

ERDC-CRREL Letter Report 11-10



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Engineer Research and  
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## **Poleline Road Disposal Area Hydrologic Analysis and Modeling Summary Report**

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## **PREFACE**

This report was prepared by Colby Snyder, Environmental Modeling Specialist at Opalia Environmental and Beth N. Astley, Research Physical Scientist, at the Engineering Research and Development Center (ERDC), Cold Regions Research and Engineering Laboratory (CRREL). Questions or comments about this report can be directed to [Beth.N.Astley@usace.army.mil](mailto:Beth.N.Astley@usace.army.mil).

The authors wish to acknowledge the following CRREL personnel for contributions to this work: Sarah E. Kopczynski, formally of CRREL, provided a hydrologic assessment and stratigraphic interpretations and Ann Staples of CRREL maintained the water level pressure transducers and water level databases.

## **INTRODUCTION**

This report summarizes efforts to define the hydrology of the Poleline Road Disposal Area (PRDA), Operable Unit B (OUB), located on approximately 300 acres of Joint Base Elmendorf-Richardson (JBER) (formerly Fort Richardson) in Anchorage, Alaska (Figure 1, Site Location). The goal of hydrogeologic investigation work done between 2006 and 2010 was to refine the CSM and help develop a long-term monitoring plan for the PRDA.

Earlier reports generated throughout the course of CRREL's involvement at this site detail geologic, hydrologic and geophysical site characterizations; Table 1 outlines all reports/research done by CRREL at the PRDA.

## **BACKGROUND**

### **History of Contamination**

The PRDA was identified in the early 1990s based on interviews with former military personnel and historic aerial photography. Four burial areas were identified: A-1, A-2, A-3 and A-4. Areas A-1 and A-2 contained buried munitions and Areas A-3 and A-4 contained chemical warfare identification kits (CAIS) (Figure 1, Source Area).

The principal contamination at OUB is chlorinated solvents in soil and groundwater. The chemicals of concern (COCs) are: 1,1,2,2-tetrachloroethane (1,1,2,2-PCA), trichloroethene (TCE) and tetrachloroethene (PCE). Areas A-3 and A-4 are likely the primary source of site groundwater contamination, since COCs are associated with the CAIS kits. A single 'hot spot' was defined during the remedial investigation that includes both areas A-3 and A-4 (USARAK 2003). The Record of Decision (ROD) defines the hot spot as the area with groundwater contamination exceeding 1.0 mg/L 1,1,2,2-PCA (Figure 1, Source Area).

A dual-phased, high vacuum extraction (HVE) treatability study was conducted between March and October 1998 and six-phase soil heating (SPSH) treatability studies were conducted in 1997 and 1999. The SPSH treatability studies incorporated soil heating and HVE to facilitate removal of contaminants from soil and groundwater (Figure 1, Treatment). The SPSH was discontinued in 1999 and decommissioned in 2002 (USARAK 2003).

The first detection of non-aqueous phase liquid (NAPL) was from monitoring well AP-3992 in 1996 (Figure 1, Source Area). NAPL was also observed in AP-3746 during sampling in May 2003, following a strong 7.9 M earthquake in November 2002. This earthquake, centered 176 miles north northeast of Anchorage Alaska, shook for 30 seconds causing minor structural damage in the Anchorage area. On Fort Richardson, a steel drinking water well casing ruptured during the earthquake, providing evidence for intense movement within the ground. It is possible that the earthquake was responsible for re-distributing product at the base of the hill at Poleline Road.

As a result of the NAPL detected in AP-3746, four additional wells, AP-4521, AP-4522, AP-4523, and AP-4524, were installed in 2004 at the base of the hill near AP-3746 but were not sampled. These wells initially contained water but dried up during operation of an SVE system

between May 2005 and January 2006 and remained dry as of December 2010. Organic vapors emanating from these wells were initially strong enough to require the use of respirators when working nearby when these wells were uncapped. A gray, greasy film, presumably product-related, has been observed on equipment deployed in these wells (Figure 1, Source Area).

### **Geologic Context**

PRDA is located east of Poleline Road in a topographically low, relatively flat area surrounded by a wooded hill to the west, a large wetland to the south and southwest, and low wooded hills to the north and east (Figure 1, Potential Receptor). The hydrogeology of Fort Richardson has been studied in detail (Astley et al. 2000, Hunter et al. 2000a, Hunter et al. 2000b, Kopczynski 2000) as has the area surrounding Poleline Road (Kopczynski and Lawson 2001, Kopczynski et al. 2003, Snyder et al. 2005). Table 1 lists hydrogeological and geophysical investigations since 1994.

Key features of the site geology are noted below and discussed in detail in the “Refined 3D Geologic Model of the Poleline Road Disposal Area, Operable Unit B, Fort Richardson, Alaska” report (Snyder et al. 2005):

1. The area in the vicinity of PRDA is comprised largely of glacial and glacial-fluvial deposits (Yehle and Schmoll, 1989).
2. The geology of PRDA is extremely complex. The strata were formed by glacial activity and exhibit a wide range of hydraulic properties. Four major hydrostratigraphic units were identified at Poleline Road, they include: kame deposits, fines, till deposits, and bedrock (Figure 2).
3. The bedrock is considered the lower boundary of the site, groundwater flow and potential contaminant transport within the bedrock has not been investigated.
4. The kame is comprised of gravels, sands and a minor component of fine-grained materials. It is assumed to be the primary aquifer; relative to other units at the site it is the most permeable.
5. The fine-grained units and till are not considered ‘permeable.’
6. Reliable hydraulic testing has not been done on the individual units encountered at the PRDA. Qualitative permeabilities are implied by the structure of the units but no quantitative estimates can be made.

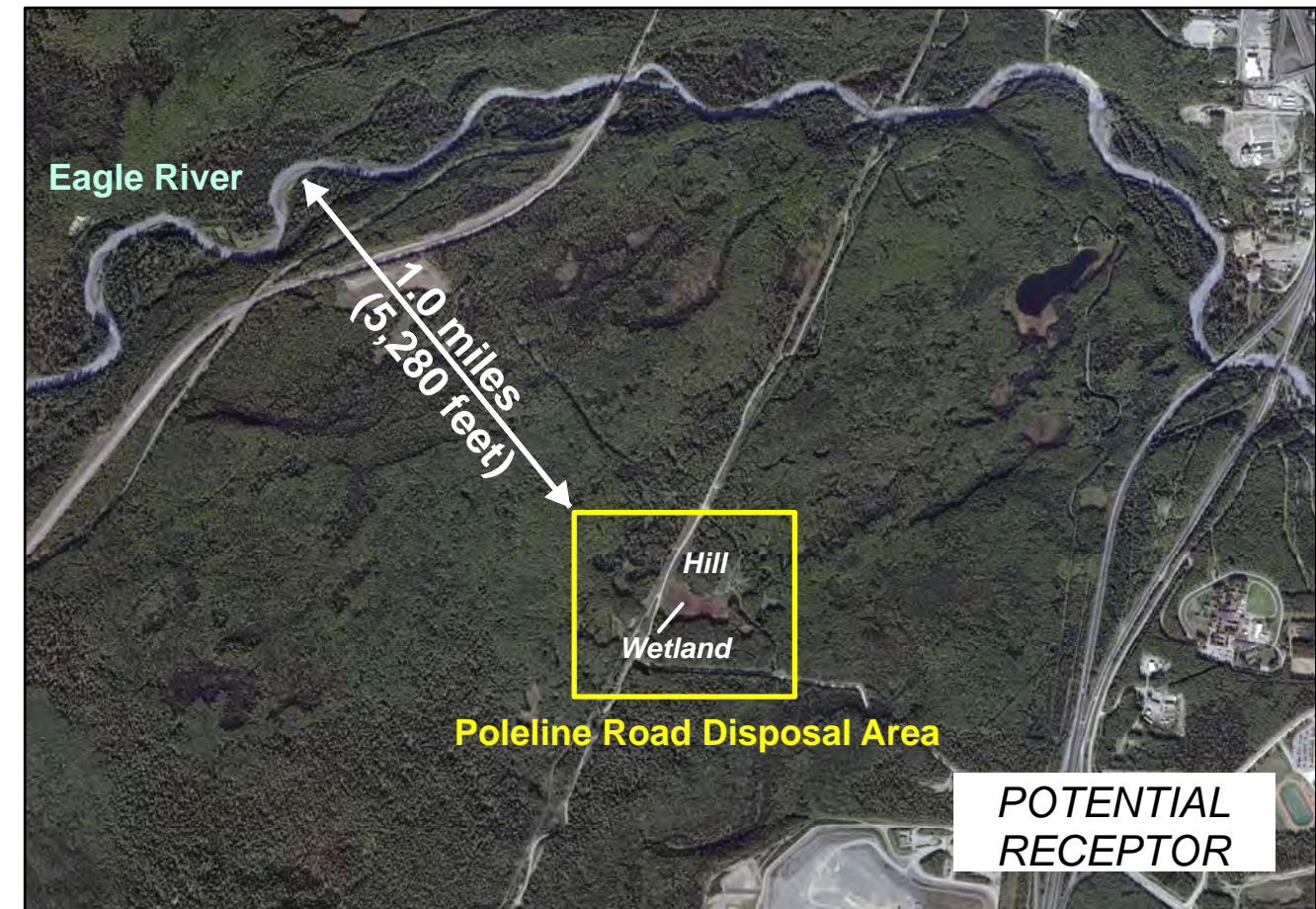
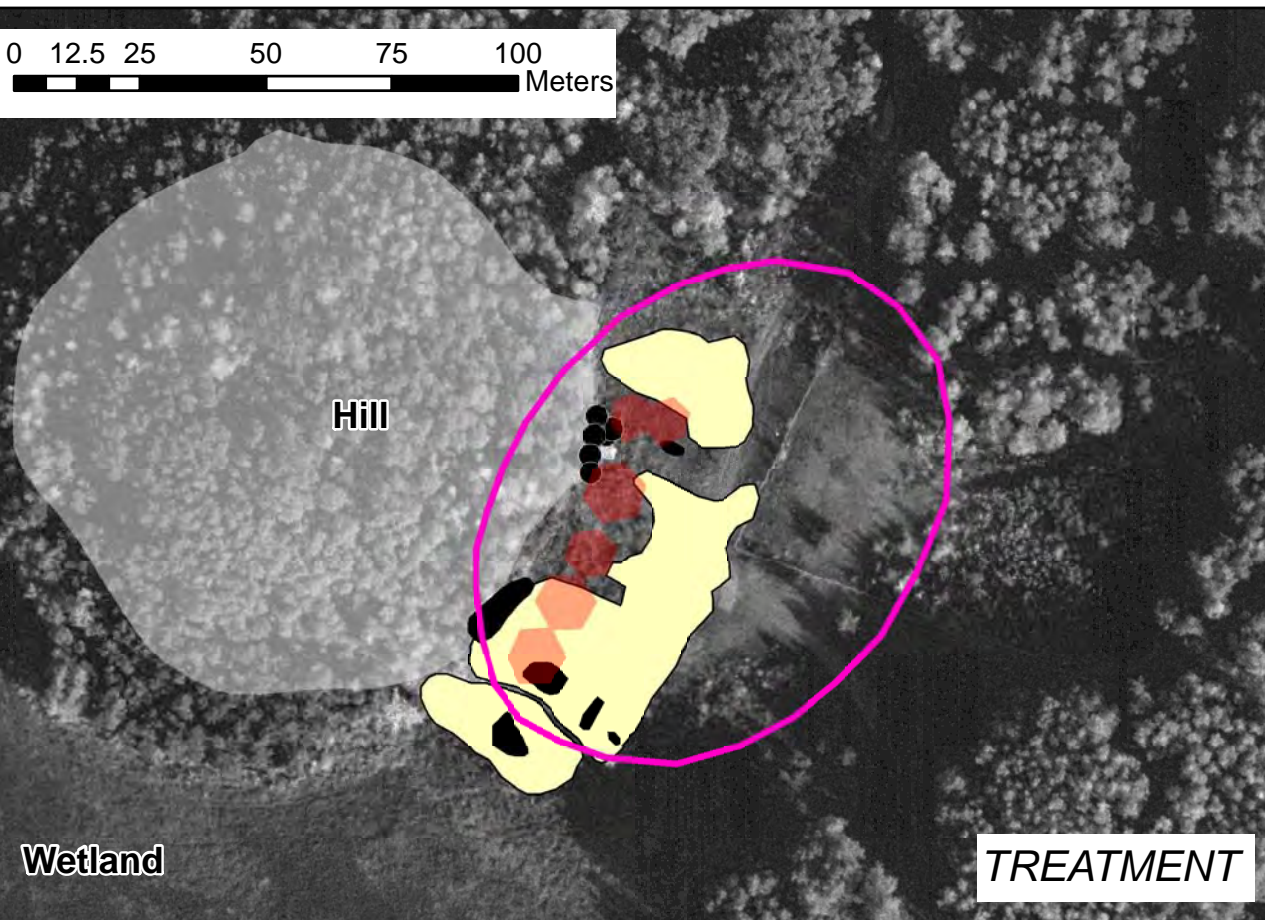
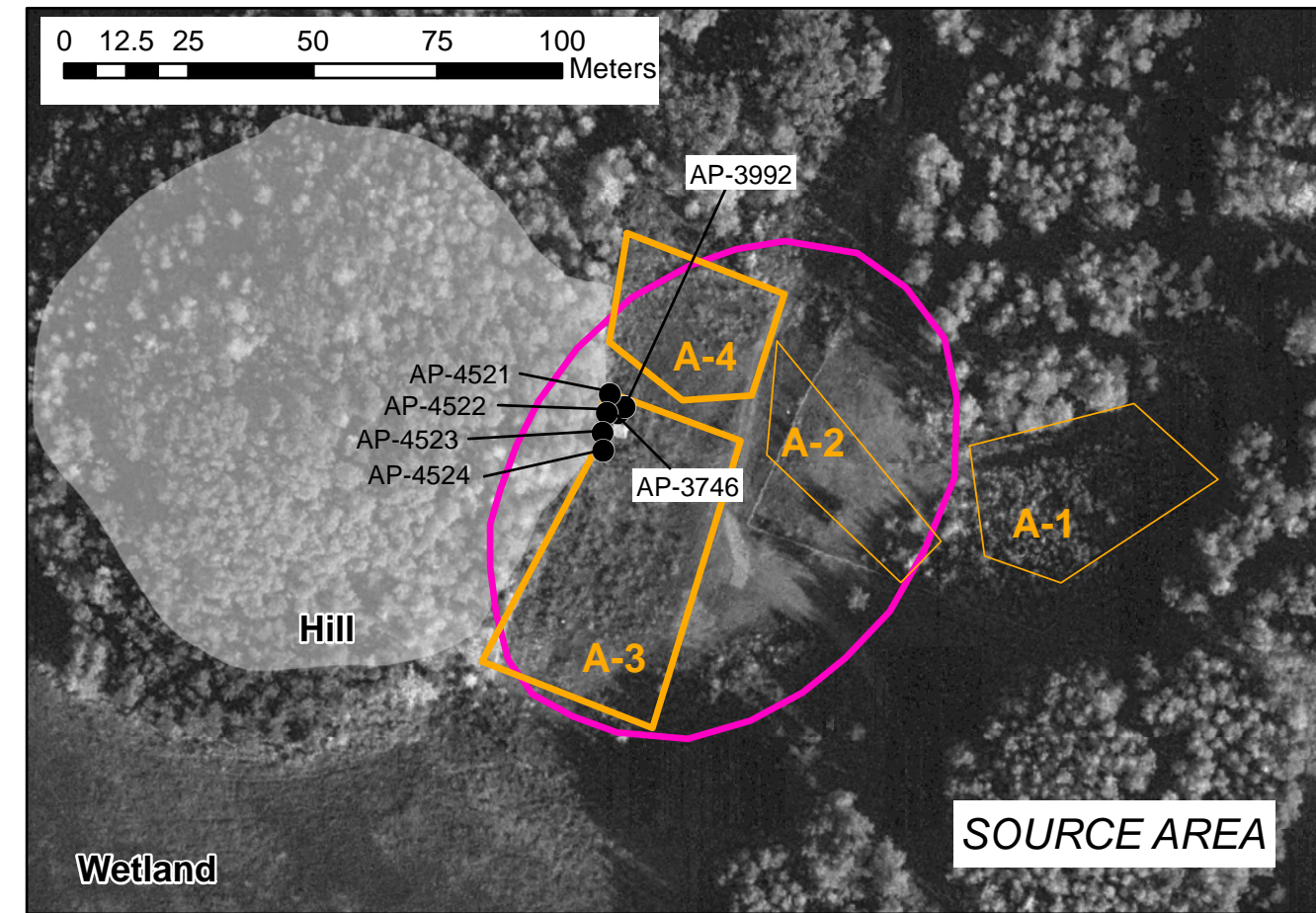
# LEGEND

## Source Area

- Product Encountered
- Investigation Areas
- Focus of Remedial Effort
- Hot Spot  
*\*Hot Spot defined in ROD as area exceeding 1,000 ug/L PCA*

## Treatment

- Area Excavated
- Intensive Excavation
- Soil Heating Array
- Hot Spot
- Product Encountered



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Figure 1  
Location,  
Source Area,  
Treatment and  
Receptor



Table 1. CRREL investigation reports and technical memorandums (TM) for PRDA.

