

**Devens 2008 Monitoring Update**  
Arsenic Fate, Transport and Stability Study  
Groundwater, Surface Water, Soil and Sediment Investigation  
Fort Devens Superfund Site  
Devens, Massachusetts

Robert G. Ford<sup>1</sup>, Steven Acree<sup>3</sup>, Bob Lien<sup>1</sup>, Kirk G. Scheckel<sup>2</sup>,  
Randall Ross<sup>3</sup>, Todd Luxton<sup>2</sup>, and Patrick Clark<sup>1</sup>  
USEPA National Risk Management Research Laboratory

<sup>1</sup>Land Remediation and Pollution Control Division  
Soils and Sediments Management Branch  
Andrew W. Breidenbach Environmental Research Center  
26 W. Martin Luther King Dr, Cincinnati, OH 45268

<sup>2</sup>Land Remediation and Pollution Control Division  
Waste Management Branch  
Center Hill Research Facility  
5995 Center Hill Ave, Cincinnati, OH 45224

<sup>3</sup>Ground Water and Ecosystems Restoration Division  
Applied Research and Technical Support Branch  
Robert S. Kerr Environmental Research Center  
919 Kerr Research Dr, Ada, OK 74820

Table of Contents	2
List of Figures	3
Notice	4
1 Introduction	5
1.1 Site Background	5
1.2 Scope and Objectives	6
2 Hydrologic Studies	8
2.1 Monitoring Network	8
2.1.1 Groundwater and Surface Water Monitoring Locations	8
2.1.2 Cove Piezometers	9
2.1.3 Sediment Temperature Sensors	9
2.2 Recent Results	9
2.2.1 Groundwater/Surface Water Elevation Data	9
2.2.2 Potentiometric Surface	10
2.2.3 Seepage Measurements	10
2.3 Hydrologic Summary	10
3 Groundwater and Surface Water Chemistry Studies	24
3.1 Monitoring Network	24
3.2 Recent Results	24
3.2.1 Groundwater Chemistry Trends: RSK Wells	25
3.2.2 Groundwater Chemistry Trends: Shepley's Hill Landfill	25
3.2.3 Surface Water Chemistry Trends	26
3.4 Chemistry Summary	26
3.5 References	27
Appendix A. Location Data	30
Appendix B. Summary of field chemistry data for groundwater sampled from RSK and Army wells within Red Cove Study Area and within Shepley's Hill Landfill.	34
Appendix C. Summary of field chemistry data for surface water sampled from within Red Cove adjacent to Shepley's Hill Landfill.	37
Appendix D. Summary of chemistry data for groundwater sampled from RSK wells within Red Cove Study Area adjacent to Shepley's Hill Landfill.	39
Appendix E. Summary of chemistry data for surface water sampled from within Red Cove Study Area adjacent to Shepley's Hill Landfill.	42
Appendix F. Groundwater elevation data used to create potentiometric surfaces.	44

## Figures

Figure 1.	Supplemental monitoring network established near Red Cove.	12
Figure 2.	Approximate locations of the supplemental sediment temperature data loggers deployed within the western portion of Red Cove.	13
Figure 3.	Locations of new piezometers installed on June 12, 2008; all manual flux meter deployments during calendar years 2007-2008; and all surface water locations sampled from a pontoon boat during calendar years 2006-2008	14
Figure 4.	(A) Illustration of vertically nested temperature buttons deployed at piezometer locations PZ13 and PZ14 in Red Cove. (B) Temperature readings for buttons deployed during the period June 12, 2008 to September 12, 2008.	15
Figure 5.	Comparative plot of groundwater elevations at wells RSK7, RSK12, RSK15, RSK19, and RSK37, and surface water elevations in Red Cove at monitoring point STAFF1.	16
Figure 6.	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).	17
Figure 7.	Potentiometric surface at the water table on February 12, 2008, produced using existing shallow wells and enhanced RSK network.	18
Figure 8.	Potentiometric surface at the water table on April 28, 2008, produced using existing shallow wells and enhanced RSK network.	19
Figure 9.	Potentiometric surface at the water table on June 10, 2008, produced using existing shallow wells and enhanced RSK network.	20
Figure 10.	Potentiometric surface at the water table on August 19-21, 2008, and locations of lake-bed piezometers in which hydraulic heads were measured in comparison to the pond level.	21
Figure 11.	Potentiometric surface at the water table on September 15, 2008, and locations of lake-bed piezometers in which hydraulic heads were measured in comparison to the pond level.	22
Figure 12.	Locations, dates and magnitude of water flux ( $\text{ft}^3/\text{day}$ based on flux meter area of $2.47 \text{ ft}^2$ ) measured via manual deployments of the advective flux meter within Red Cove.	23
Figure 13.	Results for dissolved ( $<0.45 \mu\text{m}$ ) $\text{NH}_3\text{-N}$ , $\text{CH}_4$ , K, and Ca for groundwater sampled from RSK cluster wells, RSK water table wells, and SHL wells within the landfill.	28
Figure 14.	Comparison of major ion chemistry in groundwater sampled from screens completed at the water table for RSK well installations.	29

## Notice

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. This report has been subjected to internal Agency review and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

The following individuals are acknowledged for assistance in field sampling and laboratory analyses: Carol Stein and Dave McTigue (Gannett Fleming, Inc.); Mark White, Lynda Callaway, Kristie Hargrove, and Cherri Adair (USEPA/ORD-Ada); Tim Bridges and Dan Granz (USEPA-Region 1 Laboratory) and personnel with Shaw Environmental, Inc. under Contract EP-C-08-034. Ginny Lombardo (RPM), Bill Brandon, and Rick Sugatt (USEPA-Region 1 Boston) provided project guidance and coordination of on-site activities during this investigation. The following individuals are acknowledged for critical and constructive review of this report: Ginny Lombardo and Bill Brandon (USEPA-Region 1), Hui Liang (Massachusetts Department of Environmental Protection), and Scott Jacobs (USEPA/ORD).

## 1 Introduction

This document presents results from site monitoring activities during calendar year 2008 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 work was to provide EPA Region 1 with additional data to evaluate whether site characteristics have varied from conditions documented in the Ford et al. (2008).

### 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 (SHL) encompasses approximately 84 acres in the northeast corner of the former Main Post at Fort Devens (Ford et al., 2008; 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.

In addition, an Explanation of Significant Differences for the Shepley's Hill Landfill, dated April 2005, amended the ROD by implementing the contingency remedy and modifying the contingency remedy to provide for pretreatment of the groundwater prior to discharge to the Devens POTW. The Final 100% Submittal of the RD/RA Workplan (page 3-1, Section 3.0) states that the response objective of the extraction system is to contain the arsenic plume in the vicinity of the base boundary near the north end of the landfill.

## 1.2 Scope and Objectives

This report summarizes hydrologic and chemistry data collected from existing (Ford et al., 2008) and new monitoring locations during calendar year 2008. Activities were directed towards supplementing the dataset presented in Ford et al. (2008) through acquisition of data from the following location categories: 1) locations previously sampled only once during calendar years 2006-2007, 2) existing locations within and adjacent to Shepley's Hill Landfill not previously sampled for full suite water chemistry by EPA/ORD, and 3) new locations within Red Cove.

The monitoring effort was divided between field-based sampling and laboratory-based characterization. Reporting and analysis of data resulting from this effort are presented in the following order: 1) Section 2 – hydrologic studies and 2) Section 3 – groundwater and surface water chemistry. No additional sediment samples were collected during calendar year 2008.

## 2 Hydrologic Studies

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

- Determination of groundwater flow rates and directions within the unconsolidated overburden in the Red Cove area of Plow Shop Pond,
- Estimation of groundwater and arsenic flux rates in the overburden, and
- Evaluation of the spatial and temporal nature of groundwater/surface water interactions within the study area.

The initial results of the ongoing investigations were reported in Ford et al. (2008) using hydrologic data available through October 2007. Since then, monitoring of the hydrologic system has continued to provide a broader and more representative basis for remedial decisions. Data and results from these ongoing studies are discussed below.

### 2.1 Monitoring Network

As noted in Ford et al. (2008), approximately forty monitoring wells and a surface water measurement (staff) gauge were installed in the vicinity of Red Cove (Figure 1) to estimate groundwater flow rates and directions. Initially, twenty-one wells were installed in four clusters surrounding Red Cove in September 2005 using a Geoprobe 6600 rig. 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. Well clusters RSK1-7, RSK8-12, RSK13-15, RSK16-19, and RSK36-43 were designed and installed to provide complete vertical coverage of the unconsolidated deposits from the depth of drilling refusal to the water table at each well cluster location. None of the wells penetrated bedrock. Based on the available logs from nearby wells N2, N3, SHL-4, unconsolidated deposits in this area are predominantly composed of fine to coarse sand with varying fractions of coarser and finer-grained materials. The saturated thickness of the unconsolidated deposits adjacent to Red Cove varies primarily as a function of bedrock elevation but is estimated to range from approximately 15 ft to 30 ft based on the depth of drilling refusal at wells RSK1, RSK8, RSK13, RSK16, and RSK41. Construction details for the RSK well network are provided in Appendix A.

Fourteen piezometers have been installed in Plow Shop Pond to allow comparison of hydraulic head within the sediments with that of the pond. Construction details for the piezometer network are provided in Appendix A. 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 was used to measure the magnitude and direction of water movement across the sediment/water interface at select locations in Red Cove.

#### *2.1.1 Groundwater and Surface Water Monitoring Locations*

The supplemental monitoring network adjacent to Red Cove remains as reported in Ford et al. (2008). No additional wells were installed in 2008.



### *2.1.2 Cove Piezometers*

During 2008, two additional piezometers were installed in Red Cove in support of studies using the advective flux meter. The locations of new piezometers PZ13 and PZ14 are shown in Figure 3 with reference to all piezometer, advective flux meter, and surface water sampling locations within Red Cove.

### *2.1.3 Sediment Temperature Sensors*

An additional transect of sediment temperature sensors (Figure 2) has been deployed in the western portion of Red Cove to better define the variability in potential locations of groundwater discharge. Results from these sensors will be available in calendar year 2009. Vertically nested deployments of temperature sensors were installed at new piezometer locations PZ13 and PZ14 to further explore the use of sediment temperature to map out groundwater discharge to the cove. A schematic of the deployment configuration is shown in Figure 4A. One temperature sensor was suspended within the water column approximately 3 feet above the sediment surface. The remaining temperature sensors were deployed on the sediment surface, 1 foot below the sediment surface, and 2 feet below the sediment surface. Continuous temperature readings logged during the period June 12, 2008 to September 12, 2008 are shown in Figure 4B. Paired results for common depths at both locations are plotted to better illustrate differences in temperature between the two monitoring locations within Red Cove. In general, temperature fluctuations are more variable in surface water, likely due to diurnal variations in surface temperatures. This variability decreases with depth relative to the sediment surface. In addition, temperatures at a depth of 2 feet below the sediment surface were generally colder at location PZ14 (near PZ5), which is a known location for plume discharge within Red Cove (see Ford et al., 2008).

## 2.2 Recent Results

As noted in Ford et al. (2008), the most significant influences on groundwater flow rates and directions within the overburden near Red Cove appear to be precipitation and surface water elevation in Plow Shop Pond. During 2008, 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 every four hours using pressure transducers/data loggers. These data and the results of periodic groundwater elevation measurements performed using a water level indicator were used to evaluate changes in water table elevations and the potentiometric surface in the vicinity of Red Cove. It is noted that the staff gauge (STAFF1) used to measure surface water levels in Red Cove was damaged during the winter of 2008 by beaver activity and was out of commission between February 2 and May 1, 2008.

### *2.2.1 Groundwater/Surface Water Elevation Data*

As noted in Ford et al. (2008), pond stage and groundwater elevations in wells adjacent to Red Cove are highly correlated. Between November 2007 and August 2008, pond stage ranged from approximately 217 ft AMSL to 218.4 ft AMSL (Figure 5). The temporal trends in groundwater elevations during this period were similar to those observed in the surface water elevations.

A comparison of the temporal fluctuations in hydraulic head differences between groundwater elevations measured in the water-table wells surrounding Red Cove and surface water elevations (Figure 6) demonstrates that groundwater flow directions were generally toward Red Cove, indicating that groundwater discharge to the pond continued to occur in this area. As indicated

by the negative values in Figure 6, the hydraulic gradient reversed for brief periods near wells RSK 37 and, to a lesser extent, RSK19 during the fall and winter when pond stage was relatively high and rapid stage changes occurred.

### *2.2.2 Potentiometric Surface*

Groundwater elevations were measured in selected wells on February 12, April 28, June 10, August 19-21, and September 15, 2008. These data were used to estimate the potentiometric surface at the water table on each date (Figures 7, 8, 9, 10, and 11). Potentiometric surfaces focusing on groundwater flow adjacent to Red Cove (Figures 7, 8, and 11) are contoured using a contour interval of 0.5 ft. Site-wide potentiometric surfaces (Figures 9 and 10) are contoured using a contour interval of 1.0 ft to improve clarity.

