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Oak Ridge, Tennessee

Natural and Accelerated Bioremediation Research (NABIR) Field Research Center (FRC) Site Characterization Plan

Revised April 2001

UT-BATTELLE
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Environmental Sciences Division

Natural and Accelerated Bioremediation Research (NABIR) Field Research Center (FRC) Site Characterization Plan

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ACRONYMS

BY/BY	BoneYard/Burn Yard
CERCLA	Comprehensive Environmental Restoration, Compensation, and Liability Act
DC	Direct Conductivity
DO	Dissolved Oxygen
DOE	Department of Energy
ESD	Environmental Sciences Division
FRC	Field Research Center
NABIR	Natural and Accelerated Bioremediation Research
QA/QC	Quality Assurance/Quality Control
RI	Remedial Investigation
SAA	Satellite Accumulation Area
VOC	Volatile Organic Compound

1. INTRODUCTION

The Environmental Sciences Division (ESD) at the Oak Ridge National Laboratory has established a Field Research Center (FRC) on the U.S. Department of Energy (DOE) Oak Ridge Reservation in Tennessee for the DOE Headquarters Office of Biological and Environmental Research. The FRC provides a site for investigators in the Natural and Accelerated Bioremediation Research (NABIR) program to conduct research and obtain samples related to in situ bioremediation. The NABIR program is designed to increase the understanding of fundamental biogeochemical approaches for cleaning up DOE's contaminated legacy waste sites. The FRC is integrated with existing and future laboratory and field research and provides a means of examining the biogeochemical processes that influence bioremediation under controlled, small-scale field conditions.

The FRC lies within the Y-12 Plant area of responsibility on the Oak Ridge Reservation (Fig. 1.1). The Y-12 Plant is located in Bear Creek Valley adjacent to the city of Oak Ridge.

The FRC includes a 243-acre (98-ha), previously disturbed contaminated area to be used for conducting experiments on a plume of contaminated groundwater. The FRC also includes a 404-acre (163-ha) background area (Fig. 1.1), which provides for comparison studies in an uncontaminated area, and ancillary structures located within a 3.2-mile (5.2-km) radius of each other on the Oak Ridge Reservation.

1.1 PURPOSE AND ORGANIZATION

The purpose of this document is to describe the site characterization activities to be conducted by FRC staff at the Bear Creek Valley FRC in fiscal years 2000 and early 2001. NABIR Investigators will also conduct more detailed site characterization work, however, their activities will be described in separate work plans and are not within the scope of this document.

A description of the Bear Creek Valley geology and hydrology, and site conditions and existing data available for the background and contaminated areas is provided in Sect. 2. Tasks associated with the two phases of work to be conducted as part of the site characterization are described in Sect. 3. Sections 4 through 7 describe procedures for sampling, hydraulic characterization, field analyses, and laboratory analyses. Quality control measures are described in Sect. 8, and health and safety and waste management issues are discussed in Sects. 9 and 10, respectively.

In addition to this Site Characterization Plan, several other documents were developed that provide specific information on how work will be conducted at the FRC including the FRC Management Plan, which describes the roles and responsibilities of interested parties and regulatory requirements for working at the site; the FRC Quality Assurance Plan, which outlines Quality Assurance/Quality Control (QA/QC) measures and data management procedures, and describes the chain of custody, sample handling, labeling, and tracking procedures that will be used to maintain sample quality; and the FRC Health and Safety Plan, which describes health and safety measures that will be adhered to when conducting field work at the site.

1.2 OBJECTIVES

The contaminated site includes the commingled groundwater plume found in the shallow unconsolidated sediments (<10 m depth), in the Nolichucky Shale, and in the Maynardville Limestone that originated from Y-12's S-3 Waste Disposal Ponds and Bone Yard/Burn Yard. However, the initial focus of NABIR investigations is on the shallow, easily accessible unconsolidated sediments that overlie the Nolichucky Shale. Contaminants in this plume and in the shallow saturated and unsaturated sediment include uranium, Tc-99, stable strontium, nitrate, barium, cadmium, volatile organic contaminants and other inorganics and radionuclides of interest to NABIR investigators. Initially, test plots of approximately one-half to one-quarter acre situated in proximity to the S-3 Ponds parking lot (Fig. 1.2) are slated for use by NABIR projects. As the NABIR investigations proceed, other test plots are targeted for use farther down Bear Creek Valley and within the background area. The site characterization work discussed in this plan is primarily focused on the collection of preliminary characterization data from the areas around the S-3 Ponds site. As NABIR projects expand to new test plots, additional characterization data will be collected as needed.

- The objectives of the site characterization work are as follows:
- Obtain data necessary for selection of field sites with a high probability of success for NABIR projects at the field scale.
- Determine the extent and concentration of uranium and nitrate; and
- Establish the basic hydraulic and biogeochemical characteristics of potential sites (with suitable contaminant concentrations and plume definition).
- Provide potential NABIR investigators with the information needed to design experiments and determine whether a site is suitable for their proposed project.
- The activities documented in this plan are primarily focused on characterization of the contaminated site, and on providing the degree of characterization necessary for initial experimental design. It is not intended to be all-inclusive, and it is expected that NABIR investigators will conduct their own detailed characterization where additional data are required.

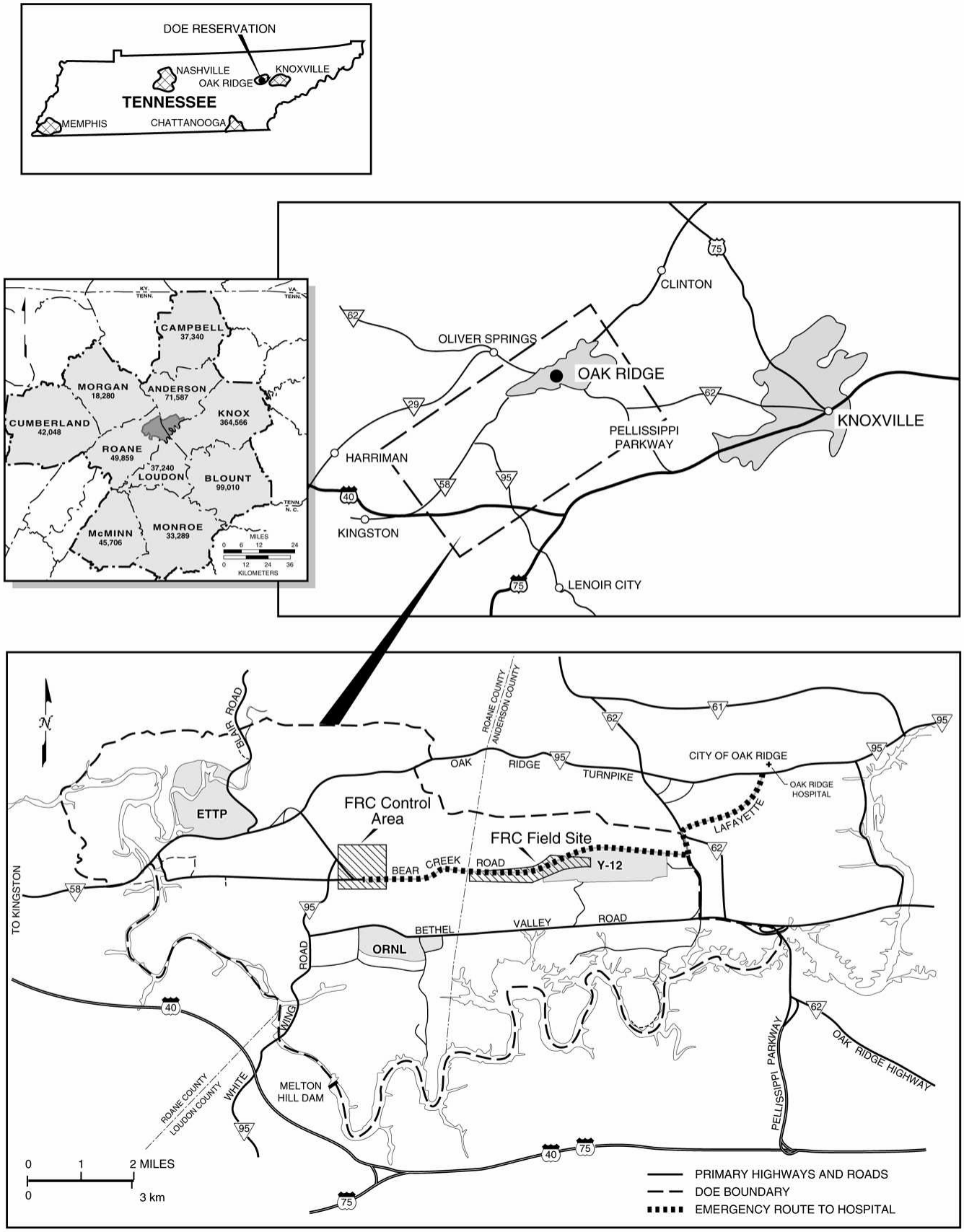


Fig. 1.1. Location of the FRC in Oak Ridge, Tennessee.

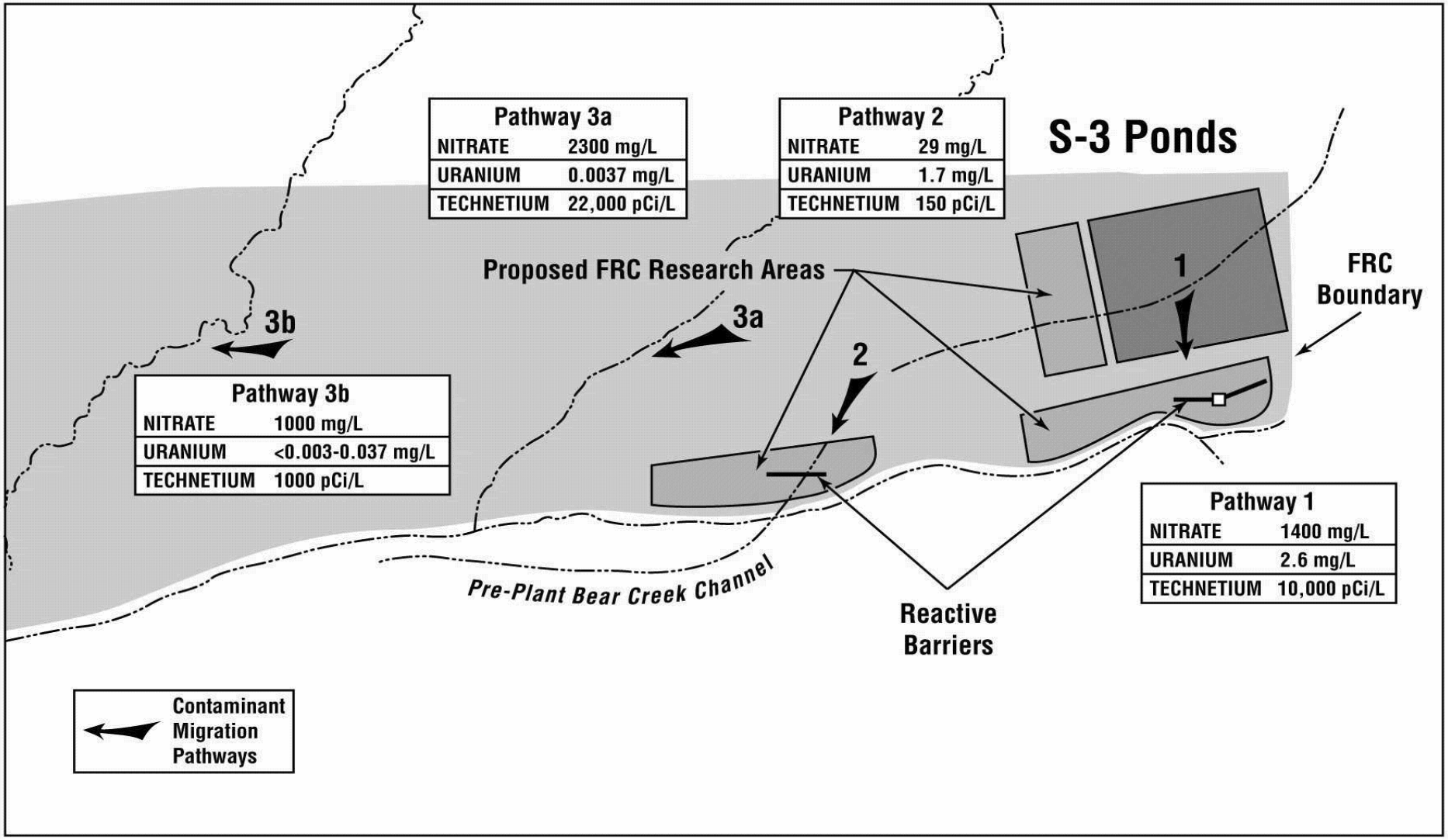


Figure 1.2. S-3 ponds contaminant migration pathways and proposed research plots.

