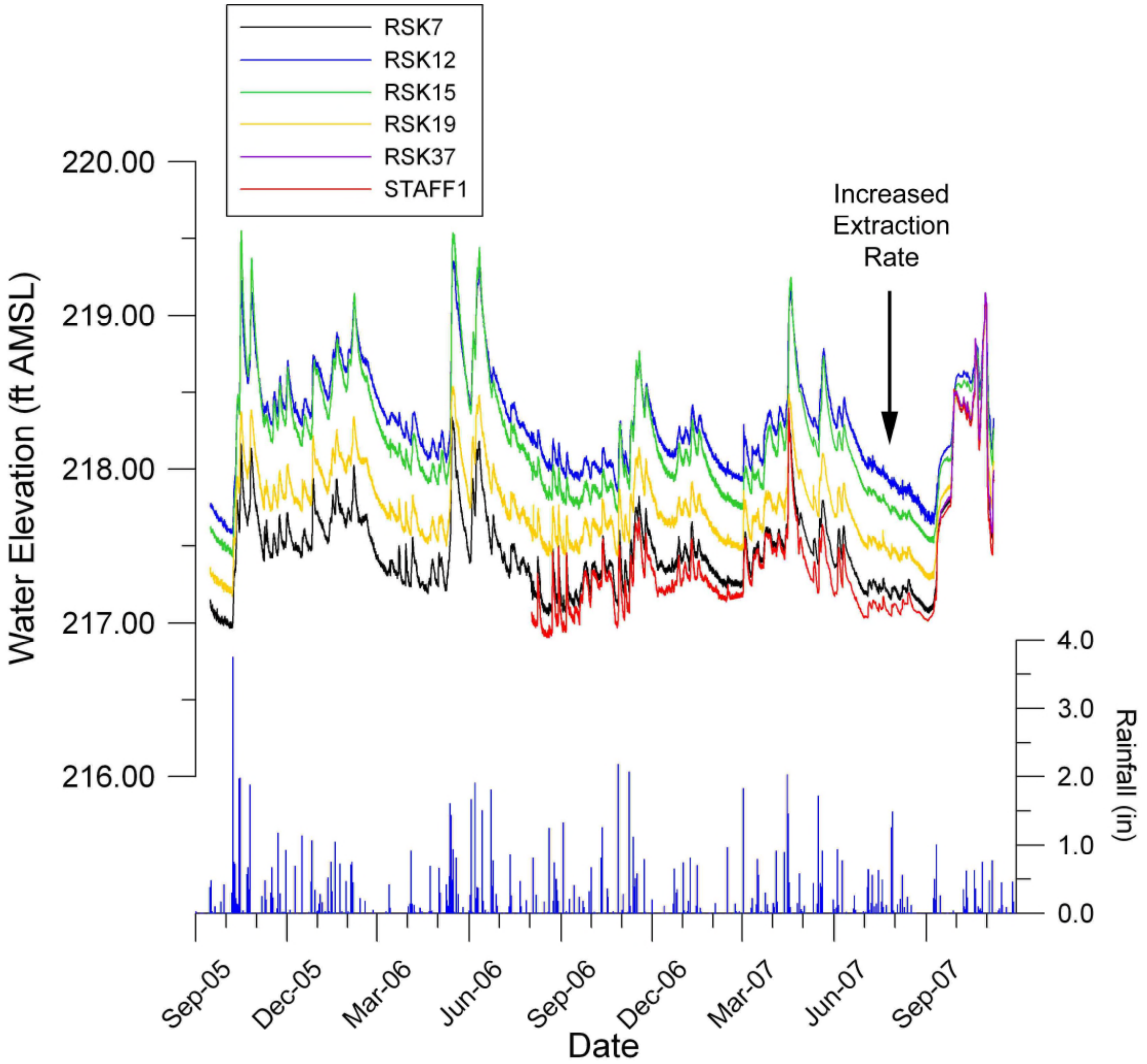

Figure 6. Comparative plot of rainfall at Fitchburg Municipal Airport, groundwater elevations at wells RSK7, RSK12, RSK15, RSK19, and RSK37, and surface water elevations in Red Cove at monitoring point STAFF1. The date on which the extraction rate from the SHL groundwater extraction system was increased to values greater than 40 gal/min is noted for reference.

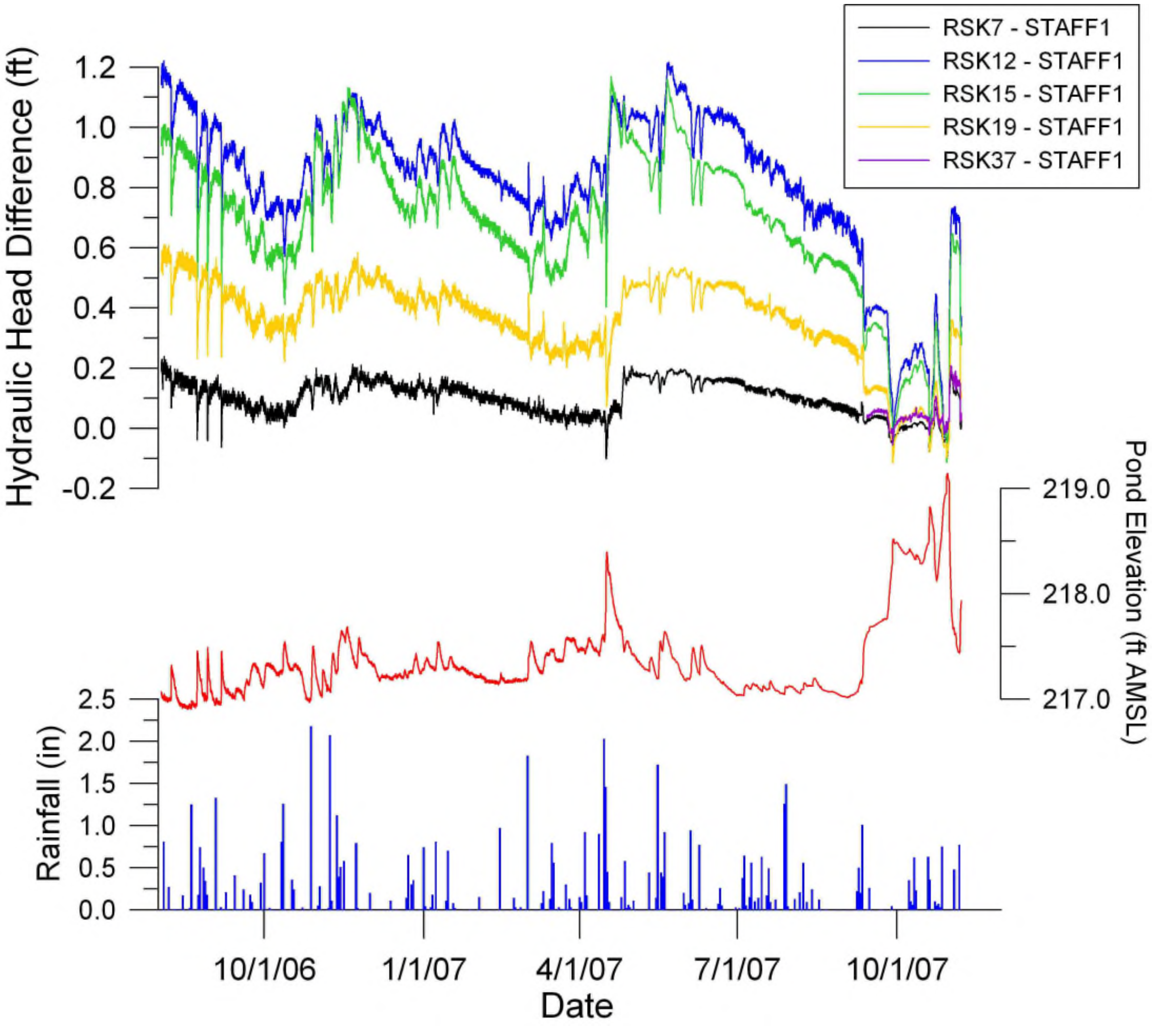

Figure 7. Hydraulic head differences between wells screened at the water table immediately adjacent to Red Cove and surface water elevations measured at STAFF1 compared with pond stage (STAFF1) and rainfall measured at the Fitchburg Municipal Airport. The hydraulic head differences are calculated as groundwater elevation minus surface water elevation. Positive differences signify potential for groundwater flow to Red Cove (*i.e.*, groundwater discharge to Red Cove). Negative differences signify potential for surface water flow to the aquifer (*i.e.*, Red Cove recharges the aquifer).

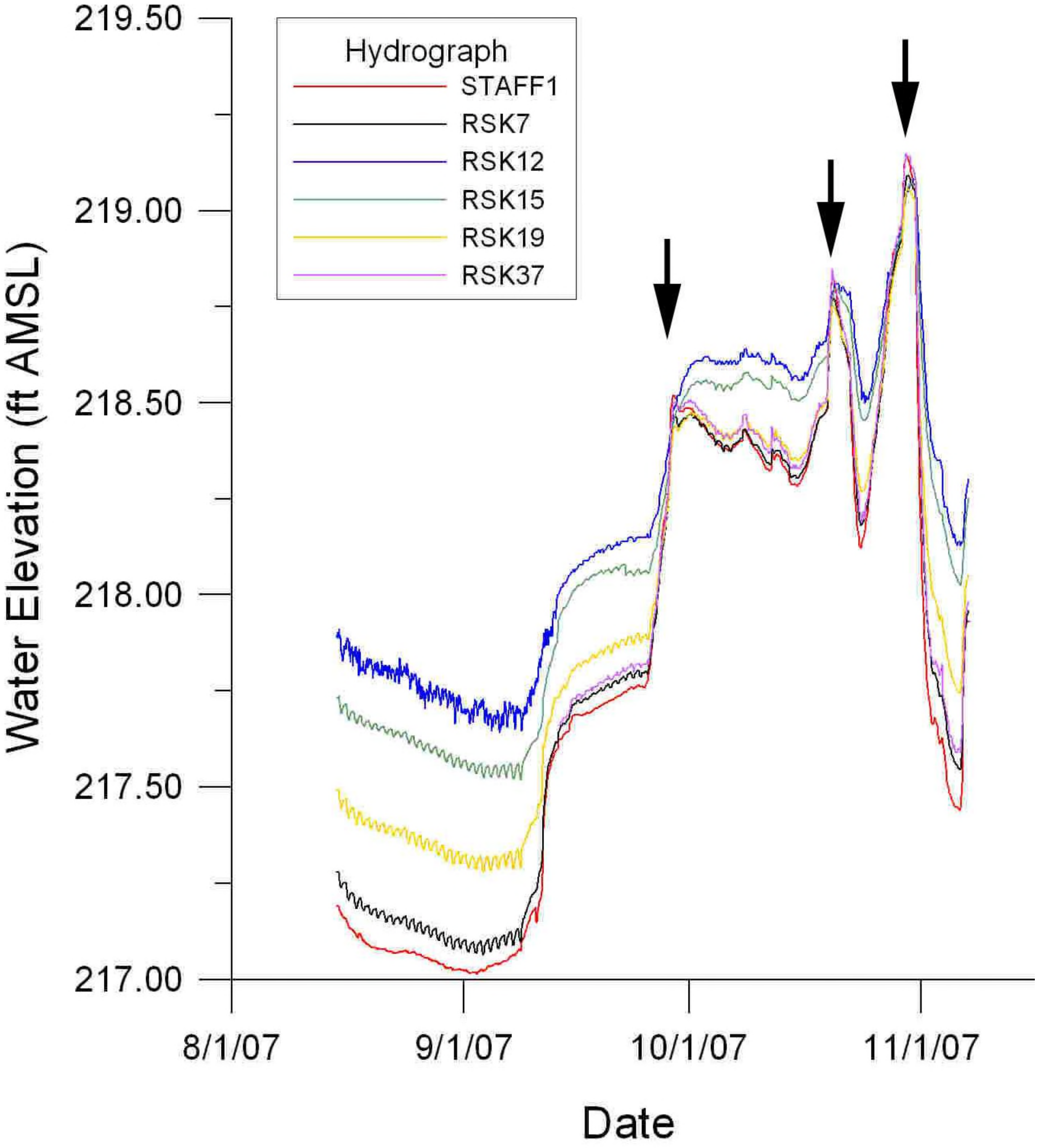

Figure 8. Groundwater and surface water elevations during a period of abnormally high pond stage during the fall of 2007. Points at which the pond briefly recharged the aquifer during periods of rapid rises in pond elevation are noted by arrows.

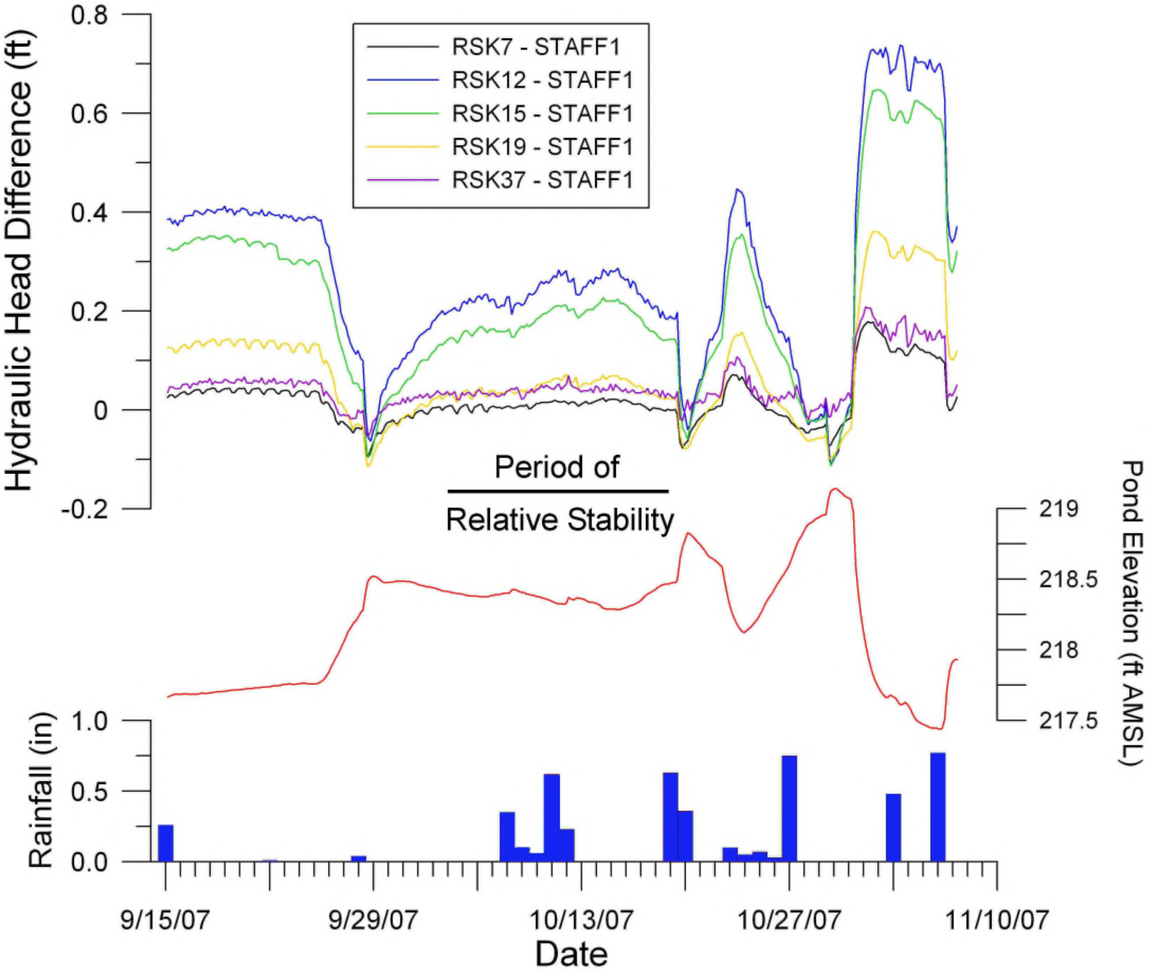

Figure 9. Hydraulic head differences between wells screened at the water table immediately adjacent to Red Cove and surface water elevations measured at STAFF1 compared with pond stage (STAFF1) and rainfall measured at the Fitchburg Municipal Airport during the period of abnormally high pond stage in the fall of 2007. The hydraulic head differences are calculated as groundwater elevation minus surface water elevation. Higher hydraulic head differences indicate higher hydraulic gradients. Positive differences signify potential for groundwater flow to Red Cove (*i.e.*, groundwater discharge to Red Cove). Negative differences signify potential for surface water flow to the aquifer (*i.e.*, Red Cove recharges the aquifer).

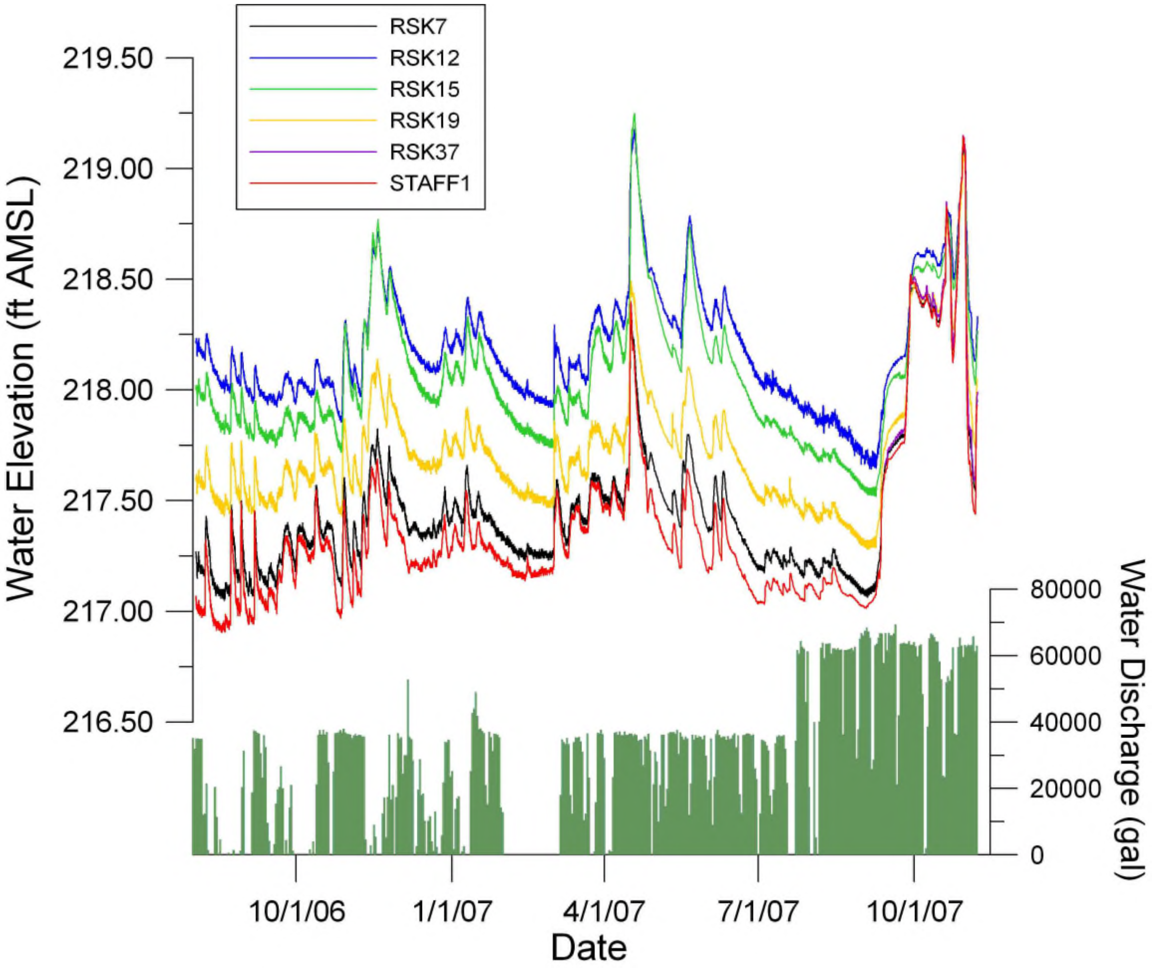

Figure 10. Comparative plot of daily water discharge from the SHL treatment system, groundwater elevations at wells surrounding Red Cove, and surface water elevations in Red Cove measured at monitoring point STAFF1 for the period August 2006 to November 2007.

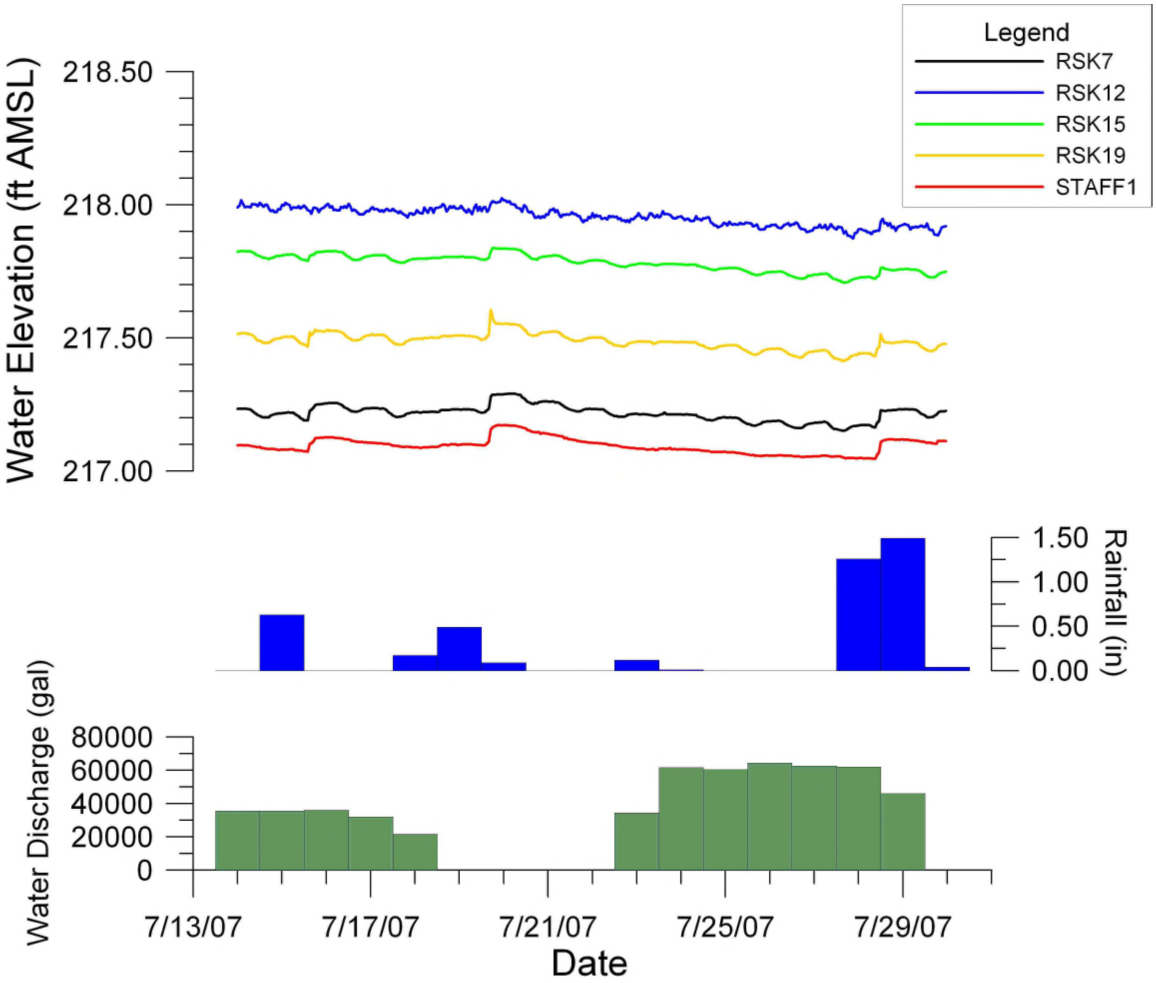

Figure 11. Comparative plot of daily water discharge from the SHL treatment system, rainfall, groundwater elevations at wells immediately adjacent to Red Cove, and surface water elevations in Red Cove measured at monitoring point STAFF1 for the period July 13 – 30, 2007.

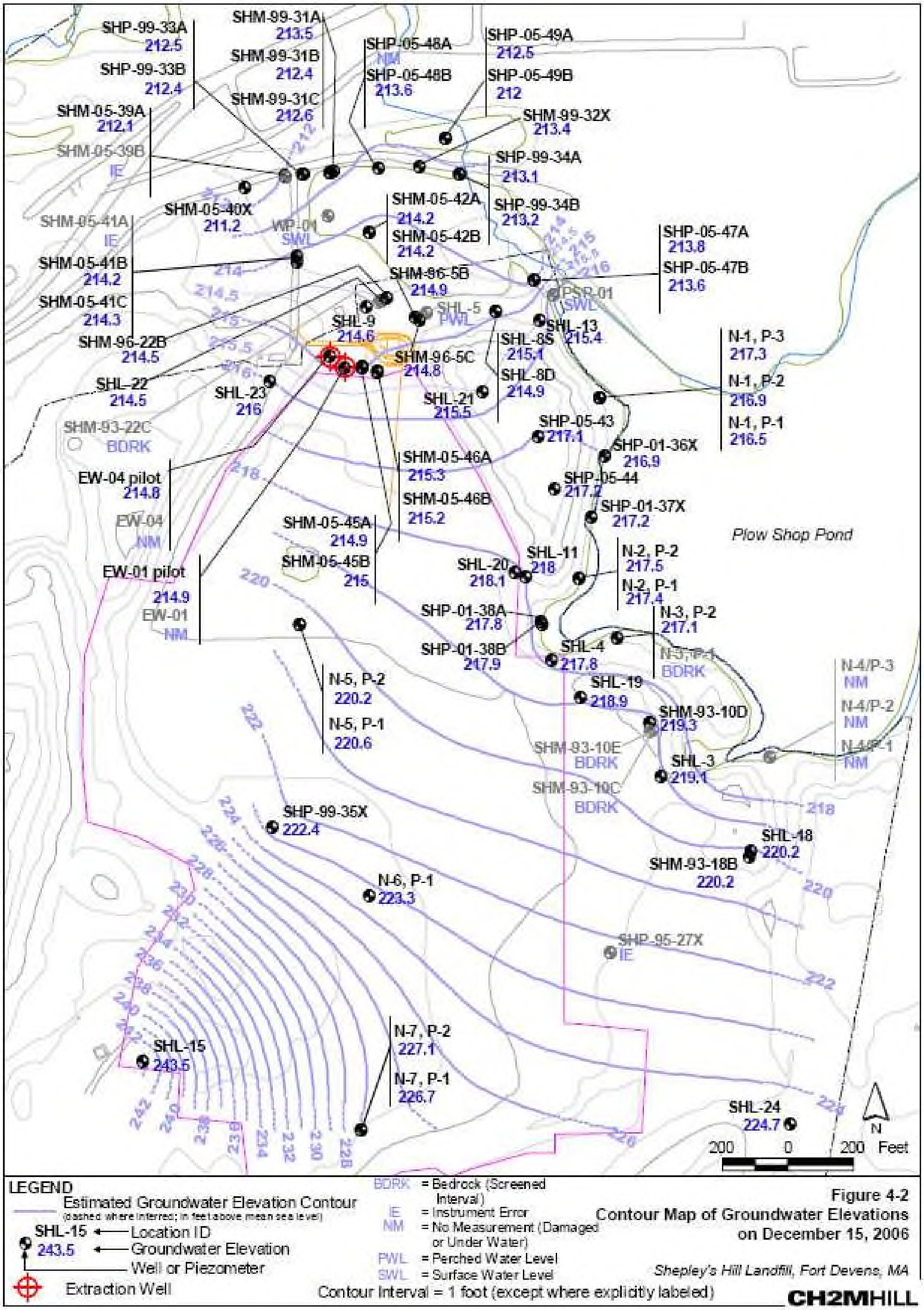

Figure 12. Site-wide contour map of groundwater elevations on December 15, 2006, provided in the 2006 annual report (CH2MHill, 2006).

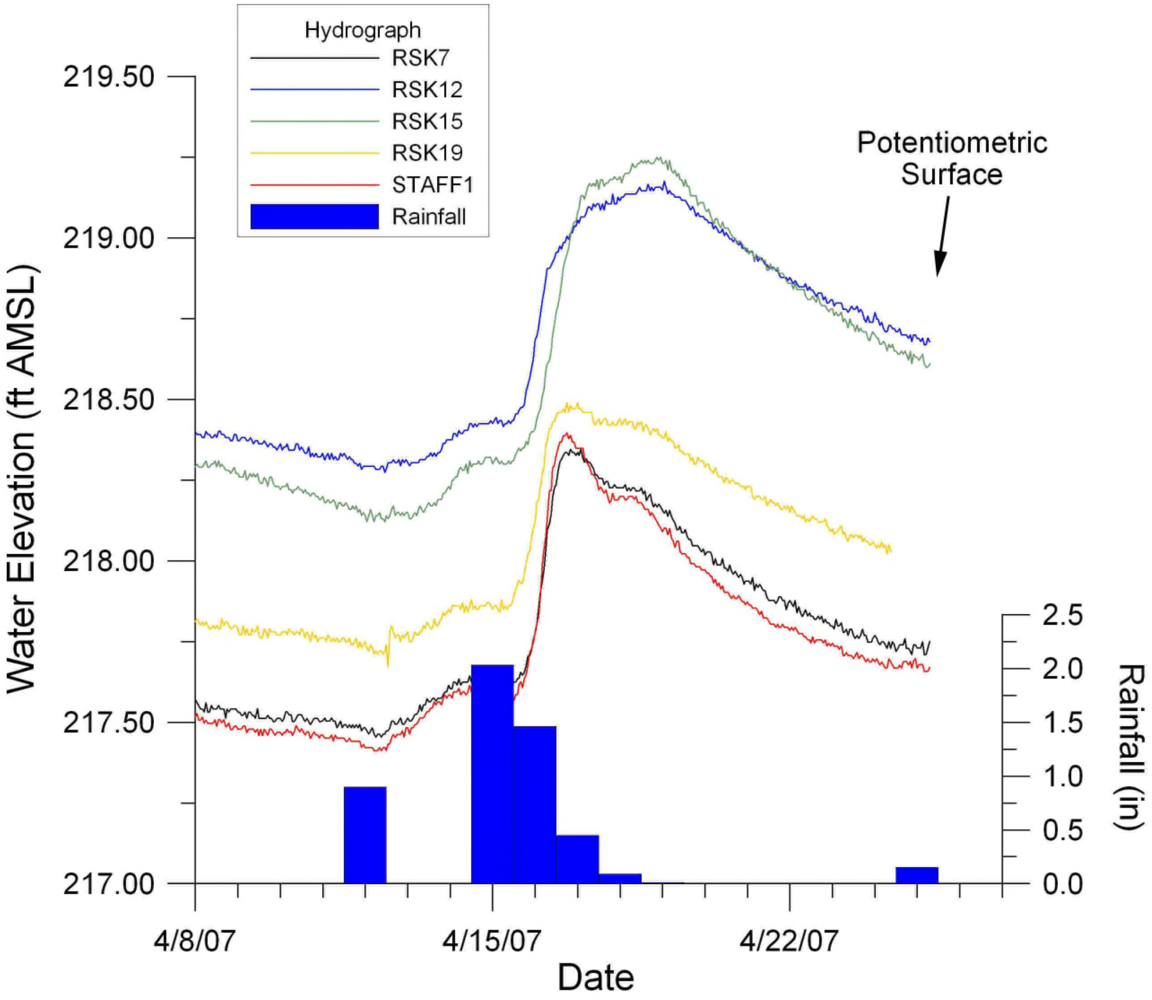

Figure 13. Detailed comparison of groundwater elevations in wells surrounding Red Cove, surface water elevations measured at STAFF1, and rainfall at Fitchburg Municipal Airport between April 8 and 26, 2007. The point in time at which water level measurements were made for creation of a potentiometric surface is also depicted.

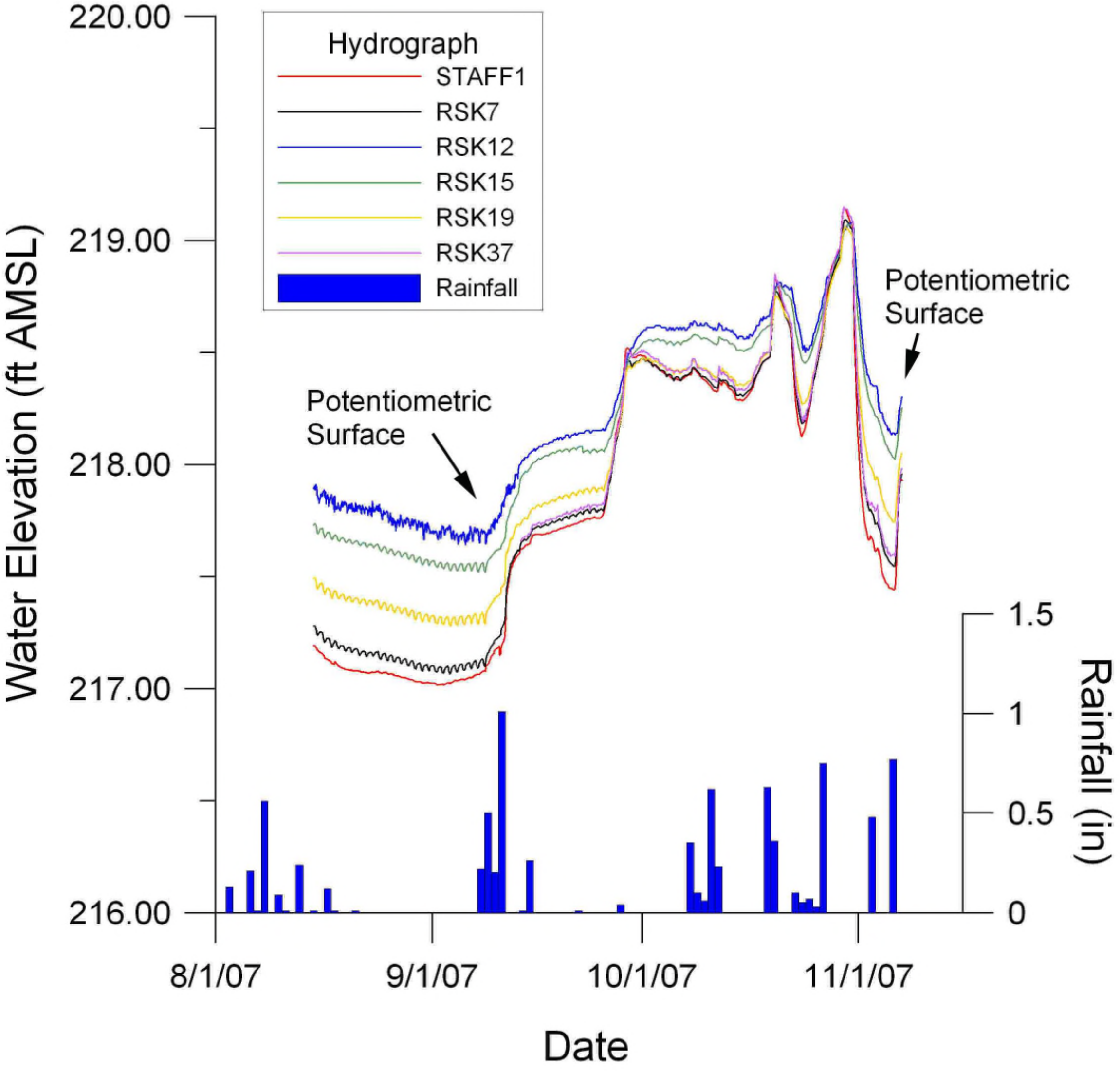

Figure 14. Detailed comparison of groundwater elevations in wells surrounding Red Cove, surface water elevations measured at STAFF1, and rainfall at Fitchburg Municipal Airport between August 1 and November 14, 2007. The points in time at which water level measurements were made for creation of potentiometric surfaces are also depicted.

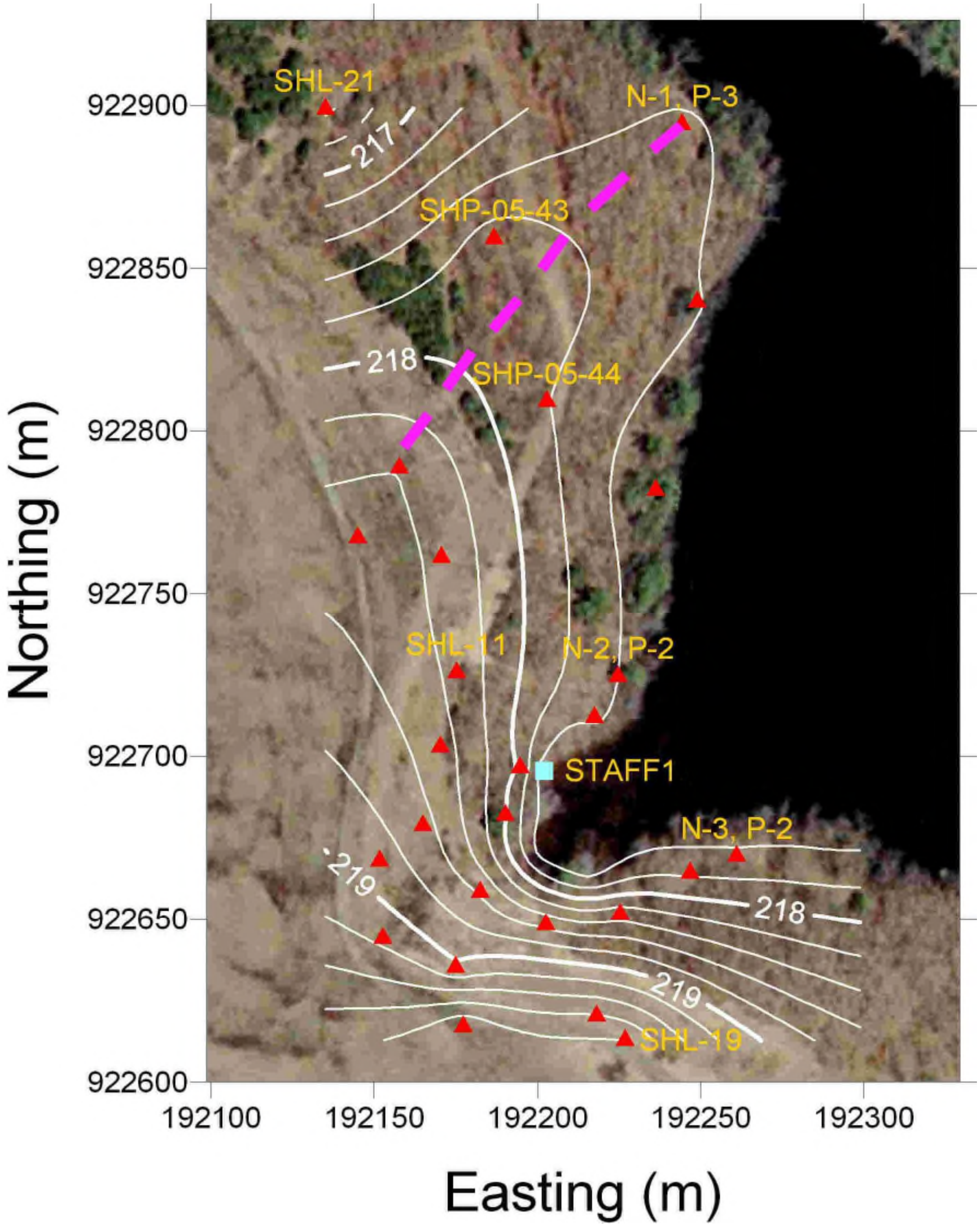

Figure 15. Potentiometric surface on April 26, 2007, produced using existing shallow wells and enhanced RSK network. Wells are depicted by red triangles and the surface water monitoring point is depicted by a blue square. Well names were generally omitted to improve figure clarity. Groundwater elevation contours are depicted in units of feet with a contour interval of 0.2 ft. The approximate location of the groundwater divide separating flow toward Red Cove and the western portion of Plow Shop Pond from flow toward the extraction system is depicted as a dashed magenta line.

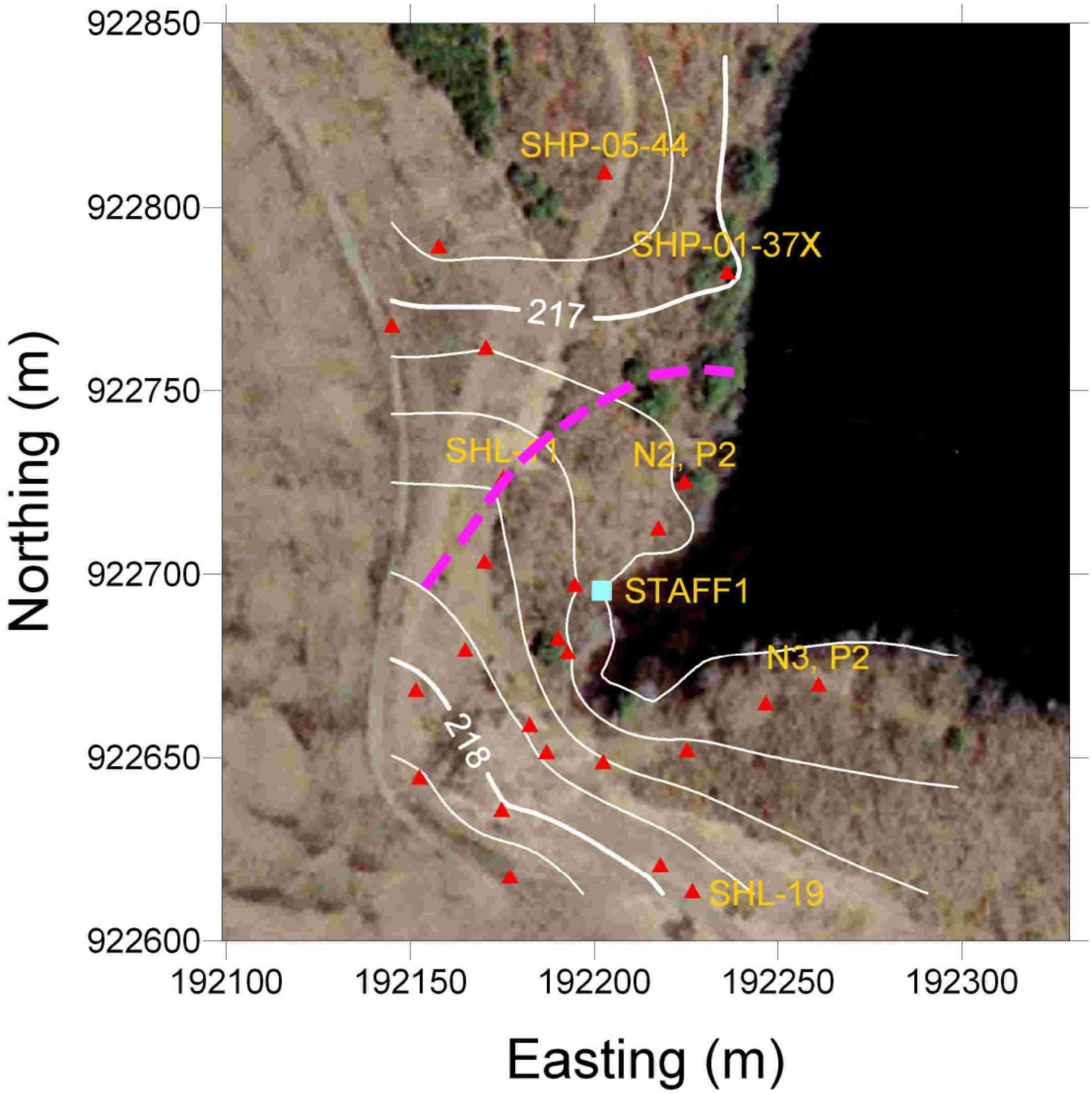

Figure 16. Potentiometric surface on September 10, 2007, produced using shallow existing wells and enhanced RSK network. Wells are depicted by red triangles and the surface water monitoring point is depicted by a blue square. Well names were generally omitted to improve figure clarity. Groundwater elevation contours are depicted in units of feet with a contour interval of 0.2 ft. The approximate location of the groundwater divide separating flow toward Red Cove and the western portion of Plow Shop Pond from flow toward the extraction system is depicted as a dashed magenta line.

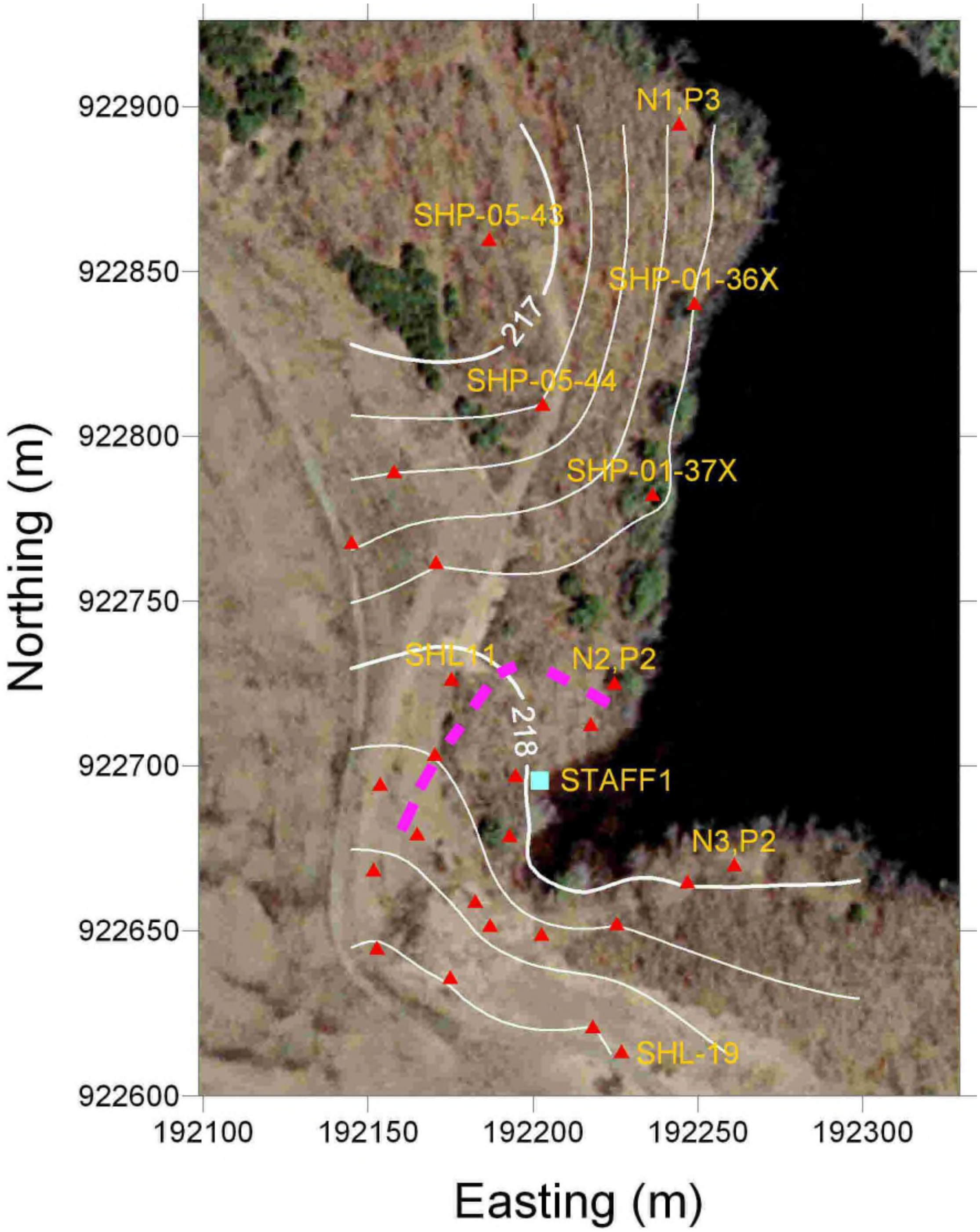

Figure 17. Potentiometric surface on November 7, 2007, produced using shallow existing wells and enhanced RSK network. Wells are depicted by red triangles and the surface water monitoring point is depicted by a blue square. Well names were generally omitted to improve figure clarity. Groundwater elevation contours are depicted in units of feet with a contour interval of 0.2 ft. The approximate location of the groundwater divide separating flow toward Red Cove and the western portion of Plow Shop Pond from flow toward the extraction system is depicted as a dashed magenta line.

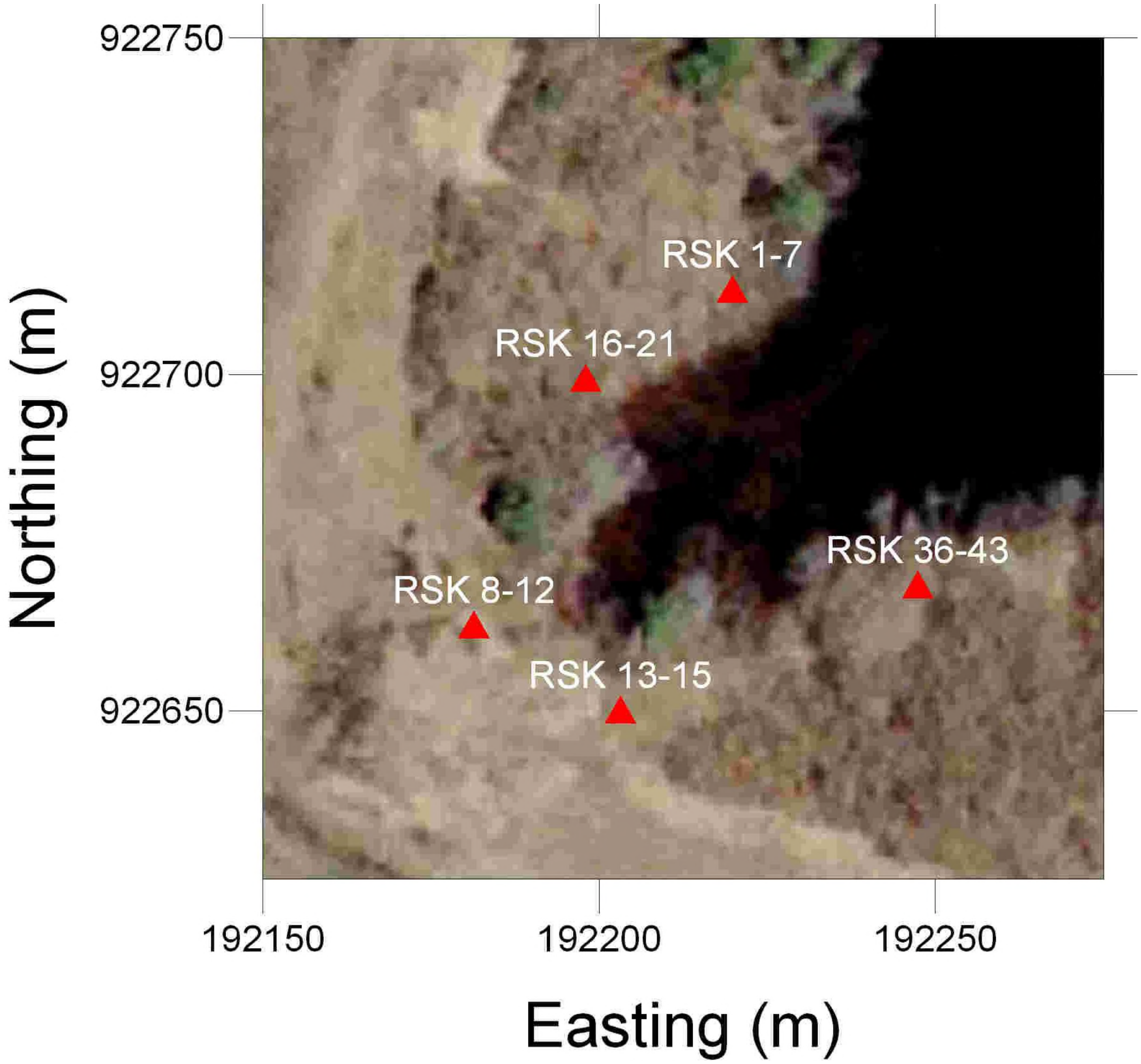

Figure 18. Well clusters used for determination of vertical hydraulic gradients and hydraulic conductivity structure.

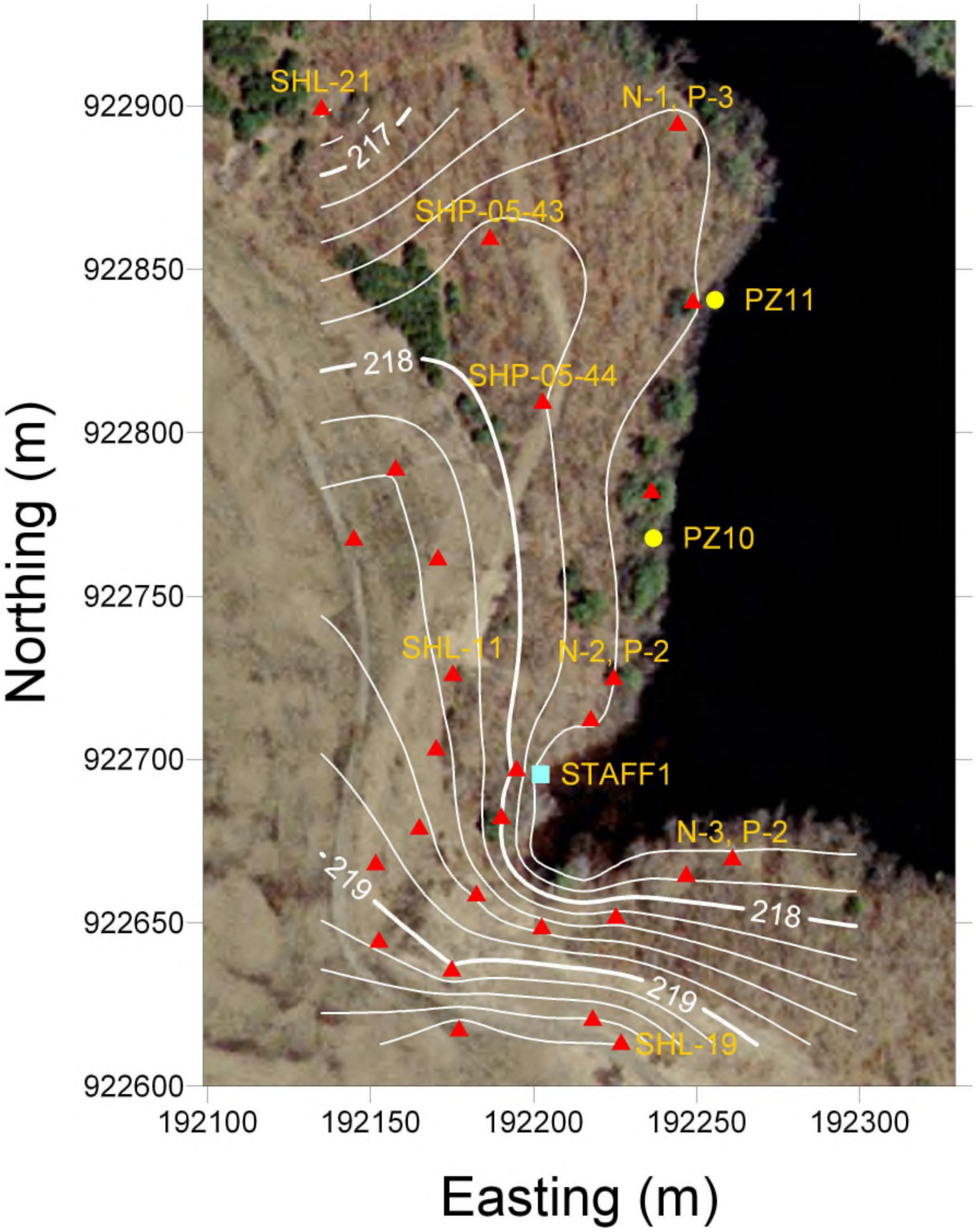

Figure 19. Potentiometric surface on April 26, 2007, and locations of lake-bed piezometers in which hydraulic heads were measured in comparison to the pond level at the same location. Yellow dots indicate piezometer locations at which the potential direction of flow was from the sediments to the surface water (*i.e.*, upward). Wells are depicted by red triangles and the surface water monitoring point is depicted by a blue square. Well names were generally omitted to improve figure clarity. Groundwater elevation contours are depicted in units of feet with a contour interval of 0.2 ft.

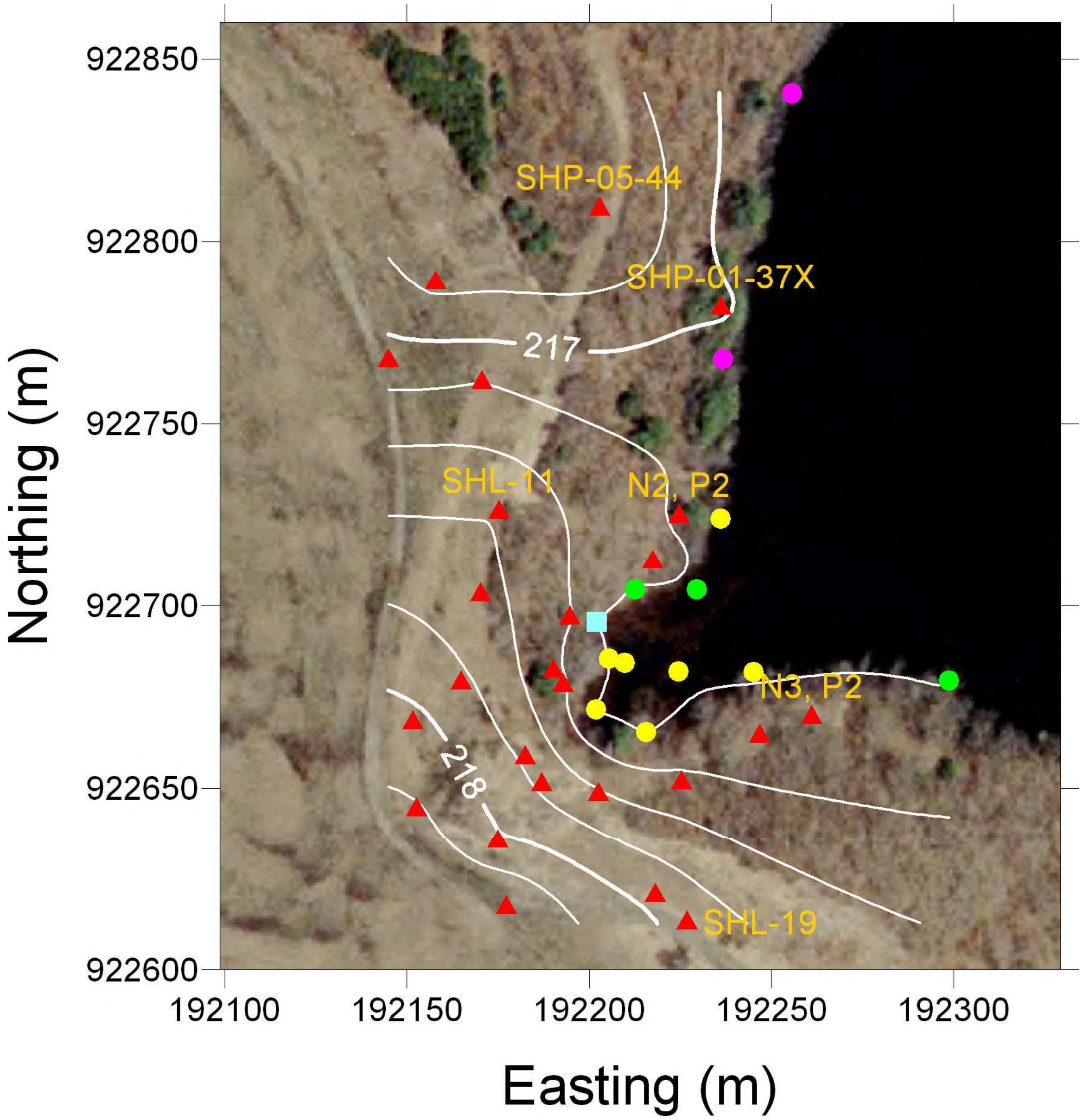

Figure 20. Potentiometric surface on September 10, 2007, and locations of lake-bed piezometers in which hydraulic heads were measured in comparison to the pond level at the same location. Yellow dots indicate piezometer locations at which the potential direction of flow was from the sediments to the surface water. Magenta dots indicate piezometer locations at which the potential direction of flow was from the surface water to the sediments (*i.e.*, downward). Green dots indicate locations where the gradient was considered to be insignificant (*i.e.*, no discernible flow direction). Wells are depicted by red triangles and the surface water monitoring point is depicted by a blue square. Well names were generally omitted to improve figure clarity. Groundwater elevation contours are depicted in units of feet with a contour interval of 0.2 ft.