<b>Year</b>	<b>Report Name</b>	<b>Summary</b>
1994	Reconnaissance Ground-Penetrating Radar and Electromagnetic Induction Surveys of the Poleline Road Site, Fort Richardson, Alaska	Geophysical investigation of burial trenches and search for other source areas
1995	Geophysical Investigations of the Poleline Road Disposal Area, Fort Richardson, Alaska	Geophysical survey after excavation of source areas to check for remaining buried objects
2001	Preliminary Geophysical Investigations at the Poleline Road Disposal Area, Fort Richardson, Alaska	Geophysical Investigation to check for remaining buried debris
2001	Preliminary Hydrogeological Interpretations of the Poleline Road Disposal Area, Fort Richardson, Alaska	Geologic conceptual site model, initial contaminant plume maps
2002	Preliminary Observations from Geophysical Investigations Conducted at the Poleline Road Disposal Area, OUB, Fort Richardson AK, Summer 2002	Results of geophysical investigation of PRDA geology including depth to bedrock
2002	Historical Aerial Photographic Analysis of the Poleline Road Disposal Area, OUB, Fort Richardson, Alaska	Analysis of historic aerial photographs from 1950-2001 to check for additional burial sites
2004	Maps of Poleline Road Plumes and Groundwater Table 1997-2003, OUB, Fort Richardson, Alaska	2D contaminant plume contour maps and groundwater flow contours
2005	Refined 3D Geologic Model of the Poleline Road Disposal Area, OUB, Fort Richardson, Alaska	Results of 3D geologic modeling effort and updated conceptual site model
2007	2007 Poleline Road Disposal Area Geophysical Study (TM)	Geophysical Investigation to determine if a source area is remaining south of the main site
2008	Refined Geologic Interpretations from June 2007 Drilling (AP-5245, AP-5246)	Geologic findings from drilling and geologic re-interpretation of old borehole logs
2011	Hydrologic Assessment and Water Level Records for the Poleline Road Disposal Area 1995-2011, Fort Richardson, Alaska	Water level measurements and hydrologic trends to support 3D modeling and an updated conceptual site model

## Regional Hydrogeology

Groundwater is recharged within the regional aquifer from the Chugach Mountains, marshes at the base of the Chugach, and upper reaches of streams flowing off the Chugach (Figure 2). In these recharge areas, streams lose water to groundwater and are termed “losing streams”. The opposite is called a “gaining stream” and occurs when there is a net groundwater gain to stream from groundwater. Ship Creek is a losing stream from the base of the Chugach to approximately where it crosses Vanderberg Ave. (extends northward from Boniface Parkway) on JBER-Elmendorf where it becomes a gaining stream. The black arrows in Figure 2 depict schematically the portion of Ship Creek that is losing (up arrows) and gaining (down arrows). Groundwater seeps can be seen along the bluffs where groundwater springs discharge directly into Knik Arm. Poleline Road is situated in a recharge area where rainwater and snowmelt join the regional aquifer and flow toward Knik Arm.

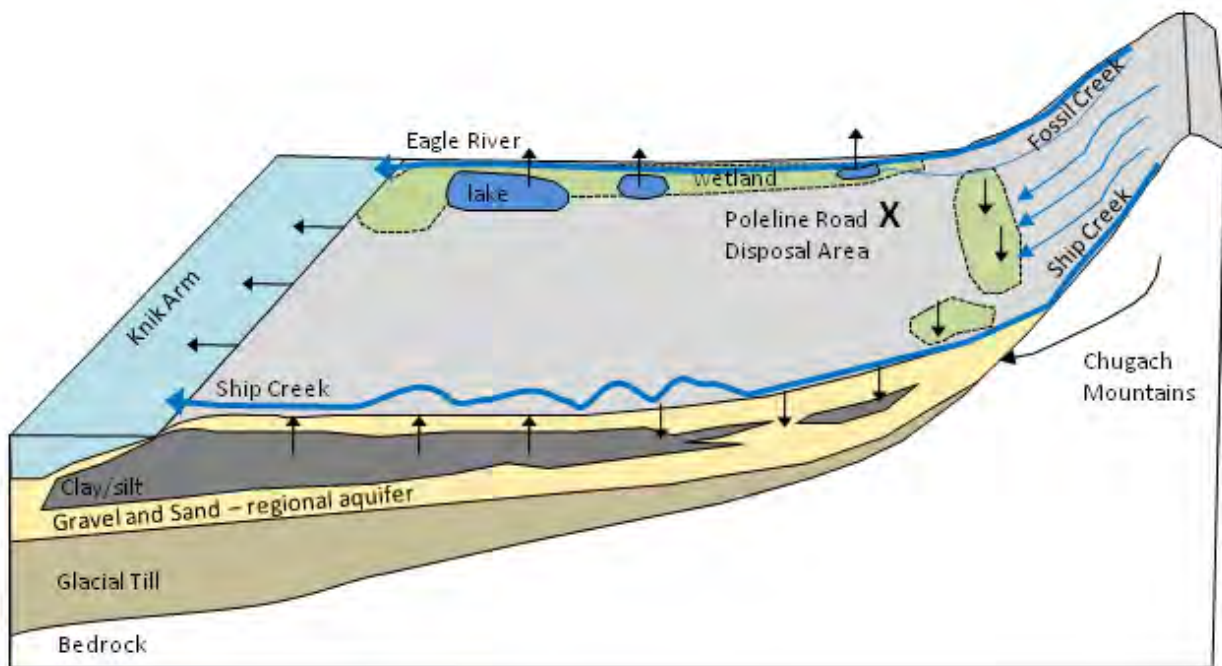


Figure 2. Generalized hydrogeologic cross section from the Chugach Mountains to Knik Arm on JBER. The black arrows indicate the groundwater vertical gradient. The blue lines with arrows indicate streams. Near the mountains, surface water flows downward into the ground under streams and marshes. Downgradient of PRDA, ground water flows upward into surface water bodies such as Ship Creek and the Eagle River.

## HYDROLOGIC ASSESSMENT

The groundwater hydrological trends from water level elevations at PRDA were analyzed in order to determine aquifer characteristics and to better define how contaminants are migrating away from the source area. The complete hydrologic assessment can be found in the CRREL letter report, Hydrologic Assessment and Water Level Records for the Poleline Road Disposal Area 1995-2011, Fort Richardson Alaska (Astley et al. 2011).

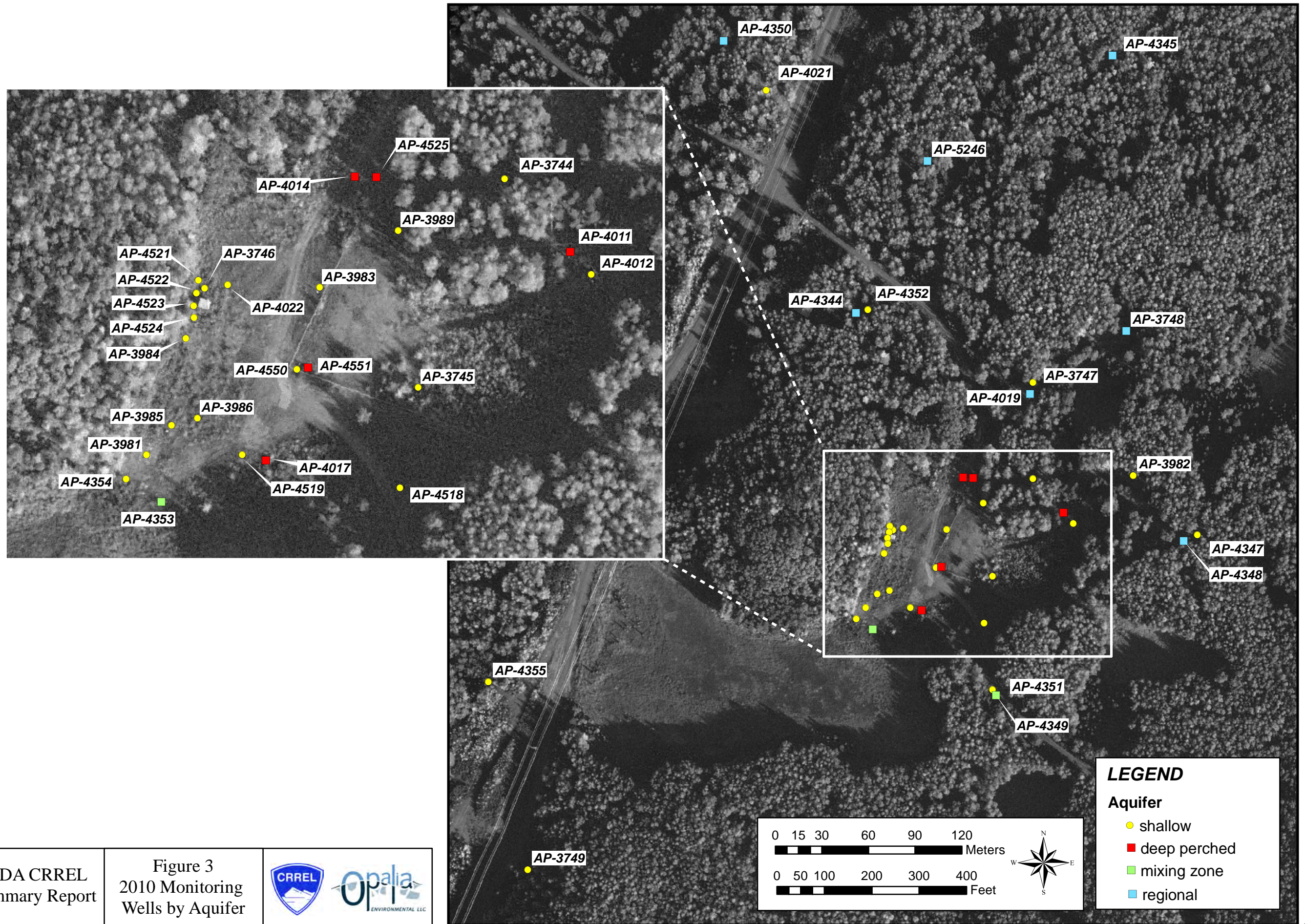
Eighteen wells at PRDA were instrumented with in-situ automated water level recording devices, collecting measurements twice daily. These wells serve as the primary data set for the hydrologic


assessment. Manual water elevation measurements were also collected from all wells during the assessment.

The hydrologic assessment quantified different trends in the shallow versus deep (regional) aquifer and classified wells as screened in the shallow aquifer, deep perched aquifer, deep regional aquifer, and mixing zone (Figure 3). The hydrologic assessment also defined response to recharge in the shallow and deep aquifer which may influence contaminant plume dynamics. In addition this assessment identified wells screened in perched water tables and aquitards which are discussed in the Conceptual Site Model section.

The key findings of the hydrologic assessment are:

- 3 distinct aquifers were defined at Poleline Road: shallow, deep perched, and deep regional. A fourth area termed the “mixing zone” is where the deep perched aquifer is missing and groundwater from the shallow aquifer can migrate down toward bedrock.
- The shallow aquifer is present in the hotspot area and groundwater in this aquifer remains above remedial action goals.
- A tracer study suggests flow rates within the shallow aquifer average between 0.54 and 0.58 feet per day. These shallow wells are screened within a hydraulically conductive kame deposit.
- The deep perched aquifer underlies the shallow aquifer. This aquifer has a low amount of water and does not show seasonal variation which suggests that seepage is the primary recharge mechanism. Although it contains dissolved contaminants, the role of this aquifer in contaminant migration away from PRDA is smaller than the shallow aquifer. The deep perched aquifer is more accurately described as an aquitard.
- The deep regional aquifer is the deepest and largest aquifer at the site. It shows annual variations similar to other areas of JBER-Richardson suggesting it is hydraulically connected to the regional groundwater table. This aquifer is the only pathway found for dissolved contaminants to leave the PRDA.
- The water level trends can be used to determine which aquifer a well is screened within. Wells in the shallow aquifer have an annual peak in the spring followed by a smaller fall peak in most years (Figure 4). The mixing zone wells tend to trend weakly with the shallow aquifer since they are also recharged by infiltration; however, they are screened below the shallow aquifer. Wells in the deep perched aquifer have very small water level variations with no repeatable pattern. Wells in the deep regional aquifer have a late fall/early winter maximum each year (Figure 4).
- Daily water level records allowed for individual wells to be evaluated. This evaluation aided development of the conceptual site model, defined which aquifer each well was screened within and detected changes that signaled structural problems with some monitoring wells.



PRDA CRREL Summary Report	Figure 3 2010 Monitoring Wells by Aquifer	
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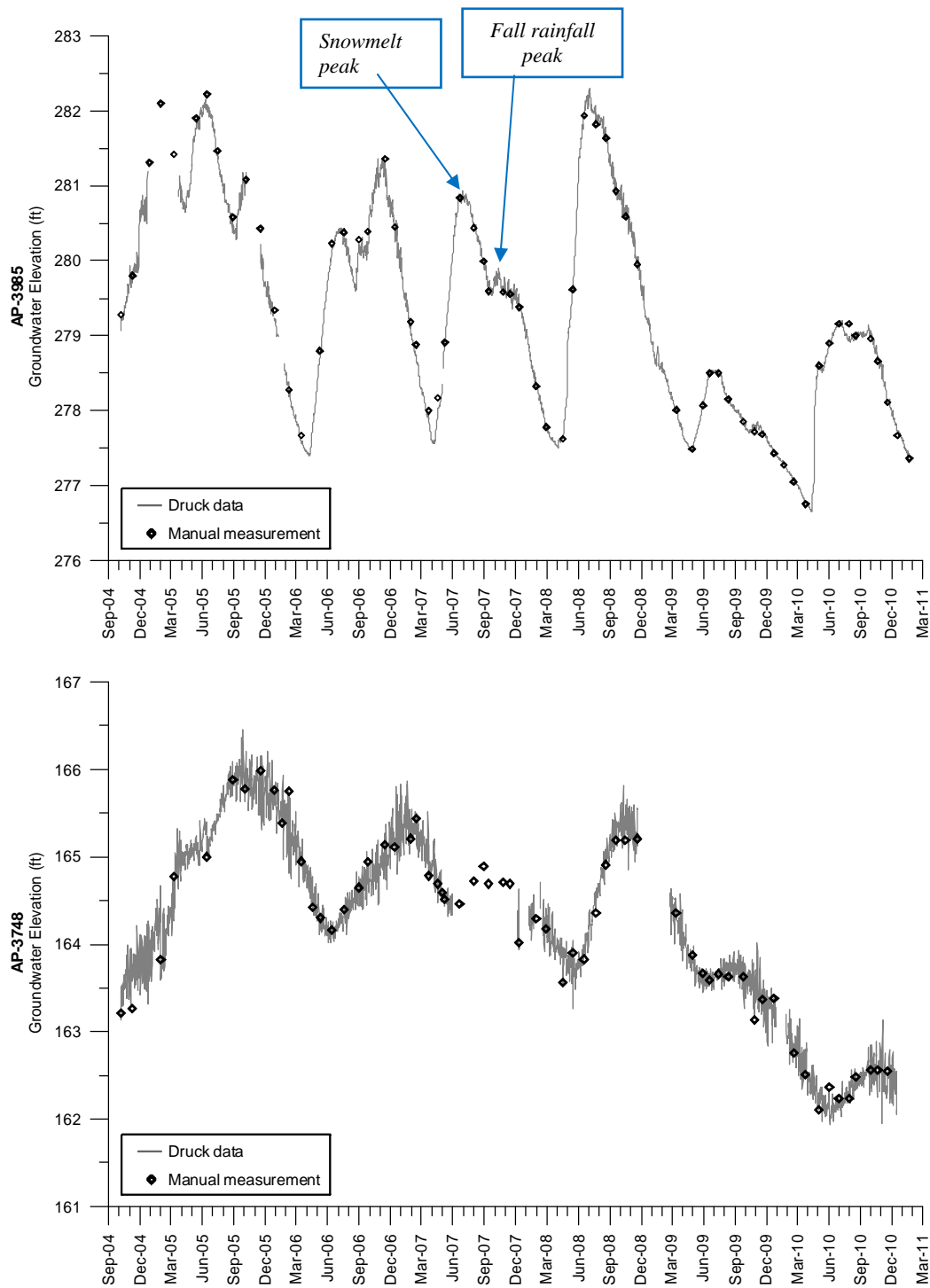


Figure 4. A water elevation record from AP-3985 (top) using a pressure transducer (Druck®) depicts the annual water elevation fluctuation in the shallow aquifer. The primary peak in the early summer each year is generally due to snowmelt infiltration. In most years, a second, usually smaller, peak occurs in the fall or-early winter due to rainfall. AP-3748 (bottom) is screened in the regional aquifer. The annual peak in groundwater elevation in this aquifer occurs in the fall to winter.