2. BACKGROUND

2.1 GEOLOGY

The geology of Bear Creek Valley displays an inclined layer-cake-style stratigraphy that is observed on a regional scale where limestone- and dolomite-dominated rock groups are interbedded with predominantly clastic shale groups, and on the scale of outcrops where clastic beds are interlayered with carbonate beds. The orientation of geologic units is parallel and coincident to the valleys and ridges. Three primary fracture sets have been identified: parallel to bedding, perpendicular to bedding along strike, and vertical parallel to dip (Dreier et al. 1987; Solomon et al. 1992). Additional fracture sets may also exist, and local deformation may alter the orientation of the fracture sets relative to the regional structural grain. Fracture density ranges from about 15 to 30 fractures per meter based on rock coring and geophysical logging (Lee et al. 1992).

Bear Creek Valley is underlain by rocks of three regionally important stratigraphic units: the Rome Formation, the Conasauga Group, and the Knox Group that typically dip 45 degrees to the southeast and has a geologic strike of N55E. All of these rocks were formed over 500 million years ago in the Cambrian geologic age. General descriptions of the stratigraphy of geological units on the Oak Ridge Reservation are provided in the Bear Creek Valley Remedial Investigation (RI) Report (DOE 1997) and Hatcher et al. (1992). These units can be grouped into those that are mainly clastic (i.e., shales) and generally have lower permeability, and those that are mainly carbonates and are generally more permeable (Solomon et al. 1992).

The Rome Formation and the Conasauga Group crop out in Bear Creek Valley on Pine Ridge and dip to the southeast beneath Bear Creek Valley. The primary geologic units of interest that underlie the FRC are the Maynardville Limestone 67-136 m (220-445 ft) thick and Nolichucky Shale 190 m (620 ft) thick, both of which are sub-units of the Conasauga Group. The Maynardville Limestone and Nolichucky Shale underlie both the FRC field site and control area. With the exception of the Maynardville Limestone, the Conasauga Group is a sequence of shale, siltstone, and thin-bedded limestone. Some formations, however, include laterally continuous limestone beds that can be several meters thick, and high permeability zones parallel to bedding planes may exist, especially where karstification has enlarged fractures in limestone beds. The Maynardville Limestone, the uppermost member of the Conasauga Group, is a massively bedded limestone and dolomite with fracturing and karstification. The Maynardville Limestone forms the floor of Bear Creek Valley and contains the channel of Bear Creek along most of the valley. The Nolichucky Shale is located just up slope and stratigraphically lower than the Maynardville Limestone. The Knox Group (i.e., Copper Ridge Dolomite) underlies and forms Chestnut Ridge, the southern boundary of Bear Creek Valley.

The primary porosity of the rocks underlying the field site is low, typically less than 2 percent in the Maynardville Limestone and approximately 10 percent in the Nolichucky Shales (Dorsch et. al. 1996, and Goldstrand 1995). The total porosity of the residuum is typically 30 to 50 percent. Diagenesis, fracturing, and in the case of the carbonates, solution weathering (i.e., karstification) of bedrock have resulted in secondary porosity and increased permeability through which most fluid movement occurs (Solomon et al. 1992). Shevenell and Beauchamp (1994) have shown that the occurrence of cavities in the Maynardville Limestone decreases significantly below a depth of approximately 23 m (75 ft). Below a depth of 23 m, water-bearing zones are generally associated with fractures. Cavities are generally filled with silt and range in size from <0.3 m (1 ft) to >3 m (10ft), although, over 70 percent of cavities are <1.2 m (5 ft).

Overlying the bedrock on the Oak Ridge Reservation is unconsolidated material that consists of weathered bedrock (referred to as residuum or saprolite), man-made fill, alluvium, and colluvium. Silty and clayey residuum comprises a majority of the unconsolidated material in this area. The depths to unweathered bedrock differ throughout the Oak Ridge Reservation because of the different thickness of fill and alluvium and the particular weathering characteristics of the bedrock units. The total thickness of these materials typically

ranges from 3 to 15 m (10 to 50 ft) (Hoos and Bailey 1986). The thickness of residuum overlying the Nolichucky shale within the FRC field sites is typically between 5 and 10 m (20 and 30 ft) thick. The average thickness of residuum overlying the Maynardville Limestone is typically less than 3 m (10 ft). Between the unconsolidated residuum and competent bedrock is a transition zone of weathered fractured bedrock. In general, the shales tend to be fissile while the carbonate interlayers are more resistant, imparting a "washboard" shape to the saprolite/bedrock interface. A thin veneer of organic- and clay-rich soil overlies the saprolite with a thickness of 0.5 to 3m (1.6 to 9.8 ft) that approximates the depth of the root zone. The soil layer thickens in undisturbed, wooded areas.

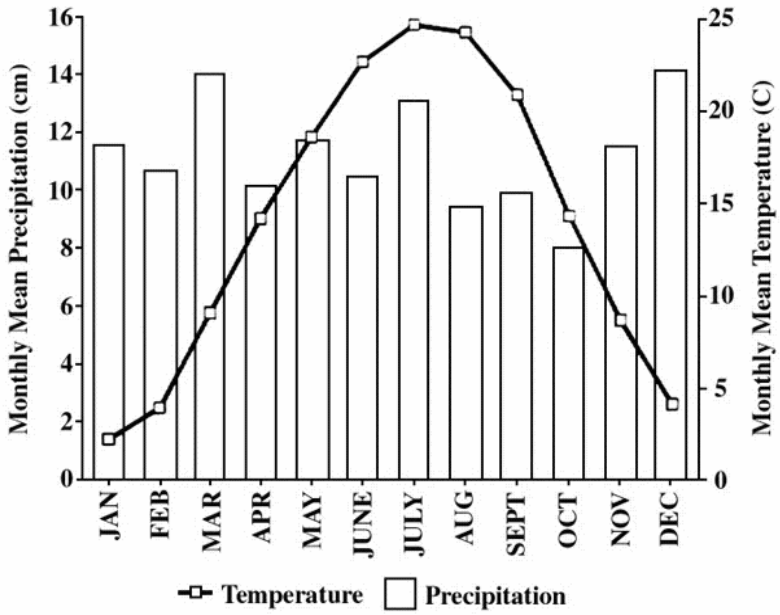
Mineralogical analyses conducted by Lee et al. (1991) and Schreiber (1995) show that the predominant minerals in the shales include illite, quartz, kaolinite, chlorite, calcite, and plagioclase feldspar. Schreiber (1995) identified fracture coatings of calcite, goethite, and kaolinite. The carbonates contain low-Mg calcite, dolomite, and ferroan dolomite (Foreman, 1991). The high clay content of the weathered saprolite creates a high porosity (30 to 50%), low permeability matrix that has an enormous impact on flow and transport characteristics since it serves as a source/sink through matrix diffusion during solute migration.

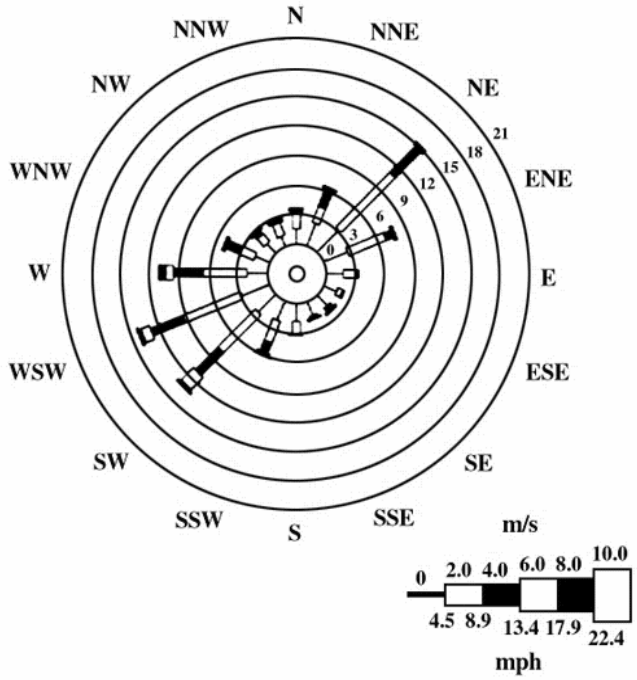
2.2 HYDROLOGY

The FRC receives an average of 137 cm of precipitation per year, much of it occurring in the winter months. Precipitation and other weather data are available from two permanent weather stations located on the east and west ends of Y-12, respectively. Monthly precipitation recorded from 1950-1995 is shown in Fig. 2.1.

Bear Creek flows down the middle of the site adjacent to Bear Creek Road. The flow in Bear Creek is supplemented by small tributaries originating on the southern slope of Pine Ridge and by springs emanating mainly from the base of Chestnut Ridge. The tributaries convey shallow groundwater that has discharged to the surface and stormflow. In its upper reaches, Bear Creek follows a relatively straight course along geologic strike close to the contact between the Maynardville Limestone and Nolichucky Shale. The original channel on the west side of the S-3 Ponds site was filled with rubble during pond construction and rerouted to its present location (Law Engineering 1983).

The hydrogeology of Bear Creek Valley differs significantly between the mainly clastic formations (i.e., the Nolichucky Shale) and mainly carbonate formations (i.e., the Maynardville Limestone). In Bear Creek Valley, the contact between the Maynardville Limestone and the Nolichucky Shale roughly corresponds to the axis of the valley and marks a major transition from predominantly lower permeability clastic formations to higher permeability carbonate dominant formations. Groundwater in the clastic formations generally migrates along-strike in the unconsolidated residuum, transition zone and/or bedrock until eventually discharging to a tributary of Bear Creek. This surface water can enter the Maynardville groundwater system through losing sections of Bear Creek. Figure 2.2 shows a conceptual model for the movement of groundwater, surface water and contaminants in Bear Creek Valley (Bear Creek Valley RI Report 1997).