At the site-wide scale, shallow groundwater appears to flow in a generally south to north direction (Figures 10 and 11). In each case, the potentiometric surface indicates overburden groundwater continues to discharge to Plow Shop Pond in the vicinity of Red Cove. Groundwater elevation data used to create the potentiometric surfaces are provided in Appendix F.

### *2.2.3 Seepage Measurements*

A sensitive bidirectional advective flux meter (Lien, 2006) was used to directly measure the velocity and direction of water movement across the sediment/water interface in Red Cove. The tool was deployed at five new locations during calendar year 2008 in order to provide greater coverage relative to measurements of sediment temperature and hydraulic gradients for piezometers installed in Red Cove (Figures 3 and 12). The magnitude and direction of advective flux measured in the western and central portions of Red Cove were consistent with historical measurements during calendar year 2007 (see Ford et al., 2008). At a location near piezometer PZ6, the magnitude and direction of flux was similar to observed flux near piezometer location PZ5. Within the northern portion of Red Cove displaying upward advective flux, the magnitude of groundwater discharge was generally less than other portions of Red Cove. For a location adjacent to piezometer PZ13, recharge from surface water into the underlying aquifer was observed on August 21, 2008. This monitoring location is positioned within the portion of the aquifer where groundwater hydraulic gradients transition from a potential for surface water discharge to aquifer recharge adjacent to Plow Shop Pond (see Figures 10 and 11).

## 2.3 Hydrologic Summary

As noted in Ford et al. (2008), groundwater is discharging to Red Cove under most conditions. Additional seepage measurements conducted during 2008 support this general observation, as well as aquifer potentiometric data that identify the transition from an area of discharge to recharge starting near the northeastern corner of Red Cove and extending north along the western shore of Plow Shop Pond. Limited, continuous monitoring of surface water and sediment temperature in locations that represent the observed range in groundwater flux to Red Cove support the notion of using sediment temperature to map out patterns in groundwater discharge for the cove as a whole.

Investigations currently underway will provide continuous groundwater elevation data obtained using pressure transducers/data loggers from a broader range of monitoring wells within the RSK

well network. Groundwater elevations in approximately twenty wells are being monitored using these loggers. This effort should allow for a more detailed interpretation of the spatial and temporal variations in hydraulic gradients surrounding Red Cove. No new well installations are being proposed at this time. In addition, sediment temperature data from a transect of sensors deployed in the western-most portion of Red Cove will be available in 2009 and may enhance our understanding of the spatial variability of groundwater discharge to Red Cove.

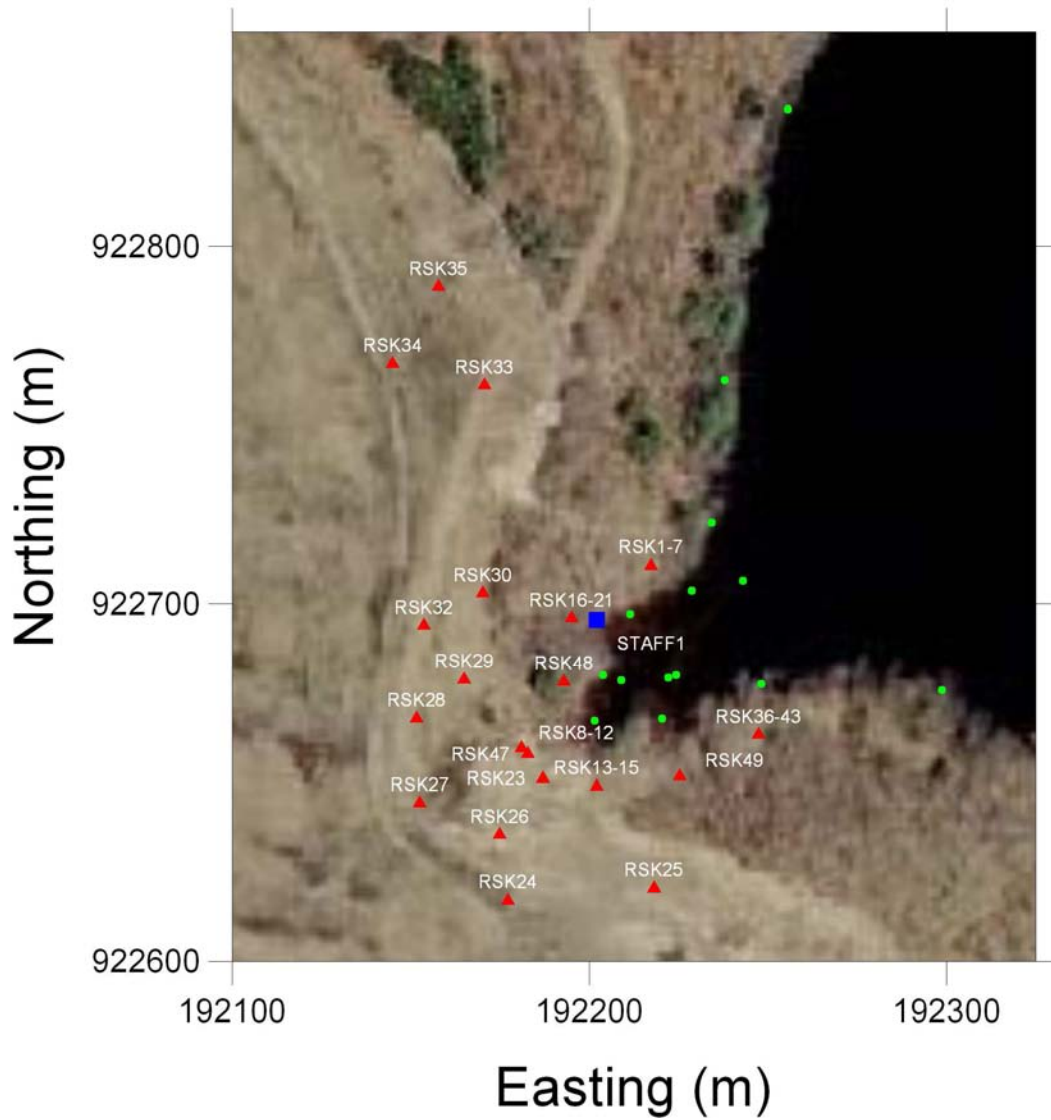


Figure 1. Supplemental monitoring network established near Red Cove. Red triangles mark groundwater well locations. Green dots are the locations of piezometers within the cove. The blue square marks the location of the Red Cove staff gauge (STAFF1).

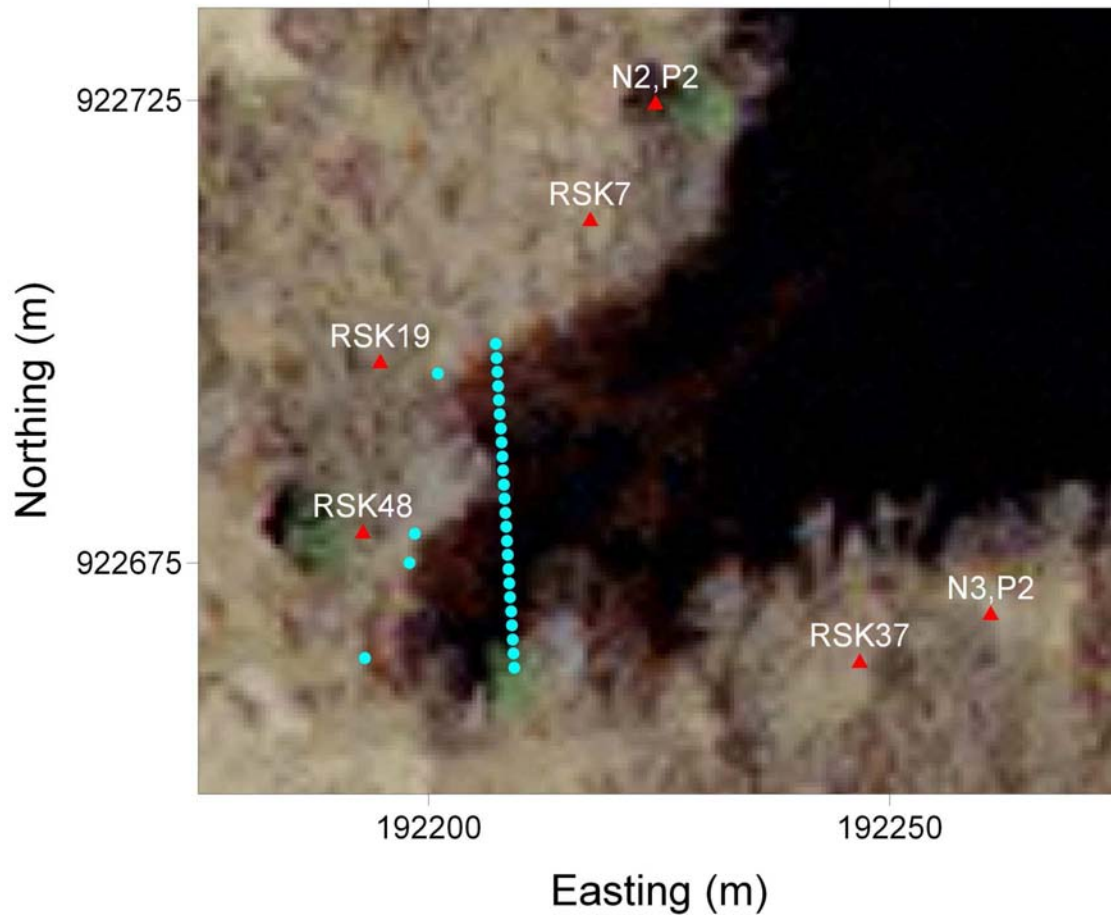


Figure 2. Approximate locations (blue dots) of the supplemental sediment temperature data loggers deployed within the western portion of Red Cove. Nearby wells (red triangles) are depicted for reference.

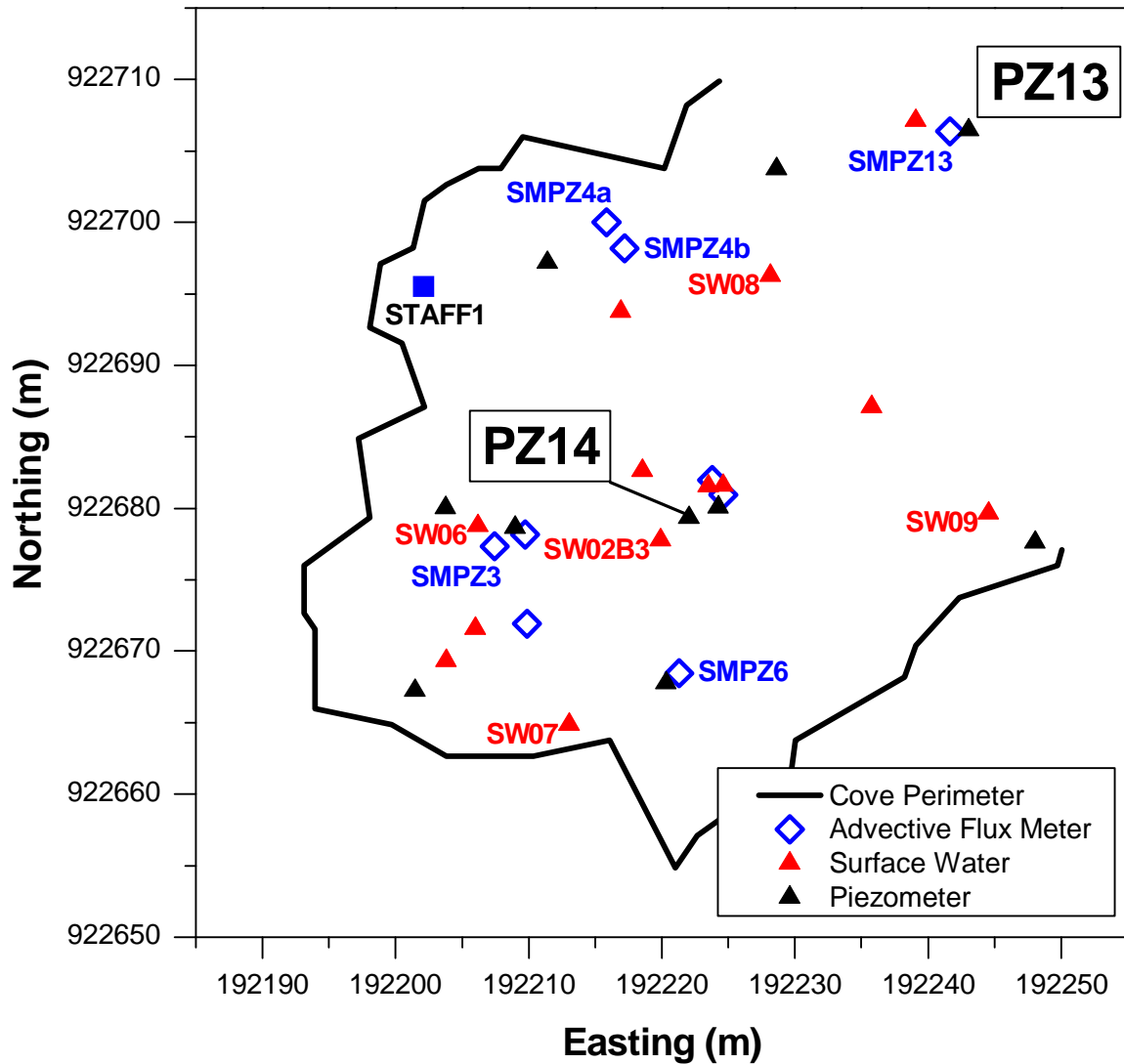


Figure 3. Locations of new piezometers (PZ13 and PZ14) installed on June 12, 2008; all manual flux meter deployments (blue diamonds) during calendar years 2007-2008; and all surface water locations (red triangles) sampled from a pontoon boat during calendar years 2006-2008 (see Ford et al., 2008 and Appendix A). New surface water and flux meter locations for 2008 are labeled.