## **MODELING AT POLELINE ROAD DISPOSAL AREA**

### **Modeling History**

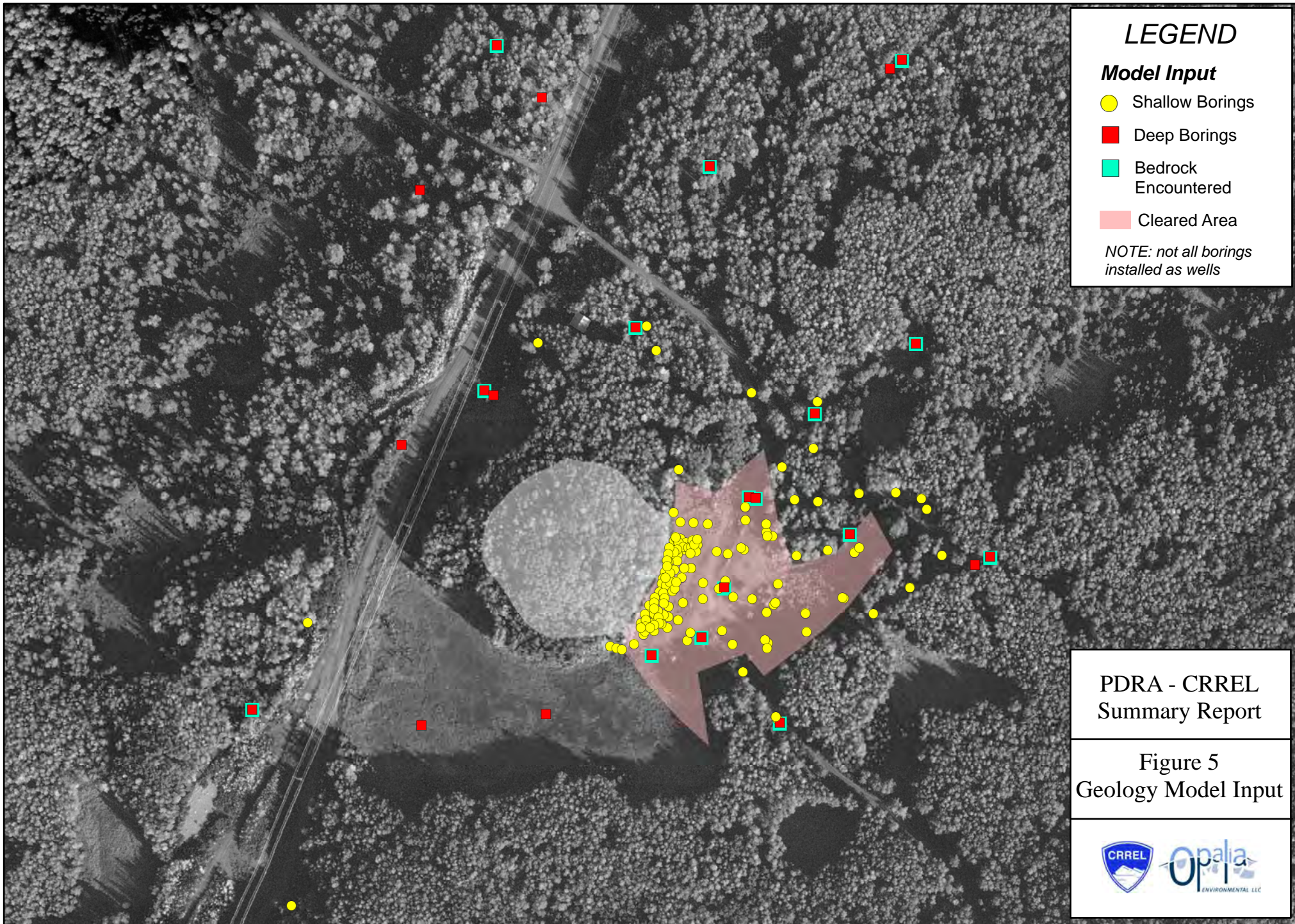
The original model focused on depicting the site geology and sought to represent the distribution of all the stratigraphic units present at the PRDA. The geologic model highlighted the complexity of the site and lead to a ‘simplified’ permeability model where the individual stratigraphic units were not the focus. The stratigraphic units were assigned to 2 categories permeable and impermeable in order to define the aquifer extent. Finally, contaminant plume models were generated for COCs within the aquifer defined by the permeability model. The results of the contaminant plume modeling are discussed below. The original geologic model and the permeability model are discussed in previous CRREL documents (Snyder et al. 2005, Kopczynski et al. 2008).

### **Modeling Approach**

The contaminant plume models are 3-dimesional models depicting the contaminant distribution within the modeled site aquifer. The plume models utilize algorithms included as part of the EarthVision ® modeling software applying a technique called minimum tension gridding. This gridding method involves a phased approach that includes a weighted average calculation, followed by the application of a cubic function. The initial weighted average captures the underlying “global” trends in the data. The subsequent iterations use the cubic function to incorporate the local variation.

### **Input Data**

The original geologic model and the permeability model used a total of 165 boreholes as input; of the 165, 27 (16%) extend to depths greater than 15 meters (50 feet); 16 (11%) extend to bedrock and 36 (21%) are outside of the cleared area of the site. The deep wells are located across the site, ½ in the cleared area and ½ outside of the cleared area. The limited data at depth and the clustered distribution of boreholes provides a data with different input resolutions, resulting in a data set with a low spatial density outside of the cleared area and a high spatial density within the cleared area (Figure 5). The vertical data collected from borings varies depending on the scope of each drilling event but generally ranges from 1 sample/5 ft to 1 sample/10 feet. It is important to keep the limitations of the input data in mind when reviewing the modeled aquifer distribution and plume extents particularly outside of the cleared area where these delineations are less certain.



# LEGEND

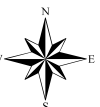
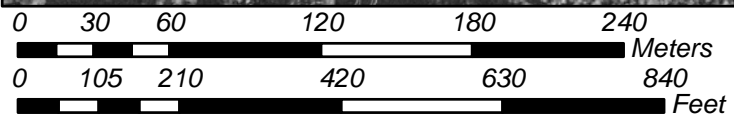
## Model Input

- Shallow Borings
- Deep Borings
- Bedrock Encountered
- Cleared Area

*NOTE: not all borings installed as wells*

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Figure 5  
Geology Model Input



### **Contaminant Plume Maps**

Contaminant plume maps were generated for 3 of the COCs: 1,1,2,2-tetrachloroethane (1,1,2,2-PCA), trichloroethene (TCE) and tetrachloroethene (PCE). Plumes were plotted for several sampling events between November 1997 and October 2009; these maps are shown in Figure 6 (1997 to 2009 comparison), Figure 7 (2009 Seasonal Data), Figure 8 (1,1,2,2-PCA 1997-2007) and Figure 9 (TCE 1997-2007). It is important to note that contaminant plumes only exist in the localized shallow aquifer. There is a single consistent exceedance of the TCE maximum contaminant level (MCL) in a deep well (AP-4344) but no other consistently measurable contamination in the deep regional aquifer (discussed further in the conceptual site model (CSM) section).

The PCE plume has the smallest extent; it is limited to the source area with occasional detections in a single downgradient well (Figure 7). 1,1,2,2-PCA and TCE both have continuous plumes that extend from the source area to the downgradient edge of the shallow aquifer (in vicinity of AP-3747). The extension of these plumes to the southwest under the wetland is possible but currently not defined (Figure 7).

Key observations from the analysis of the plume maps:

1. The plume maps demonstrate a significant decline in contaminant concentrations since 1997 (Figure 6);
2. The hot spot as defined in the ROD (the area with groundwater contamination exceeding 1.0 mg/L 1,1,2,2-PCA) no longer exists (Figure 6). 1,1,2,2-PCA concentrations greater than 1.0 mg/L have not been measured since October 2007;
3. Source area versus downgradient contamination is indicated by seasonal variation in plume concentrations (Figures 8 and 9); and
4. The source area has shrunk since 1997; it appears there is residual contamination in fewer wells at present. This is discussed below.

### *Seasonal Trends*

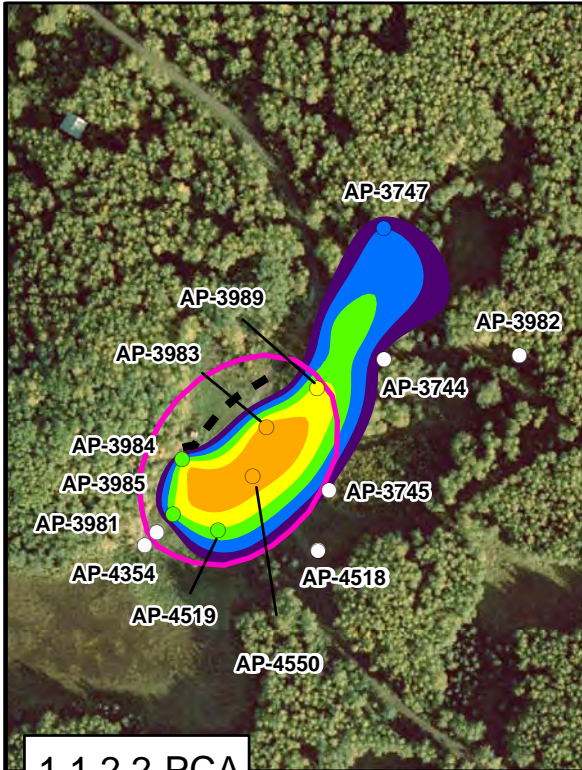
Variation in contaminant concentrations are often a result of seasonal fluctuations in groundwater table elevations. Characterization of contaminant response to groundwater table fluctuations depends on the location of the well. The contaminant response in the source area will be different than the contaminant response downgradient.

In the source area, as recharge (precipitation and snowmelt) moves through the vadose zone it can mobilize residual contamination present above the groundwater table and transport it downward to mix with the underlying groundwater. Water level fluctuations can also mobilize contamination in areas where a smear zone is present. Contamination present in the smear zone comes into contact with the groundwater table during periods of high groundwater levels, resulting in increased dissolved contaminant concentrations. Seasonal trends in the source area are difficult to trace in any one well due to the timing of sampling events relative to when recharge reaches the groundwater table, however overall trends in the plume maps imply a seasonal trend. This trend is highlighted in Figures 8 and 9, specifically November 1997 versus June 1998, September 2002 versus March 2002, October 2005 versus June 2005 and October 2007 versus June 2007.

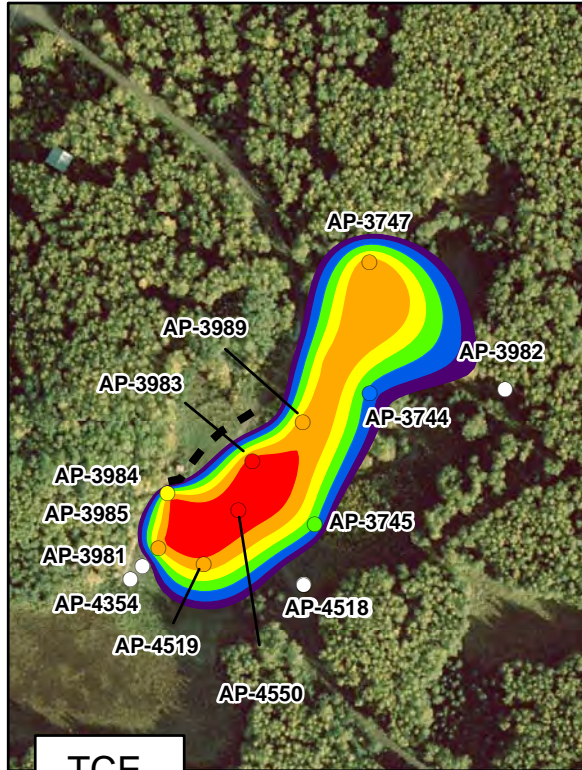
In these maps the spring/summer plumes have less overall contamination than fall, when recharge peaks. As the overall contaminant levels have declined due to treatment the magnitude of the seasonal variation has also declined. These maps also suggest the source area has shrunk. A seasonal response in the contaminant data was seen in AP-3983, AP-3984, AP-3989, AP-4015 initially. The seasonal response currently is seen in AP-3983 and AP-4550 (Figure 7).

It is assumed there is no source present in the unsaturated soils in the downgradient portion of the plume (outside of the identified source area); therefore clean water infiltrating through the vadose zone and entering the groundwater system should result in dilution of contaminant concentrations seasonally. At PRDA variation in the downgradient wells is difficult to discern because of the frequency of water quality sampling relative to the timing of groundwater highs and lows. There is also a time lag between seasonal introduction of contaminants in the source area and when this increase in contaminants could be detected downgradient.

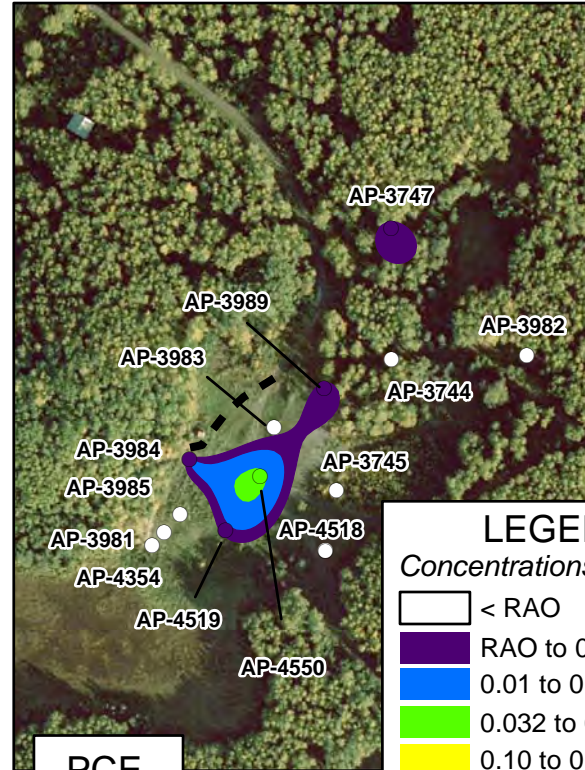
OCTOBER 2009



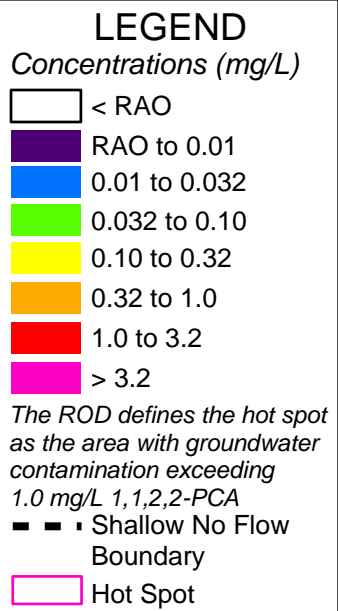
**1,1,2,2-PCA**  
RAO: 0.0042



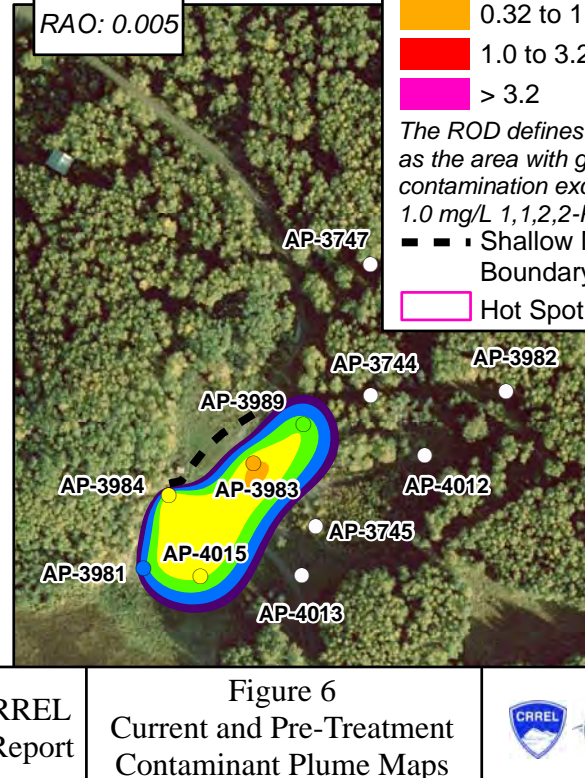
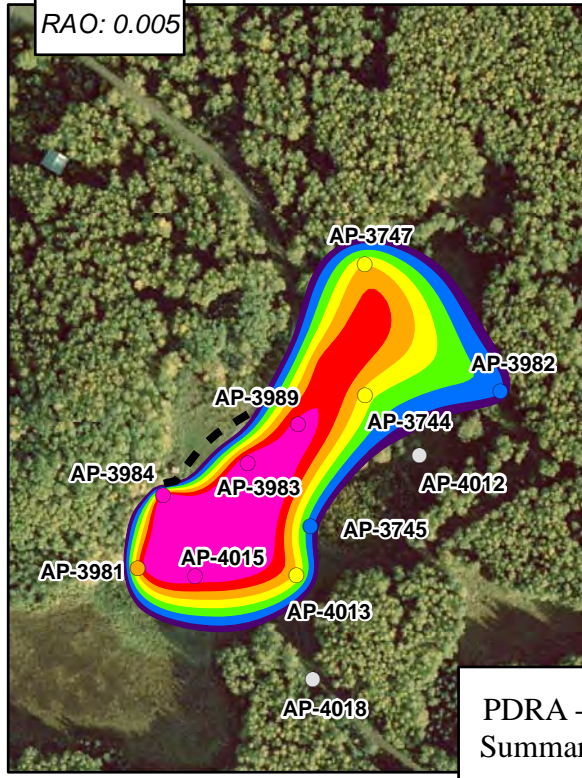
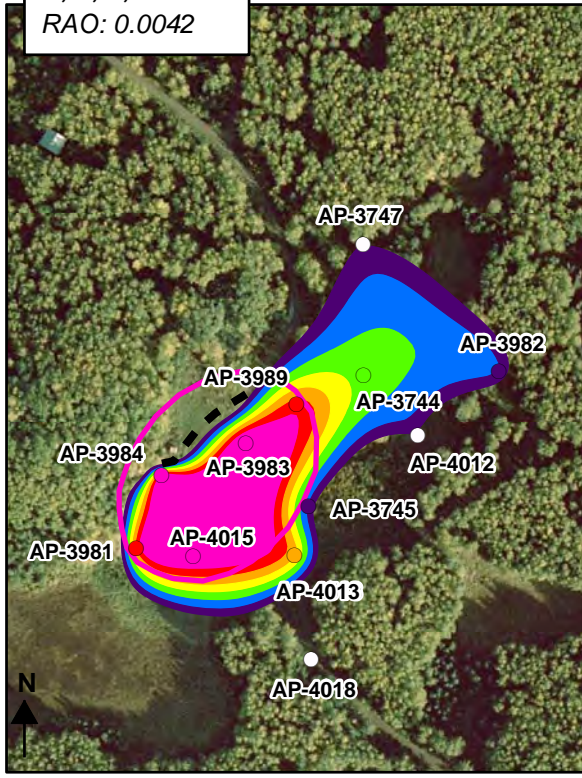
**TCE**  
RAO: 0.005