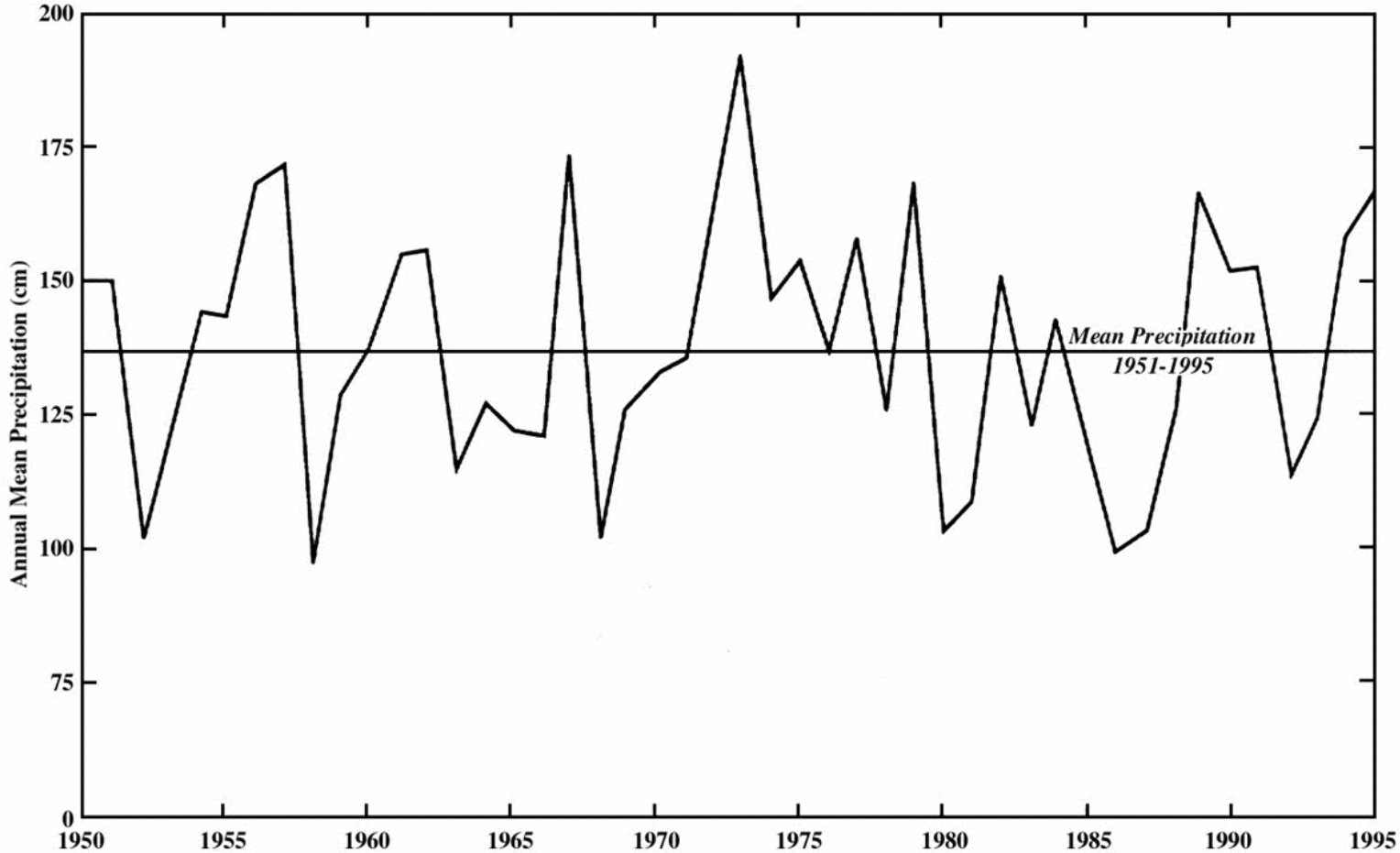


Figure 2.1 Meteorological data of ORR. (Source NOA)

The orientations of well-connected fractures or solution conduits are predominantly parallel to bedding planes (e.g., geological strike) and enhance the effect of anisotropy caused by layering. Remnants of this bedding plane fracturing are also present in the unconsolidated zone, which results in dominance of strike-parallel groundwater flow paths in both the unconsolidated zone and bedrock. Fracture aperture width generally decreases with depth in all formations and thus restricts the depth of active groundwater circulation. Active (or open) fractures occur at greater depths in the Knox Group and the Maynardville Limestone than in the shale members of the Conasauga Group, and therefore, active groundwater circulation is deeper in these carbonate formations (Fig. 2.2).

2.3 SITE CONDITIONS AND EXISTING DATA

Site conditions and existing data for the background and contaminated sites are described in greater detail in the following sections. Because the background and contaminated sites are located in similar hydrogeologic environments, the data presented is generally relevant to both sites.

2.3.1 Background site

The background site has been the target of a number of hydrologic investigations over the past 12 years. No known contaminants have been disposed in this location throughout the history of DOE operations. A majority of the wells were installed in 1987 as part of a hydrologic characterization activity to evaluate the site for proposed waste disposal facilities. As part of this investigation, four pumping tests (Gierke et al. 1988; Lee et al. 1992) and a dye tracer test (Lee et al. 1992) were conducted. Subsequently, the dye tracer site and a neighboring pumping test site were developed into three experimental field sites and additional instrumentation was added. The locations of these three sites are shown on Fig. 2.3; well locations within these sites are shown in Figs. 2.4 and 2.5. The purpose of the later activities was to evaluate flow and transport processes in fractured porous media and to determine their effect on representative sampling and monitoring. As part of these activities, additional wells, piezometers, and tensiometers were installed and extensive water level, water chemistry, precipitation, and transport data sets have been acquired.

Because of the large hydraulic conductivity contrast between the permeable soil and the underlying low permeability saprolite, a perched zone of saturation (stormflow zone) is created within a meter of the surface in non-developed zones. The majority of infiltrated water moves parallel to the land surface through this zone, discharging to local crosscutting streams (Solomon et al. 1992). The remaining recharge migrates both vertically (Solomon et al. 1992) and laterally (Moline et al. 1998) through saturated fractures to the water table zone. Within the upper 8.5 m, recharge fluxes have been estimated at between 0.2 and 0.4 m/yr with a mean vertical water velocity within the fractures of approximately 0.12 m/day based on CFC, tritium, and helium dating methods (Cook et al. 1996).

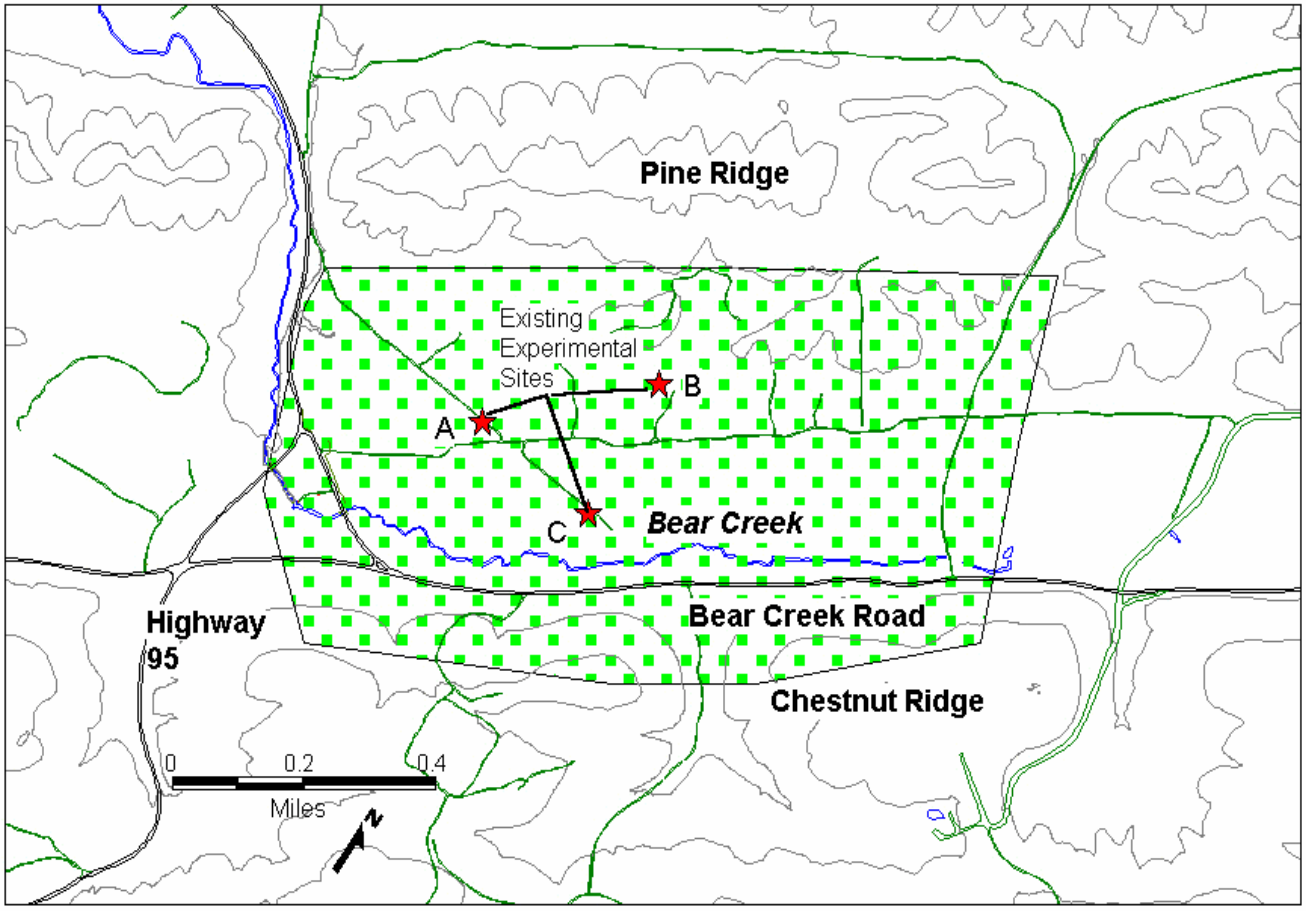
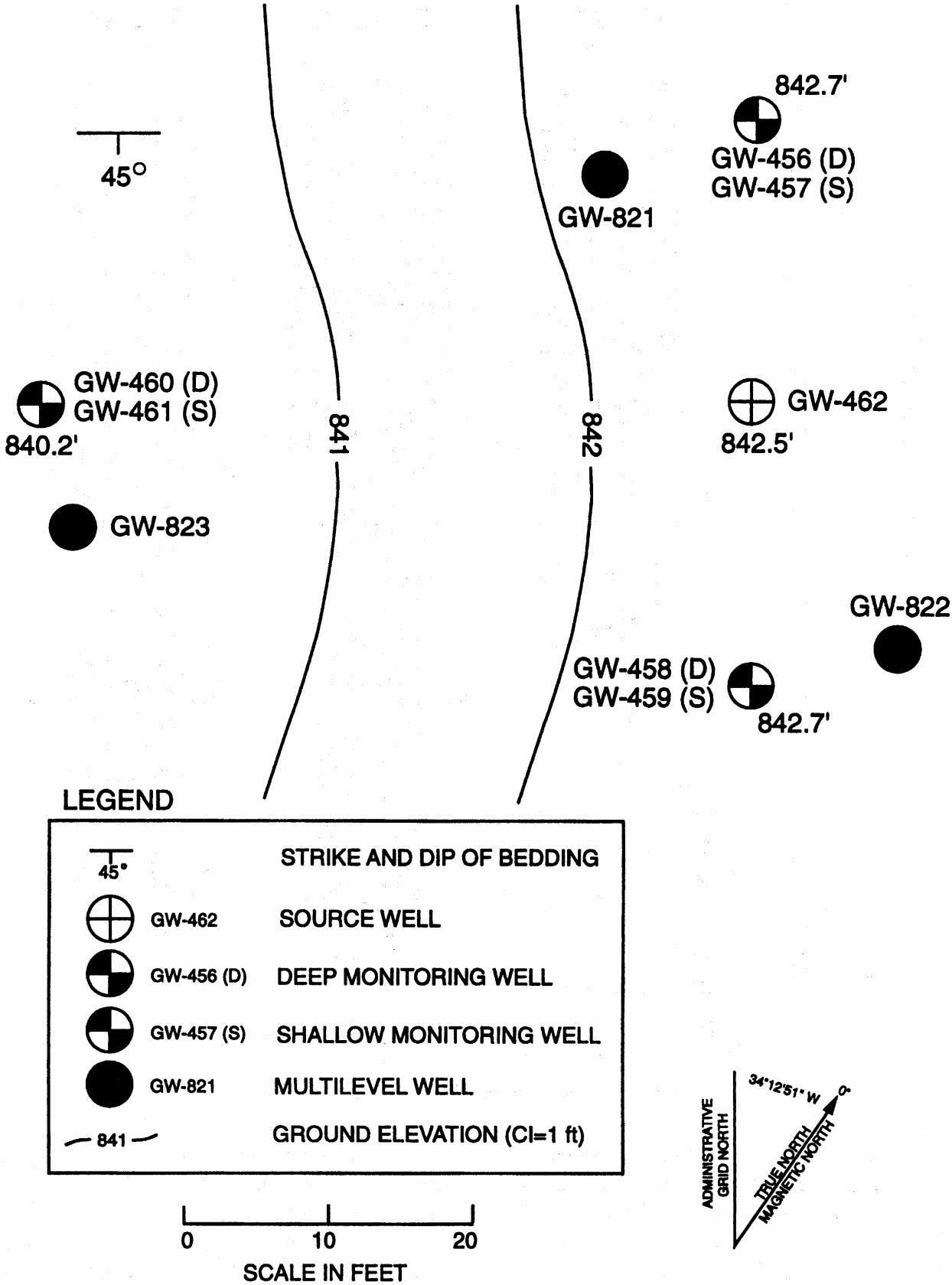