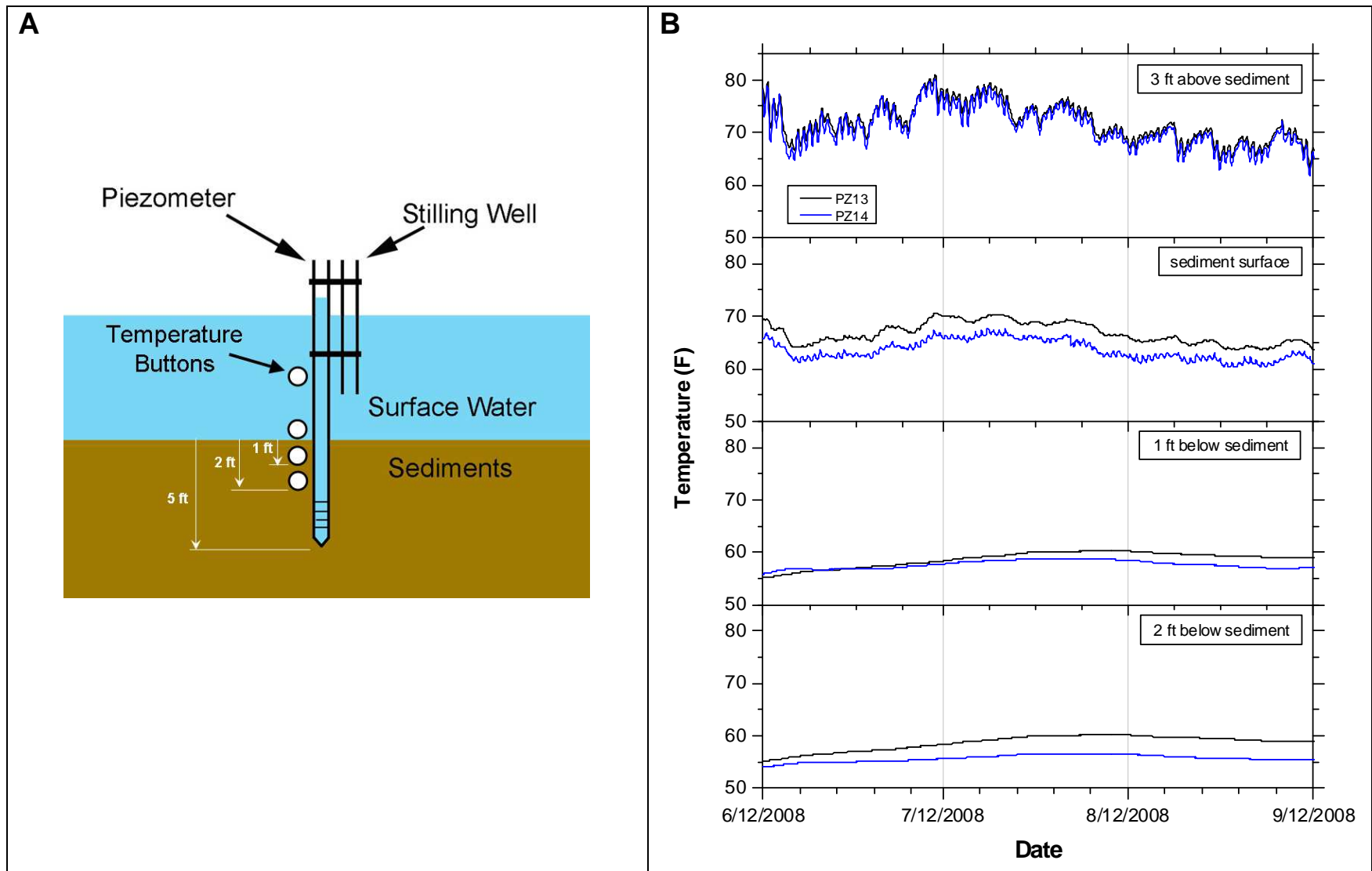


Figure 4. (A) Illustration of vertically nested temperature buttons deployed at piezometer locations PZ13 and PZ14 in Red Cove (locations in Figure 3). (B) Temperature readings for buttons deployed during the period June 12, 2008 to September 12, 2008.

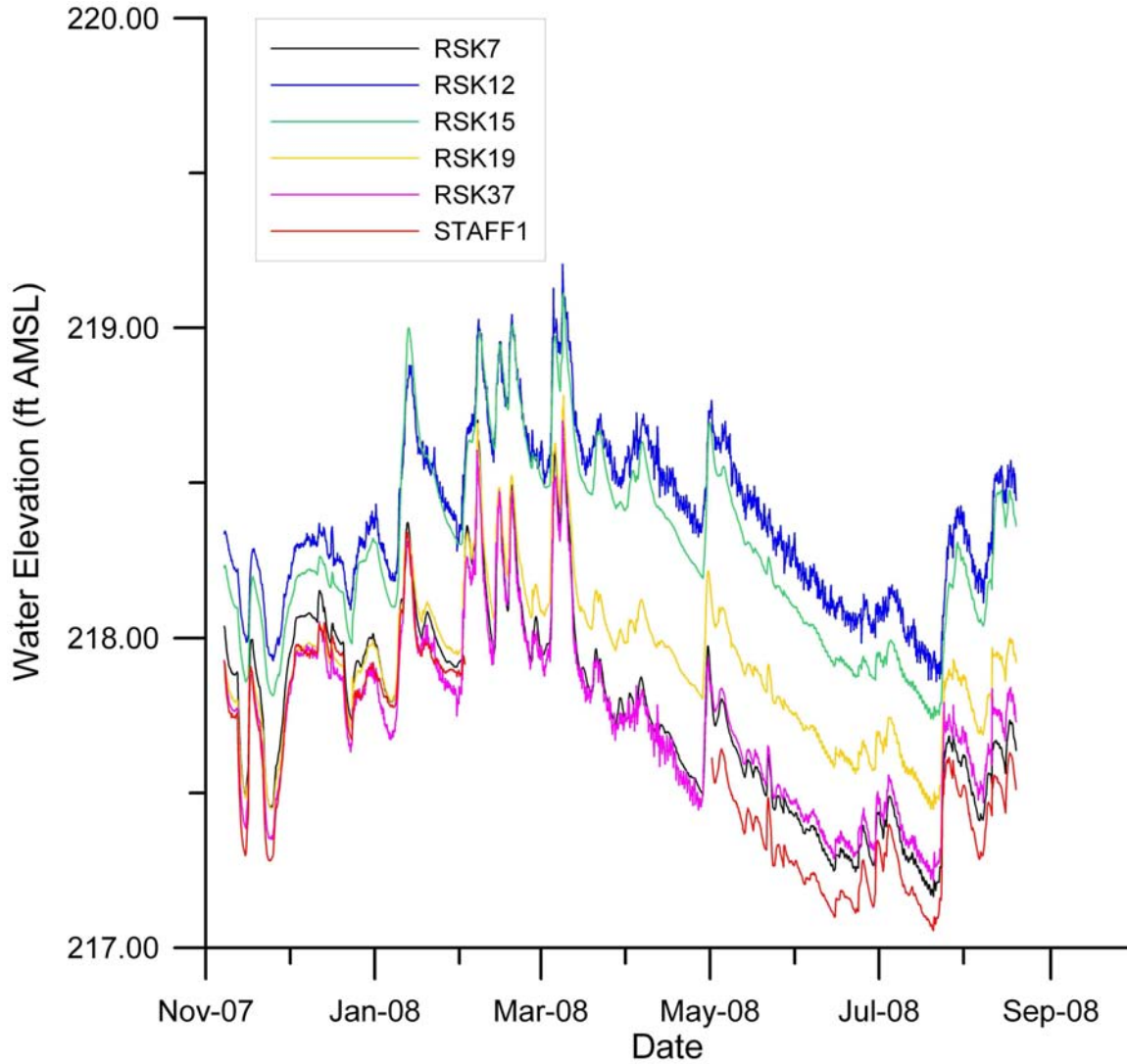


Figure 5. Comparative plot of groundwater elevations at wells RSK7, RSK12, RSK15, RSK19, and RSK37, and surface water elevations in Red Cove at monitoring point STAFF1.



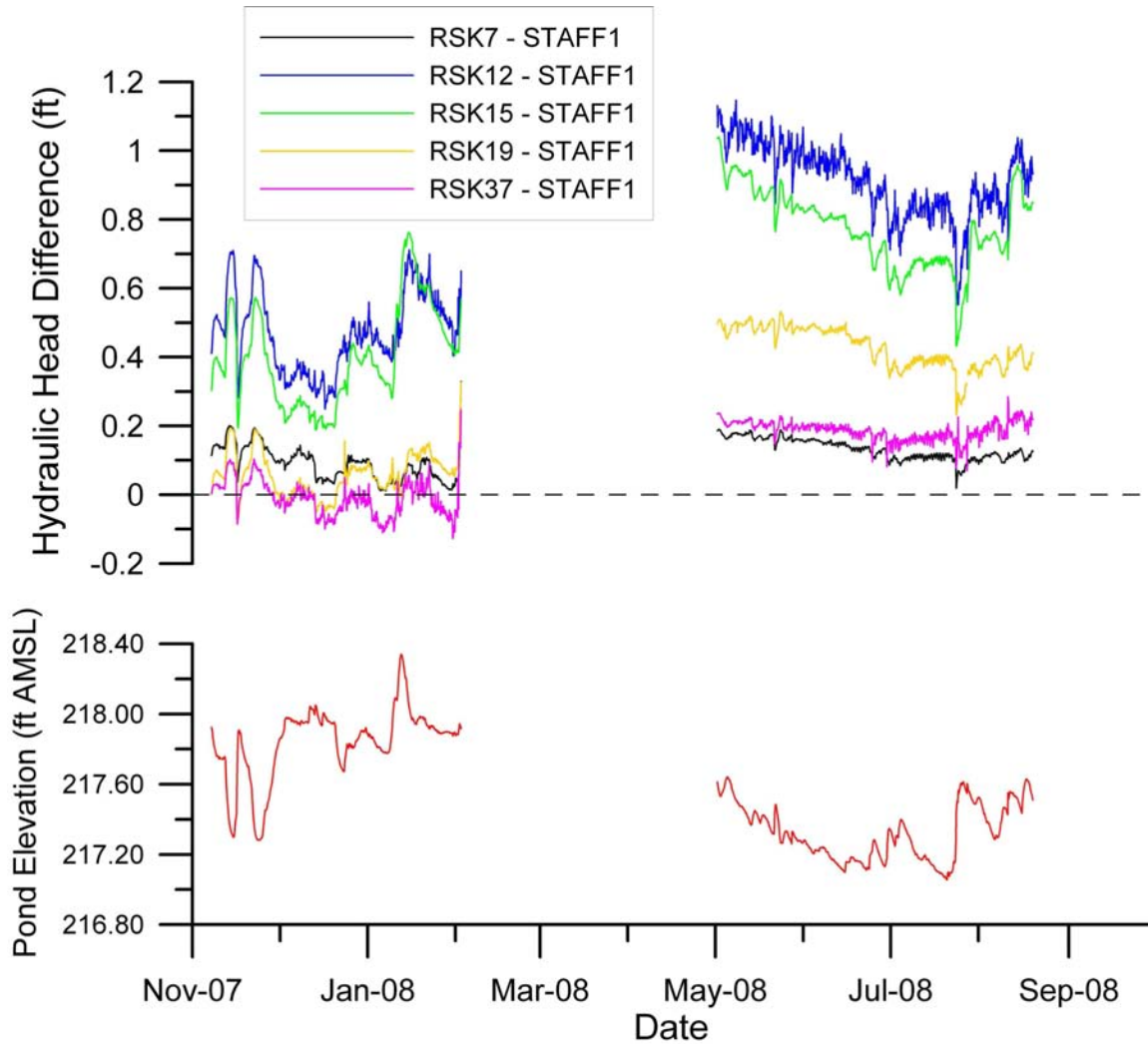


Figure 6. Hydraulic head differences between wells screened at the water table immediately adjacent to Red Cove and surface water elevations measured at STAFF1 compared with pond stage (STAFF1). The hydraulic head differences are calculated as groundwater elevation minus surface water elevation. Positive 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.*, water moves from Red Cove into the aquifer).