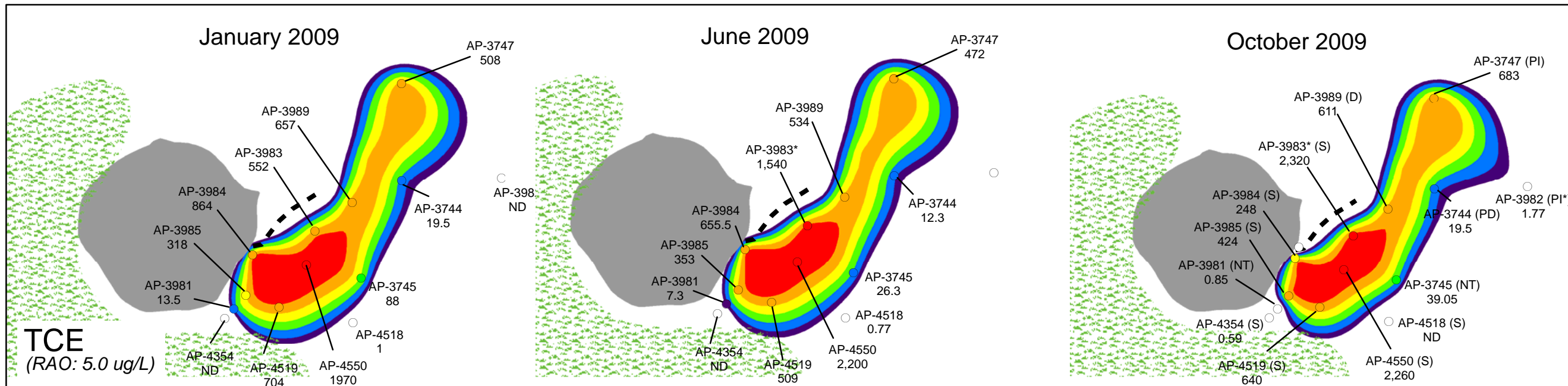


**PCE**  
RAO: 0.005



NOVEMBER 1997





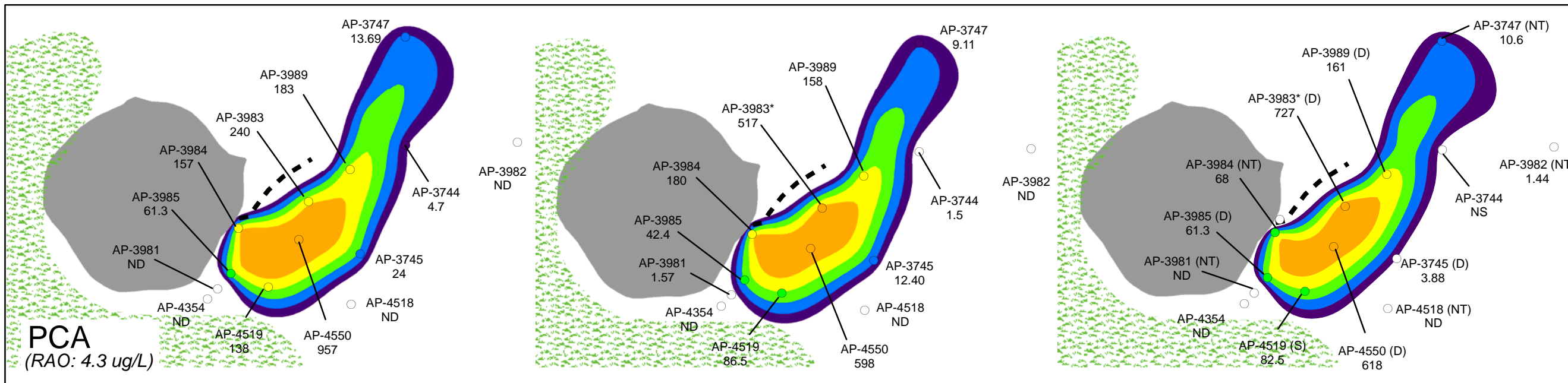
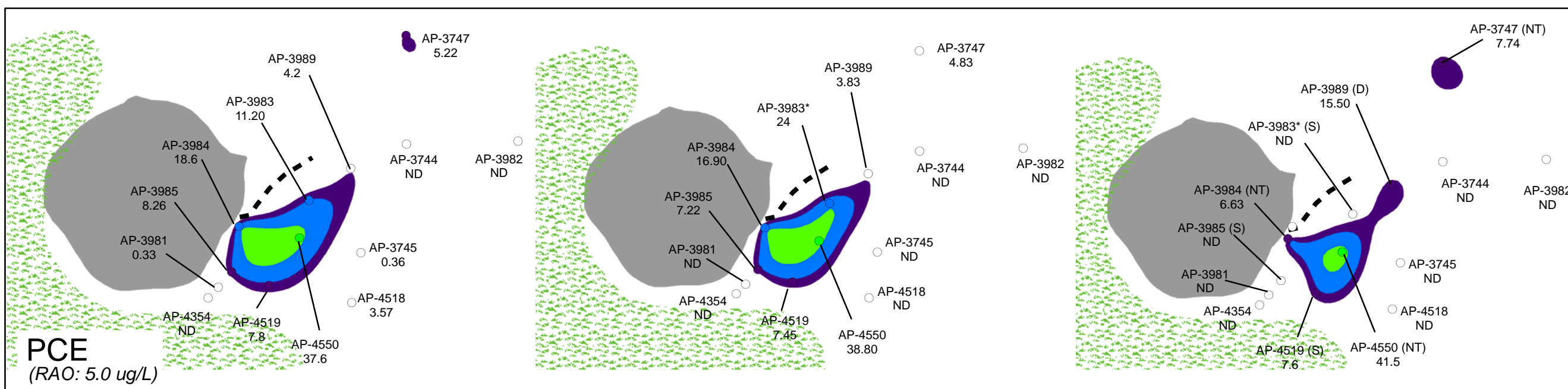
**LEGEND**

**PCE, TCE and PCA Concentrations (ug/L)**

- <math>< \text{RAO}</math>
- RAO to 10
- 10 to 32
- 32 to 100
- 100 to 320
- 320 to 1,000
- > 1,000
- GW Boundary
- Hill
- Wetland

**NOTES:**

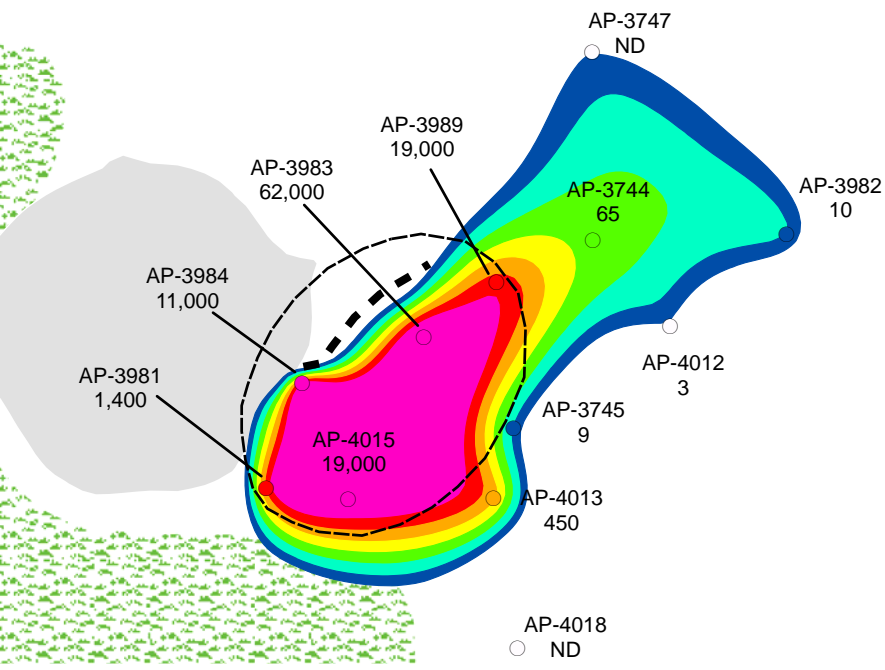
1. October 2007 was the last sampling event where PCA was observed at concentrations exceeding the hot spot criterion of 1,000 ug/L
2. AP-3983\* was purged dry during both the June and October 2009 sampling events



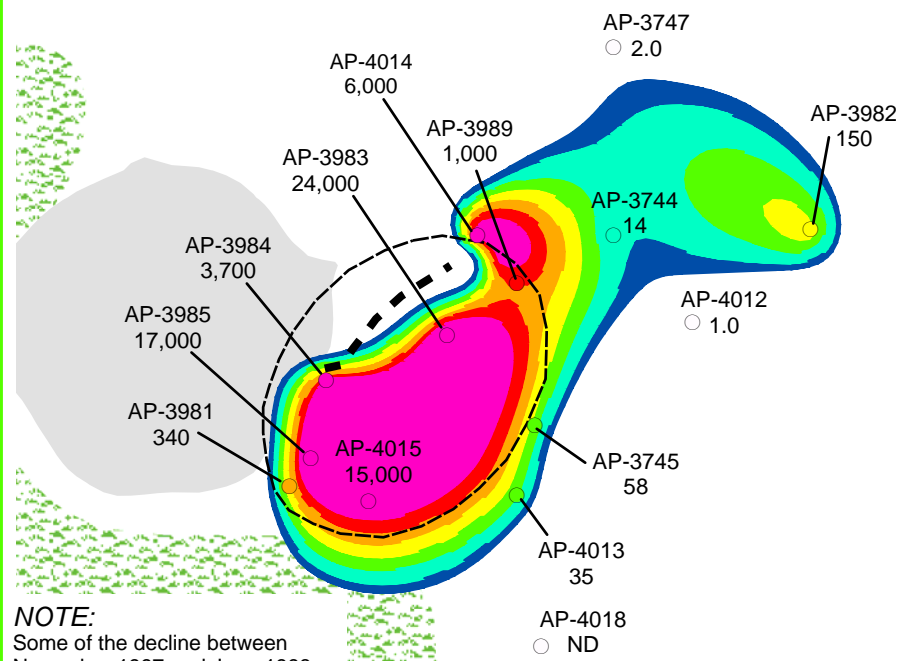
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Figure 7.  
2-Dimensional Contaminant  
Plume Maps for January 2009,  
June 2009 and October 2009