Figure 2.3. Proposed FRC Background Area



Fig, 2.4 Well Types and locations at experimental site A, located within the FRC Background site

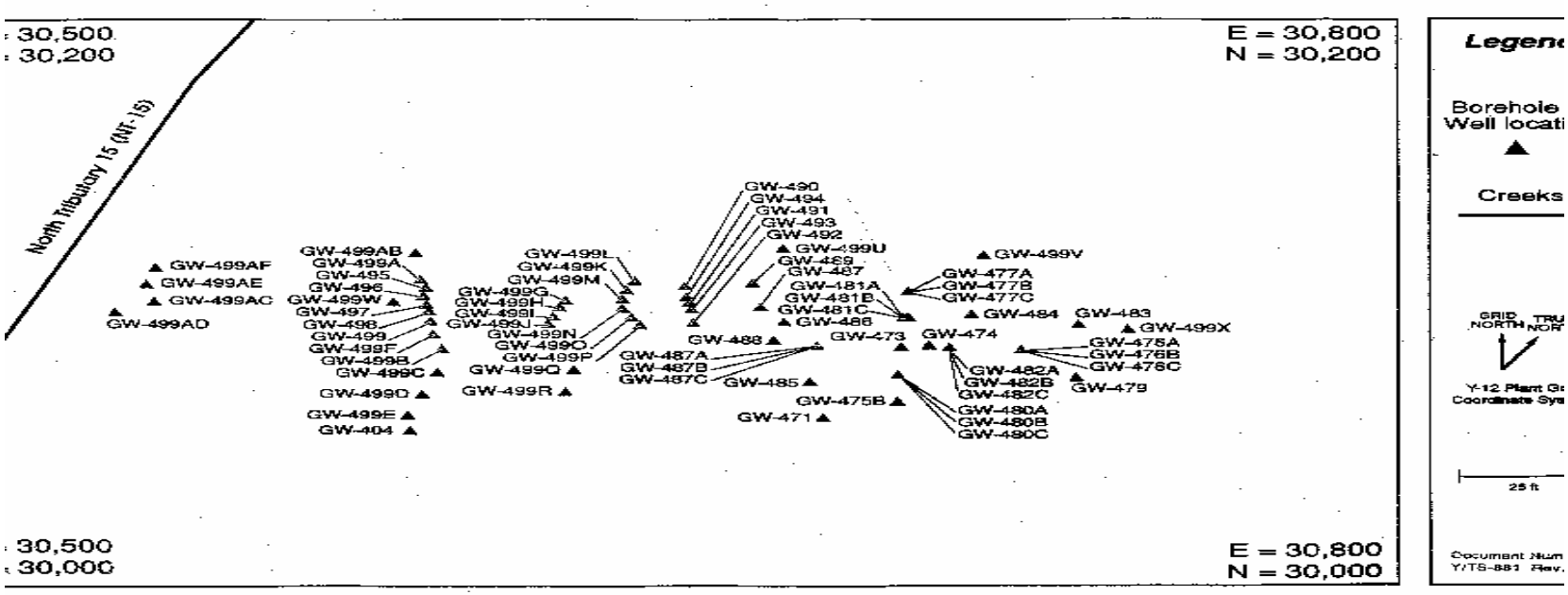


Fig. 2.5. Well locations at experimental site B, located within the FRC Background site.

The majority of groundwater flux in the saturated zone is focused within an interval defined by the interface between the competent bedrock and overlying highly-weathered saprolite, commonly referred to as the "transition zone." This zone is generally defined as the interval between auger refusal and good core recovery by conventional rotary or cable tool methods. Characteristics of this zone are dense fractures and the relative absence of weathering products that contribute to poor core recovery and greater resistance to auger penetration. These characteristics also result in a significantly higher permeability as compared to both the overlying saprolite and underlying bedrock (Moline et al. 1998). The water table fluctuates from less than a meter near streams to three meters or more seasonally and during individual storm events. The transition zone tends to be saturated throughout most or all of the year and groundwater moves through this zone laterally in directions that are heavily influenced by fracture orientation and characteristics (Moline et al. 1998). Tracer tests in the shallow groundwater zone have demonstrated strike-preferential flow oblique to the average hydraulic gradient (Moline et al. 1998; Schreiber et al. 1999; Lee et al. 1992). Pumping tests conducted at two sites (Gierke et al. 1988; Lee et al. 1992) have demonstrated greater transmissivity along strike, and estimates of horizontal anisotropy based on the pump test data range from 8:1 to 30:1, strike to dip.

Long-term multiple tracer injections by Sanford and Solomon (1998) and Jardine et al. (1999), revealed a high degree of fracture connectivity along strike which led to the preferential migration of solutes in these subsurface environments.

Bulk hydraulic conductivity in these geologic materials varies over 7 orders of magnitude (10^{-2}-10^{-9} cm/s), depending on the presence or absence of fractures within the volume of influence and their characteristics (e.g., aperture, spacing, connectivity), (Wilson and Luxmoore 1988; Wilson et al. 1989, 1992). The low end most likely represents unfractured matrix. In general, hydraulic conductivity decreases with depth (Wilson and Luxmoore 1988; Solomon et al. 1992). Storativities within the Nolichucky Shale range from 1×10^{-3} to 5×10^{-4} based on analysis of pumping test results using a variety of approaches (Gierke et al. 1988).

A number of tracer tests were conducted within the background site to evaluate transport behavior and identify key processes affecting transport. Two processes contribute significantly to retardation of solute transport and the storage of solute mass in the matrix sorption and matrix diffusion. High clay content within the weathered matrix coupled with high porosity and small pore size impart a large surface area for sorption of reactive solutes within the matrix and, secondarily, on fracture surfaces. In addition, these same characteristics result in a large, relatively immobile volume of pore water that acts as a reservoir for storage of solutes that diffuse into the matrix through the fracture walls. The result is a significant slowing of the transport rates and creation of secondary sources within the matrix that can and do release solutes over long periods of time. Because fracture flow rates are high, mass can be transported rapidly through preferred fracture flow pathways. This is particularly true of colloids and bacteria that reside only in the fractures due to size exclusion from the matrix. However, the overall mass flux may be low because of the low overall fracture porosity and, in the case of solutes, because of mass transfer into the matrix pores and onto solid surfaces.

Extensive sampling of water chemistry within the stormflow zone, vadose zone, and shallow groundwater zone was conducted at the experimental field sites instrumented in the shallow unconsolidated zone and bedrock within the background site from 1995 through 1998. Sampling initially consisted of two separate sampling events conducted during a wet seasonal (January 1995) and dry season (July 1995) period within the multilevel wells at one of the field research sites (Schreiber 1995; Schreiber et al. 1999). These data demonstrated that the shallow groundwater at the field site is neutral to slightly alkaline (pH 7-8) and can be divided into four major water types: Ca-HCO_3, Ca-Na-HCO_3, Na-Ca-HCO_3, and Na-Ca-HCO_3-SO_4 waters.

A follow-on investigation was conducted that included intense sampling of stormflow tubes, vadose zone multilevel samplers, and numerous multilevel and standard wells for ion chemistry, stable isotopes, helium, and CFCs (Van der Hoven et al. 1997). The sampling events were conducted monthly for a period of 14 months from November 1996 through January 1998 to capture seasonal changes in water chemistry. In addition, storm-event sampling was conducted using a subset of the well network to measure high frequency changes in groundwater chemistry and during these sampling events precipitation and water from a nearby cross-cutting stream were also sampled. These data are currently being evaluated and incorporated into geochemical and groundwater flow models.

2.3.2 Contaminated Field Site

The Oak Ridge Reservation was placed on the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) National Priorities List in 1989. Subsequently, the Remedial Investigation/Feasibility Study for the Bear Creek Valley Watershed has been completed to address contamination associated with former waste disposal activities in Bear Creek Valley (U.S. DOE 1997). The Record of Decision was signed in May of 2000

Source Areas - The principal waste areas and contaminant sources in Bear Creek Valley—the S-3 Ponds Site, the Oil Landfarm and Bone Yard/Burn Yard (BY/BY) area (including the Oil Landfarm, Hazardous Chemical Disposal Area, and Sanitary Landfill 1), and the Bear Creek Burial Grounds—are located in the upper 2.2 miles (3.5 km) of the valley on the sub-crop of the Nolichucky Shale (Fig. 2.6). Solid and liquid waste disposal has caused shallow sediment (residuum) and shallow groundwater contamination at all of these waste sites. Where dense liquids were disposed at the S-3 Site and Bear Creek Burial Ground, contamination of deep groundwater in the Nolichucky Shale has also occurred. Of these waste disposal units, the S-3 Ponds and BY/BY are the primary contributors of contamination to the FRC field site.