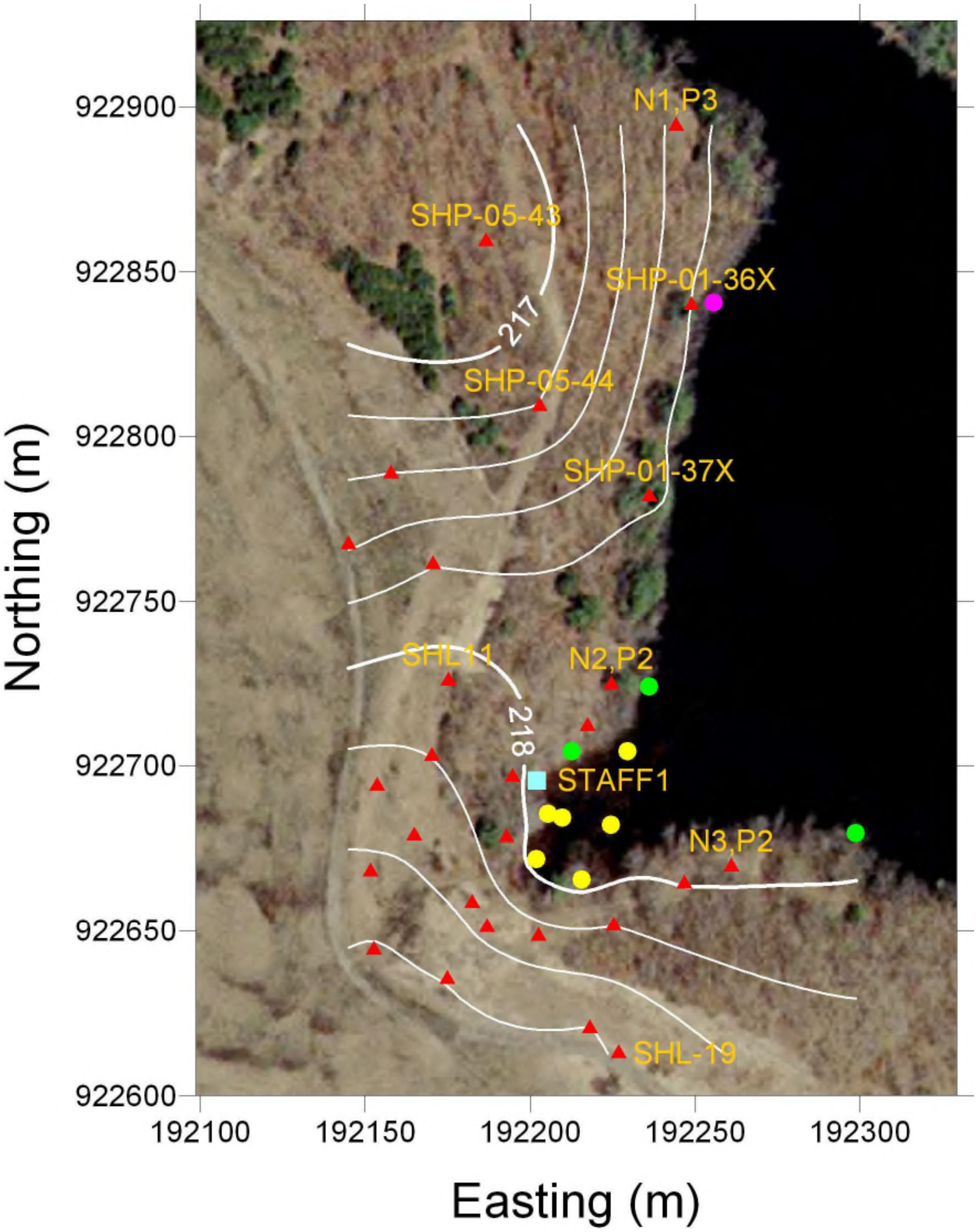

Figure 21. Potentiometric surface on November 7, 2007, and locations of lake-bed piezometers in which hydraulic heads were measured in comparison to the pond level at the same location. Yellow dots indicate piezometer locations at which the potential direction of flow was from the sediments to the surface water. Magenta dots indicate piezometer locations at which the potential direction of flow was from the surface water to the sediments (*i.e.*, downward). Green dots indicate locations where the gradient was considered to be insignificant (*i.e.*, no discernible flow direction). Wells are depicted by red triangles and the surface water monitoring point is depicted by a blue square. Well names were generally omitted to improve figure clarity. Groundwater elevation contours are depicted in units of feet with a contour interval of 0.2 ft.

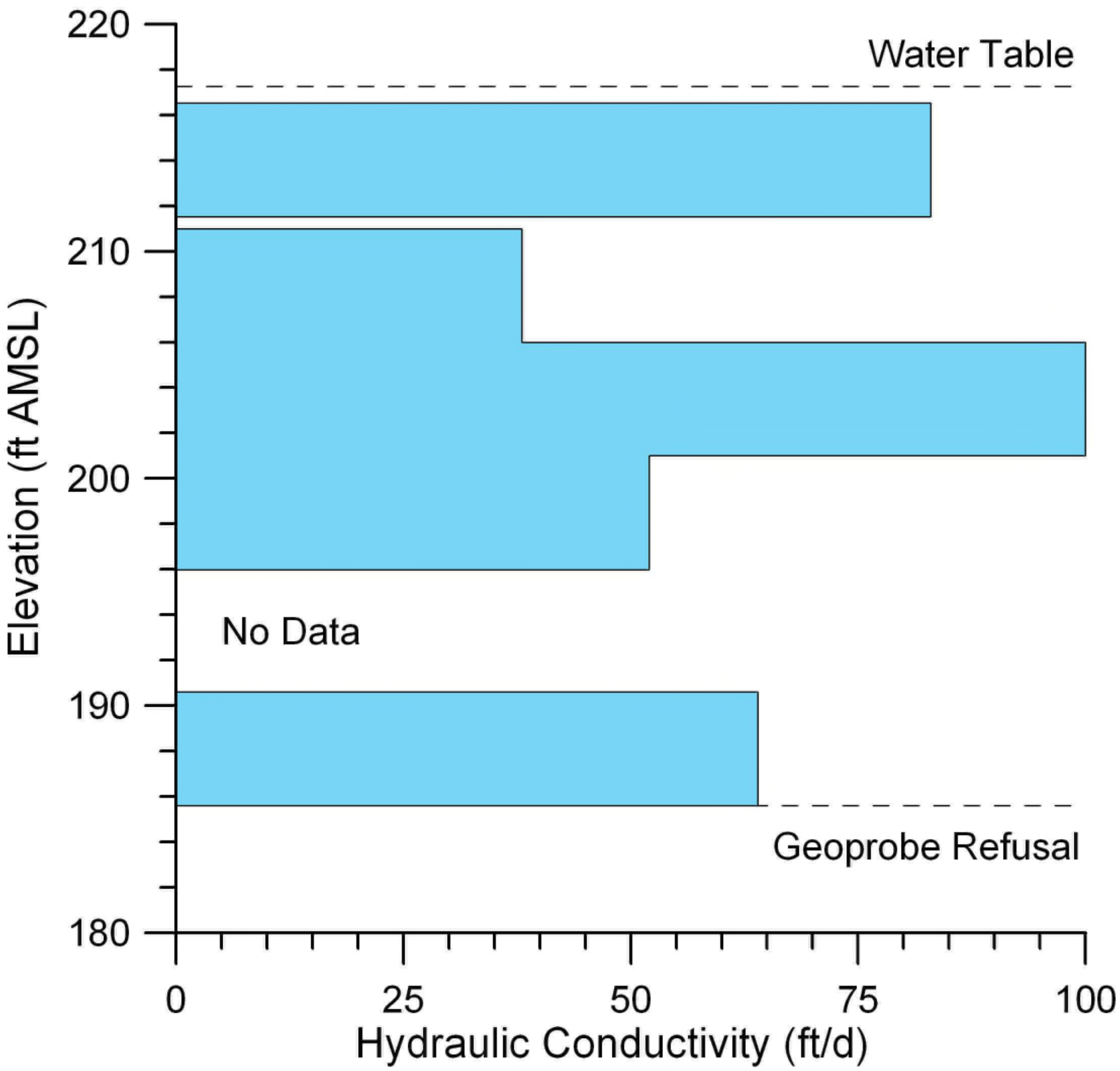

Figure 22. Hydraulic conductivity profile at well cluster RSK1-7.

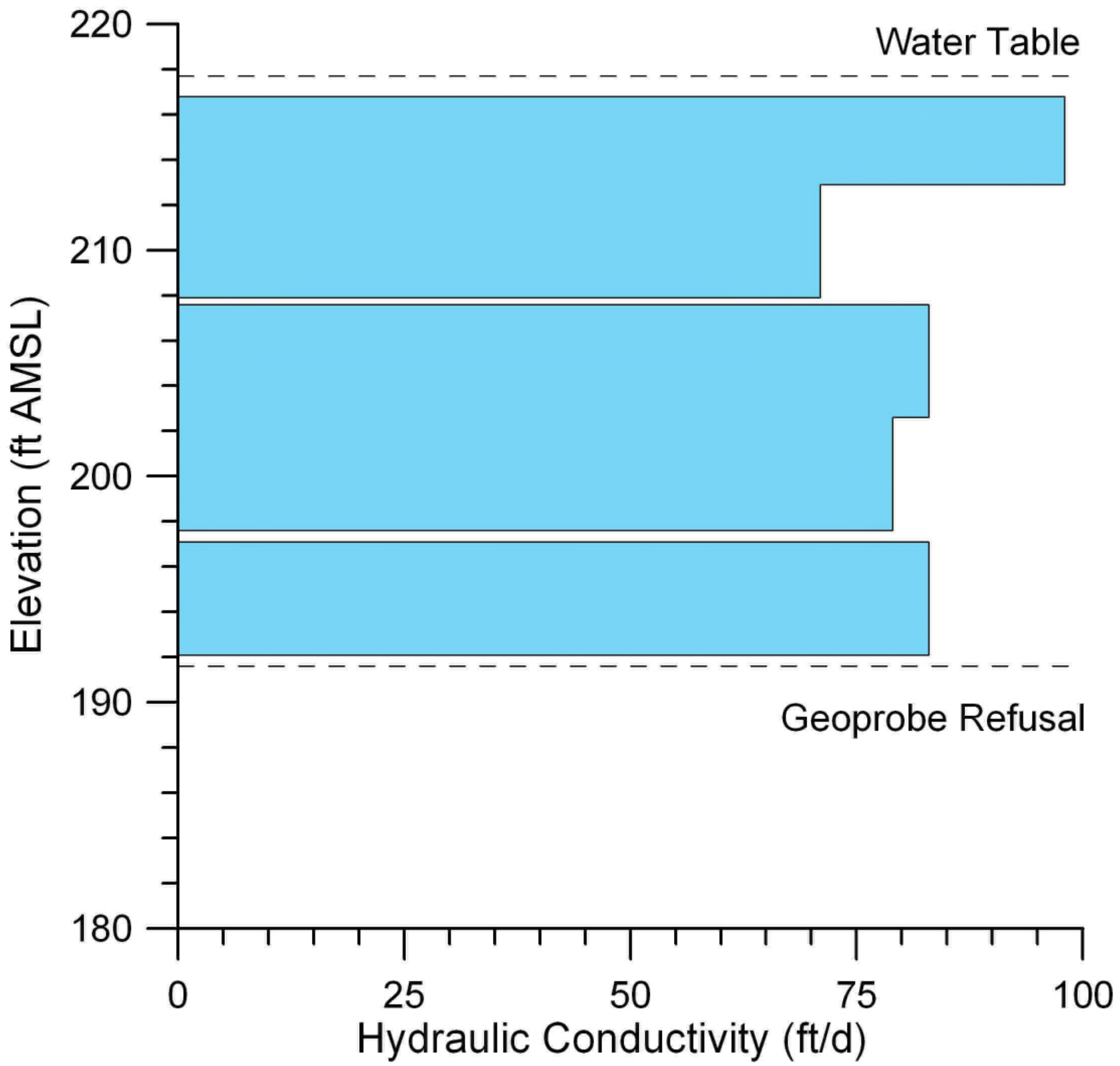

Figure 23. Hydraulic conductivity profile at well cluster RSK8-12. Analyses represent updated solutions relative to the preliminary estimates provided in the previous interim report.

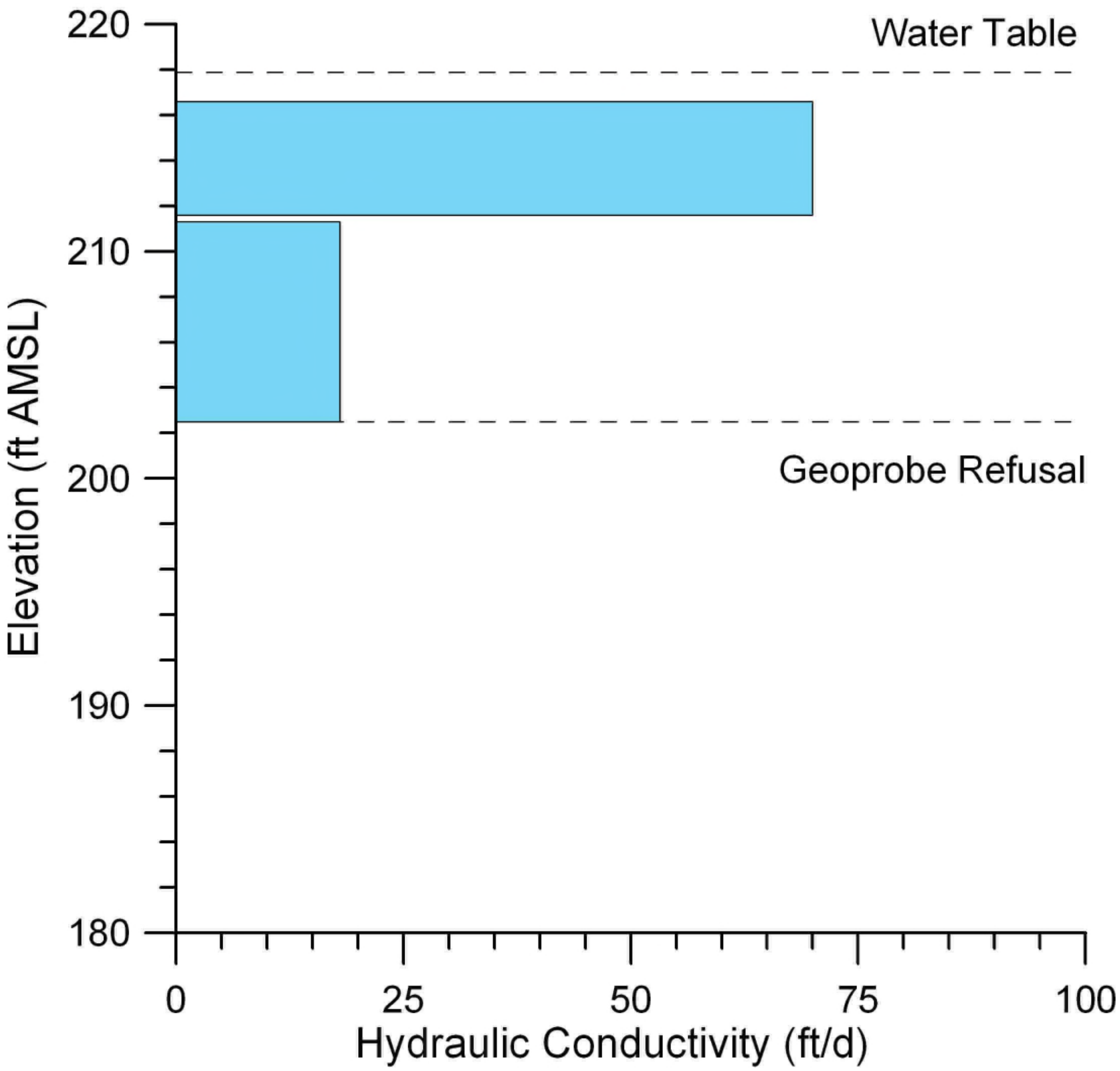

Figure 24. Hydraulic conductivity profile at well cluster RSK13-15.

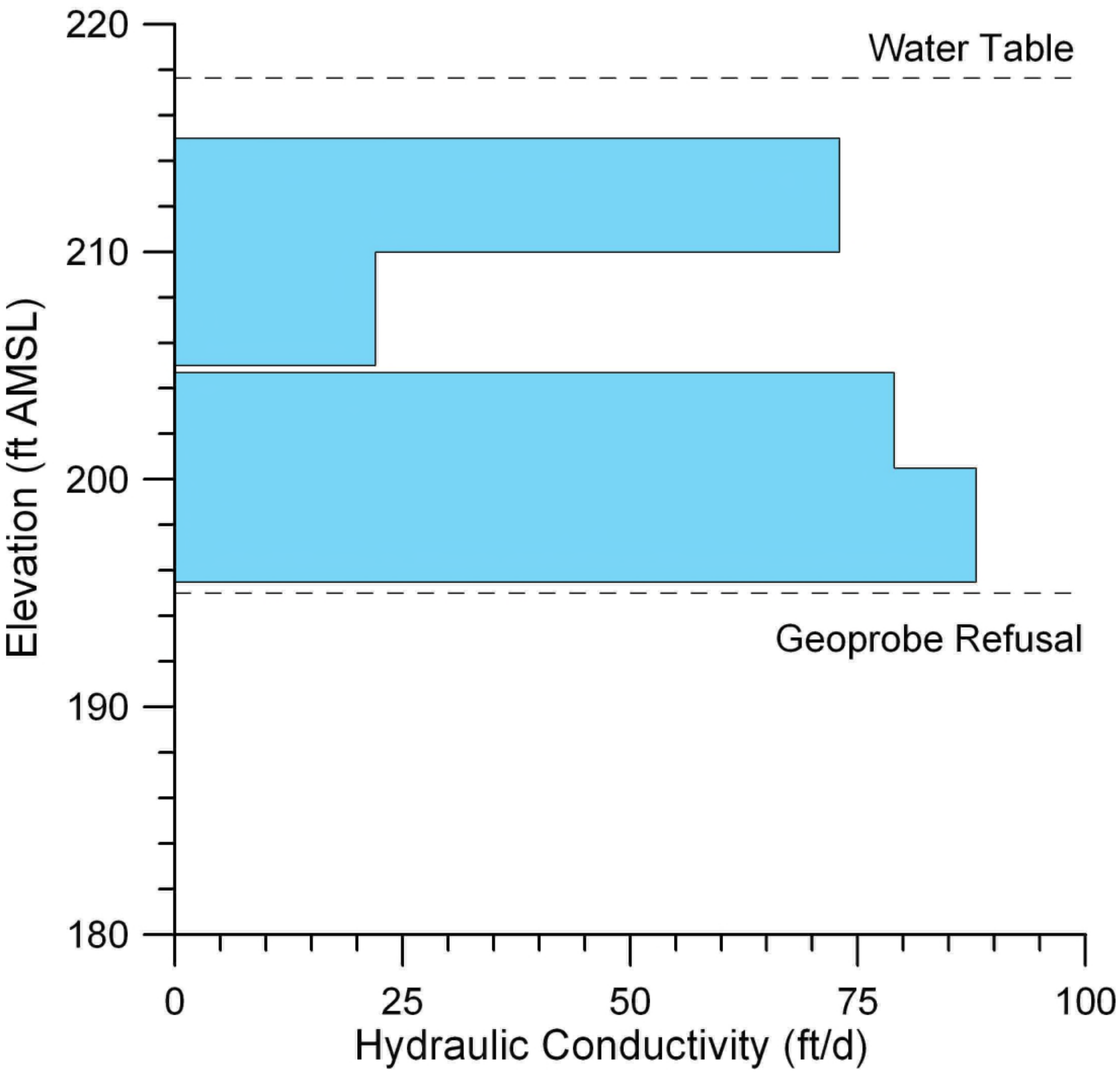

Figure 25. Hydraulic conductivity profile at well cluster RSK16-21.

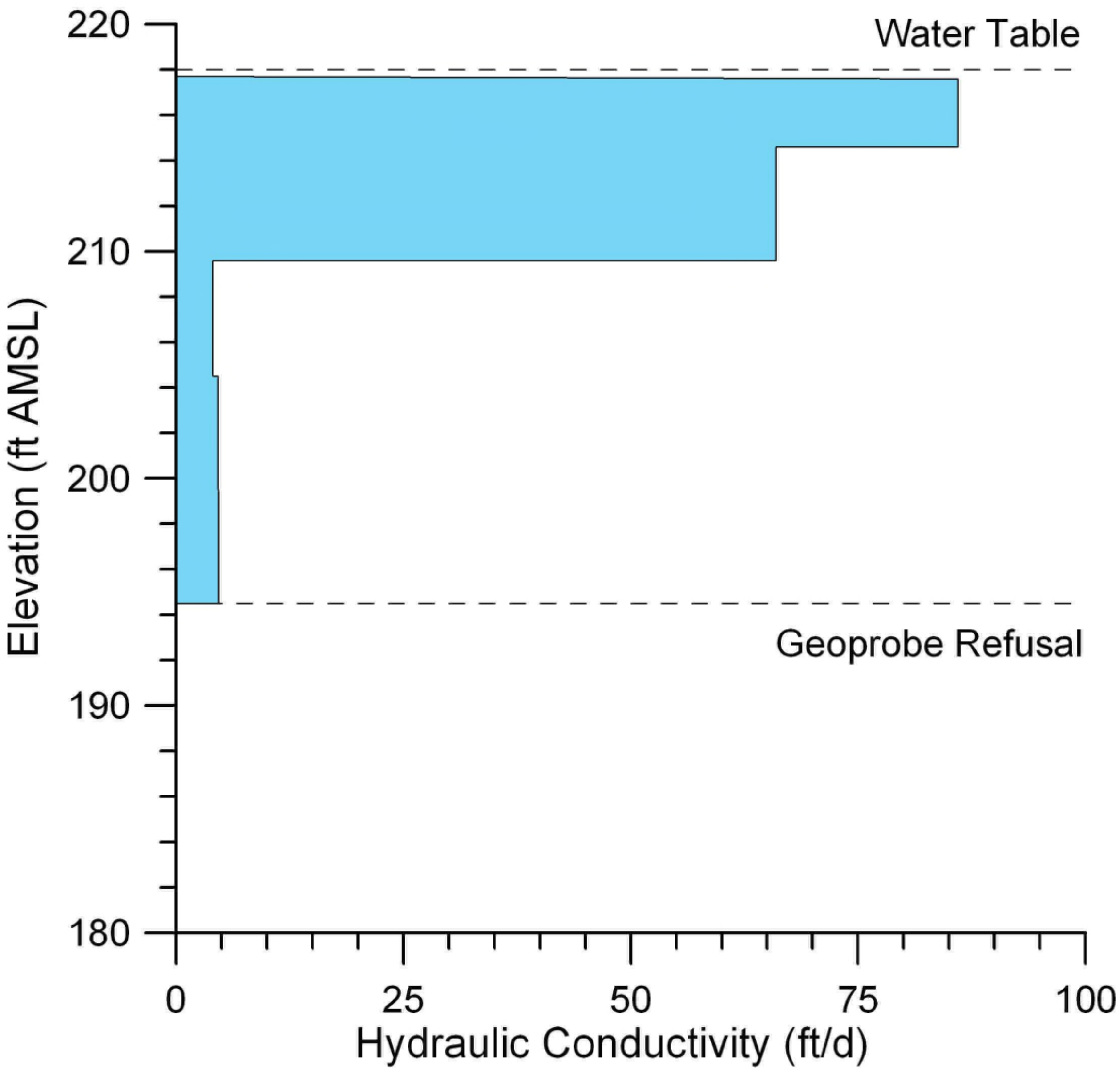

Figure 26. Hydraulic conductivity profile at well cluster RSK36-43.

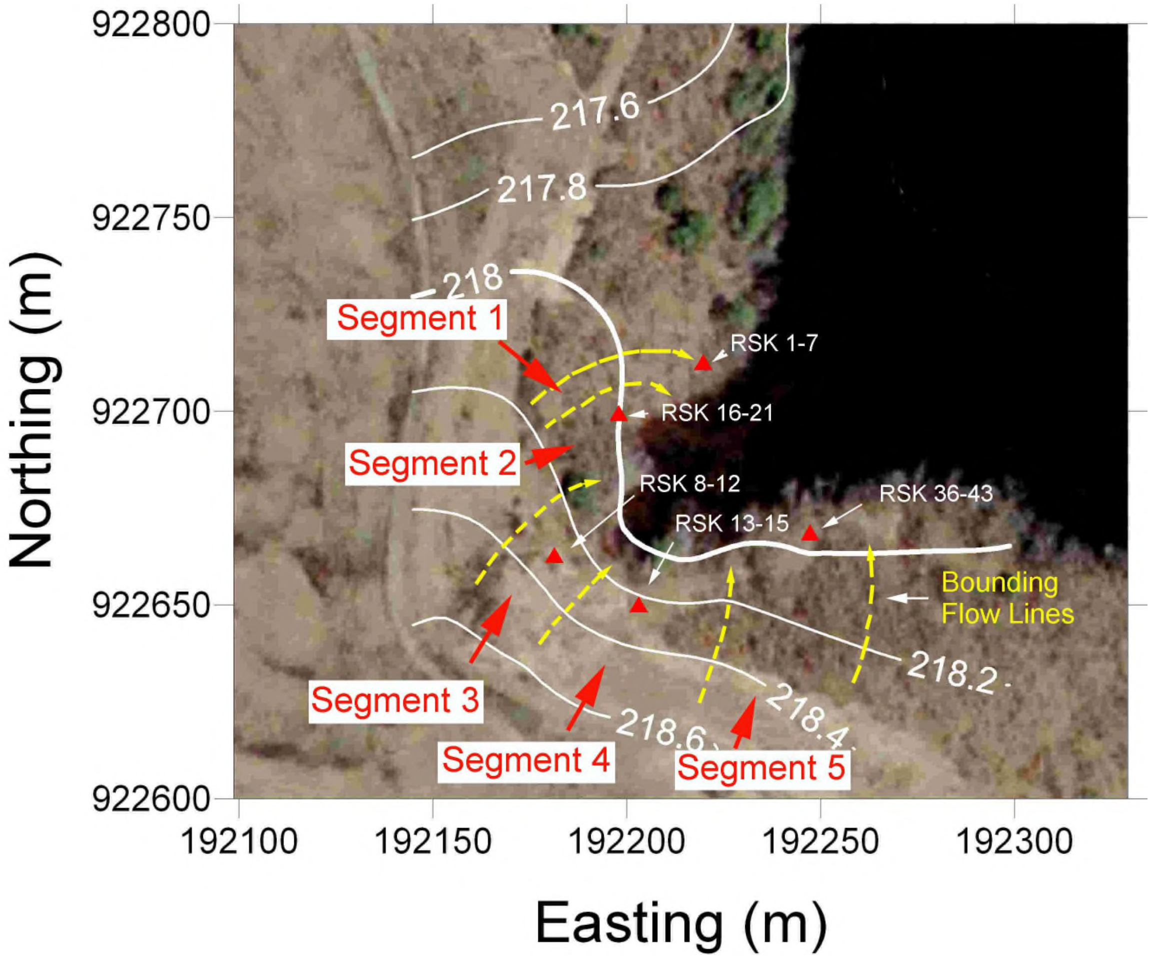

Figure 27. Potentiometric surface on November 7, 2007, and typical example of flowpaths used in estimation of groundwater and dissolved arsenic flux. Well clusters used in flux calculations are depicted as red triangles. Groundwater elevation contours are depicted in units of feet with a contour interval of 0.2 ft.

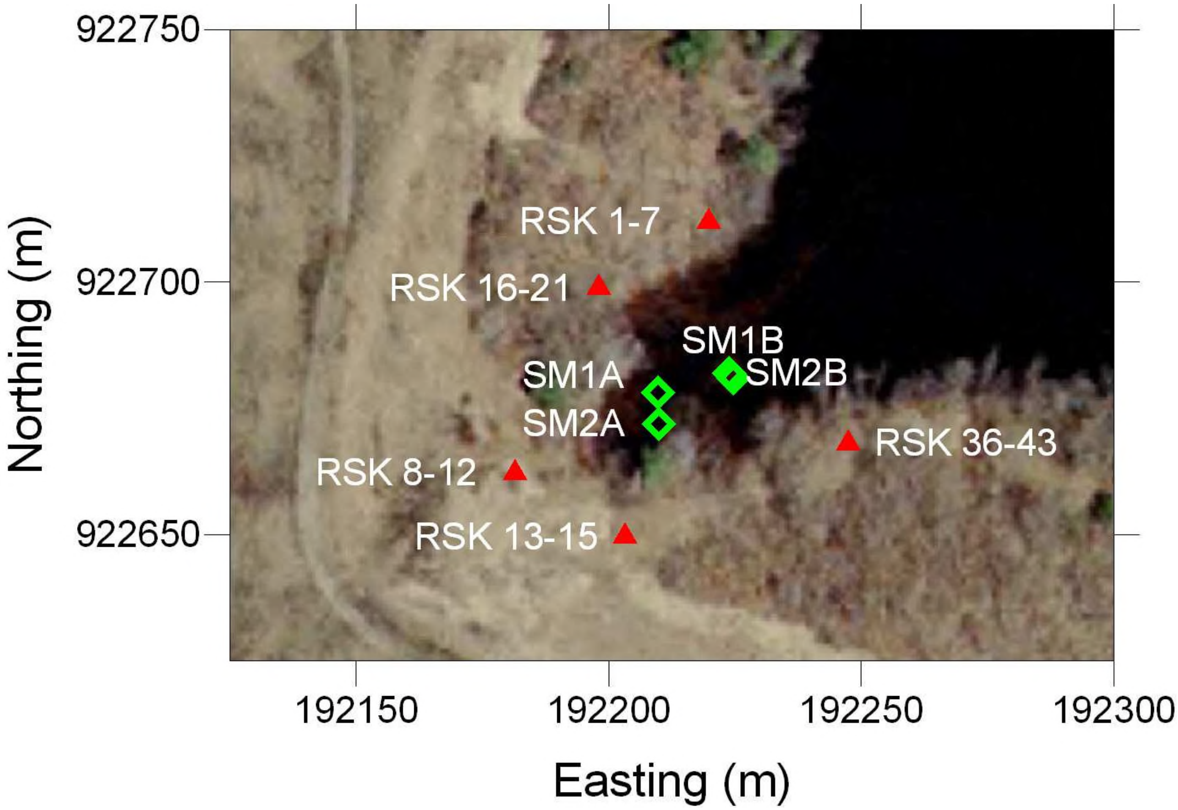

Figure 28. Approximate locations of seepage measurements made using an advective flux meter (green diamonds).

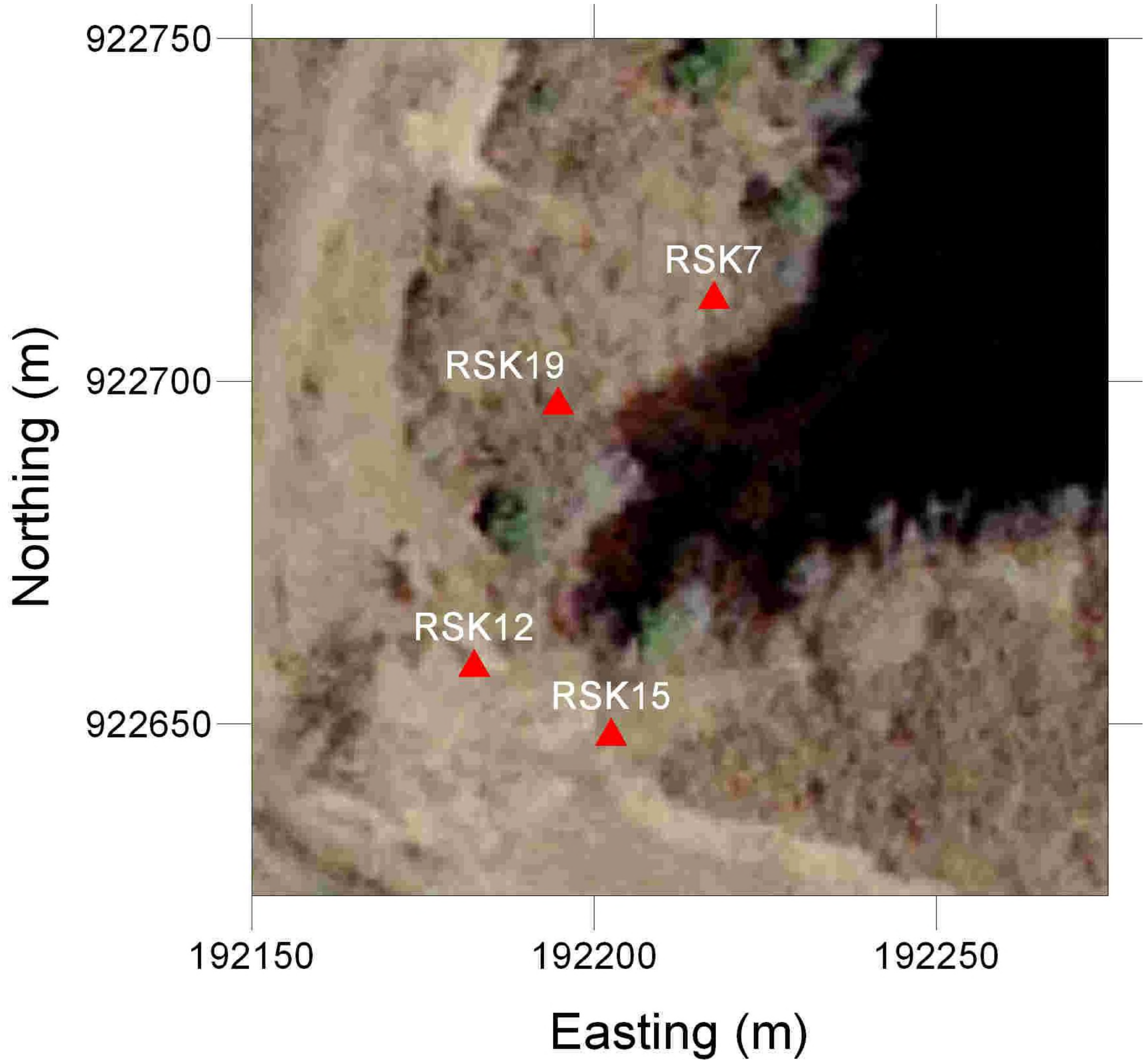

Figure 29. Locations of wells screened at the water table where groundwater temperatures were measured using data loggers.

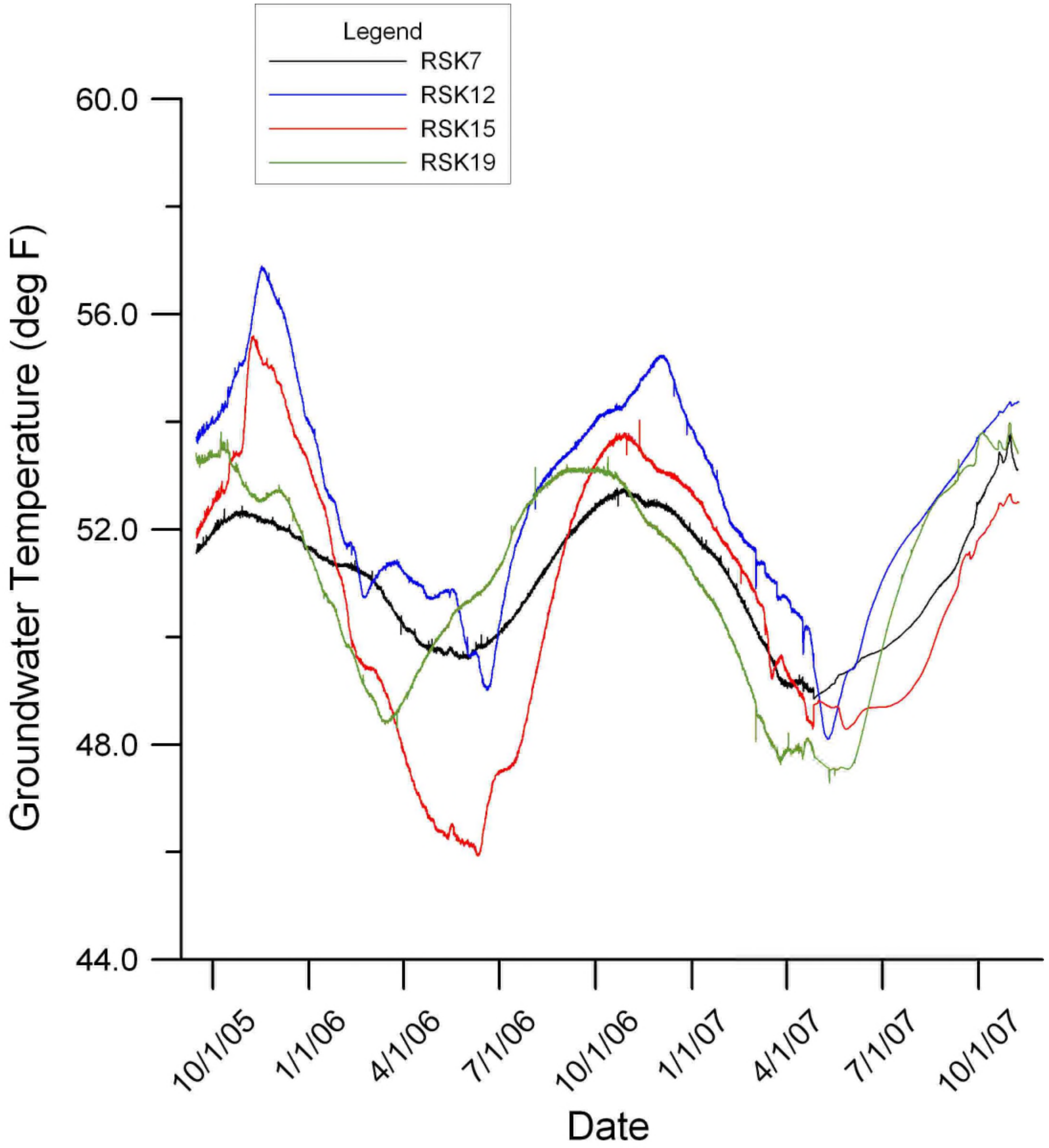

Figure 30. Groundwater temperature measured using data loggers in wells screened at the water table surrounding Red Cove.

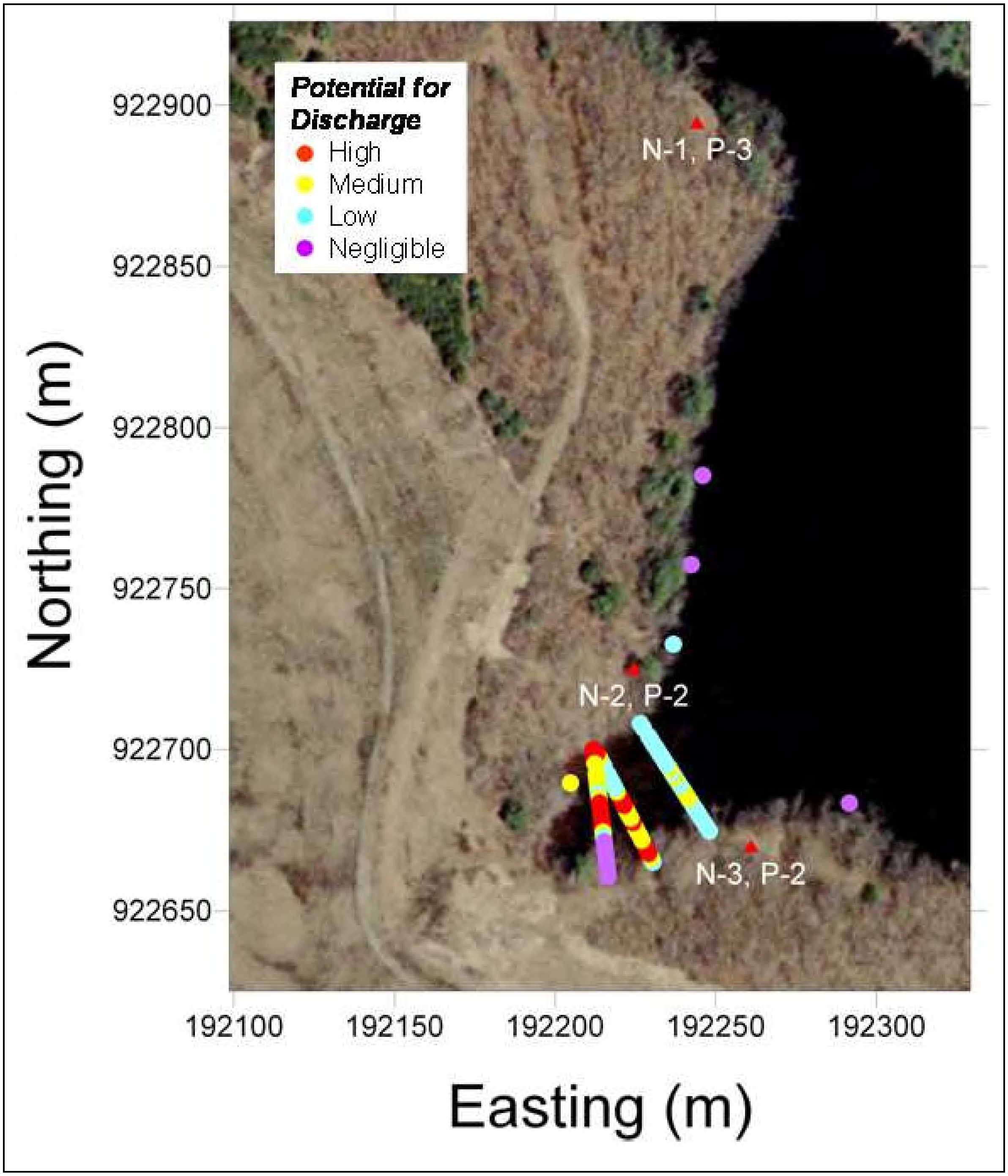

Figure 31. Classed posting map of sediment temperatures at 8:00 a.m. on March 20, 2007 (groundwater temperature range was 49-51 deg F). Temperatures were classed using the following ranges: Red (48 deg F to < 52 deg F), Yellow (46 deg F to < 48 deg F), Blue (40 deg F to < 46 deg F), and Purple (33 deg F to < 40 deg F). Wells N1,P3; N2,P2; and N3,P2 are plotted (red triangles) for reference.

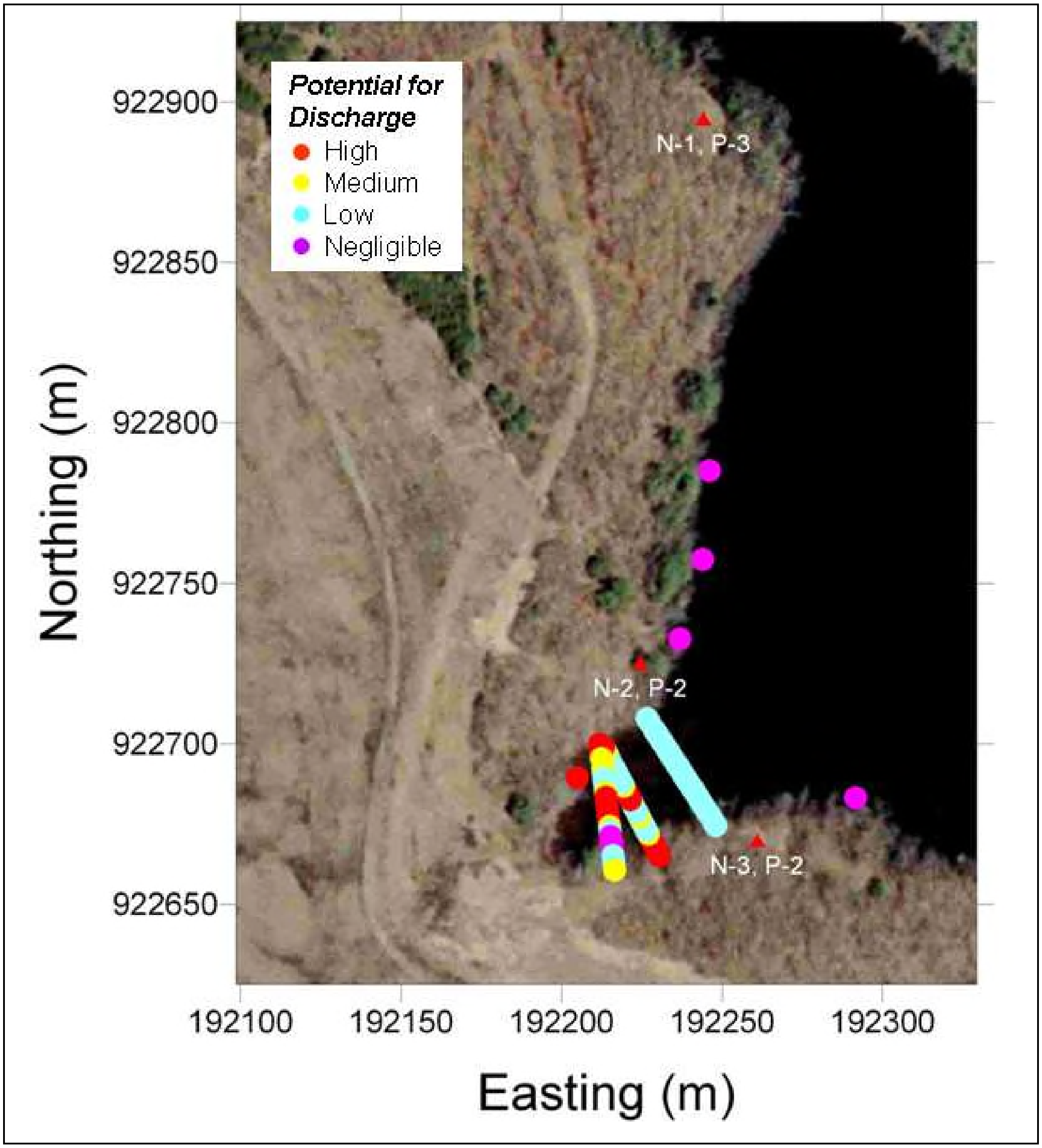

Figure 32. Classed posting map of sediment temperatures at noon on August 22, 2007 (groundwater temperature range was 50-53 deg F). Temperatures were classed using the following ranges: Red (49 deg F to < 53 deg F), Yellow (53 deg F to < 55 deg F), Blue (55 deg F to < 60 deg F), and Purple (60 deg F to < 66 deg F).

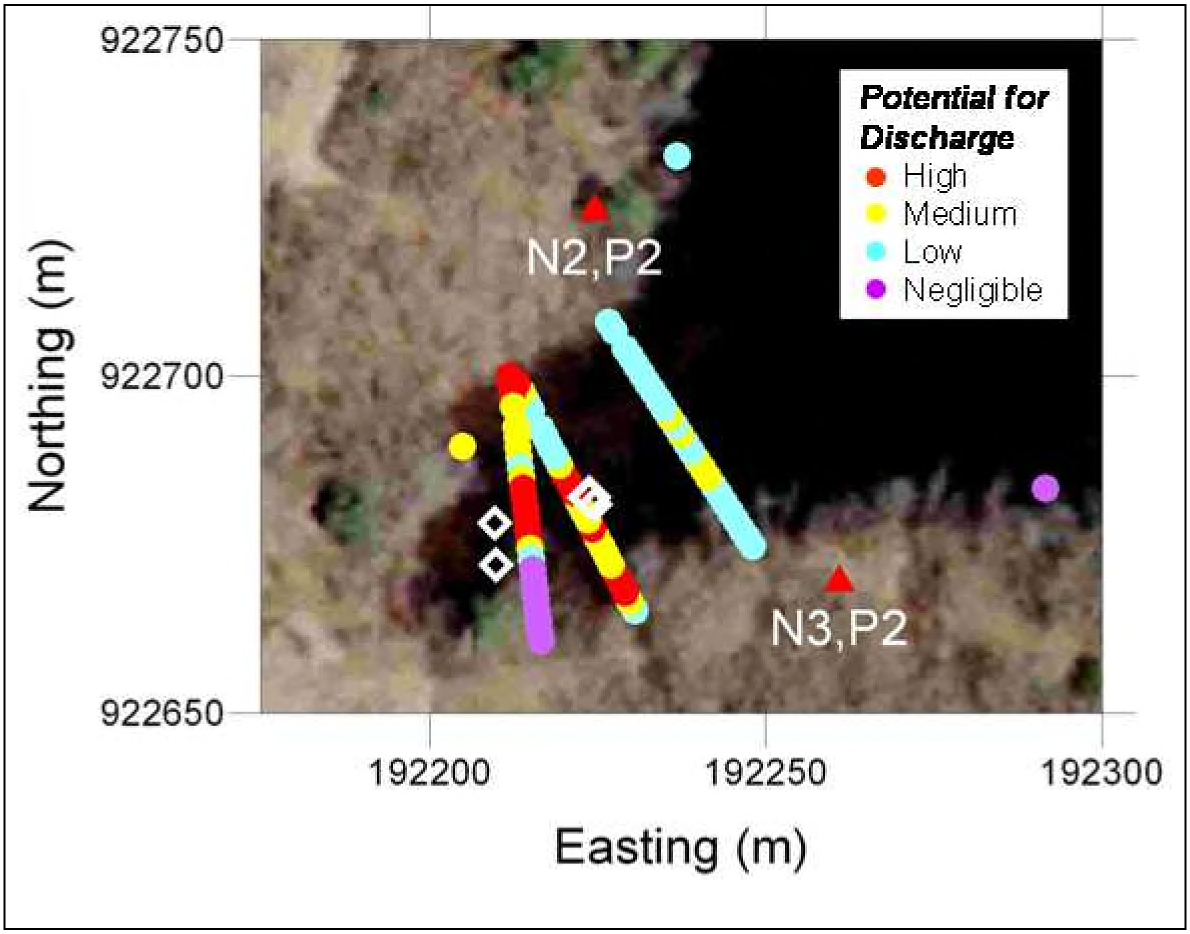

Figure 33. Zoomed portion of classed posting map of sediment temperatures at 8:00 a.m. on March 20, 2007 in Red Cove (groundwater temperature range was 49-51 deg F). Temperatures were classed using the following ranges: Red (48 deg F to < 52 deg F), Yellow (46 deg F to < 48 deg F), Blue (40 deg F to < 46 deg F), and Purple (33 deg F to < 40 deg F). Locations where the advective flux meter was deployed in Red Cove are plotted as white diamonds. Wells N2,P2 and N3,P2 are plotted (red triangles) for reference.

Table 1. Average groundwater elevations in shallow wells surrounding Red Cove compared to surface water elevations measured at STAFF1 for the period August 2, 2006 to November 7, 2007.

Monitoring Location	Water Elevation (ft AMSL)	Groundwater Elevation Minus Surface Water Elevation * (ft)
RSK7	217.40	0.11
RSK12	218.16	0.87
RSK15	218.02	0.73
RSK19	217.68	0.39
STAFF1	217.29	

* Positive differences in elevations indicate a potential flow direction toward the pond.

Table 2. Average groundwater elevations in shallow wells surrounding Red Cove compared to surface water elevations measured at STAFF1 for the period October 4 to October 19, 2007.

Monitoring Location	Water Elevation (ft AMSL)	Groundwater Elevation Minus Surface Water Elevation * (ft)
RSK7	218.38	0.01
RSK12	218.61	0.24
RSK15	218.55	0.18
RSK19	218.42	0.05
RSK37	218.41	0.04
STAFF1	218.37	

* Positive differences in elevations indicate a potential flow direction toward the pond.

Table 3. Vertical hydraulic gradients at well clusters surrounding Red Cove in 2005/2006.

Well	9/15/05 Groundwater Elevation (ft AMSL)	i_v	8/2/06 Groundwater Elevation (ft AMSL)	i_v	10/19/06 Groundwater Elevation (ft AMSL)	i_v
RSK7	217.14	0.003	217.27	0.011	217.42	0.008
RSK1	217.17		217.38		217.50	
RSK19	217.35	0.003	217.60	0.004	217.65	0.003
RSK16	217.39		217.66		217.70	
RSK12	217.76	NS			218.03	NS
RSK8	217.77				218.05	
RSK15	217.62	NS	218.05	-0.004	217.90	NS
RSK13	217.63		218.01		217.91	

Note: Positive vertical hydraulic gradient (i_v) indicates potential for upward flow.
NS = Not Significant. The hydraulic head difference was less than 0.02 ft.

Table 4. Vertical hydraulic gradients at well clusters surrounding Red Cove in 2007.

Well	4/26/07 Groundwater Elevation (ft AMSL)	i_v	11/7/07 Groundwater Elevation (ft AMSL)	i_v
RSK7	217.65	0.011	217.95	NS
RSK1	217.76		217.97	
RSK19	217.97	0.004	218.05	0.004
RSK16	218.01		218.09	
RSK12	218.59	NS	218.34	NS
RSK8	218.58		218.35	
RSK15	218.56	NS	218.27	NS
RSK13	218.57		218.27	
RSK37	217.76	0.005	217.99	NS
RSK41	217.81		218.00	

Note: Positive vertical hydraulic gradient (i_v) indicates potential for upward flow.
NS = Not Significant. The hydraulic head difference was less than 0.02 ft.

Table 5. Hydraulic head differences between piezometers in Red Cove and surface water.

Piezometer	Date	Hydraulic Head Difference * (ft)	Potential Flow Direction
PZ1	9/11/07	0.25	UP
	11/6/07	0.43	UP
PZ2	9/11/07	0.11	UP
	11/6/07	0.07	UP
PZ3	9/11/07	0.04	UP
	11/6/07	0.03	UP
PZ4	9/11/07	0.01	Not Significant
	11/6/07	0.02	Not Significant
PZ5	9/11/07	0.05	UP
	11/6/07	0.08	UP
PZ6	9/11/07	0.11	UP
	11/6/07	0.14	UP
PZ7	9/11/07	0.07	UP
PZ8	9/11/07	0.00	Not Significant
	11/6/07	0.03	UP
PZ9	9/12/07	0.04	UP
	11/6/07	0.02	Not Significant
PZ10	4/26/07	0.19	UP
	9/12/07	-0.14	DOWN
PZ11	4/26/07	0.04	UP
	9/12/07	-0.27	DOWN
	11/6/07	-0.26	DOWN
PZ12	9/12/07	-0.01	Not Significant
	11/6/07	-0.02	Not Significant

* Hydraulic head differences were calculated by subtracting the depth to water measured in the piezometer from the depth to water measured in the stilling well using a common reference point.

Table 6. Groundwater and Arsenic Flux Calculated from Potentiometric Surface Maps.

Date	**Well Cluster**	**Hydraulic Conductivity (ft/d)**	**Saturated Overburden (ft)**	**Hydraulic Gradient (ft/ft)**	**Water Flux (ft^3/d)**	**Diss. As (mg/l)**	**As Flux (g/d)**
4/26/07	RSK1-7	67	32	0.005	659	0.72	13.4
	RSK8-12	83	27	0.006	1546	0.81	35.5
	RSK13-15	35	15	0.013	767	0.26	5.6
	RSK16-19	66	23	0.007	1129	0.74	23.7
	RSK37-41 (shallow)	75	8	0.011	744	0.01	0.2
	RSK37-41 (deep)	4.4	15	0.011	82	0.34	0.8
				Totals	**4268**		**79.2**
11/7/07	RSK1-7	67	32	0.002	122	0.72	2.5
	RSK8-12	83	27	0.004	662	0.81	15.2
	RSK13-15	35	16	0.004	254	0.26	1.9
	RSK16-19	66	23	0.003	291	0.74	6.1
	RSK37-41 (shallow)	75	8	0.003	243	0.01	0.07
	RSK37-41 (deep)	4.4	15	0.003	27	0.34	0.3
				Totals	**1476**		**26.0**

Table 7. Seepage Flow Measured Using a Bidirectional Advective Flux Meter.

Location	Date	Seepage Flow (ft^3/d)	Flow Direction
SM1A	4/24/07	0.229 +/- 0.060	UP
SM2A	4/24/07	0.224 +/-0.034	UP
SM2B	4/26/07	0.197 +/-0.084	UP
SM1B	4/26/07	0.223 +/-0.039	UP
SM1B	8/21/07	0.158 +/-0.009	UP
SM1B	11/6/07	0.091 +/-0.015	UP

3 Groundwater Chemistry Studies

The objectives of the groundwater chemistry studies performed at the Fort Devens sediments research site included determination of the spatial and temporal patterns in arsenic concentrations adjacent to Red Cove, the chemical speciation of arsenic, and the chemical characteristics of groundwater for the purpose of delineating potential contributions from groundwater underlying Shepley's Hill Landfill and defining the conditions supporting arsenic transport. Investigations included installation of wells adjacent to Red Cove and within the shallow aquifer underlying sediments within Red Cove. Data and results from these studies are discussed below.

3.1 Monitoring Network

Twenty-six (26) monitoring wells with five-foot screens were installed in the overburden in the vicinity of Red Cove to facilitate collection of groundwater samples at different depths within the saturated overburden. Additional details on well construction are provided under the section entitled Hydrologic Studies. The sampled wells were grouped in five clusters around the perimeter of Red Cove and are designated RSK 1-7, RSK 16-20, RSK 8-12, RSK 13-15, and RSK 37-42 (Figure 34). Well clusters RSK 1-7, RSK 16-20 and RSK 37-42 each had two screens completed at similar depths; RSK 3/6, RSK 17/20, and RSK 39/42, respectively. Except for well cluster RSK 37-42, each of the well clusters were sampled at least twice during the period from March 2006 to September 2007 (see Appendices). Sampling at screened interval RSK 2 in the RSK 1-7 cluster was discontinued due to continual silt accumulation within the screen. In addition to wells installed below land surface, a network of ten, short-screened (0.5 foot, stainless steel) well points was installed by hand underneath sediments in Red Cove (Figure 34). These well points were designated RCTW 1-10, and their location relative to surface water sampling within Red Cove are shown in Figure 34. The RCTW wells were sampled at least twice during the period March 2006 to September 2007 (see Appendices). Groundwater chemistry from Wells RCTW 5, RCTW 8 and RCTW 9 are not reported for August 2007 due to visible evidence of damage and inconsistencies in chemical readings from previous sampling events and nearby wells. EPA/ORD also collected groundwater samples from Shepley's Hill Landfill wells N5-P1, N5-P2, SHM-96-22B, and SHM-93-22C on September 13, 2007 for analysis of dissolved methane (September 15, 2007 Memorandum; Ford to Lombardo-Region 1). The elevation of well screens that were installed and sampled by EPA/ORD, as well as select existing wells, is shown in Figure 35. Two cross-sectional views are shown that are generally aligned along an east-west and north-south transect at Red Cove (see Figure 35), although it should be noted that these well screens do not lie on a planar transect. These views demonstrate that EPA/ORD well screens overlap in depth with the depths sampled by existing wells within the Red Cove Study Area for which historical data are available for comparison.

3.2 Groundwater Chemistry Trends: RSK Wells and Shepley's Hill Landfill

The vertical distribution of dissolved (0.45 μm filtered) arsenic in groundwater intercepted by RSK well clusters is shown in Figure 36. Data from all sampling events are shown independently (Appendix, Tables G.1-G.6), revealing a general consistency in arsenic concentration at a given depth over the period of observation (March 2006 – September 2007). Well clusters RSK 1-7, RSK 16-20, and RSK 8-12 all displayed the highest concentrations of arsenic throughout the saturated depth within the aquifer adjacent to Red Cove. Dissolved arsenic concentrations ranged from 400-1000 μg/L (Figure 36). In general, lower concentrations of dissolved arsenic, typically less than 400 μg/L, were observed at well clusters RSK 13-15 and RSK 37-42. There was distinct stratification in the distribution of dissolved arsenic at well cluster RSK 37-42, with concentrations <200 μg/L in the more shallow screened intervals (RSK 37, RSK 38, RSK 39, RSK 42) and ≥500 μg/L for the deepest two screened intervals (RSK 40 and RSK 41). These data also indicate that the higher calculated flux of arsenic for the RSK 16-20 and RSK 8-12 well clusters is attributable to higher concentrations of arsenic in groundwater. In addition, depth profiles for dissolved arsenic acquired via direct-push sampling by EPA Region 1 in 2004 are also shown. Based on the reported locations for these sampling locations (Carol Stein, Gannett-Fleming, Inc.; 12/14/2007 e-mail communication), these data are referenced to well clusters RSK 16-20 (Region 1 location RC1) and RSK 8-12 (Region 1 location RC2). Depth-discrete data for the RC1 vertical profile are fully consistent with observations at RSK 16-20. Disparities exist between data collected at RSK 8-12 and RC2, particularly at mid-depth for these vertical profiles. As a point of reference, historical concentrations of total arsenic reported by the Army are shown for wells SHL-4, SHL-11, SHL-20, and SHP-01-38A. These reported values are consistent with observations at similar depths and location for RSK wells (i.e., SHL-4 and RSK 15; SHP-38A-1 and RSK 12; SHL-20 and RSK 1; SHL-11 and RSK 7).

Vertical trends for a selection of groundwater chemical parameters for RSK wells are shown in Figure 37. Patterns in geochemical parameters that may be indicative of microbially-driven processes are shown for the five RSK well clusters in Figure 38. Alkalinity, as indicated by the concentration of bicarbonate, is lowest in well clusters RSK 13-15 and RSK 37-42 (generally <200 mg HCO_3/L). In general, well clusters RSK 8-12 and RSK 16-20 have the lowest sulfate concentrations and highest ammonia-nitrogen concentrations. This contrasts with well cluster RSK 1-7, which has relatively low concentrations of ammonia-nitrogen and the highest concentrations of sulfate. The observed microbial signature for groundwater chemistry at well clusters RSK 8-12 and RSK 16-20 may be due either to microbial activity within the aquifer at the location of the well screens or due to transport of groundwater that has already been influenced by microbial activity from upgradient source areas. Patterns in major element chemistry for RSK wells and a selection of existing wells adjacent to Red Cove (SHL-4, SHL-11, SHL-20, and SHP-01-38A) and within Shepley's Hill Landfill (south – N7-P1, N7-P2; central – SHP-99-29X, N5-P1, N5-P2; north – SHL-9, SHL-22, SHM-93-22C, SHM-96-22B) are represented by concentrations of chloride, sodium, and potassium in Figure 38 (See Figure 12 for well locations within Shepley's Hill Landfill.). In general, the salt content reflected by these chemical parameters is higher in EPA/ORD well clusters RSK 1-7, RSK 16-20, and RSK 8-12 compared to that observed at RSK 13-15 and RSK 37-42, but all well screen compositions appear to fall along a general linear trend. The salt content in existing wells adjacent to Red Cove is comparable for similar screen depths (i.e., SHL-4, SHL-11, SHL-20, and SHP-01-38A). Salt content for existing wells installed within the landfill generally fall within the range observed at RSK wells. Whereas the trend for Na-Cl composition is very similar for RSK and landfill wells, there appears to be some disparity between the potassium concentration for well N5-P2 installed across the water table within the central portion of the landfill.

Comparison of groundwater arsenic concentrations as a function of iron, calcium, and bicarbonate are shown in Figure 39 for RSK wells and several existing wells within or just north of Shepley's Hill Landfill (south – N7-P1, N7-P2; central – SHP-99-29X, N5-P1, N5-P2; north –

SHL-9, SHL-22, SHM-93-22C, SHM-96-22B) and adjacent to the Red Cove Study Area (SHL-4, SHL-11, SHL-20, and SHP-01-38A). These data demonstrate that there is concurrence between historical and contemporary measurements of groundwater chemistry for existing wells adjacent to Red Cove that are in close proximity to RSK wells (i.e., SHL-4 and RSK 15; SHP-01-38A and RSK 12; SHL-20 and RSK 1; SHL-11 and RSK 7). These data also reveal some disparity in groundwater chemistry observed in existing wells installed within Shepley's Hill Landfill and RSK wells adjacent to Red Cove. Groundwater chemistry at the N7-P1,P2 piezometer cluster appears to be similar to that observed at RSK 13-15 and the shallowest four screen intervals at RSK 37-42. Inspection of the piezometric surface determined for the landfill on December 15, 2006 (Figure 12) indicates the potential for groundwater flow from the location of N7-P1,P2 to a portion of the aquifer screened by well clusters RSK 13-15 and RSK 37-42 adjacent to Red Cove. Examination of groundwater chemistry data for existing wells within the central and northern portions of the landfill indicates disparity in groundwater chemistry relative to that observed at RSK wells. Within the central portion of the landfill, arsenic appears to be highest near the bottom of the aquifer (e.g., N5-P1 and SHP-99-29X) and exceeds the concentration of arsenic in groundwater adjacent to Red Cove by a factor of three to four. The elevation at which the highest arsenic concentration is observed at piezometer pair N5 (~145 ft AMSL) coincides with the elevation of highest arsenic concentration observed in wells located immediately down gradient of the groundwater extraction system (see well SHM-93-22B; Figure 39). It is also evident that chemical conditions vary dramatically as a function of depth in the central portion of the landfill, as reflected by the concentration of bicarbonate and calcium observed at N5-P1 (deep) and N5-P2 (shallow). The concentration of these two constituents is higher near the water table where arsenic concentration is approximately two orders-of-magnitude lower (compare N5-P2 and N5-P1).