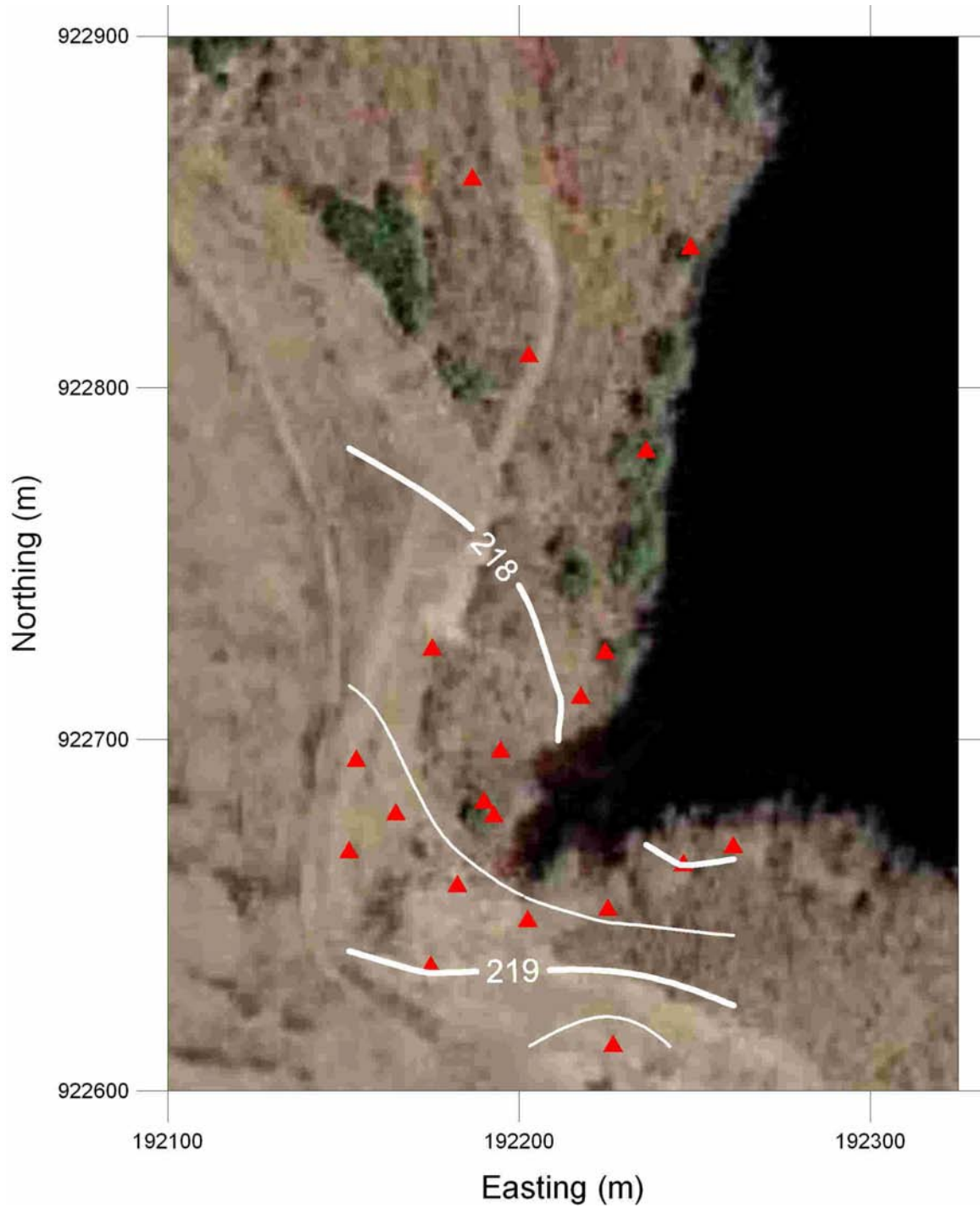


Figure 7. Potentiometric surface at the water table on February 12, 2008. Locations of monitoring points used to produce the potentiometric surface are depicted by red triangles. Well names were omitted to improve figure clarity. Groundwater elevation contours are depicted in units of feet with a contour interval of 0.5 ft.

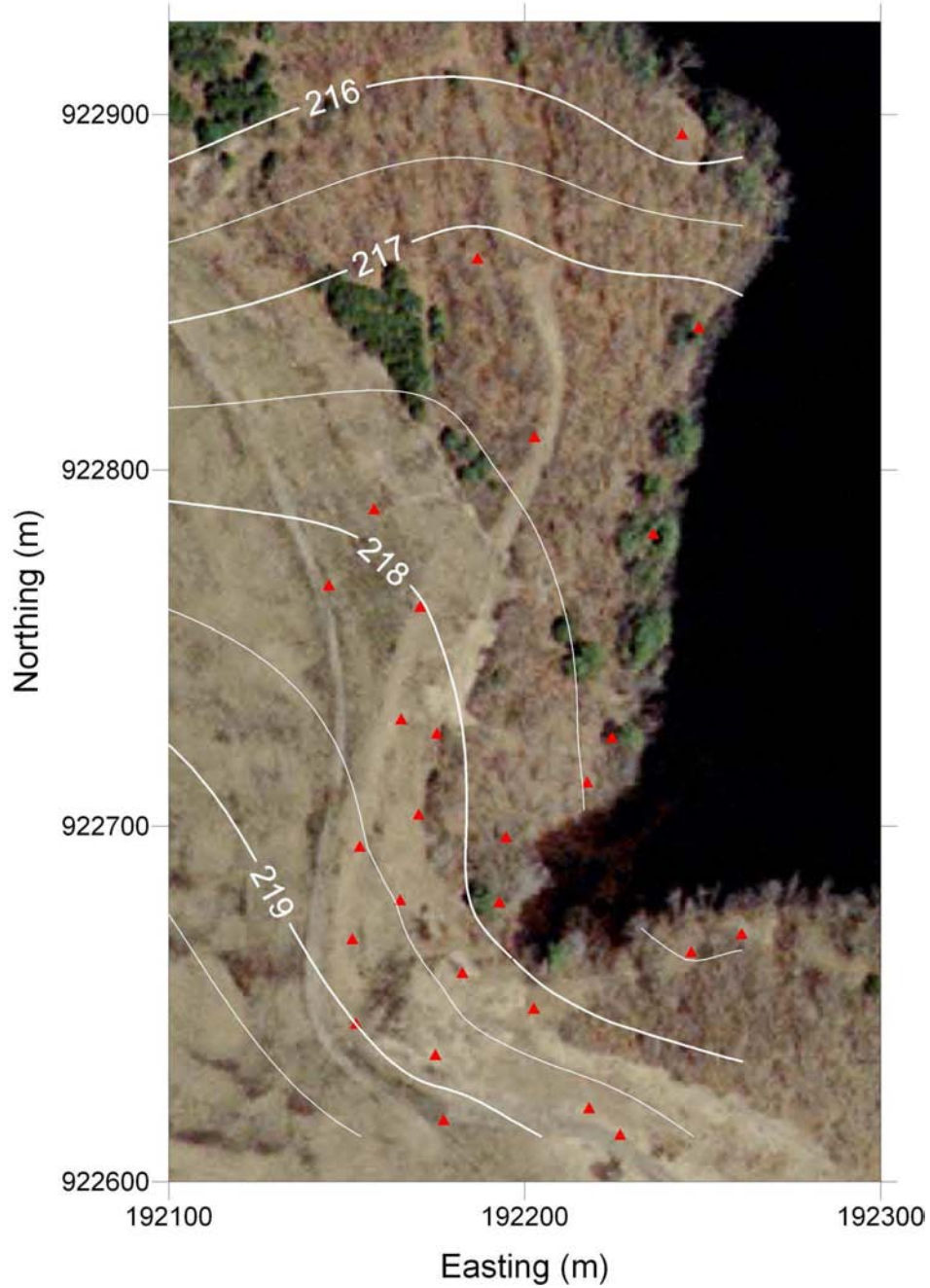


Figure 8. Potentiometric surface at the water table on April 28, 2008. Locations of monitoring points used to produce the potentiometric surface are depicted by red triangles. Well names were omitted to improve figure clarity. Groundwater elevation contours are depicted in units of feet with a contour interval of 0.5 ft.

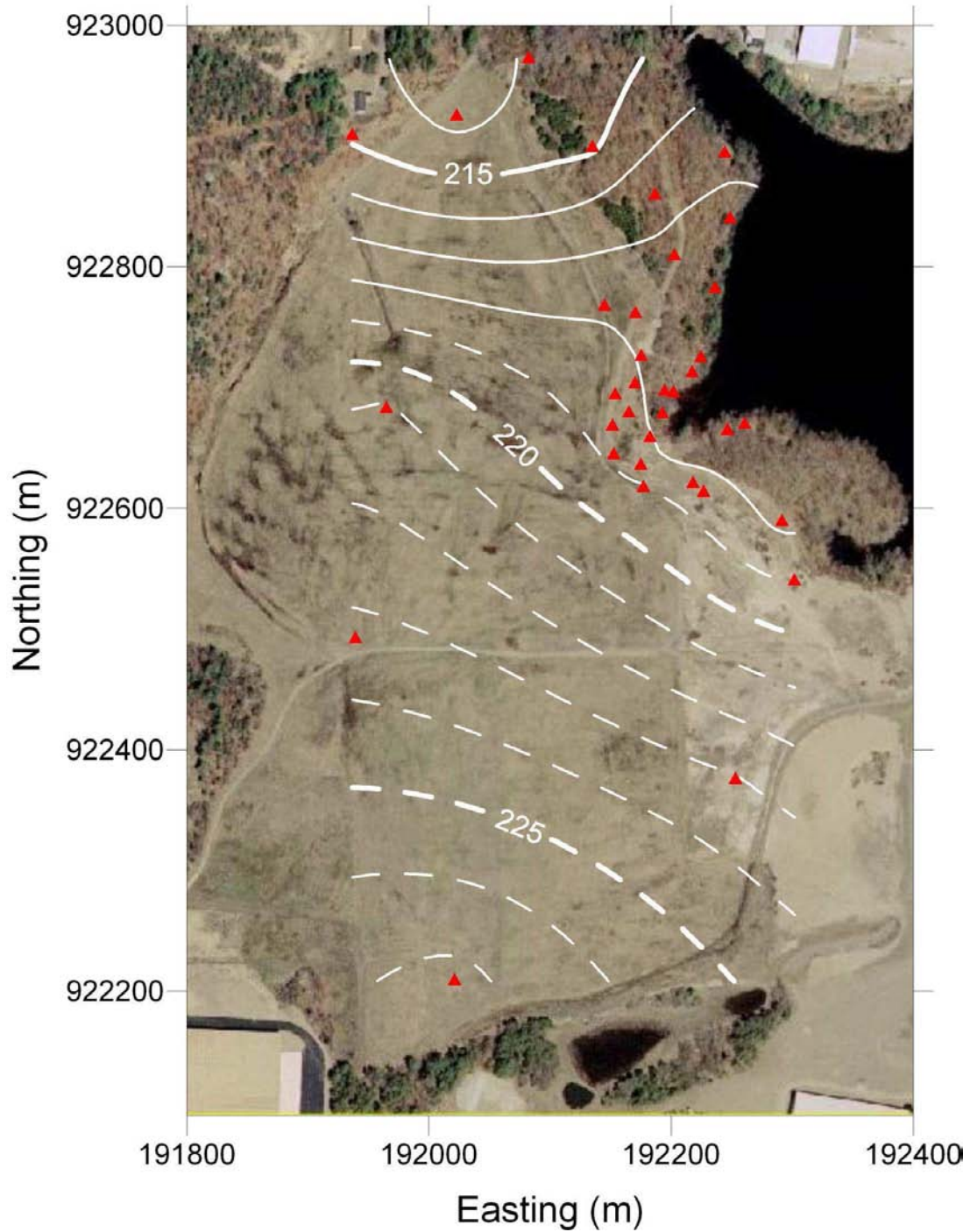


Figure 9. Potentiometric surface at the water table on June 10, 2008. Locations of monitoring points used to produce the potentiometric surface are depicted by red triangles. Well names were omitted to improve figure clarity. Groundwater elevation contours are depicted in units of feet with a contour interval of 1 ft; dashed lines indicate a region of the aquifer with less hydraulic control under the existing monitoring network.