A brief history of the two main waste disposal units contributing to contamination within the FRC field site follows:

The S-3 Ponds site contained four unlined surface impoundments constructed in 1951. It received liquid nitric acid/uranium-bearing wastes via the Nitric Acid Pipeline at a rate of approximately 2.5 million gallons/year (10 million liters/year) until 1983. The Ponds were approximately 122 m × 122 m (400 ft × 400 ft) in dimension and 5.2 m (17 ft) deep. Infiltration was the primary release mechanism to sediment and groundwater. The Ponds were neutralized and biodenitrified in 1984 and subsequently closed and capped under the Resource Conservation and Recovery Act in 1988. The site is currently a large asphalt parking lot. In late 1997 two subsurface permeable reactive barriers were installed at Pathway 1 and 2 in the vicinity of the S-3 Ponds to demonstrate the technology and intercept contaminated groundwater migrating to Bear Creek and its tributaries (Fig. 1.2) (Watson et. al., 1999).

The BY/BY consists of the Boneyard, Burnyard, and Hazardous Chemical Disposal Area (HCDA). The Boneyard contained unlined shallow trenches that were used for disposal of construction debris and to burn magnesium chips and wood. The Burnyard was used from 1943 to 1968 and received wastes, metal shavings, solvents, oils, and laboratory chemicals, which were burned in two unlined trenches. The Hazardous Chemical Disposal Area (HCDA), which was built over the burnyard, handled compressed gas cylinders and reactive chemicals, the residues of which were placed in a small, unlined pit. The HCDA has been capped; however, the rest of the BY/BY has not been capped (U.S. DOE 1997).

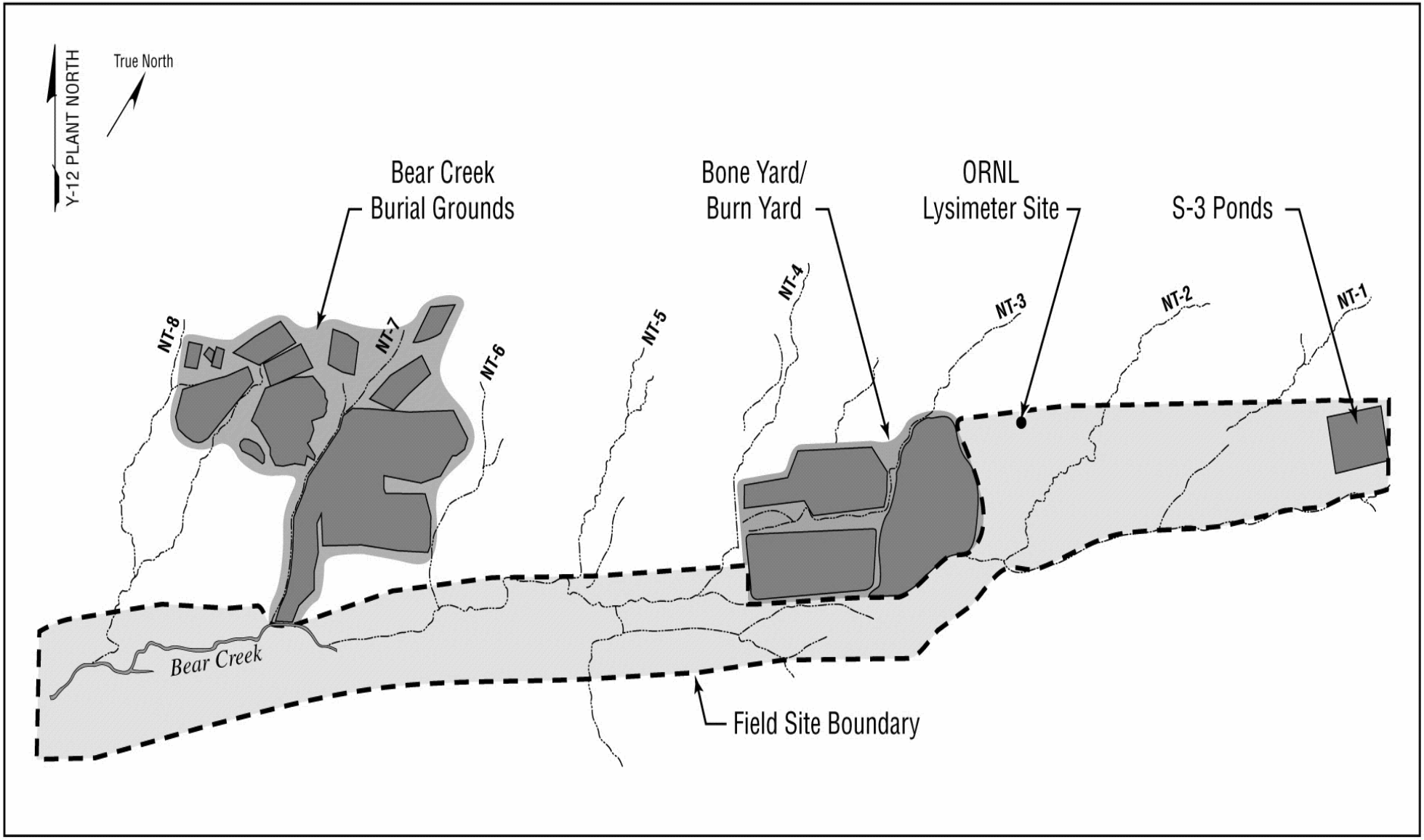


Figure 2.6 FRC boundary near Bear Creek Valley waste units.

Existing Data - The primary sources of existing site characterization data for the contaminated area of the FRC are listed below:

1. Comprehensive Environmental Restoration, Compensation, and Liability Act (CERCLA) data collected for the Remedial Investigation and Feasibility Study Reports (U.S. DOE 1997)
2. CERCLA treatability study data collected in the vicinity of the S-3 Ponds to assess the viability of permeable reactive barriers (LMES 1997a, Bechtel Jacobs Company 1998)
3. EM-50 data (Watson et. al., 1999) collected from the permeable reactive barrier sites (Fig. 1.2)
4. Defense Programs groundwater data collected as part of the Y-12 compliance-monitoring program

Some of the relevant data collected during these studies include:

1. Groundwater data from existing monitoring wells located in the Maynardville Limestone, Nolichucky Shale, and overlying saprolite
2. Groundwater data from sampling of push-probe piezometers installed in the saprolite and fill around the S-3 Ponds and reactive barriers site
3. Uranium data from 10 coreholes located adjacent to the southwest corner of the S-3 Ponds
4. Analytical and stratigraphic information from 10 boreholes in the vicinity of the S-3 Ponds
5. Pumping tests on the Pathway 2 reactive barrier trench, and 2 pumping tests on bedrock wells located in Pathway 3 near NT-2 (LMES 1997)
6. A tracer study test conducted at the Pathway 2 site
7. A tracer study test conducted in the Maynardville Limestone

Contaminant Pathways - This data suggests that contaminants migrate away from the waste disposal units using the following pathways (Fig 2.2). Contaminated shallow groundwater (<15 m) in the unconsolidated residuum and bedrock at sources on the Nolichucky Shale generally migrates along geological strike with local influences from topography, and discharges to tributaries of Bear Creek or directly to Bear Creek causing Bear Creek to become contaminated. An old stream channel near the headwaters of Bear Creek (Fig. 1.2) may have also impacted contaminant transport in the past. The current impact of this old stream channel is unclear. Contaminants in intermediate groundwater in the Nolichucky Shale also migrate through fractures along strike and discharge to Bear Creek tributaries (i.e., NT-1 and NT-2 at the S-3 Ponds, and NT-3 at the BY/BY). At depths of >200 ft. (70 m) groundwater and contaminant migration in the Nolichucky Shale is slow due to the decrease in fracture aperture and spacing found at these depths. However, due to the high dissolved solids contents of the liquid wastes disposed at the S-3 Ponds site contamination has migrated to depths as great as 400 ft (130 m) in the Nolichucky shales.

Three contaminant transport pathways are suggested in an electromagnetic terrain conductivity map compiled from a survey conducted in 1983 (Ketelle and Pin 1983). The conductivity distribution suggests along-strike transport to the southwest and northeast of the pond, southwest transport toward the creek, and a bifurcation of the plume exiting to the west side of the S-3 ponds consistent with the buried channel location (Fig. 2.7). The disappearance of the conductivity anomaly and reappearance further west adjacent to a stream tributary is consistent with deepening transport through strike-parallel fractures and re-emergence due to discharge into the tributary. The 1983 survey suggests the value of additional surface geophysical methods, particularly for delineating the location and extent of high hydraulic conductivity pathways (e.g., stream channel) and plume development in the 17 years since the survey was conducted.

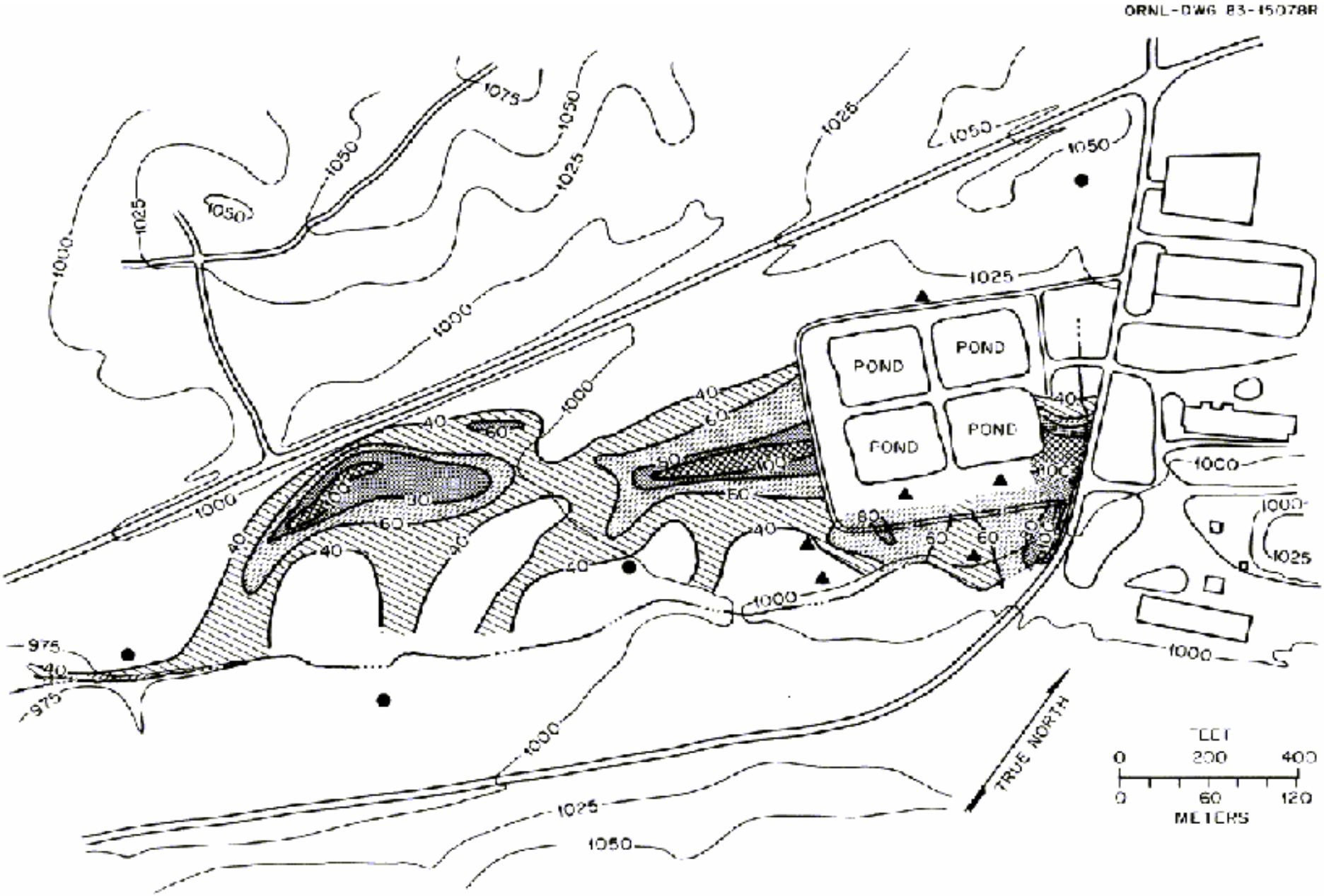


Fig. 2.7 Apparent terrain conductivity map of the study area (Ketelle and Pin, 1983)