In order to better understand these disparities in groundwater chemistry through the saturated thickness of the aquifer, vertical trends in groundwater chemistry for the central and northern portions of the landfill were examined in relation to observations adjacent to Red Cove. This analysis was conducted to assist interpretation of the potential relationships (or lack thereof) between elevated arsenic observed within the landfill and the Red Cove Study Area. Vertical trends in potassium and arsenic are shown for several screened intervals within the landfill and RSK wells in Figure 40. For the central portion of the landfill, the aquifer is screened near the water table (N5-P2, SHP-99-29X) and within bedrock (N2-P1) with approximately 60 feet of saturated aquifer thickness not being sampled. Beyond the northern portion of the landfill, there is a selection of wells that provide reasonable coverage of the entire saturated thickness (SHL-5, SHL-9, SHM-96-5C, SHM-93-22B, SHM-96-5B, and SHL-22) including bedrock (SHM-93-22C). It should be noted that the well screens listed beyond the northern portion of the landfill are not a true cluster of well screens. The aerial distribution of these well locations falls within a circle with an approximate diameter of 60 meters (Figure 40, middle panel). Potassium was chosen as a point of reference relative to groundwater transport, and patterns for this constituent (Figure 40, left panel) were then compared to that observed for arsenic (Figure 40, right panel).

The concentrations of potassium and arsenic observed at RSK wells fall within the range of concentrations observed at wells located within the landfill. Existing wells representative of the southern portion of the landfill (i.e., represented by wells SHL-15, N7-P2, N7-P1 located southwest of Red Cove) show observed potassium and arsenic concentrations that are lower than observed concentrations at EPA/ORD well clusters RSK 8-12, RSK 16-20, and RSK 1-7. There is general correspondence with concentrations of these elements observed at EPA/ORD well clusters RSK 13-15 and RSK 37-42. The concentrations of these constituents are generally lower just beyond the northern portion of the landfill across the saturated thickness corresponding to screen depths at Red Cove (specifically EPA/ORD well clusters RSK 8-12, RSK 37-42, RSK 1-7; approximate elevation >185 ft AMSL). Finally, concentrations of these constituents within the central portion of the landfill bracket observations at the RSK well clusters. In order to capture the potential influence of the groundwater P&T system on these observations, the time trend in potassium and arsenic concentrations during 2006 and part of 2007 just beyond the north portion of the landfill is included in Figure 40. For potassium there appears to be a slight decrease in concentration over the screened depth based on comparison of the mean and standard deviation for the entire data set (January 2006 – October 2007; CH2MHill, 2006; Ginny Lombardo, 12/21/2007 e-mail correspondence) compared to that observed during October 2007 alone (Figure 40, left panel). This same general trend is also apparent for arsenic concentrations observed across the same depth interval, although it is unclear if this is due to ongoing groundwater extraction or seasonal influences in groundwater flow or chemistry. It should be noted that the maximum concentration of potassium occurs at a shallower depth (~165 ft AMSL) than the maximum arsenic concentration (~145 ft AMSL).

One possible source of arsenic in groundwater may be derived from dissolution of natural forms of arsenic present in site soils due to association with iron-bearing minerals such as iron oxides or iron sulfides (Gannett Fleming, 2006). Since there appears to be a general increase in the concentration of arsenic and iron in groundwater from the southern to northern extent of the landfill, calculations were carried out to estimate to what extent this could be attributed to dissolution of site soils. Background soil composition data used to calculate potential ranges of arsenic and iron that could be generated by soil dissolution were taken from the 1993 RI Addendum. For the purpose of calculation, it was assumed that dissolution of soil iron resulted in release of arsenic at a ratio equivalent to that in the soil material. Subsequently, an equivalent arsenic concentration in groundwater was determined for a range of iron concentration that encompassed the range of iron observed in site groundwater (Shepley's Hill Landfill and Red Cove Study Area). The results of these calculated ranges are shown in Figure 41 (left panel) along with groundwater data for RSK wells and existing wells representative of the south (N7-P1, N7-P2, SHL-15) and central (SHP-99-29X, N5-P1, N5-P2) portions of the landfill. The range of possible As-Fe compositions derived from congruent dissolution of all site-derived soils (including compositional outliers) is inclusive of compositions estimated from aquifer fines recovered during development of well screens RSK 2 and RSK 37 (Table 8). Some of the groundwater compositions observed at well cluster RSK 37-42, RSK 13-15, and the north portion of the landfill (SHL-15, N7-P1, N7-P2) could be reasonably explained by the process of soil dissolution. The composition at well screen N5-P2 also falls within the range bracketed by estimated soil contributions, although it should be noted that this calculation approach ignores potential chemical factors (e.g., redox) that could alter the As:Fe ratio in groundwater. In contrast, arsenic concentrations observed in groundwater at well clusters RSK 8-12, RSK 16-20, and RSK 1-7 are significantly higher than that attributable to dissolution of a background soil source. This observation suggests a source of arsenic other than that attributable to shallow background soils. As seen in previous data presentations, the groundwater compositions observed at RSK well clusters with highest arsenic concentrations are bracketed by groundwater compositions from wells SHP-99-29X (or N5-P1) and N5-P2. This suggests the possibility that groundwater compositions observed at EPA/ORD well cluster RSK 8-12 (saturated thickness ~25 feet) may be due to converging groundwater flow lines moving from a portion of the landfill west-southwest of Red Cove where the saturated thickness is approximately 70 feet.

In order to illustrate the concept of converging groundwater flow lines, a cross-section through the aquifer through existing well locations SHP-99-29X and SHL-4 is shown in Figure 42 (bottom panel; approximate locations of RSK 8-12 and RSK 13-15 also shown). An aerial view of these well locations, along with RSK well clusters (color coded), is shown in the top left-hand panel of Figure 42. Based on the calculated potentiometric surface for site groundwater (Figure 12; CH2MHill, 2006), there is no hydrologic evidence to support flow from the portion of the landfill and aquifer screened at locations SHP-99-29X or N5-P1,P2 to groundwater observed to discharge into Red Cove. However, given the lack of alternative locations within the landfill with available chemistry data, estimates of possible groundwater mixing due to converging flow lines must rely on the available contemporaneous data from within the boundary of Shepley's Hill Landfill. Employing observed concentrations of potassium and arsenic at well cluster RSK 8-12 during September 2007, relative mixtures of groundwater from SHP-99-29X & N5-P2 or N5-P1 & N5-P2 can be estimated. Assuming a simplified binary mixture of waters and conservative transport for arsenic or potassium, mixing estimates are shown below. (Note that groundwater from N5-P2 must be included in order to achieve potassium concentrations observed at RSK 8-12.) These calculations should only be viewed as a preliminary estimate of a *potential* source of the groundwater composition observed at RSK well clusters with highest arsenic concentrations. However, these estimates indicate that a mixture of groundwater sources originating from upgradient portions of the landfill could reasonably represent the chemical characteristics of groundwater discharging into Red Cove.

RSK 8-12 Sept 2007 Avg. Composition	Binary Mixture #1		Binary Mixture #2	
	SHP-99-29X 2953 µg As/L 0.6 mg K/L	N5-P2 29.6 µg As/L 21 mg K/L	N5-P1 4451 µg As/L 5.9 mg K/L	N5-P2 29.6 µg As/L 21 mg K/L
734 µg As/L	24%	76%	16%	84%
13.1 mg K/L	39%	61%	52%	48%

Trends in the concentrations of ammonia (as NH_3-N; 2006-2007 period) and methane (September 2007) observed at RSK well clusters support the potential influence of solid waste degradation on groundwater chemistry (Figure 42; upper right-hand panel). There is a general linear relationship between ammonia and potassium in groundwater chemistry observed at RSK well clusters. Of these well clusters, RSK 8-12 and RSK 16-20 show the highest concentrations of ammonia and potassium. In addition, potassium concentrations at these well clusters exceed those observed at existing landfill wells SHP-99-29X and N5-P1. Although there is a more limited dataset, methane concentrations at well clusters RSK 13-15 and RSK 8-12 are generally consistent with the range of methane concentrations observed at existing landfill wells SHP-99-29X, N5-P2 and N5-P1. Based on these trends, elevated concentrations of ammonia and methane could potentially indicate an influence of solid waste degradation on groundwater chemistry, given that existing well N5-P2 is completed within buried landfill material and the proximity of the well screen at SHP-99-29X to buried solid waste. These observations suggest the need for a more complete characterization of the vertical and aerial extent of groundwater constituents within the saturated aquifer underlying the central portion of the landfill, particularly the area that is upgradient to Red Cove relative to groundwater flow potential (CH2MHill, 2006). The potential importance of this data gap is illustrated by examination of the vertical trends in ammonia and methane observed at well clusters N5-P1,P2, RSK 13-15, and RSK 8-12 (Figure 43). The methane concentration observed at well screen RSK 10 is consistent with that observed at shallow well screen N5-P2 within the central portion of the landfill. As illustrated in Figure 43, there is nearly 60 feet of saturated overburden aquifer for which monitoring data are not available within the central portion of the landfill. This data gap for such a large portion of the aquifer in contact with the landfill significantly limits the reliability of estimating the sources or extent of arsenic flux through the aquifer. This presents a significant limitation to understanding arsenic transport to Red Cove, as well as remedial design options that might be available to reduce/eliminate this contaminant discharge.

3.3 Groundwater Chemistry Trends: RSK Wells and Red Cove

Comparison of major element chemistry for shallow groundwater underneath Red Cove and groundwater from RSK wells is shown in Figure 44. A linear trend was fit to the data from RSK wells in order to simplify the presentation. The range of concentrations for chloride, sodium and potassium are highlighted for well clusters RSK 1-7, RSK 16-20 and RSK 8-12. This comparison reveals that the water chemistry in the majority of RCTW wells, with the exception of two locations sampled in 2006, is consistent with the chemical conditions of RSK wells where the highest concentrations of arsenic were observed. As a point of reference, concentrations of chloride, sodium and potassium are also shown for shallow surface water samples collected from Red Cove during 2006-2007. In general, shallow surface water is chemically distinct from shallow groundwater within the cove as demonstrated by the significant disparity in potassium concentrations. The range in potassium concentrations for RCTW wells was 6.1-13.4 mg/L (except RCTW6 at 2.6 and 5.8 mg/L in August 2006 and August 2007, respectively), whereas the observed range for shallow surface water in Red Cove was 1.2-2.0 mg/L during 2006-2007. It should be noted that RCTW6 is located proximate to the region of Red Cove where sediment temperature button data indicated significant influence by surface water (e.g., Figure 33). This information indicates that potassium may be used as a marker to estimate the influence of shallow surface water on chemical characteristics in shallow groundwater and deep surface water proximate to sediments within Red Cove.

Snapshots of shallow groundwater chemistry underlying Red Cove are shown in Figures 45 and 46. These data were collected from shallow RCTW wells that were sampled during August 2006 and August 2007. These discrete data were used to generate isoconcentration contours for the portion of the cove in which RCTW wells were installed. In general, these observations indicate that the highest arsenic concentrations in shallow groundwater occur within the central portion of the cove, although this observation is limited somewhat by the number and distribution of monitoring points. Analysis of the chemical speciation of arsenic in groundwater indicates that arsenite [As(III)] is the predominant form in both RSK and RCTW wells (Figure 47). Measurement for the chemical species arsenate [As(V)], MMA and DMA indicated these species were present at or below the analytical detection limit (generally <15 μg/L). Patterns in the concentration of bicarbonate, dissolved iron and sulfate also suggest that microbial sulfate-reduction may be occurring within the southeast area of the cove. Generally, microbial sulfate reduction would result in elevated alkalinity and depressed sulfate concentrations. If reduced iron were present, it would likely be scavenged from groundwater during precipitation of iron sulfide. These chemistry patterns were generally consistent for both monitoring dates.

3.4 Groundwater Chemistry Summary

Comparison of water chemistry data from multiple sources and sampling dates indicates general consistency among existing wells adjacent to Red Cove and EPA/ORD well installations monitored as part of this study. Based on hydrologic data reported in the previous section and the depth distribution of arsenic within the overburden adjacent to Red Cove, elevated concentrations of arsenic can be attributed, in part, to groundwater from the aquifer underlying Shepley's Hill Landfill. While chemical mixing calculations for groundwater sampled under the central portion of the landfill are reflective of chemical characteristics observed at well cluster RSK 8-12, the lack of available chemistry data or monitoring points for reasonable upgradient groundwater flow paths prevents identification of the source of elevated arsenic discharging to Red Cove. For RSK wells, elevated arsenic concentrations generally correlate with reducing conditions that maintain elevated concentrations of reduced iron in groundwater. Comparison of water chemistry in shallow groundwater underlying Red Cove (RCTW wells) and the chemistry of shallow surface water indicates that groundwater discharge constitutes a significant source of arsenic in Red Cove. Analysis of patterns in potassium concentrations throughout groundwater and surface water indicate that this constituent, in combination with shallow sediment temperature data, provides a reasonable tracer for mapping locations of arsenic plume discharge into Red Cove. The pattern in potassium concentrations in RCTW wells relative to shallow surface water is consistent with the interpreted distribution of groundwater discharge within Red Cove as reflected by in-situ measurements of groundwater discharge and shallow sediment temperature.

3.5 References

CH2MHill, 2006 Annual Report, Shepley's Hill Landfill Long Term Monitoring & Maintenance, Devens, Massachusetts". Prepared for the Department of the Army, BRAC Environmental, Devens, Massachusetts.

Gannett Fleming, Inc., 2006. "Final Expanded Site Investigation, Grove Pond and Plow Shop Pond, Ayer, Massachusetts", prepared for the U. S. Environmental Protection Agency, Region 1, Boston, Massachusetts. (http://www.epa.gov/ne/superfund/sites/devens/246620.pdf)

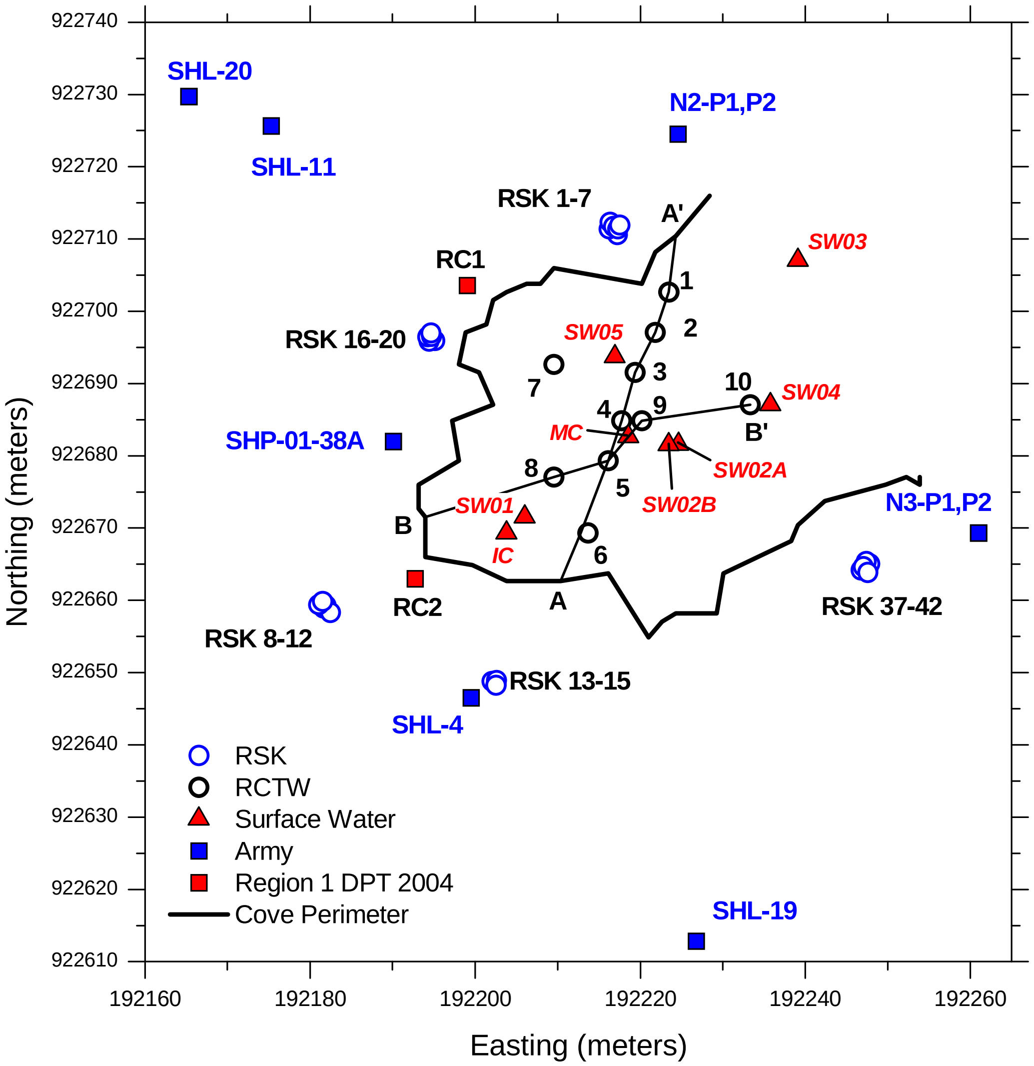

Figure 34. Aerial locations of RSK and RCTW wells installed by EPA/ORD within the groundwater aquifer adjacent to and underlying Red Cove. The locations of nearby wells installed by the Army are shown for reference. Estimated locations are shown for EPA Region 1 direct-push sampling locations conducted in 2004. Sections labeled A-A’ and B-B’ are referenced in Figure 35.

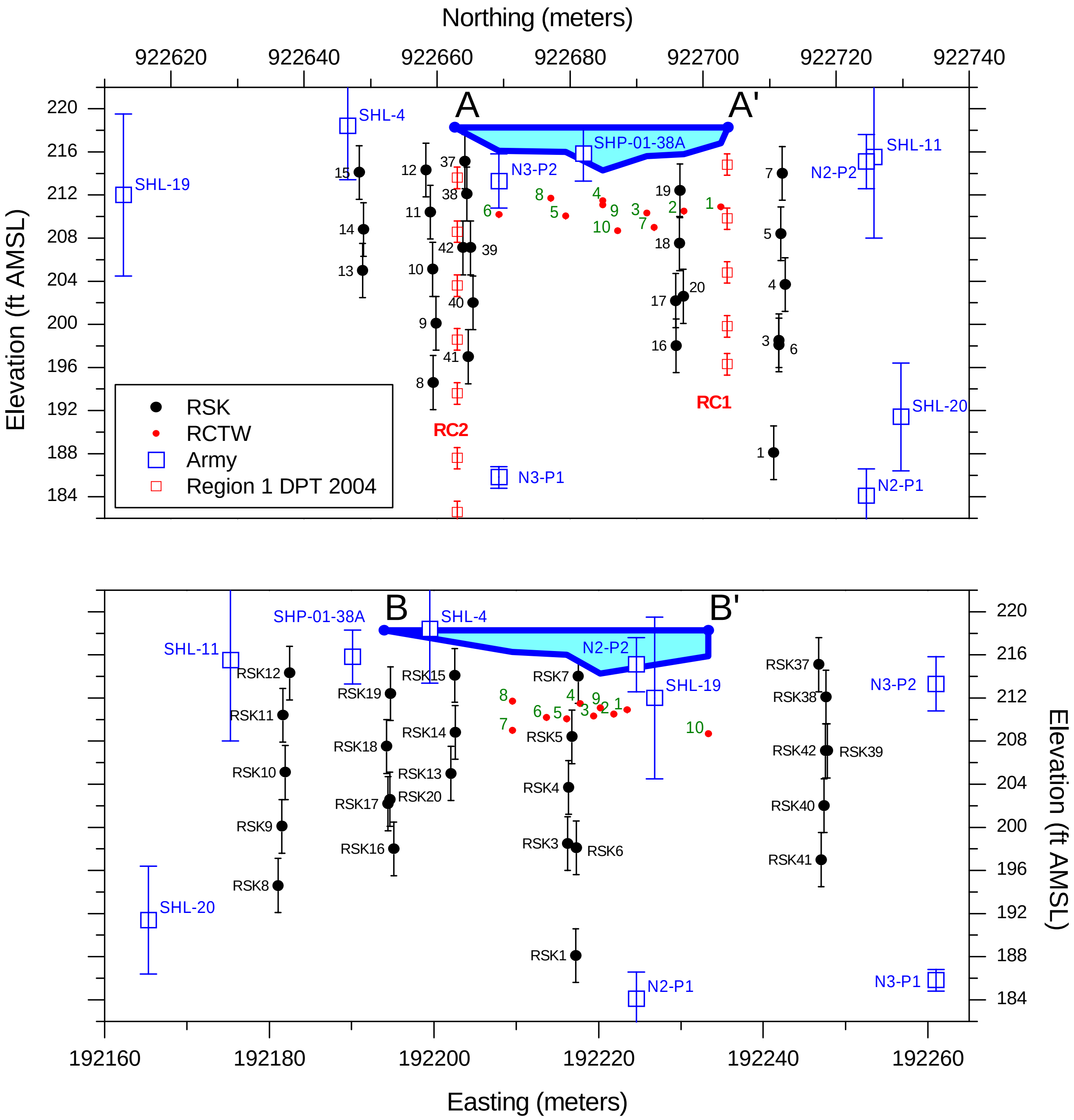

Figure 35. Cross-sectional view of the distribution of screened depths of the EPA/ORD groundwater chemistry monitoring network (RSK and RCTW wells) and nearby wells installed by the Army. Two views are shown consistent with sections A-A’ and B-B’ depicted in Figure 29. Well mid-depth and screen length are depicted as a data point with error bars. Surface water in Red Cove is represented by the blue shaded region.

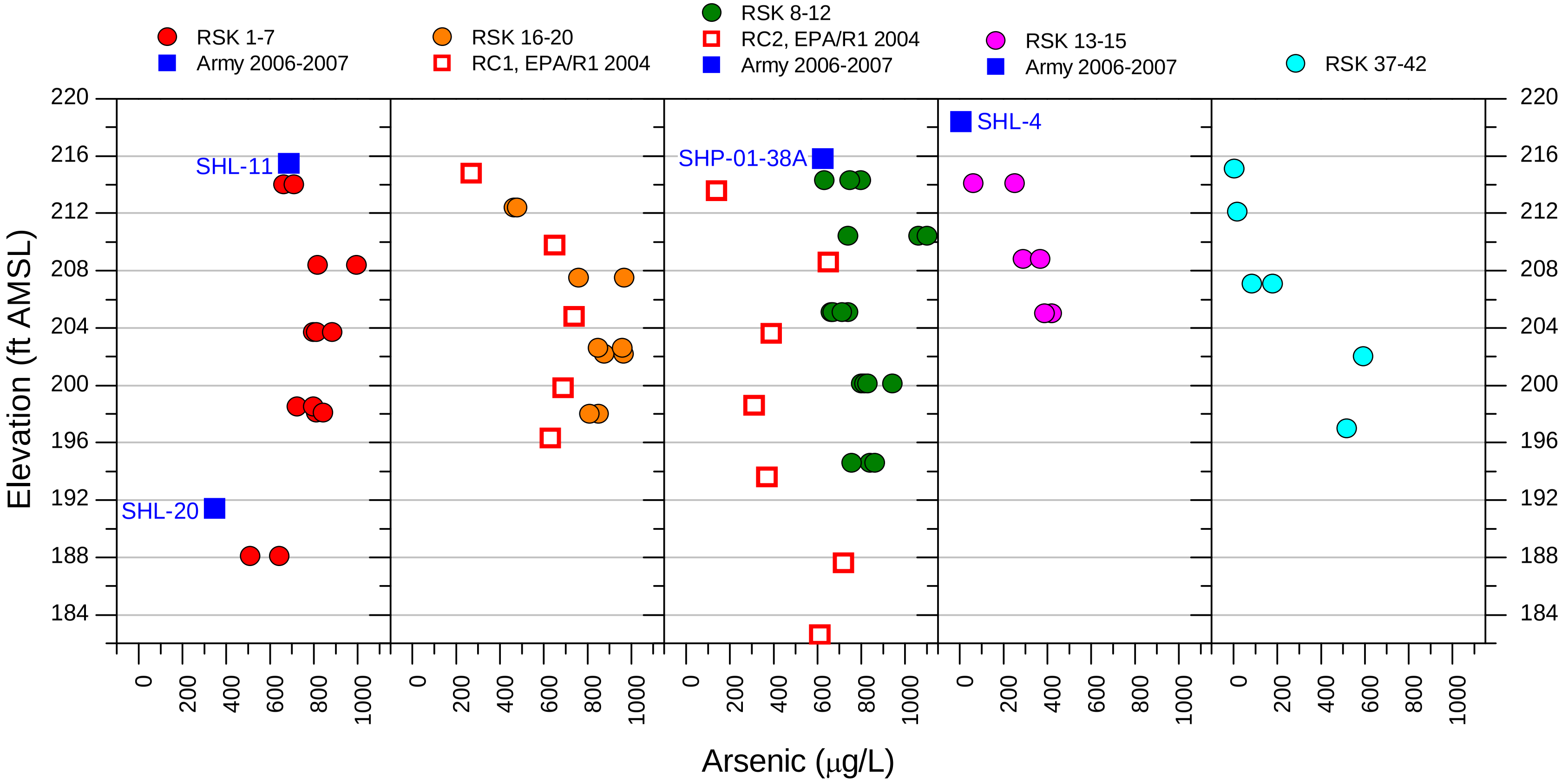

Figure 36. Distribution of dissolved (0.45 μm filtered) arsenic as a function of depth within the aquifer adjacent to Red Cove; all data collected for RSK wells are shown. Also shown are dissolved arsenic concentrations for samples collected at locations RC1 and RC2 by Region 1 in 2004 using direct push sampling technology. Average total arsenic concentrations reported for 2006-2007 are shown for nearby Army wells. The depth distribution of hydraulic conductivity measured for RSK well screens is shown for reference.

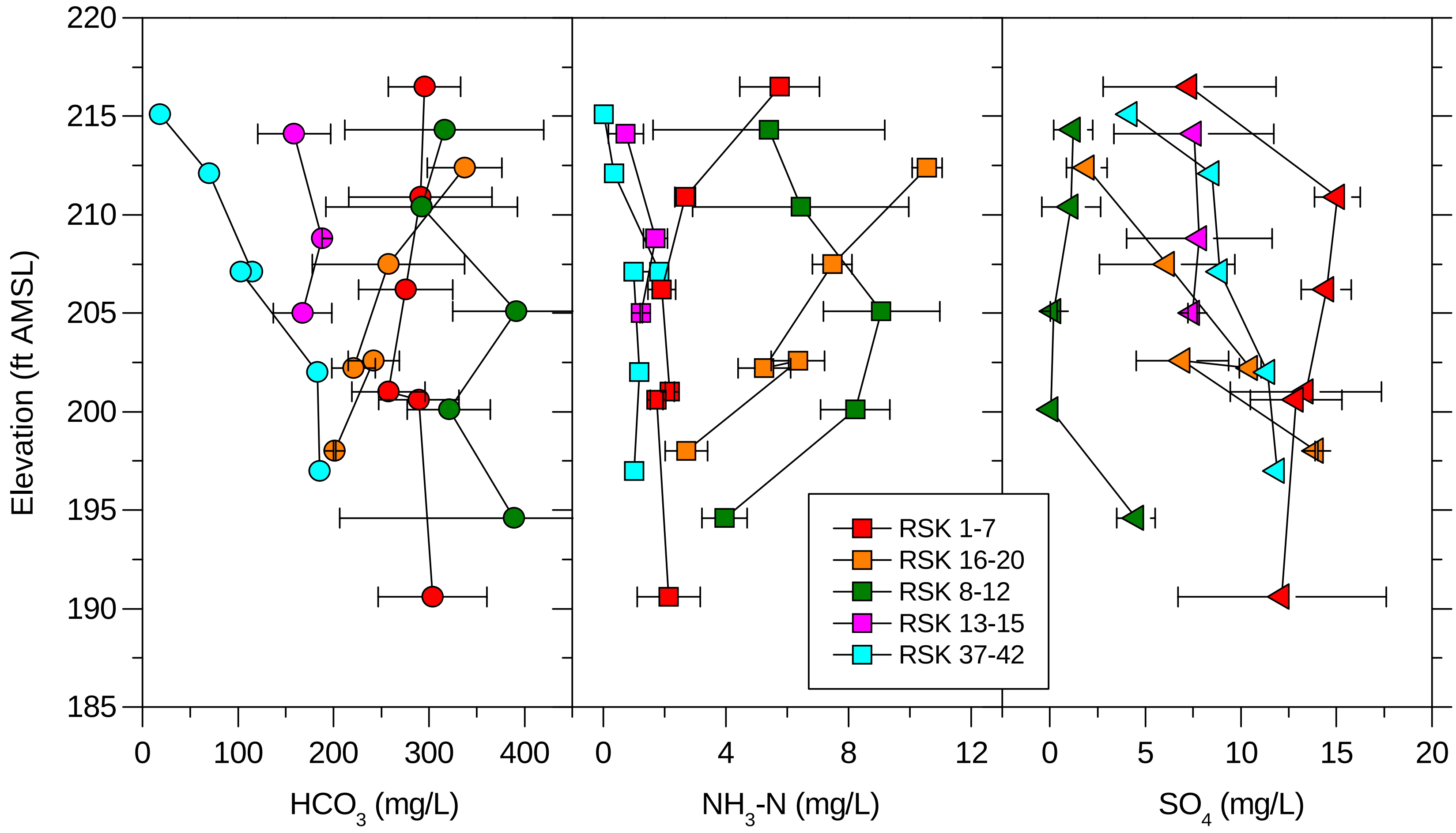

Figure 37. Comparison of bicarbonate (HCO_3), ammonia-nitrogen (NH_3-N) and sulfate (SO_4) concentrations as a function of depth among all RSK well clusters. The mean and standard deviation is shown for all sampling dates (see Appendices for individual data). (Values for HCO_3 can be calculated from alkalinity by the following formula: HCO_3 (mg/L) = 1.219 * Alkalinity (mg $CaCO_3$/L).)

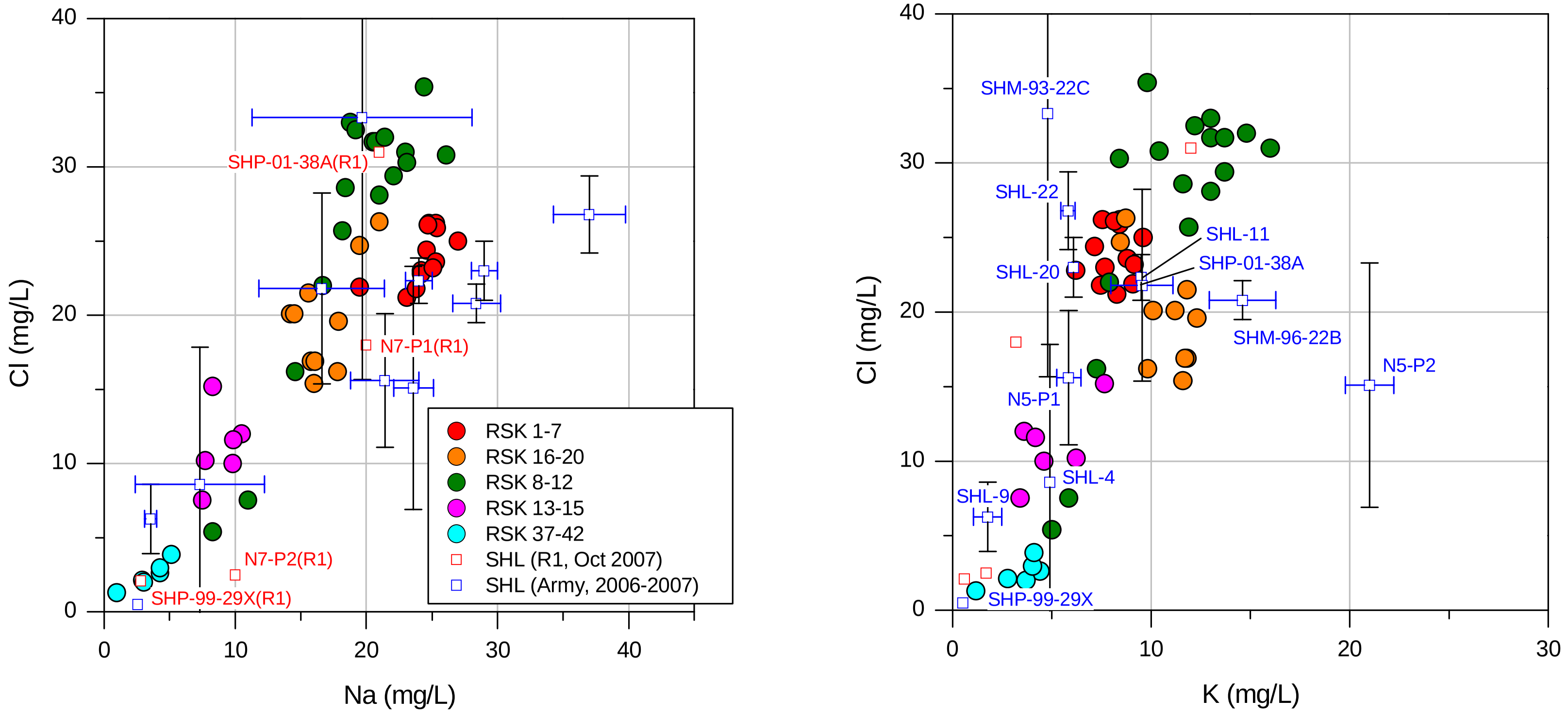

Figure 38. Patterns in the concentrations of dissolved (0.45 µm filtered) sodium (Na), potassium (K), and chloride (Cl) are shown for RSK wells. Also shown are similar dissolved concentration data collected by Region 1 in October 2007 for a select set of Army wells, as well as the average and standard deviation of all total concentration measurements conducted by the Army in 2006-2007. See Appendix A for location of all Army wells within and adjacent to Shepley's Hill Landfill.

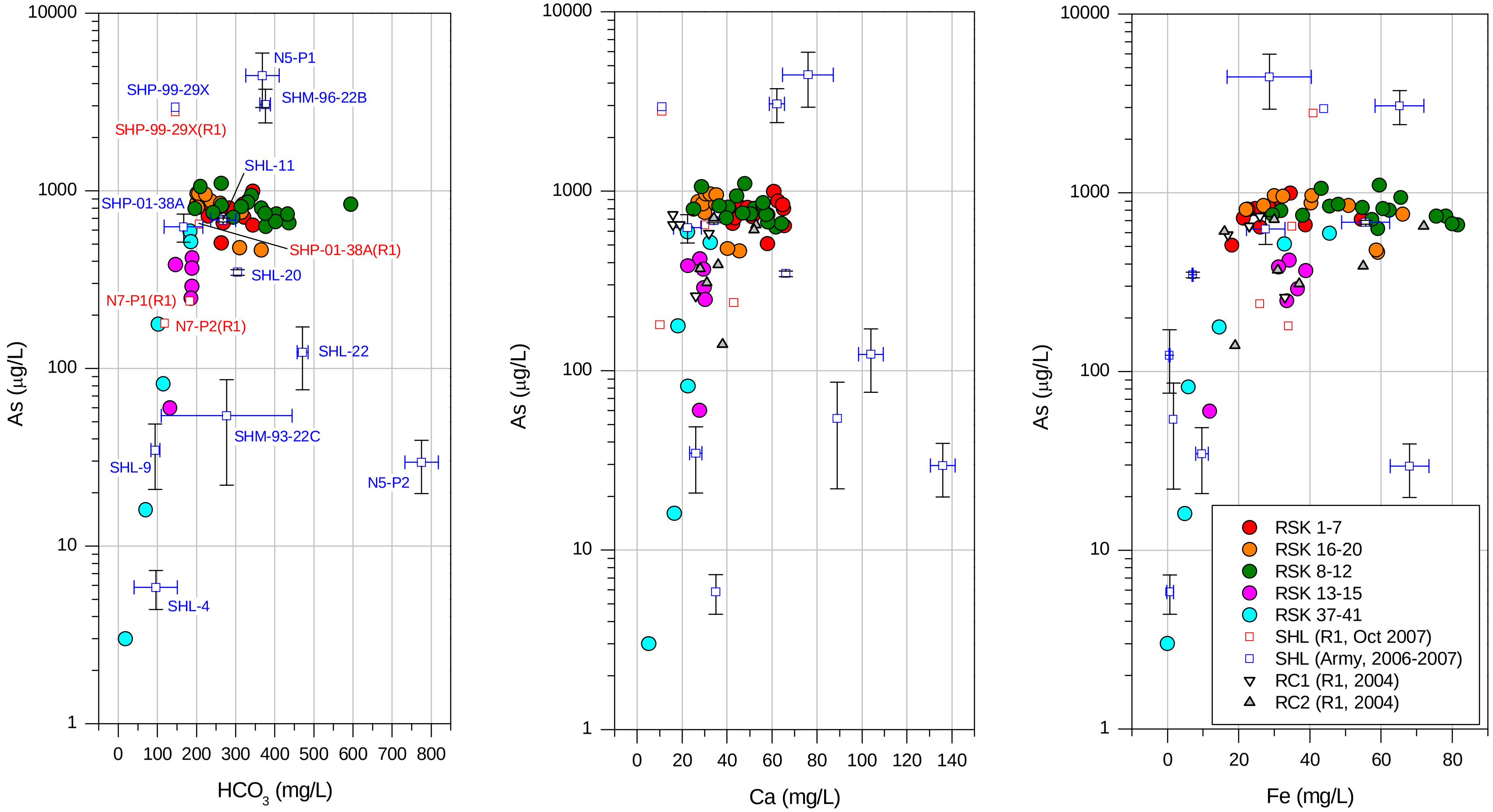

Figure 39. Patterns in the concentrations of bicarbonate (HCO_3), dissolved (0.45 µm filtered) calcium (Ca), dissolved iron (Fe), and dissolved arsenic (As; 0.45 µm filtered) are shown for RSK wells. Also shown are similar dissolved concentration data collected by Region 1 in October 2007 for a select set of Army wells, as well as the average and standard deviation of all total concentration measurements conducted by the Army in 2006-2007. Data for As, Ca, and Fe are shown for direct-push samples collected by Region 1 in 2004 adjacent to Red Cove.

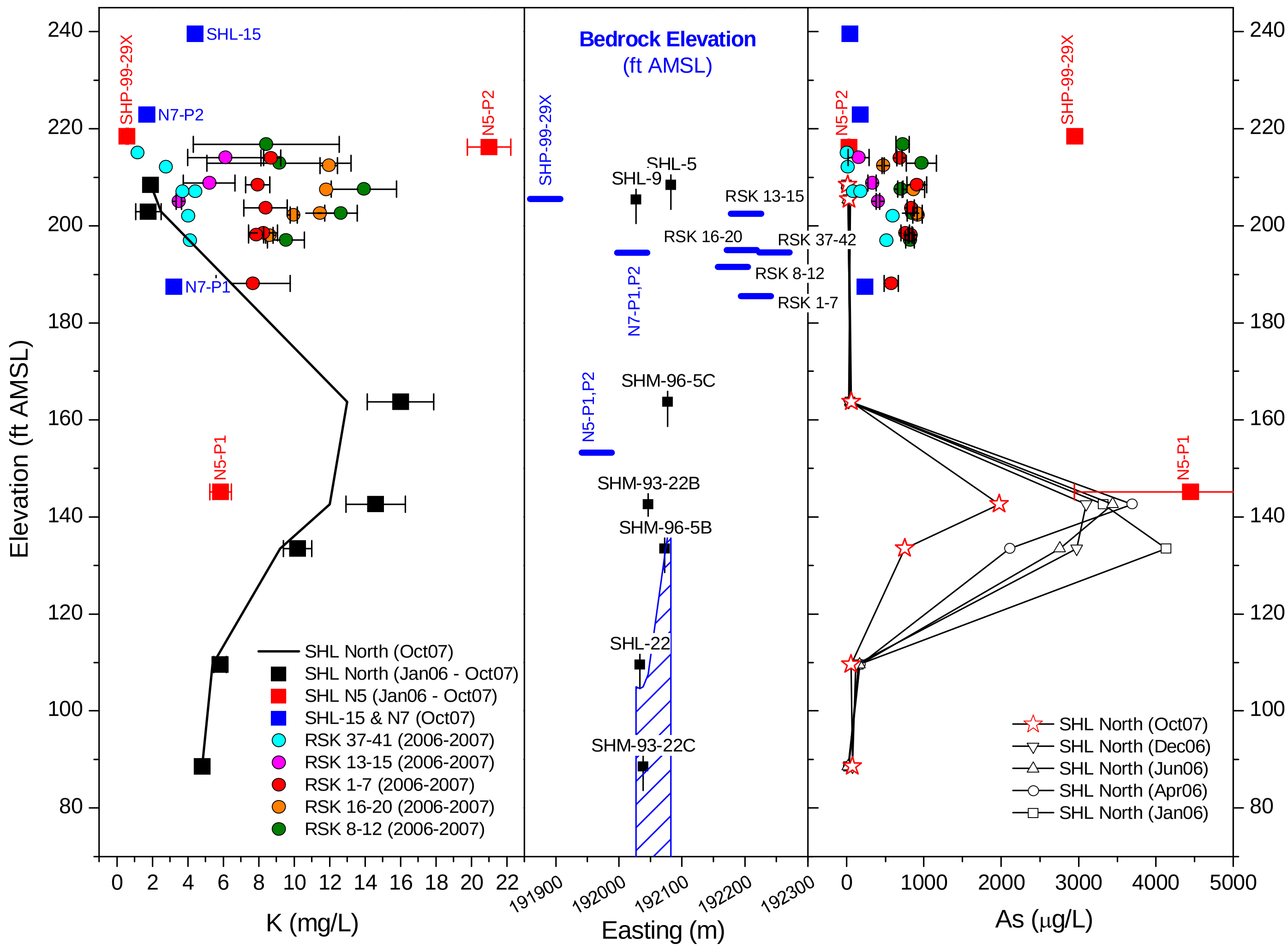

Figure 40. Vertical trends in groundwater chemistry for RSK wells and existing wells within the southern, central portions and just north of Shepley's Hill Landfill (SHL). Left panel – potassium concentration as a function of screen elevation; middle panel – elevation of bedrock for displayed wells (blue hashed area for wells in northern portion of SHL); right panel – arsenic concentration as a function of screen elevation. 'SHL North' refers to wells SHL-5, SHL-9, SHM-96-5C, SHM-93-22B, SHM-96-5B, SHL-22, and SHM-93-22C.

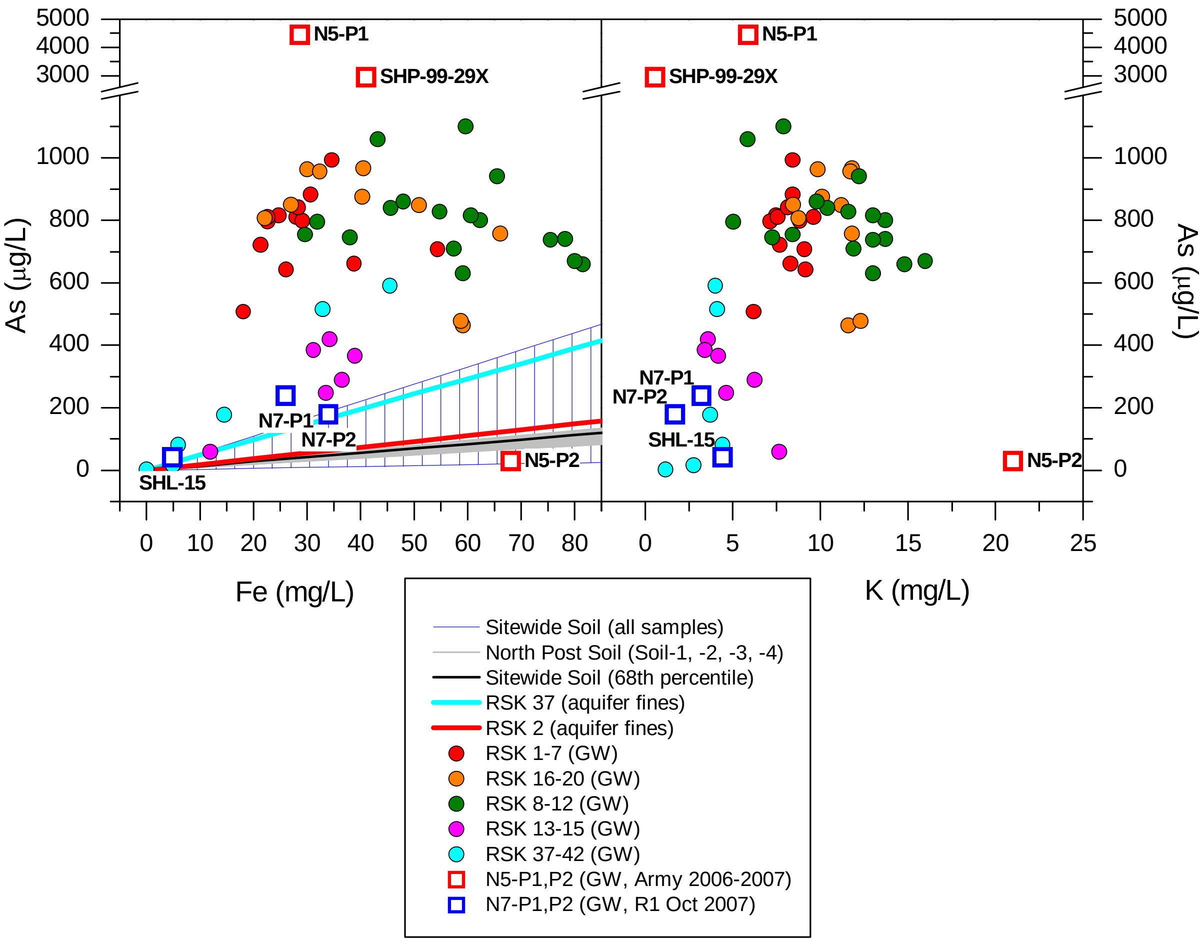

Figure 41. Concentration of arsenic versus iron (left panel) and potassium (right panel) for RSK wells and existing piezometer clusters in the southern and central portions of Shepley’s Hill Landfill (CH2MHill, 2006; Ginny Lombardo, 12/21/2007 e-mail correspondence). Linear trends shown for site soils (1993 RI Addendum) and aquifer fines recovered during development of well screens at RSK 2 and RSK 37 (Table 8) are calculated based on the measured ratio of extractable iron and arsenic in solid materials assuming congruent dissolution of these elements. The blue-hatched region is based on all site soils, including those considered to be compositional outliers. The y-axis has a break at 2600 µg/L As to facilitate display of all data.

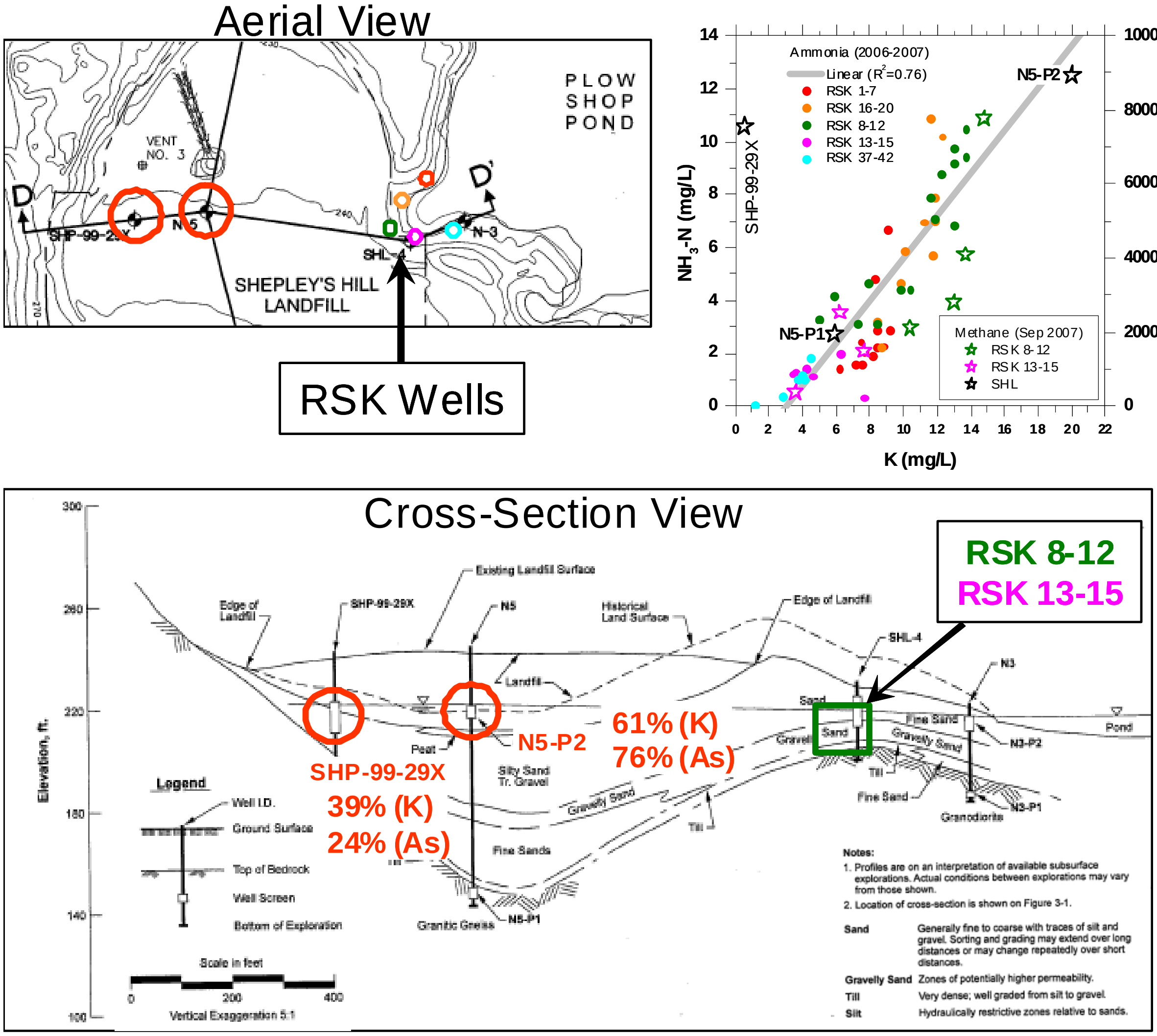

Figure 42. Location of SHP-99-29X and N5- P2 wells within the central portion of Shepley's Hill Landfill (SHL) relative to RSK well clusters adjacent to Red Cove ('aerial view'). Upper, right-hand panel displays groundwater concentrations of ammonia (NH_3-N) and methane (CH_4) versus potassium. The gray trend line represents a linear fit to all ammonia-potassium data for RSK wells (EPA/ORD 2006-2007). Methane data were collected by EPA/ORD during September 2007 from well clusters RSK 13-15, RSK 8-12, SHP-99-29X and N5-P1,P2. Bottom panel displays relative elevations of sampled well screens; percentages (red text) show estimates of mixtures from groundwater at N5-P2 and SHP-99-29X needed to approximately reproduce average potassium/arsenic concentrations observed at RSK 8-12 for September 2007. Source of aerial and cross-section landfill views: Harding ESE, Inc. 2003. Shepley's Hill Landfill Supplemental Groundwater Investigation, Devens Reserve Forces Training Area. Devens, Massachusetts.

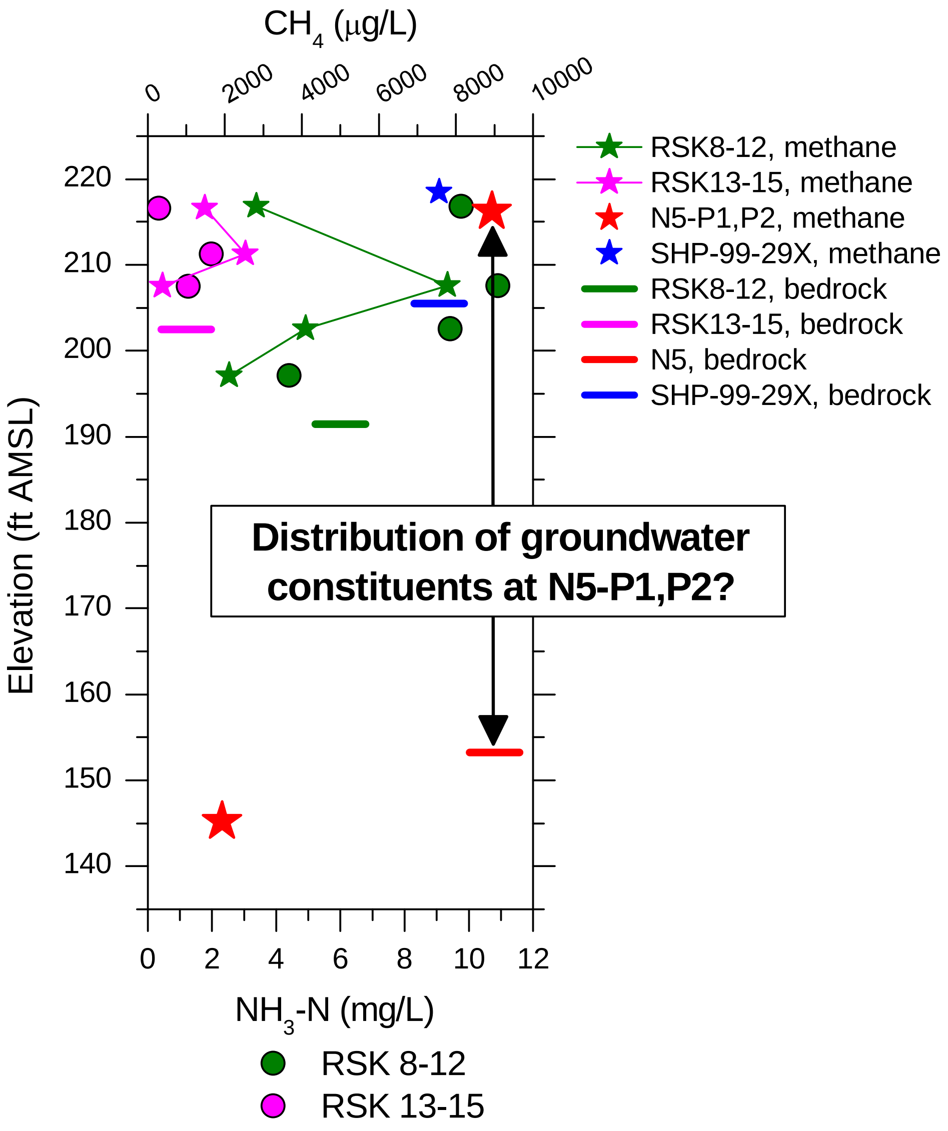

Figure 43. Concentrations of ammonia (NH_3-N) and methane (CH_4) measured in groundwater for a subset of RSK wells and at SHL wells SHP-99-29X, N5-P2, and N5-P1 during September 2007. The elevation of bedrock is shown for the sampled locations.

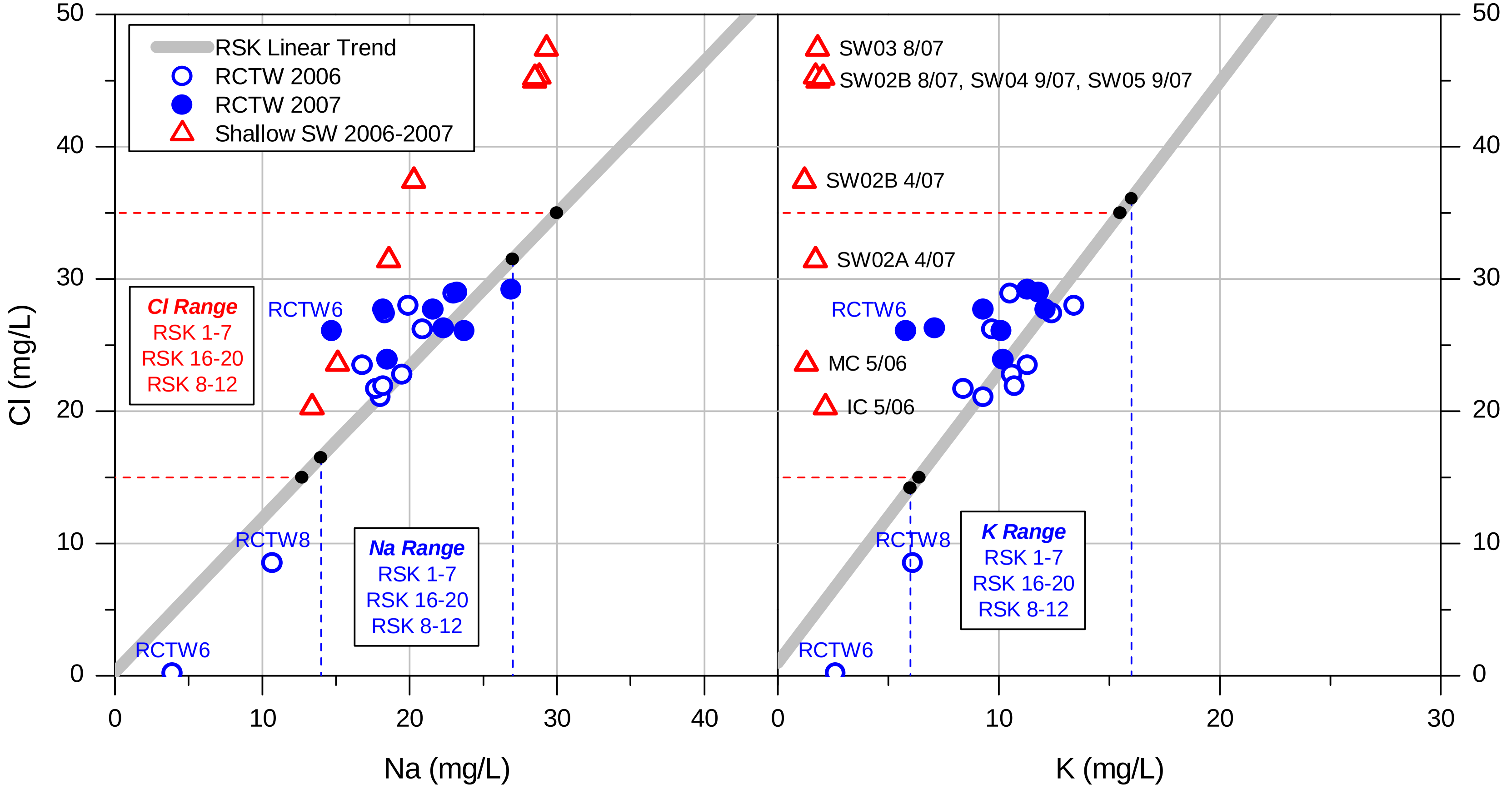

Figure 44. Measured concentrations of chloride (Cl), sodium (Na) and potassium (K) for groundwater samples collected from RCTW wells during 2006-2007. For comparison, linear trends fit to RSK groundwater data shown in Figure 32 are shown, along with the range of concentrations observed for well clusters RSK 1-7, RSK 16-20 and RSK 8-12. Data for Red Cove surface water samples (shallowest depth) collected during 2006 and 2007 are shown for reference; data label shows sampling month and year.

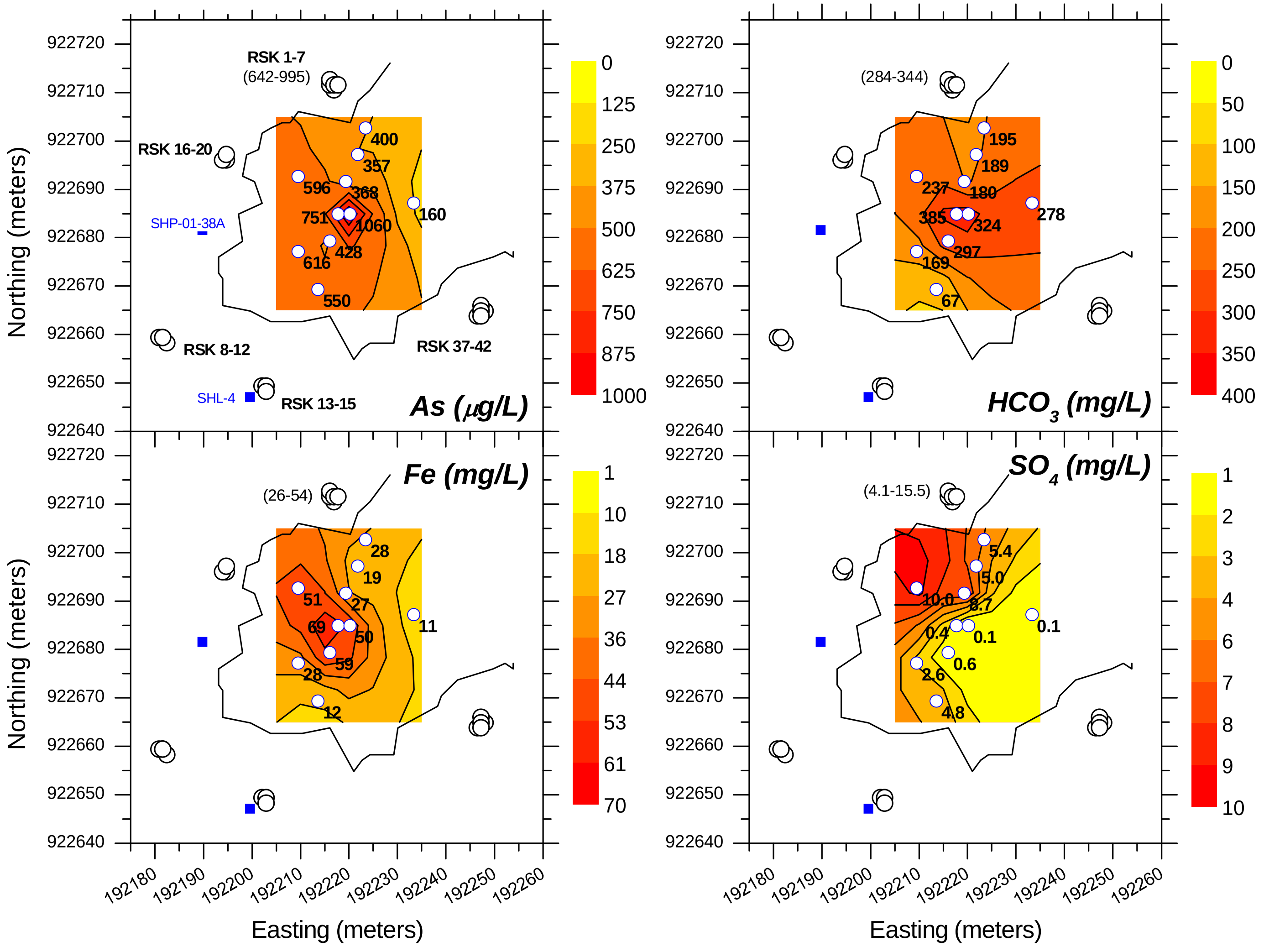

Figure 45. Spatial pattern in shallow groundwater chemistry underneath Red Cove sediments based on contouring of chemical data collected for wells RCTW 1-10 during August 2006. Individual well screen concentrations are shown in black text next to the RCTW well location. The ranges of As, bicarbonate (HCO_3), Fe, and sulfate (SO_4) concentrations for RSK 1-7 are shown in parentheses for comparison.