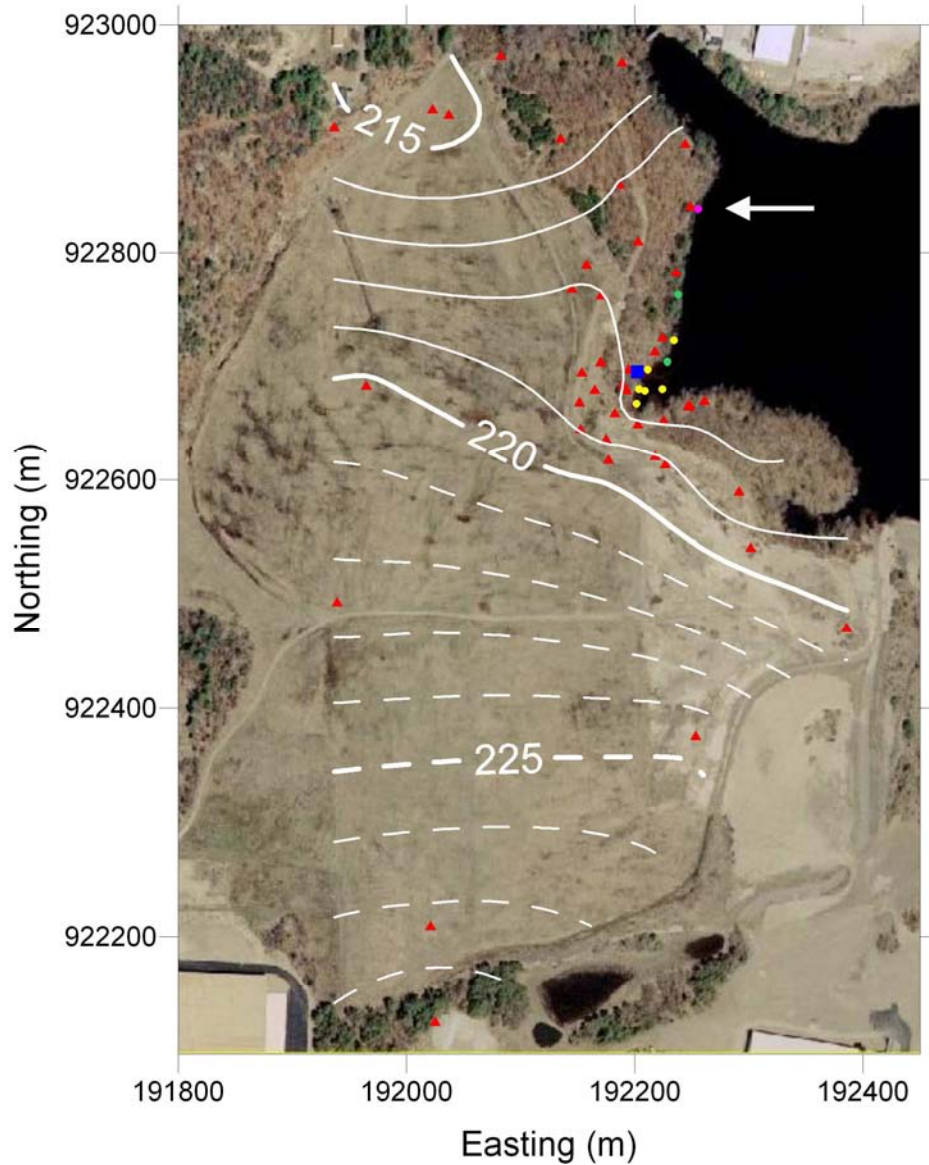


Figure 10. Potentiometric surface at the water table on August 19-21, 2008, and locations of lake-bed piezometers in which hydraulic heads were measured in comparison to the pond level. Yellow dots indicate piezometer locations at which the potential direction of flow was from the sediments to the surface water. The magenta dot (highlighted by arrow) is the only location 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 omitted to improve figure clarity. Groundwater elevation contours are depicted in units of feet with a contour interval of 1 ft; dashed lines indicate a region of the aquifer with less hydraulic control under the existing monitoring network.

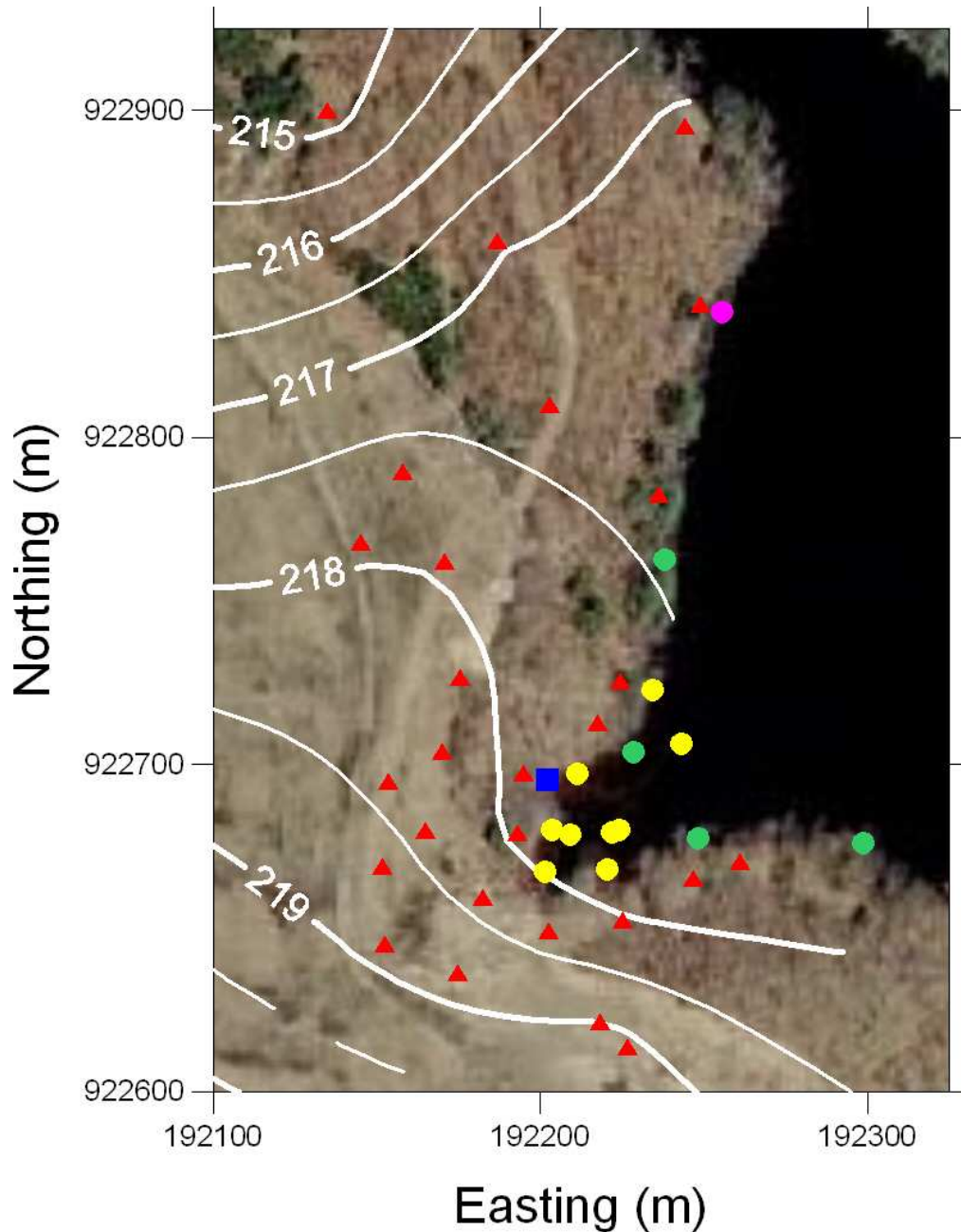


Figure 11. Potentiometric surface at the water table on September 15, 2008, and locations of lake-bed piezometers in which hydraulic heads were measured in comparison to the pond level. Yellow dots indicate piezometer locations at which the potential direction of flow was from the sediments to the surface water. The magenta dot is the only location 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 omitted to improve figure clarity. Groundwater elevation contours are depicted in units of feet with a contour interval of 0.5 ft.

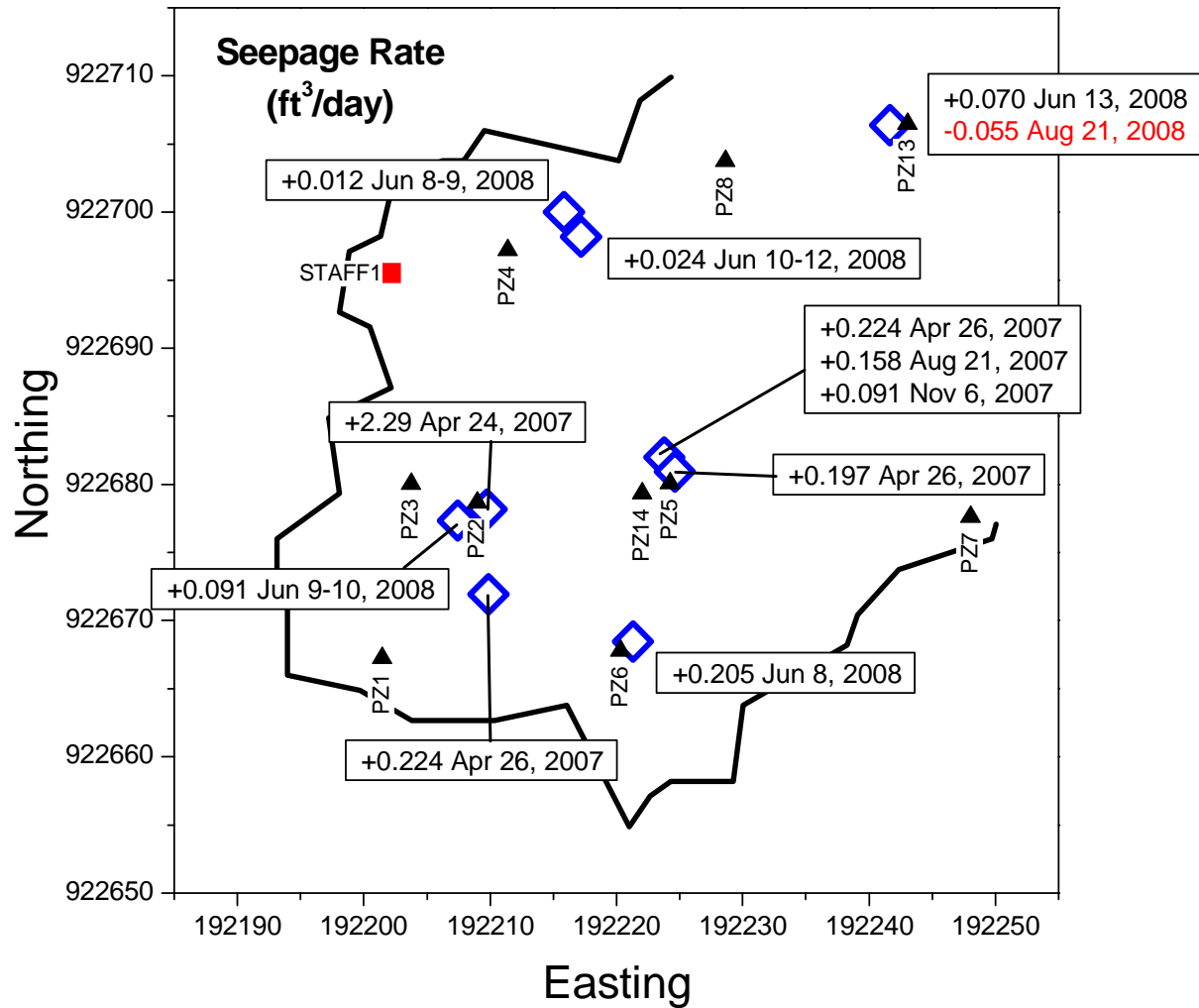


Figure 12. Locations, dates and magnitude of water flux (ft<sup>3</sup>/day based on flux meter area of 2.47 ft<sup>2</sup>) measured via manual deployments of the advective flux meter within Red Cove; positive values correspond to an upward flux (groundwater discharge to surface water) and the negative value corresponds to a downward flux (surface water recharge to underlying aquifer).

### 3 Groundwater and Surface Water Chemistry Studies

The objectives of the groundwater and surface water 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. Monitoring activities during calendar year 2008 included 1) sampling from existing RSK and SHL wells that had not been sampled for a complete suite of water chemistry measurements by EPA/ORD during 2005-2007, 2) sampling at select screens at well cluster RSK36-43 to confirm vertical chemistry trend, and 3) sampling at additional locations in Red Cove to provide additional coverage for water chemistry in shallow and deep surface water.

#### 3.1 Monitoring Network

Additional sampling was conducted at the following locations to more fully map arsenic concentrations at the water table between the eastern edge of Shepley's Hill Landfill and the RSK well clusters adjacent to Red Cove (see Figure 1): RSK25, RSK26, RSK27, RSK28, RSK29, RSK30, and RSK32. The following well screens within the RSK36-43 cluster were sampled to confirm previously observed vertical distribution in groundwater chemistry: RSK37, RSK39, and RSK41. Finally, the following wells within Shepley's Hill Landfill were sampled as a supplement to existing historical data (see Figure 74A in Ford et al., 2008): N6-P1, SHP-99-35X, N5-P1, and N5-P2. (It should be noted that sampling of SHL wells N5-P1, N5-P2, SHP-99-29X, SHM-96-22B, and SHM-93-22C by EPA/ORD personnel on 13 September 2007 was conducted only for collection of samples for determination of dissolved methane.)