After entering Bear Creek tributaries, contaminants migrate in surface water directly to Bear Creek. Bear Creek intermittently loses and gains surface water to groundwater in the Maynardville Limestone throughout the length of the valley. Losing reaches of Bear Creek carry contaminants into shallow groundwater in the Maynardville Limestone. Contaminants that reach the intermediate depths of the Maynardville Limestone [30 to 90 m (100 to 300 ft)] are not attenuated as rapidly as contaminants in shallow groundwater. Solution cavities and solutionally-enlarged fractures exist in the Maynardville Limestone in this interval and are probably well connected by fractures. Because of its depth, this zone is isolated from dilution effects seen in shallower zones. Thus, flow rates are probably slower than those in the shallow interval, but contaminant plumes are more persistent and extend farther along the valley. This zone constitutes an important contaminant transport pathway and could be targeted for research by NABIR investigators. In the deep interval [greater than 100-m (328-ft) depth], flow through fractures dominates groundwater movement, and flow zones become less frequent as fracture density decreases with depth.

Contaminants - For data analysis purposes during the Bear Creek Valley Remedial Investigation, waste areas and plumes were divided into functional areas (FA). The two functional areas that fall within the FRC field site include the S-3 Ponds FA in the Nolichucky Shale unconsolidated zone and bedrock and Maynardville Limestone FA. A summary of analytical results for wastes, soil, groundwater, and surface water samples collected in the S-3 Ponds FA and groundwater and surface water in the Maynardville Limestone FA are provided in Appendix A Table A1 and A2, respectively (DOE 1997). Data on frequency of detection, maximum and average detected values, and whether an analyte is a site-related contaminant (SRC) are also provided in Tables A1 and A2 (Appendix A).

Sediment - The residuum in the vicinity of the former S-3 Ponds will be the primary source of sediment contaminated with radionuclides and metals for the FRC. Table A-1 (Appendix A) lists the contaminants detected in samples collected in 10 boreholes drilled for the RI in the residuum immediately adjacent to the S-3 Ponds (Fig. 2.8). Geologic logs for these borings (identified as S3-1 through S3-10 in Fig. 2.8) are included in Appendix B. The residuum is contaminated with metals (barium, copper, lead, mercury, nickel, vanadium and zinc), radionuclides (uranium, Tc-99, and Th-230), and organics (acetone, methylene chloride, tetrachloroethylene, and toluene) above background concentrations. There are other contaminants detected above background levels but at a lower frequency and concentration. U-233/234 was detected at a maximum concentration of 17 pCi/g and average concentration of 2.1 pCi/g. U-238 was detected at a maximum concentration of 43 pCi/g and average concentration of 4.6 pCi/g. Concentrations of metals and radionuclides were highest near the southwest corner of the former S-3 Ponds site (Fig. 2.8). This area is the primary area proposed for NABIR research.

An additional 10 borings were drilled and sampled by ORNL for a technology demonstration project in the residuum in this area to the southwest of the S-3 Ponds (unpublished data from Roh and Lee). The samples were analyzed for uranium only (Appendix A, Fig. A.1 and Table A-3). The maximum concentration of U-238 detected in these samples was 162 pCi/g (490 ppm). All of the samples from the residuum are depleted relative to the amount of U-235 present (i.e., U-235/U238 is <4.6% on an activity basis). There appears to be zones of elevated uranium in the unsaturated zone at a depth of 0.6 to 0.9 m (2 to 3 ft), near the water table at a depth of 2.5 to 3.1 m (8 to 10 ft), and near the bottom of the residuum at a depth of 5.9 to 6.2 m (19 to 20 ft).

Soil background concentrations for inorganic and radionuclides in various soils types across the reservation are available in Martin Marietta Energy Systems (1993). Mineralogical characterization information on the Nolichucky Shales is also available in (Lee et al. 1991).

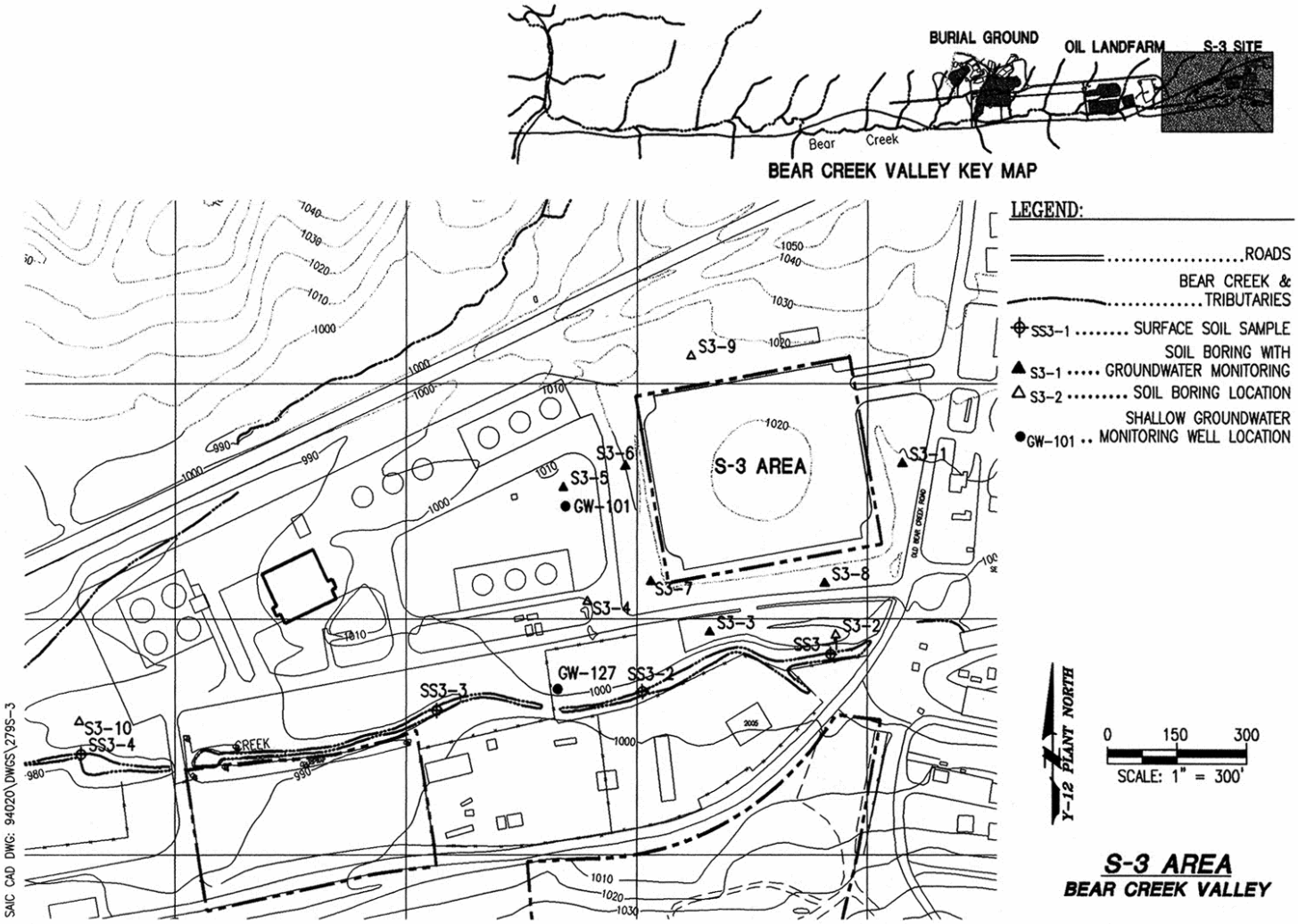


Figure 2.8 BCV RI borehole locations surrounding the S-3 ponds site.

Groundwater - Contaminants in the commingled S-3 Ponds and BY/BY plume include radionuclides (uranium, Sr-99, and Tc-99), metals (strontium, cadmium, barium, boron, mercury, chromium), volatile organic contaminants (VOCs), nitrate, and lesser amounts of other contaminants. Although the S-3 Ponds site is a source of all of these contaminants, the BY/BY site has contributed primarily uranium and VOCs to the Maynardville Limestone. There are also some unknown sources of VOCs (PCE, TCE and DCE) in the Maynardville Limestone.

The S-3 ponds site is located on a groundwater divide so contamination has migrated both to the west and east. The extent of nitrate, gross alpha (indicator of uranium) and gross beta (indicator of Tc-99) in Bear Creek Valley is shown on Fig. 2.9. Nitrate is an excellent indicator of the extent of the S-3 Ponds plume . Most of the uranium (gross alpha) contamination detected in the Maynardville Limestone west of the BY/BY, probably originated from the BY/BY. The extent of uranium contamination detected in groundwater wells screened in the unconsolidated zone and bedrock around the S-3 Ponds is shown on Fig. 2.10. Typical groundwater quality of shallow piezometers installed in the unconsolidated zone near the S-3 Ponds as part of the reactive barriers project is summarized in Appendix A, Table A-4. Background reference concentrations for inorganic analytes detected in groundwater at the Oak Ridge Y-12 Plant are listed in Lockheed Martin Energy Systems (1996).

Concentrations of dissolved oxygen in the residuum at the reactive barrier sites are generally 2 ppm but vary between 1 and 4 ppm, Eh varies between 100 and 300 mV, and pH varies between 5 and 6.5. The reactive barriers at the S-3 Ponds site were installed using guar gum. After the guar was broken down by injecting an enzyme, microbial activity in the gravel filled trenches associated with the barriers increased dramatically especially the sulfur and iron reducing microbes. Pre-guar gum concentrations of nitrate (>1,000 ppm) and uranium (>2 ppm) in these trenches were reduced dramatically to the low ppb level after the guar gum was injected, suggesting the potential for removal of these contaminants through microbial activity.

Results of a bromide tracer test conducted in the unconsolidated zone at the Pathway 2 reactive barriers site (located within the contaminated field site) indicated an average peak concentration arrival velocity of approximately 2 m/day (7 ft/day). The bromide was transported directly to nearby springs located in Bear Creek. However, a large mass of bromide remained in the vicinity of the injection well suggesting matrix diffusion has a significant impact on transport at this site. Pathway 2 is near the location of an old Bear Creek stream channel and the springs in Bear Creek, therefore, transport rates in the residuum at other locations are expected to be as much as an order of magnitude less than this relatively rapid-flow pathway.