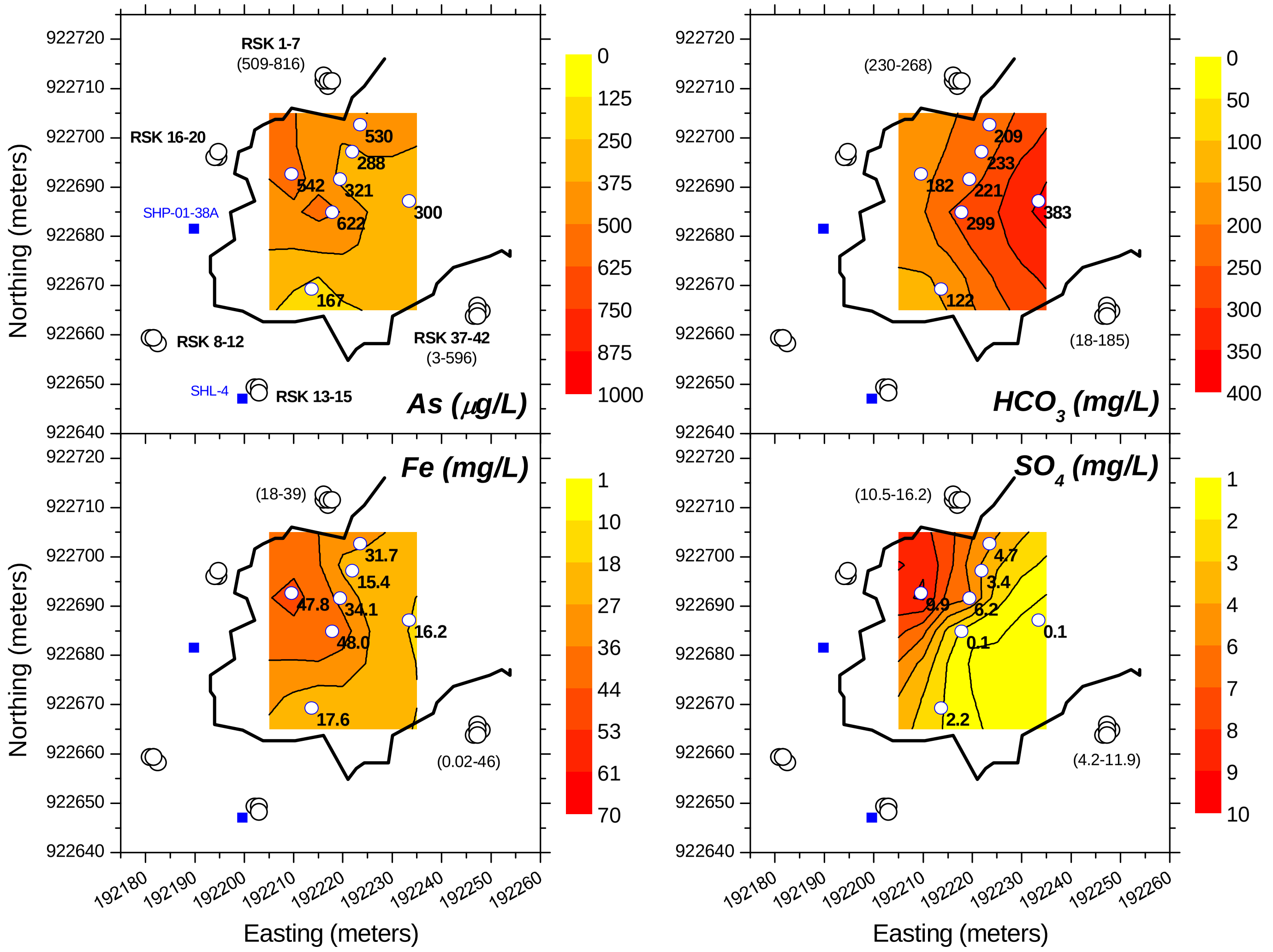

Figure 46. Spatial pattern in shallow groundwater chemistry underneath Red Cove sediments based on contouring of chemical data collected for wells RCTW 1-10 during August 2007. Individual well screen concentrations are shown in black text next to the RCTW well location. The ranges of As, bicarbonate (HCO_3), Fe, and sulfate (SO_4) concentrations for RSK 1-7 and RSK 37-42 are shown in parentheses for comparison.

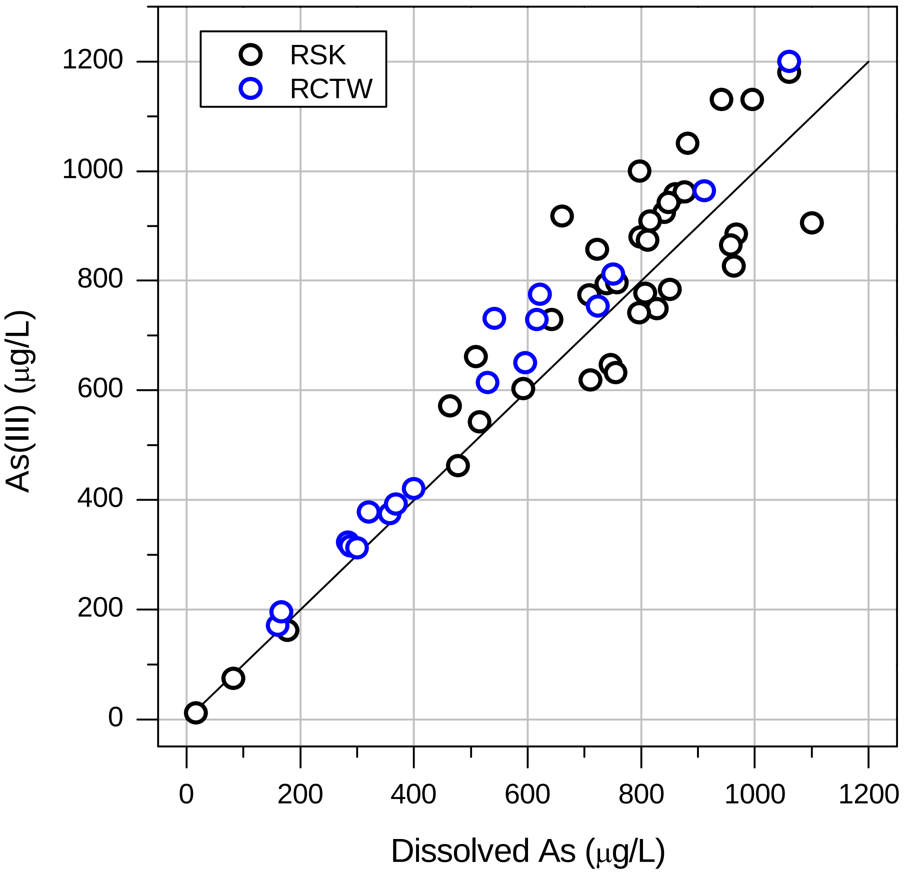

Figure 47. Comparison of the measured concentrations of dissolved (0.45 μm filtered) arsenic and the arsenite [As(III)] chemical species in filtered groundwater sampled from RSK and RCTW wells. The line represents a direct linear correlation between the two measurements.

Table 8. Concentration data for aquifer solids collected during purging of well screens at RSK2 and RSK37 along with groundwater data collected on August 8, 2006 (RSK2) and August 22, 2007 (RSK37).

Element	RSK2		RSK37	
	Aquifer Solids (mg/kg)	Groundwater (mg/L)	Aquifer Solids (mg/kg)	Groundwater (mg/L)
Al	8260	ND	34200	ND
Ca	3500	64.9	2320	5.1
Fe	5410	28.5	25400	0.02
K	1690	8.3	5040	1.2
Mg	1060	10.1	4740	1.2
Mn	185	3.6	264	0.01
Si	10600	17.7	29400	3.4
	(mg/kg)	(μg/L)	(mg/kg)	(μg/L)
As	*10*	*814*	*124*	*3*
Cr	6.3	1	35	ND
Cu	4.2	0.5	32.2	0. 2
Hg	0.04	0.06	0.06	0.02
Ni	7.4	12	37.6	0.6
Pb	3.7	ND	22.7	ND
Zn	9.5	15	59.6	40

4 Surface Water and Sediment Chemistry Studies

The objectives of the surface water and sediment chemistry studies performed at the Fort Devens sediments research site included determination of the spatial patterns in metals concentrations in sediments within Red Cove, the chemical speciation of arsenic in sediments, and the spatial patterns in the chemical characteristics of surface water in several locations within the cove. The purpose of these measurements was to identify contaminants in addition to arsenic that might influence risk due to exposure to sediments and/or surface water and to assess the relative contribution of groundwater discharge and sediments to contaminant concentrations in overlying surface water. In addition, knowledge of the characteristics of in-place contaminated sediments was used as a point of reference for assessing the chemical stability of sediment-associated arsenic. Investigations included the collection of sediment cores in three transects across Red Cove and collection of depth-discrete chemistry data for surface water, including limited collection of suspended solids at a location of known contaminated groundwater discharge. Data and results from these studies are discussed below.

4.1 Monitoring Network

Sampling of sediment, co-located pore water/shallow groundwater, and surface water was conducted from a pontoon boat during September 2005 (sediment coring, push-point sampling), May 2006 (surface water), April 2007 (sediment coring, surface water), August 2007 (surface water), and September 2007 (surface water). Push-point samples were collected via peristaltic pump according to the low-flow sampling protocol employed for groundwater wells. The locations of push-point sampling points are shown in Figure 48. A total of 12 intact sediment cores were collected from Red Cove along three transects (Figure 49). The length of recovered sediment core ranged from 16 to 39 inches. Sediment core sleeves were immediately capped upon retrieval and frozen on-site prior to shipment to an EPA laboratory. Sediments collected from Transect 2 (“0201-0204” series) and Transect 3 (“0301-0303” series) were typified by a black organic gelatinous layer overlaying a dense sand layer. All cores collected exhibited this visual characteristic except for a single core (SCT0303) that exhibited an additional layer of black material within the sandy layer. Sediment cores collected from Transect 1 (“0101-0103” series) were comprised of a gelatinous organic layer overlaying a very fine sand- and silty-layer. The cores were partitioned into 2-4 inch segments and allowed to dry in the absence of oxygen in order to preserve the chemical speciation of redox-sensitive constituents within the sediment. Each segment was analyzed for elemental composition with microwave-assisted acid extraction, and the arsenic solid-phase speciation was determined for a majority of the core sections using X-ray Absorption Near-Edge Spectroscopy (XANES). Depth-discrete surface water samples were collected from several locations within Red Cove to ascertain the spatial distribution of arsenic within the water column. Samples were retrieved via peristaltic pump following equilibration of in-situ water quality parameters measured using a YSI 556 water quality sonde deployed at the sampling depth (see Appendices). Monitoring point SW02B was located proximate to the existing seepage meter deployment SM1B and EPA/ORD cove piezometer PZ5 (see Figures 24, 29 and 49). The location of all surface water monitoring points is shown in Figure 49. The relative locations of sediment cores and temperature button transects (Section 2) are shown in Figure 50 in order to facilitate discussion of apparent patterns in groundwater discharge and sediment arsenic concentrations. Discussion of results from analysis of sediment chemistry, pore water chemistry and surface water chemistry follows.

4.2 Sediment Chemistry

The transition zone from groundwater to surface water in Red Cove is characterized by a sharp transition from reducing to oxidizing conditions. This is visually evidenced by the pervasive precipitation of reddish-orange iron oxides along the cove shoreline and within the water column in locations with minimal growth of aquatic plants. The formation of iron oxides in these locations is due to discharge of groundwater with high concentrations of ferrous iron [Fe(II)] and/or release of Fe(II) from sediments, which subsequently comes in contact with dissolved oxygen. Based on measurements in RSK wells, dissolved oxygen concentrations are too low in groundwater to support significant oxidation and precipitation of Fe(II) within the aquifer. Elevated dissolved iron concentrations similar to those observed in RSK and RCTW wells were also observed in push-point samples collected from a depth of approximately two feet below the sediment surface (Figure 51). Thus, the majority of Fe(II) oxidation and precipitation occurs following groundwater discharge into overlying surface water, which is supported by comparison to the lower acid-extractable iron concentrations in aquifer solids retrieved during development of well screens from the northern and southern boundaries of the cove (Table 8). Comparison of the acid-extractable concentration of iron in these aquifer solids (0.5-2.5 wt% Fe) to those observed in shallow sediments (<4 inches below sediment-water interface; 1.5-37.4 wt% Fe) throughout Red Cove (Figure 52, left panel) confirm that the majority of ferrous iron oxidation and precipitation within the cove occurs in proximity to the sediment surface. As discussed later, this is also consistent with the depth distribution of acid-extractable iron in sediment cores.

Comparison of the solid phase concentration of arsenic in these aquifer solids (10-124 mg/kg As) to shallow sediments (137-8600 mg/kg As) or suspended solids (6533 mg/kg As) collected within Red Cove indicates that precipitation of iron with coprecipitation/sorption of arsenic is the most likely source of elevated concentrations observed in Red Cove solids. There is a consistent relationship between acid-extractable iron and arsenic in shallow sediments throughout Red Cove and suspended solids collected at depth from surface water sampling location SW02B (Figure 52, right panel). As documented for similar settings (Ford et al., 2005), the most likely source of the reddish-orange precipitates is the mineral ferrihydrite. Based on the theoretical chemical formula of the mineral ferrihydrite, the iron content of the pure mineral is approximately 58.1 wt% Fe ($Fe_5HO_8 \cdot 4H_2O$; Berquo et al., 2007). As a point of reference, this compares to the following iron contents of common iron-bearing minerals in reduced environments: 1) mackinawite (FeS), 58.1 wt% Fe; 2) pyrite (FeS_2), 46.5 wt% Fe; and siderite ($FeCO_3$), 48.2 wt% Fe. These are all commonly occurring iron-bearing minerals in low-temperature environments that are extractable under the analytical conditions employed for determination of solid phase iron in Red Cove solids. Measured sediment iron concentrations on the order of 20 wt% Fe or more are indicative of a significant contribution from these types of minerals. The total acid-extractable iron content will generally be diluted below that for the pure mineral due to organic carbon derived from aquatic plant die-off and sands/silts from soil erosion.

In an effort to survey sediment chemistry and mineralogy below the sediment-water interface and to determine its impact on the potential attenuation, mobilization, and bioavailability of arsenic, the solid-state speciation of arsenic in the sediment was determined. The elements released by microwave-assisted acid digestion indicate Fe, Mn, Al, Si, S, As and Cr as the most abundant elements of those measured (Appendix L). Acid-extractable arsenic concentrations ranged between 137-8600 mg/kg in the top two inches of the sediment, but tended to decrease rapidly with depth (Figure 53). The rapid decline in the concentration of arsenic in the sediment profile indicates that arsenic derived from groundwater discharge accumulates or is sequestered at or near the sediment-water interface. Although other elements in the cove indicate a partial correlation, Fe is consistently associated with arsenic horizontally and vertically throughout the sediment thickness (Figure 52; see Appendix J for all depths).

In addition to the bulk elemental analysis, the solid-phase speciation of arsenic was determined in each core segment with bulk XANES. Spectra for the set of arsenic reference phases used to represent possible arsenic species anticipated for conditions at Red Cove are shown in Figure 54. Bulk XANES analysis of the top two inches of sediment identify a mix of 2 to 4 primary arsenic bearing phases over all 12 sediment cores (Tables 9-11 and Figures 55-57). The most common phase identified was As(III) or As(V) adsorbed/coprecipitated with iron oxide as represented by As(III) or As(V) coprecipitated with ferrihydrite. Arsenic was also associated with iron sulfides as a reduced adsorbed species, either arsenite coprecipitated with pyrite or mackinawite. The profile distribution and concentration of each of the arsenic solid phases identified by XANES spectroscopy in the Red Cove sediments is presented in Figures 55-57. Speciation of arsenic in the top two inches of sediment appears to show some general spatial trends (Figure 58; left panel). First, arsenic speciation in shallow sediments is dominated by partitioning of As(III) or As(V) to an iron oxide such as ferrihydrite. Secondly, arsenic is more common in its reduced form, As(III), in the middle to western portion of the cove, whereas a greater fraction of As(V) appears in the eastern portion of the cove. Finally, the presence of arsenic associated with iron sulfides in shallow sediments primarily occurs in the middle of the cove where evidence of groundwater discharge with elevated arsenic concentrations is strongest. This is generally consistent with the distribution of acid-extractable sulfur in shallow Red Cove sediments (Figure 58; right panel). It has previously been documented that iron oxides have a greater capacity for arsenic uptake than iron sulfides (Wilkin, 2006). This behavior is also apparent for Red Cove where shallow sediments with the highest iron and arsenic contents generally have lower sulfur contents with a weak correlation between solid phase arsenic and sulfur ($R^2 = 0.14$).

4.3 Surface Water Chemistry

Trends in surface water chemistry as a function of depth in Red Cove are shown in Figures 59-62. Characterization data for suspended solids collected from deep surface water at sampling location SW02B (April 2007) are shown in Figure 60. X-ray diffraction data and chemical composition confirm that the solids consist of the hydrous iron oxide mineral, ferrihydrite. The lower iron content for this natural sample (i.e., 37.8 wt% versus 58.1 wt% for the ideal mineral structure) is due to the presence of other coprecipitated elements such as calcium, sodium and potassium. This poorly crystalline mineral phase commonly precipitates out in surface water bodies where dissolved, ferrous iron comes in contact with dissolved oxygen (Ford et al., 2006). This mineral precipitate has a reddish-orange color and is the source of the orange hue imparted to the surface water at this sampling location (photograph in Figure 60). This same mineral precipitate is the source of the orange staining along the banks surrounding Red Cove. Ferrihydrite has the capacity to sorb weight percent levels of arsenic [as As(III) or As(V)], particularly under situations in which arsenic is present in solution during mineral precipitation (Ford, 2002). The potential for iron sulfide formation to occur within the water column was assessed by comparing measured redox and pH characteristics of water samples to the relative stability of ferrihydrite-pyrite and ferrihydrite-mackinawite solid pairs (Figure 63). These comparisons indicate that the shallow sediment layer is the only location where iron sulfides may persist based on thermochemical considerations. In addition, assessment of the potential stability of poorly crystalline orpiment, relative to iron sulfides, indicates that the precipitation of a pure arsenic sulfide phase is not supported from thermochemical considerations (Figure 64). Thus, sorption of aqueous arsenic onto iron oxides appears to be the most likely control on solid phase arsenic speciation within the water column. Aqueous arsenic speciation below the sediment surface (push-point samples) and surface water in Red Cove is dominated by arsenite [As(III)] (Figure 65; left panel). The depth trend in distribution between As(III) and As(V) within the water column generally indicates that the dominance of As(III) continues throughout the water column (Figure 65; right panel).

The arsenic sorption characteristics of ferrihydrite precipitating within the Red Cove water column was characterized through examination of measured dissolved and particulate concentrations of arsenic and iron in filtered (0.45 μm) and unfiltered surface water samples. Particulate concentrations were determined by difference for unfiltered (acid digested) and filtered samples. The results of this analysis are shown in Figure 66 (left panel), where an in-situ arsenic sorption capacity of approximately 20,000 mg As/kg ferrihydrite was estimated based on the best fit of the Langmuir isotherm equation to the data. The patterns in dissolved ferrous iron [Fe(II)] and particulate iron as a function of dissolved total iron are shown in the right panel of Figure 66. These data indicate that elevated dissolved iron within the water column is attributed primarily to Fe(II) and these elevated Fe(II) concentrations drive the formation of particulate iron (as ferrihydrite). This reaction is sustained by the generally shallow depth within the cove and the availability of dissolved oxygen. Published data from a similar setting indicates that Fe(II) oxidation and precipitation of ferrihydrite is a rapid reaction (Ford et al., 2006), which serves to sequester arsenic derived from groundwater discharge and maintain relatively low concentrations of arsenic in shallow surface water (see Figures 59-62 and Appendices).

Trends in the general water chemistry of deep surface water, as reflected in concentrations of chloride, potassium and sodium, are shown in Figure 67. The concentration of potassium can be used as an indicator of the relative distribution of groundwater (represented by RCTW chemistry) and shallow surface water (shown as a hashed, gray area in each panel). Based on analysis of these data, surface water sampling locations IC, SW04, and SW05 appear to represent areas within the cove in which surface water chemistry is less strongly influenced by groundwater discharge. In contrast, surface water sampling locations MC and SW02B appear to be dominated by groundwater discharge, with locations SW02A and SW03 displaying compositions indicative of intermediate influence of the two water sources. It should be noted that the values plotted for “deep” surface water have been interpolated from measured depths for each dataset to represent a consistent height above the sediment surface. For depths closer to the sediment surface at locations SW02A, SW02B and SW03, the water chemistry trends closer to that of groundwater sampled from neighboring RCTW wells. This observation is illustrated in Figure 68 with comparison of contoured potassium concentrations in RCTW wells to concentrations in the deepest surface water sample collected at each location. Smaller differences in potassium concentrations in shallow groundwater and deep surface water indicate a significant influence from groundwater discharge. It should be noted that this comparison does not take into account the potential influence of vertical mixing within the water column as a result of seasonal turnover or other physical factors such as wind. However, comparison of results from measurement of shallow sediment temperatures within the cove to contoured potassium concentrations in shallow groundwater indicate reasonable correspondence between interpreted locations of groundwater discharge to surface water (Figure 69).

The range of interpolated arsenic concentrations for equivalent depths in deep surface water as a function of interpolated potassium concentrations is shown in Figure 70. In addition, measured dissolved arsenic and potassium concentrations are shown for the shallowest surface water sample collected at each location. Again, there is a clear distinction between the chemical composition of shallow and many of the deep surface water data, including locations MC and SW02B. Potential regulatory benchmarks for surface water are also shown on this plot (USEPA, 2006a; USEPA, 2006b). For arsenic, current statutes list both acute and chronic ambient water quality criteria (AWQC) for arsenic in fresh waters as 340 μg/L and 150 μg/L, respectively.

Comparison of the distribution of arsenic concentrations in shallow groundwater (RCTW wells), sediments and deep surface water is provided in Figure 71. Historical sediment data for Red Cove are also shown as a point of reference (Figure 71; left panel). There is general correspondence between contaminated groundwater discharge and elevated arsenic concentrations in deep surface water. The highest concentrations of arsenic in deep surface water appear to occur where sediment data suggests iron sulfides are being produced. The spatial relationship between calculated arsenic flux at RSK wells and Red Cove sediment concentrations is shown in Figure 71. Isoconcentration contours for sediment arsenic were derived from EPA/ORD shallow sediment data and historical data available for Red Cove (Gannett Fleming, 2006). Comparison of the distribution of potassium in shallow groundwater underlying Red Cove and the pattern in arsenic sediment concentrations indicates a general relationship to contaminated groundwater discharge (Figure 72). It should be noted that sediments most likely provide a record of accumulated arsenic flux from groundwater, while the potassium data reflect an instantaneous measure in time of contaminated groundwater discharge.

4.4 Sediment and Surface Water Chemistry Summary

Sediment and surface water chemistry data all indicate that arsenic is present in a reduced form within Red Cove. Patterns in the concentrations of major elements in groundwater, surface water and sediments point to discharge of contaminated groundwater as the primary source of elevated arsenic in Red Cove sediments and deep surface water. Patterns in sediment temperature and potassium concentration distribution in shallow groundwater underlying Red Cove generally align with the estimated distribution of contaminated groundwater discharge into the cove. The elevated concentration of potassium in deep surface water appears to be an indicator for plume discharge. There is general correspondence between the locations of highest sediment arsenic concentrations and suspected locations of contaminated groundwater discharge. Precipitation of ferrous iron derived, in part, from groundwater discharge is prevalent throughout the cove following exposure to dissolved oxygen within surface water. Iron oxide precipitation results in sequestration of arsenic within the water column and appears to be the primary cause for lower arsenic concentrations observed in shallow surface water. However, iron oxide precipitates formed within the water column are unstable in reducing sediments and may likely serve as a continued source of arsenic flux to surface water after settling out from the water column. While the highest concentration of arsenic observed in deep surface water was co-located with a known area of plume discharge, elevated concentrations of arsenic in locations with less dominant influence of groundwater discharge document the potential instability of arsenic in contaminated sediments.

4.5 References

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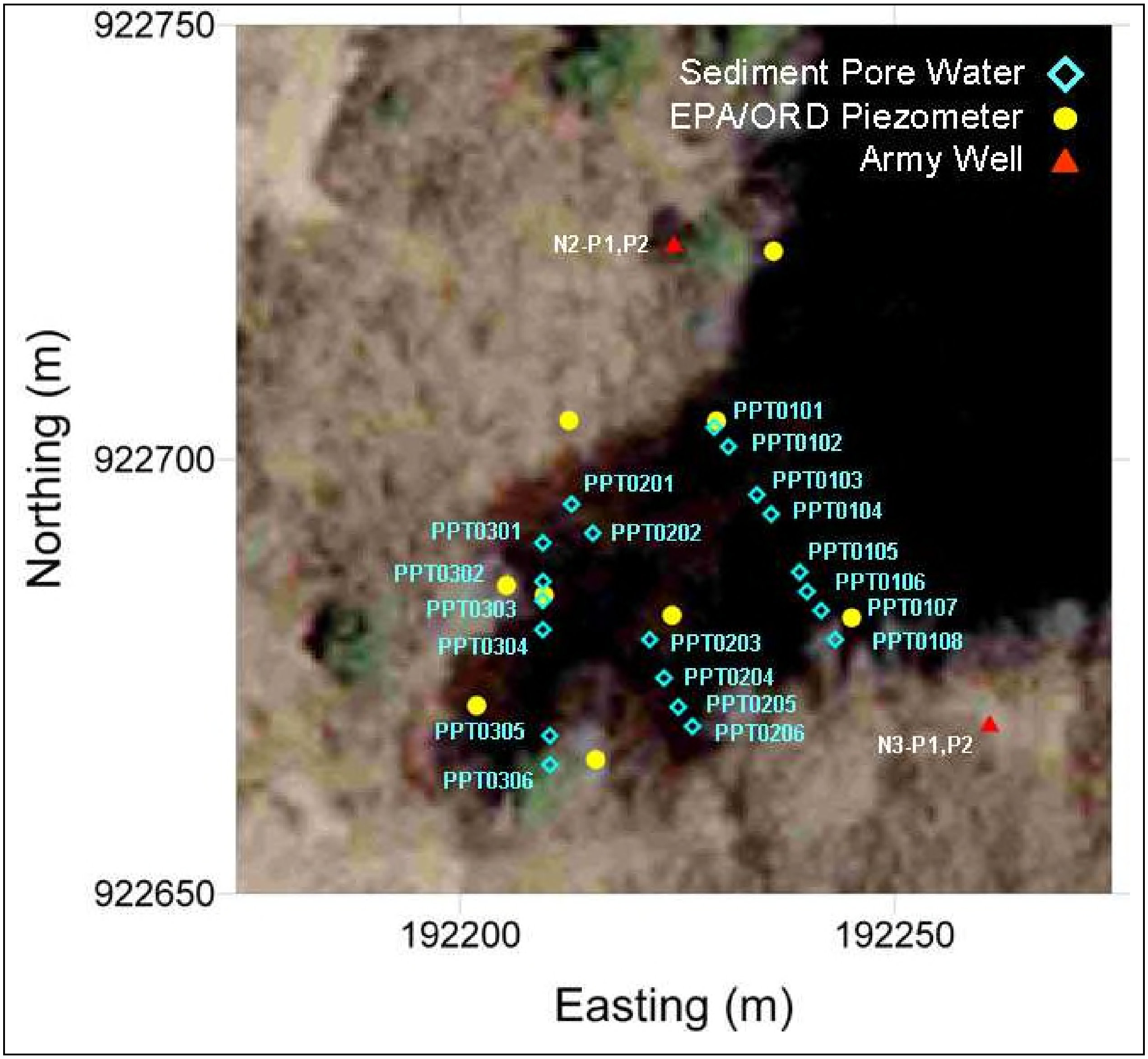


Figure 48. Location of push-point sampling locations for collection of sediment pore water within Red Cove during September 2005. Locations of EPA/ORD piezometers and Army wells shown for reference.

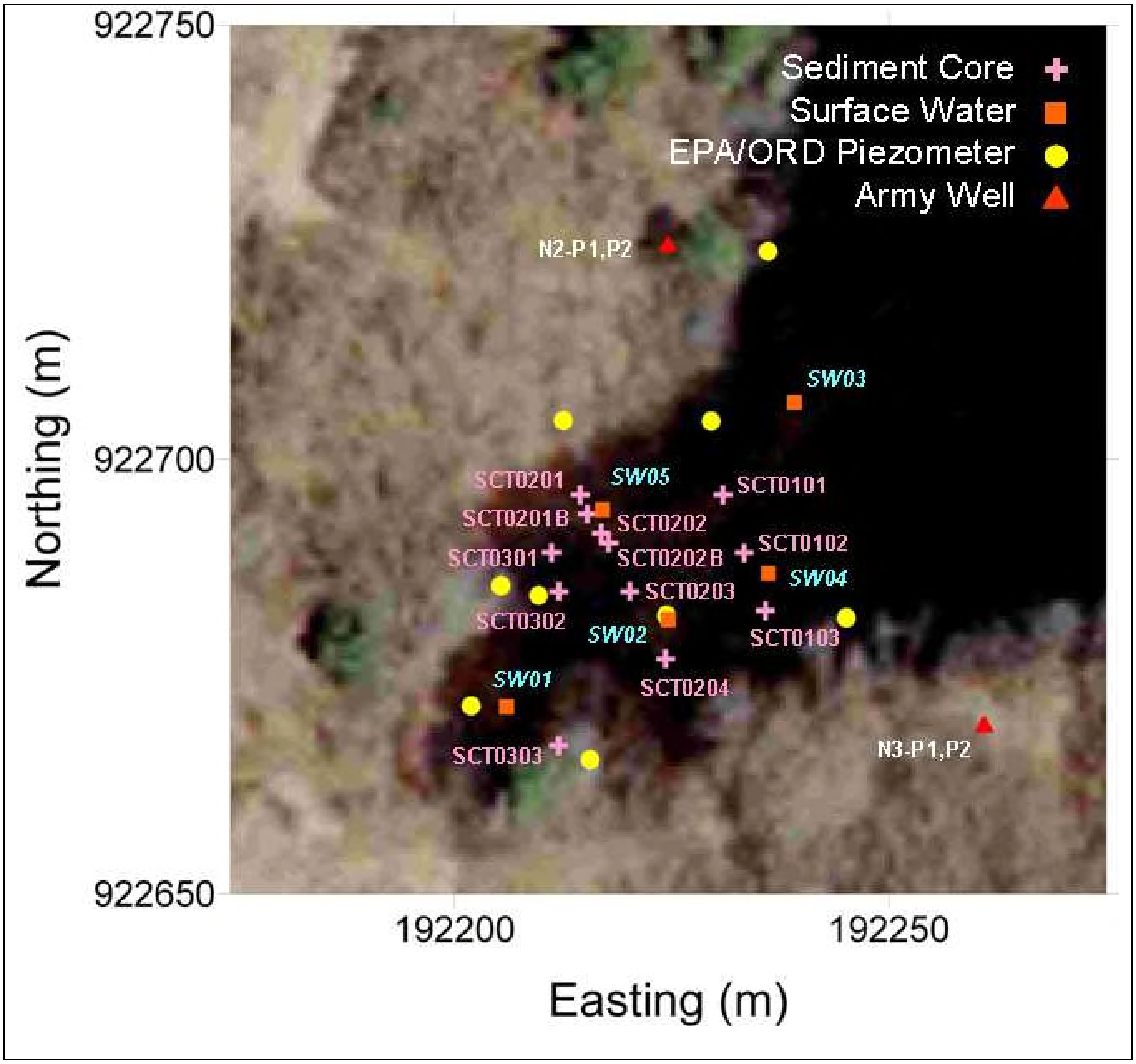


Figure 49. Location of sampling locations for collection of sediment cores within Red Cove during September 2005 (transects “T02” and “T03”) and April 2007 (transect “T01”). Locations of EPA/ORD piezometers and Army wells shown for reference.

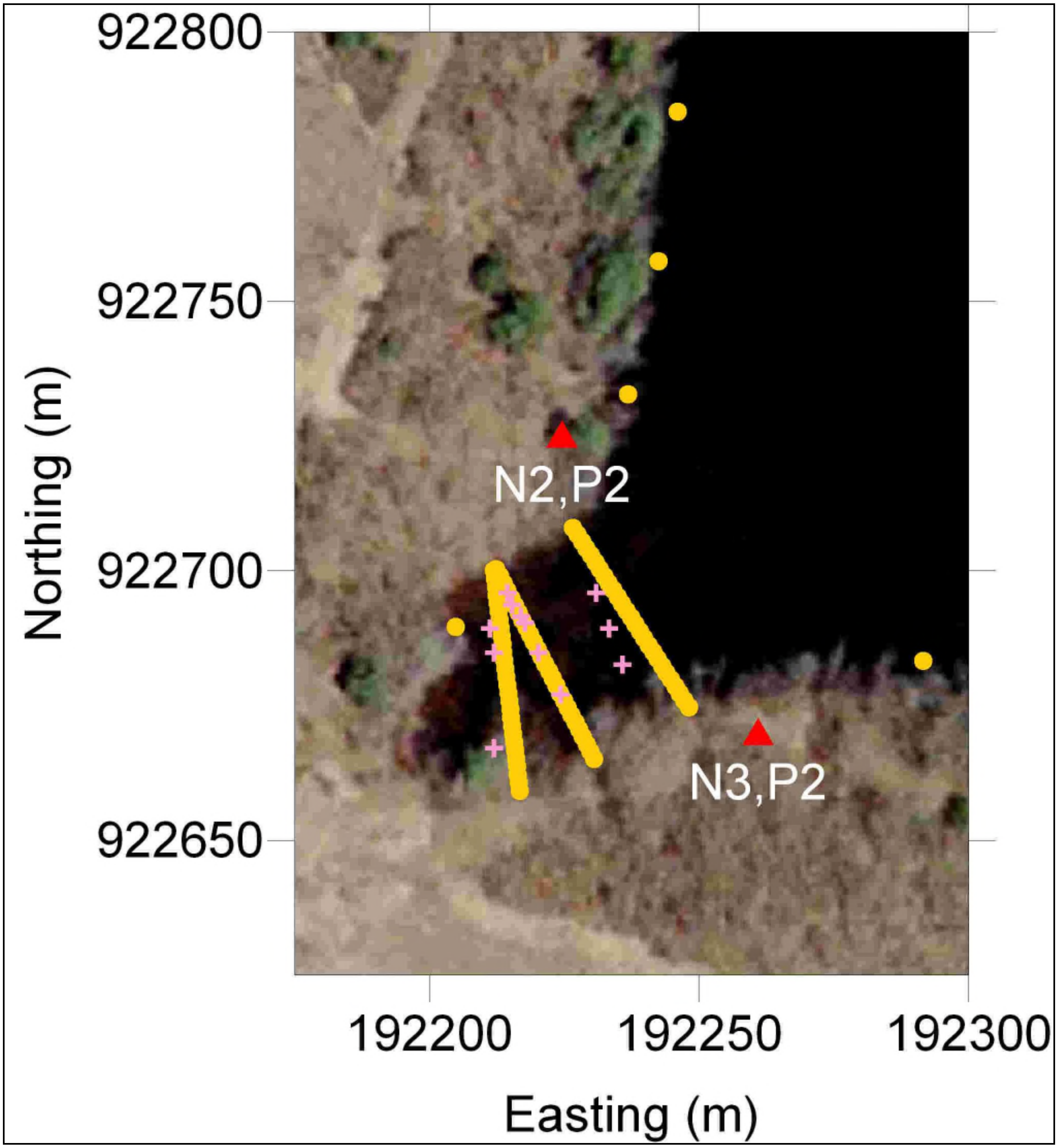


Figure 50. Location of sediment cores (pink crosses) relative to locations of temperature button transects (filled yellow circles) installed in sediments within Red Cove.

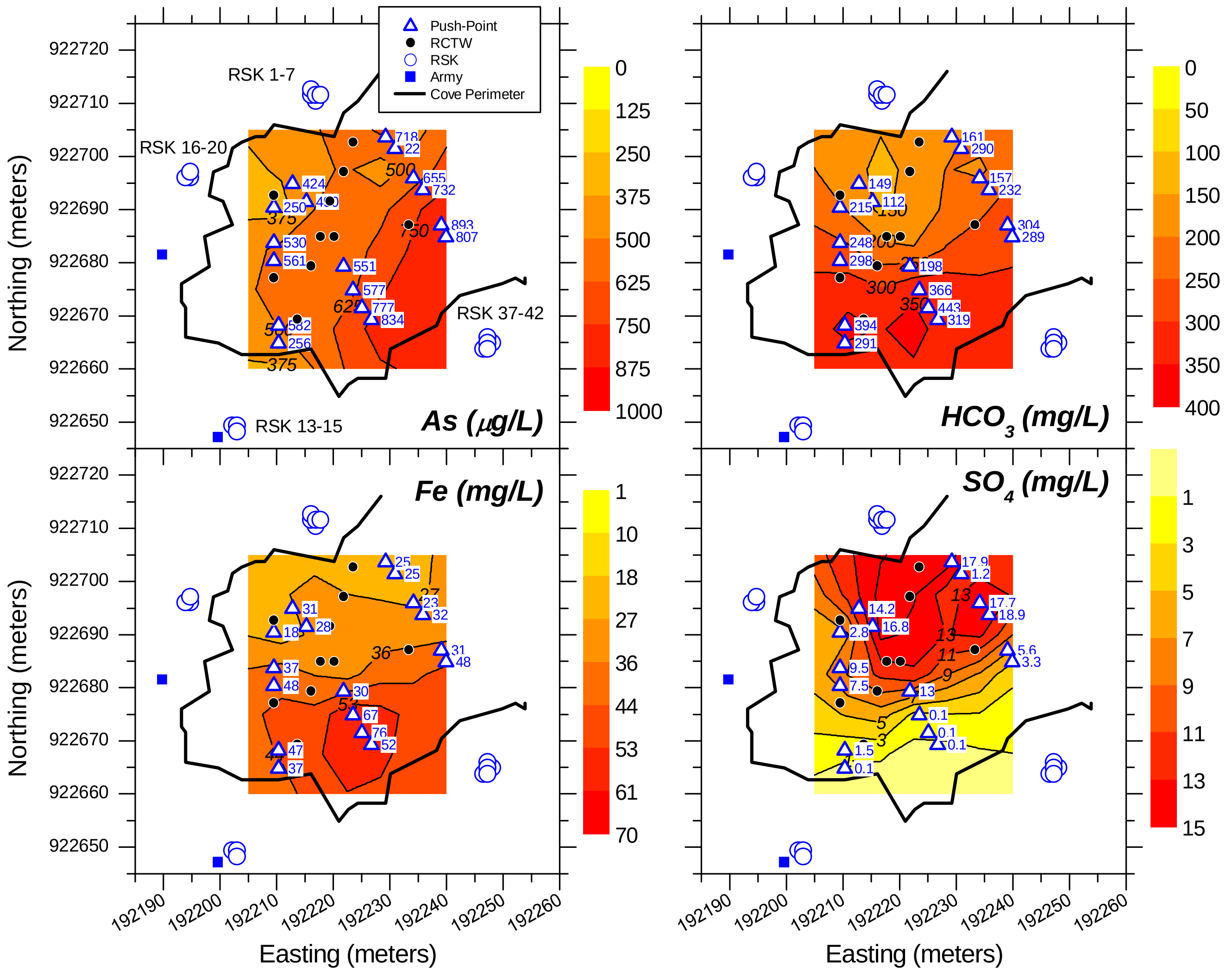


Figure 51. Spatial pattern in sediment pore water chemistry approximately 2 feet below the sediment surface in Red Cove based on contouring of chemical data collected by push-point sampling during September 2005. Individual concentrations are shown in blue text next to the push-point sample location and contoured concentrations throughout the cove are shown in black text.

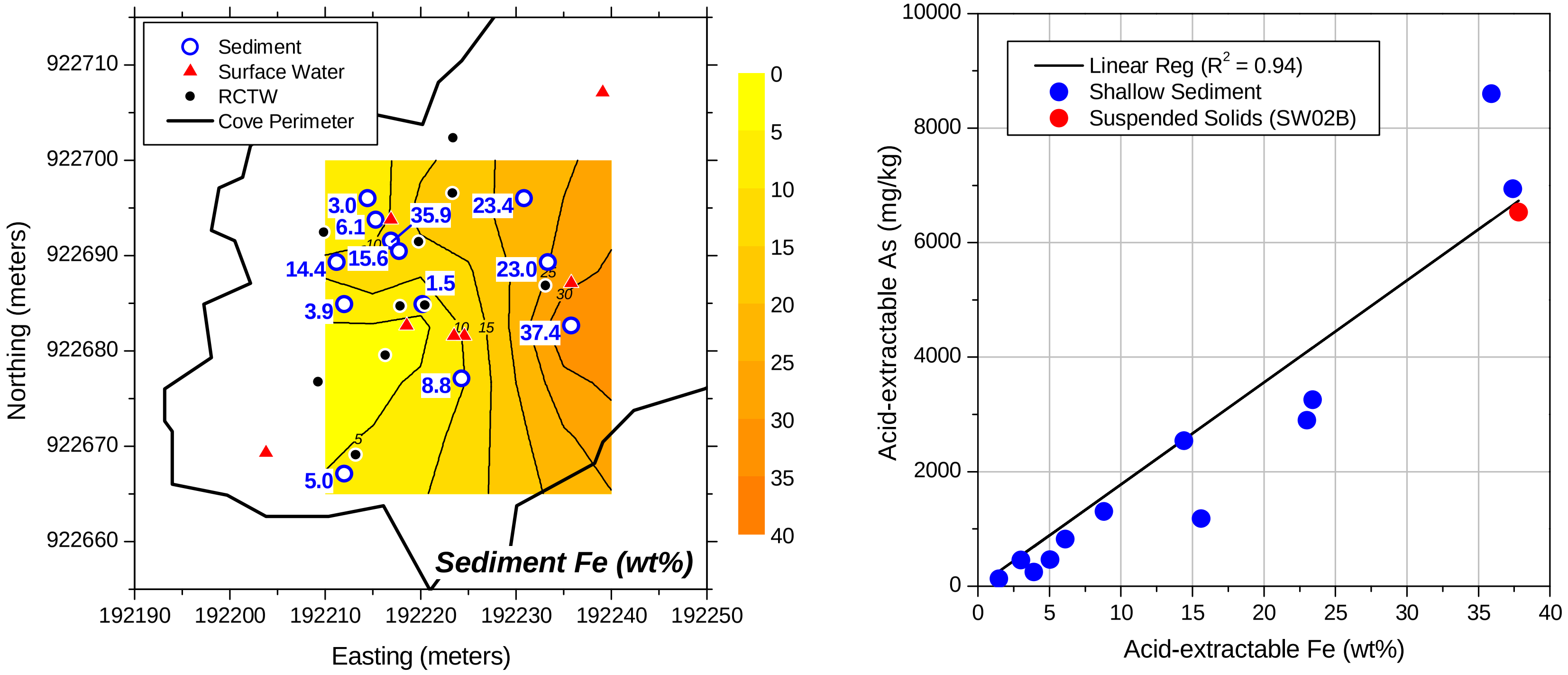


Figure 52. Concentration of iron (Fe, wt%) in the core section retrieved from the sediment surface for cores collected by EPA/ORD in Red Cove during September 2005 and April 2007 (left panel). Isoconcentration contours were developed from individual data. Locations for RCTW wells and surface water sampling are also shown. Relationship between solid phase iron and arsenic for shallow sediments and the suspended solids collected from surface water sampling location SW02B (right panel).

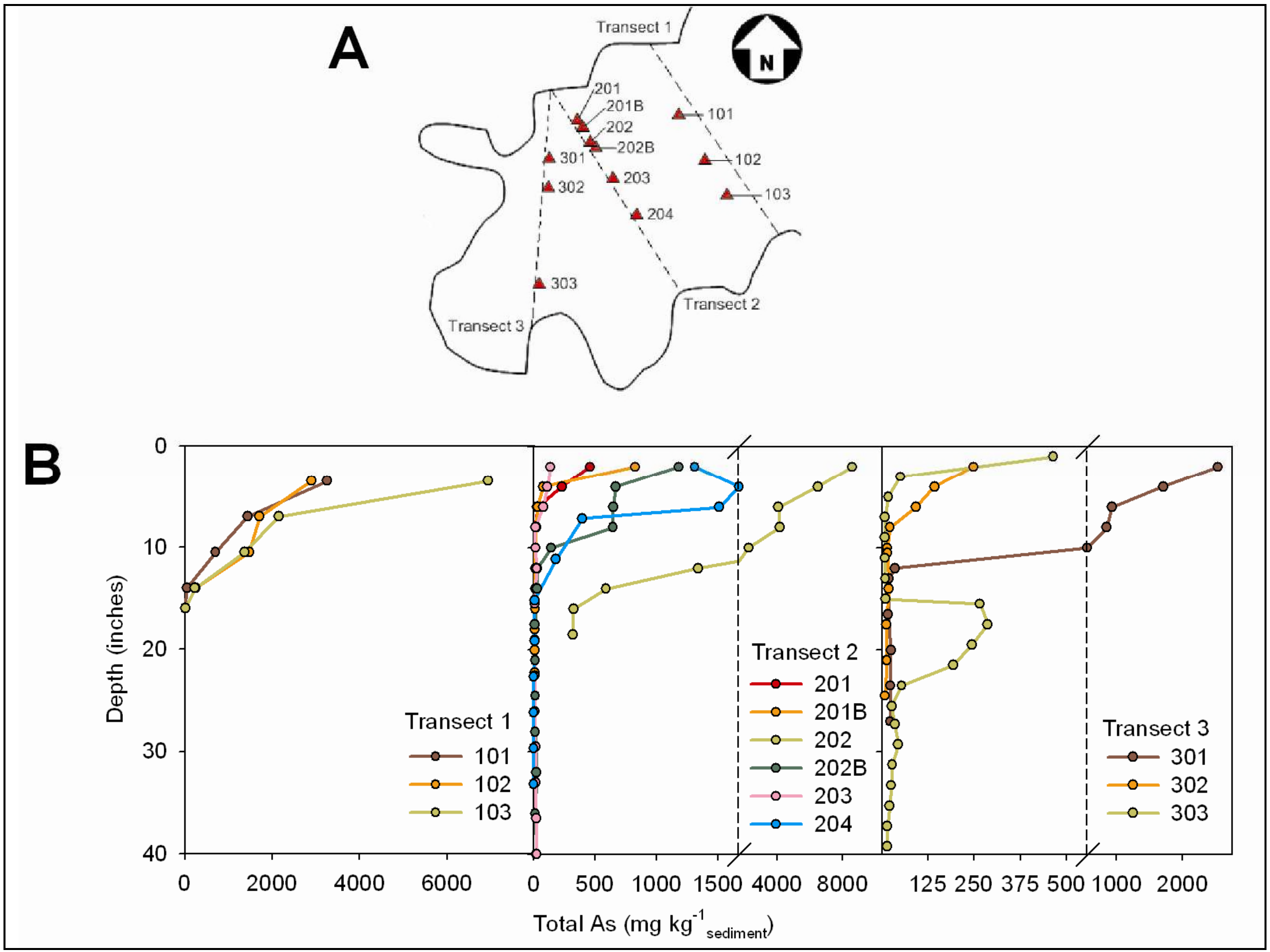


Figure 53. A) Sediment core locations in Red Cove, red triangles indicate the location of the sediment samples. B) Arsenic concentration profiles for the sediment cores. The dashed line in the concentration profile graphs for transects 2 and 3 contain a break in the concentration of As in the sediments at 1600 and 556 mg As kg^{-1}sediment, respectively.

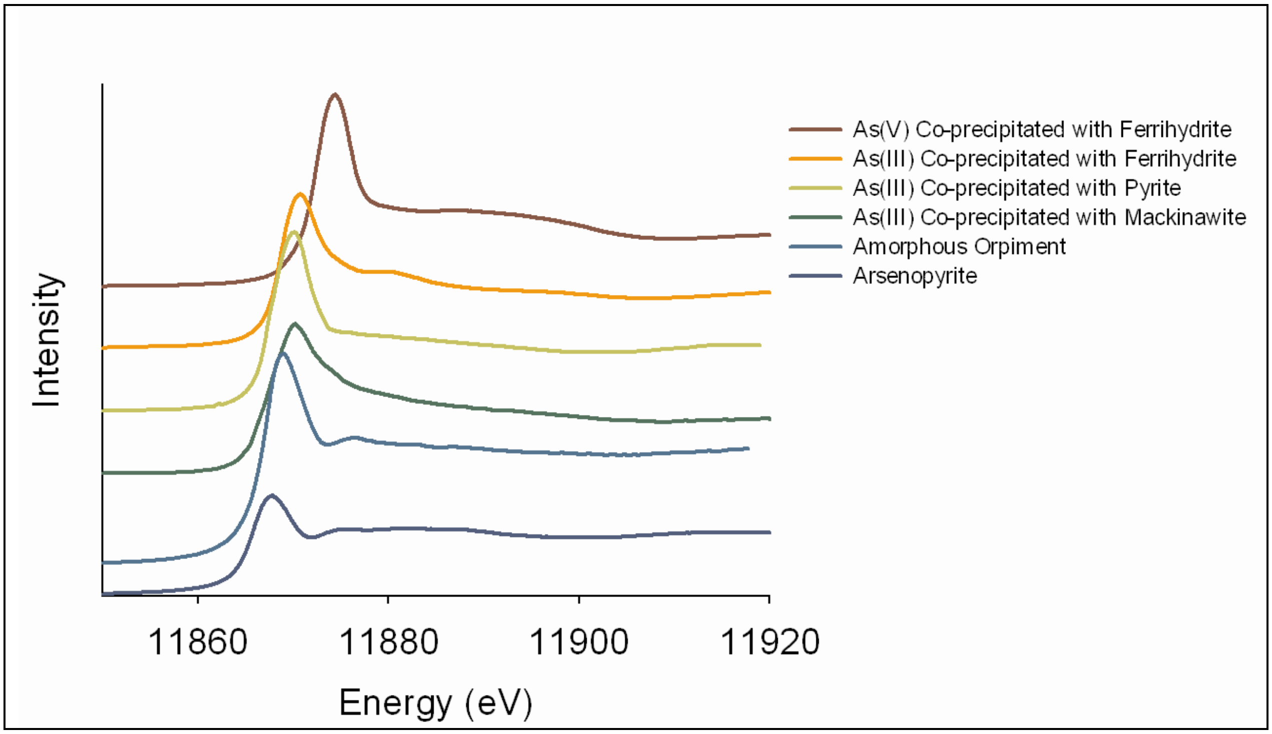


Figure 54. Basis set of XANES spectra for arsenic model compounds used in fitting sample spectra from sediment cores retrieved from Red Cove during September 2005 (Transects 2 and 3) and March 2007 (Transect 1). Arsenopyrite is a natural mineral specimen, while the remaining model compounds were synthesized in the laboratory using published procedures (Ford et al., 2006; Wilkin and Ford, 2006).

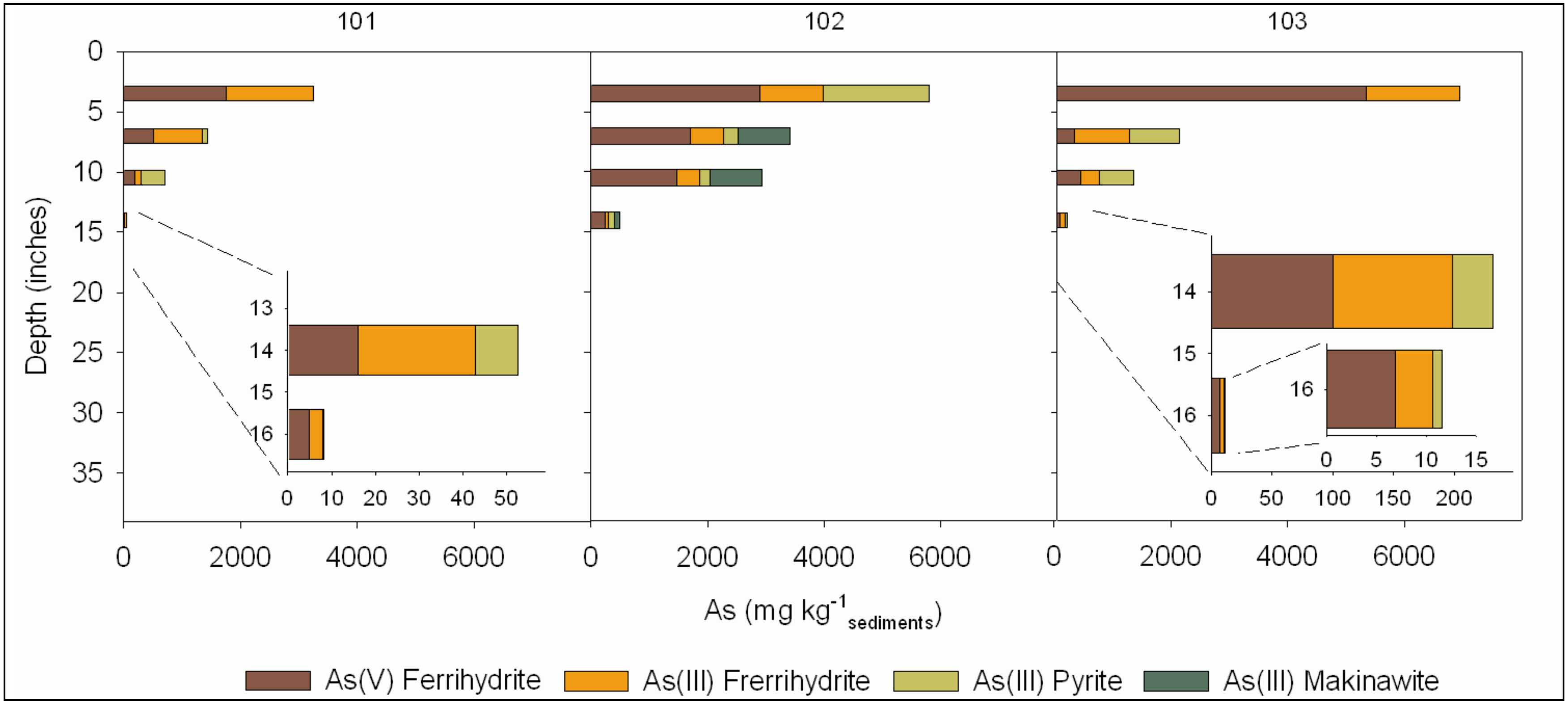


Figure 55. Results from the speciation of arsenic by XANES analysis for sediment core locations along Transect 1 (see Figure 49).

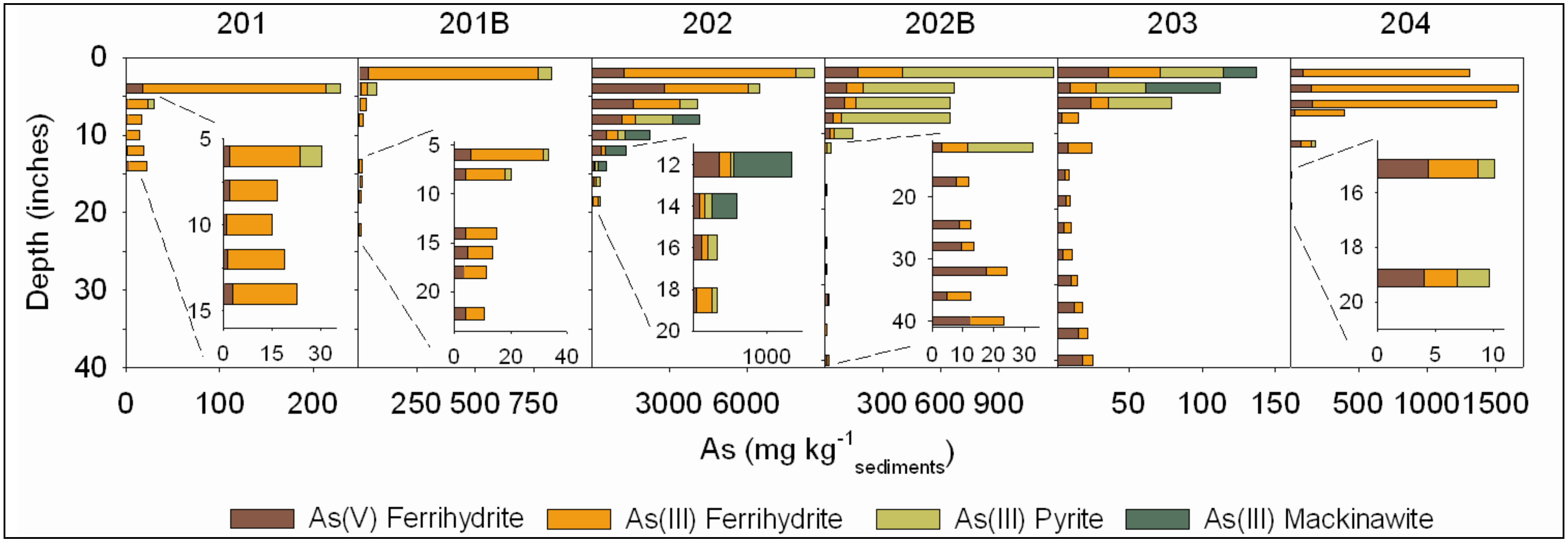


Figure 56. Results from the speciation of arsenic by XANES analysis for sediment cores located along Transect 2 (see Figure 49).

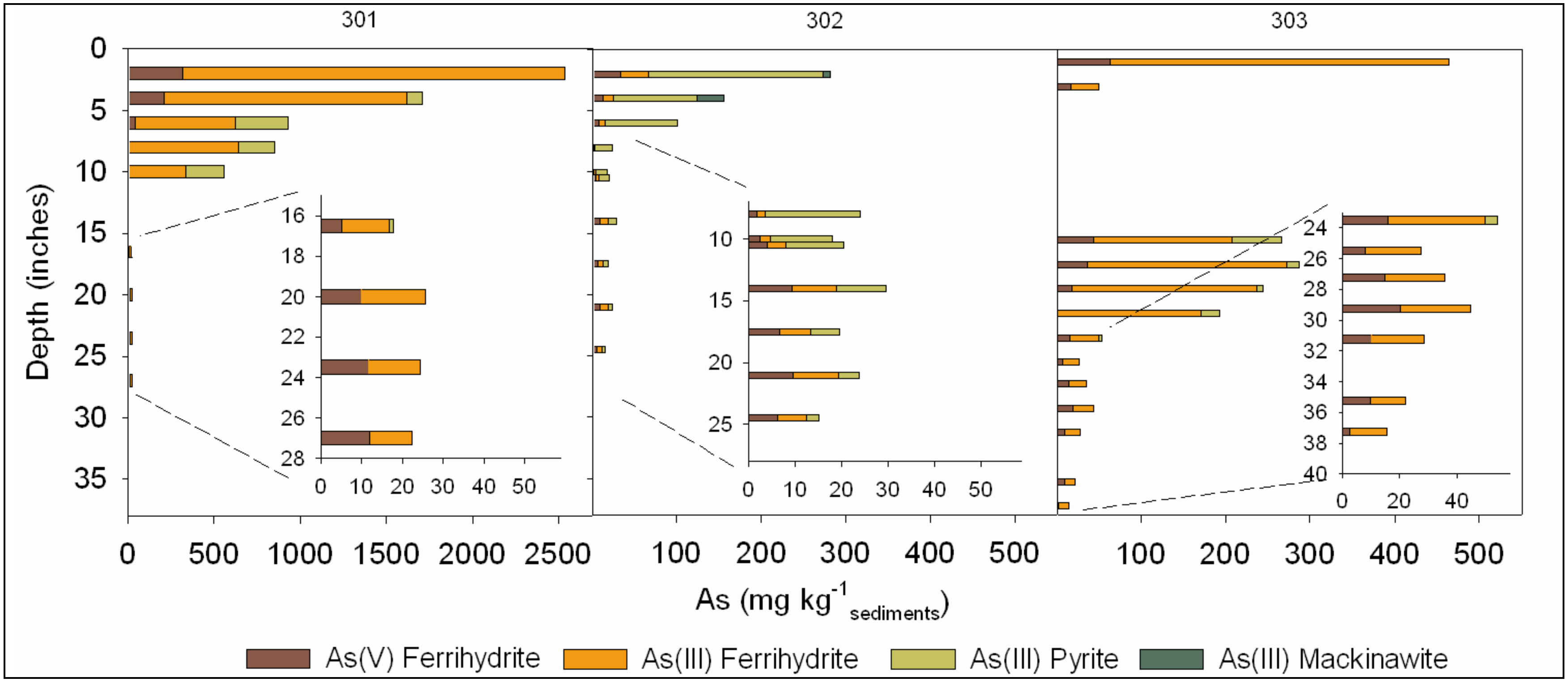


Figure 57. Results from the speciation of arsenic by XANES analysis for sediment cores located along Transect 3 (see Figure 49).