Sampling for RSK wells and landfill wells N5-P1 and N5-P2 was conducted using a peristaltic pump according to methods employed in Ford et al. (2008). Due to the depth to water in landfill wells N6-P1 and SHP-99-35X, down-hole sampling devices were needed to recover water. For location N6-P1, a manual Waterra inertial pump with foot valve was used to purge the screened interval. With this equipment, it was possible to provide a continuous flow of groundwater routed through an enclosed YSI sonde for monitoring water quality. For location SHP-99-35X, insufficient water within the well screen and low recharge prevented use of the Waterra inertial pump. A 12V submersible pump was used at this location to fill the sample tubing, which was subsequently retrieved from the well casing and emptied into a bucket for sampling and water quality measurements. This sampling approach was repeated on the subsequent day, with sampling dates and times noted in the appendices.

Sampling of surface water was conducted at several additional locations to map out differences in water chemistry between shallow and deep surface water for areas within Red Cove that had not previously been sampled (see Figure 3). Water quality measurements were conducted at all locations (SW02B3, SW06, SW07, SW08, SW09), but filtered (0.45  $\mu\text{m}$ ) water samples for laboratory analyses were only collected from locations SW02B3, SW06, and SW07.

#### 3.2 Recent Results

As noted in Ford et al. (2008), the primary flux of arsenic discharging into Red Cove was located between well clusters RSK13-15 and RSK1-7. In addition, arsenic concentrations in deep



surface water were highest near sampling locations MC and SW02B, corresponding to an identified location of arsenic plume discharge. During 2008, RSK water table wells closer to the eastern edge of SHL were sampled to provide additional information on the location and dimensions of the arsenic plume discharging into Red Cove. Also, additional surface water locations were sampled to provide more complete coverage for water chemistry in Red Cove.

### *3.2.1 Groundwater Chemistry Trends: RSK Wells*

Groundwater chemistry data for water table wells located between the eastern edge of Shepley's Hill Landfill and previously sampled RSK well clusters adjacent to Red Cove are provided in the appendices (Tables B.1 and D.1). Arsenic concentrations were generally greater at wells RSK30, RSK32, RSK29, RSK28 and RSK27 compared to wells RSK26 and RSK25 (see Figure 1 for locations). The distribution of arsenic across these wells generally aligns with the highest arsenic flux calculated for potential flow paths to Red Cove (see Figure 72 in Ford et al., 2008). Arsenic concentrations observed at RSK26 and RSK25 are consistent with those previously observed near the water table at well clusters RSK13-15 and RSK36-43.

The vertical trend in water chemistry, including arsenic concentration, for screens sampled at the RSK36-43 well cluster is consistent with data presented in Ford et al. (2008). As previously observed, arsenic concentrations are low within the shallow portion of the saturated aquifer (RSK37) and increase significantly at depth (RSK41). There appears to have been no significant change to the water chemistry in this portion of the aquifer.

### *3.2.2 Groundwater Chemistry Trends: Shepley's Hill Landfill*

Groundwater chemistry data for wells N6-P1, SHP-99-35X, N5-P1 and N5-P2 located within Shepley's Hill Landfill are provided in the appendices (Tables B.2 and D.2). Time series sampling was conducted during well purging at these locations to determine whether steady-state conditions could be achieved with the volume typically purged from the well casing during sampling. In addition to water quality measurements to establish achievement of chemical stability, water samples were periodically sampled for laboratory analyses. Wells N6-P1 and N5-P2 appear to achieve chemical stabilization within the typical time (and volume) for well purging previously employed at these locations. While large changes were observed for concentrations of dissolved As and Fe at well screen N5-P1, the relative percent change was at or below about 15% by the final sampling event. It should be noted that stabilization at N5-P1 was achieved after purging at least 23 liters (~6 gallons) of groundwater. Due to the difficulty in retrieving water from well SHP-99-35X, it is uncertain whether water samples are representative of groundwater chemistry in this portion of the aquifer. As in 2007, methane concentrations in groundwater sampled from well N5-P2 are highest, consistent with a screened interval that intercepts landfill waste.

Results for ammonia and methane data for sampled SHL and RSK wells are plotted in Figure 13. As a point of reference, ammonia data for RSK well clusters are plotted in Figure 13A as a function of potassium concentration for years 2005-2008. New data from RSK well screens completed at the water table, located between the eastern edge of Shepley's Hill Landfill and RSK well clusters, show a similar relationship. The lowest ammonia and potassium concentrations were observed in wells RSK25 and RSK26, comparable to that observed at the water table well screen RSK37 within well cluster RSK36-43. Dissolved methane

concentrations are also shown for RSK and SHL wells sampled during 2007-2008. In general, methane concentrations at RSK water table wells (630 µg/L for RSK26; 1790-6250 µg/L for RSK27, 28, 30, and 32) overlap with the range observed at SHL piezometer pair N5-P1 (1480-1940 µg/L) and N5-P2 (8940-10600 µg/L) and are similar to the range of methane concentrations previously observed at well cluster RSK8-12 (2110-7780 µg/L). (Note that only the highest and lowest measured methane concentrations are shown in Figure 13A for well clusters RSK8-12 and RSK13-15 for clarity.) Results for ammonia versus calcium concentrations for the same wells are shown in Figure 13B. The elevated concentrations of ammonia and methane in shallow groundwater along the western edge of Red Cove suggest the influence of landfill constituents on water chemistry. Elevated Ca concentrations in combination with relatively low ammonia concentrations also suggest that groundwater chemistry at well cluster RSK1-7 may be distinct from that observed at well clusters RSK16-20 and RSK8-12. Given the consistency in observed hydraulic gradient and arsenic concentrations, the source of the majority of arsenic flux discharging into Red Cove appears to derive from a location within the aquifer due west of the cove, consistent with previous observations (see Figure 72 in Ford et al., 2008).

Possible distinctions in groundwater chemistry at the water table were assessed further through evaluation of major ion chemistry. Presentation of these data in the form of Stiff diagrams for a selection of RSK well screens installed at the water table is shown in Figure 14. The Stiff diagram provides a composite view of major ion chemistry by inclusion of concentrations (expressed as mean charge equivalents for all sampling dates) for Mg, Ca, Na + K, SO<sub>4</sub>, HCO<sub>3</sub>, and Cl. The dimensions of the shaded region within the plotted polygon reflect the concentrations of these constituents, where polygons with smaller shaded area generally correspond to groundwater with lower total dissolved solids. This method of presentation more clearly shows that the water chemistry at well screens RSK25 and RSK26 is similar to that observed at RSK37 and distinct from shallow groundwater compositions west and north of Red Cove. From this view, it also appears that shallow groundwater at well screen RSK15 may be represented by a mixture of upgradient groundwater between the locations of RSK27 and RSK25.

### 3.2.3 *Surface Water Chemistry Trends*

Results from surface water sampling during calendar year 2008 are provided in Tables C.1 and E.1 in the appendices. Dissolved (<0.45 µm) arsenic concentrations at location SW07 are comparable to those previously observed at locations IC and SW01 (Ford et al., 2008). The concentration of arsenic within the deep surface water at location SW06 was slightly elevated relative to location SW07, but still below ambient water quality criteria. However, consistent with historical measurements at similar locations (MC and SW02B2), arsenic in deep surface water at location SW02B3 was the highest (313 µg/L). There appears to be a continuing source of arsenic plume discharge within this area of Red Cove. This is also supported by the elevated concentrations of ammonia, calcium and potassium in deep surface water at location SW02B3 (Table E.1).

## 3.3 Chemistry Summary

Chemistry trends in groundwater and surface water within the Red Cove Study Area are consistent with observations during calendar years 2005-2007. Characterization of groundwater

sampled from RSK well screens completed at the water table provides further spatial delineation of the arsenic plume that is the primary source of arsenic flux discharging into Red Cove. These results also support the previous recommendation for the installation of additional wells within Shepley's Hill Landfill to better delineate the vertical distribution of arsenic concentrations along potential flow paths that pass through the region of the aquifer screened between RSK26 and SHL-11 (see Figure 74 in Ford et al., 2008). These new monitoring locations will also make it feasible to more reliably project groundwater flow paths underlying central and southern portions of the landfill that appear to be the origin of contaminated groundwater discharging into Red Cove.

### 3.4 References

Ford, R.G., K.G. Scheckel, S. Acree, R. Ross, B. Lien, T. Luxton, and P. Clark, 2008. Final Report: Arsenic Fate, Transport and Stability Study, Groundwater, Surface Water, Soil and Sediment Investigation, Fort Devens Superfund Site, Devens, Massachusetts, Internal Report, U.S. Environmental Protection Agency, Cincinnati, OH. (<http://www.epa.gov/region1/superfund/sites/devens/296835.pdf>)

Lien, B.K., 2006. Development and demonstration of a bidirectional advective flux meter for sediment-water interface, EPA/600/R-06/122, U.S. Environmental Protection Agency, Cincinnati, OH. (<http://www.epa.gov/ORD/NRMRL/pubs/600r06122/600r06122.pdf>)

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).

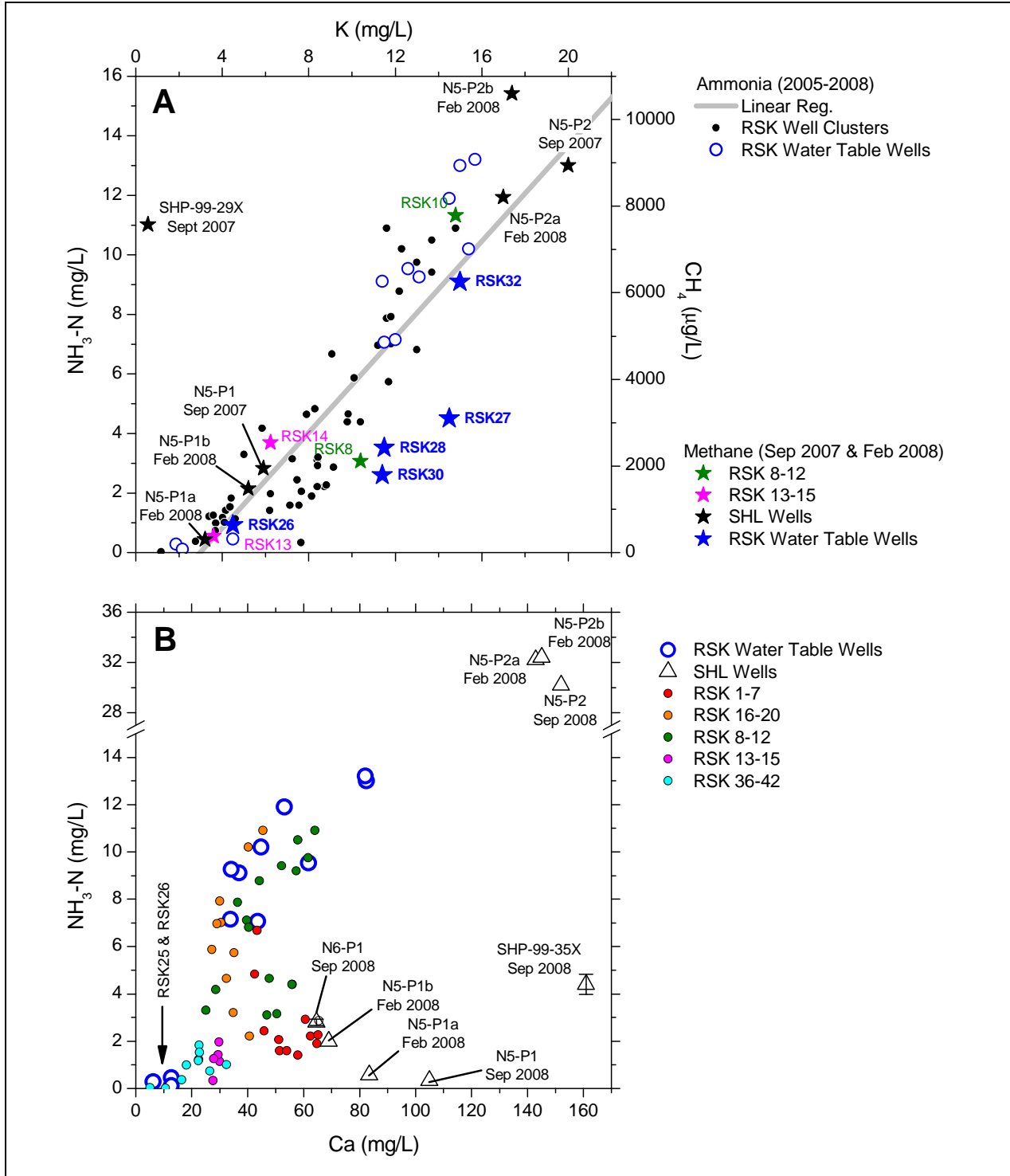


Figure 13. Results for dissolved ( $<0.45 \mu\text{m}$ )  $\text{NH}_3\text{-N}$ ,  $\text{CH}_4$ , K, and Ca for groundwater sampled from RSK cluster wells, RSK water table wells, and SHL wells within the landfill. A)  $\text{NH}_3\text{-N}$  and  $\text{CH}_4$  as a function of K. B)  $\text{NH}_3\text{-N}$  as a function of Ca. Designations “a” and “b” refer to the first and last groundwater sample analyzed for locations N5-P1 and N5-P2 for time series sampling; mean and standard deviation shown for measurements at N6-P1 and SHP-99-35X.