A pumping test was recently conducted (Bechtel Jacobs Company 1998) in a well located adjacent to NT-1 within the field site boundary. The well is screened across approximately 150 ft of the Nolichucky Shale bedrock. At a pumping rate of 3 gpm and duration of seven days, a transmissivity of 4.6×10^{-6} m^2/s (5.0×10^{-5} ft^2/s) and storage coefficient of 1.4×10^{-3} was calculated from the drawdown data in nearby wells. These values correspond well with data collected from other hydraulic testing conducted in the Nolichucky bedrock interval (Gierke et al. 1988).

Only one pumping test has been conducted in the Maynardville Limestone in Bear Creek Valley. The wells used to conduct this test are located in the background area. A transmissivity of 1.2×10^{-3} m^2/s (1.3×10^{-2} ft^2/s) and storage coefficient of 6.5×10^{-4} was calculated from the drawdown data in nearby wells. The hydraulic conductivity of the Maynardville was estimated to be 8.4×10^{-3} cm/sec (Gierke et al. 1988).

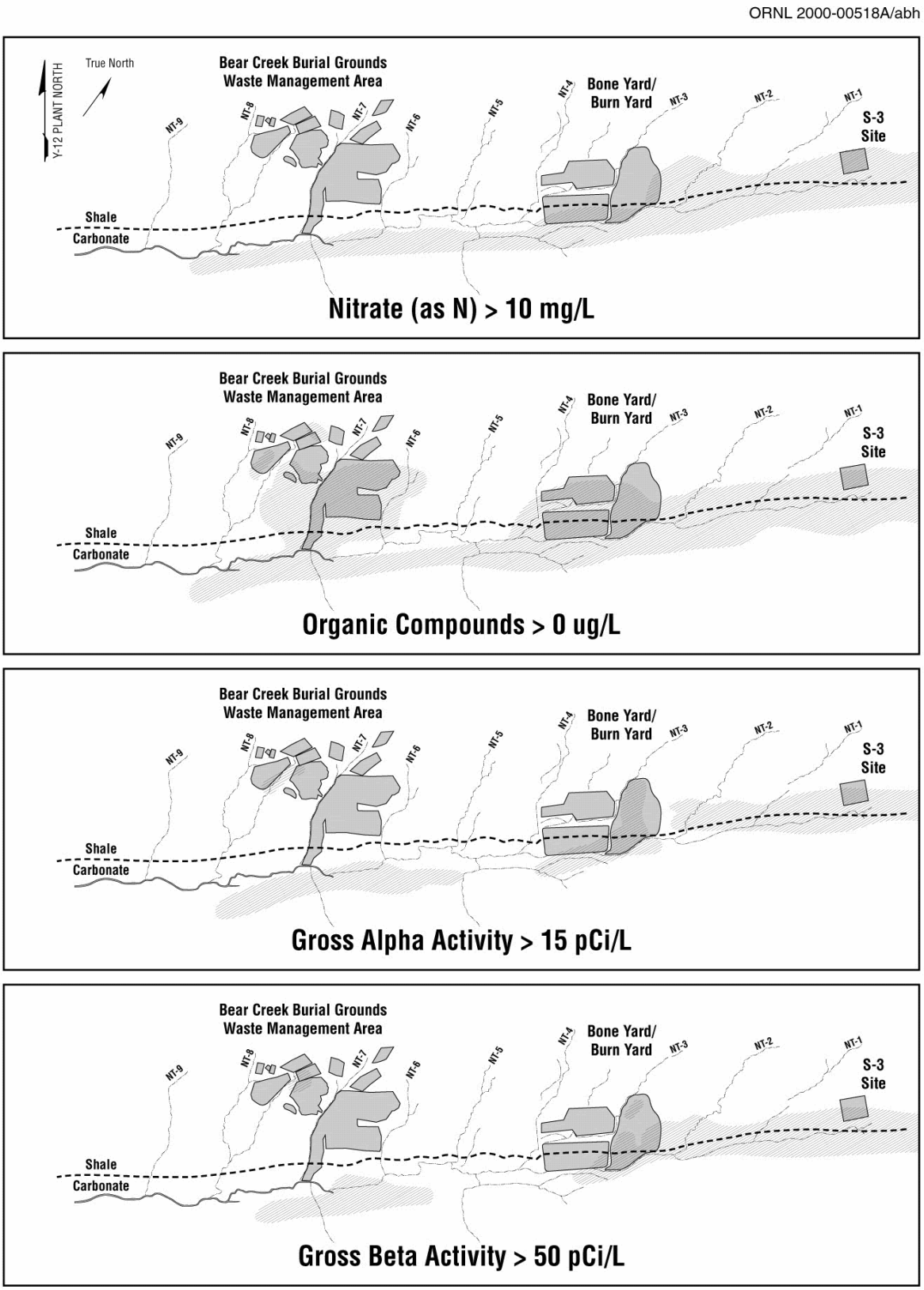


Figure 2.9 Groundwater contamination in the Bear Creek hydrogeologic regime.

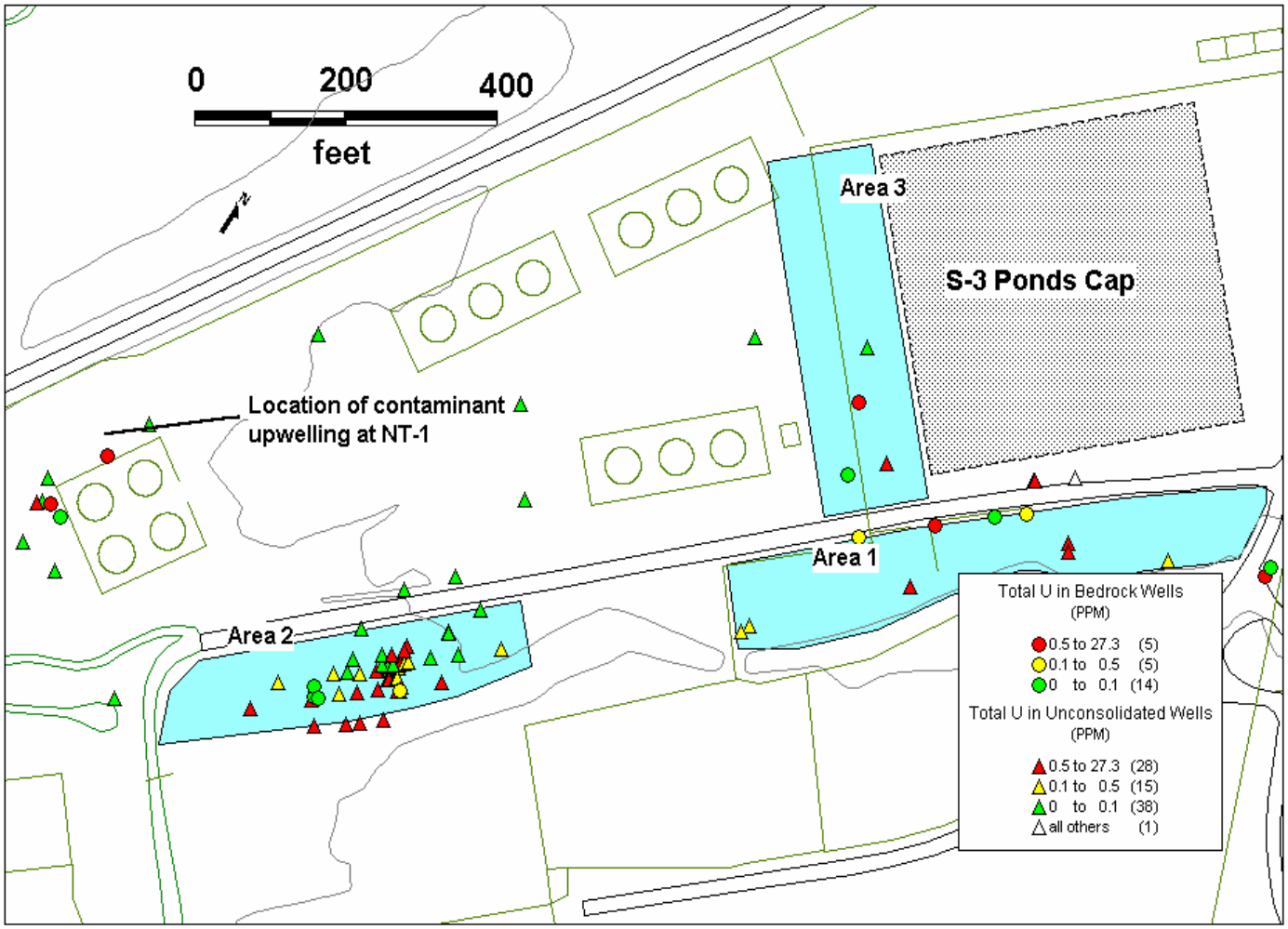


Figure 2.10. Distribution of uranium in bedrock and unconsolidated wells

2.4 HYDROGEOLOGIC ENVIRONMENTS AVAILABLE FOR NABIR RESEARCH

There are three hydrogeologic environments available for NABIR research in the FRC contaminated field site and background area:

- Unconsolidated residuum and Nolichucky Shale transition zone near the S-3 Ponds at depths of < 15 m (45 ft)
- Nolichucky Shale near the S-3 Ponds at depths of 15-20 m (45-70 ft)
- Maynardville Limestone downgradient of the BY/BY

Hydrogeologic environment one (1) is likely to be the primary hydrogeologic environment for NABIR research and site characterization because this shallow zone around the S-3 Ponds site has contaminants of interest to NABIR and is easily accessible and inexpensive to sample. Figure 2.11 shows the location of potential field plots in the vicinity of the S-3 Ponds. Three main areas have been targeted as candidates for field plots. These areas generally correspond to the three Pathways described in the Bear Creek Valley Remedial Investigation report. Areas 1 and 3 (Fig. 2.11) are known to have high nitrate and other ions and high uranium (Table A-4) in at least some piezometers and are contaminated primarily because they are in close proximity to the S-3 Ponds. The Pathway 1 reactive barrier is located in Area 1. Area 2 includes the Pathway 2 reactive barrier and has the highest density of shallow piezometers of the three areas. Contamination detected within Area 2 is probably associated with the old Bear Creek stream channel (Fig. 1.2). Due to the presence of this stream channel in Area 2, the hydraulic conductivity of the residuum at Area 2 is likely to be significantly higher than at Areas 1 and 3. Although it is likely that the old stream channel runs through part of Area 3 (Fig. 1.2) it is unknown if the channel has any current impact on groundwater transport. It seems likely that the old channel impacted surface water flow in the past but is now above groundwater levels within Area 3. Area 2 generally has lower ion and nitrate (e.g., 50 ppm) concentrations than detected within Areas 1 and 3. However, at the bedrock residuum interface the concentration of nitrate at Area 2 can exceed 1,000 ppm in some wells.

Hydrogeologic environments (2) and (3) are also available for NABIR research. The Maynardville Limestone is available to NABIR investigators but is not the primary geologic unit proposed for FRC research. There are several locations where there are sufficient wells located along contaminant transport pathways that NABIR investigators could conduct transport studies on fractured rock if desired. All three environments have been contaminated with uranium, Tc-99, metals, nitrate, and organics.