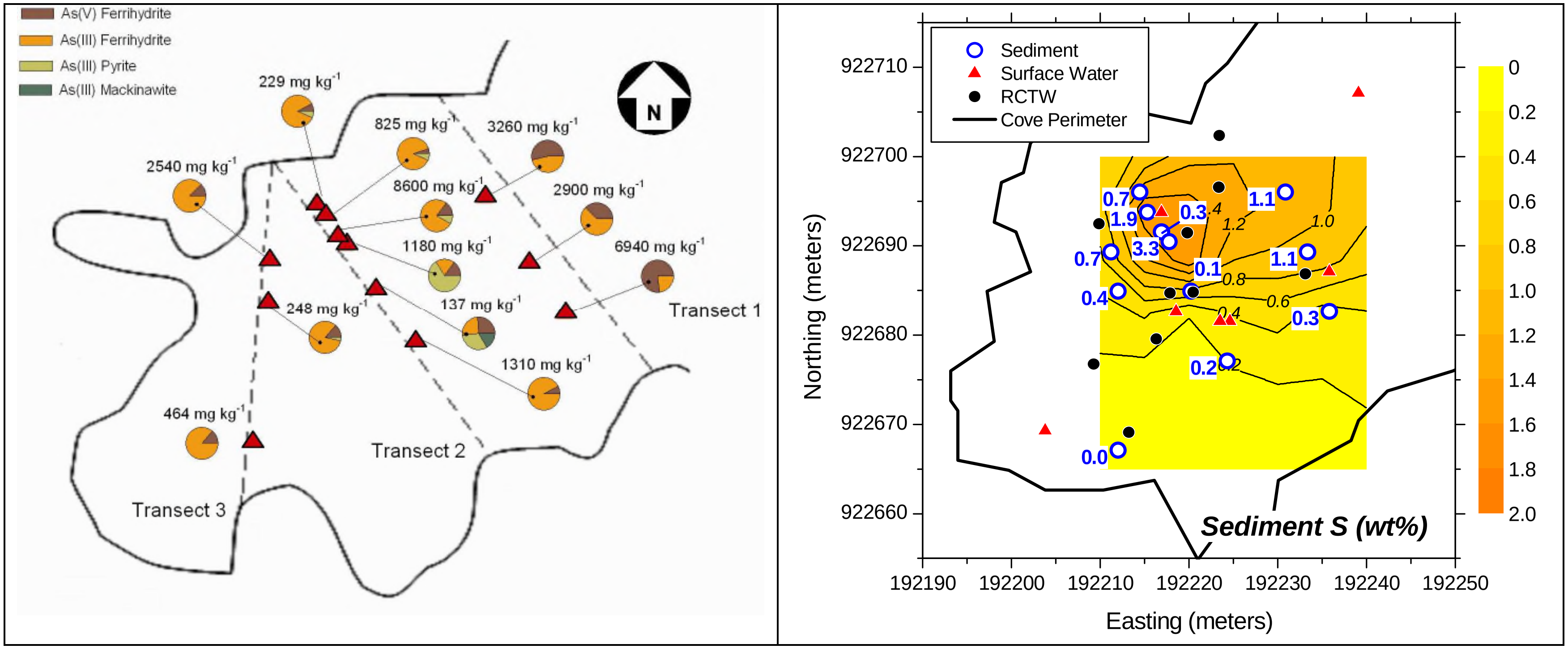


Figure 58. Total quantity and relative percentage of arsenic species present in the top two inches of sediment collected from Red Cove (left panel). Distribution of acid-extractable sulfur for shallow sediments in Red Cove (right panel). Isoconcentration contours developed from individual data (shown in blue text). Locations of RCTW wells and surface water sampling locations also shown.

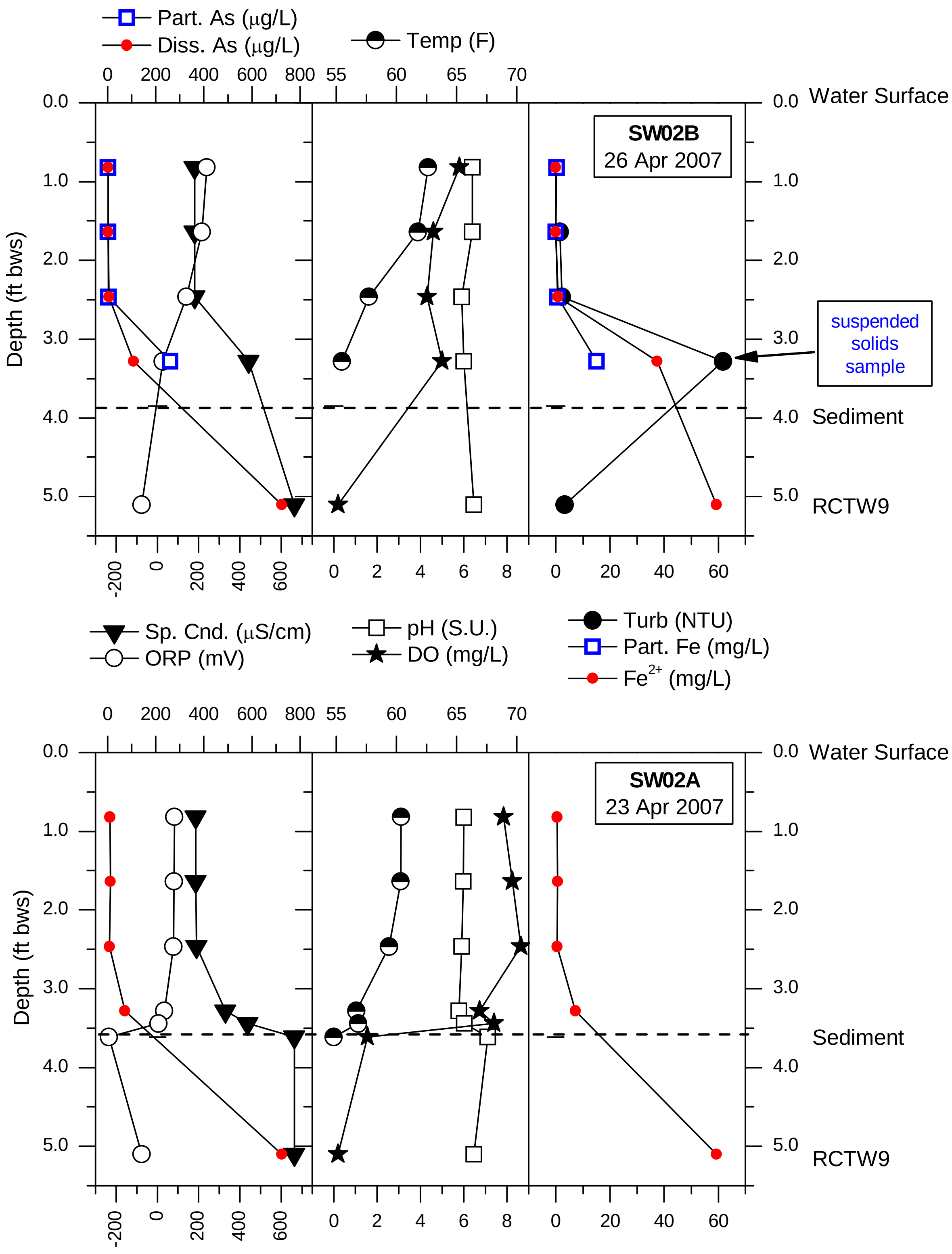
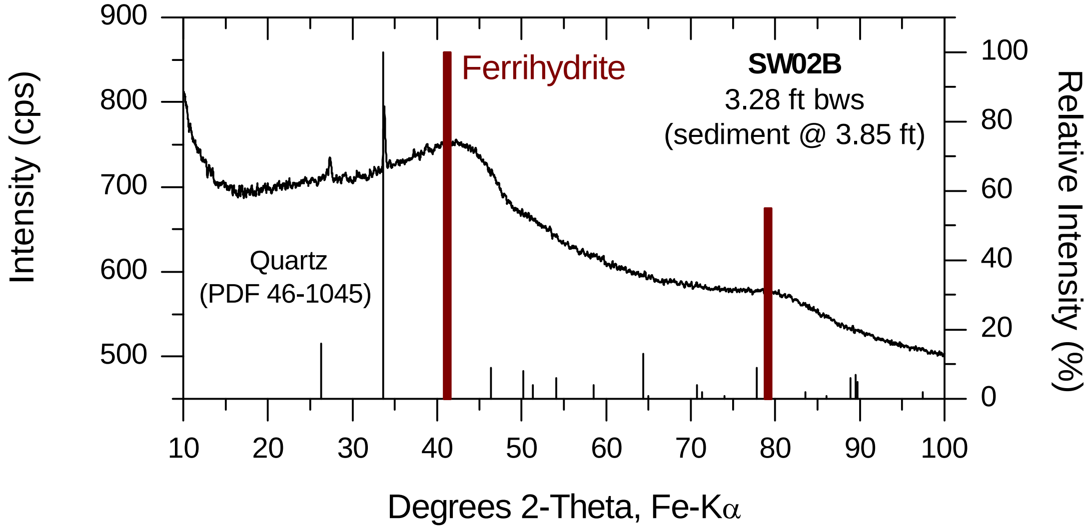


Figure 59. Water quality data at surface water sampling locations SW02B and SW02A for April 2007. Data for closest RCTW well sampled on April 27, 2007 shown for reference.



Major Elements (weight %)		Minor Elements (mg/kg)	
Fe	37.81	As	6533
Ca	5.78	Cr	ND
Na	2.64	Cu	41
K	1.14	Hg	ND
Si	0.63	Ni	14
Mg	0.53	Pb	7
Mn	0.09	Zn	179

Figure 60. Mineralogical characterization of suspended solids recovered from the water column in Red Cove at the SW02 sampling location (0.57 feet above sediments; ft bws = feet below water surface; ND = not detected). Solids were collected on pre-weighed 0.2 µm membrane filters by pumping directly from the sampling depth through an in-line filter housing; five separate 200-mL samples filtered at a pumping rate of approximately 50 mL/min. The mass concentration of total suspended solids was determined to be 39.8 ± 4.1 mg/L (n=5). All solids were composited for analysis by X-ray diffraction (top panel; Q = quartz); major and minor element concentrations determined by difference for unfiltered and filtered (0.45 µm) water samples. Photograph was taken from the pontoon boat at seepage meter deployment adjacent to SW02B sampling location.

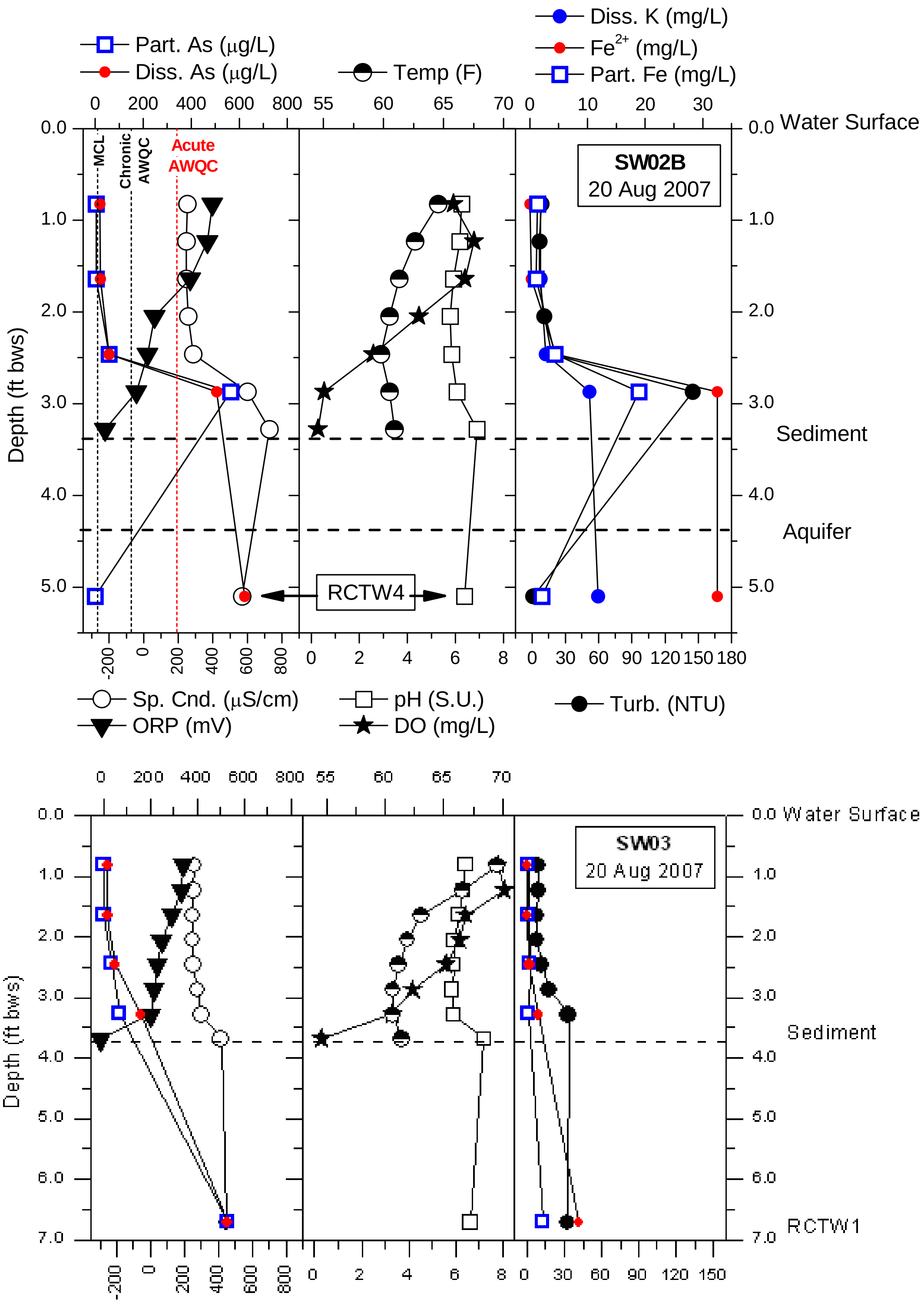


Figure 61. Water quality data at surface water sampling locations SW02B and SW03 for August 2007. Data for closest RCTW wells sampled during August 21-23, 2007 are shown for reference.

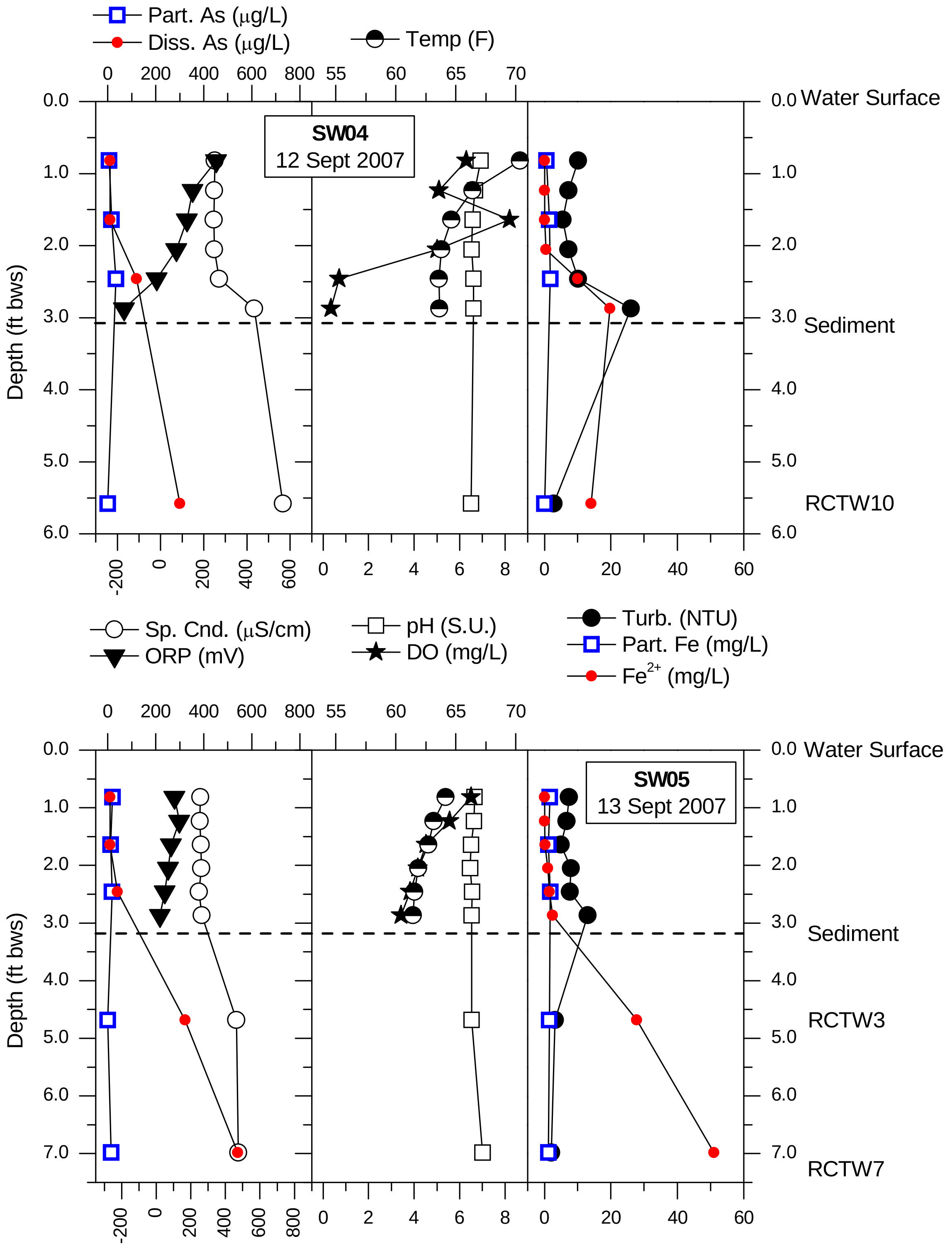


Figure 62. Water quality data at surface water sampling locations SW04 and SW05 for September 2007. Data for closest RCTW wells sampled during August 21-23, 2007 are shown for reference.

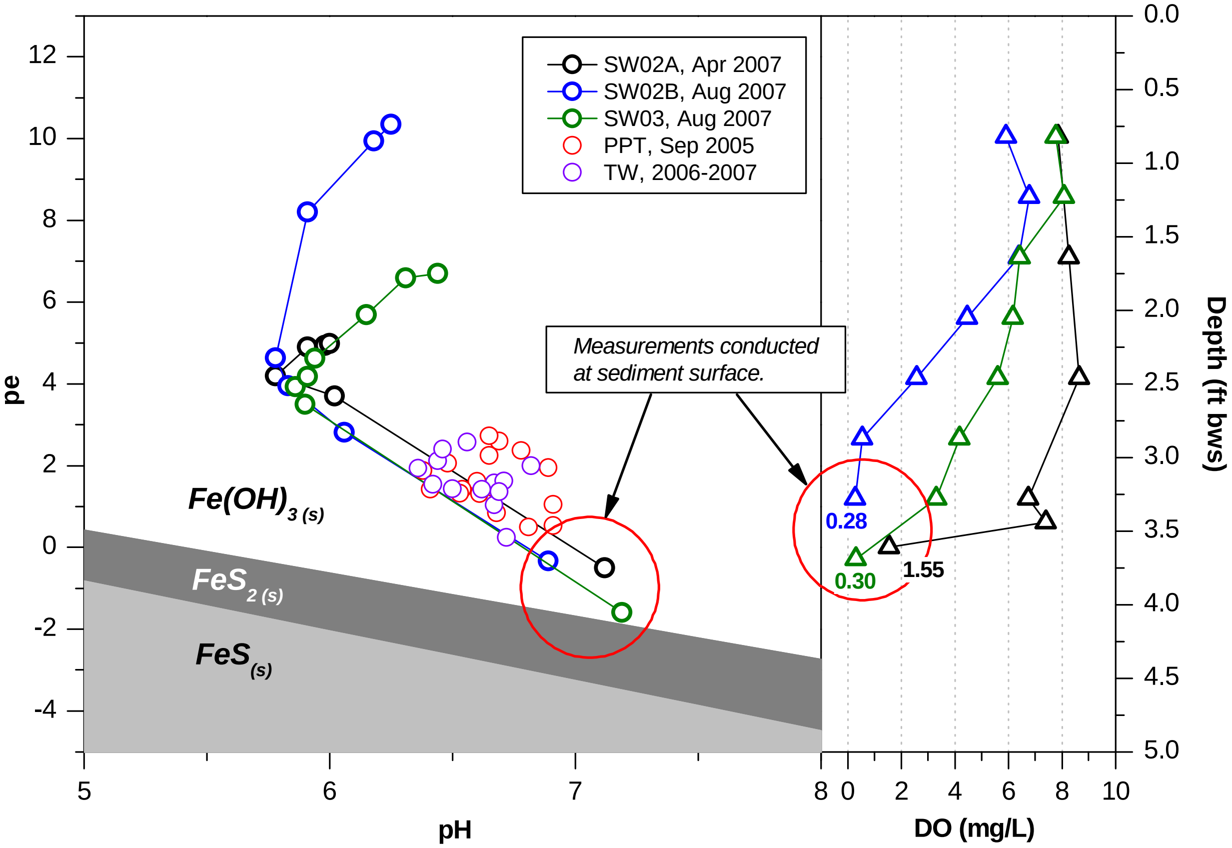


Figure 63. (Left) Comparison of measured water chemistry relative to stability fields for ferrihydrite [represented as $Fe(OH)_3$], pyrite (FeS_2), and mackinawite (FeS). Platinum electrode readings of oxidation-reduction potential (ORP) were converted to electron activity based on reference to the standard hydrogen electrode. Stability fields were constructed as binary systems, i.e., $Fe(OH)_3$-FeS_2 and $Fe(OH)_3$-FeS. Data points enclosed within a red circle are for measurements in which the YSI sonde was allowed to come in contact with sediments. Based on platinum electrode measurements, these shallow sediments displayed the lowest ORP relative to all other groundwater and surface water measurements. (Right) Dissolved oxygen concentration measured as a function of depth below water surface. PPT = push-point samples, RCTW = tubing wells completed in shallow aquifer underlying sediments

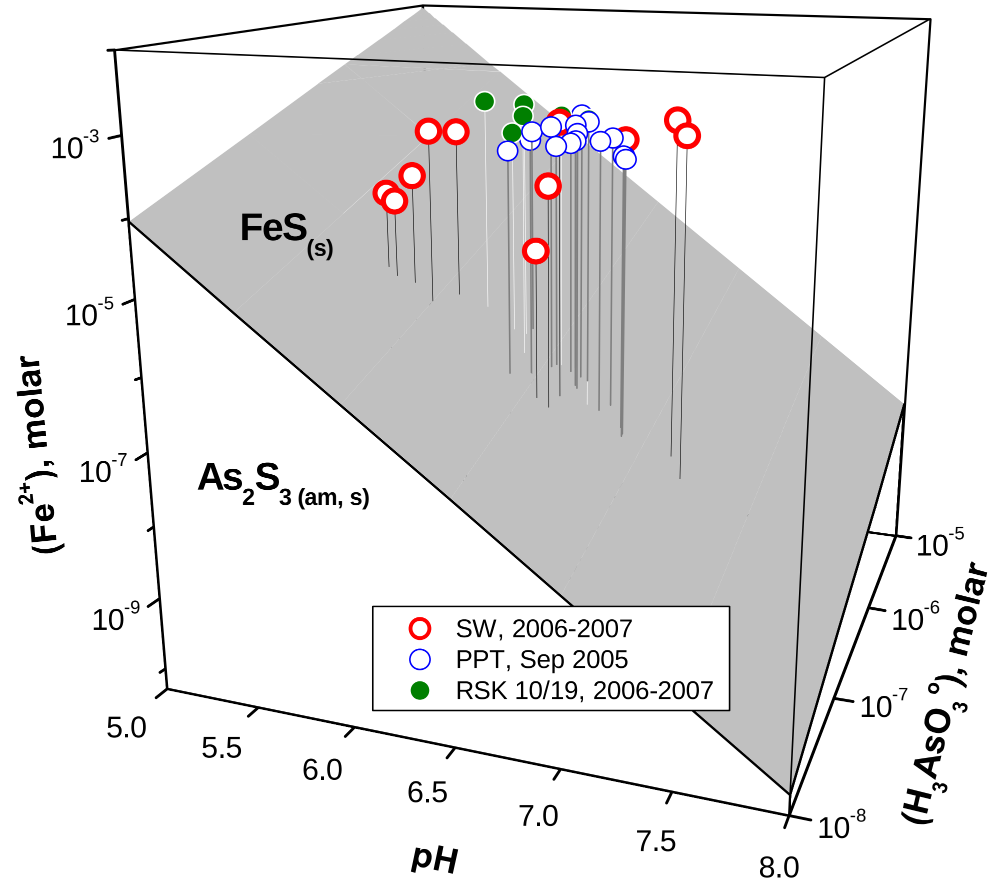


Figure 64. Relative stability of low-temperature sulfide mineral forms of iron (FeS) and arsenic (As_2S_3, poorly crystalline) based on comparison of measured water characteristics (pH, ferrous iron, arsenite concentrations) to thermodynamic predictions. The gray planar surface shown in the figure is based on the chemical reaction expression $3FeS_{(s)} + 2As(OH)_3^o + 6H^+ = As_2S_{3(s)} + 3Fe^{2+} + 6H_2O$ (Wilkin and Ford, 2006). For surface water, only data for monitoring points <1.5 ft above the sediment surface are shown; depths >1.5 ft above sediments are not reasonably represented by this expression due to higher dissolved oxygen concentrations. Chemical conditions for RSK 10 and RSK 19 well screens also shown to represent most reducing conditions (low sulfate, high ammonia) observed in aquifer prior to discharge to Red Cove. PPT = push-point samples

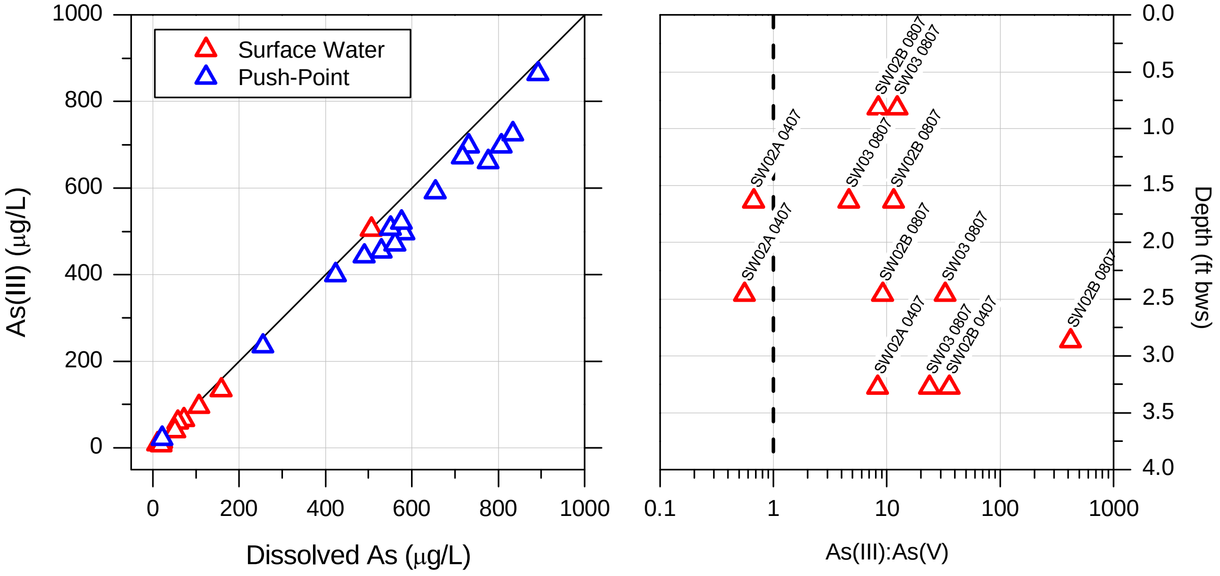


Figure 65. Comparison of the measured concentrations of dissolved arsenic and the arsenite [As(III)] chemical species in filtered push-point and surface water samples from Red Cove (left panel). The line represents a direct linear correlation between the two measurements. The mass ratio of As(III) and As(V) is shown as a function of depth below water surface (ft bws) for surface water samples collected from Red Cove (right panel). Sample location and date (e.g., SW02A 0407 for April 2007) is shown for each data point.

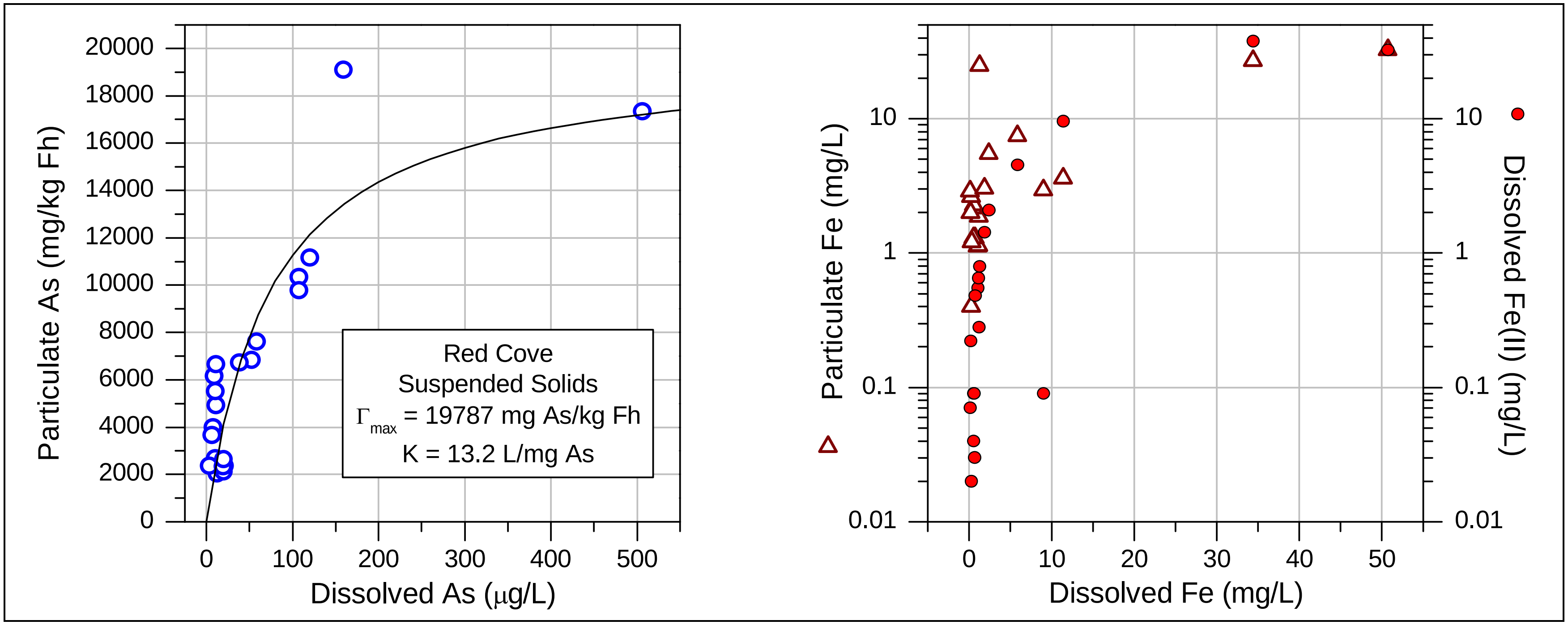


Figure 66. Evaluation of arsenic sorption data for suspended solids within the Red Cove water column for sampling locations SW02A, SW02B, SW03, SW04 and SW05. Particulate concentrations of arsenic and iron were determined by difference for unfiltered and filtered (0.45 µm) samples. Data describing arsenic partitioning (left panel) were fit with a Langmuir isotherm; values for maximum sorption capacity (Γ_{max}) and sorption coefficient (K) are shown based on a best fit regression. Fh = ferrihydrite (nominal formula weight = 480 g/mole as $Fe_5HO_8 \cdot 4H_2O$).

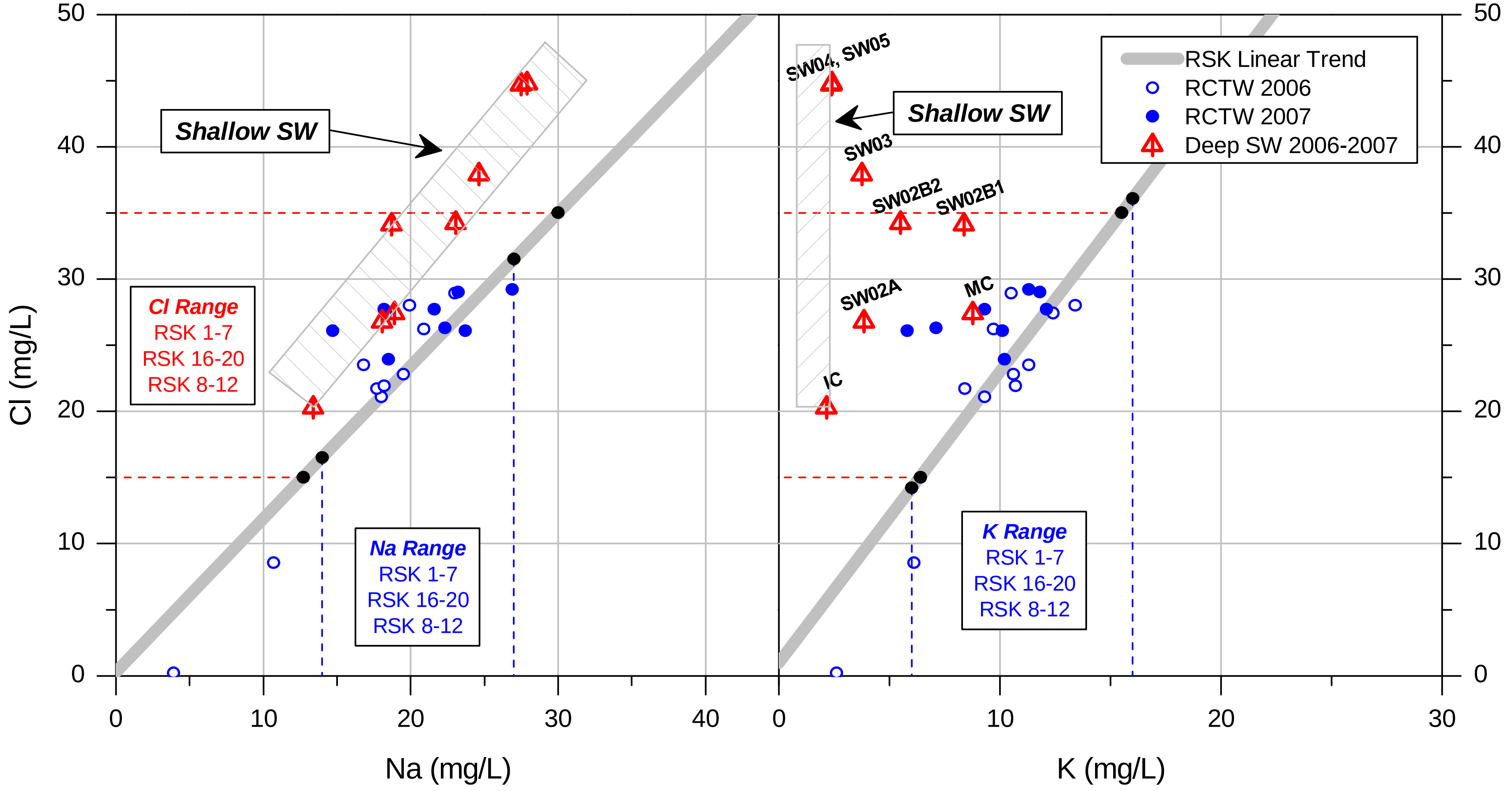


Figure 67. Measured concentrations of chloride (Cl), sodium (Na) and potassium (K) for deep surface water samples and shallow groundwater sampled from RCTW wells during 2006-2007. Values shown for deep surface water were interpolated from existing data for a consistent height above the sediment surface of approximately 0.6-0.7 feet; actual concentrations change with proximity to sediment (see Appendices). For comparison, linear trend fits to RSK groundwater data shown in Figure 32 are included, along with the range of concentrations observed for well clusters RSK 1-7, RSK 16-20 and RSK 8-12. The range in concentration for Red Cove surface water samples (shallowest depth; Figure 34) collected during 2006 and 2007 are shown for reference as the light-gray hatched area.

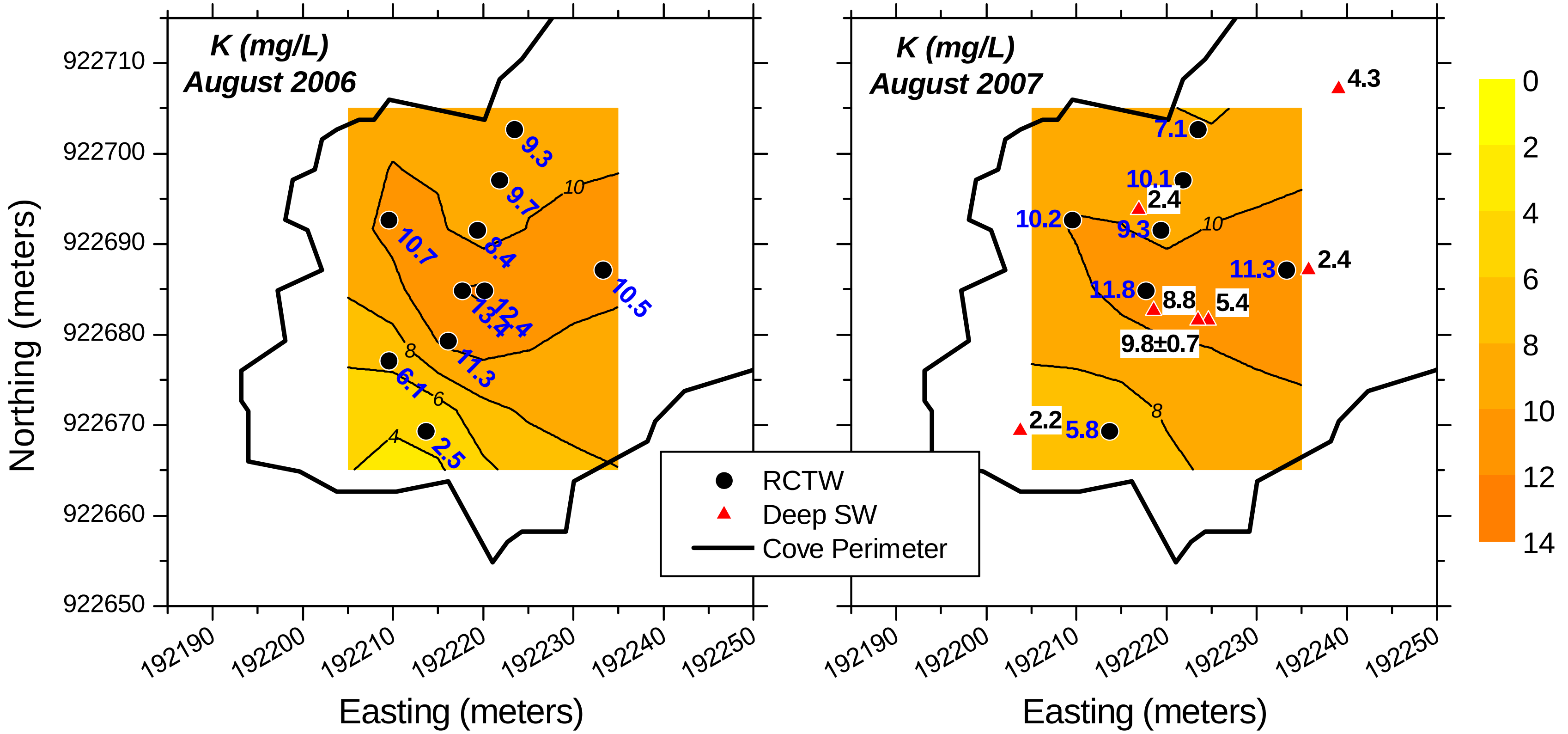


Figure 68. Distribution of potassium (K) concentrations in shallow groundwater (RCTW wells) and deep surface water above the sediment surface in Red Cove. Isoconcentration contours were developed using the measured values at RCTW wells (blue text). Measured values for all surface water sampling locations (2006-2007) are shown in black text on the right panel.

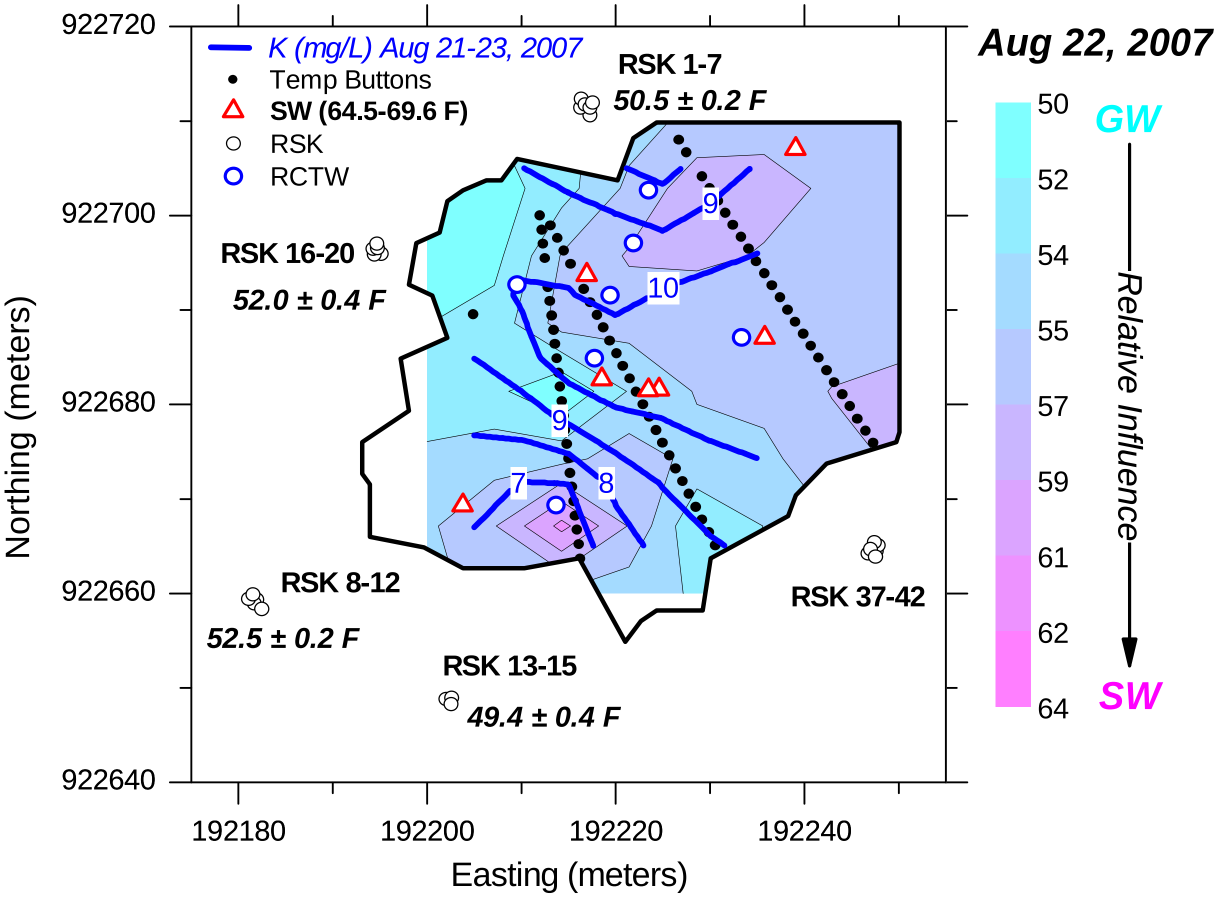


Figure 69. Comparison of sediment temperature distribution (August 22, 2007) to contoured potassium concentrations (mg/L) in RCTW wells measured during August 21-23, 2007. The relative influence from groundwater and surface water on observed sediment temperatures is estimated based on the color gradation shown to the right of the plot. Shown for reference are groundwater temperatures for RSK well screens completed near the water table for the period July 22 – August 22, 2007 (mean ± standard deviation). Temperature data were not available for RSK 37-42 well cluster location, but during the period Sept 13 – Oct 13, 2007 temperatures were 55.2 ± 0.1 F.

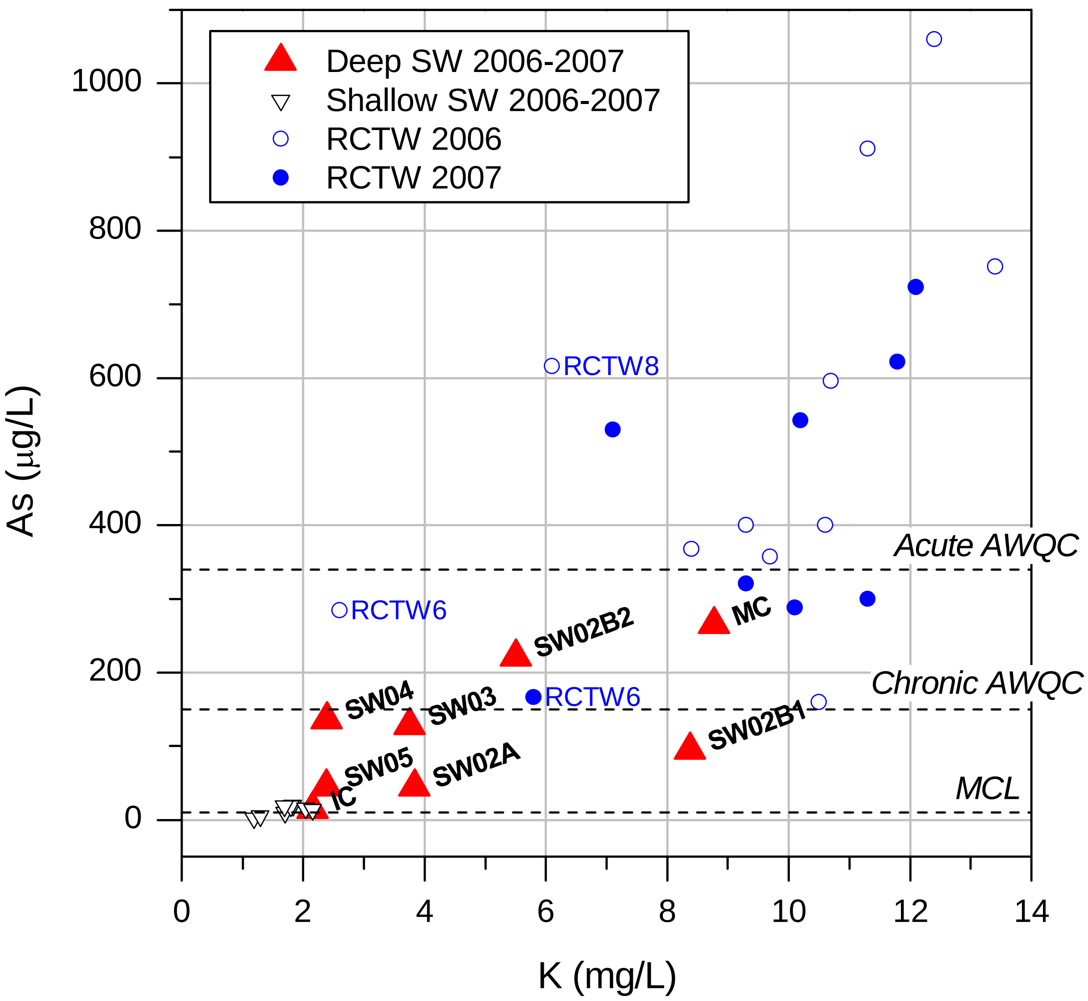


Figure 70. Comparison of arsenic (As) and potassium (K) concentrations for deep and shallow surface water in Red Cove to concentrations observed in underlying shallow groundwater (filtered, 0.45 µm). Values shown for deep surface water were interpolated from existing data for a consistent height above the sediment surface of approximately 0.6-0.7 feet; actual concentrations increase with proximity to sediment (see Appendices). Shallow surface water data are for depths below water surface of <0.5 feet. MCL = Maximum Contaminant Level, AWQC = Ambient Water Quality Criterion

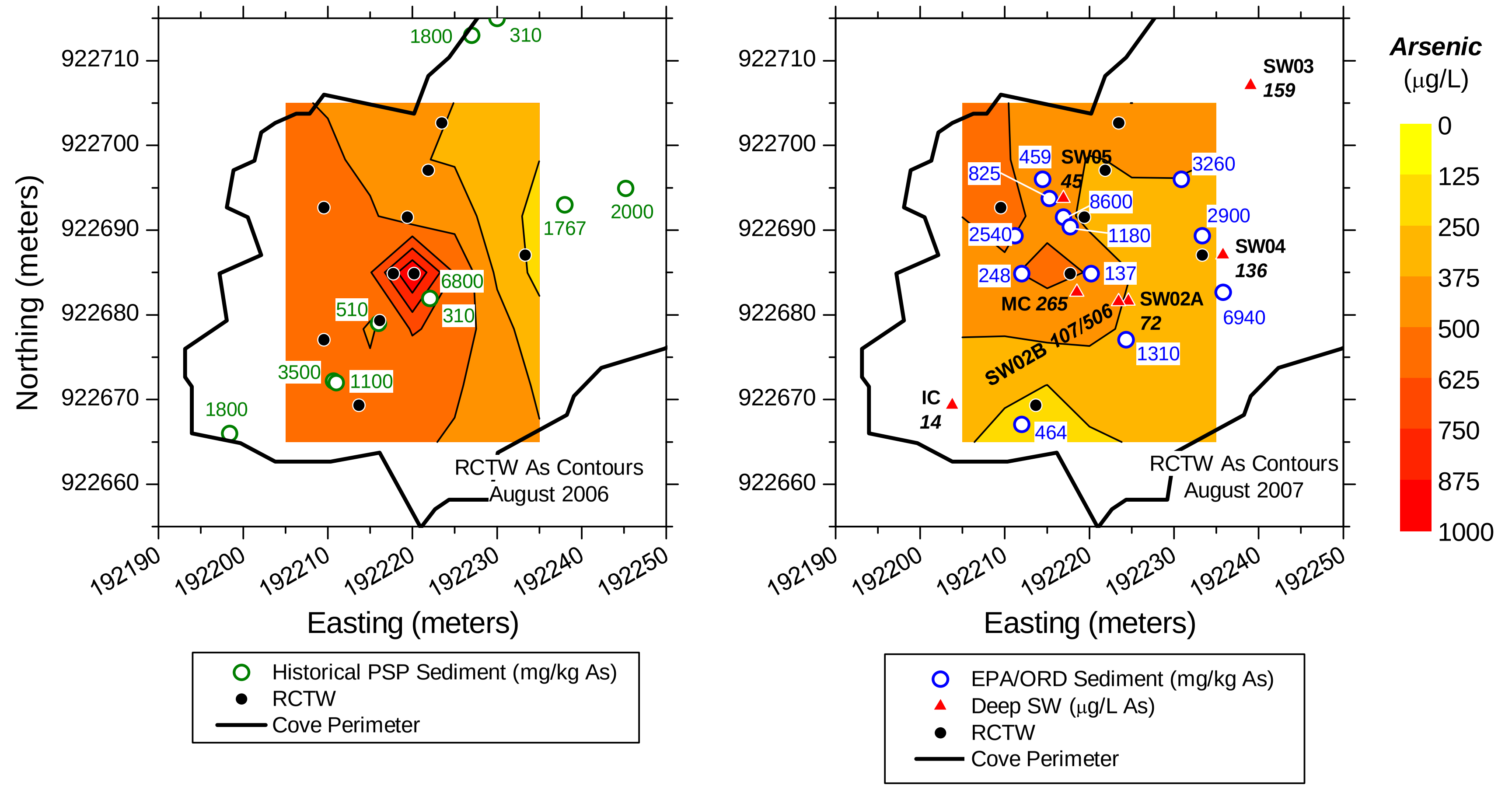


Figure 71. Comparison of arsenic concentrations in sediment, deep surface water and shallow groundwater in Red Cove. Historical sediment data collected for Plow Shop Pond shown in the left panel (Gannett Fleming, 2006). Sediment and surface water data collected by EPA/ORD shown in the right panel. Contoured concentrations are for shallow groundwater based on data from RCTW wells.

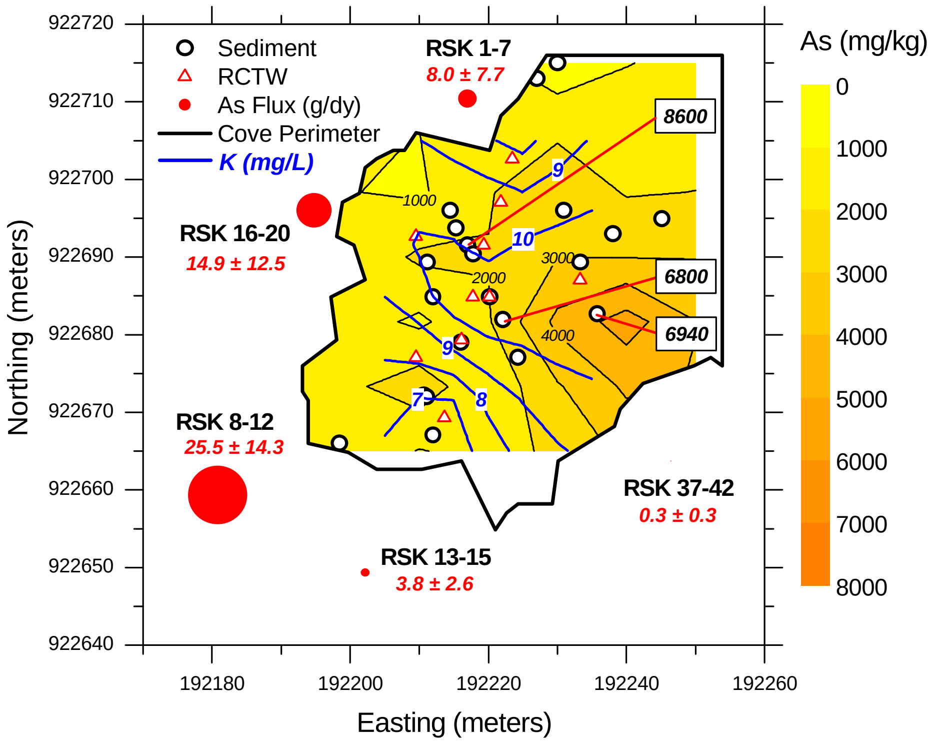


Figure 72. Comparison in estimated groundwater fluxes of arsenic for RSK well locations to the distribution of potassium in shallow groundwater (August 2007; RCTW well contours) and the contoured distribution in sediment arsenic concentration based on historical and EPA/ORD sediment data. The three highest sediment concentrations are highlighted on the right side of the graph; sediment sample with 6800 mg/kg As from location adjacent to SW02B (suspended solids collected from SW02B deep surface water had 6533 mg/kg As on April 2007). Groundwater arsenic fluxes represent the mean of two sampling dates averaged over all screen depths for the RSK well cluster.

Table 9. Concentration of arsenic and speciation of the arsenic solid phase as determined by linear combination fitting of XANES data for Transect 1.

Core	Depth (in)	As (mg kg^{-1})	Arsenic Species (Percent)			
			As(V)-Fh	As(III)-Fh	As(III)-py	As(III)-mack
1	3.5	3260	54	46	0	0
	7	1440	36	58	6	0
	10.5	703	27	16	57	0
	14	52.6	30	51	19	0
	16	8.2	60	38	2	0
2	3.5	2900	37	63	0	0
	7	1710	33	15	53	0
	10.5	1470	26	12	61	0
	14	245	24	44	32	0
3	3.5	6940	77	23	0	0
	7	2150	17	44	40	0
	10.5	1370	33	24	42	0
	14	232	43	42	15	0
	16	11.6	60	32	8	0

Table 10. Concentration of arsenic and speciation of the arsenic solid phase as determined by linear combination fitting of XANES data for Transect 2.

Core	Depth (in)	As (mg kg^{-1})	Arsenic Species (Percent) As(V)-Fh	As(III)-Fh	As(III)-py	As(III)-mack
1	2	459.0	-	-	-	-
	4	229.0	8	86	7	0
	6	30.4	6	71	23	0
	8	16.6	12	88	0	0
	10	15.0	5	95	0	0
	12	18.7	6	94	0	0
	14	22.7	13	87	0	0
1B	2	825.0	5	88	7	0
	4	76.2	14	32	54	0
	6	33.5	17	77	6	0
	8	20.2	20	69	10	0
	10	15.7	-	-	-	-
	12	16.0	-	-	-	-
	14	15.0	27	73	0	0
	16	13.6	35	65	0	0
	18	11.5	31	69	0	0
	20	11.3	-	-	-	-
	22.25	10.7	38	62	0	0
2	2	8600	15	77	8	0
	4	6490	43	50	7	0
	6	4080	39	45	16	0
	8	4160	29	12	35	24
	10	2260	25	21	11	43
	12	1340	26	12	3	59
	14	588	14	11	17	58
	16	326	33	26	41	0
	18.5	322	13	66	20	0
2B	2	1180	15	19	66	0
	4	669	17	13	70	0
	6	649	16	9	75	0
	8	646	7	7	86	0
	10	145	18	17	65	0
	12	32.7	9	25	65	0
	14	26.8	-	-	-	-
	17.5	12	65	35	0	0
	21	12.5	-	-	-	-
	24.5	12.7	71	29	0	0
	28	13.5	71	29	0	0
	32	24.2	73	27	0	0
	36	12.4	39	61	0	0
	40	23.2	53	47	0	0
3	2	137.0	26	26	31	17
	4	112.0	9	16	30	45
	6	79.3	30	15	55	0
	8	15.6	25	75	0	0
	10	14.7	-	-	-	-
	12	24.8	34	66	0	0
	15.5	9.1	66	34	0	0
	19	9.9	67	33	0	0

	22.5	10.7	48	52	0	0
	26	11.3	40	60	0	0
	29.5	14.8	70	30	0	0
	33	18.3	70	30	0	0
	36.5	21.8	71	29	0	0
	40	25.3	71	29	0	0
4	2	1310	8	92	0	0
	4	1670	9	91	0	0
	6	1510	11	89	0	0
	7.125	397	9	91	0	0
	11.125	183	43	43	13	0
	15.125	10.1	44	42	14	0
	19.125	9.65	41	31	28	0
	22.625	-	-	-	-	-
	26.125	-	-	-	-	-
	29.625	-	-	-	-	-
	33.125	-	-	-	-	-

Table 11. Concentration of arsenic and speciation of the arsenic solid phase as determined by linear combination fitting of XANES data for Transect 3.

	Depth	As	Arsenic Species (Percent)			
Core	(in)	(mg kg^{-1})	As(V)-Fh	As(III)-Fh	As(III)-py	As(III)-mack
1	2	2540	12	88	0	0
	4	1710	12	82	5	0
	6	930	5	62	33	0
	8	850	0	76	24	0
	10	556	0	60	40	0
	12	36.8	-	-	-	-
	13	19.7	-	-	-	-
	16.5	17.9	28	65	6	0
	20	25.7	38	62	0	0
	23.5	24.3	48	52	0	0
	27	22.4	53	47	0	0
2	2	248	13	83	4	0
	4	143	9	69	22	0
	6	92.3	9	91	0	0
	8	22.4	8	92	0	0
	10	15.7	15	85	0	0
	10.5	16.4	25	75	0	0
	14	20.1	47	53	0	0
	17.5	12.9	52	48	0	0
	21	14.2	68	32	0	0
	24.5	8.91	70	30	0	0
3	1	464.0	14	86	0	0
	3	51.0	33	67	0	0
	5	18.3	-	-	-	-
	7	9.5	-	-	-	-
	9	8.3	-	-	-	-
	11	9.0	-	-	-	-
	13	10.0	-	-	-	-
	15	11.3	-	-	-	-
	15.5	266.0	17	61	22	0
	17.5	287.0	13	82	5	0
	19.5	244.0	8	89	3	0
	21.5	193.0	0	89	11	0
	23.5	54.0	29	63	7	0
	25.5	27.4	29	71	0	0
	27.25	35.7	41	59	0	0
	29.25	44.9	45	55	0	0
	31.25	28.6	35	65	0	0
	33.25	26.1	-	-	-	-
	35.25	22.1	44	56	0	0
	37.25	15.4	17	83	0	0
	39.25	15.4	-	-	-	-

5 Summary and Recommendations

The following sections provide a summary of existing conditions maintaining elevated levels of arsenic within Red Cove, an assessment of remedial alternatives that may be employed to address groundwater and sediment contamination, and recommendations for additional site characterization efforts needed to support evaluation of remedial alternatives for site restoration. Discussion of remedial alternatives for groundwater and sediment cleanup is for information purposes only.

5.1 Red Cove – Existing Conditions

Analysis of hydrologic and chemistry data collected from the Red Cove Study Area during September 2005 to November 2007 indicate that groundwater with elevated concentrations of arsenic currently discharges into Red Cove. Based on current and historical data for the distribution of arsenic in shallow sediments within Plow Shop Pond (Gannett Fleming, 2006), the arsenic concentrations observed in Red Cove sediments appear consistent with groundwater discharge as a source of arsenic contamination. The distribution of arsenic flux measured at RSK well clusters in combination with the piezometric surface depicting groundwater flow potential for the aquifer underlying the landfill (CH2MHill, 2006) indicate that the primary source of arsenic originates from a direction west-southwest of Red Cove. Since the speciation of arsenic is dominated by inorganic forms, there is no unique signature to differentiate whether this contamination is due solely to materials disposed within the landfill, due solely to the result of landfill-induced reducing conditions liberating natural sources of arsenic in overburden, till or bedrock, or some combination of these factors.

Comparison of water chemistry data from well screens installed within the aquifer underlying the central portion of the landfill indicates that mixing of groundwater near the water table (N5-P2 completed in disposed material) and at depth within the overburden (SHP-99-29X) or bedrock groundwater (N5-P1) provides a reasonable match to chemical conditions observed throughout the saturated overburden thickness at RSK well cluster RSK 8-12 (See Section 3.2). In contrast, the water chemistry observed at well screens installed within the southern portion of the landfill (N7-P1,P2) does not provide a reasonable match to the water chemistry observed at RSK well clusters RSK 8-12 and RSK 16-20 (see Figures 40 and 41). However, based on the groundwater piezometric surface determined within the boundary of the landfill (CH2MHill, 2006), there is not a likely flow path from groundwater at well locations N5-P1,P2 and SHP-99-29X to the RSK 8-12 and RSK 16-20 well clusters. Thus, the elevated concentrations of arsenic observed at these RSK well clusters appears to originate from a portion of the aquifer between the aerial locations of existing wells N5-P1,P2/SHP-99-29X and N7-P1,P2. In addition, the water chemistry observed at existing locations N5-P1,P2 and SHP-99-29X may, in part, reflect flow contributions from groundwater originating further upgradient within the aquifer underlying the landfill. Currently, insufficient groundwater characterization data are available to further delineate the source of the arsenic plume discharging to Red Cove.

Presently, concentrations of arsenic observed in surface water within Red Cove are, in part, controlled by the continual precipitation of iron oxides that sequester dissolved arsenic introduced from groundwater discharge or released by diffusion from contaminated sediments.

Since the cove is a biologically productive system due to the continual, seasonal supply of degradable organic matter from aquatic plants, reducing conditions will likely prevail at the sediment-surface water interface. As previously shown in Figure 63, the lowest ORP readings for Red Cove Study Area wells sampled for chemistry data were observed within the shallow sediment layer. Thus, while the continual oxidation and precipitation of ferrous iron within the water column will serve to remove a portion of dissolved arsenic from the water column, the precipitated iron oxides are susceptible to re-dissolution and release of sequestered arsenic. This process appears to occur at surface water sampling location SW04 where sequestration of dissolved arsenic is active, as indicated by the high turbidity near the sediment-surface water interface and the high shallow sediment arsenic concentrations at sediment core locations SCT0102 and SCT0103 (Figure 71).