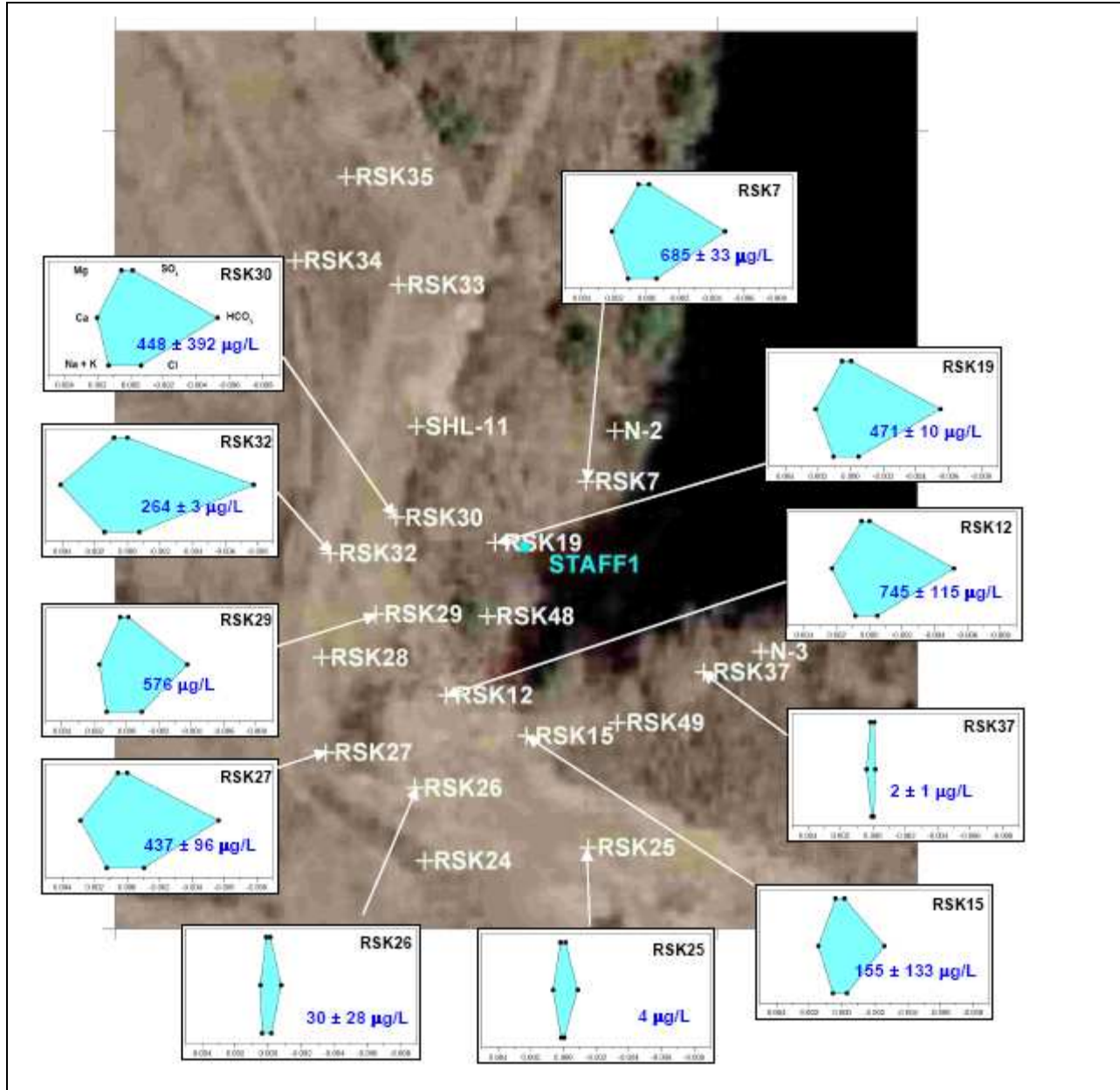


Figure 14. Comparison of major ion chemistry in groundwater sampled from screens completed at the water table for RSK well installations. Data represent the mean of all constituent measurements for each well during 2006-2008 and are presented in a Stiff diagram format with ion equivalents on the x-axis; see diagram for RSK30 for distribution of major ions (see labels for Mg, Ca, Na + K, SO<sub>4</sub>, HCO<sub>3</sub>, and Cl on plot for RSK30). Mean and standard deviation (blue text) are shown for dissolved (<0.45 µm) As at these well screens during 2006-2008. Arrows are used to link diagrams to their associated well location labeled on the underlying aerial view of the Red Cove Study Area.

## **APPENDIX A**

### **LOCATION DATA**

Northing and easting coordinates of new and existing monitoring locations were surveyed relative to the locations of existing wells at the SHL site (except for SW locations). The coordinates are reported in meters using the Massachusetts State Plane coordinate system and are reported relative to the NAD83 datum.

Table A1. Locations of new cove piezometers (surveyed) and screened intervals, new manual flux meter installments (SMPZ13 surveyed; other locations estimated by GPS and visual records), and new surface water sampling locations (estimated GPS and visual records). The coordinates are reported in meters using the Massachusetts State Plane coordinate system and are reported relative to the NAD83 datum. Depths are reported relative to the sediment/water interface at the bottom of the pond. N/A = not applicable

<b>Location Type</b>	<b>Northing (m)</b>	<b>Easting (m)</b>	<b>Top of Screen (ft below interface)</b>	<b>Bottom of Screen (ft below interface)</b>
<b>Piezometer</b>				
PZ13	922706.47	192243.04	4.5	5.0
PZ14	922679.33	192222.05	4.5	5.0
<b>Flux Meter</b>				
SMPZ3	922677.34	192207.45	N/A	N/A
SMPZ4a	922700.02	192215.84	N/A	N/A
SMPZ4b	922698.17	192217.21	N/A	N/A
SMPZ6	922668.46	192221.32	N/A	N/A
SMPZ13	922706.37	192241.67	N/A	N/A
<b>Surface Water</b>				
SW02B3	922677.80	192219.92	N/A	N/A
SW06	922678.76	192206.18	N/A	N/A
SW07	922664.85	192213.07	N/A	N/A
SW08	922696.30	192228.16	N/A	N/A
SW09	922679.62	192244.56	N/A	N/A
<b>Staff Gauge</b>				
STAFF1	922695.48	192202.11	N/A	N/A
STAFF2	922837.91	192251.77	N/A	N/A

Table A2. Surveyed locations of RSK wells and elevations of screened intervals. 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.

<b>Well</b>	<b>Northing (m)</b>	<b>Easting (m)</b>	<b>Top of Screen (ft MSL)</b>	<b>Bottom of Screen (ft MSL)</b>
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 A3. Cove piezometer locations and screened intervals. The surveyed coordinates are reported in meters using the Massachusetts State Plane coordinate system and are reported relative to the NAD83 datum. Depths are reported relative to the sediment/water interface at the bottom of the pond.

<b>Piezometer</b>	<b>Northing (m)</b>	<b>Easting (m)</b>	<b>Top of Screen (ft below interface)</b>	<b>Bottom of Screen (ft below interface)</b>
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

## **APPENDIX B**

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

Table B1. Summary of field geochemical data collected during ground-water sampling for calendar year 2008 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, ND = not detected, NM = not measured, NR = not recorded.

Location	Date	Depth to Water Table ft btoc	Temp. °C	COND μS/cm	pH	ORP mV	DO (electrode) mg/L	DO (Chemet) mg/L	Turbidity NTU	Ferrous Iron mg/L	Alk (mg/L CaCO <sub>3</sub> )
RSK30	4/30/2008	13.35	12.46	610	6.44	-423.2	0.15	NM	8.36	23.5	260
	9/16/2008	13.75	15.05	655	6.34	-34.2	0.41	NM	NR	8.2	268
RSK32	4/30/2008	17.35	11.60	839	6.13	-115.4	0.25	NM	2.70	14.8	374
	9/16/2008	17.74	15.46	880	6.21	-33.3	0.29	NM	NR	27.4	403
RSK29	9/16/2008	17.13	17.45	531	6.39	-58.5	0.23	NM	NR	15.9	187
RSK28	4/30/2008	19.53	11.63	559	6.11	-102.6	0.28	NM	11.60	17.8	215
	9/16/2008	19.95	17.25	518	6.20	-49.3	0.18	NM	NR	18.1	174
RSK27	4/29/2008	21.67	10.39	679	6.22	-77.8	0.27	NM	5.38	6.9	290
	9/17/2008	21.94	15.08	710	6.32	-54.5	0.34	NM	NR	9.8	276
RSK26	4/29/2008	21.00	8.39	210	5.47	68.1	1.47	NM	10.30	2.7	61
	9/17/2008	21.09	19.56	52	5.69	116.3	0.50	NM	NR	0.5	19
RSK25	9/17/2008	21.20	20.28	108	8.14	80.0	2.58	NM	NR	1.7	44
RSK37	9/18/2008	3.98	14.34	86	5.75	177.1	0.91	NM	NR	ND	0.03
RSK39	9/18/2008	3.79	14.20	219	6.27	-6.0	0.18	NM	NR	3.5	86
RSK41	9/18/2008	3.78	13.73	308	6.50	-59.0	0.29	NM	NR	19.0	122

Table B2. Summary of field geochemical data collected during ground-water sampling for calendar year 2008 within 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, ND = not detected, NM = not measured, NR = not recorded. Well purging was initiated at the following times: N6-P1 (9/16/2008 @ 1502), N5-P1 (2/12/2008 @ 1100) and (9/17/2008 @ 1354), N5-P2 (2/12/2008 @ 1518) and (9/17/2008 @ 1509).

Location	Date (Time)	Depth to Water Table ft btoc	Temp. °C	COND $\mu$ S/cm	pH	ORP mV	DO (electrode) mg/L	DO (Chemet) mg/L	Turbidity NTU	Ferrous Iron mg/L	Alk (mg/L CaCO <sub>3</sub> )
N6-P1	9/16/2008 (1510)	36.50	15.88	585	7.00	-161.9	1.86	NM	NR	15.3 <sup>a</sup>	NM
	9/16/2008 (1530)	NM	15.63	593	6.86	-159.6	1.80	NM	NR	NM	NM
	9/16/2008 (1600)	NM	13.44	584	6.81	-185.9	1.07	NM	NR	NM	321
SHP-99-35X	9/16/2008 (1105)	36.78	15.62	1359	7.01	-111.8	3.85 <sup>b</sup>	NM	NR	NM	670
	9/17/2008 (1040)	38.95	16.59	1161	7.08	-146.5	2.82 <sup>b</sup>	NM	NR	18.4	614
N5-P1	9/17/2008 (1500)	23.34	16.44	660	NR	-87.4	0.18	NM	NR	NM	NM
	2/12/2008 (1135)	23.67	9.11	619	6.50	-128.6	1.08	NM	9.37	7.19	NM
	2/12/2008 (1155)	NM	NR	NR	NR	NR	NR	NM	NM	NM	NM
	2/12/2008 (1230)	NM	9.23	635	6.34	-88.9	1.37	NM	1.65	15.9	300
	2/12/2008 (1335)	NM	NR	NR	NR	NR	NR	NM	NM	NM	NM
	2/12/2008 (1505)	NM	10.16	613	6.29	-92.9	NR	NM	0.87	NM	NM
N5-P2	9/17/2008 (1632)	23.64	17.02	1311	7.95 <sup>c</sup>	-54.4	0.09	NM	NR	NM	NM
	2/12/2008 (1541)	24.45	9.01	1314	6.03	-64.4	0.34	NM	10.9	57.8	633
	2/12/2008 (1558)	NM	NR	NR	NR	NR	NR	NM	NM	NM	NM
	2/12/2008 (1611)	NM	9.09	1320	6.02	-87.4	0.16	NM	NM	NM	NM
	2/12/2008 (1719)	NM	9.73	1319	6.07	-103.3	0.29	NM	1.57	58.4	628
	2/12/2008 (1730)	NM	NR	NR	NR	NR	NR	NM	NM	NM	NM

<sup>a</sup> Sample for ferrous iron was collected at time 1525.

<sup>b</sup> Values likely elevated due to air exposure in open vessel.

<sup>c</sup> Value is high relative to historical data, but no electrode performance problems were noted.

## **APPENDIX C**

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

Table C1. 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, ND = not detected, NM = not measured, NS = not sampled. Depth labeled with "sediment" indicates water quality sonde was in contact with sediments and associated pore water; assumed penetration depth of 1 inch.