NOVEMBER 1997

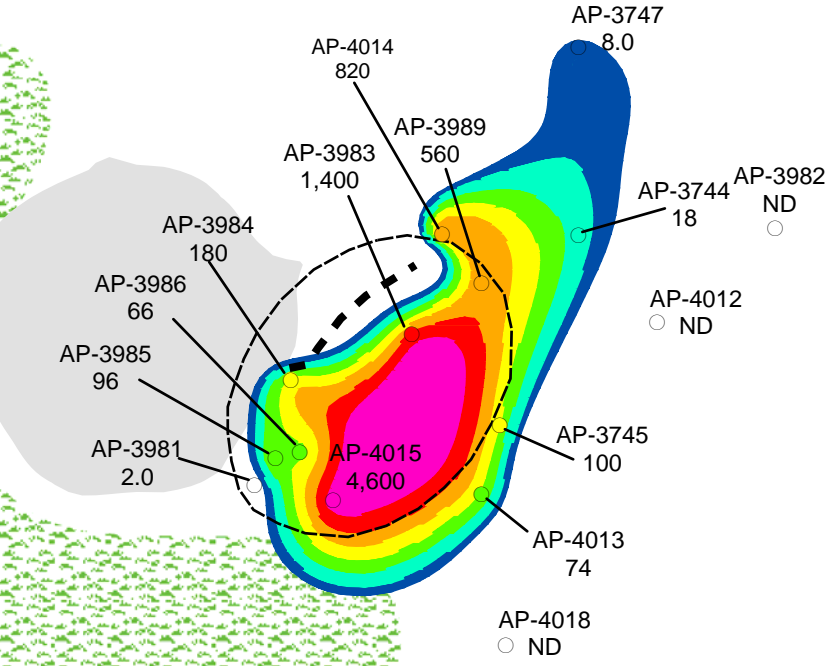


JUNE 1998

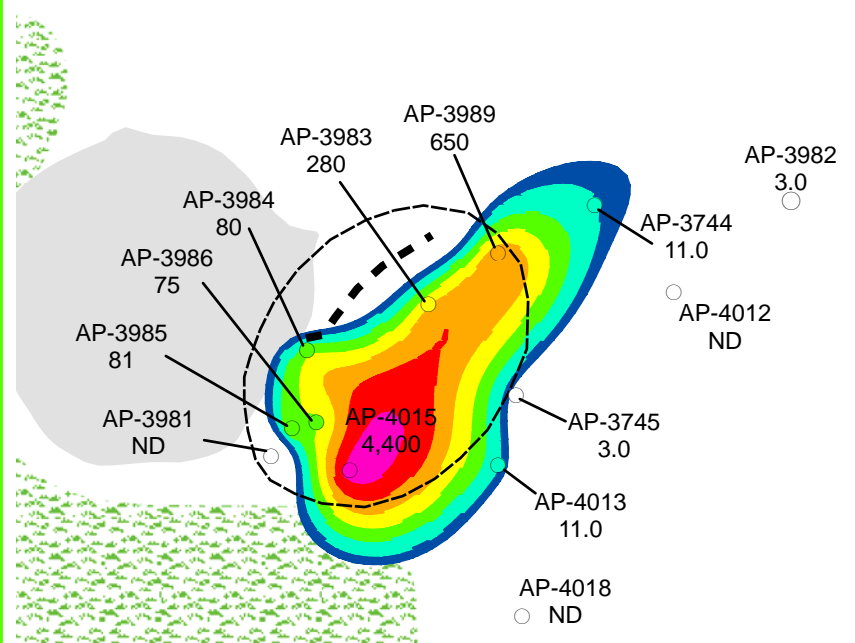


NOTE:  
Some of the decline between November 1997 and June 1998 due to treatment

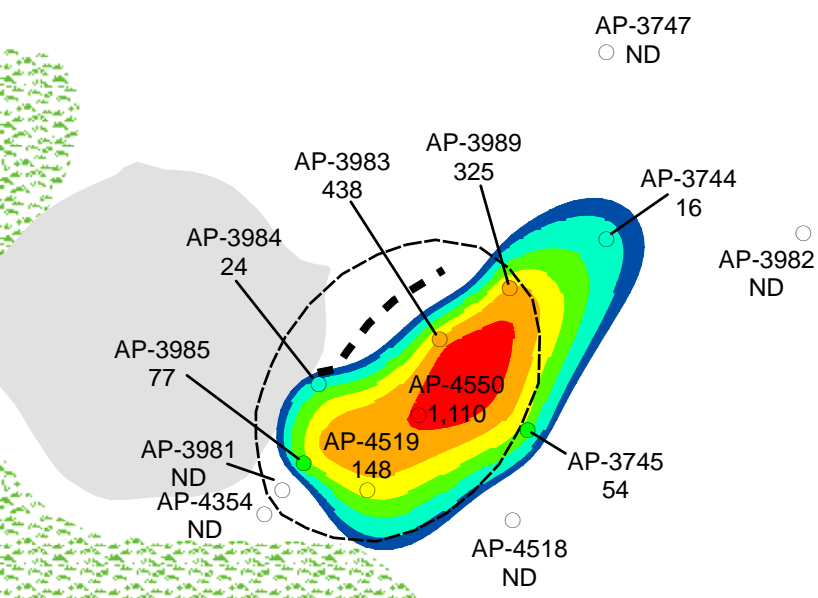
SEPTEMBER 2002



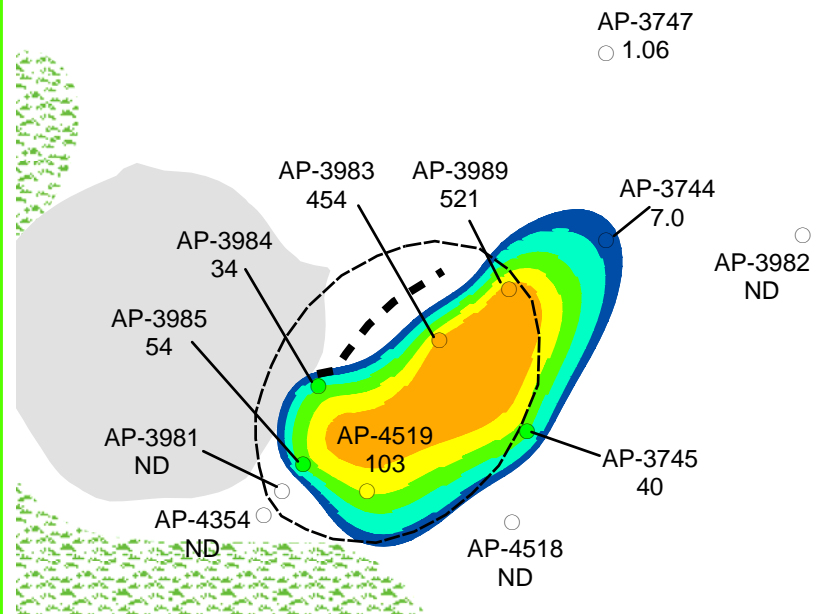
MARCH 2002



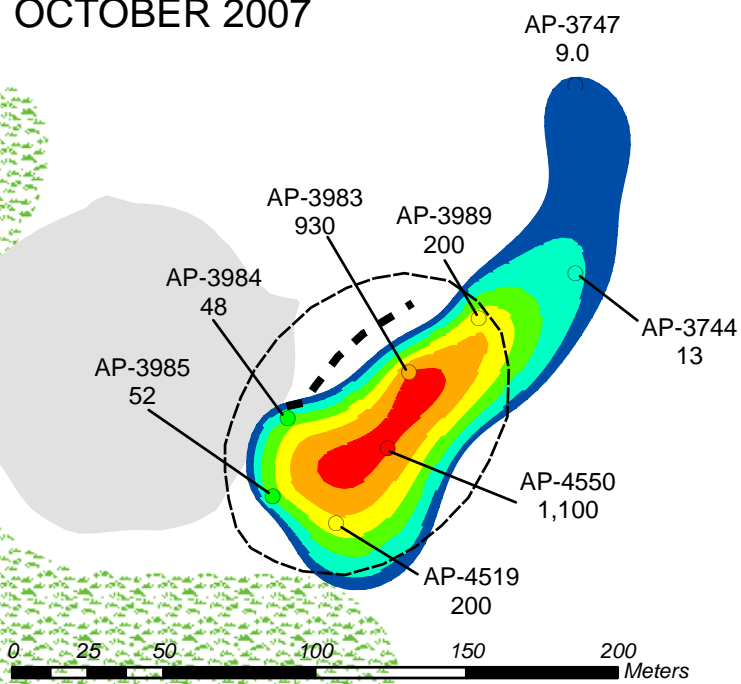
OCTOBER 2005



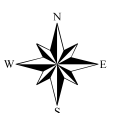
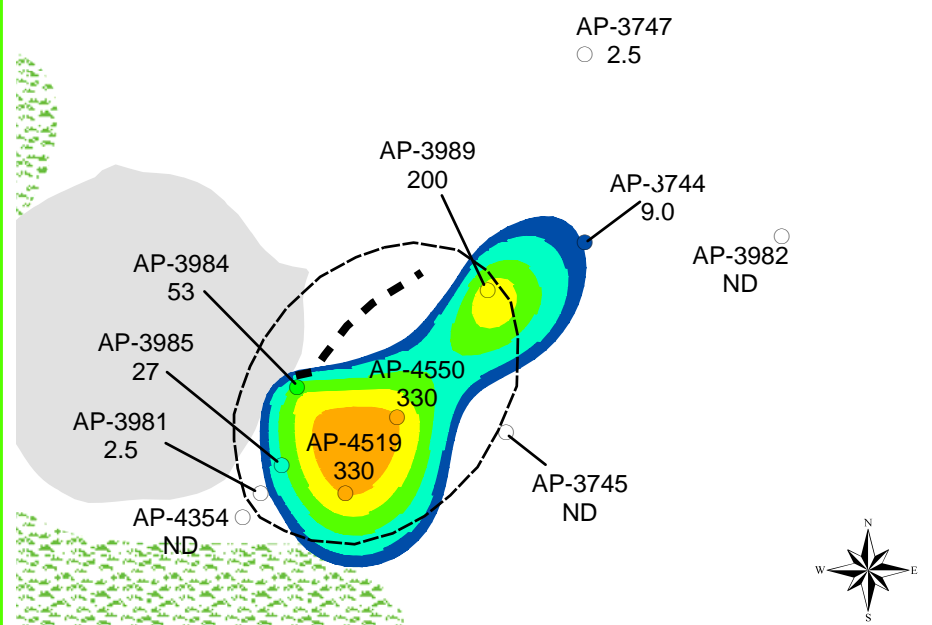
JUNE 2005



OCTOBER 2007



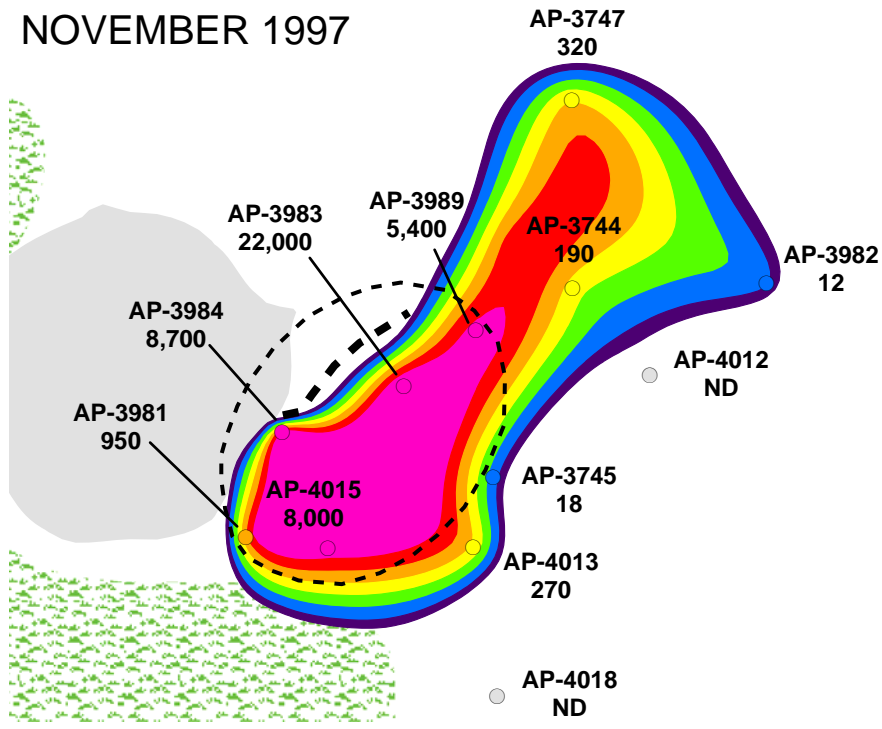
JUNE 2007



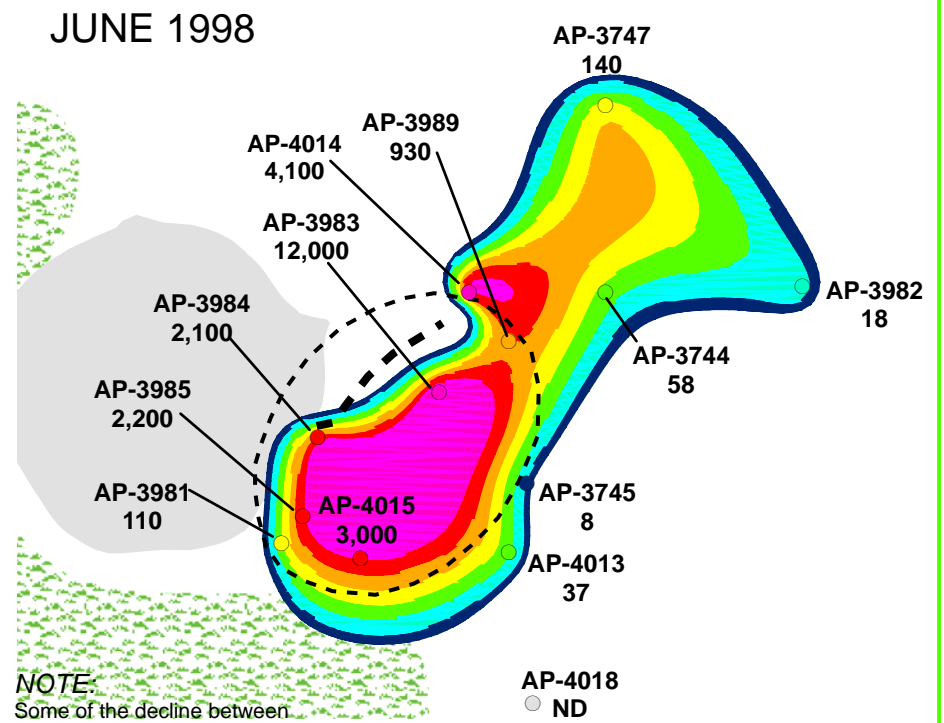
LEGEND

Hill	< 4.3 (RAO)	30 to 100	1,000 to 3,200
Wetland	4.3 to 10	100 to 300	> 3,200
Hot Spot	10 to 30	300 to 1,000	GW Boundary

NOVEMBER 1997

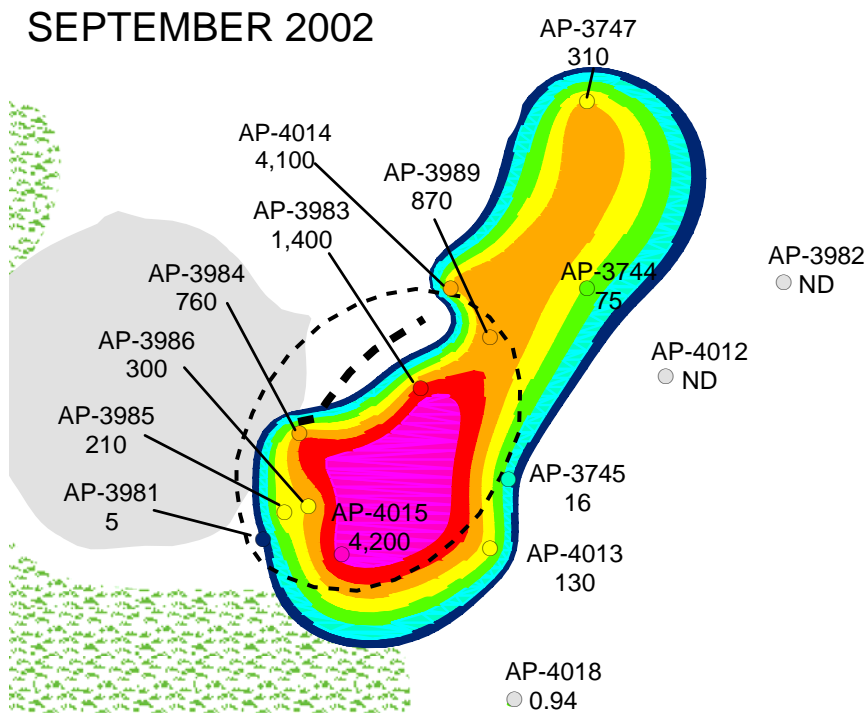


JUNE 1998

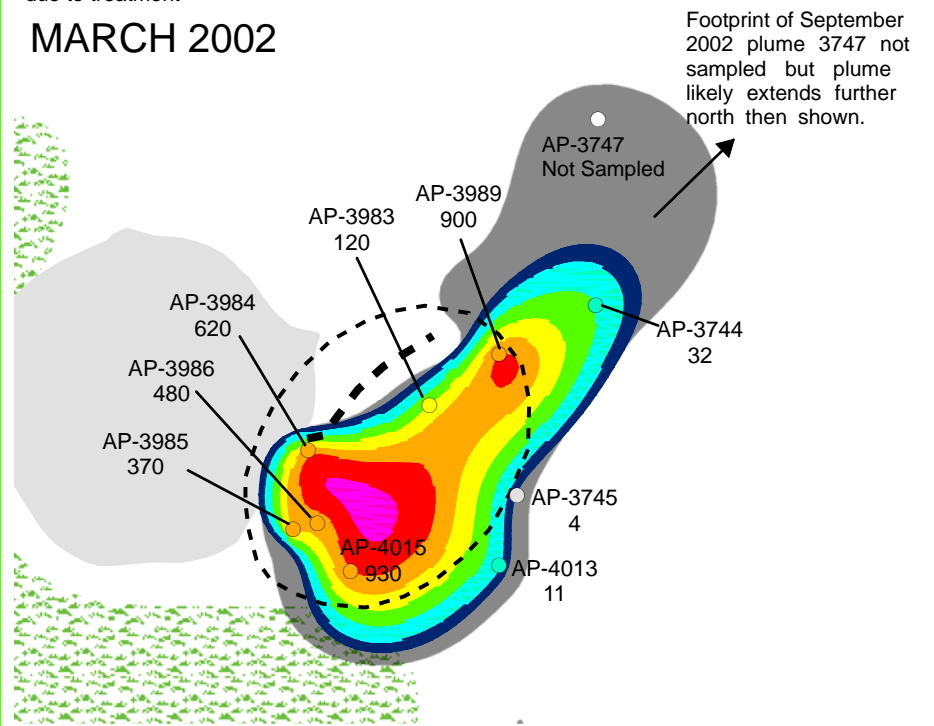


NOTE:  
Some of the decline between  
November 1997 and June 1998  
due to treatment

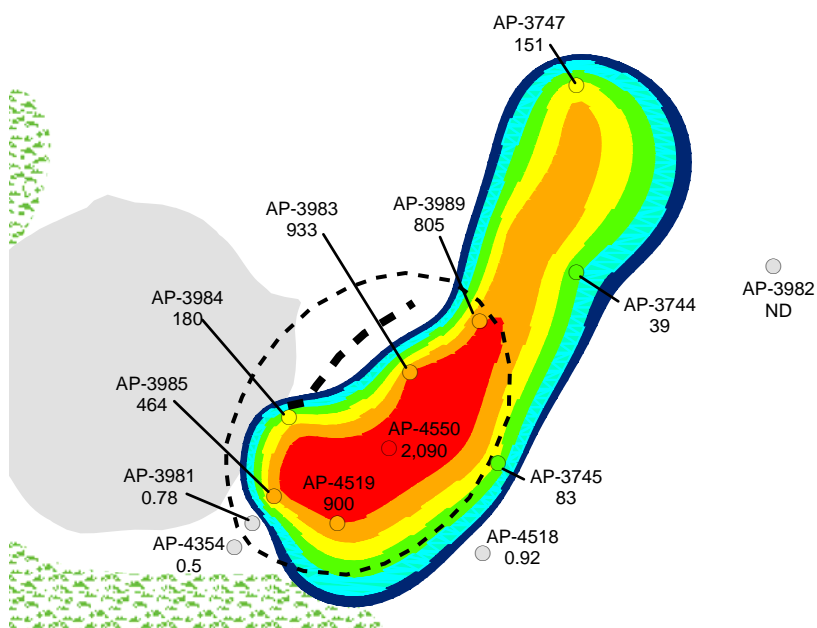
SEPTEMBER 2002



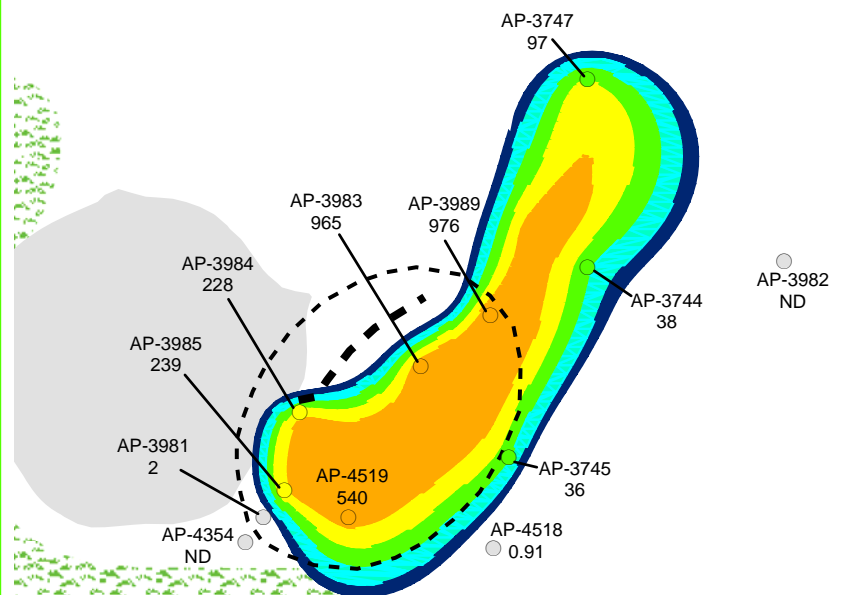
MARCH 2002



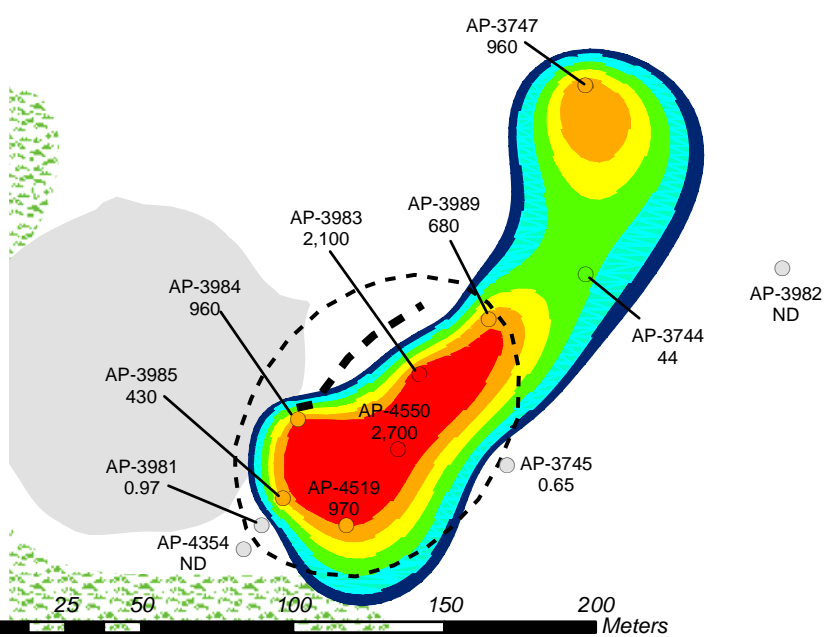
OCTOBER 2005



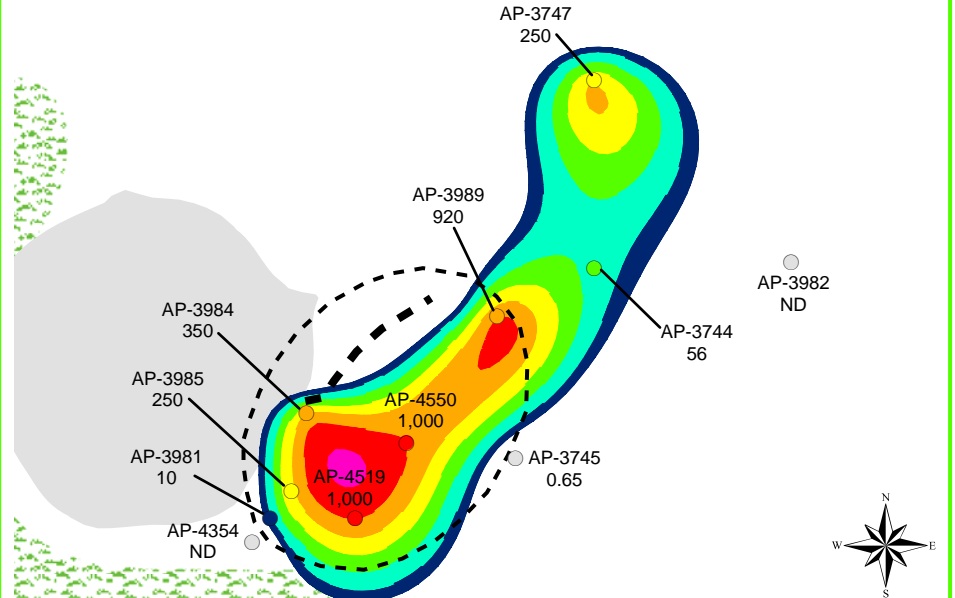
JUNE 2005



OCTOBER 2007



JUNE 2007



LEGEND

TCE (ug/L)	
Hill	< 5.2 (RAO)
Wetland	5.2 to 10
Hot Spot	10 to 32
	32 to 100
	100 to 320
	320 to 1,000
	1,000 to 3,200
	> 3,200

## CONCEPTUAL SITE MODEL

The conceptual site model for the Poleline Road Disposal Area is described below and shown in Figures 10a, 10b, and 10c.