The concentration of potassium in surface water samples can be used as a tracer for contaminated groundwater discharge. Comparison of potassium concentrations in deep surface water at SW04 (2.4 mg/L; Figure 68) and shallow groundwater at TW10 (11.3 mg/L; Figure 68) indicates that groundwater discharge does not likely control arsenic concentrations in surface water at location SW04. Rather, the dissolved (0.45 μm filtered) arsenic concentrations observed in deep surface water are most likely derived from the release of arsenic during dissolution of the iron oxides deposited in shallow sediments (Figure 73). As a point of reference, the concentration of potassium in deep surface water at sampling locations MC and SW02B ranged between 8.8-10.3 mg/L (May 2006, Aug 2007) compared to 11.8-13.4 mg/L and 12.1-12.4 mg/L at shallow groundwater locations RCTW4 (Aug 2006, Aug 2007) and RCTW9 (Aug 2006, Apr 2007), respectively. According to solid phase speciation data for shallow sediments near location SW04, arsenic predominantly resides as As(III) or As(V) associated with an iron oxide, similar to the precipitate settling out from the overlying water column (Figure 58). This pattern in arsenic recycling between contaminated sediments and overlying surface water at location SW04 is similar to that observed for a eutrophic, kettle-hole lake near Arlington, Massachusetts (Senn et al., 2007). The objective of that field study was to examine the long-term fate of a historical pulse of arsenic that ultimately became associated with sediments. In the study conducted by Senn et al. (2007), characterization of the system indicated that a majority of the contemporary arsenic load within the water column was derived from dissolution of contaminated sediments.

The result of this internal recycling of arsenic between sediments and overlying surface water is the potential maintenance of dissolved arsenic concentrations within the water column that may exceed ambient water quality criteria. Thus, the contaminated sediments could pose a long-term exposure risk to aquatic life within Red Cove surface water. The actual impact to aquatic life would need to be tested via exposure tests designed to replicate in-situ conditions within the cove. In general, the following statements can be made concerning the transport and fate of arsenic entering Red Cove based on the information documented in this report:

- The centerline of highest arsenic flux from groundwater discharging into Red Cove appears to lie between RSK well clusters RSK 13-15 and RSK 1-7.

- The chemistry of groundwater adjacent to Red Cove containing elevated concentrations of arsenic is not consistent with the chemistry observed at any single screened interval for

SHL wells N7-P1, N7-P2, SHP-99-29X, N5-P1 or N5-P2. Groundwater chemistry at well clusters with highest calculated arsenic flux (RSK 8-12 and RSK 16-20) appear to be derived from a mixture of sources and/or locations under the landfill between existing well locations N7-P1,P2 and N5-P1,P2 that are currently not monitored for chemistry.

- Measurements of shallow groundwater chemistry underneath Red Cove along with direct measurements of groundwater discharge demonstrate that the existing groundwater extraction system does not prevent arsenic plume discharge into the cove at current pumping rates.

- The highest concentration of arsenic in surface water within Red Cove was observed at a known location of groundwater discharge.

- Oxidation and precipitation of ferrous iron within surface water sequesters a portion of arsenic derived from groundwater discharge and/or contaminated sediment dissolution.

- Elevated concentrations of arsenic in deep surface water within zones where contaminated groundwater discharge appears less significant indicates that arsenic sequestered by settling iron oxide precipitates is not stable under existing conditions.

- Remediation of existing contaminated sediments within Red Cove will have limited long-term effectiveness if conducted without remediation of the groundwater plume discharging into the cove.

5.2 Analysis of Potential Remediation Alternatives

The relationship between groundwater discharge and sediment contamination in Red Cove is a critical issue that impacts possible approaches to address contaminated sediments in this portion of Plow Shop Pond.

The continued flux of arsenic anticipated from groundwater discharge into Red Cove will influence the effectiveness of any remedy evaluated or selected to address sediment contamination. It is not likely that any chosen remedy for contaminated sediments will have sufficient long-term effectiveness without significant reduction or elimination of contaminated groundwater discharge. Thus, it is important to first consider remedial approaches to address contaminated groundwater discharging into Red Cove.

5.2.1 Groundwater

There are two general approaches to address contaminated groundwater discharge to Red Cove: 1) eliminate discharge by changing the prevailing flow gradient or 2) in-situ removal of arsenic from groundwater prior to discharge to the cove. Current performance data for the groundwater extraction system at the northern end of Shepley’s Hill Landfill suggest that this type of approach may be applied in the vicinity of Red Cove. Direct measurements of groundwater discharge into Red Cove indicate that current pumping rates at the northern end of the landfill are insufficient to prevent the continued flux of arsenic discharging into the cove (Section 2.5). This is demonstrated by the continued observation of groundwater discharge into the cove at advective flux meter location SM1B from April 2007 to November 2007 even though the rate of groundwater extraction was increased from approximately 20 gpm to a sustained rate greater than 40 gpm during July 2007. It is likely that the existing groundwater extraction system would need to be supplemented to target increased capacity for extraction adjacent to Red Cove. The detailed information on local flow gradients around Red Cove and the spatial distribution of arsenic flux provided in this report present a sound basis for delineation of the dimensions and centerline of the groundwater plume along the eastern border of the landfill cap. More detailed mapping of the arsenic plume to the west-southwest of well clusters RSK 8-12 and RSK 16-20 would facilitate designing a supplemental extraction system that targets the most severe sources of contaminated groundwater discharge. Alternatively, a slurry wall or some other form of containment could be constructed to re-direct groundwater flow from Red Cove towards the existing extraction system.

In addition to implementing controls on groundwater hydrology adjacent to Red Cove, it may also be feasible to minimize arsenic discharge through manipulation of the geochemical conditions within the unconsolidated aquifer underlying Shepley’s Hill Landfill. In general, the reducing conditions in groundwater maintain iron in a soluble form and prevent precipitation of iron oxide minerals prior to discharge into Red Cove. One potential approach to induce more oxidizing conditions and maintain iron in less soluble forms could involve re-introduction of treated, oxidized water from the existing pump and treat system back into the aquifer underlying the landfill and/or immediately upgradient from the zone of discharge into Red Cove. This may necessitate development of a more detailed knowledge of groundwater flow within the landfill to support analysis for design of an appropriate infiltration system for re-introduction of treated groundwater.

Alternatively, in-situ removal of arsenic in groundwater, without additional hydrologic control, appears feasible through use of a permeable reactive barrier (PRB) system installed perpendicular to the discharge of contaminated groundwater. By positioning the PRB close to the cove shoreline, the physical dimensions and associated capital costs of the installation could be minimized. Bench and pilot tests with zero-valent iron indicate that this material would provide a likely candidate as a reactive matrix for the PRB (Lien and Wilkin, 2004; Wilkin et al., 2005; Ford et al., 2007). Long-term performance data for a zero-valent iron PRB installed under similar groundwater geochemistry at the Elizabeth City site in North Carolina indicates satisfactory long term performance characteristics, relative to barrier porosity and reactivity, could be realized within the Red Cove Study Area. Relative to these performance characteristics, zero-valent iron barrier systems demonstrate better performance characteristics for groundwater with total dissolved solids (TDS) concentration <1000 mg/L (e.g., <600 mg/L TDS at Elizabeth City site; Chapter 6 in Wilkin and Puls, 2003). A potential limitation of a zero-valent iron PRB is the generation of more reducing and higher pH conditions downgradient of the barrier, which may result in greater instability of existing contaminated sediments impacted by historical groundwater discharge. Thus, a PRB may necessitate some form of active management of sediments and/or surface water conditions within Red Cove in order to avoid further degradation of conditions supporting aquatic life in this portion of Plow Shop Pond. Performance data are not available for barrier systems employing reactive media that do not exert a strong influence on redox geochemistry within and downgradient of the barrier system.

5.2.2 Sediments

Existing information is insufficient to define the absolute contribution of contaminated sediments to the concentration of arsenic observed in deep surface water within Red Cove. In general, iron oxides precipitated in the water column will be unstable in the reducing conditions encountered following re-deposition onto sediments in Red Cove. As a point of reference, surface water sampling locations SW04 and SW05 appear to have limited influence from direct groundwater discharge. However, the concentration of dissolved arsenic in deep surface water at these locations ranged between 45-136 μg/L. The deposition and decay of organic material from aquatic plants and other natural sources within Red Cove will tend to maintain reducing conditions within shallow sediments even in the absence of the discharge of reducing groundwater. The extent that this natural process drives observed conditions within Red Cove currently cannot be assessed with reliability given the influence of contaminated groundwater discharge. It is reasonable to assume that historical accumulation of arsenic in sediments in Red Cove will continue to provide a potential long-term source of arsenic to overlying surface water, but this is poorly defined at present. The range of dissolved arsenic concentrations due to release from contaminated sediments at surface water sampling locations SW04 and SW05 appear to be lower than those observed at a known location of contaminated groundwater discharge (107-506 μg/L at locations MC and SW02B). However, these data are insufficient to define the flux of arsenic attributed solely to release from contaminated sediments.

Given the constraints of this analysis, there appears to be at least two options that may be employed to remediate sediment contamination. Provided cessation of contaminated groundwater discharge, removal of existing contaminated sediments provides a direct approach to eliminate the contaminant burden within the cove. Based on the depth distribution of arsenic within sediment cores, removal to a depth of approximately 15 inches below the existing sediment surface should be sufficient to eliminate a majority of the current mass of arsenic tied up in sediments. However, it is unclear whether this level of disturbance to the existing benthic habitat provides an acceptable remedial approach relative to a desired ecosystem restoration endpoint.

Additionally, it is reasonable to consider placement of clean material on top of contaminated sediments to provide additional capacity to sequester arsenic released from contaminated sediments and to provide improved benthic habitat. The solid material in a “reactive” cap would need several characteristics to optimize its performance: 1) capacity and selectivity for arsenic sorption in the presence of a range of dissolved constituents common to groundwater and surface water at Red Cove, 2) stability to resist dissolution due to the development of reducing conditions, and 3) permeability sufficient to prevent the potential redirection of discharging groundwater to regions further out into Plow Shop Pond. There is limited information on reactive sediment capping materials designed to sequester contaminants with chemical characteristics like arsenic. Thus, some developmental work would be necessary to identify a suitable material. In addition, this approach provides the ability to place clean solid substrate on top of the newly emplaced “reactive” material in order to improve benthic habitat.

These approaches provide alternatives to minimize release of dissolved arsenic to overlying surface water, thus minimizing potential exposure routes within the water column. As previously discussed, sediment removal may result in unacceptable disturbance to the benthic habitat and would likely require further effort to stabilize arsenic bound to the sediments or necessitate disposal of dredged sediment as a hazardous material. Likewise, increasing the stability of arsenic-bearing iron oxides within the sediment will not necessarily address routes of exposure to the benthic community within Red Cove. Thus, it is recommended that an exposure assessment be conducted that is designed to assist differentiation of the risk attributed to dissolved arsenic (or other potential risk drivers such as ammonia) versus arsenic associated with contaminated sediments. This information would also be critical to the evaluation of whether monitored natural recovery (MNR) provides a viable long-term alternative for contaminated sediments. The effectiveness of this remedial approach cannot currently be assessed given the continued influence of contaminated groundwater discharge into the cove.

5.3 Recommendations for Site Characterization

There are four issues that merit continued site characterization efforts to support evaluation of the performance of the existing pump and treat groundwater remedy and to support selection of a remedy for contaminated sediments in Red Cove. These issues are listed below along with recommendations for who could lead this effort:

1) Further delineation of the spatial extent of the arsenic plume discharging into Red Cove in order to support design of a better targeted and cost-efficient remedial system to minimize or eliminate contaminated groundwater discharge into the cove;

    - Sample groundwater chemistry at water table closer to eastern edge of landfill cap to supplement aerial coverage of existing RSK and Army wells (EPA/ORD – RSK 26, 27, 28, 29, 30, and 32)
    - Sample groundwater chemistry at discrete depths throughout the saturated overburden down to bedrock within SHL of at least three locations (Figure 74A) to characterize groundwater chemistry in saturated waste and unconsolidated aquifer between locations of existing wells N7-P1,P2 and N5-P1,P2 (Army; EPA/ORD sample splits for supplemental chemistry, if desired). Where feasible, collection of solids as a function of saturated depth is recommended in order to examine the potential correspondence between arsenic content in groundwater and co-located aquifer solids. [Adjustment to these proposed locations may be warranted with acquisition and review of additional hydrologic or chemistry data from the existing monitoring well network.]
    - Sample groundwater chemistry at discrete depths throughout the saturated overburden down to bedrock along the eastern edge of landfill cap at two locations as illustrated in Figure 74B (Army; EPA/ORD sample splits for supplemental chemistry, if desired). [Adjustment to these proposed locations may be warranted with acquisition and review of additional hydrologic or chemistry data from the existing monitoring well network.]

2) Continued assessment of the influence of the existing groundwater extraction system on potentiometric surface and flow gradients adjacent to Red Cove and discharge patterns into Red Cove (EPA/ORD). Conduct advective flux measurements in additional locations of the cove and further assess use of sediment temperature measurements to map out areas of groundwater discharge (EPA/ORD). Given the importance of local rainfall events on system hydrology, it is also recommended that an on-site meteorological station be installed and monitored in order better constrain interpretations of water level fluctuations in the aquifer (Army);

3) Evaluation of existing data and determination of supplemental sampling locations needed to design and complete an aquatic and human health exposure assessment study that targets locations within the cove that will assist in assessing the separate contributions of contaminants derived from groundwater discharge versus existing contaminated sediments (Army); and,

4) Acquisition of additional depth-resolved surface water data to better map out the spatial distribution of redox conditions and dissolved contaminants within the water column (EPA/ORD).

The first issue is warranted to improve the effectiveness and cost-efficiency of a remedial system to intercept contaminated groundwater discharge to Red Cove. According to groundwater chemistry data from the Red Cove Study Area, the centerline of highest arsenic flux adjacent to Red Cove appears to be within the zone monitored at RSK well clusters RSK 8-12 and RSK 16-20 (Figure 72). In order to optimize plume interception or groundwater extraction efficiency, knowledge of the plume dimensions further to the west-southwest of Red Cove would provide useful constraint for selecting the capacity and siting of the remedial system. It is recommended that additional monitoring points (temporary or permanent) be sampled along the eastern edge of the landfill cap to better delineate the horizontal and vertical extent of the plume that is the source of elevated arsenic concentrations discharging into Red Cove.

The second issue is warranted given the relatively short period of time over which the existing groundwater extraction system has been operating, particularly considering the operational changes that have been implemented within the past year. This information is needed to better evaluate the degree of influence this extraction system will have on groundwater potentiometric surface adjacent to the cove. The existing hydrologic monitoring network should be sufficient to accomplish this objective.

The third issue is warranted given the relatively sparse number of deployments of the advective flux meter to directly map out contaminated groundwater discharge within the cove. Since arsenic in sediment and surface water was identified as a potential contributor to unacceptable risk in Plow Shop Pond (Gannett Fleming, 2006), determining the relative contribution of exposure to groundwater discharge versus contaminated sediments for potential impacts to aquatic life or human exposure is needed. The existing data offer a good basis for a map of groundwater discharge within the cove, and future ORD work will be used to improve this understanding of groundwater discharge areas. Specifically, additional measurements using the advective flux meter in combination with additional temperature button deployments and water quality measurements will be used to develop a more detailed map of groundwater discharge within Red Cove. The greater detail will assist in selecting locations for isolating the effects of groundwater discharge and contaminated sediments on the response of potential receptors in the pond.

The last issue is warranted given the uncertainty of whether acceptable contaminant concentrations can be achieved in surface water overlying contaminated sediments with the advent of more oxidizing conditions. Supplemental measurements are warranted in areas where there appears to be limited current discharge of contaminated groundwater originating from the landfill. These measurements should be coordinated with the effort to map out groundwater discharge within the cove in order to reduce uncertainty in the interpretation of collected data.

5.4 References

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Performance Evaluations at Two Sites, EPA Report, U.S. Environmental Protection Agency, Cincinnati, OH, EPA/600/R-03/045a. (http://www.epa.gov/ada/pubs/reports/600R03045a.html)

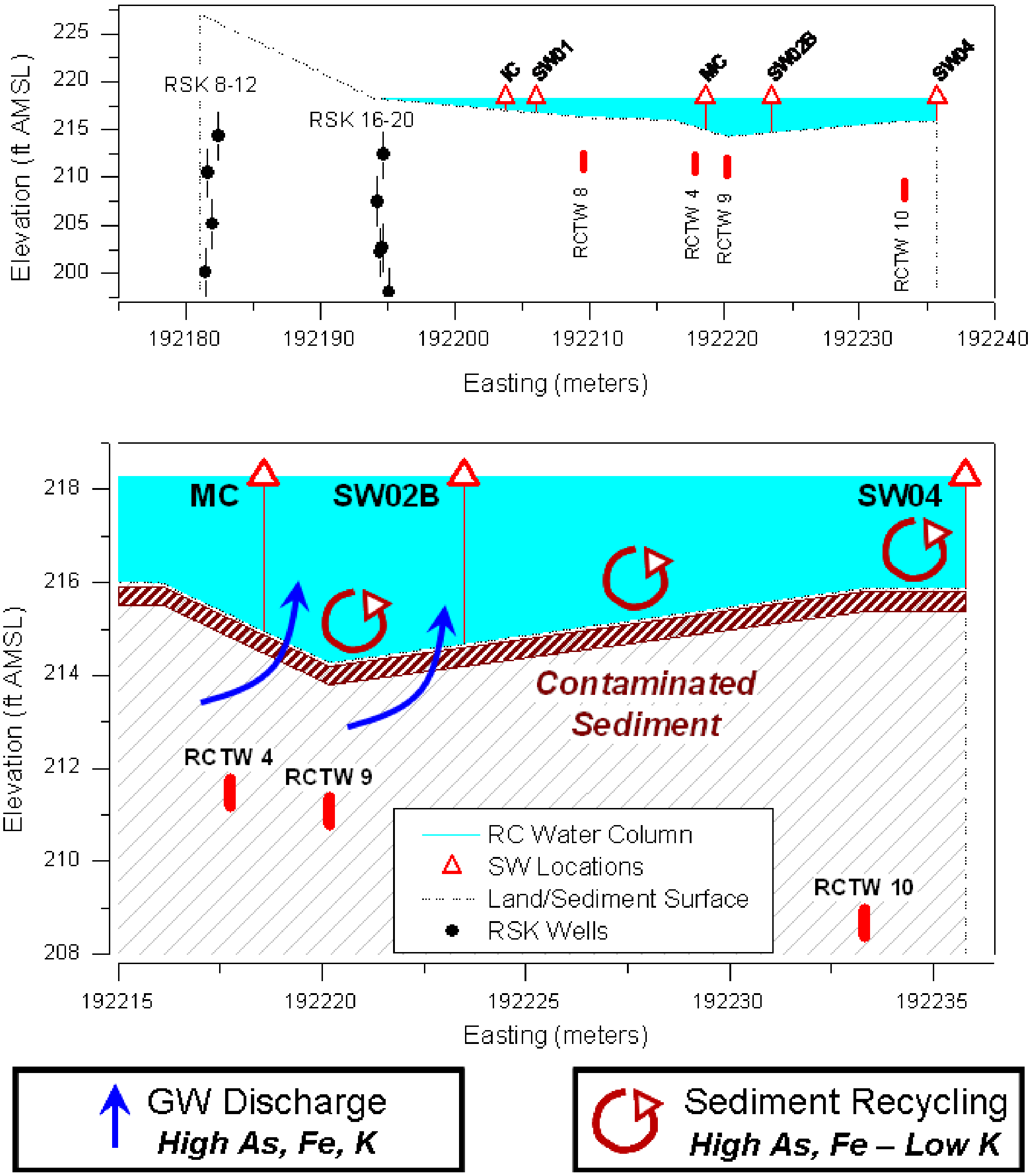


Figure 73. (Top Panel) Cross-section through Red Cove (RC) showing relative locations of RSK and RCTW wells along with surface water (SW) sampling locations. (Bottom Panel) Zoomed view from top panel showing locations of RCTW wells and neighboring surface water sampling locations where arsenic concentration in deep surface water is dominated by contaminated sediment dissolution (SW04) versus groundwater discharge (MC and SW02B). Elevated potassium concentration in deep surface water is a signature of groundwater plume discharge. Note that sediment dissolution may also contribute to arsenic at locations MC and SW02B.

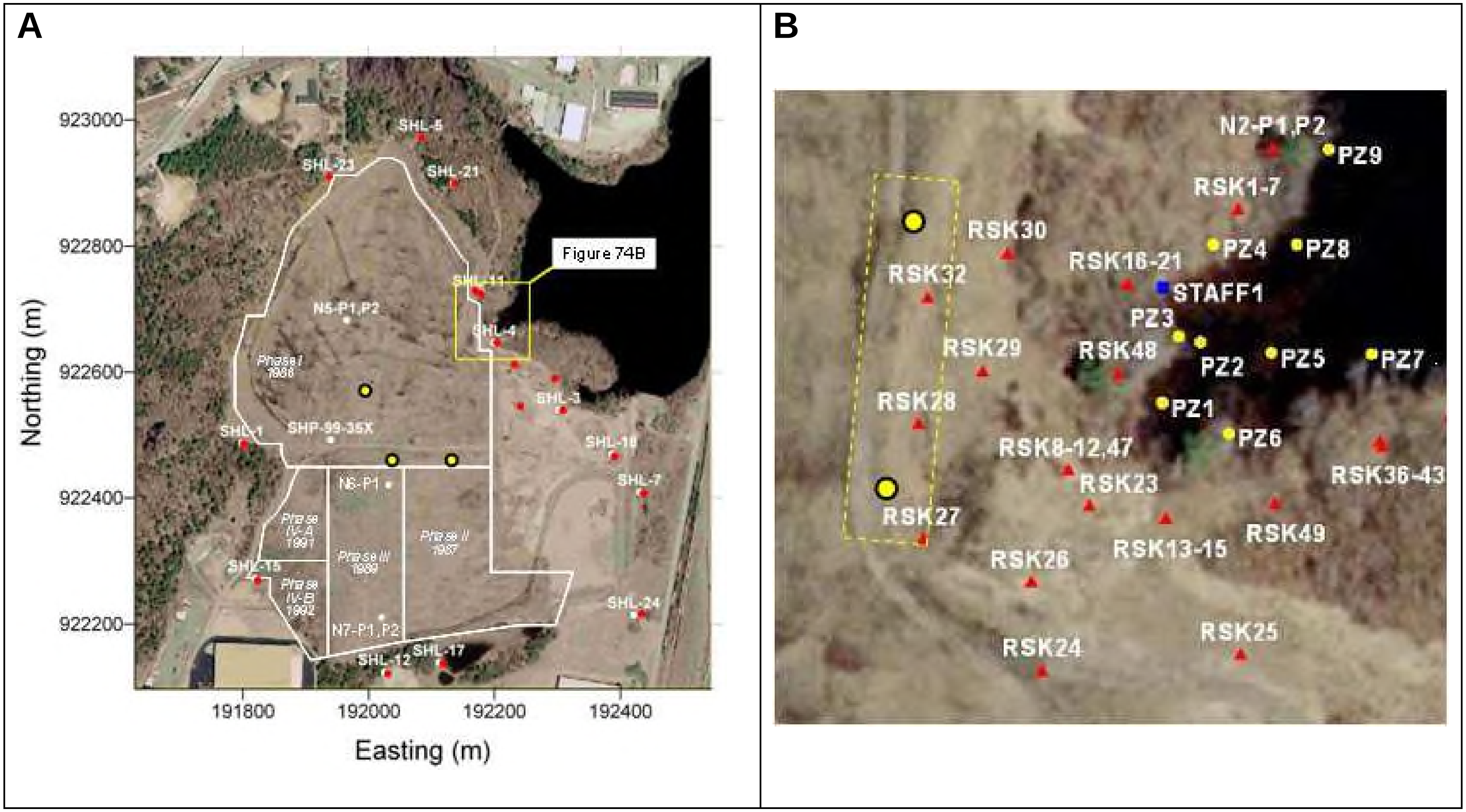


Figure 74. Proposed locations (yellow dots) for collection of additional groundwater chemistry data (A) in saturated unconsolidated aquifer within the Shepley’s Hill Landfill (SHL) and (B) along the eastern edge of the landfill cap adjacent to Red Cove. Boundaries of disposal units for SHL estimated from evaluation of Figure 1-4 in ABB-ES (1995) and locations of existing wells shown with red dots around the perimeter of the landfill; other existing wells not used shown with white dots.

APPENDIX A

SITE MAPS

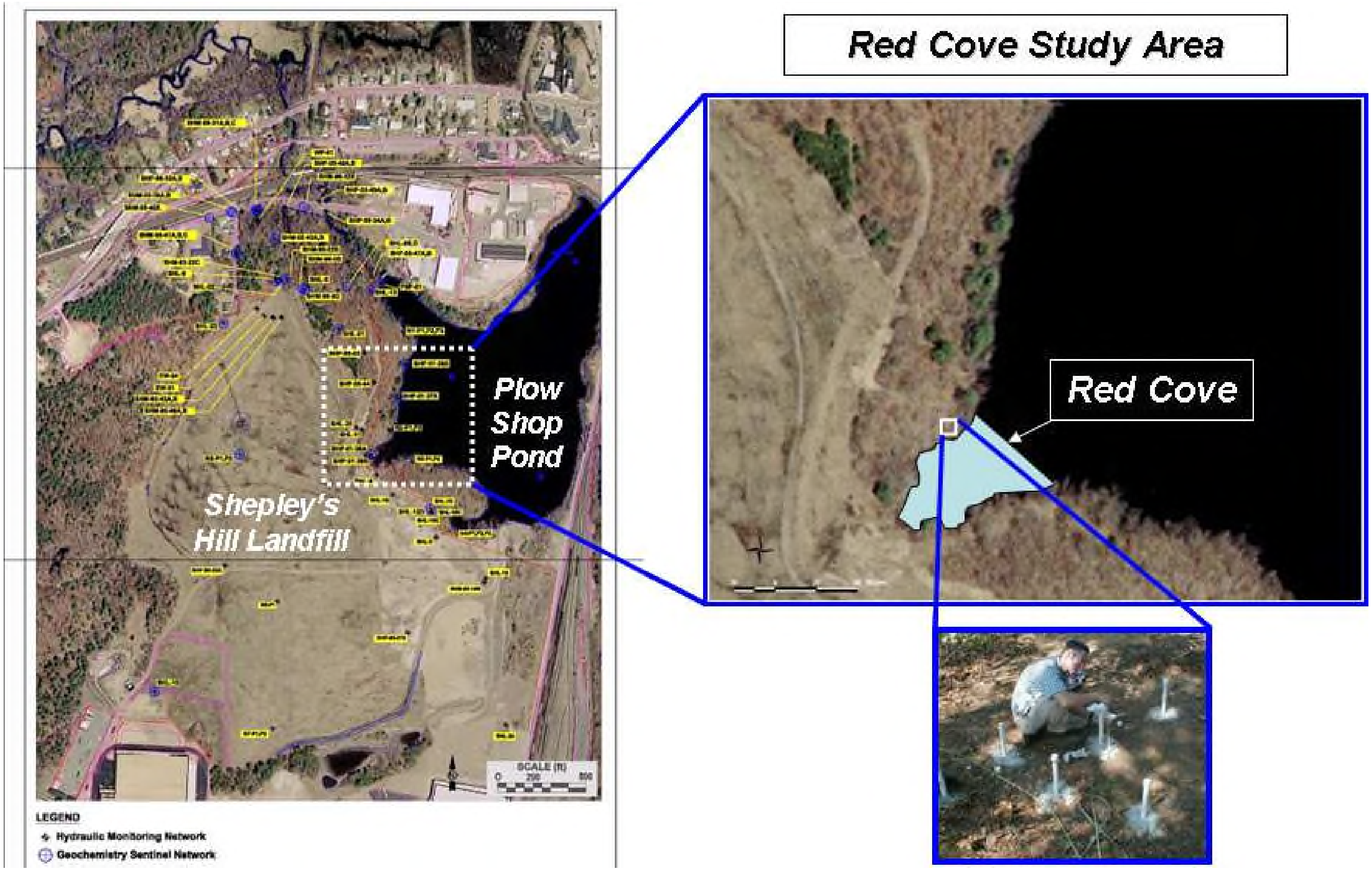


Figure A.1. Map showing location of the Red Cove Study Area of Plow Shop Pond adjacent to Shepley’s Hill Landfill at the Fort Devens Superfund Site (US ACE, 2006).

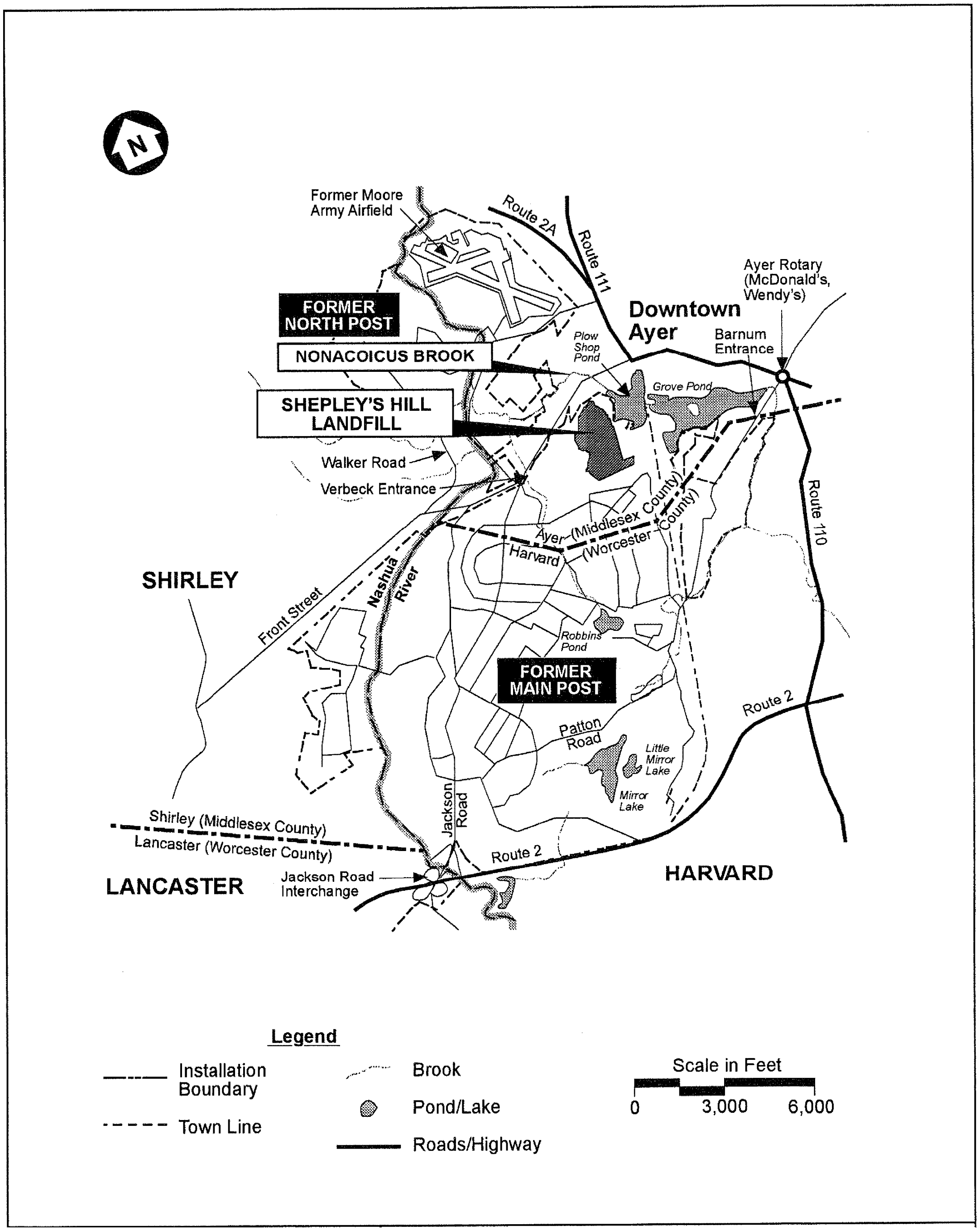


Figure A.2. Map showing location of the Fort Devens Superfund Site (US ACE, 2006).

APPENDIX B

LOCATION DATA

Northing and easting coordinates of wells were surveyed relative to the locations of existing wells at the SHL site. The coordinates are reported in meters using the Massachusetts State Plane coordinate system and are reported relative to the NAD83 datum. Elevations were surveyed relative to existing wells which are reported to use the National Geodetic Vertical Datum of 1929.

Table B.1. Well Locations and screened intervals.

Well	Northing (m)	Easting (m)	Top of Screen (ft MSL)	Bottom of Screen (ft MSL)
RSK1	922710.63	192217.25	190.6	185.6
RSK2	922710.96	192216.80	195.7	190.7
RSK3	922711.38	192216.25	201.0	196.0
RSK4	922712.34	192216.36	206.2	201.2
RSK5	922711.72	192216.75	210.9	205.9
RSK6	922711.38	192217.25	200.6	195.6
RSK7	922711.92	192217.51	216.5	211.5
RSK8	922659.41	192181.05	197.1	192.1
RSK9	922659.84	192181.51	202.6	197.6
RSK10	922659.33	192181.96	207.6	202.6
RSK11	922658.95	192181.66	212.9	207.9
RSK12	922658.31	192182.45	216.8	211.8
RSK13	922648.82	192202.03	207.5	202.5
RSK14	922648.91	192202.61	211.3	206.3
RSK15	922648.26	192202.52	216.6	211.6
RSK16	922695.95	192195.10	200.5	195.5
RSK17	922695.87	192194.42	204.7	199.7
RSK18	922696.46	192194.26	210.0	205.0
RSK19	922696.56	192194.73	214.9	209.9
RSK20	922697.00	192194.64	205.1	200.1
RSK21	922696.83	192195.26	215.9	195.9
RSK23	922650.96	192187.02	221.4	196.4
RSK24	922616.98	192177.19	221.4	216.4
RSK25	922620.30	192218.06	218.5	213.5
RSK26	922635.27	192174.88	220.3	215.3
RSK27	922644.10	192152.56	221.2	216.2
RSK28	922667.84	192151.60	218.8	213.8
RSK29	922678.74	192164.94	215.9	210.9
RSK30	922702.92	192170.15	212.4	207.4
RSK32	922693.87	192153.67	216.6	211.6
RSK33	922761.13	192170.62	215.1	210.1
RSK34	922767.20	192144.93	214.5	209.5
RSK35	922788.58	192157.75	212.4	207.4
RSK36	922663.22	192247.32	215.7	195.7
RSK37	922663.22	192247.32	217.6	212.6
RSK38	922664.19	192246.75	214.6	209.6
RSK39	922664.44	192247.63	209.6	204.6
RSK40	922665.06	192247.80	204.5	199.5
RSK41	922665.39	192247.37	199.5	194.5
RSK42	922664.69	192247.01	209.6	204.6
RSK43	922663.86	192247.55	215.7	195.7
RSK47	922664.63	192248.22	214.8	209.8
RSK48	922657.79	192182.74	215.6	215.1
RSK49	922678.18	192192.86	217.1	216.6

Table B.2. Cove piezometer locations and screened intervals. Depths are reported relative to the sediment/water interface at the bottom of the pond.

Piezometer	Northing (m)	Easting (m)	Top of Screen (ft below interface)	Bottom of Screen (ft below interface)
PZ1	922667.24	192201.46	4.5	5.0
PZ2	922678.65	192208.97	4.5	5.0
PZ3	922680.04	192203.74	4.0	4.5
PZ4	922697.20	192211.42	4.5	5.0
PZ5	922680.08	192224.25	4.5	5.0
PZ6	922667.76	192220.32	6.5	7.0
PZ7	922677.60	192248.06	6.5	7.0
PZ8	922703.75	192228.62	5.8	6.3
PZ9	922722.63	192234.24	5.6	6.1
PZ10	922762.65	192237.91	5.3	5.8
PZ11	922838.42	192255.49	4.5	5.0
PZ12	922675.88	192298.64	3.0	3.5

Table B.3. Approximate locations where advective flux meter was deployed at the water/sediment interface.

Location	Northing (m)	Easting (m)
SM1A	922,678.155	192,209.740
SM2A	922,671.907	192,209.880
SM2B	922,681.992	192,223.798
SM1B	922,680.950	192,224.623

Note: Locations were surveyed using a Trimble hand-held GPS unit and are considered accurate to approximately 20 ft.

APPENDIX C

POTENTIOMETRIC SURFACE DATA

Table C.1. Data Used for Preparation of Potentiometric Surface for April 26, 2007.

Well	Groundwater Elevation (ft AMSL)
RSK1	217.76
RSK7	217.65
RSK8	218.58
RSK12	218.59
RSK13	218.57
RSK15	218.56
RSK16	218.01
RSK19	217.97
RSK24	219.97
RSK25	219.62
RSK26	219.03
RSK27	219.15
RSK28	218.89
RSK29	218.67
RSK30	218.49
RSK33	218.35
RSK34	218.50
RSK35	218.39
RSK37	217.76
RSK41	217.81
RSK49	218.32
STAFF1	217.46
N1,P3	217.64
N2,P2	217.60
N3,P2	217.64
SHL-11	218.34
SHL-19	219.80
SHL-21	216.55
SHP-01-36X	217.65
SHP-01-37X	217.42
SHP-01-38A	218.02
SHP-05-43	217.90
SHP-05-44	217.81

Table C.2. Data Used for Preparation of Potentiometric Surface for September 10, 2007.

Well	Groundwater Elevation (ft AMSL)
RSK7	217.24
RSK12	217.77
RSK15	217.63
RSK19	217.42
RSK23	217.77
RSK24	218.42
RSK25	217.95
RSK26	218.02
RSK27	218.22
RSK28	218.06
RSK29	217.84
RSK30	217.66
RSK33	217.21
RSK34	217.09
RSK35	216.75
RSK37	217.26
RSK48	217.43
RSK49	217.46
STAFF1	217.19
N2, P2	217.18
N3, P2	217.24
SHL-11	217.59
SHL-19	217.92
SHP-01-37X	216.94
SHP-01-38A	217.44
SHP-05-44	216.53

Table C.3. Data Used for Preparation of Potentiometric Surface for November 7, 2007.

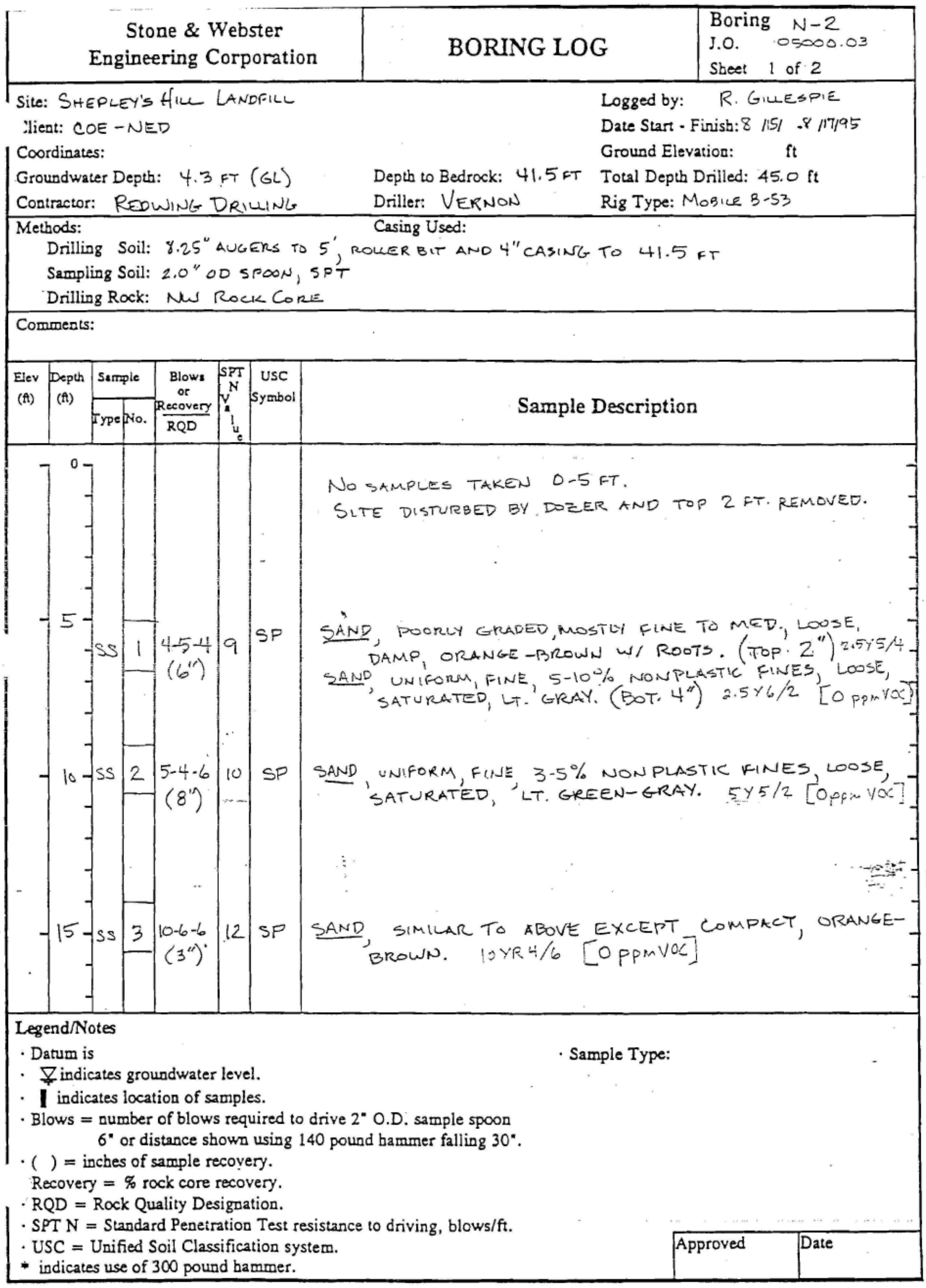
Well	Northing (m)
RSK7	217.95
RSK12	218.34
RSK15	218.27
RSK19	218.05
RSK23	218.34
RSK25	218.61
RSK26	218.59
RSK27	218.62
RSK28	218.44
RSK29	218.35
RSK30	218.20
RSK32	218.29
RSK33	217.80
RSK34	217.58
RSK35	217.40
RSK37	217.99
RSK48	218.10
RSK49	218.20
STAFF1	217.93
N-1, P-3	217.65
N-2, P-2	217.90
N-3, P-2	217.96
SHL-11	218.09
SHL-19	218.58
SHP-01-36X	217.80
SHP-01-37X	217.73
SHP-05-43	216.62
SHP-05-44	217.21

APPENDIX D

GEOLOGIC LOGS FOR EXISTING WELLS ADJACENT TO RED COVE

N2 WELL CLUSTER

(Located Approximately 50 ft from Well Cluster RSK1-7)



Stone & Webster Engineering Corporation	BORING LOG	Boring N-2 J.O. 05000.03 Sheet 1 of 2

Site: SHEPLEY'S HILL LANDFILL

Client: COE - NED

Coordinates:

Groundwater Depth: 4.3 FT (GL)

Contractor: REDWING DRILLING

Depth to Bedrock: 41.5 FT

Driller: VERNON

Logged by: R. GILLESPIE

Date Start - Finish: 8 /15/ -8 /17/95

Ground Elevation: ft

Total Depth Drilled: 45.0 ft

Rig Type: MOBILE B-53

Methods:

Casing Used:

Drilling Soil: 8.25" AUGERS TO 5', ROLLER BIT AND 4" CASING TO 41.5 FT

Sampling Soil: 2.0" OD SPOON, SPT

Drilling Rock: NW ROCK CORE

Comments:

Elev (ft)	Depth (ft)	Sample Type	Sample No.	Blows or Recovery / RQD	SPT N Value	USC Symbol	Sample Description
	0						NO SAMPLES TAKEN 0-5 FT. SITE DISTURBED BY DOZER AND TOP 2 FT. REMOVED.
	5	SS	1	4-5-4 (6")	9	SP	SAND, POORLY GRADED, MOSTLY FINE TO MED., LOOSE, DAMP, ORANGE-BROWN W/ ROOTS. (TOP 2") 2.5Y5/4 SAND, UNIFORM, FINE, 5-10% NONPLASTIC FINES, LOOSE, SATURATED, LT. GRAY. (BOT. 4") 2.5Y6/2 [0 ppmVOC]
	10	SS	2	5-4-6 (8")	10	SP	SAND, UNIFORM, FINE, 3-5% NONPLASTIC FINES, LOOSE, SATURATED, LT. GREEN-GRAY. 5Y5/2 [0ppmVOC]
	15	SS	3	10-6-6 (3")	12	SP	SAND, SIMILAR TO ABOVE EXCEPT COMPACT, ORANGE-BROWN. 10YR4/6 [0 ppmVOC]

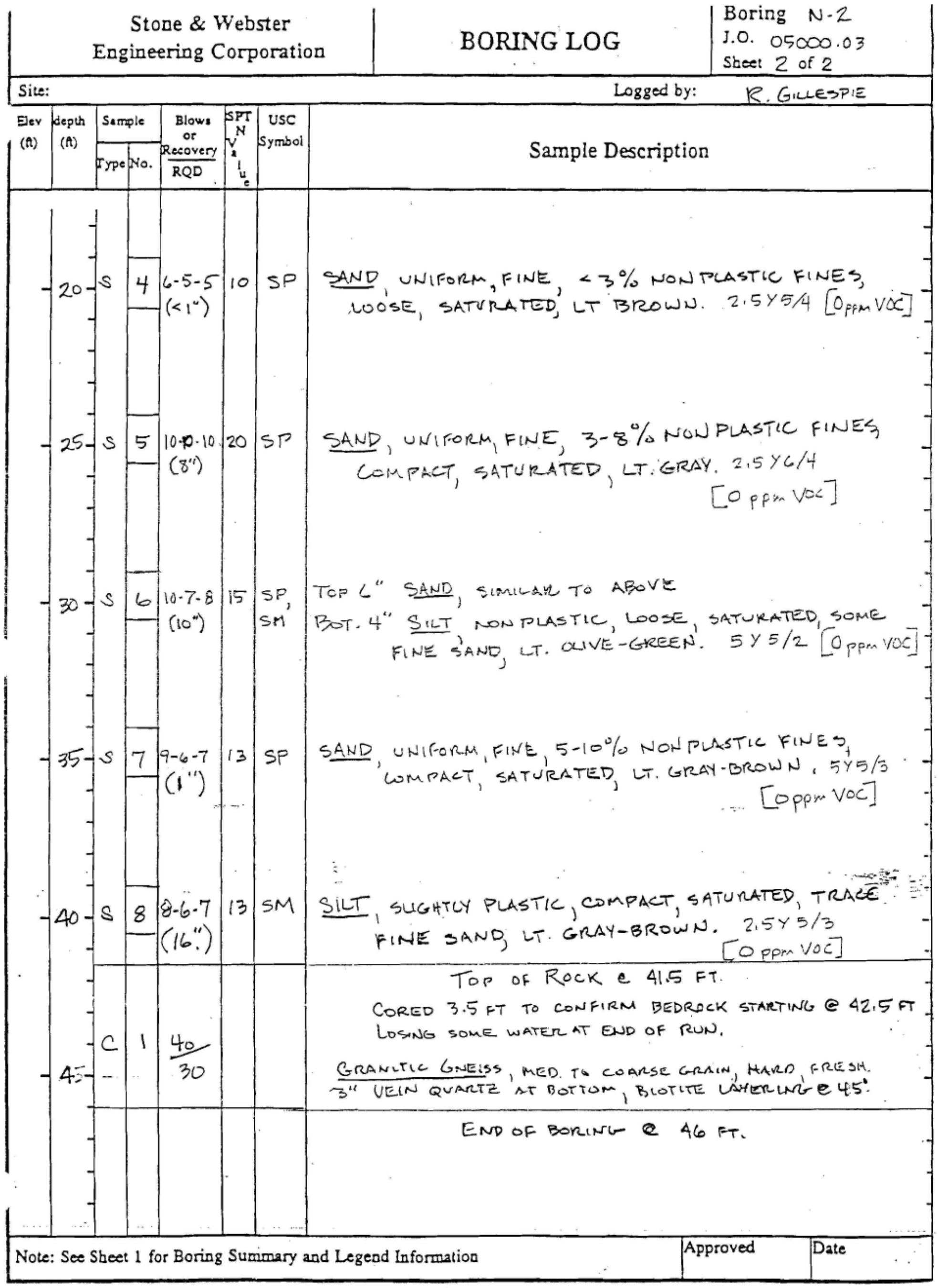
Legend/Notes

- Datum is
- ⊻ indicates groundwater level.
- ▌ indicates location of samples.
- Blows = number of blows required to drive 2" O.D. sample spoon 6" or distance shown using 140 pound hammer falling 30".
- ( ) = inches of sample recovery.
  Recovery = % rock core recovery.
- RQD = Rock Quality Designation.
- SPT N = Standard Penetration Test resistance to driving, blows/ft.
- USC = Unified Soil Classification system.
- * indicates use of 300 pound hammer.

- Sample Type:

Approved	Date

FIGURE 4-2
BORING LOG



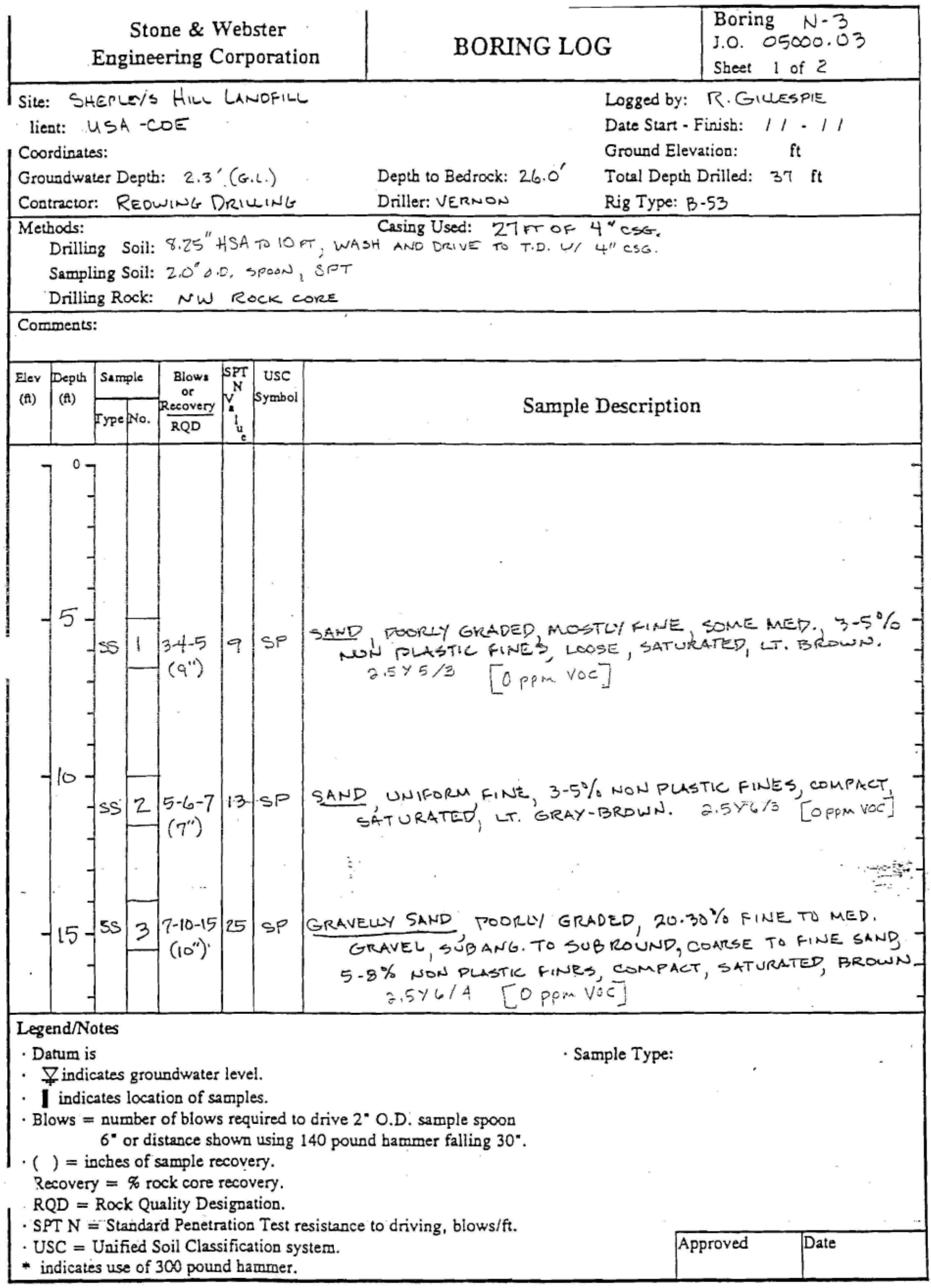
Stone & Webster Engineering Corporation	BORING LOG	Boring N-2 J.O. 05000.03 Sheet 2 of 2
Site:	Logged by:	R. GILLESPIE

Elev (ft)	depth (ft)	Sample Type	Sample No.	Blows or Recovery / RQD	SPT N Value	USC Symbol	Sample Description
	20	S	4	6-5-5 (<1")	10	SP	SAND, UNIFORM, FINE, <3% NON PLASTIC FINES, LOOSE, SATURATED, LT BROWN. 2.5Y5/4 [0 ppm VOC]
	25	S	5	10-0-10 (8")	20	SP	SAND, UNIFORM, FINE, 3-8% NON PLASTIC FINES COMPACT, SATURATED, LT. GRAY. 2.5Y6/4 [0 ppm VOC]
	30	S	6	10-7-8 (10")	15	SP, SM	TOP 6" SAND, SIMILAR TO ABOVE BOT. 4" SILT, NON PLASTIC, LOOSE, SATURATED, SOME FINE SAND, LT. OLIVE-GREEN. 5Y5/2 [0 ppm VOC]
	35	S	7	9-6-7 (1")	13	SP	SAND, UNIFORM, FINE, 5-10% NON PLASTIC FINES, COMPACT, SATURATED, LT. GRAY-BROWN, 5Y5/3 [0 ppm VOC]
	40	S	8	8-6-7 (16")	13	SM	SILT, SLIGHTLY PLASTIC, COMPACT, SATURATED, TRACE FINE SAND, LT. GRAY-BROWN. 2.5Y5/3 [0 ppm VOC]
							TOP OF ROCK @ 41.5 FT. CORED 3.5 FT TO CONFIRM BEDROCK STARTING @ 42.5 FT LOSING SOME WATER AT END OF RUN.
	45	C	1	40/30			GRANITIC GNEISS, MED. TO COARSE GRAIN, HARD, FRESH. 3" VEIN QUARTZ AT BOTTOM, BIOTITE LAYERING @ 45'.
							END OF BORING @ 46 FT.

Note: See Sheet 1 for Boring Summary and Legend Information	Approved	Date

FIGURE 4-2 cont.
BORING LOG

N3 WELL CLUSTER
(Located Approximately 50 ft from Well Cluster RSK36-43)



Stone & Webster
Engineering Corporation

BORING LOG

Boring N-3
J.O. 05000.03
Sheet 1 of 2

Site: SHEPLEY/S HILL LANDFILL
lient: USA -COE
Coordinates:
Groundwater Depth: 2.3′ (G.L.)
Contractor: REDWING DRILLING
Depth to Bedrock: 26.0′
Driller: VERNON
Logged by: R. GILLESPIE
Date Start - Finish: / / - / /
Ground Elevation: ft
Total Depth Drilled: 37 ft
Rig Type: B-53

Methods:
Drilling Soil: 8.25" HSA TO 10 FT, WASH AND DRIVE TO T.D. W/ 4" CSG.
Sampling Soil: 2.0" O.D. SPOON, SPT
Drilling Rock: NW ROCK CORE
Casing Used: 27 FT OF 4" CSG.

Comments:

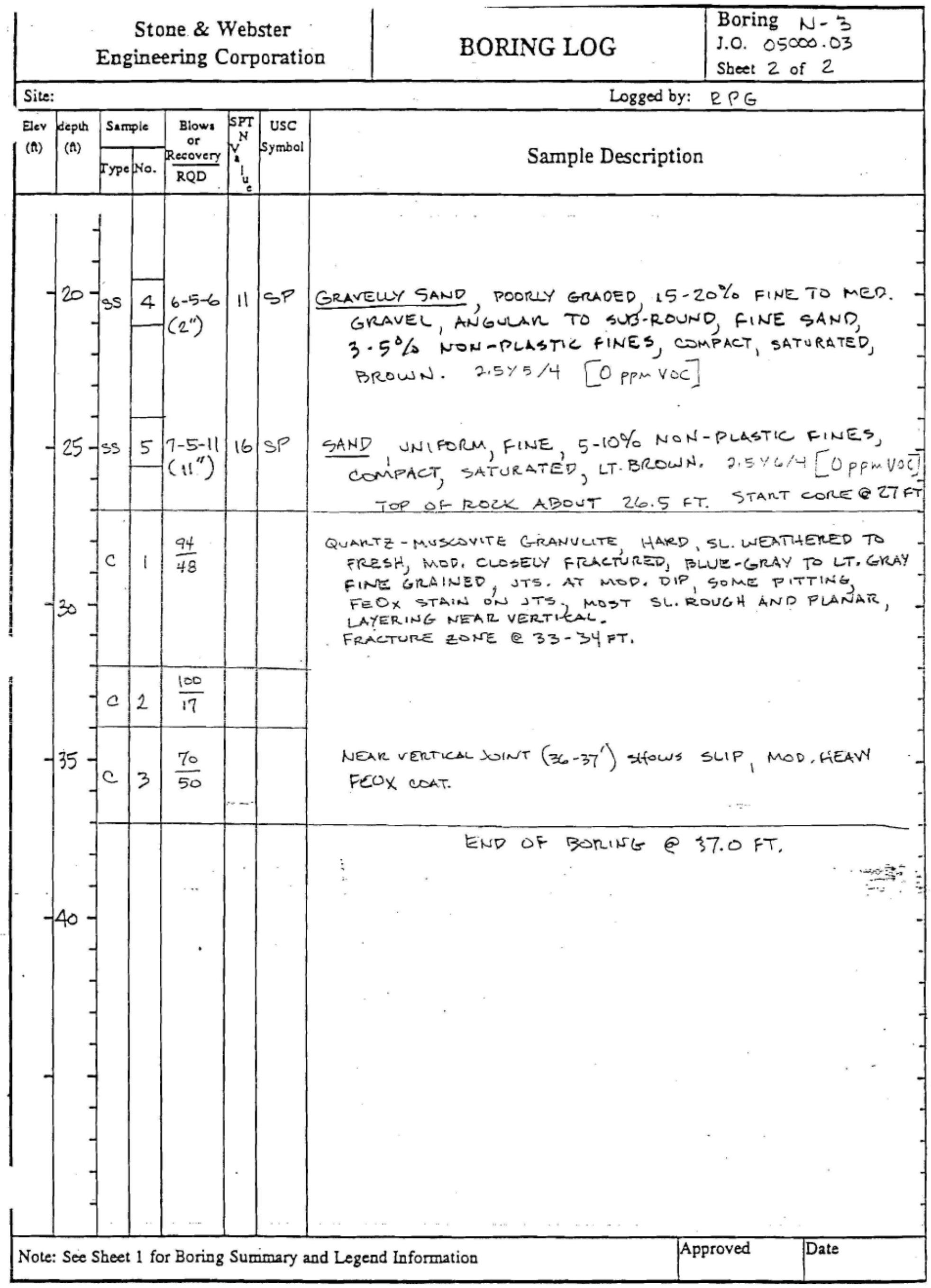
Elev (ft)	Depth (ft)	Sample Type	Sample No.	Blows or Recovery RQD	SPT N Value	USC Symbol	Sample Description
	0						
	5	SS	1	3-4-5 (9")	9	SP	SAND, POORLY GRADED, MOSTLY FINE, SOME MED., 3-5% NON PLASTIC FINES, LOOSE, SATURATED, LT. BROWN. 2.5Y 5/3 [0 ppm VOC]
	10	SS	2	5-6-7 (7")	13	SP	SAND, UNIFORM FINE, 3-5% NON PLASTIC FINES, COMPACT, SATURATED, LT. GRAY-BROWN. 2.5Y 6/3 [0 ppm VOC]
	15	SS	3	7-10-15 (10")	25	SP	GRAVELLY SAND, POORLY GRADED, 20-30% FINE TO MED. GRAVEL, SUBANG. TO SUBROUND, COARSE TO FINE SAND, 5-8% NON PLASTIC FINES, COMPACT, SATURATED, BROWN. 2.5Y 6/4 [0 ppm VOC]

Legend/Notes

- Datum is
- Sample Type:
- ⊻ indicates groundwater level.
- ▌ indicates location of samples.
- Blows = number of blows required to drive 2" O.D. sample spoon 6" or distance shown using 140 pound hammer falling 30".
- ( ) = inches of sample recovery.
- Recovery = % rock core recovery.
- RQD = Rock Quality Designation.
- SPT N = Standard Penetration Test resistance to driving, blows/ft.
- USC = Unified Soil Classification system.
- * indicates use of 300 pound hammer.

Approved	Date

FIGURE 4-2
BORING LOG



Stone & Webster
Engineering Corporation

BORING LOG

Boring N-3
J.O. 05000.03
Sheet 2 of 2

Site:

Logged by: RPG

Elev (ft)	depth (ft)	Sample Type	Sample No.	Blows or Recovery / RQD	SPT N Value	USC Symbol	Sample Description
	20	SS	4	6-5-6 (2")	11	SP	<u>GRAVELLY SAND</u>, POORLY GRADED, 15-20% FINE TO MED. GRAVEL, ANGULAR TO SUB-ROUND, FINE SAND, 3-5% NON-PLASTIC FINES, COMPACT, SATURATED, BROWN. 2.5Y5/4 [0 ppm VOC]
	25	SS	5	7-5-11 (11")	16	SP	<u>SAND</u>, UNIFORM, FINE, 5-10% NON-PLASTIC FINES, COMPACT, SATURATED, LT. BROWN. 2.5Y6/4 [0 ppm VOC] TOP OF ROCK ABOUT 26.5 FT. START CORE @ 27 FT
	30	C	1	$\frac{94}{48}$			QUARTZ-MUSCOVITE GRANULITE, HARD, SL. WEATHERED TO FRESH, MOD. CLOSELY FRACTURED, BLUE-GRAY TO LT. GRAY FINE GRAINED, JTS. AT MOD. DIP, SOME PITTING, FEOX STAIN ON JTS., MOST SL. ROUGH AND PLANAR, LAYERING NEAR VERTICAL. FRACTURE ZONE @ 33-34 FT.
		C	2	$\frac{100}{17}$			
	35	C	3	$\frac{70}{50}$			NEAR VERTICAL JOINT (36-37') SHOWS SLIP, MOD. HEAVY FEOX COAT.
	40						END OF BORING @ 37.0 FT.