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 <sub>3</sub> )	TIC mg/L C
SW02B3	4/28/2008	0.82	13.1	250	6.5	52.9	11.57	NM	12.3	ND	26	NS
		1.64	13.06	252	6.49	50.3	11.27	NM	11.5	ND	24	NS
		2.46	12.64	256	6.44	34.8	10.71	NM	15.9	0.63	32	NS
		3.28	12.71	321	6.40	-54.1	8.57	NM	103	7.20	230	NS
		sediment (3.36)	12.32	311	6.84	-204.8	0.08	NM	NM	NS	NS	NS
SW06	4/28/2008	0.33	13.86	265	6.60	37.6	9.32	NM	8.52	0.15	28	NS
		1.31	13.88	268	6.46	25.4	9.2	NM	16	3.05	44	NS
		sediment (1.40)	13.48	435	7.08	-200.2	0.14	NM	NM	NS	NS	NS
SW07	4/28/2008	0.82	12.56	252	6.48	55.3	11.12	NM	14.8	0.13	33	NS
		1.31	12.05	249	6.39	51.1	10.43	NM	12.7	ND	29	NS
		sediment (NM)	12.33	355	7.08	-217.9	0.12	NM	NM	NS	NS	NS
SW08	4/29/2008	0.82	14.09	249	6.56	67.7	7.18	NM	8.83	ND	47	NS
		2.46	12.86	273	6.26	22.9	5.81	NM	19.8	1.20	47	NS
		sediment (5.50)	12.99	511	6.69	-156.7	0.47	NM	NM	NS	NS	NS
SW09	4/29/2008	0.82	14.05	248	6.62	44.9	7.45	NM	8.15	NM	22	NS
		2.46	13.13	285	6.38	-36.6	4.35	NM	38.6	4.20	104	NS
		sediment (3.69)	13.3	379	6.44	-79.9	2.04	NM	NM	NS	NS	NS

## **APPENDIX D**

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

Table D1. Summary of chemistry data for groundwater samples collected during calendar year 2008 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 <sub>4</sub> mg/L	NH <sub>3</sub> -N mg/L	CH <sub>4</sub> mg/L
RSK30	4/30/2008	0.726	67.1	1.55	37.0	11.4	6.1	19.9	20.7	2.74	9.11	1.79
	9/16/2008	0.171	59.6	1.89	44.8	15.4	7.47	25.3	24.5	9.40	10.2	NS
RSK32	4/30/2008	0.262	55.0	1.85	82.4	15.0	9.2	21.4	25.7	ND	13.0	6.25
	9/16/2008	0.266	63.2	1.36	82.0	15.7	10.6	25.1	26.0	1.37	13.2	NS
RSK29	9/16/2008	0.576	45.1	4.81	33.9	12	4.81	21.4	33.0	4.98	7.15	NS
RSK28	4/30/2008	0.600	37.2	0.76	43.6	11.5	6.8	22.3	31.7	2.03	7.07	2.42
	9/16/2008	0.463	34.6	0.61	34.2	13.1	4.91	19.7	34.0	9.39	9.26	NS
RSK27	4/29/2008	0.504	46.6	0.67	53.1	14.5	6.7	22.5	34.9	0.93	11.9	3.10
	9/17/2008	0.369	51.2	0.58	61.8	12.6	7.2	18.9	39.5	ND	9.53	NS
RSK26	4/29/2008	0.049	19.2	0.39	12.7	4.5	2.2	11.4	12.8	10.6	0.45	0.63
	9/17/2008	0.010	1.16	0.39	6.22	1.87	0.77	2.07	ND	0.89	0.28	NS
RSK25	9/17/2008	0.004	2.59	0.80	12.7	2.16	2.08	1.97	1.42	6.44	0.11	NS
RSK37	9/18/2008	0.001	ND	0.03	10.6	2.09	2.59	1.58	1.91	4.92	ND	NS
RSK39	9/18/2008	0.061	5.99	6.82	22.8	4.36	3.2	4.33	2.76	9.57	1.53	NS
RSK41	9/18/2008	0.441	34.3	3.84	26.5	3.69	3.62	4.8	4.52	11.2	0.74	NS
	MDL	0.00002	0.005	0.001	0.03	0.06	0.03	0.04	0.118	0.226	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 D2. Summary of chemistry data for groundwater samples collected during calendar year 2008 within 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 (Time)	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 <sub>4</sub> mg/L	NH <sub>3</sub> -N mg/L	CH <sub>4</sub> mg/L
N5-P1	2/12/2008 (1135)	0.885	8.2	4.69	83.5	3.2	10.9	20.3	28.6	10.1	0.57	0.30
	2/12/2008 (1155)	1.740	9.2	5.86	89.6	4.4	11.8	22.1	24.5	9.27	0.69	NS
	2/12/2008 (1230)	3.760	22.3	6.32	81.5	4.6	10.8	19.8	18.6	8.51	1.46	NS
	2/12/2008 (1335)	4.380	30.9	6.31	74.0	5.0	9.9	18.4	17.0	8.21	1.82	NS
	2/12/2008 (1505)	4.700	36.0	6.34	69.0	5.2	9.4	17.7	16.4	8.24	2.00	1.48
	9/17/2008 (1500)	0.441	3.09	6.56	105	3.68	13.7	24.9	22.5	9.19	0.33	NS
N5-P2	2/12/2008 (1541)	0.206	65.4	0.56	143	17.0	15.6	20.9	16.6	0.13	32.2	8.20
	2/12/2008 (1558)	0.035	67.1	0.38	147	17.6	16.1	22.6	17.1	ND	32.6	NS
	2/12/2008 (1611)	0.034	67.2	0.38	147	17.7	16.0	21.3	17.3	ND	32.4	NS
	2/12/2008 (1719)	0.034	67.2	0.39	145	17.4	15.9	22.5	17.2	ND	32.4	NS
	2/12/2008 (1730)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	10.60
	9/17/2008 (1632)	0.031	69.5	0.42	152	17.3	15.4	19.7	16.4	0.76	30.2	NS
N6-P1	9/16/2008 (1510)	0.350	29.8	2.85	63.2	5.71	6.06	16.3	18.3	20.4	2.67	NS
	9/16/2008 (1530)	0.350	28.4	2.84	65.8	5.87	6.27	16	16.7	19.9	2.95	NS
	9/16/2008 (1600)	0.354	27.8	2.85	64.9	5.78	6.25	19.2	17.6	20.0	2.78	NS
SHP-99-35X	9/16/2008 (1105)	0.195	28.5	13.9	161	8.11	12.1	83.9	23.5	35.6	4.70	NS
	9/17/2008 (1040)	0.137	23.7	13.3	161	7.56	12	66.7	22.9	21.6	4.09	NS
	MDL	0.00002	0.005	0.001	0.03	0.06	0.03	0.04	0.118	0.226	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 E**

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

Table E1. 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. [Note: No samples were collected at locations SW08 and SW09.]

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 <sub>4</sub> mg/L	NH <sub>3</sub> -N mg/L	CH <sub>4</sub> mg/L
SW02B3	4/28/2008	2.46	0.006	0.37	0.28	12.2	1.70	2.18	30.6	51.0	6.59	0.17	NS
		1.64	0.008	0.45	0.29	12.3	1.76	2.17	30.0	52.2	6.65	0.25	NS
		0.82	0.018	1.55	0.31	12.8	1.96	2.19	29.1	49.8	6.64	0.37	NS
		0.00	0.313	63.4	1.18	41.4	8.92	5.63	22.0	37.1	2.29	5.04	NS
SW06	4/28/2008	0.98	0.015	1.39	0.30	12.7	1.83	2.23	30.8	49.1	6.41	1.20	NS
		0.00	0.054	6.41	0.37	14.7	2.63	2.46	29.1	53.4	6.87	0.45	NS
SW07	4/28/2008	0.49	0.007	0.51	0.24	12.2	1.72	2.16	30.4	53.5	6.89	0.27	NS
		0.00	0.007	0.72	0.28	12.3	1.8	2.14	28.5	47.9	6.66	0.21	NS
MDL			0.00002	0.005	0.001	0.03	0.06	0.03	0.04	0.118	0.226	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 F**

### **Groundwater Elevation Data used to Create Potentiometric Surfaces**

Table F1. Data used to Create February 12, 2008, Potentiometric Surface.

<b>Monitoring Point</b>	<b>Groundwater Elevation (ft AMSL)</b>
RSK7	217.98
RSK12	218.67
RSK15	218.63
RSK19	218.09
RSK26	218.97
RSK28	218.78
RSK29	218.63
RSK32	218.63
RSK37	217.99
RSK48	218.18
RSK49	218.38
N-2, P-2	217.85
N-3, P-2	217.94
SHL-11	218.37
SHL-19	219.83
SHP-01-36X	217.86
SHP-01-37X	217.71
SHP-01-38A	218.21
SHP-05-43	217.47
SHP-05-44	217.66

Table F2. Data used to Create April 28, 2008, Potentiometric Surface

<b>Monitoring Point</b>	<b>Groundwater Elevation (ft AMSL)</b>
RSK7	217.49
RSK12	218.39
RSK15	218.16
RSK19	217.77
RSK24	219.32
RSK25	218.75
RSK26	218.71
RSK27	219.00
RSK28	218.75
RSK29	218.48
RSK30	218.29
RSK32	218.53
RSK33	218.03
RSK34	218.19
RSK35	217.90
RSK37	217.46
RSK48	217.76
RSK49	217.82
N-1, P-3	215.74
N-2, P-2	217.38
N-3, P-2	217.46
N-5, P-2	221.55
SHL-11	218.13
SHL-19	218.79
SHL-20	218.27
SHM-05-46A	214.63
SHP-01-36X	217.39
SHP-01-37X	217.21
SHP-05-43	217.26
SHP-05-44	217.35

Table F3. Data used to Create June 10, 2008, Potentiometric Surface

<b>Monitoring Point</b>	<b>Groundwater Elevation (ft AMSL)</b>
RSK7	217.34
RSK12	218.17
RSK19	217.64
RSK24	219.10
RSK25	218.53
RSK26	218.52
RSK27	218.79
RSK28	218.56
RSK29	218.30
RSK30	218.10
RSK32	218.34
RSK33	217.79
RSK34	217.86
RSK37	217.38
RSK48	217.65
STAFF1	217.18
N-1, P-3	216.84
N-2, P-2	217.27
N-3, P-2	217.32
N-5, P-2	221.14
N-7, P-2	227.32
SHL-3	218.94
SHL-5	214.10
SHL-10	217.77
SHL-11	217.95
SHL-19	218.53
SHL-21	214.86
SHL-23	214.85
SHM-05-45A	213.66
SHP-01-36X	217.16
SHP-01-37X	217.03
SHP-05-43	216.83
SHP-05-44	217.06
SHP-95-27X	223.08
SHP-99-35X	223.32

Table F4. Data used to Create August 19-21, 2008, Potentiometric Surface

<b>Monitoring Point</b>	<b>Groundwater Elevation (ft AMSL)</b>
RSK7	217.62
RSK12	218.42
RSK15	218.33
RSK19	217.89
RSK24	219.62
RSK25	219.08
RSK26	218.84
RSK27	218.95
RSK28	218.66
RSK29	218.48
RSK30	218.30
RSK32	218.47
RSK33	218.05
RSK34	218.04
RSK35	217.85
RSK37	217.73
RSK41	217.75
RSK43	217.72
RSK48	217.88
RSK49	217.92
STAFF1	217.47
N-1, P-3	217.41
N-2, P-2	217.60
N-3, P-2	217.67
N-5, P-2	220.24
N-7, P-2	227.32
SHL-3	219.45
SHL-5	215.76
SHL-10	218.31
SHL-12	228.91
SHL-13	215.08
SHL-18	220.26
SHL-19	219.15
SHL-21	215.24
SHL-23	215.21
SHM-05-45A	214.33
SHM-05-46A	214.59
SHP-01-36X	217.52
SHP-01-37X	217.39
SHP-01-38A	217.97
SHP-01-38B	218.10
SHP-05-43	217.07
SHP-05-44	217.34
SHP-95-27X	224.75
SHP-99-35X	222.47



Table F5. Data used to Create September 15, 2008, Potentiometric Surface

<b>Monitoring Point</b>	<b>Groundwater Elevation (ft AMSL)</b>
RSK7	217.65
RSK12	218.41
RSK15	218.34
RSK19	217.89
RSK25	219.05
RSK26	218.81
RSK27	218.86
RSK28	218.62
RSK29	218.43
RSK30	218.25
RSK32	218.42
RSK33	217.97
RSK34	217.94
RSK35	217.74
RSK37	217.71
RSK48	217.91
RSK49	218.04
STAFF1	217.54
N1,P3	217.20
N2,P2	217.60
N3,P2	217.66
N5,P2	220.08
N6,P1	222.93
N7,P2	227.25
SHL-3	218.92
SHL-10	218.65
SHL-11	218.13
SHL-12	229.10
SHL-13	215.09
SHL-18	220.19
SHL-19	219.13
SHL-21	214.78
SHL-23	214.68
SHM-05-45A	214.73
SHP-01-37X	217.40
SHP-05-43	216.97
SHP-05-44	217.28
SHP-95-27X	224.81
SHP-99-29X	221.15
SHP-99-35X	222.43