### Source Area

The source area for chlorinated organic compounds (a mixture of TCE, PCE, and 1,1,2,2-PCA), is located in the hot spot area defined in the OUB ROD (Figure 6). The ROD defines the hot spot as the area with groundwater contamination exceeding 1.0 mg/L 1,1,2,2-PCA. There have been no 1,1,2,2-PCA concentrations exceeding 1.0 mg/L in samples from monitoring wells since October 2007, and therefore the hot-spot no longer exists as defined in the ROD (Figure 6).

### Aquifers

The Poleline Road site conceptual model has evolved as new geologic, geophysical, and hydrologic data have provided a better understanding of the aquifers. The most recent conceptual site model differentiates the groundwater regime into three “aquifers” (Figures 10a, 10b, and 10c): the shallow aquifer, the deep perched aquifer, and the regional aquifer.

#### *Shallow aquifer*

The shallow aquifer is present from the surface to approximately 40 feet bgs and extends from the cleared area northeast to at least AP-3747. It is underlain by a layer of glacial till with low hydraulic conductivity that acts as a semi-confining layer. The shallow aquifer contains the source area and the highest COC concentrations. The perched zone described in previous documents is considered part of the shallow aquifer. Recharge to the shallow aquifer is supplied by infiltration therefore groundwater elevations are closely tied to snowmelt and rainfall with distinct seasonal patterns, typically showing a seasonal water level peak in both the spring and the fall. The amount of groundwater in the shallow aquifer is small compared to the regional aquifer. This was confirmed by a tracer study that showed dye concentrations remaining stable over a period of 2 years with little lateral or vertical migration. The general groundwater flow direction is from the former hotspot area to the northeast towards AP-3747. Fine-grained sediment, associated with the edge of a hill, bounds the shallow aquifer to the west and is shown as the “no-flow boundary” on Figure 10a and 10b. Borings drilled to the west of this boundary did not encounter enough groundwater to sample and during repeated sampling efforts these wells remain dry. AP-5246, AP-4344, and AP-3748 (Figure 10c) did not encounter a shallow aquifer therefore the glacial till that underlies the shallow aquifer must pinch out north of AP-3747. Shallow groundwater likely migrates downward to join the deep regional aquifer beyond AP-3747.

#### *Deep Perched Aquifer*

The deep perched aquifer is located within a relatively impermeable till that locally perches the shallow groundwater extending from approximately 95 to 126 feet bgs. This till is referred to as an aquifer since it has enough water to sample in some places, but in fact this area is more characteristic of an aquitard. It is most closely associated with the previously described intermediate aquifer (Figure 10a and b). The deep perched aquifer is located above a layer of laminated glacial silt (termed the “basal silt”) or directly on the bedrock surface. The deep perched aquifer is characterized by a small volume of water and no seasonal groundwater

variation suggesting this aquifer is not directly hydraulically connected to the shallow or regional aquifers (Figure 10b). Groundwater and contaminants can either seep slowly through the till or along the outside of monitoring wells that penetrate the till until they reach the bedrock or basal silt layer where a thin layer of perched groundwater is present. Contaminant concentrations are above MCLs in samples from the deep perched aquifer wells, however due to uncertainties associated with boring installation in areas of dense non-aqueous phase liquid (DNAPL) and the limited volume of groundwater within the well screens, chemical data results may not be representative of this aquifer. It is not known if there is a pathway between the deep perched aquifer and regional aquifer but based on the lack of groundwater variation it is presumed that the mechanism of this connection would be a slow diffusive process through the low permeability till.

### *Regional aquifer*

The regional aquifer is the primary aquifer across the Anchorage Bowl where groundwater migrates from the base of the Chugach Mountains towards Knik Arm (Figure 2). At PRDA, it surrounds the shallow and deep perched aquifers on all sides at depths of approximately 140 to 190 feet bgs. The aquifer gradient is northwest according to groundwater elevation data at Poleline Road and in the vicinity of the JBER-Richardson Cantonment Area. Groundwater elevations within this aquifer fluctuate annually with highest levels in the fall or early winter months. This aquifer contains the most groundwater of the three aquifers discussed here and likely has the greatest velocities. Although groundwater velocity of the regional aquifer has not been measured at Poleline Road specifically, velocities from regional aquifer wells nearby on the JBER-Richardson Main Cantonment area average 1.6-2.5 ft/day according to data collected by CRREL groundwater flow systems installed in regional aquifer monitoring wells (Astley et al. 2000). Average bulk hydraulic conductivities at Poleline Road were estimated by Woodward-Clyde (1996) to range from .03 to 284 ft/day and Kopczyński et al. (2003) at 0.6 to 121.4 ft/day.

The regional aquifer is the only potential pathway for contaminants to migrate away from the Poleline Road Disposal Area (Figure 10a and c). Dilution is the primary mechanism for natural attenuation in the regional aquifer. AP-4344 is the only regional aquifer well with contaminant concentrations (TCE) above MCL. The TCE concentrations in AP-4344 are at least an order of magnitude less than the concentrations measured in the shallow source area.

### **The Hill**

The feature termed “the hill” is a topographic high that bounds the site to the west. The geologic materials that core the hill are unknown but it is presumed to be a bedrock high or sediment with very low hydraulic conductivity. A dry boring (AP-5245) drilled into bedrock west of AP-4344 in June 2007 (Figure 10b) suggests that the regional groundwater is impeded by a geologic boundary preventing westward flow of water under the hill. This is consistent with the “no flow boundary” that impedes shallow groundwater from migrating northward toward the hill. The “no flow boundary” forces groundwater and contaminants to flow around the hill locally (Figure 10c).

### **Contaminant Migration**

Within the shallow aquifer groundwater and contaminants follow the local northeast gradient. There are a few viable downgradient contaminant transport pathways. These pathways were

assessed using geologic and contaminant plume models as well as qualitative observations. Shallow contaminants can migrate to the deep regional aquifer within:

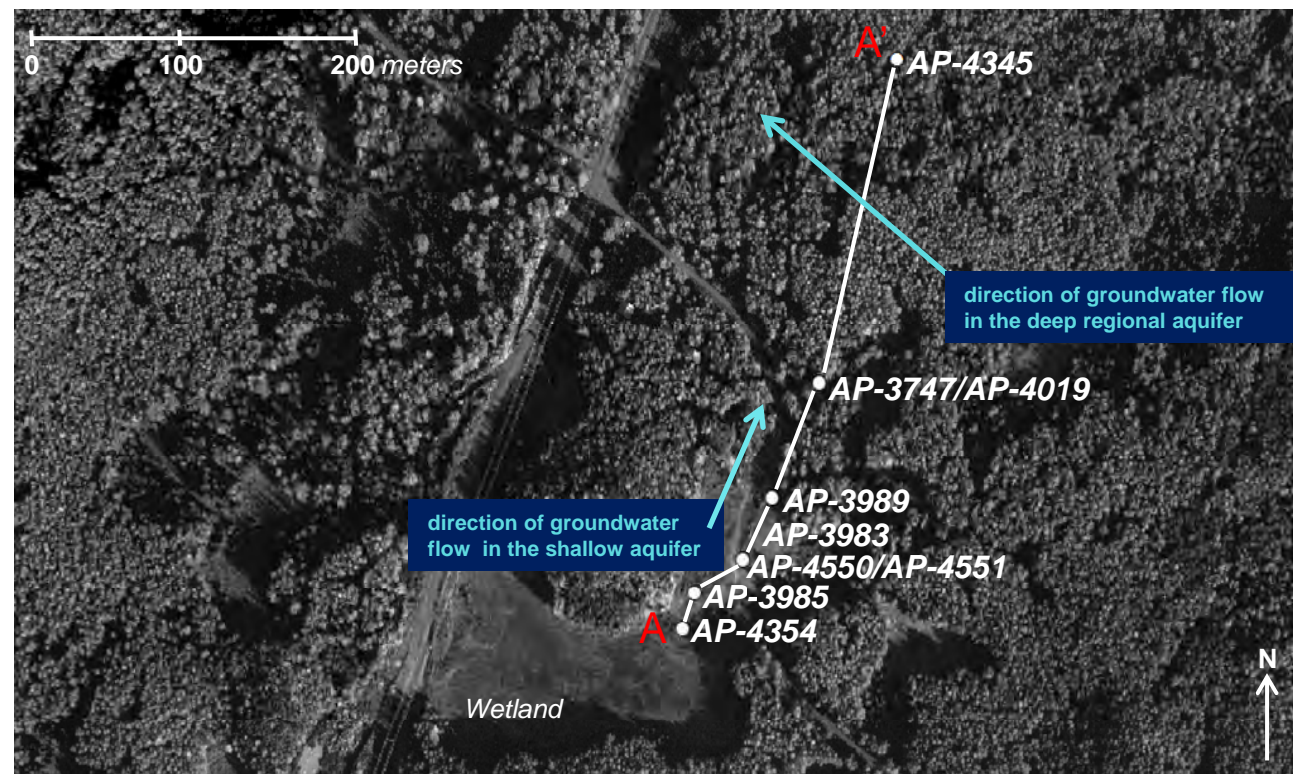
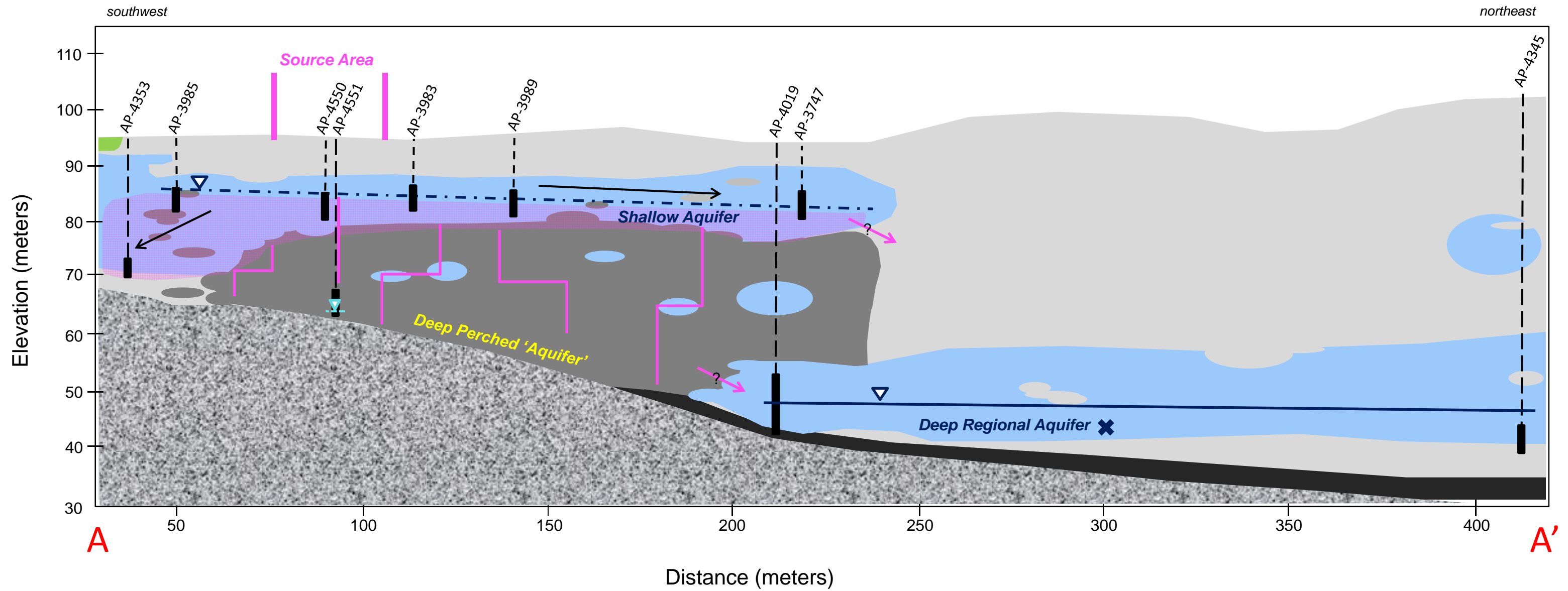
- the mixing zone
- by migrating vertically beyond the extent of the till and
- via a diffusive process through the till

The confining till is absent within the “mixing zone” which is located slightly up-gradient of the source area and adjacent to the wetland. As a result contaminants can migrate downward in the mixing zone. AP-4353, located within this zone, is screened below the shallow aquifer and has consistent concentrations of 1,1,2,2-PCA and TCE above MCL as well as groundwater trends similar to the shallow aquifer. Based on chemical and groundwater elevation data, groundwater migrates vertically from the shallow aquifer and mixes with deeper groundwater near the wetland. This deep groundwater then migrates east around the deep perched aquifer where it eventually flows northwest with the regional gradient (Figure 10c). AP-4349 and AP-4348 are deep wells located downgradient of AP-4353. Contaminant concentrations here were measured once in June 2003 and again at AP-4349 in October 2010. These wells have very low contaminant concentrations suggesting this pathway is viable; however the concentrations were below MCLs and appear to be diluted significantly.

Another pathway, termed the “vertical migration pathway” would allow contaminated groundwater from the shallow aquifer to migrate downward where the confining till pinches out. The location of where this occurs is not known, but existing chemical and boring data suggest it this occurs north/northeast of AP-3747/AP-4019 (Figure 10a).

As mentioned above if contamination is migrating through the till to the deep perched aquifer there could be a slow diffusive pathway that would result in the introduction of this contamination to the regional aquifer.

While contaminant concentrations have declined several orders of magnitude from pre-treatment levels in the source area, the residual contamination is sufficient to maintain dissolved plumes that exceed standards. As a result, contaminant levels will likely remain above MCLs in the source area within the shallow aquifer. Since there are pathways with the potential to introduce contaminants to the regional aquifer, continued sampling of the regional aquifer is of primary importance.