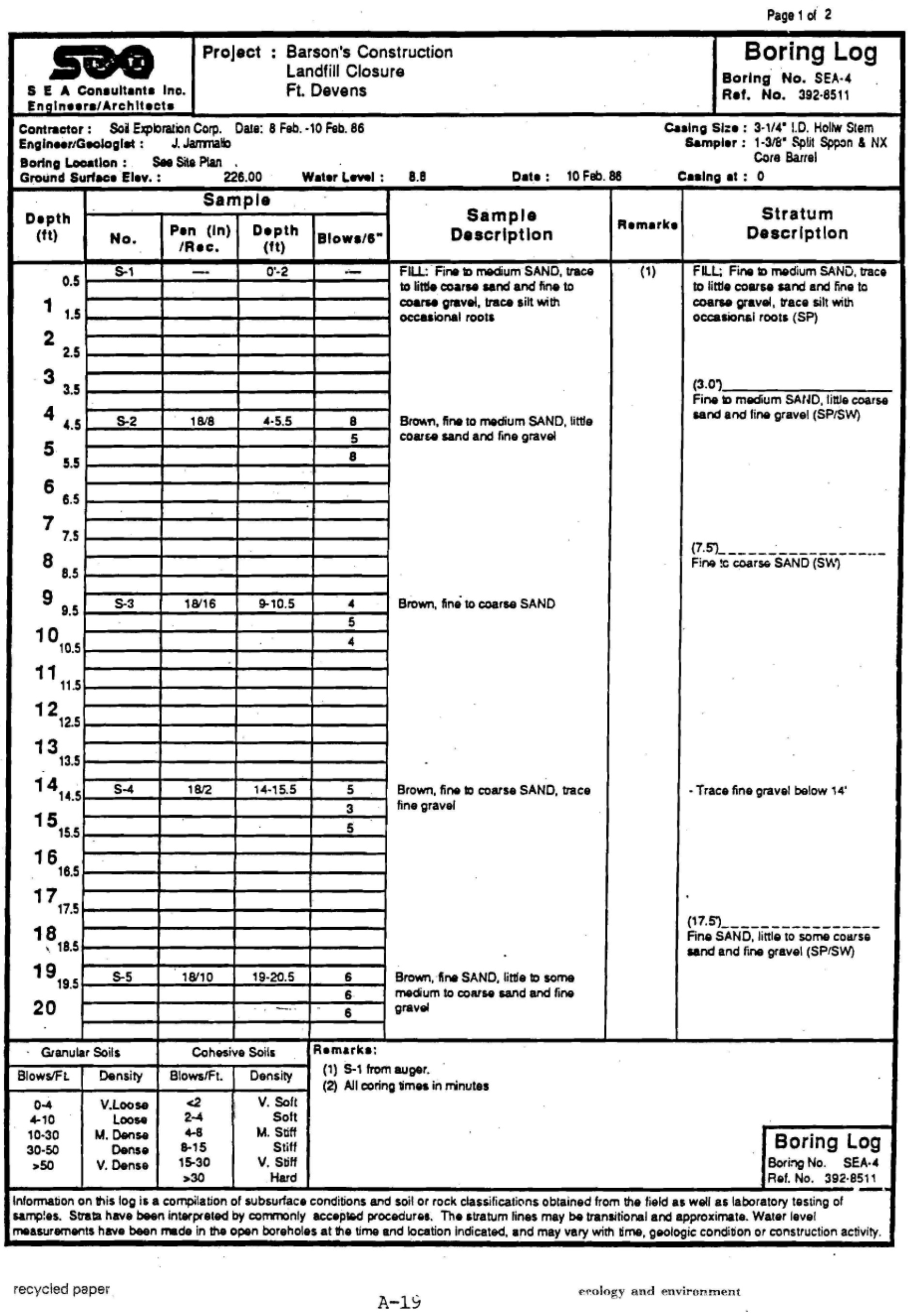
Note: See Sheet 1 for Boring Summary and Legend Information

Approved	Date

FIGURE 4-2 cont.
BORING LOG

BORING SEA-4

(Located Approximately 10 ft from Well Cluster RSK13-15)



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S E A Consultants Inc.
Engineers/Architects

Project : Barson's Construction
Landfill Closure
Ft. Devens

Boring Log
Boring No. SEA-4
Ref. No. 392-8511

Contractor : Soil Exploration Corp. Date: 8 Feb. -10 Feb. 86
Engineer/Geologist : J. Jammalo
Boring Location : See Site Plan
Ground Surface Elev. : 226.00 **Water Level :** 8.8 **Date :** 10 Feb. 86
Casing Size : 3-1/4" I.D. Hollw Stem
Sampler : 1-3/8" Split Sppon & NX Core Barrel
Casing at : 0

Depth (ft)	Sample No.	Sample Pen (in) /Rec.	Sample Depth (ft)	Sample Blows/6"	Sample Description	Remarks	Stratum Description
0.5	S-1	—	0'-2	—	FILL: Fine to medium SAND, trace to little coarse sand and fine to coarse gravel, trace silt with occasional roots	(1)	FILL; Fine to medium SAND, trace to little coarse sand and fine to coarse gravel, trace silt with occasional roots (SP)
3 3.5							(3.0') Fine to medium SAND, little coarse sand and fine gravel (SP/SW)
4 4.5	S-2	18/8	4-5.5	8	Brown, fine to medium SAND, little coarse sand and fine gravel		
5				5			
5.5				8			
7 7.5							(7.5') Fine to coarse SAND (SW)
9 9.5	S-3	18/16	9-10.5	4	Brown, fine to coarse SAND		
10				5			
10.5				4			
14 14.5	S-4	18/2	14-15.5	5	Brown, fine to coarse SAND, trace fine gravel		- Trace fine gravel below 14'
15				3			
15.5				5			
17 17.5							(17.5') Fine SAND, little to some coarse sand and fine gravel (SP/SW)
19 19.5	S-5	18/10	19-20.5	6	Brown, fine SAND, little to some medium to coarse sand and fine gravel		
20				6			
				6			

Granular Soils		Cohesive Soils	
Blows/Ft.	Density	Blows/Ft.	Density
0-4	V.Loose	<2	V. Soft
4-10	Loose	2-4	Soft
10-30	M. Dense	4-8	M. Stiff
30-50	Dense	8-15	Stiff
>50	V. Dense	15-30	V. Stiff
		>30	Hard

Remarks:
(1) S-1 from auger.
(2) All coring times in minutes

Boring Log
Boring No. SEA-4
Ref. No. 392-8511

Information on this log is a compilation of subsurface conditions and soil or rock classifications obtained from the field as well as laboratory testing of samples. Strata have been interpreted by commonly accepted procedures. The stratum lines may be transitional and approximate. Water level measurements have been made in the open boreholes at the time and location indicated, and may vary with time, geologic condition or construction activity.

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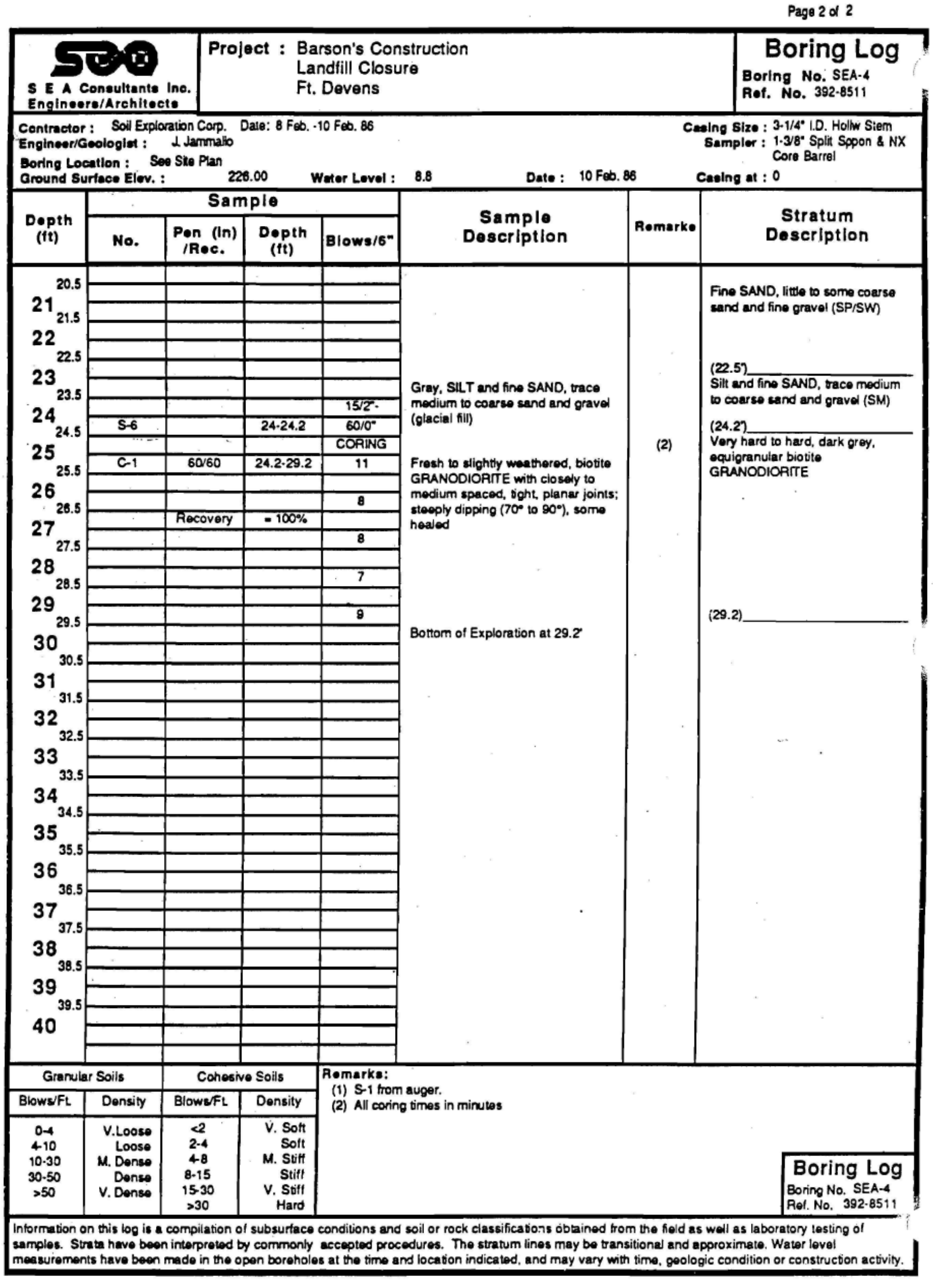

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S E A Consultants Inc.
Engineers/Architects

Project : Barson's Construction
Landfill Closure
Ft. Devens

Boring Log

Boring No. SEA-4
Ref. No. 392-8511

Contractor : Soil Exploration Corp. Date: 8 Feb. -10 Feb. 86
Engineer/Geologist : J. Jammalio
Boring Location : See Site Plan
Ground Surface Elev. : 226.00 **Water Level :** 8.8 **Date :** 10 Feb. 86
Casing Size : 3-1/4" I.D. Hollw Stem
Sampler : 1-3/8" Split Sppon & NX Core Barrel
Casing at : 0

Depth (ft)	Sample				Sample Description	Remarks	Stratum Description
	No.	Pen (In) /Rec.	Depth (ft)	Blows/6"			
20.5							
21							Fine SAND, little to some coarse sand and fine gravel (SP/SW)
21.5							
22							
22.5							
23							(22.5') Silt and fine SAND, trace medium to coarse sand and gravel (SM)
23.5					Gray, SILT and fine SAND, trace medium to coarse sand and gravel (glacial fill)		
24				15/2"-			
24.5	S-6		24-24.2	60/0"			(24.2')
25				CORING		(2)	Very hard to hard, dark grey, equigranular biotite GRANODIORITE
25.5	C-1	60/60	24.2-29.2	11	Fresh to slightly weathered, biotite GRANODIORITE with closely to medium spaced, tight, planar joints; steeply dipping (70° to 90°), some healed		
26							
26.5				8			
27		Recovery	= 100%				
27.5				8			
28							
28.5				7			
29							
29.5				9			(29.2)
30					Bottom of Exploration at 29.2'		
30.5							
31							
31.5							
32							
32.5							
33							
33.5							
34							
34.5							
35							
35.5							
36							
36.5							
37							
37.5							
38							
38.5							
39							
39.5							
40							

Granular Soils		Cohesive Soils	
Blows/Ft.	Density	Blows/Ft.	Density
0-4	V.Loose	<2	V. Soft
4-10	Loose	2-4	Soft
10-30	M. Dense	4-8	M. Stiff
30-50	Dense	8-15	Stiff
>50	V. Dense	15-30	V. Stiff
		>30	Hard

Remarks:
(1) S-1 from auger.
(2) All coring times in minutes

Boring Log
Boring No. SEA-4
Ref. No. 392-8511

Information on this log is a compilation of subsurface conditions and soil or rock classifications obtained from the field as well as laboratory testing of samples. Strata have been interpreted by commonly accepted procedures. The stratum lines may be transitional and approximate. Water level measurements have been made in the open boreholes at the time and location indicated, and may vary with time, geologic condition or construction activity.

P2 xtra blows

A-20

APPENDIX E

Summary of field chemistry data for groundwater sampled from RSK wells within Red Cove Study Area adjacent to Shepley's Hill Landfill

Table E.1. Summary of field geochemical data collected during ground-water sampling on March 13-14, 2006 adjacent to Shepley's Hill Landfill. The following abbreviations are used within the table: ft btoc = feet below top of casing, COND = specific conductance, ORP = oxidation-reduction potential (measured with platinum electrode), DO = dissolved oxygen, Alk = alkalinity, TIC = total inorganic carbon, NM = not measured, NS = not sampled.

Location	Date	Depth to Water Table ft btoc	Temp. ℃	COND μS/cm	pH	ORP mV	DO (electrode) mg/L	DO (Chemet) mg/L	Turbidity NTU	Ferrous Iron mg/L	Alk (mg/L $CaCO_3$)	TIC mg/L C
RSK1	NS	--	--	--	--	--	--	--	--	--	--	--
RSK2	NS	--	--	--	--	--	--	--	--	--	--	--
RSK3	NS	--	--	--	--	--	--	--	--	--	--	--
RSK4	NS	--	--	--	--	--	--	--	--	--	--	--
RSK5	NS	--	--	--	--	--	--	--	--	--	--	--
RSK6	NS	--	--	--	--	--	--	--	--	--	--	--
RSK7	NS	--	--	--	--	--	--	--	--	--	--	--
RSK8	3/14/2006	9.72	11.6	534	6.97	38.6	NM	1-2	7.46	NM	NM	47.6
RSK9	3/14/2006	9.2	9.2	584	6.79	-108.2	NM	1-2	1.00	NM	NM	51.9
RSK10	3/14/2006	9.1	9.1	613	6.56	-83.9	NM	1	1.38	NM	NM	57.9
RSK11	3/13/2006	9.48	9.4	608	6.53	15.0	NM	4	0.95	NM	NM	51.7
RSK12	3/14/2006	9.14	12.5	534	6.35	-46.6	NM	4-5	2.03	NM	NM	73.9
RSK13	NS	--	--	--	--	--	--	--	--	--	--	--
RSK14	NS	--	--	--	--	--	--	--	--	--	--	--
RSK15	NS	--	--	--	--	--	--	--	--	--	--	--
RSK16	3/14/2006	1.78	10.9	469	6.79	-123.0	NM	1-2	2.78	NM	NM	39.7
RSK17	3/14/2006	2.1	11.2	462	6.92	-93.8	NM	2-3	3.10	NM	NM	40.3
RSK18	3/14/2006	1.95	8.1	519	6.73	-115.0	NM	1	7.21	NM	NM	39.6
RSK19	3/14/2006	2.05	7	604	6.73	-105.0	NM	1	NM	NM	NM	61
RSK20	3/14/2006	2.2	8.6	471	6.88	-119.0	NM	3-4	4.07	NM	NM	43.9
RSK37	NS	--	--	--	--	--	--	--	--	--	--	--
RSK38	NS	--	--	--	--	--	--	--	--	--	--	--
RSK39	NS	--	--	--	--	--	--	--	--	--	--	--
RSK40	NS	--	--	--	--	--	--	--	--	--	--	--
RSK41	NS	--	--	--	--	--	--	--	--	--	--	--
RSK42	NS	--	--	--	--	--	--	--	--	--	--	--

Table E.2. Summary of field geochemical data collected during ground-water sampling on May 15-18, 2006 adjacent to Shepley's Hill Landfill. The following abbreviations are used within the table: ft btoc = feet below top of casing, COND = specific conductance, ORP = oxidation-reduction potential (measured with platinum electrode), DO = dissolved oxygen, Alk = alkalinity, TIC = total inorganic carbon, NM = not measured, NS = not sampled.

Location	Date	Depth to Water Table ft btoc	Temp. ℃	COND µS/cm	pH	ORP mV	DO (electrode) mg/L	DO (Chemet) mg/L	Turbidity NTU	Ferrous Iron mg/L	Alk (mg/L $CaCO_3$)	TIC mg/L C
RSK1	NS	--	--	--	--	--	--	--	--	--	--	--
RSK2	NS	--	--	--	--	--	--	--	--	--	--	--
RSK3	NS	--	--	--	--	--	--	--	--	--	--	--
RSK4	NS	--	--	--	--	--	--	--	--	--	--	--
RSK5	NS	--	--	--	--	--	--	--	--	--	--	--
RSK6	NS	--	--	--	--	--	--	--	--	--	--	--
RSK7	NS	--	--	--	--	--	--	--	--	--	--	--
RSK8	NS	--	--	--	--	--	--	--	--	--	--	--
RSK9	5/18/2006	8.40	15.58	591	6.57	-109.3	0.35	<0.1	8.90	NM	257.4	71.4
RSK10	NS	--	--	--	--	--	--	--	--	--	--	--
RSK11	NS	8.64	--	--	--	--	--	--	--	--	--	--
RSK12	NS	--	--	--	--	--	--	--	--	--	--	--
RSK13	5/18/2006	7.21	13.92	281	6.59	-85.2	0.30	<0.1	1.70	NM	119.6	31.6
RSK14	5/18/2006	7.02	12.07	363	6.51	-80.6	0.40	<0.1	1.14	NM	154.2	40.6
RSK15	5/18/2006	7.21	13.85	349	6.36	-47.0	0.29	<0.1	2.77	NM	152.2	48.5
RSK16	NS	--	--	--	--	--	--	--	--	--	--	--
RSK17	NS	--	--	--	--	--	--	--	--	--	--	--
RSK18	NS	--	--	--	--	--	--	--	--	--	--	--
RSK19	NS	--	--	--	--	--	--	--	--	--	--	--
RSK20	NS	--	--	--	--	--	--	--	--	--	--	--
RSK37	NS	--	--	--	--	--	--	--	--	--	--	--
RSK38	NS	--	--	--	--	--	--	--	--	--	--	--
RSK39	NS	--	--	--	--	--	--	--	--	--	--	--
RSK40	NS	--	--	--	--	--	--	--	--	--	--	--
RSK41	NS	--	--	--	--	--	--	--	--	--	--	--
RSK42	NS	--	--	--	--	--	--	--	--	--	--	--

Table E.3. Summary of field geochemical data collected during ground-water sampling on August 8-10, 2006 adjacent to Shepley's Hill Landfill. The following abbreviations are used within the table: ft btoc = feet below top of casing, COND = specific conductance, ORP = oxidation-reduction potential (measured with platinum electrode), DO = dissolved oxygen, Alk = alkalinity, TIC = total inorganic carbon, NM = not measured, NS = not sampled.

Location	Date	Depth to Water Table ft btoc	Temp. °C	COND µS/cm	pH	ORP mV	DO (electrode) mg/L	DO (HACH) mg/L	Turbidity NTU	Ferrous Iron mg/L	Alk (mg/L $CaCO_3$)	TIC mg/L C
RSK1	8/10/2006	6.18	15.4	628	6.75	-98.6	NM	0.35	2.62	21.5	282	58.6
RSK2	8/8/2006	6.10	15.7	604	6.76	-109.6	NM	0.34	8.00	26.75	268	64.2
RSK3	8/10/2006	6.60	14.3	546	6.64	-107.3	NM	0.24	1.23	21.75	179	56.0
RSK4	8/10/2006	6.18	15.2	627	6.84	-108.0	NM	0.32	1.25	22.75	269	57.8
RSK5	8/10/2006	6.42	14.4	545	6.68	-108.4	NM	0.31	0.43	22.75	263	59.0
RSK6	8/8/2006	6.00	16.6	628	6.69	-118.3	NM	0.44	5.65	18.25	261.4	60.4
RSK7	8/10/2006	6.10	14.2	541	6.45	-88.8	NM	0.27	1.34	42.00	264	43.8
RSK8	NS	--	--	--	--	--	--	--	--	--	--	--
RSK9	NS	--	--	--	--	--	--	--	--	--	--	--
RSK10	NS	--	--	--	--	--	--	--	--	--	--	--
RSK11	NS	--	--	--	--	--	--	--	--	--	--	--
RSK12	NS	--	--	--	--	--	--	--	--	--	--	--
RSK13	NS	--	--	--	--	--	--	--	--	--	--	--
RSK14	NS	--	--	--	--	--	--	--	--	--	--	--
RSK15	NS	--	--	--	--	--	--	--	--	--	--	--
RSK16	NS	--	--	--	--	--	--	--	--	--	--	--
RSK17	NS	--	--	--	--	--	--	--	--	--	--	--
RSK18	NS	--	--	--	--	--	--	--	--	--	--	--
RSK19	NS	--	--	--	--	--	--	--	--	--	--	--
RSK20	NS	--	--	--	--	--	--	--	--	--	--	--
RSK37	NS	--	--	--	--	--	--	--	--	--	--	--
RSK38	NS	--	--	--	--	--	--	--	--	--	--	--
RSK39	NS	--	--	--	--	--	--	--	--	--	--	--
RSK40	NS	--	--	--	--	--	--	--	--	--	--	--
RSK41	NS	--	--	--	--	--	--	--	--	--	--	--
RSK42	NS	--	--	--	--	--	--	--	--	--	--	--

Table E.4. Summary of field geochemical data collected during ground-water sampling on April 23-27, 2007 adjacent to Shepley's Hill Landfill. The following abbreviations are used within the table: ft btoc = feet below top of casing, COND = specific conductance, ORP = oxidation-reduction potential (measured with platinum electrode), DO = dissolved oxygen, Alk = alkalinity, TIC = total inorganic carbon, NM = not measured, NS = not sampled.

Location	Date	Depth to Water Table ft btoc	Temp. ℃	COND μS/cm	pH	ORP mV	DO (electrode) mg/L	DO (HACH) mg/L	Turbidity NTU	Ferrous Iron mg/L	Alk (mg/L $CaCO_3$)	TIC mg/L C
RSK1	NS	--	--	--	--	--	--	--	--	--	--	--
RSK2	NS	--	--	--	--	--	--	--	--	--	--	--
RSK3	NS	--	--	--	--	--	--	--	--	--	--	--
RSK4	NS	--	--	--	--	--	--	--	--	--	--	--
RSK5	NS	--	--	--	--	--	--	--	--	--	--	--
RSK6	NS	--	--	--	--	--	--	--	--	--	--	--
RSK7	NS	--	--	--	--	--	--	--	--	--	--	--
RSK8	4/25/2007	9.48	11.7	626	6.72	-110.4	NM	0.00	0.94	NM	272	67.5
RSK9	4/25/2007	8.94	12.3	607	6.63	-113.1	NM	0.00	0.42	NM	279	66.6
RSK10	4/25/2007	8.87	11.4	716	6.37	-96.4	NM	0.45	0.55	NM	355	89.1
RSK11	4/25/2007	9.21	12.0	382	6.47	-108.0	NM	0.44	0.34	NM	82	41.3
RSK12	4/25/2007	8.88	10.3	311	6.41	-108.0	NM	0.37	0.43	NM	161	32.3
RSK13	NS	--	--	--	--	--	--	--	--	--	--	--
RSK14	NS	--	--	--	--	--	--	--	--	--	--	--
RSK15	NS	--	--	--	--	--	--	--	--	--	--	--
RSK16	4/24/2007	1.49	14.4	467	6.77	-123.4	NM	0.01	1.82	NM	164	62.7
RSK17	4/24/2007	1.75	15.6	467	6.66	-156.3	NM	0.12	0.35	NM	194	38.1
RSK18	4/24/2007	1.70	13.6	548	6.43	-111.6	NM	0.30	0.57	NM	258	55.1
RSK19	4/24/2007	1.75	14.1	638	6.41	-93.3	NM	0.22	1.36	NM	299	62.0
RSK20	4/24/2007	1.97	12.3	480	6.47	-116.2	NM	0.33	0.64	NM	214	48.3
RSK37	NS	--	--	--	--	--	--	--	--	--	--	--
RSK38	NS	--	--	--	--	--	--	--	--	--	--	--
RSK39	NS	--	--	--	--	--	--	--	--	--	--	--
RSK40	NS	--	--	--	--	--	--	--	--	--	--	--
RSK41	NS	--	--	--	--	--	--	--	--	--	--	--
RSK42	NS	--	--	--	--	--	--	--	--	--	--	--

Table E.5. Summary of field geochemical data collected during ground-water sampling on August 20-23, 2007 adjacent to Shepley's Hill Landfill. The following abbreviations are used within the table: ft btoc = feet below top of casing, COND = specific conductance, ORP = oxidation-reduction potential (measured with platinum electrode), DO = dissolved oxygen, Alk = alkalinity, TIC = total inorganic carbon, NM = not measured, NS = not sampled.

Location	Date	Depth to Water Table ft btoc	Temp. ℃	COND µS/cm	pH	ORP mV	DO (electrode) mg/L	DO (HACH) mg/L	Turbidity NTU	Ferrous Iron mg/L	Alk (mg/L $CaCO_3$)	TIC mg/L C
RSK1	8/21/2007	6.37	13.7	514	6.40	NM	NM	0.37	0.88	10.5	216	55.3
RSK2	NS	--	--	--	--	--	--	--	--	--	--	--
RSK3	8/21/2007	6.76	16.9	499	6.48	NM	NM	0.78	1.17	18.25	189	46.8
RSK4	8/21/2007	6.96	14.3	531	6.85	NM	NM	1.04	0.75	19.25	196	53.8
RSK5	8/21/2007	6.60	13.5	459	6.62	NM	NM	0.45	0.58	24.5	195	49.0
RSK6	8/21/2007	6.29	15.6	557	6.81	NM	NM	1.02	0.88	19.0	213	57.6
RSK7	8/21/2007	6.10	14.2	541	6.45	NM	NM	0.39	2.53	32.0	220	63.3
RSK8	NS	--	--	--	--	--	--	--	--	--	--	--
RSK9	NS	--	--	--	--	--	--	--	--	--	--	--
RSK10	NS	--	--	--	--	--	--	--	--	--	--	--
RSK11	NS	--	--	--	--	--	--	--	--	--	--	--
RSK12	NS	--	--	--	--	--	--	--	--	--	--	--
RSK13	NS	--	--	--	--	--	--	--	--	--	--	--
RSK14	NS	--	--	--	--	--	--	--	--	--	--	--
RSK15	NS	--	--	--	--	--	--	--	--	--	--	--
RSK16	NS	--	--	--	--	--	--	--	--	--	--	--
RSK17	NS	--	--	--	--	--	--	--	--	--	--	--
RSK18	NS	--	--	--	--	--	--	--	--	--	--	--
RSK19	NS	--	--	--	--	--	--	--	--	--	--	--
RSK20	NS	--	--	--	--	--	--	--	--	--	--	--
RSK37	8/22/2007	4.38	13.6	312	6.09	NM	NM	2.50	13.6	0.0	15	7.0
RSK38	8/22/2007	4.36	13.9	294	6.14	NM	NM	0.60	0.81	6.5	57	24.8
RSK39	8/22/2007	4.17	17.1	184	6.44	NM	NM	0.76	2.47	7.75	94	31.2
RSK40	8/22/2007	4.22	16.3	152	6.31	NM	NM	0.47	3.18	21.0	150	42.8
RSK41	8/22/2007	4.19	15.2	45	6.24	NM	NM	1.30	6.89	17.75	152	43.5
RSK42	8/22/2007	4.40	15.5	212	6.17	NM	NM	0.68	3.40	15.25	84	27.9

Table E.6. Summary of field geochemical data collected during ground-water sampling on September 11-13 and October 30, 2007 adjacent to Shepley's Hill Landfill; October 30 sampling conducted by EPA Region 1 Laboratory. The following abbreviations are used within the table: ft btoc = feet below top of casing, COND = specific conductance, ORP = oxidation-reduction potential (measured with platinum electrode), DO = dissolved oxygen, Alk = alkalinity, TIC = total inorganic carbon, NM = not measured, NS = not sampled.

Location	Date	Depth to Water Table ft btoc	Temp. ℃	COND µS/cm	pH	ORP mV	DO (electrode) mg/L	DO (HACH) mg/L	Turbidity NTU	Ferrous Iron mg/L	Alk (mg/L $CaCO_3$)	TIC mg/L C
RSK1	NS	--	--	--	--	--	--	--	--	--	--	--
RSK2	NS	--	--	--	--	--	--	--	--	--	--	--
RSK3	NS	--	--	--	--	--	--	--	--	--	--	--
RSK4	NS	--	--	--	--	--	--	--	--	--	--	--
	10/30/2007	NM	11.31	502	6-7	1.9	0.09	NM	0.37	NM	210	NM
RSK5	NS	--	--	--	--	--	--	--	--	--	--	--
RSK6	NS	--	--	--	--	--	--	--	--	--	--	--
RSK7	NS	--	--	--	--	--	--	--	--	--	--	--
RSK8	9/11/2007	10.29	15.2	605	6.73	-124.2	--	0.14	2.59	27.00	487	67.4
RSK9	9/12/2007	9.74	15.4	691	6.55	-100.2	--	0.59	2.04	36.75	300	88.5
RSK10	9/11/2007	9.68	15.2	838	6.32	-95.7	--	0.10	2.79	32.25	358	110.0
	10/30/2007	NM	12.89	753	6.18	-94.9	0.19	NM	0.44	NM	330	NM
RSK11	9/11/2007	10.05	14.7	791	6.27	-110.5	--	0.00	1.51	36.25	331	102.0
RSK12	9/11/2007	9.71	16.1	714	6.45	-82.3	--	0.59	3.64	49.00	309	102.0
RSK13	9/12/2007	8.57	17.7	346	6.59	-74.0	--	0.79	0.69	12.75	155	41.1
RSK14	9/12/2007	8.48	18.2	356	6.29	-53.8	--	0.16	1.88	12.25	154	52.9
RSK15	9/12/2007	8.73	16.7	283	5.87	43.8	--	0.02	1.06	10.75	108	60.9
RSK16	NS	--	--	--	--	--	--	--	--	--	--	--
RSK17	NS	--	--	--	--	--	--	--	--	--	--	--
RSK18	NS	--	--	--	--	--	--	--	--	--	--	--
RSK19	NS	--	--	--	--	--	--	--	--	--	--	--
RSK20	NS	--	--	--	--	--	--	--	--	--	--	--
RSK37	NS	--	--	--	--	--	--	--	--	--	--	--
RSK38	NS	--	--	--	--	--	--	--	--	--	--	--
RSK39	NS	--	--	--	--	--	--	--	--	--	--	--
RSK40	NS	--	--	--	--	--	--	--	--	--	--	--
RSK41	NS	--	--	--	--	--	--	--	--	--	--	--
RSK42	NS	--	--	--	--	--	--	--	--	--	--	--

APPENDIX F

Summary of field chemistry data for groundwater sampled from RCTW wells within Red Cove Study Area adjacent to Shepley's Hill Landfill.

Table F.1. Summary of field geochemical data collected from RCTW wells underneath Red Cove adjacent to Shepley's Hill Landfill. The following abbreviations are used within the table: ft bswi = feet below sediment-water interface, COND = specific conductance, ORP = oxidation-reduction potential (measured with platinum electrode), DO = dissolved oxygen, Alk = alkalinity, TIC = total inorganic carbon, NM = not measured, NS = not sampled.

Location	Date	Screen Depth ft bswi	Temp. ℃	COND µS/cm	pH	ORP mV	DO (electrode) mg/L	DO (HACH) mg/L	Turbidity NTU	Ferrous Iron mg/L	Alk (mg/L $CaCO_3$)	TIC mg/L C
RCTW1	8/8/2006	3.00	27.8	447	6.67	-102.4	NM	1.80	1.20	NM	160	36.4
	8/21/2007		16.2	451	6.64	NM	NM	NM	33.20	41.75	167	41.2
RCTW2	8/8/2006	1.00	28.0	446	6.44	-69.9	NM	2.00	0.72	NM	155	38.6
	8/21/2007		19.0	411	6.18	NM	NM	NM	9.30	20.50	148	45.9
RCTW3	5/16/2006	1.50	12.0	399	6.56	-65.2	0.33	NM	NM	NM	NM	NM
	8/8/2006		27.5	438	6.50	-111.5	NM	1.70	1.20	NM	148	32.4
	8/21/2007		18.2	463	6.52	NM	NM	NM	3.20	27.75	175	43.6
RCTW4	8/9/2006	1.10	21.8	666	6.36	-88.0	NM	1.40	0.71	44.50	316	69.6
	8/23/2007		15.9	569	6.37	NM	NM	NM	0.88	32.50	222	58.9
RCTW5	8/9/2006	1.25	19.7	568	6.42	-115.0	NM	0.53	1.22	46.25	243	59.8
RCTW6	8/9/2006	2.10	22.5	129	6.82	-83.7	NM	0.80	11.80	8.75	55	11.9
	8/23/2007		17.2	279	6.57	NM	NM	0.70	1.95	16.00	97	24.1
RCTW7	5/17/2006	3.80	19.9	459	6.67	-143.8	0.19	NM	NM	NM	NM	NM
	8/8/2006		26.8	555	6.72	-182.9	NM	0.45	4.50	15.50	194	33.2
	8/21/2007		16.8	474	7.02	NM	NM	NM	2.02	51.00	168	35.8
RCTW8	8/9/2006	1.00	19.3	323	6.71	-110.0	NM	0.29	0.92	24.75	139	26.2
RCTW9	8/9/2006	1.25	26.2	627	6.69	-116.7	NM	1.00	16.50	39.00	266	55.0
	4/27/2007		10.9	663	6.46	-76.4	NM	0.21	3.33	59.25	298	63.6
RCTW10	8/9/2006	2.50	27.2	548	6.62	-112.0	NM	1.50	1.25	11.50	232	54.8
	8/22/2007		20.2	567	6.50	NM	NM	5.10	2.77	14.00	NM	75.3

APPENDIX G

Summary of field chemistry data for surface water sampled from within Red Cove adjacent to Shepley's Hill Landfill

Table G.1. Summary of field geochemical data collected for surface water in Red Cove adjacent to Shepley's Hill Landfill. The following abbreviations are used within the table: ft bws = feet below water surface, COND = specific conductance, ORP = oxidation-reduction potential (measured with platinum electrode), DO = dissolved oxygen, Alk = alkalinity, TIC = total inorganic carbon, NM = not measured, NS = not sampled.

Location	Date	Depth ft bws	Temp. °C	COND µS/cm	pH	ORP mV	DO (electrode) mg/L	DO (HACH) mg/L	Turbidity NTU	Ferrous Iron mg/L	Alk (mg/L $CaCO_3$)	TIC mg/L C
IC1	5/17/2006	1.64	10.51	159	5.97	120.6	5.33	NM	NM	NM	NM	NS
IC2		1.94	10.08	144	5.93	133.3	4.70	NM	NM	NM	NM	NS
MC1	5/17/2006	1.64	10.64	133	6.10	170.6	6.50	6-8	NM	NM	NM	NS
MC2		4.18	10.79	566	6.62	-96.5	0.19	NM	NM	NM	NM	NS
SW01	4/23/2007	0.82	14.73	173	6.04	102.2	8.48	NM	NM	NM	NM	NS
		1.64	14.34	175	5.87	102.6	7.76	NM	NM	NM	NM	NS
		2.05	14.47	175	5.87	102.2	8.40	NM	NM	NM	NM	NS
SW02A	4/23/2007	0.82	15.78	185	6.00	83.1	7.85	6.90	3.84	0.55	24.20	6.95
		1.64	15.75	186	5.98	80.4	8.25	7.50	6.68	0.65	NM	7.13
		2.46	15.23	189	5.91	77.2	8.64	NM	3.27	0.48	23.20	6.5
		3.28	13.71	331	5.78	33.9	6.73	NM	NM	5.50	82.60	32
		3.44	13.8	437	6.02	6.2	7.40	NM	NM	NM	NM	NM
		3.61	12.67	663	7.12	-233.6	1.55	NM	NM	NM	NM	NM
SW02B	4/26/2007	0.82	17.03	181	6.41	238.4	6.18	5.80	NM	0.02	NM	NS
		1.64	16.56	180	6.4	215.4	6.39	4.60	1.53	0.04	NM	NS
		2.46	14.28	181	5.9	142.0	6.87	4.30	2.35	0.79	NM	NS
		3.28	13.05	443	6.0	27.5	6.13	5.00	61.90	37.5	NM	NS
	8/20/2007	0.82	18.08	254	6.25	396.7	5.92	10.10	8.54	0.03	40	11.7
		1.23	17.02	246	6.18	370.5	6.78	NM	6.78	NM	NM	NS
		1.64	16.28	247	5.91	268.3	6.39	7.00	6.50	0.28	42	13.2
		2.05	15.85	257	5.78	63.1	4.47	NM	11.10	NM	NM	NS
		2.46	15.45	287	5.83	23.2	2.57	1.40	17.30	4.50	72	19.8
		2.87	15.85	599	6.06	-41.3	0.54	0.90	145.00	32.50	196	61.1
		3.28	16.06	727	6.89	-221.4	0.28	NM	NM	NM	NM	NS
SW03	8/20/2007	0.82	20.86	258	6.44	192.5	7.77	6.40	9.01	0.09	38	10.8
		1.23	19.23	254	6.31	182.5	8.07	NM	9.43	NM	NM	NS
		1.64	17.26	249	6.15	126.6	6.42	7.30	8.03	0.09	40	11.8
		2.05	16.62	246	5.94	63.6	6.17	NM	7.58	NM	NM	NS
		2.46	16.19	254	5.91	37.7	5.60	8.40	11.90	2.07	50	16.9
		2.87	15.93	275	5.85	22.8	4.17	NM	18.00	NM	NM	NS
		3.28	15.92	301	5.90	-1.8	3.30	4.70	33.40	9.5	94	27.5
		3.69	16.33	416	7.19	-293.5	0.30	NM	NM	NM	NM	NS
SW04	9/12/2007	0.82	21.3	251	6.94	258.2	1.93	6.30	10.20	0.00	36	10.6
		1.23	19.1	248	6.68	149.2	1.29	5.10	7.22	0.00	44	NS
		1.64	18.12	246	6.58	122.8	0.66	8.20	5.60	0.09	51	11.1
		2.05	17.66	248	6.54	74.0	0.25	5.00	7.21	0.56	39	NS
		2.46	17.55	270	6.61	-16.7	0.04	0.70	10.10	10.00	79	18.8
		2.87	17.58	434	6.61	-168.4	0.01	0.35	26.10	19.75	82	NS
SW05	9/13/2007	0.82	17.87	255	6.65	106.6	6.50	14.80	7.41	0.07	54	12.2
		1.23	17.31	254	6.64	132.0	5.56	4.70	6.65	0.02	31	NS
		1.64	17.06	258	6.51	86.7	4.52	3.50	4.96	0.22	61	13.7
		2.05	16.59	261	6.46	68.3	4.16	4.00	8.02	1.12	44	NS
		2.46	16.42	246	6.55	49	3.82	NM	7.74	1.43	60	14.8
		2.87	16.35	265	6.54	21.1	3.43	6.00	13.10	2.50	55	NS

APPENDIX H

Summary of chemistry data for groundwater sampled from RSK wells within Red Cove Study Area adjacent to Shepley's Hill Landfill.

Table H.1. Summary of chemistry data for groundwater samples collected on March 13-14, 2006 adjacent to Shepley's Hill Landfill. The following abbreviations are used within the table: ND = not detected, NS = not sampled, QL = quantitation limit.

Location	Date	As mg/L	Fe mg/L	Mn mg/L	Ca mg/L	K mg/L	Mg mg/L	Na mg/L	Cl mg/L	SO_4 mg/L	NH_3-N mg/L	TOC mg/L
RSK1	NS	--	--	--	--	--	--	--	--	--	--	--
RSK2	NS	--	--	--	--	--	--	--	--	--	--	--
RSK3	NS	--	--	--	--	--	--	--	--	--	--	--
RSK4	NS	--	--	--	--	--	--	--	--	--	--	--
RSK5	NS	--	--	--	--	--	--	--	--	--	--	--
RSK6	NS	--	--	--	--	--	--	--	--	--	--	--
RSK7	NS	--	--	--	--	--	--	--	--	--	--	--
RSK8	3/14/2006	0.755	29.6	3.50	46.9	8.40	6.63	23.1	30.3	5.68	3.11	2.32
RSK9	3/14/2006	0.827	54.8	0.879	36.4	11.6	5.20	18.4	28.6	ND	6.82	3.01
RSK10	3/14/2006	0.710	57.4	1.04	39.6	11.9	5.18	18.2	25.7	0.358	7.11	3.54
RSK11	3/13/2006	1.100	59.6	2.31	47.7	7.90	5.96	16.7	22.0	0.385	4.64	3.13
RSK12	3/14/2006	0.746	38.0	2.11	50.4	7.25	6.69	14.6	16.2	1.74	3.15	4.21
RSK13	NS	--	--	--	--	--	--	--	--	--	--	--
RSK14	NS	--	--	--	--	--	--	--	--	--	--	--
RSK15	NS	--	--	--	--	--	--	--	--	--	--	--
RSK16	3/14/2006	0.807	22.1	2.42	40.6	8.73	6.91	21.0	26.3	13.9	2.22	1.50
RSK17	3/14/2006	0.963	30.0	1.20	32.4	9.83	6.27	17.8	16.2	10.9	4.65	2.39
RSK18	3/14/2006	0.967	40.5	1.02	30.5	11.8	6.68	15.8	16.9	8.64	7.01	3.01
RSK19	3/14/2006	0.478	58.7	1.22	40.2	12.3	6.20	17.9	19.6	2.69	10.2	14.20
RSK20	3/14/2006	0.957	32.4	1.42	35.1	11.7	7.08	16.1	16.9	8.65	5.73	2.18
RSK37	NS	--	--	--	--	--	--	--	--	--	--	--
RSK38	NS	--	--	--	--	--	--	--	--	--	--	--
RSK39	NS	--	--	--	--	--	--	--	--	--	--	--
RSK42	NS	--	--	--	--	--	--	--	--	--	--	--
RSK40	NS	--	--	--	--	--	--	--	--	--	--	--
RSK41	NS	--	--	--	--	--	--	--	--	--	--	--
	MDL	0.00002	0.005	0.001	0.03	0.06	0.03	0.04	0.100	0.100	0.02	0.14
	QL	0.0001	0.017	0.004	0.08	0.18	0.08	0.14	1.00	1.00	0.10	1.00

Table H.2. Summary of chemistry data for groundwater samples collected on May 15-18, 2006 adjacent to Shepley's Hill Landfill. The following abbreviations are used within the table: ND = not detected, NS = not sampled, QL = quantitation limit.

Location	Date	As mg/L	Fe mg/L	Mn mg/L	Ca mg/L	K mg/L	Mg mg/L	Na mg/L	Cl mg/L	SO_4 mg/L	NH_3-N mg/L	TOC mg/L
RSK1	NS	--	--	--	--	--	--	--	--	--	--	--
RSK2	NS	--	--	--	--	--	--	--	--	--	--	--
RSK3	NS	--	--	--	--	--	--	--	--	--	--	--
RSK4	NS	--	--	--	--	--	--	--	--	--	--	--
RSK5	NS	--	--	--	--	--	--	--	--	--	--	--
RSK6	NS	--	--	--	--	--	--	--	--	--	--	--
RSK7	NS	--	--	--	--	--	--	--	--	--	--	--
RSK8	NS	--	--	--	--	--	--	--	--	--	--	--
RSK9	5/18/2006	0.815	60.6	0.804	40.4	13.0	5.48	21.0	28.1	ND	7.87	1.80
RSK10	NS	--	--	--	--	--	--	--	--	--	--	--
RSK11	NS	--	--	--	--	--	--	--	--	--	--	--
RSK12	NS	--	--	--	--	--	--	--	--	--	--	--
RSK13	5/18/2006	0.384	31.1	1.92	22.4	3.38	3.17	7.47	7.55	7.64	1.22	1.31
RSK14	5/18/2006	0.367	38.9	2.86	29.5	4.17	4.17	9.85	11.6	10.5	1.42	1.46
RSK15	5/18/2006	0.249	33.5	2.88	30.1	4.61	4.70	9.81	10.0	10.5	1.14	1.33
RSK16	NS	--	--	--	--	--	--	--	--	--	--	--
RSK17	NS	--	--	--	--	--	--	--	--	--	--	--
RSK18	NS	--	--	--	--	--	--	--	--	--	--	--
RSK19	NS	--	--	--	--	--	--	--	--	--	--	--
RSK20	NS	--	--	--	--	--	--	--	--	--	--	--
RSK37	NS	--	--	--	--	--	--	--	--	--	--	--
RSK38	NS	--	--	--	--	--	--	--	--	--	--	--
RSK39	NS	--	--	--	--	--	--	--	--	--	--	--
RSK42	NS	--	--	--	--	--	--	--	--	--	--	--
RSK40	NS	--	--	--	--	--	--	--	--	--	--	--
RSK41	NS	--	--	--	--	--	--	--	--	--	--	--
	MDL	0.00002	0.005	0.001	0.03	0.06	0.03	0.04	0.100	0.100	0.02	0.14
	QL	0.0001	0.017	0.004	0.08	0.18	0.08	0.14	1.00	1.00	0.10	1.00

Table H.3. Summary of chemistry data for groundwater samples collected on August 8-10, 2006 adjacent to Shepley's Hill Landfill. The following abbreviations are used within the table: ND = not detected, NS = not sampled, MDL = method detection limit, QL = quantitation limit.

Location	Date	As mg/L	Fe mg/L	Mn mg/L	Ca mg/L	K mg/L	Mg mg/L	Na mg/L	Cl mg/L	SO_4 mg/L	NH_3-N mg/L	TOC mg/L
RSK1	8/10/2006	0.642	26.1	3.98	65.4	9.14	9.12	25.1	23.2	8.29	2.87	2.43
RSK2	8/8/2006	0.814	28.5	3.64	64.9	8.31	10.1	24.8	23.4	7.59	2.04	2.41
RSK3	8/10/2006	0.798	29.1	3.4	65.1	8.81	10.2	25.3	23.6	10.6	2.27	2.4
RSK4	8/10/2006	0.882	30.7	2.77	62.5	8.4	9.95	25.4	25.9	15.5	2.22	2.08
RSK5	8/10/2006	0.995	34.6	2.28	60.7	8.42	9.47	25.3	26.2	14.2	2.92	2.17
RSK6	8/8/2006	0.841	28.3	3.23	64.7	8.14	10.3	24.7	26.1	11.2	1.89	2.22
RSK7	8/10/2006	0.708	54.4	2.36	43.3	9.07	6.14	19.5	21.9	4.10	6.67	2.71
RSK8	NS	--	--		--	--	--	--	--	--	--	--
RSK9	NS	--	--	--	--	--	--	--	--	--	--	--
RSK10	NS	--	--	--	--	--	--	--	--	--	--	--
RSK11	NS	--	--	--	--	--	--	--	--	--	--	--
RSK12	NS	--	--	--	--	--	--	--	--	--	--	--
RSK13	NS	--	--	--	--	--	--	--	--	--	--	--
RSK14	NS	--	--	--	--	--	--	--	--	--	--	--
RSK15	NS	--	--	--	--	--	--	--	--	--	--	--
RSK16	NS	--	--	--	--	--	--	--	--	--	--	--
RSK17	NS	--	--	--	--	--	--	--	--	--	--	--
RSK18	NS	--	--	--	--	--	--	--	--	--	--	--
RSK19	NS	--	--	--	--	--	--	--	--	--	--	--
RSK20	NS	--	--	--	--	--	--	--	--	--	--	--
RSK37	NS	--	--	--	--	--	--	--	--	--	--	--
RSK38	NS	--	--	--	--	--	--	--	--	--	--	--
RSK39	NS	--	--	--	--	--	--	--	--	--	--	--
RSK42	NS	--	--	--	--	--	--	--	--	--	--	--
RSK40	NS	--	--	--	--	--	--	--	--	--	--	--
RSK41	NS	--	--	--	--	--	--	--	--	--	--	--
	MDL	0.00002	0.005	0.001	0.03	0.06	0.03	0.04	0.100	0.100	0.02	0.14
	QL	0.0001	0.017	0.004	0.08	0.18	0.08	0.14	1.00	1.00	0.10	1.00

Table H.4. Summary of chemistry data for groundwater samples collected on April 23-27, 2007 adjacent to Shepley's Hill Landfill. The following abbreviations are used within the table: ND = not detected, NS = not sampled, QL = quantitation limit.

Location	Date	As mg/L	Fe mg/L	Mn mg/L	Ca mg/L	K mg/L	Mg mg/L	Na mg/L	Cl mg/L	SO_4 mg/L	NH_3-N mg/L	TOC mg/L
RSK1	NS	--	--	--	--	--	--	--	--	--	--	--
RSK2	NS	--	--	--	--	--	--	--	--	--	--	--
RSK3	NS	--	--	--	--	--	--	--	--	--	--	--
RSK4	NS	--	--	--	--	--	--	--	--	--	--	--
RSK5	NS	--	--	--	--	--	--	--	--	--	--	--
RSK6	NS	--	--	--	--	--	--	--	--	--	--	--
RSK7	NS	--	--	--	--	--	--	--	--	--	--	--
RSK8	4/25/2007	0.860	48.0	4.39	56.0	9.8	8.25	24.4	35.4	3.92	4.39	2.30
RSK9	4/25/2007	0.941	65.5	0.92	44.2	12.2	5.5	19.2	32.5	ND	8.77	2.53
RSK10	4/25/2007	0.739	75.5	1.19	57.4	13.0	6.91	18.8	33.0	0.37	9.20	3.07
RSK11	4/25/2007	0.941	43.2	1.25	28.6	5.9	3.94	11.0	7.52	2.88	4.18	1.38
RSK12	4/25/2007	0.860	31.9	1.23	25.1	5.01	3.52	8.28	5.39	1.88	3.30	1.22
RSK13	NS	--	--	--	--	--	--	--	--	--	--	--
RSK14	NS	--	--	--	--	--	--	--	--	--	--	--
RSK15	NS	--	--	--	--	--	--	--	--	--	--	--
RSK16	4/24/2007	0.850	27.0	1.77	34.9	8.4	5.97	19.5	24.7	14.0	3.20	2.55
RSK17	4/24/2007	0.876	40.3	1.38	27.2	10.1	4.54	14.2	20.1	10.1	5.87	1.78
RSK18	4/24/2007	0.757	66.1	1.42	30.0	11.8	4.75	15.6	21.5	3.64	7.92	2.14
RSK19	4/24/2007	0.464	59.1	1.2	45.5	11.6	6.44	16.0	15.4	1.17	10.9	2.84
RSK20	4/24/2007	0.848	50.9	1.57	29.1	11.2	4.91	14.5	20.1	5.23	6.96	2.00
RSK37	NS	--	--	--	--	--	--	--	--	--	--	--
RSK38	NS	--	--	--	--	--	--	--	--	--	--	--
RSK39	NS	--	--	--	--	--	--	--	--	--	--	--
RSK42	NS	--	--	--	--	--	--	--	--	--	--	--
RSK40	NS	--	--	--	--	--	--	--	--	--	--	--
RSK41	NS	--	--	--	--	--	--	--	--	--	--	--
	MDL	0.00002	0.005	0.001	0.03	0.06	0.03	0.04	0.100	0.100	0.02	0.14
	QL	0.0001	0.017	0.004	0.08	0.18	0.08	0.14	1.00	1.00	0.10	1.00

Table H.5. Summary of chemistry data for groundwater samples collected on August 20-23, 2007 adjacent to Shepley's Hill Landfill. The following abbreviations are used within the table: ND = not detected, NS = not sampled, MDL = method detection limit, QL = quantitation limit.

Location	Date	As mg/L	Fe mg/L	Mn mg/L	Ca mg/L	K mg/L	Mg mg/L	Na mg/L	Cl mg/L	SO_4 mg/L	NH_3-N mg/L	TOC mg/L
RSK1	8/21/2007	0.509	18.1	3.08	57.9	6.19	8.35	24.2	22.8	16.0	1.41	2.40
RSK2	NS	--	--	--	--	--	--	--	--	--	--	--
RSK3	8/21/2007	0.722	21.3	2.71	51.2	7.67	7.4	24.2	23.0	16.2	2.06	2.15
RSK4	8/21/2007	0.797	22.6	2.46	51.4	7.14	7.91	24.6	24.4	14.9	1.59	1.99
RSK5	8/21/2007	0.816	24.7	1.99	45.9	7.46	7.15	23.8	21.8	15.9	2.44	1.76
RSK6	8/21/2007	0.811	22.6	3.13	54.0	7.55	8.17	24.8	26.2	14.6	1.59	1.94
RSK7	8/21/2007	0.661	38.8	2.07	42.5	8.28	6.12	23.1	21.2	10.5	4.83	2.64
RSK8	NS	--	--	--	--	--	--	--	--	--	--	--
RSK9	NS	--	--	--	--	--	--	--	--	--	--	--
RSK10	NS	--	--	--	--	--	--	--	--	--	--	--
RSK11	NS	--	--	--	--	--	--	--	--	--	--	--
RSK12	NS	--	--	--	--	--	--	--	--	--	--	--
RSK13	NS	--	--	--	--	--	--	--	--	--	--	--
RSK14	NS	--	--	--	--	--	--	--	--	--	--	--
RSK15	NS	--	--	--	--	--	--	--	--	--	--	--
RSK16	NS	--	--	--	--	--	--	--	--	--	--	--
RSK17	NS	--	--	--	--	--	--	--	--	--	--	--
RSK18	NS	--	--	--	--	--	--	--	--	--	--	--
RSK19	NS	--	--	--	--	--	--	--	--	--	--	--
RSK20	NS	--	--	--	--	--	--	--	--	--	--	--
RSK37	8/22/2007	0.003	0.02	0.01	5.09	1.17	1.19	0.96	1.31	4.19	0.03	0.67
RSK38	8/22/2007	0.016	4.94	2.3	16.5	2.77	2.83	2.93	2.15	8.47	0.37	0.87
RSK39	8/22/2007	0.082	5.93	7.56	22.6	4.41	2.92	4.26	2.62	8.90	1.83	0.81
RSK42	8/22/2007	0.177	14.5	5.0	18.1	3.7	2.42	3.04	2.01	8.91	0.99	1.09
RSK40	8/22/2007	0.592	45.5	3.72	22.4	4.02	3.39	4.29	2.98	11.4	1.18	1.04
RSK41	8/22/2007	0.516	32.9	4.23	32.4	4.11	4.18	5.15	3.88	11.9	1.01	1.05
	MDL	0.00002	0.005	0.001	0.03	0.06	0.03	0.04	0.100	0.100	0.02	0.14
	QL	0.0001	0.017	0.004	0.08	0.18	0.08	0.14	1.00	1.00	0.10	1.00

Table H.6. Summary of chemistry data for groundwater samples collected on September 11-13, 2007 adjacent to Shepley's Hill Landfill; October 30, 2007 sampling and analysis conducted by EPA Region 1 Lab. The following abbreviations are used within the table: ND = not detected, NM = not measured, NS = not sampled, MDL = method detection limit, QL = quantitation limit.

Location	Date	As mg/L	Fe mg/L	Mn mg/L	Ca mg/L	K mg/L	Mg mg/L	Na mg/L	Cl mg/L	SO_4 mg/L	NH_3-N mg/L	TOC mg/L
RSK1	NS	--	--	--	--	--	--	--	--	--	--	--
RSK2	NS	--	--	--	--	--	--	--	--	--	--	--
RSK3	NS	--	--	--	--	--	--	--	--	--	--	--
RSK4	NS	--	--	--	--	--	--	--	--	--	--	--
	10/30/2007	0.810	28.0	2.70	49.0	9.6	7.8	27	25.0	13.0	NM	NM
RSK5	NS	--	--	--	--	--	--	--	--	--	--	--
RSK6	NS	--	--	--	--	--	--	--	--	--	--	--
RSK7	NS	--	--	--	--	--	--	--	--	--	--	--
RSK8	9/11/2007	0.84	45.6	3.88	55.8	10.4	7.80	26.1	30.8	3.93	4.39	2.40
RSK9	9/12/2007	0.80	62.3	0.80	52.1	13.7	6.51	22.1	29.4	ND	9.41	3.00
RSK10	9/11/2007	0.66	81.5	0.92	64.1	14.8	7.63	21.4	32.0	ND	10.9	3.90
	10/30/2007	0.670	80.0	0.89	58.0	16.0	7.3	23.0	31.0	ND	NM	NM
RSK11	9/11/2007	0.74	78.2	1.87	58.0	13.7	6.9	20.7	31.7	ND	10.5	3.57
RSK12	9/11/2007	0.63	59.1	2.09	61.6	13.0	7.29	20.5	31.7	ND	9.75	3.41
RSK13	9/12/2007	0.42	34.2	2.55	27.9	3.59	3.99	10.5	12.0	7.28	1.26	1.50
RSK14	9/12/2007	0.29	36.5	1.92	29.7	6.23	3.68	7.7	10.2	5.11	1.97	2.43
RSK15	9/12/2007	0.06	11.9	0.80	27.6	7.64	4.95	8.3	12.0	4.57	0.34	2.31
RSK16	NS	--	--	--	--	--	--	--	--	--	--	--
RSK17	NS	--	--	--	--	--	--	--	--	--	--	--
RSK18	NS	--	--	--	--	--	--	--	--	--	--	--
RSK19	NS	--	--	--	--	--	--	--	--	--	--	--
RSK20	NS	--	--	--	--	--	--	--	--	--	--	--
RSK37	NS	--	--	--	--	--	--	--	--	--	--	--
RSK38	NS	--	--	--	--	--	--	--	--	--	--	--
RSK39	NS	--	--	--	--	--	--	--	--	--	--	--
RSK42	NS	--	--	--	--	--	--	--	--	--	--	--
RSK40	NS	--	--	--	--	--	--	--	--	--	--	--
RSK41	NS	--	--	--	--	--	--	--	--	--	--	--
	MDL	0.00002	0.005	0.001	0.03	0.06	0.03	0.04	0.100	0.100	0.02	0.14
	QL	0.0001	0.017	0.004	0.08	0.18	0.08	0.14	1.00	1.00	0.10	1.00

APPENDIX I

Summary of chemistry data for groundwater sampled from RCTW wells within Red Cove Study Area adjacent to Shepley's Hill Landfill.

Table I.1. Summary of chemistry data for groundwater samples collected from RCTW wells adjacent to Shepley's Hill Landfill. The following abbreviations are used within the table: ND = not detected, NS = not sampled, MDL = method detection limit, QL = quantitation limit.

Location	Date	As mg/L	Fe mg/L	Mn mg/L	Ca mg/L	K mg/L	Mg mg/L	Na mg/L	Cl mg/L	SO_4 mg/L	NH_3-N mg/L	TOC mg/L
RCTW1	8/8/2006	0.400	28.4	2.51	28.2	9.3	4.79	18.0	21.1	5.39	7.23	5.12
	8/21/2007	0.530	31.7	1.29	30.6	7.1	4.67	22.3	26.3	4.73	4.13	4.00
RCTW2	8/8/2006	0.357	18.8	2.09	27.0	9.7	5.64	20.9	26.2	5.03	8.19	2.64
	8/21/2007	0.288	15.4	1.63	23.5	10.1	5.27	23.7	26.1	3.37	7.89	4.60
RCTW3	8/8/2006	0.368	26.7	0.78	28.3	8.4	4.83	17.7	21.7	8.73	5.50	2.98
	8/21/2007	0.321	34.1	0.84	31.3	9.3	5.05	21.6	27.7	6.20	5.17	4.10
RCTW4	8/9/2006	0.751	68.9	1.14	55.0	13.4	7.18	19.9	28.0	0.44	9.26	2.90
	8/23/2007	0.622	48.0	0.76	39.6	11.8	4.83	23.2	29.0	ND	7.52	2.54
RCTW5	8/9/2006	0.911	59.1	1.45	44.3	11.3	5.76	16.8	23.5	0.58	7.31	2.75
RCTW6	8/9/2006	0.284	11.7	0.69	8.7	2.6	1.30	3.9	0.2	4.83	0.79	3.38
	8/23/2007	0.167	17.6	0.96	22.0	5.8	3.33	14.7	26.1	2.17	1.26	2.22
RCTW7	5/17/2006	0.400	41.8	0.77	24.7	10.6	4.65	19.5	22.8	12.3	6.75	NS
	8/8/2006	0.596	51.1	0.67	27.2	10.7	5.04	18.2	21.9	10.0	7.58	2.06
	8/21/2007	0.542	47.8	0.64	24.1	10.2	4.10	18.5	23.9	9.95	6.58	2.09
RCTW8	8/9/2006	0.616	28.4	0.91	22.5	6.1	3.30	10.7	8.56	2.65	3.68	2.27
RCTW9	8/9/2006	1.060	50.2	1.78	51.0	12.4	7.17	18.3	27.4	ND	7.84	3.57
	4/27/2007	0.723	57.8	1.86	53.2	12.1	7.46	18.2	27.7	ND	7.86	2.61
RCTW10	8/9/2006	0.160	11.4	2.70	56.2	10.5	9.57	23.0	28.9	ND	6.30	3.01
	8/22/2007	0.300	16.2	3.41	68.5	11.3	10.9	26.9	29.2	ND	5.82	4.80
	MDL	0.00002	0.005	0.001	0.03	0.06	0.03	0.04	0.100	0.100	0.02	0.14
	QL	0.0001	0.017	0.004	0.08	0.18	0.08	0.14	1.00	1.00	0.10	1.00

APPENDIX J

Summary of chemistry data for surface water sampled from within Red Cove Study Area adjacent to Shepley's Hill Landfill.