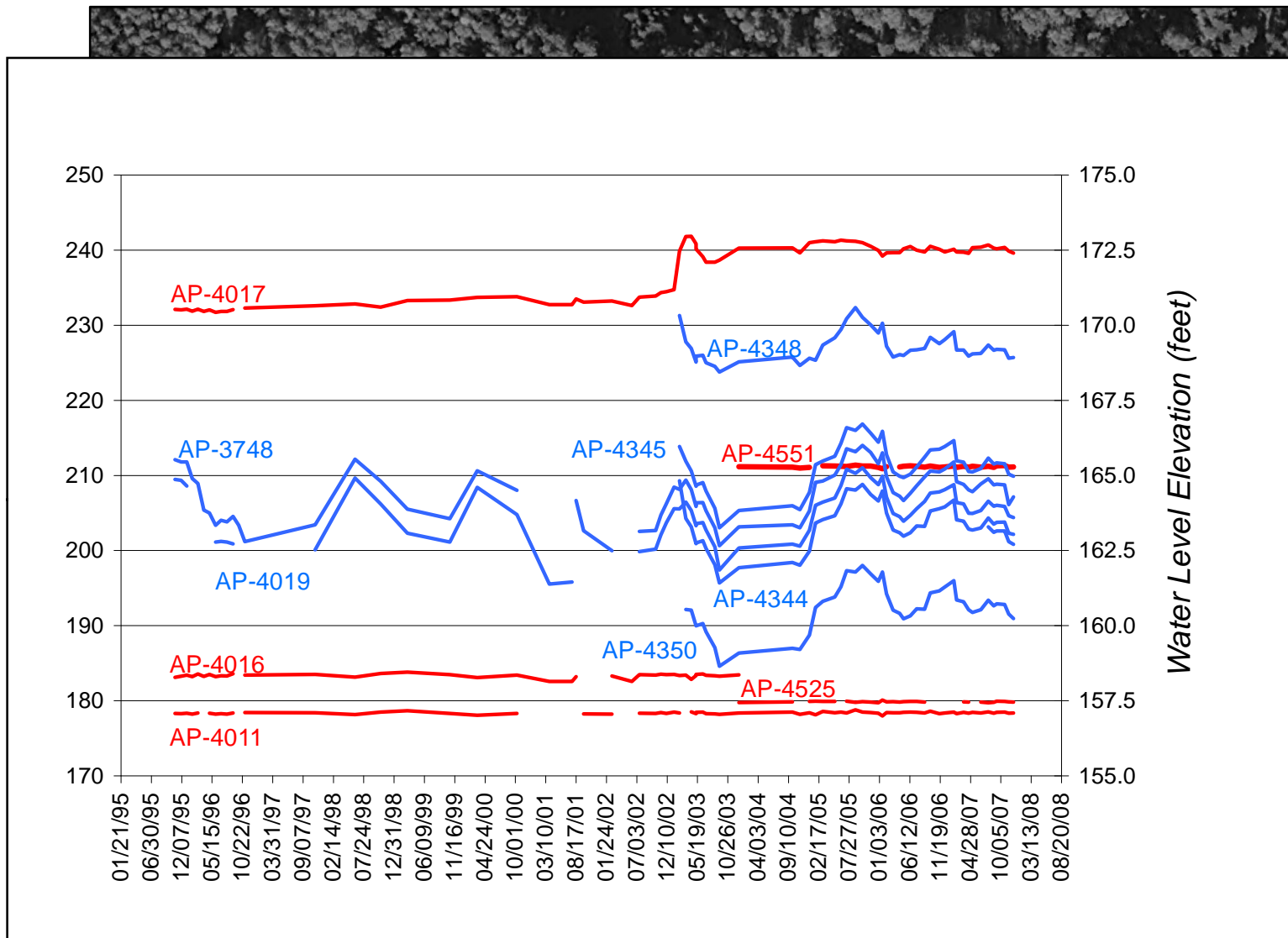
**LEGEND**

<b>CROSS SECTION</b>	<b>SHALLOW AQUIFER</b>
Wetland	Groundwater Table
Aquifer Extent, Permeable	Direction of groundwater flow
Sediments	
Less Permeable	
Sediments	<b>DEEP REGIONAL AQUIFER</b>
Confining Unit (Till)	Potentiometric Surface
Basal Silt	Groundwater flows in to the page
Bedrock	<b>DEEP PERCHED AQUIFER</b>
<b>CONTAMINATION</b>	Measured Water Level
Potential Contaminant Migration Pathway	
Extent of Dissolved Plume	

PRDA CREEL Summary Report

Figure 10a Conceptual Site Model

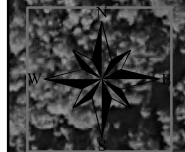
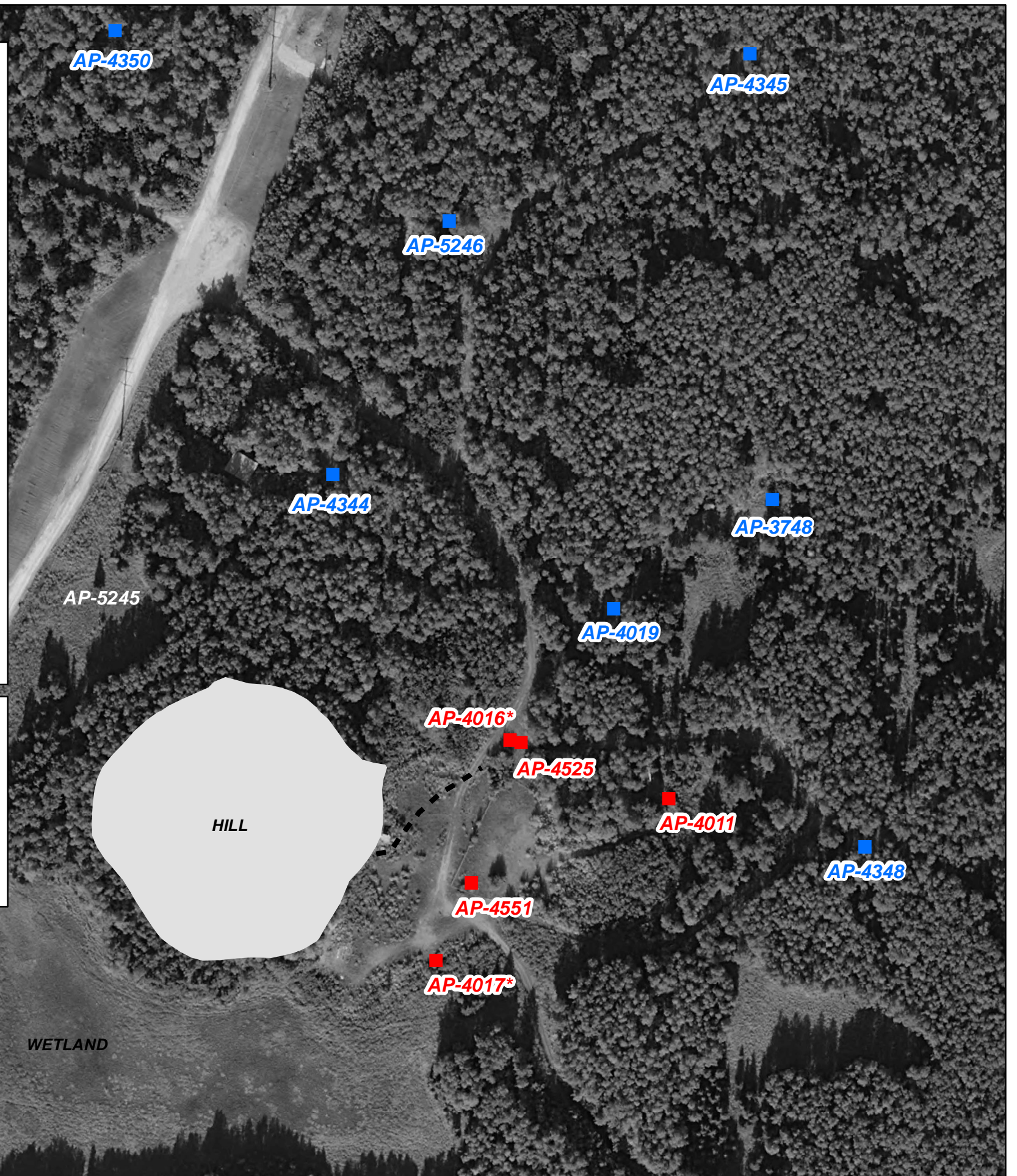
CREEL Opala ENVIRONMENTAL LLC



**SEASONAL VARIATION (feet)**

1996	2007
AP-4011: 0.2	AP-4011: 0.3
AP-4016: 0.4	AP-4016: NA
AP-4017: 0.6	AP-4017: 8.0*
AP-3748: 2.7	AP-4525: 0.2
AP-4019: 1.9	AP-4551: 0.2
AP-3748: 1.4	AP-3748: 1.4
AP-4019: 1.1	AP-4019: 1.1
AP-4344: 1.1	AP-4344: 1.1
AP-4345: 1.2	AP-4345: 1.2
AP-4348: 0.9	AP-4348: 0.9

**\*NOTE:**  
 1. AP-4017 was damaged in the 2002 earthquake and will be decommissioned  
 2. AP-4016 was decommissioned and replaced with AP-4525



**LEGEND**

<span style="color: blue;">■</span> Deep Regional Aquifer Well (seasonal groundwater variation)	<span style="color: red;">■</span> Deep Perched Aquifer Well (no groundwater variation)	<span style="border: 1px solid black; display: inline-block; width: 15px; height: 15px;"></span> No Groundwater Encountered	- - - Shallow No-Flow Boundary
---	---	---	--------------------------------

0 10 20 40 60 80 Meters

0 35 70 140 210 280 Feet

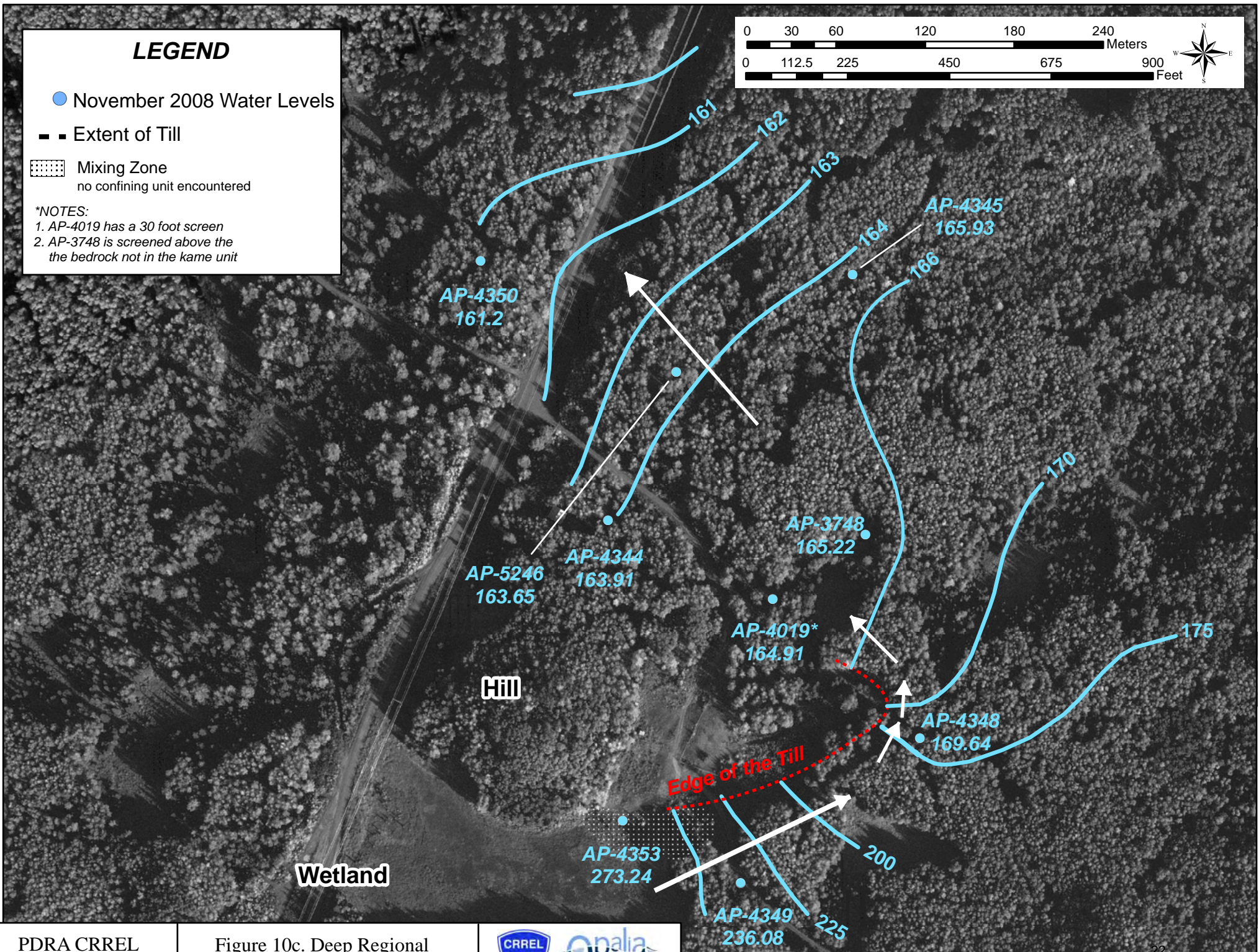
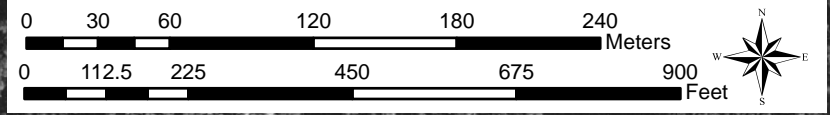
# LEGEND

● November 2008 Water Levels

■ ■ Extent of Till

▨ Mixing Zone  
no confining unit encountered

- \*NOTES:  
 1. AP-4019 has a 30 foot screen  
 2. AP-3748 is screened above the the bedrock not in the same unit

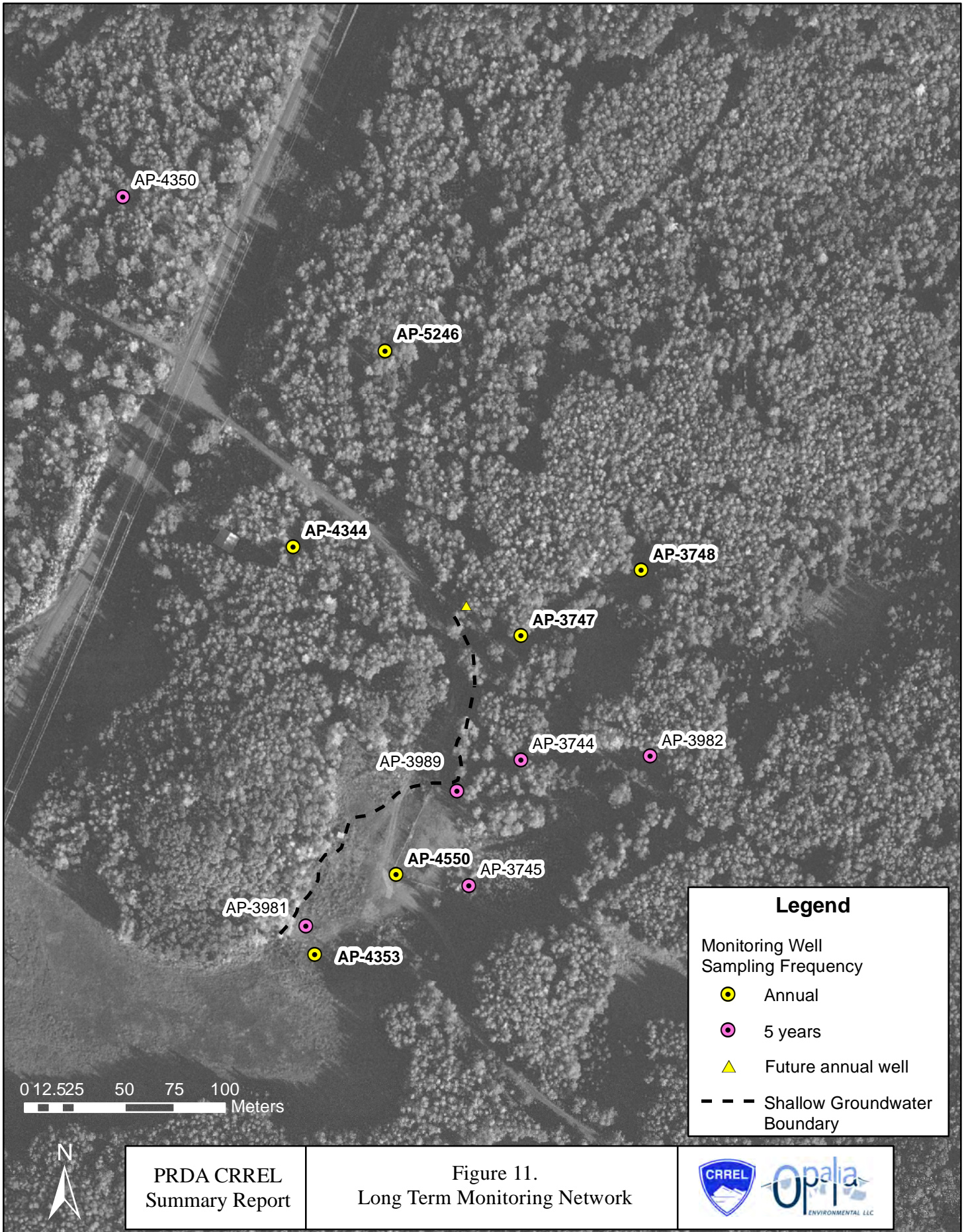


## **RECOMMENDATIONS**

A Long-Term Monitoring Plan was completed in 2010 based on a comprehensive analysis of hydrology and contaminant trends at PRDA. This work confirms the lack of complete exposure pathways present at this site. The long-term monitoring network is shown in Figure 11 and more detailed recommendations for each well are contained in Appendix A. As long-term monitoring goes forward there are several points to consider. Below are recommendations for future work as it relates to long-term monitoring of this site.

### **Monitoring Reports**

This new conceptual site model presented in this report should be incorporated in to the yearly monitoring reports and updated as new data is collected. Recent monitoring reports refer to the old CSM and discuss trends in wells determined to be damaged.



## **Trend Analysis**

Evaluating trends in groundwater quality data is an important component of the long-term monitoring plan. The Mann-Kendall test is a non-parametric statistical procedure that is well suited for analyzing trends in data over time (Gilbert, 1987). The test results determine if concentrations within a well are increasing, decreasing or stable over time. A Mann-Kendall test is currently performed annually using the entire data set available at select wells for the PRDA. The Mann-Kendall test should not be used when seasonal variation is apparent in the data as is the case at the PRDA. We recommend continuing with the trend analysis but using only the fall data points from the post-initial treatment data set starting in the fall of 2000 (the 2002 remediation did not appear to effect dissolved contamination). Some wells that currently show no trend using the entire data set would likely show stable or decreasing trends if only fall data were used in the trend analysis.

Future contractors who monitor groundwater at PRDA should identify when detection limits changed historically to avoid false trends as well as define how to handle non-detects. For example, the contractor would need to decide when a non-detect should be input as the detection limit or half the detection limit. If this is not addressed the following scenario is possible:

*A well that had been measured as non-detect with a detection limit of 1 is assigned a contaminant value equal to 1/2 the non-detect for the analysis and shows a stable trend over time. At some point the detection limit changes to 0.5 and now trace values are measured (0.6, 0.8 etc). If the 1/2 detection limit method is used on the data, the result could suggest an increasing trend that is not real.*

Inspection of the data may reveal the issue but these types of changes should be identified up-front to avoid false trends.

## **Outstanding Issues**

The specific analyses for annual versus 5-year sampling still need to be defined. In addition the frequency of geochemical sampling used to help evaluate natural attenuation needs to be determined.

The following information should be incorporated into subsequent monitoring reports to guide trend analysis and to avoid misleading trends.

1. AP-4017 data should not be used after November 2002 when the well was damaged by an earthquake.
2. AP-3983 data should not be used after April 2010 when the well was damaged due to frost jacking.
3. AP-4019 has a 30-foot screen and therefore the chemical results may not be comparable to other deep regional wells. In 2010, Army project managers decided to replace AP-4019 with a replacement well containing a 10-foot screen. AP-4019 should not be sampled as part of the LTM Plan unless it is replaced.

## **BIBLIOGRAPHY**

- Astley, B.N., A. Staples, and C. Snyder (2012) Hydrologic Assessment and Water Level Records for the Poleline Road Disposal Area 1995-2011, Fort Richardson Alaska. ERDC-CRREL Letter Report 12-06.
- Astley, B.N., C. F. Snyder, D.E. Lawson, C.R. Williams, T.J. Hall, J. Denner (2000) Ground water data from Fort Richardson, Alaska, for the period April 1997 to March 2000. CRREL Draft Report, Prepared for US ARMY Alaska Dir. of Public Works, Fort Richardson, AK 99505.
- Gilbert, R.O. (1987) Statistical Methods for Environmental Pollution Monitoring, van Norstrand Reinhold, New York.
- Hunter, L.E., D.E. Lawson, S.R. Bigl, P.B. Robinson, and J. D. Schlagel (2000a) Glacial geology and stratigraphy of Fort Richardson, Alaska: A review of available data on the hydrogeology. Hanover, ERDC/CRREL Technical Report TR-00-3
- Hunter, L.E., D.E. Lawson, S.R. Bigl, B.N. Astley, C.F. Snyder, and F.E. Perron, Jr. (2000b) Geological investigations and hydrogeological model of Fort Richardson, Alaska. Hanover, ERDC/CRREL Technical Report TR-00-18
- Kopczynski, S.E., C. Snyder, and B. Astley (2008) Refined Geologic Interpretations from June 2007 Drilling (AP-5245, AP-5246) Poleline Road Disposal Area, Operable Unit B, Fort Richardson, Alaska. Prepared for U.S. Army Alaska Directorate of Public Works, Fort Richardson, Alaska
- Kopczynski, S.E., S.R. Bigl, G.S. Baker, J.V. Holmes, D.C. Finnegan, A.J. Delaney, and J.L. Andrews. (2003) Hydrogeology of the Poleline Road Disposal Area, OUB, Fort Richardson Alaska. CRREL Interim Draft Report. Prepared for U.S. Army Alaska Directorate of Public Works, Fort Richardson, Alaska
- Kopczynski, S.E. and D.E. Lawson (2001) Preliminary Hydrological Interpretations of the Poleline Road Disposal Area, Fort Richardson, Alaska. CRREL Interim Draft Report. Prepared for U.S. Army Alaska Directorate of Public Works, Fort Richardson, Alaska
- Kopczynski, Sarah. (2000) A hydrological model of groundwater flow: cantonment area Fort Richardson, Alaska. Masters Thesis, UNH. Prepared for U.S. Army Alaska Directorate of Public Works, Fort Richardson, AK.
- Snyder, C., S.E. Kopczunski, and B. Astley (2005) Refined 3D Geologic Model of the Poleline Road Disposal Area, Operable Unit B, Fort Richardson, Alaska. Prepared for U.S. Army Alaska Directorate of Public Works, Fort Richardson, Alaska.

USARAK (2003) Five-Year Review Report, First Five Year Review Report for Fort Richardson, Alaska. Prepared by U.S. Army Alaska Directorate of Public Works.

Woodward-Clyde (1996) Groundwater Flow Model Report, derived from Remedial Investigation Report, Operable Unit B, Poleline Road Disposal Area, Fort Richardson, Alaska. Prepared for USACE, Alaska District, September 1996.

Yehle, L.A. and H.R. Schmoll (1989) Surficial geologic map of the Anchorage B-7 SW quadrangle, Alaska. Anchorage, AK: U.S. Geological Survey, Open-File Report 89-318.

## **FIGURES**

Figure 1. Site Location, Source Area, Treatment Areas and Potential Receptor

Figure 2. Generalized Hydrogeologic Cross Section the Chugach Mountains to Knik Arm on JBER

Figure 3. 2010 Monitoring wells by aquifer

Figure 4. Water elevation trends

Figure 5. Geology Model Input

Figure 6. November 1997 and October 2009 PCE, 1,1,2,2-PCA and TCE Plumes

Figure 7. 2009 PCE, 1,1,2,2-PCA and TCE Plumes

Figure 8. Seasonal Trends in PCA Plumes

Figure 9. Seasonal Trends in TCE Plumes

Figure 10. Conceptual Site Model

Figure 10a: Conceptual Site Cross Section

Figure 10b: Deep Perched Aquifer

Figure 10c: Deep Regional aquifer

Figure 11. Long-Term Monitoring Network

# **Appendix A**

## Monitoring Well Evaluation for Long Term Monitoring

## Appendix A: Monitoring Well Evaluation for Long Term Monitoring

### Long-Term Monitoring Objectives

The shallow aquifer at PRDA has been sufficiently characterized to conclude that further intensive monitoring will not result in new findings. Emphasis should be placed on monitoring the contamination in the regional aquifer while maintaining a few wells in the shallow aquifer to monitor trends in the source area. If contaminant concentrations increase significantly in the source area, additional wells could be sampled to verify trends and to determine changes to plume concentrations and spatial extent. Sampling should occur when the regional water table is at its annual peak when possible (usually in the fall) to ensure the maximum concentrations are being monitored long-term.

### Long-Term Monitoring Network

As part of the long-term monitoring plan, each monitoring well location was reviewed for inclusion in the long-term monitoring network. The decision to include a well in the long-term monitoring network was based on historical contaminant concentrations, well screen depth and interval, aquifer, water level records, and well condition. Justification for each well selection is discussed below.

The proposed long-term monitoring network will sufficiently monitor changes in the down-gradient regional aquifer; the only known exposure pathway. The source area is in a locally perched aquifer. Limited annual sampling is all that is necessary to monitor changes in the source area as there is no direct pathway for exposure. Wells included for sampling prior to the CERCLA 5-year review will provide a more comprehensive look at the source area.

PRDA monitoring wells are shown in Figure 3. Wells recommended for long-term monitoring are shown in Figure 11 and listed in Tables A1 (annual sampling) and A2 (5-year sampling). Wells recommended for decommissioning are listed in Table A3. Table A4 contains wells that should be maintained until they are no longer needed as contingency wells. Contingency wells could be sampled in the future in the event that site conditions change or contaminant concentrations increase. The value of these wells could be reviewed as part of the 5-year review process.

### Down-gradient Wells

**AP-3747** is the furthest down-gradient shallow well with contaminant exceedances; they vary from ND to above MCLs. Changes in concentrations in this area are important to understanding the potential for changes in migration of contaminants beyond the shallow aquifer. This well is recommended for **annual** sampling.

Data suggest the shallow aquifer pinches out north of AP-3747 where contamination most likely migrates downward. Once contaminants reach the regional aquifer they are diluted by at least an order of magnitude. Continued sampling of down-gradient regional wells will identify changes in contamination migration pathways.

**AP-3748** is a regional well down-gradient of the source area where trace contamination has been detected historically. This well is recommended for **annual** sampling.

**AP-4344** is a regional well down-gradient of the source area where TCE consistently exceeds the MCL. Changes in concentrations in this area are important to understanding changes in contaminant behavior in the regional aquifer. This well is recommended for **annual** sampling.

**AP-5246** is a regional well down-gradient of the source area where trace contamination was detected after the well was installed. This well is recommended for **annual** sampling.

**AP-4353** is screened at greater depth than wells in the source area and has consistent contaminant exceedances suggesting downward vertical migration of contamination. Therefore,

continued monitoring of AP-4353 is warranted and if contaminant concentrations begin increasing in this well other down-gradient wells (specifically AP-4349) could be sampled. This well should be sampled **annually**. After the AP-4019 replacement well is completed, the frequency of sampling at AP-4353 should be re-evaluated to determine if sampling prior to the 5-year review is sufficient.

**New Well** A new well is recommended in the vicinity of AP-4019. AP-4019 is a deep regional with a 30-foot screen interval that should be decommissioned. The inclusion of the new well in the long term sampling network would depend on the chemical results.

AP-3982 is a shallow well located to the east of the current contaminant plumes but historically was the eastern edge of the plume. No contaminants are currently detected here. This well should be monitored periodically as a sentry well. This well should be sampled **prior to the 5-year review**.

AP-4350 is the furthest down-gradient regional well, contamination has never been detected at this location. This well should be monitored periodically as a sentry well. This well should be sampled **prior to the 5-year review**.

AP-4347 is down-gradient and screened in the regional aquifer, it is recommended this well is kept as a contingency location to be sampled if concentrations in AP-4353 begin to increase.

AP-4349 is down-gradient of AP-4353 and screened in the regional aquifer, it is recommended this well is kept as a contingency location to be sampled if concentrations in AP-4353 begin to increase.

AP-4345 is screened in the regional aquifer and contamination has never been detected at this location. This well is not in the down-gradient direction but could be kept as a contingency well.

AP-4551 is screened in the deep perched aquifer. It is not recommended for sampling but can be retained as a contingency well in case it becomes necessary to monitor concentrations in the till.

### **Source Area Wells**

There are several wells located in the source area. While it is important to maintain an understanding of trends in the source area, the objective of the long-term network is to monitor changes down-gradient of the source area.

**AP-4550** is located in the hot spot and currently has the highest contaminant concentrations observed in the shallow aquifer. Continued monitoring of this well is important to understanding changing trends in the source area. This well is recommended for **annual** sampling.

AP-3744, AP-3745, and AP-3981 and AP-3989: In the event increasing concentrations are observed in AP-4550 these wells can be sampled to quantify changes in the plume configuration. It is recommended these wells are sampled **prior to the 5-year review**.

- a. AP-3981 is located near the southwestern edge of the hot spot. Contaminant concentrations here are relatively low. AP-3981 has a long record and will provide a representative sample near the up-gradient edge of the hot spot.
- b. AP-3744 and AP-3745 help to delineate the edge of the shallow contaminant plumes to the northeast and east respectively.
- c. AP-3989 is near the down-gradient edge of the hot spot but up-gradient of the plume edge

### **Other Source Area Wells:**

These wells are **not recommended for continued monitoring** but not recommended for decommissioning at this time. If no changes are observed prior to the next 5-year review these wells could be considered for decommissioning.

- a. AP-3985 and AP-4354 are located near the southwestern edge of the hot spot. Contaminant concentrations in these wells are relatively low. Sampling of AP-3985 and AP-4354 should be suspended. AP-3981 provides a representative sample in this area.
- b. AP-3984 and AP-3986 are also located in the hot spot. AP-4550 adequately represents the hot spot. These wells are not recommended for continued sampling.
- c. AP-4022 is located at the base of the "hill" within the hot spot and could be sampled after an event that could release product from the soil such as a significant earthquake.
- d. AP-4519 replaced well AP-4015 which previously contained the highest contaminant concentrations observed in the source area. AP-4519 is screened deeper than AP-4015 and has lower concentrations than were observed in AP-4015. This well is not necessary for annual sampling because trends in the source area can be evaluated based on AP-4550.
- e. AP-4518 is southeast of the source area and was a replacement well for AP-4013. This well could be sampled in the event of changes in the source area.

**Other Wells**

AP-3749 and AP-4355 are located southeast of the source area. These wells are up-gradient from the source area and are not contaminated. Continued sampling of these wells is not recommended except to evaluate hydrologic changes up-gradient.

<b>Table A1. Wells recommended for Annual Sampling</b>				
Monitoring Well ID	Aquifer	Screened Interval (feet bgs)	Total Depth (feet below TOC)* (2009)	Depth to Groundwater (feet below TOC) (October 2009)
AP-3747	Shallow	20.0-30.0	32.2	28.17
AP-3748	Deep	164.9-169.9	171.6	135.37
AP-4344	Deep	152.1-162.1	163.5	151.67
AP-4353**	Shallow	57.0-67.0	70	33.33
AP-4550	Shallow	32.0-42.0	43	27.1
AP-5246	Deep	148.0-158.0	161	152.1
<i>New well</i>	Deep	NA	NA	NA

\* Total depths from field survey conducted in spring 2009.

\*\*screened in the shallow aquifer below the groundwater table

New well will replace AP-4019.

<b>Table A2. Wells recommended for Five Year Sampling (2012 and at succeeding 5-year reviews)</b>				
Monitoring Well ID	Aquifer	Screened Interval (feet bgs)	Total Depth (feet below TOC)* (2009)	Depth to Groundwater (feet below TOC) (October 2009)
AP-3744	Shallow	26.5-36.5	37.6	29.76
AP-3745	Shallow	18.0-28.0	29.8	23.5
AP-3981	Shallow	29.0-39.0	40.7	25.14
AP-3982	Shallow	24.0-34.0	32	28.25
AP-3989	Shallow	24.0-34.0	36.3	29.83
AP-4350	Deep	176.3-186.3	188.6	150.06

\* Total depths from field survey conducted in spring 2009.

<b>Table A3. Monitoring Well Network: Wells to be Decommissioned</b>					
Monitoring Well ID	Aquifer	Screened Interval (feet bgs)	Total Depth (feet below TOC)* (2009)	Depth to Groundwater (feet below TOC) (October 2009)	Reason to Decommission
AP-3746	Shallow	9.0 -19.0	23.5	dry	not enough water to sample, bentonite in screen
AP-3983	Shallow	18.0-28.0	30.3	25.97	damaged in 2010
AP-4011	Deep	111.2-137.3	138.4	121.92	screened in till, 26-foot screen
AP-4012	Shallow	12.8-38.35	39.18	22.03	always ND, AP-3982 could be used instead
AP-4014	Other	49.3-59.3	59.85	dry	usually dry well, screened in till
AP-4017	Deep	76.0-96.0	98.2	66.32	damaged in 2002, screened in till
AP-4019	Deep	130.0-150.4	153	138.2	30-foot well screen
AP-4021	Perched	59-89.3	90.08	89.96	usually dry well, perched water table
AP-4348	Deep	141-151	153.54	138.16	damaged in 2010
AP-4351	Shallow	38.5-48.5	50.83	30.6	AP-4518 is sufficient to monitor changes in this direction
AP-4352	Perched	20.3-30.3	33	dry	usually dry well, perched water table
AP-4521	Perched	10-20	22.8	22.75	not enough water to sample
AP-4522	Perched	9.3-19.3	22.1	21.94	not enough water to sample
AP-4523	Perched	9.3-19.3	31.5	NS	not enough water to sample
AP-4524	Perched	9.9-19.9	22.69	22.42	not enough water to sample
AP-4525	Deep	113.0-123.0	127	126.56	not enough water to sample, screened in till

NS = not sampled

\* Total depths from field survey conducted in spring 2009.

<b>Table A4. Monitoring Well Network: Contingency Wells</b>					
Monitoring Well ID	Aquifer	Screened Interval (feet bgs)	Total Depth (feet below TOC)* (2009)	Depth to Groundwater (feet below TOC) (October 2009)	Future Well Use
AP-3749	Shallow	12.0-22.0	24.6	22.25	evaluate hydrologic changes up-gradient
AP-3984	Shallow	20.0-30.0	32.5	29.46	evaluate changes in source area
AP-3985	Shallow	22.0-32.0	32.6	27.28	evaluate changes in source area
AP-3986	Shallow	23.0-33.0	36.3	27.06	evaluate changes in source area
AP-4022	Shallow	29.0-33.0	34.55	32.3	use to detect new product releases from base of hill (such as after an earthquake)
AP-4345	Deep	149.0-161.0	186.5	157.74	evaluate down-gradient changes
AP-4347	Shallow	34-44	46	38.54	Sample if AP-4353 increases
AP-4349	Deep	70.8-80.8	180.39	76.57	Sample if AP-4353 increases
AP-4354	Shallow	7.4-17.4	18	12.5	evaluate changes in source area
AP-4355	Shallow	75.5-85.5	88.23	25.49	evaluate hydrologic changes up-gradient
AP-4518	Shallow**	33.6-43.6	46.8	27.19	evaluate changes southeast of source area
AP-4519	Shallow	33.9-43.9	47.1	27.22	evaluate changes in source area
AP-4551	Deep	87.7-97.7	98.3	95.84	monitor changes in deep perched aquifer

\* Total depths from field survey conducted in spring 2009.

\*\*screened in shallow aquifer but below the groundwater table