Table J.1. Summary of chemistry data for groundwater samples collected from RCTW wells adjacent to Shepley's Hill Landfill. The following abbreviations are used within the table: ND = not detected, NS = not sampled, MDL = method detection limit, QL = quantitation limit, ft above sed = feet above sediment.

Location	Date	Height (ft above sed)	As mg/L	Fe mg/L	Mn mg/L	Ca mg/L	K mg/L	Mg mg/L	Na mg/L	Cl mg/L	SO_4 mg/L	NH_3-N mg/L	TOC mg/L
IC1	NS	0.46	--	--	--	--	--	--	--	--	--	--	--
IC2	5/17/2006	0.16	0.014	2.41	0.40	11.2	2.16	2.1	13.4	20.3	5.91	0.10	NS
MC1	5/17/2006	3.36	0.006	0.43	0.17	7.6	1.3	1.49	15.1	23.6	6.02	0.10	NS
MC2	5/17/2006	0.82	0.265	56.4	1.07	38.2	8.77	5.43	18.9	27.4	0.74	0.08	NS
SW01	NS	1.68	--	--	--	--	--	--	--	--	--	--	--
	NS	0.86	--	--	--	--	--	--	--	--	--	--	--
	NS	0.45	--	--	--	--	--	--	--	--	--	--	--
SW02A	4/23/2007	2.79	0.010	1.05	0.20	9.3	1.7	1.72	18.6	31.4	6.39	0.36	3.53
		1.97	0.012	1.14	0.19	9.4	1.78	1.71	18.6	30.5	6.19	0.44	4.41
		1.15	0.008	0.72	0.18	8.8	1.61	1.66	18.9	27.1	5.50	0.29	3.94
		0.33	0.072	15.1	0.85	25.3	5.42	3.73	17.5	26.6	4.64	2.13	2.91
SW02B	4/23/2007	3.03	0.003	0.24	0.13	7.8	1.19	1.51	20.3	37.4	8.09	0.05	NS
		2.21	0.003	0.50	0.14	7.8	1.15	1.5	19.6	43.5	7.91	0.02	NS
		1.39	0.007	1.25	0.28	9.9	1.7	1.79	17.4	37.2	7.63	0.28	NS
		0.57	0.107	34.4	1.15	42.1	9.32	5.83	18.9	33.7	1.39	5.37	NS
	8/20/2007	2.46	0.020	0.70	0.06	15.6	1.83	2.59	28.5	45.0	3.63	0.13	3.9
		1.64	0.021	1.19	0.17	16.0	1.83	2.67	26.9	42.6	3.61	0.08	4.7
		0.82	0.058	5.86	0.62	18.6	2.76	2.95	23.3	36.1	3.22	0.66	3.3
		0.41	0.506	50.7	1.19	47.6	10.3	6.29	22.7	31.0	0.28	5.99	2.9
SW03	8/20/2007	2.89	0.019	0.53	0.03	14.9	1.8	2.44	29.3	47.4	3.69	ND	6.3
		2.07	0.020	0.59	0.06	15.2	1.78	2.53	27.4	44.3	3.58	0.05	4.6
		1.25	0.052	2.42	0.29	17.0	2.43	2.8	25.7	40.6	3.44	0.43	3.9
		0.43	0.159	11.4	0.60	23.6	4.31	3.69	24.2	36.8	2.71	1.64	3.6
SW04	9/12/2007	2.26	0.019	0.36	0.02	14.5	1.69	2.47	28.8	45.3	3.68	0.05	5.30
		1.44	0.020	0.26	0.07	14.4	1.54	2.41	28.8	46.5	3.97	0.04	5.19
		0.62	0.136	8.98	0.53	18.4	2.39	2.99	27.9	44.8	2.88	0.81	5.64
SW05	9/12/2007	2.36	0.016	0.11	0.04	15.7	2.04	2.55	28.5	45.2	3.63	0.28	4.28
		1.54	0.015	0.22	0.06	16.2	2.42	2.72	28.5	44.8	3.98	0.64	4.04
		0.72	0.045	1.84	0.10	16.1	2.38	2.71	27.5	44.7	3.72	0.54	9.95
		MDL	0.00002	0.005	0.001	0.03	0.06	0.03	0.04	0.100	0.100	0.02	0.14
		QL	0.0001	0.017	0.004	0.08	0.18	0.08	0.14	1.00	1.00	0.10	1.00

APPENDIX K

Tabulated metal concentrations for sediment cores collected from the three transects in Red Cove as determined by microwave assisted HNO_3 extraction.

			Microwave-assisted HNO3 Extraction (mg/kg)												
Transect	Core ID	Depth (in.)	As	Fe	S	Al	Mn	Cr	Cu	Pb	Zn	Hg	Cd	Ni	Si
1	101	3.5	3260.0	234000	10900	2170	1820	122.0	23.1	21.6	147.0	0.7	3.1	18.5	3300
		7	1440.0	158000	23800	8250	10400	1070.0	36.4	99.5	167.0	11.9	5.2	32.2	20200
		10.5	703.0	37100	17300	15300	1640	2410.0	115.0	133.0	239.0	60.1	1.5	21.4	26100
		14	52.6	4100	843	9600	338	47.2	2.3	49.6	9.4	1.0	0.0	9.6	12200
		16	8.2	3030	<14.7	14000	116	12.2	1.7	7.1	9.5	0.3	0.0	0.0	20700
	102	3.5	2900.0	230000	11400	2610	3360	95.4	24.9	23.2	191.0	0.4	3.3	20.7	34400
		7	1710.0	227000	24300	6200	10600	855.0	25.7	84.2	129.0	6.4	4.9	19.8	23100
		10.5	1470.0	80200	23100	11700	3660	1930.0	38.7	108.0	164.0	38.4	1.4	20.6	31900
		14	245.0	13800	3850	8980	570	23.9	9.2	5.9	12.1	0.4	0.0	12.7	9440
	103	3.5	6940.0	374000	2480	593	1500	21.7	0.0	11.2	28.6	0.2	7.5	0.0	39700
		7	2150.0	258000	1730	12700	3610	26.1	13.2	23.2	39.3	0.1	3.3	9.0	23800
		10.5	1370.0	199000	9800	23900	6260	623.0	26.1	66.9	73.9	4.6	3.4	18.4	28700
		14	232.0	24500	4690	8380	733	417.0	11.3	27.4	42.0	8.2	0.0	5.9	14600
		16	11.6	2420	44.7	7710	123	10.0	1.6	5.9	0.0	0.0	0.0	0.0	12800
2	201	2	459.0	30000	6500	11900	581	299.0	10.0	33.0	64.7	0.0	0.0	20.9	15800
		4	229.0	25200	7880	7120	547	35.4	3.6	8.9	14.2	0.0	0.0	16.5	9850
		6	30.4	5610	489	8760	325	18.7	3.3	8.0	3.2	0.0	0.0	7.5	13000
		8	16.6	3870	339	10500	128	14.6	3.7	9.9	4.9	0.0	0.0	6.1	14600
		10	15.0	6540	22.9	13500	112	20.3	2.6	8.1	9.6	0.0	0.0	8.0	17200
		12	18.7	8170	63	16200	140	21.9	4.2	8.0	13.2	0.0	0.0	11.0	17900
		14	22.7	9310	266	15300	150	22.2	4.5	7.9	16.7	0.0	0.0	16.8	16400
	201B	2	825.0	60900	18600	5950	3690	127.0	18.6	255.0	287.0	0.0	0.8	10.0	9680
		4	76.2	12800	2910	13300	248	26.0	12.6	12.1	20.9	0.0	0.0	12.1	14300
		6	33.5	9810	1190	15000	138	44.9	17.5	6.6	16.5	0.0	0.0	26.4	16100
		8	20.2	7380	46.2	13100	106	22.4	5.1	5.7	14.1	0.0	0.0	16.0	14800
		10	15.7	6240	<14.7	14100	95	24.1	5.5	6.5	13.0	0.0	0.0	14.0	17900
		12	16.0	7800	<14.7	13700	111	21.9	8.7	6.5	15.9	0.0	0.0	14.3	16500
		14	15.0	7140	<14.7	13900	160	27.8	7.7	6.2	14.5	0.0	0.0	15.5	18300
		16	13.6	6810	<14.7	11100	114	16.7	5.1	6.0	12.7	0.0	0.0	11.7	14400
		18	11.5	6120	<14.7	9530	90	21.8	6.3	4.8	14.3	0.0	0.0	13.8	12400
		20	11.3	5480	<14.7	10500	100	23.5	5.3	4.6	11.9	0.0	0.0	15.3	14200
2	201B	22.25	10.7	5160	<14.7	10000	88	36.5	6.9	4.9	12.7	0.0	0.0	22.5	14900
	202	2	8600	359000	2970	509	1280	18.9	0	12.5	32.2	0	3.06	1.72	22900
		4	6490	362000	2240	361	1520	11.2	0	8.14	26.7	0	4.53	0	26800

		6	4080	343000	3670	820	2580	13.6	0	9.07	29.5	0	4.47	0	24400
		8	4160	304000	10600	2520	8500	28.1	0	16.9	46.9	0	4.02	5.91	23400
		10	2260	305000	5970	1450	6650	40.8	0	23.7	42.1	0	4.07	3.7	22000
		12	1340	272000	17400	3120	12700	204	0	58.6	100	0	2.86	9.99	21000
		14	588	130000	52700	8330	13000	1650	26.8	129	202	0	0	26.4	21000
		16	326	32000	22100	12200	1150	2530	43.6	121	194	0	0	20.4	22500
		18.5	322	26700	8940	4620	771	175	13.5	23.8	31.1	0	0	9.91	12900
	202B	2	1180	156000	32500	7010	12600	774	20.9	390	425	0	0.841	17.1	18100
		4	669	64000	23100	12700	2450	2750	45.8	238	316	0	0	21	20100
		6	649	57500	14100	11200	1990	812	28	118	139	0	0	15.7	21200
		8	646	53000	12600	8340	1880	363	18.8	49.5	67.3	0	0	12.2	17800
		10	145	19000	4070	9720	1580	89.8	6.41	18.8	17.4	0	0	7.67	7650
		12	32.7	8920	879	14800	1800	18.4	5.2	20.8	8.18	0	0	6.07	7690
		14	26.8	8330	397	14500	847	11	5.66	22.4	7.41	0	0	3.58	8800
		17.5	12	5880	<14.7	10700	124	11.7	2.95	9.43	9.87	0.116	0	5.95	13500
		21	12.5	7340	<14.7	11000	123	20.9	3.28	7.95	12.5	0.207	0	10.3	12700
		24.5	12.7	7570	<14.7	14100	167	14.6	4.56	5.77	14.6	0	0	10.2	18100
		28	13.5	8400	<14.7	7760	83	8.01	4.24	3.5	12.7	0.116	0	7.82	9180
		32	24.2	10100	<14.7	7890	75	9.75	4.88	4.33	15	0	0	9.84	8920
		36	12.4	5440	<14.7	4690	50	9.9	5.9	2.7	10.6	0	0.0	8.0	5260
		40	23.2	8190	<14.7	6360	104	9.35	7.82	5.48	12.7	0	0	8.52	8270
	203	2	137.0	14600	1140	19800	247	37.6	9.6	12.1	22.5	0.0	0.0	12.3	20000
		4	112.0	13000	992	19500	213	37.4	11.9	10.9	20.7	0.0	0.0	11.1	21500
		6	79.3	10100	749	15800	173	28.0	5.7	8.3	16.0	0.0	0.0	9.5	18600
		8	15.6	4970	<14.7	11500	105	18.3	5.4	5.9	7.9	0.0	0.0	9.5	15800
		10	14.7	4980	<14.7	8000	56	12.9	4.2	4.6	8.5	0.0	0.0	8.8	9950
		12	24.8	6670	<14.7	15400	97	28.6	8.0	6.7	12.4	0.0	0.0	15.4	18100
		15.5	9.1	5310	<14.7	5220	54	9.9	5.6	3.8	12.7	0.1	0.0	7.9	5190
		19	9.9	5780	<14.7	5440	74	11.7	5.9	5.4	13.6	0.1	0.0	6.9	6530
		22.5	10.7	4840	<14.7	8560	63	10.5	5.9	4.2	12.7	0.2	0.0	6.5	13100
		26	11.3	6020	<14.7	6330	60	11.4	3.7	4.3	12.5	0.1	0.0	8.2	6770

	Core	Depth	Microwave-assisted HNO3 Extraction (mg/kg)											
Transect	ID	(in.)	As	Fe	S	Al	Mn	Cr	Cu	Pb	Zn	Hg	Cd	Ni	Si
	204	2	1310	87900	2130	24300	2300	136	39.2	90.5	76.9	0	0	32.2	21400
		4	1670	106000	1740	20900	2130	110	31.1	73.1	70.3	0	0	28.4	20900
		6	1510	116000	712	13400	1700	70.1	21	42.3	68.1	0	0	21.7	13400
		7.125	397	55100	159	16500	1250	38.1	20.2	34	52.8	0	0	18.3	17300
		11.13	183	26700	<14.7	23400	856	32.7	28.6	22	58.3	0.47	0	32.2	27700

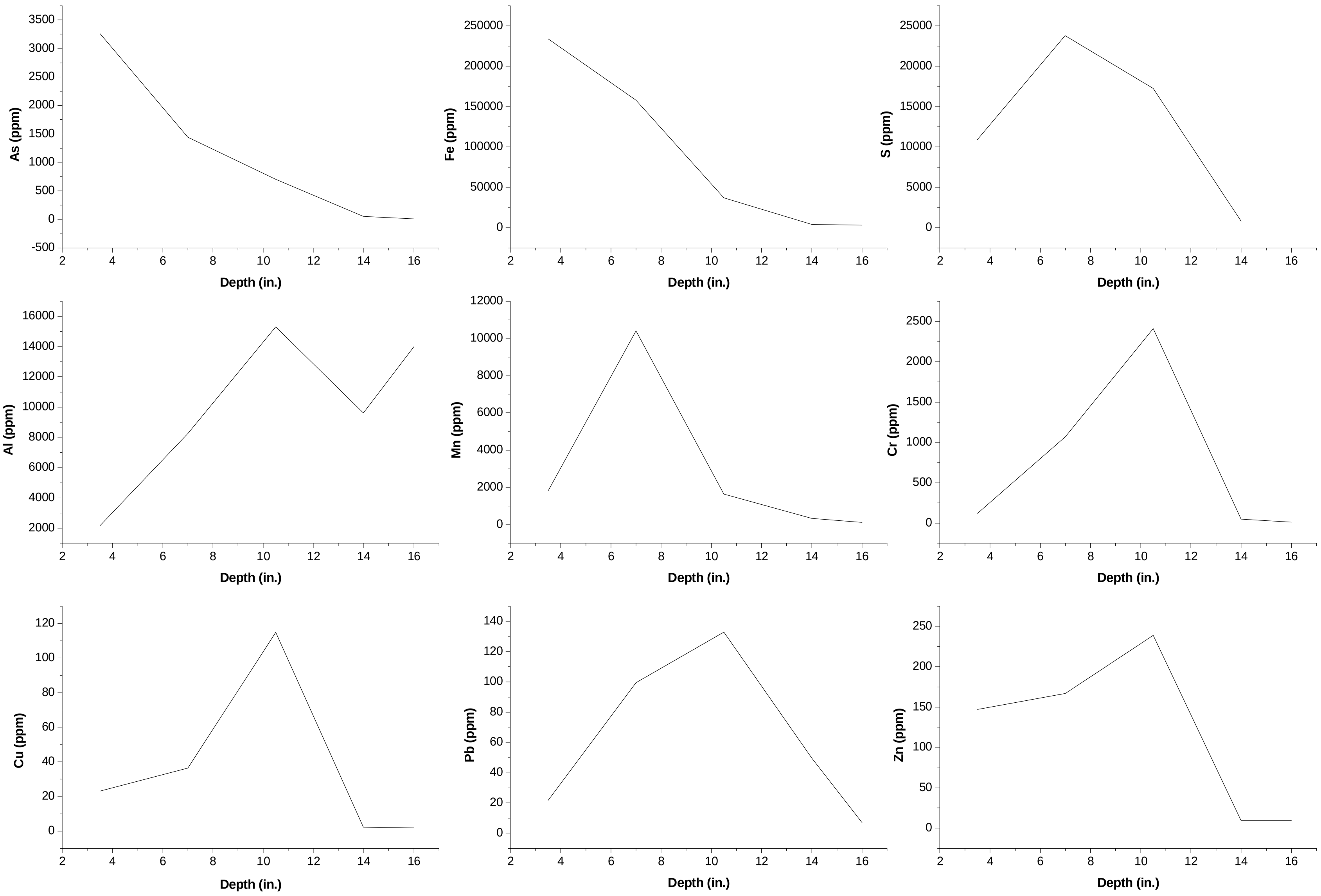
		15.13	10.1	4330	<14.7	5810	71	7.51	3.12	3.85	10.8	0.0409	0	6.09	8880
		19.13	9.65	5700	<14.7	6540	101	9.44	3.22	3.34	12.5	0	0	7.04	9400
3	301	2	2540	144000	6590	9050	3370	225	36.2	999	987	0.06	7.7	12.1	20500
		4	1710	104000	7560	9760	1810	104	21.2	471	400	0	0	10.6	22500
		6	930	59800	9950	10600	751	35.5	16.6	104	90.7	0	0	10.8	25400
		8	850	55700	12300	7410	536	39.2	9.72	33	35.7	0	0	10.7	19200
		10	556	47000	13300	6050	489	27.6	6.37	22.3	27.1	0	0	10.1	11100
		12	36.8	5600	399	8620	215	7.37	0	7.41	7.28	0	0	1.91	11300
		13	19.7	5650	45.6	11400	113	10.3	0	6.04	10.1	0	0	3.56	15200
		16.5	17.9	8050	<14.7	13800	104	9.4	4.4	3.8	10.9	0.1	0.0	8.9	13500
		20	25.7	7060	<14.7	5880	53	9.4	5.1	3.8	11.6	0.0	0.0	9.6	7180
		23.5	24.3	7890	<14.7	7180	59	12.2	6.5	4.1	12.4	0.0	0.0	10.5	9060
		27	22.4	6010	<14.7	6530	60	9.6	4.6	5.5	13.2	0.1	0.0	8.7	6690
	302	2	248	39100	4070	24100	1380	37.2	31.3	1040	778	0	3.23	18.8	17200
		4	143	30400	3160	16000	999	21.5	18.1	619	486	0	1.82	15.6	11600
		6	92.3	21500	1240	15200	590	11.1	8.6	276	201	0	0	10.7	9620
		8	22.4	6420	16	6880	131	5.65	2.93	44.1	56.3	0	0	5.41	6550
		10	15.7	3760	<14.7	5870	60	4.1	0.0	4.6	9.4	0.0	0.0	3.1	7040
		10.5	16.4	3480	<14.7	7420	50	4.46	0	4.83	8.73	0	0	2.58	9830
		14	20.1	6530	<14.7	8660	79	11.8	3	5.01	11.5	0	0	7.25	8500
		17.5	12.9	6020	<14.7	4040	69	7.29	4.98	9.86	17.2	0	0	5.53	3740
		21	14.2	7430	<14.7	8700	139	8.92	7.2	42	36.9	0.082	0	6.39	12500
		24.5	8.91	5660	<14.7	5450	110	5.02	7.29	82.2	73.6	0.095	0	5.47	7350
	303	1	464.0	50400	219	11900	537	22.1	11.5	37.1	71.2	0.0	0.0	13.7	16300
		3	51.0	11500	<14.7	6330	146	9.4	6.1	12.1	32.5	0.0	0.0	7.1	7570
		5	18.3	7420	<14.7	6520	100	7.8	5.9	6.4	19.7	0.0	0.0	6.9	7390
		7	9.5	5900	<14.7	8460	90	7.9	6.7	4.5	14.9	0.0	0.0	5.8	12500
		9	8.3	5830	<14.7	8560	106	7.9	4.6	4.7	14.4	0.0	0.0	5.7	12600
		11	9.0	5520	<14.7	9300	103	8.0	4.1	4.4	13.2	0.0	0.0	5.4	14200

	Core	Depth	Microwave-assisted HNO3 Extraction (mg/kg)											
Transect	ID	(in.)	As	Fe	S	Al	Mn	Cr	Cu	Pb	Zn	Hg	Cd	Ni	Si
3	303	13	10.0	5760	<14.7	8490	87	8.2	4.9	4.6	14.8	0.0	0.0	6.0	12500
		15	11.3	6000	<14.7	6820	94	11.9	4.0	4.0	18.2	0.0	0.0	5.9	9210
		15.5	266.0	20400	7780	12000	735	751.0	25.2	53.0	85.7	0.0	0.0	12.2	15300
		17.5	287.0	18300	8770	8350	215	506.0	16.7	39.8	54.8	0.0	0.0	11.5	15100
		19.5	244.0	26600	9050	5010	338	30.0	6.9	9.4	23.1	0.0	0.0	16.7	7650
		21.5	193.0	36100	9740	6200	475	17.0	6.3	5.8	20.9	0.0	0.0	36.2	5200
		23.5	54.0	12500	1610	7570	211	8.3	3.6	6.8	12.1	0.0	0.0	7.8	7540

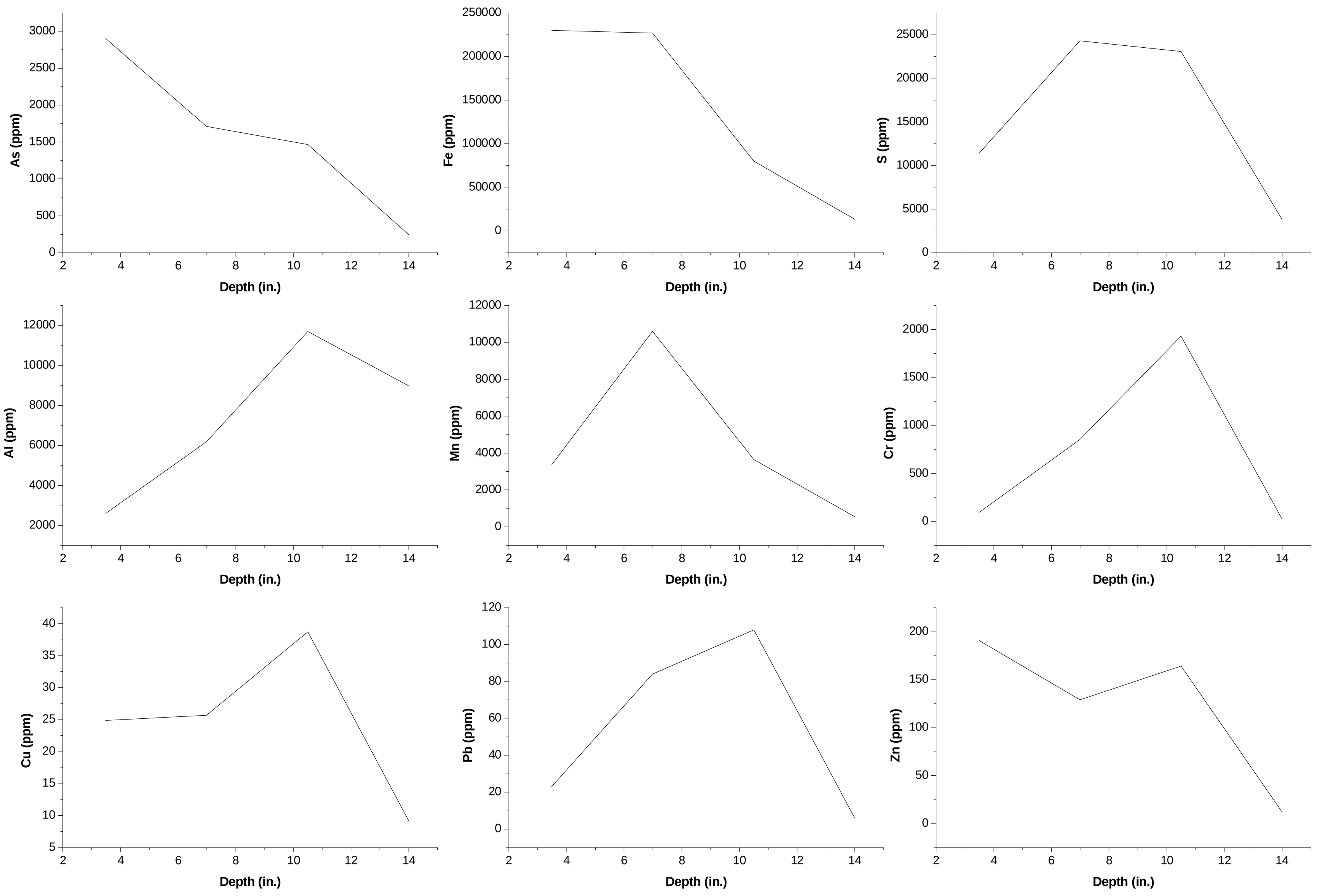
25.5	27.4	7370	<14.7	9130	103	10.8	<2.56	4.2	17.1	0.0	0.0	7.4	8170
27.25	35.7	9360	<14.7	15300	163	20.5	4.5	5.9	17.8	0.0	0.0	11.2	17400
29.25	44.9	12700	<14.7	16600	190	32.9	3.6	6.5	21.0	0.0	0.0	13.1	20100
31.25	28.6	7960	<14.7	11700	117	15.3	<2.56	4.6	14.8	0.0	0.0	7.8	12200
33.25	26.1	7380	<14.7	11000	131	12.8	3.5	4.6	15.7	0.0	0.0	7.0	12300
35.25	22.1	7250	<14.7	11000	122	14.0	4.5	4.9	15.6	0.0	0.0	7.3	13100
37.25	15.4	5430	<14.7	6090	73	9.1	3.4	4.0	14.5	0.0	0.0	5.5	6660
39.25	15.4	6570	<14.7	7120	89	14.5	4.0	4.2	15.5	0.0	0.0	7.0	7310

APPENDIX L

Elemental concentrations as a function of depth for sediment cores collected from the three transects in Red Cove as determined by microwave assisted HNO_3 extraction.



Core SCT0101



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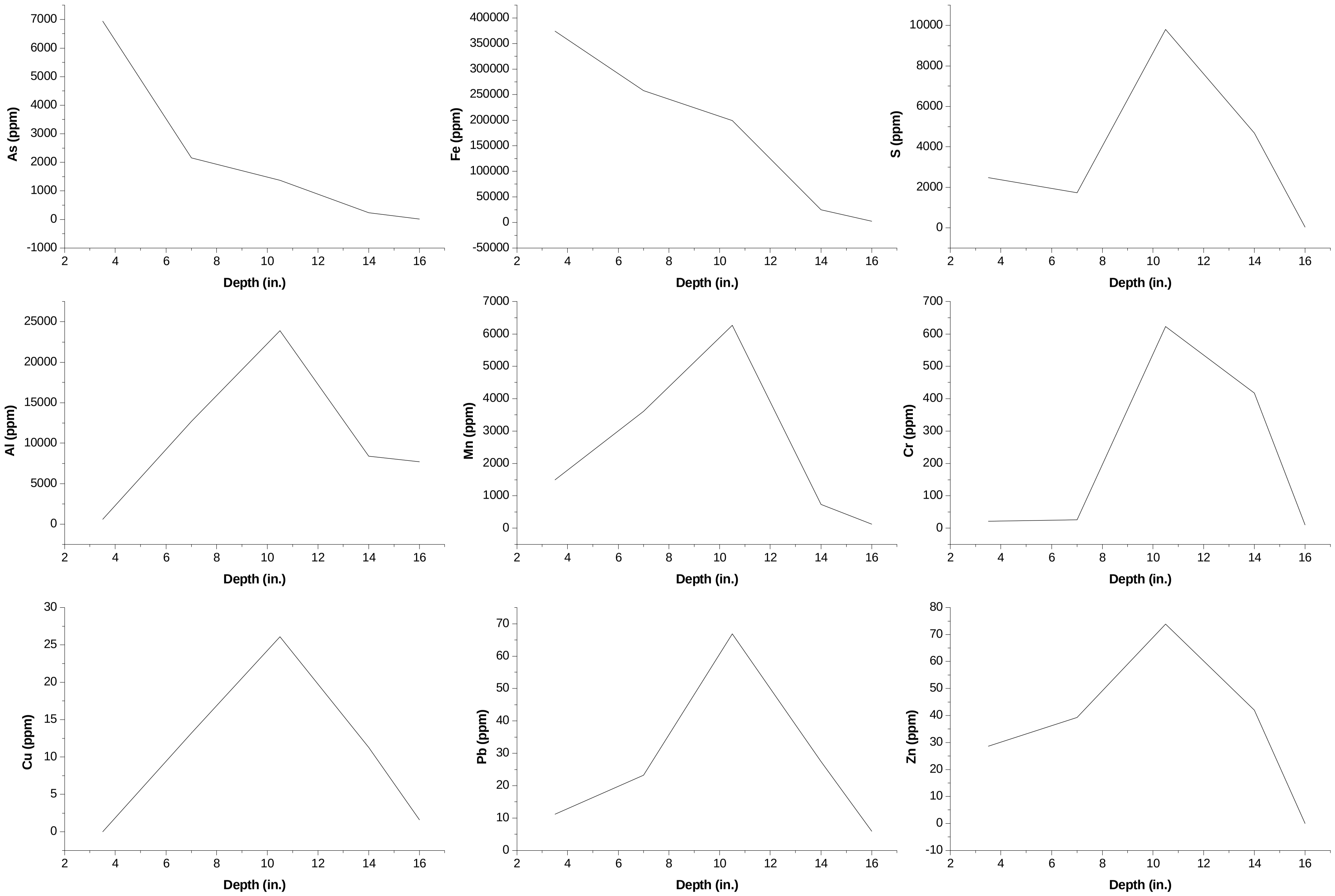

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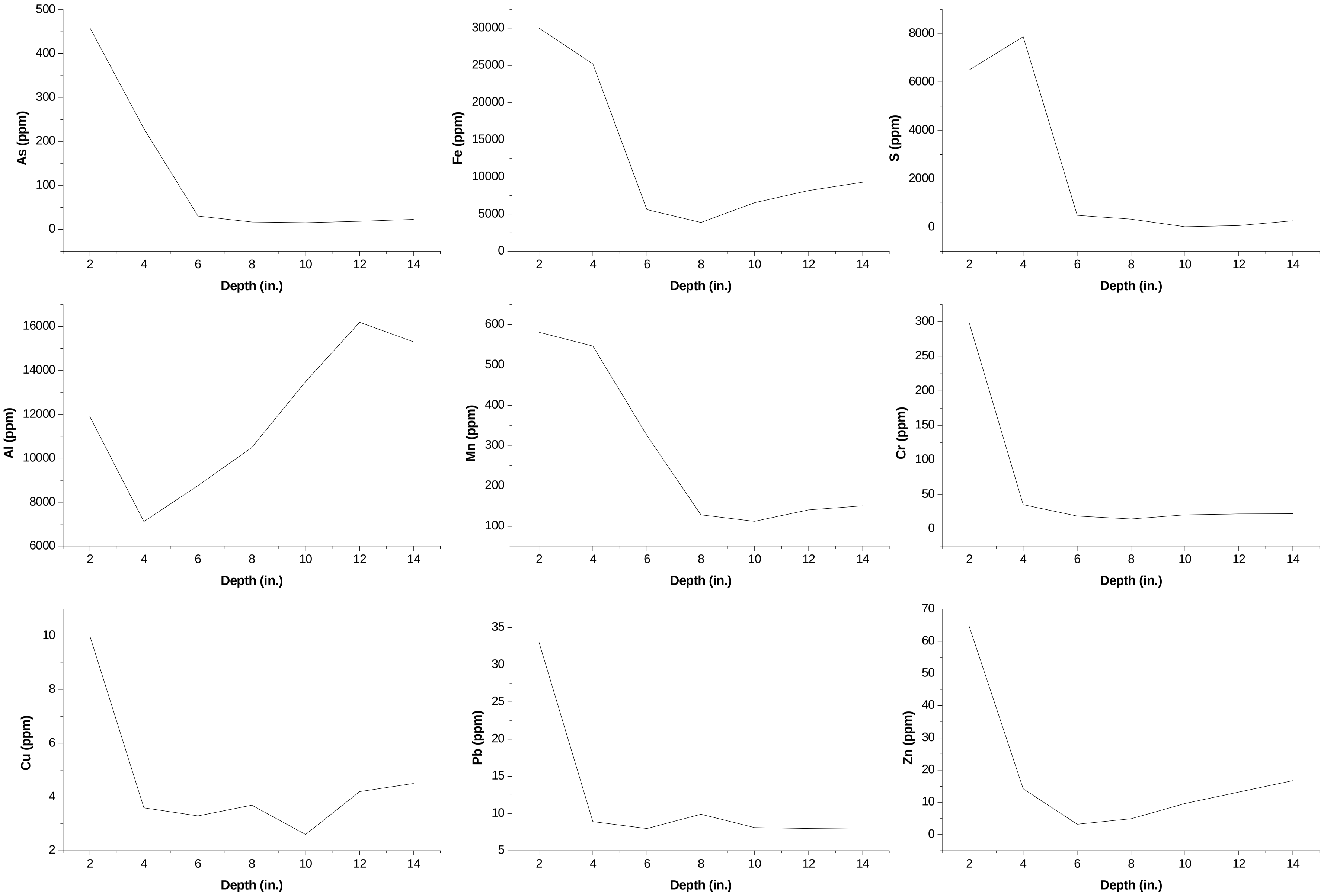

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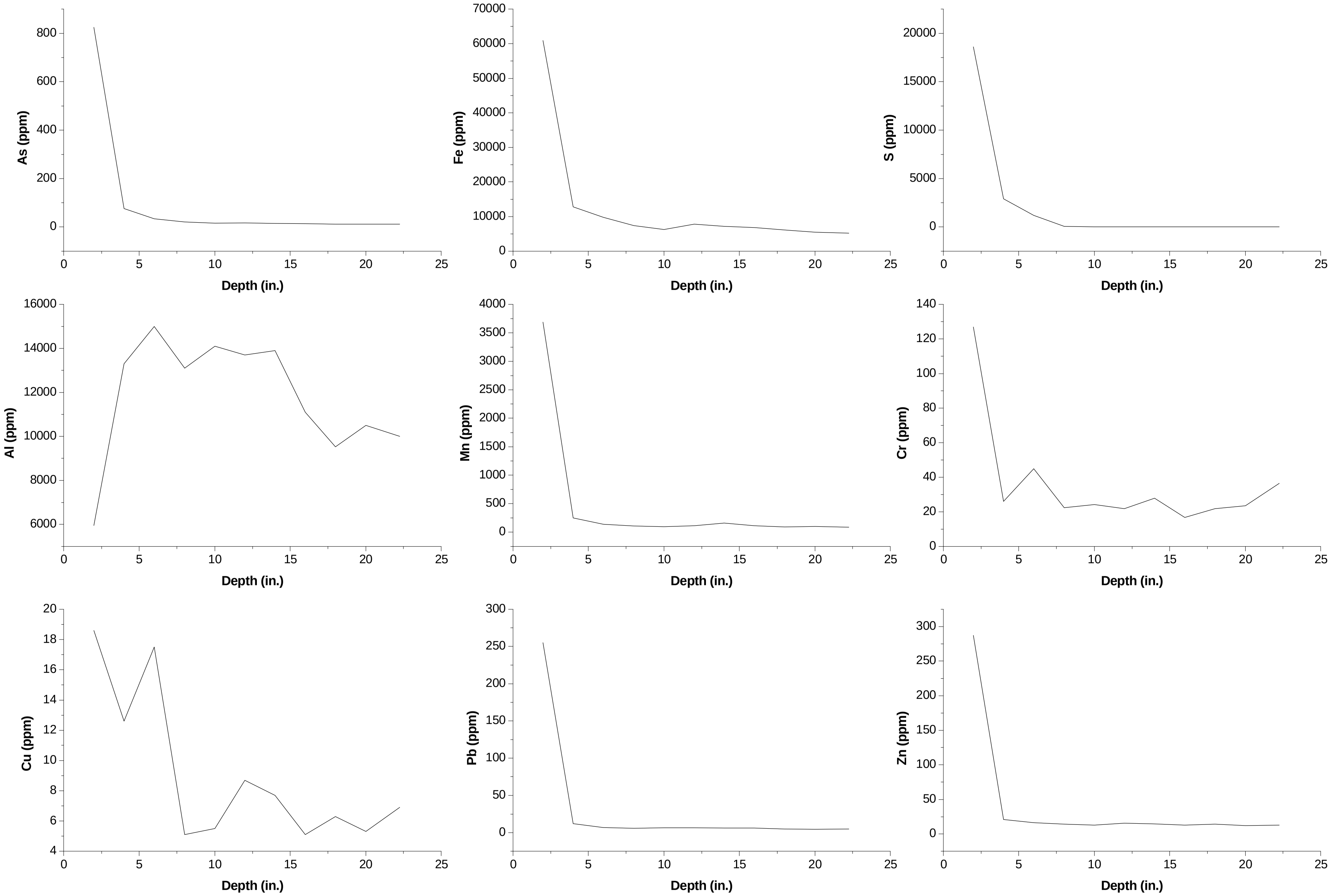

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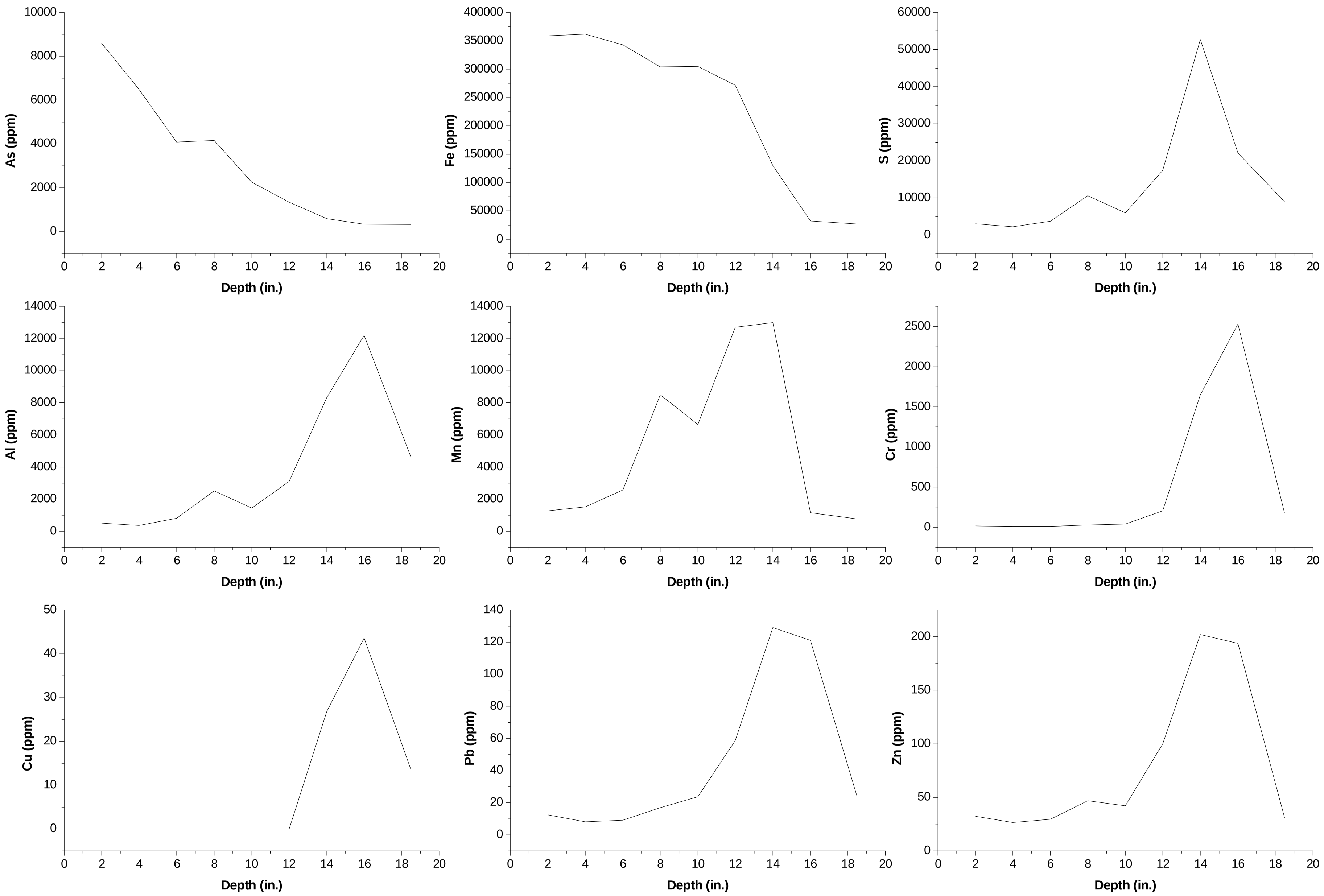

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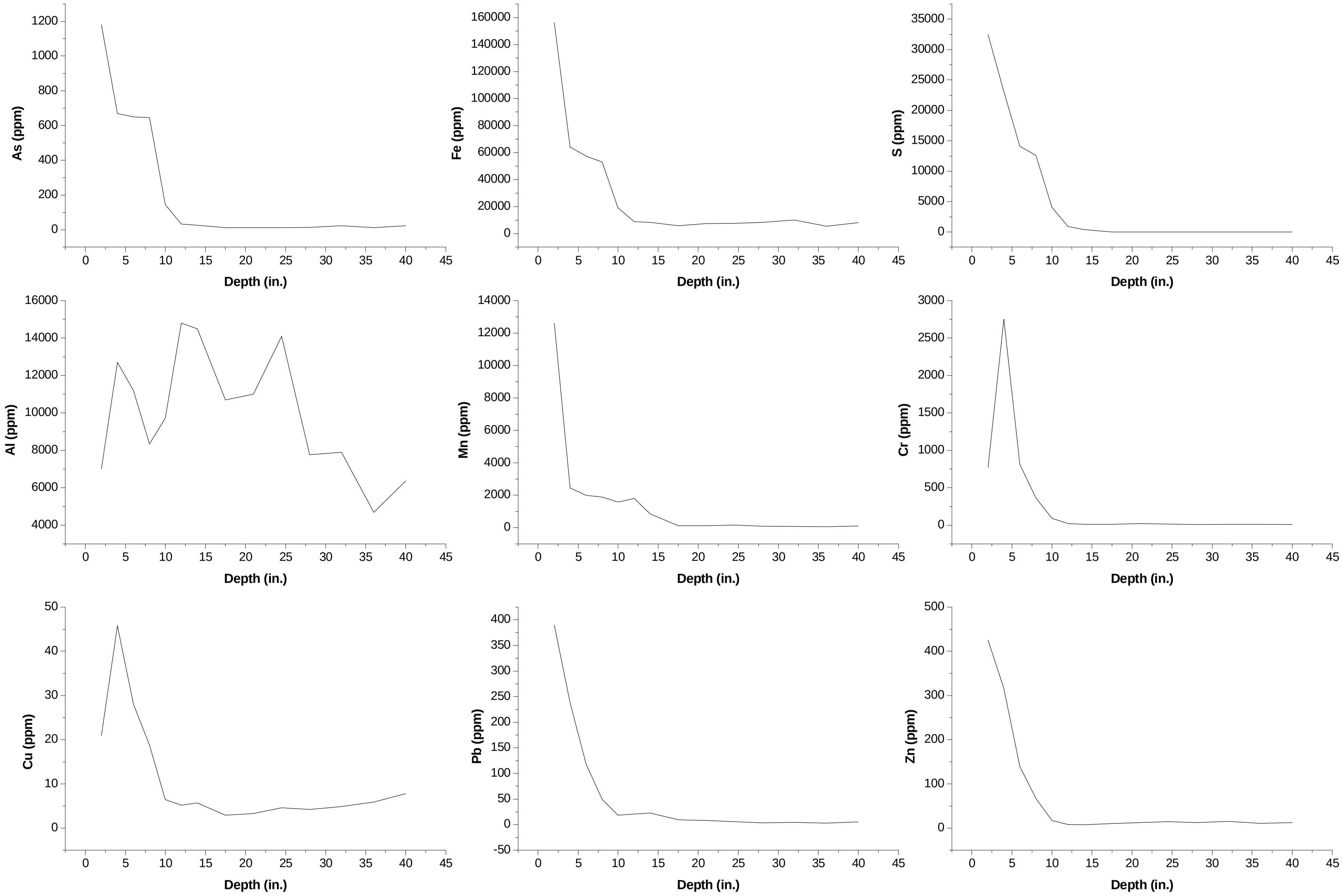

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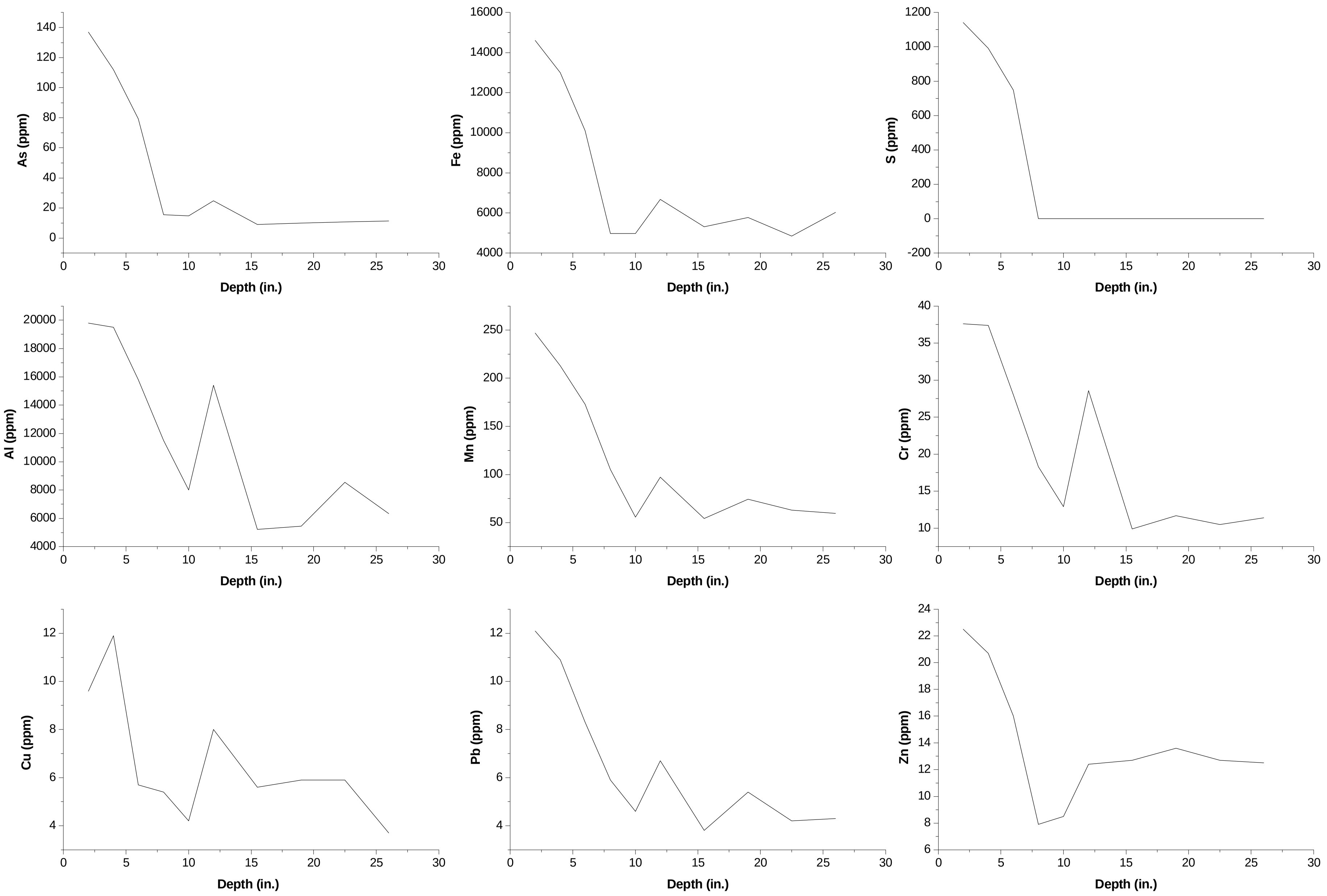

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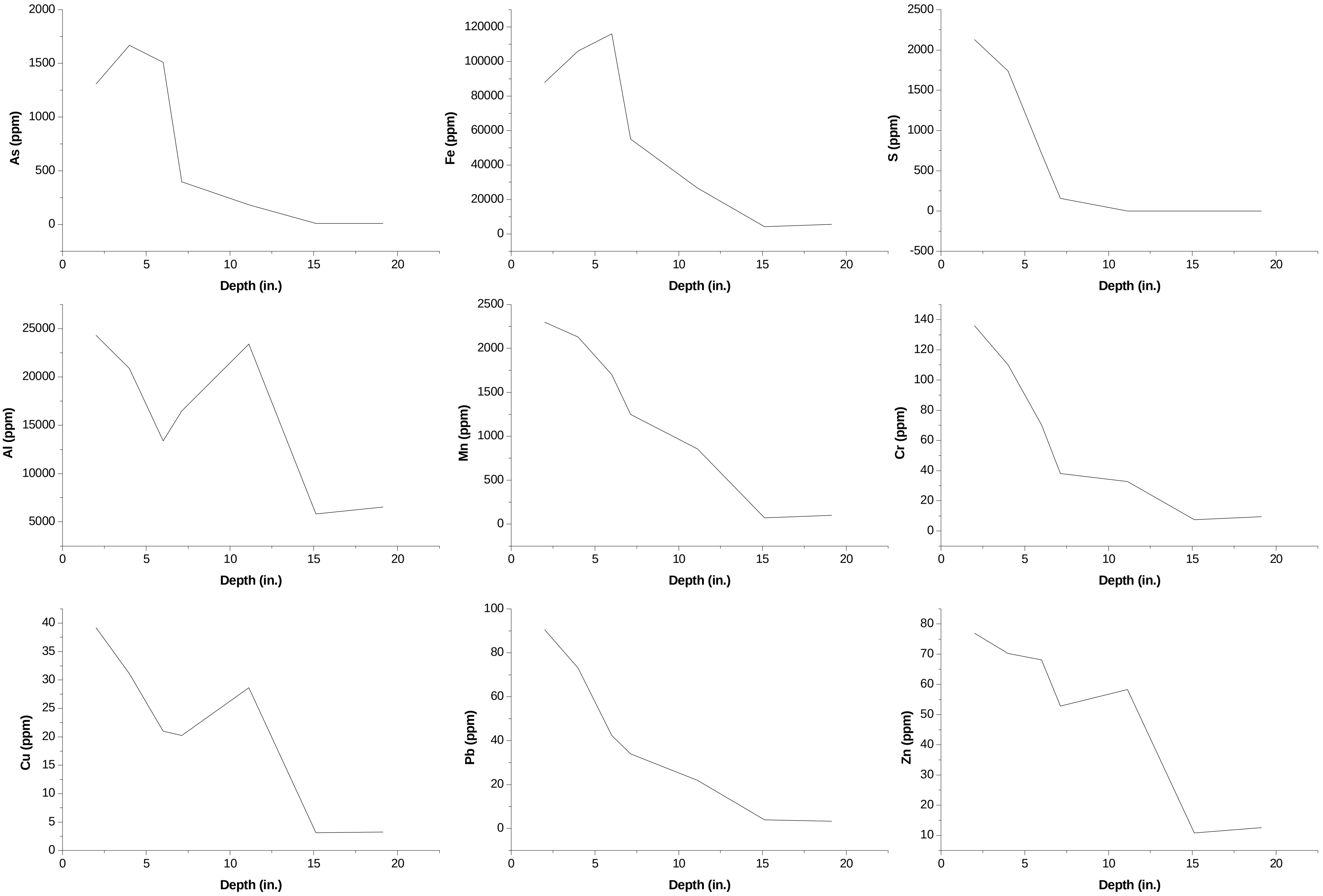

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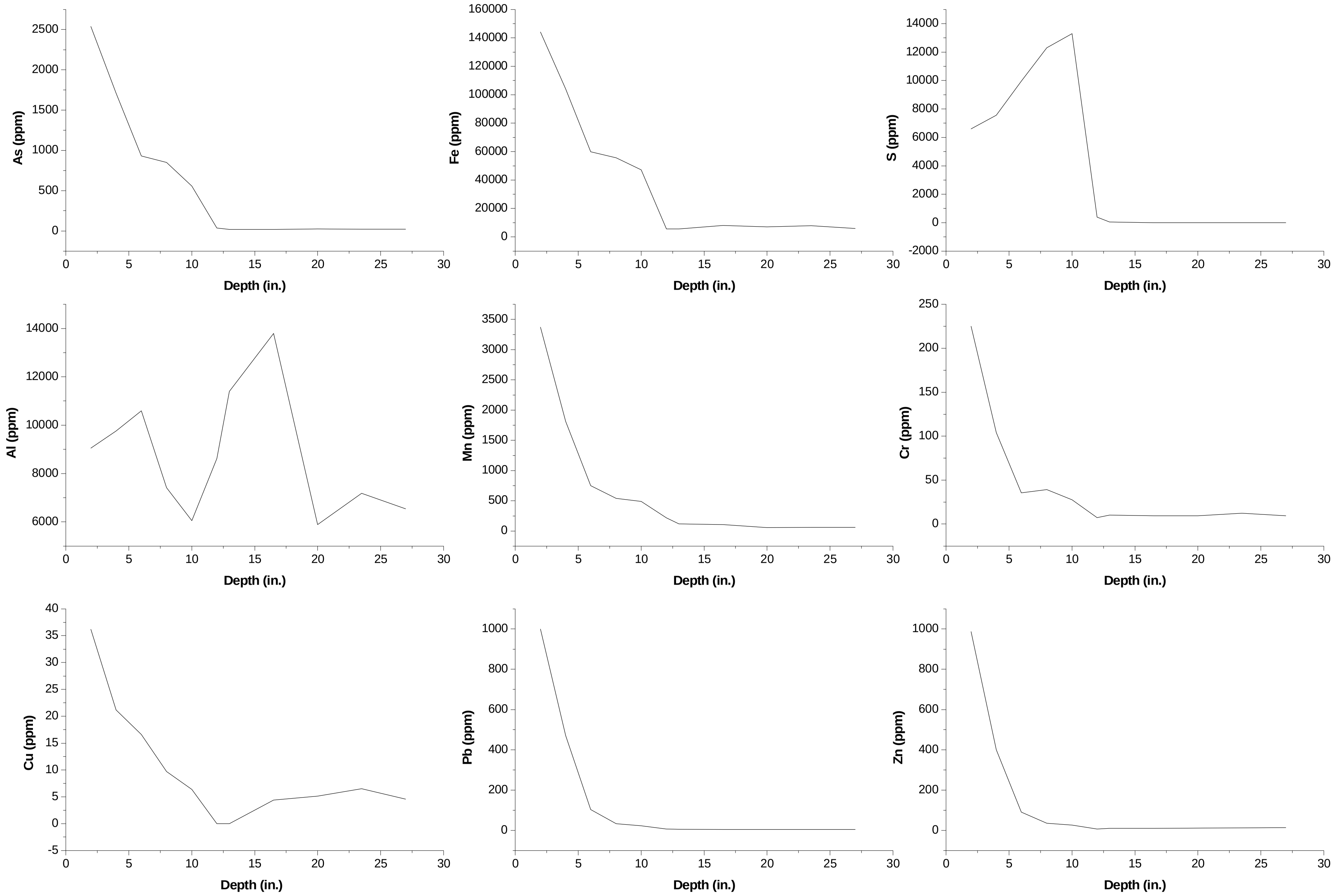

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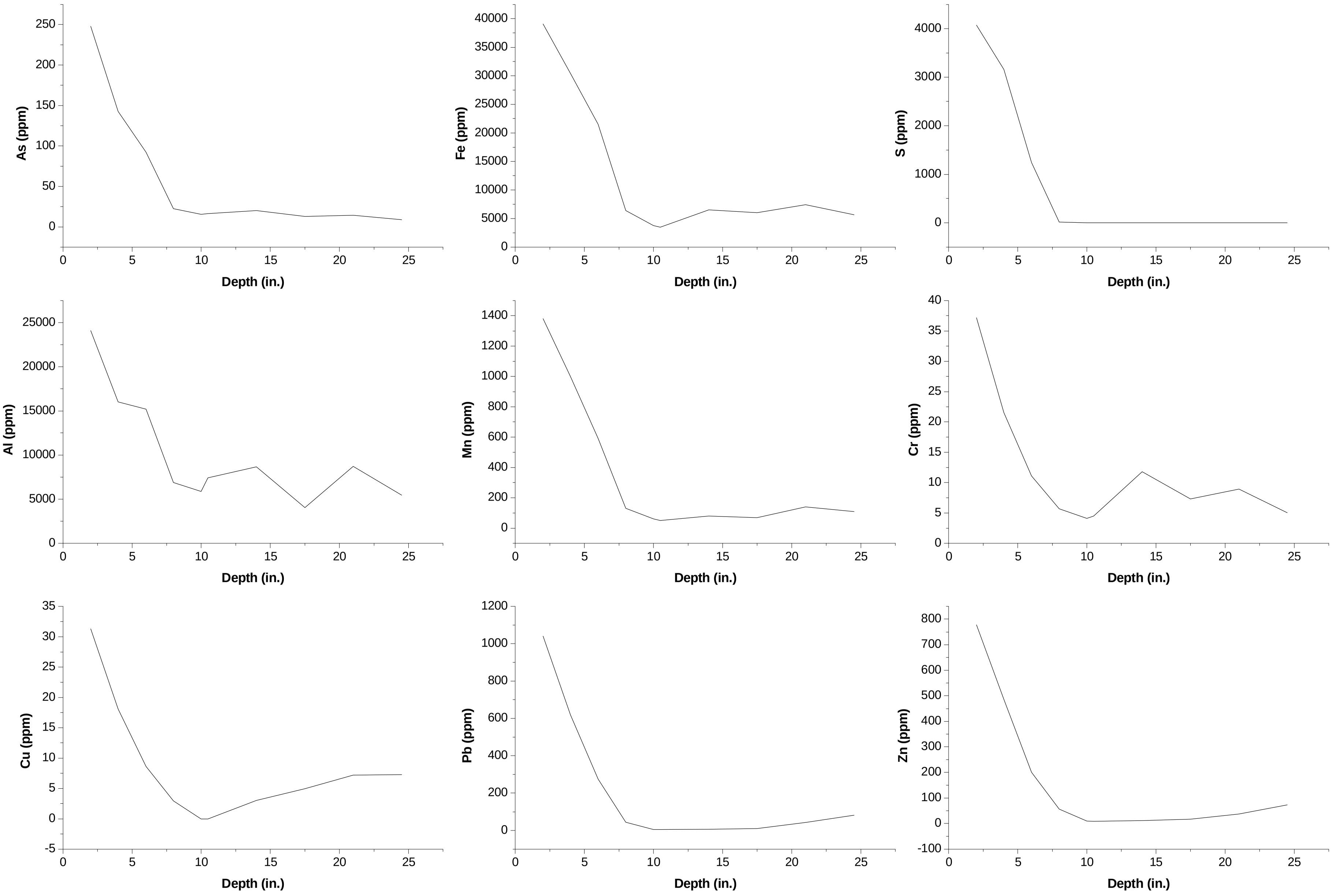

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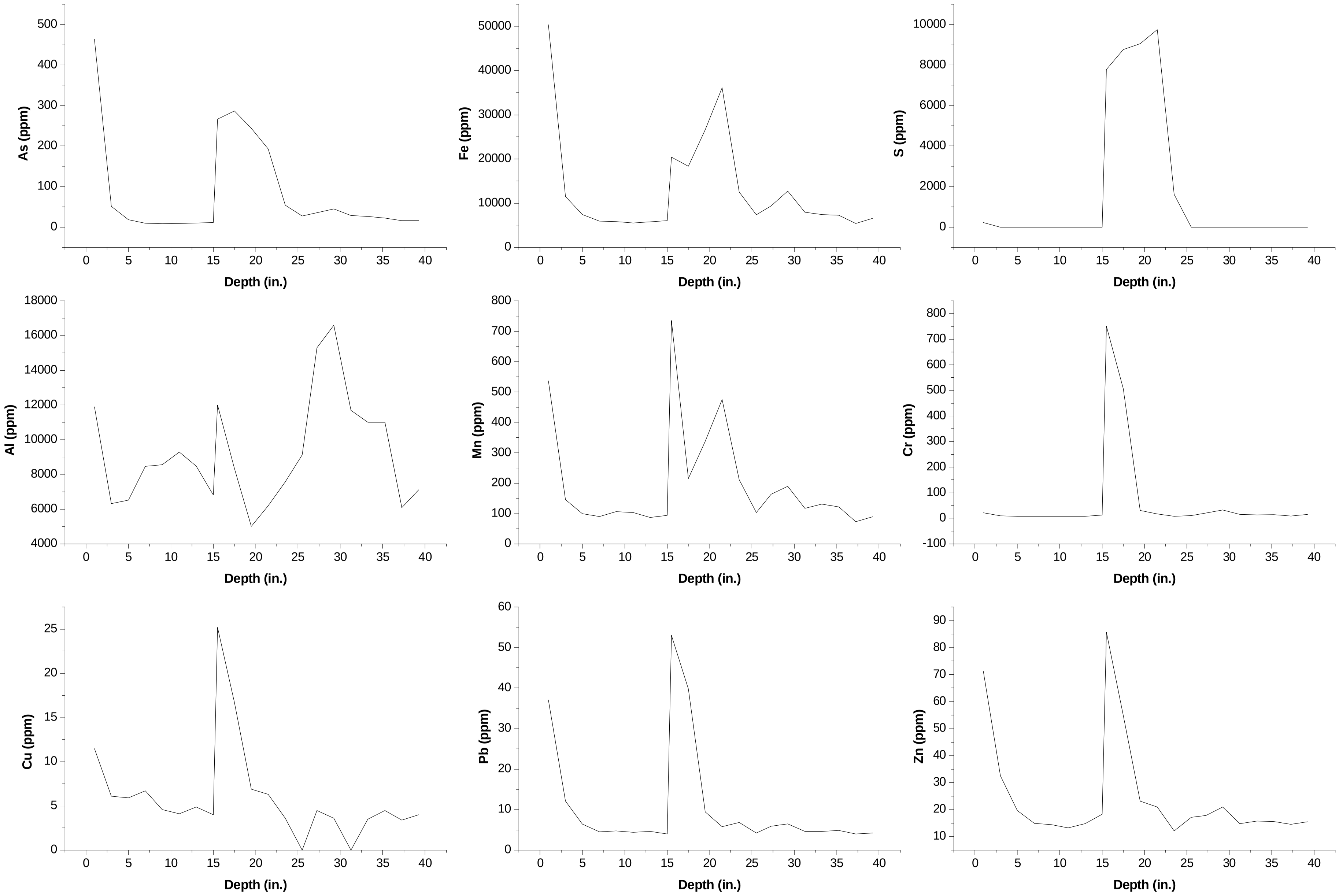

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