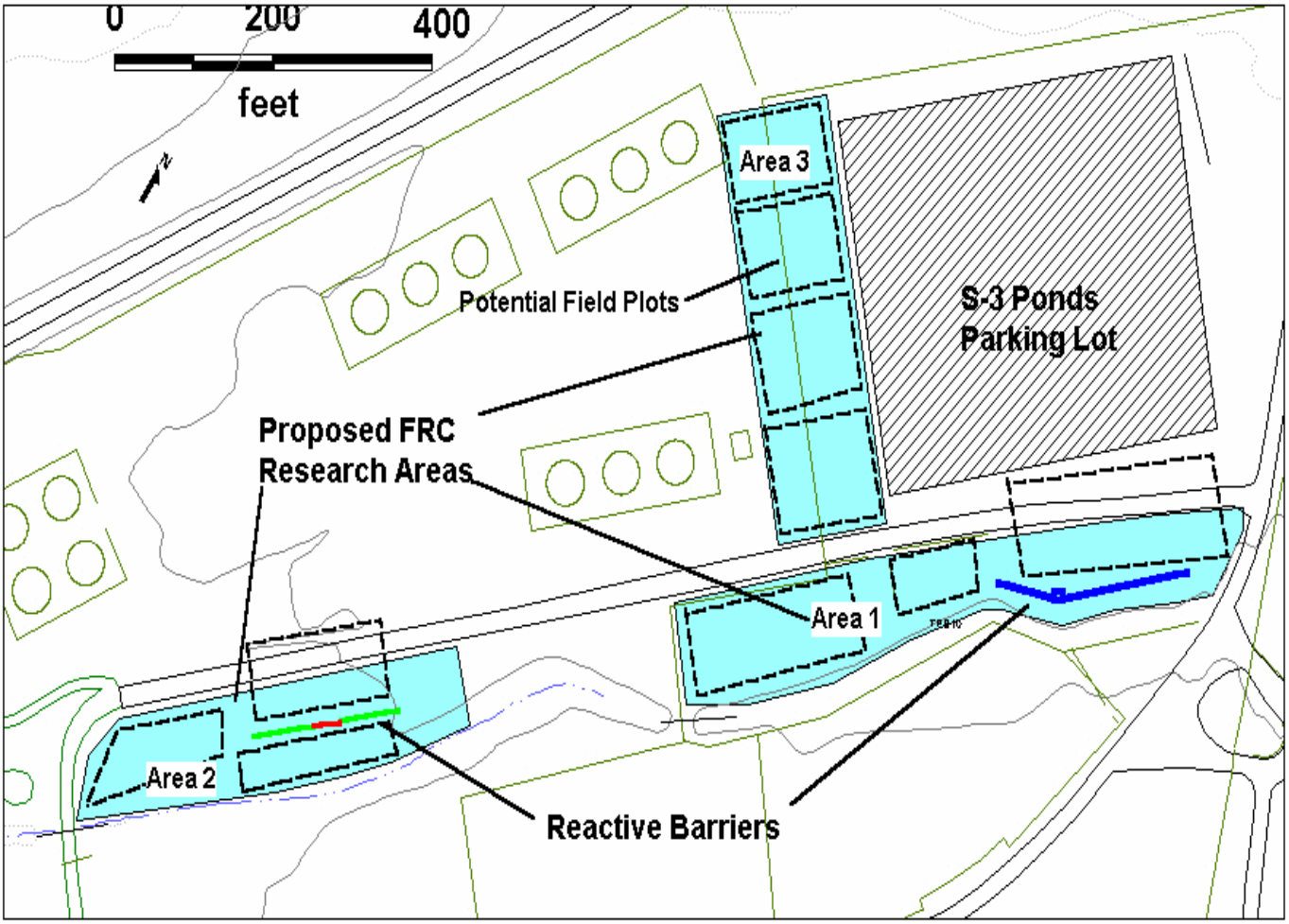


Figure 2.11. Principal areas proposed for well instrumented experimental sites near the S-3 Ponds (Note: areas outside of the three proposed areas are also available for sampling)

3. BASELINE CHARACTERIZATION TASKS

The site characterization will be conducted in a systematic phased approach. The focus of the characterization activities will be the contaminated Nolichucky Shale saprolite and underlying bedrock transition zone in the vicinity of the S-3 ponds in the three areas shown on Fig. 2.11. In addition, a limited number of samples (< 5% of the total) will be collected from existing wells located within the FRC Contaminated Area that contains the Maynardville Limestone and the FRC Background Area. Additional characterization of the Background Area and Maynardville Limestone plume will be conducted if these areas become the target of future NABIR studies. It is anticipated that in addition to the site characterization conducted by FRC staff, NABIR investigators will conduct their own site characterization prior to starting field scale experiments at the FRC. All data obtained during these activities will be entered and stored in the FRC database maintained by ORNL.

3.1 CONTAMINATED AREA NEAR THE S-3 PONDS

The site investigation in the vicinity of the S-3 Ponds (Fig. 2.11) will be conducted in two phases. The activities and objectives of each phase are described below. Phase I will begin in September 2000 and be completed in November 2000. Phase II activities will begin in November 2000 and be completed in July 2001.

3.1.1 Phase I Investigation

To be considered useful for NABIR research, the field plots in the contaminated area must have contaminants of interest to NABIR investigators such as uranium, nitrate, and/or Tc-99. It is important to determine the extent and concentration of uranium in potential field plots because uranium is likely to be the focus of a majority of studies at the FRC. *The primary goal of* Phase I *sampling is to define the areas around the S-3 Ponds with sufficiently high uranium (e.g., > 0.2 ppm) and nitrate (e.g., > 500 ppm) concentrations to be considered desirable contaminated field plots.* To accomplish this goal groundwater samples will be collected from select existing piezometers and several new piezometers installed with push-probe technology.

The locations of the new push-probe piezometers for each of the three areas around the S-3 Ponds are shown on Figs. 3.1 and 3.2. The concentration of uranium detected in existing wells screened in the bedrock and saprolite are also shown on these figures. The new well locations were selected based on a review of the existing data and an assessment of whether or not an area warranted further investigation as an FRC field plot. Table 3.1 provides a summary of the sampling and analyses to be conducted in Phase I. The existing wells that will be sampled include those anticipated to provide insight into current geochemical conditions at the contamination site but which have not been sampled for several years. These wells are identified in Figs. 3.1 and 3.2.

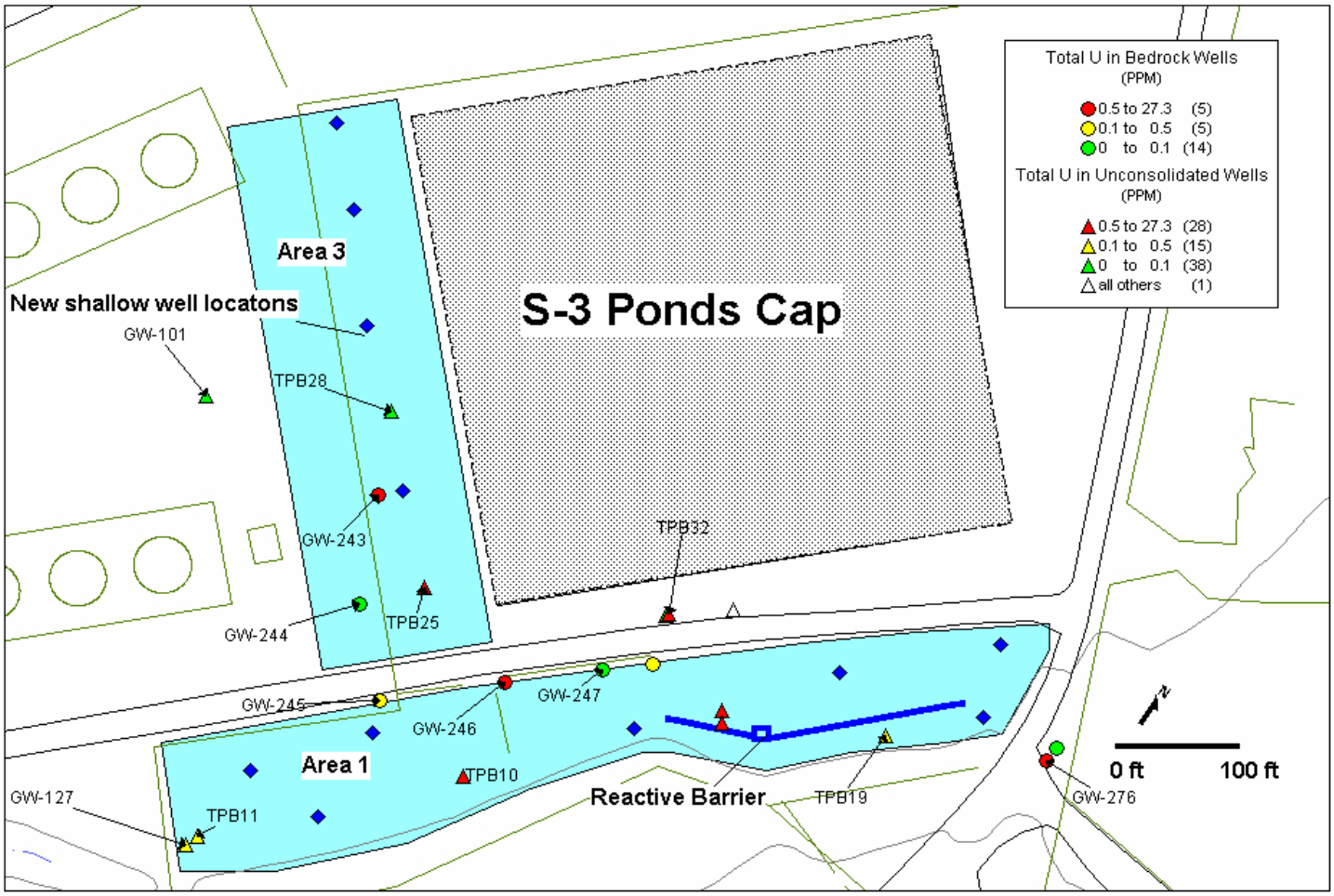


Figure 3.1 Proposed sampling locations at Areas 1 and 3 site

Table 3.1. Summary of Phase I Sampling Efforts

Location	Existing Wells	New Wells	Analyses	QC Samples
Area 1	8 locations – TPB19, TPB10, TPB11, GW276, GW127, GW245, GW246, and GW247	7 locations	Uranium by KPA and Nitrate by IC in the lab, and field parameters (sulfide, ferrous iron, specific conductance, pH, Eh, temperature, and dissolved oxygen)	2 field duplicates and 2 field blanks will be collected and analyzed
Area 2	5 locations - TPB16, TPB8, TMW14, GW835, and DP6	4 locations		
Area 3	5 locations - TPB25, TPB28, TPB32, GW101, and GW244	4 locations		

The new piezometers will be constructed of PVC pipe approximately 1 or 2 inches in diameter with a 5-ft screened interval at the bottom of the well. The elevation and coordinates of the wells will be surveyed so groundwater elevations can be determined. Water levels will be collected with a manual electronic water level indicator at least once to help assess groundwater flow directions. A more detailed description of the push-probe well construction techniques is provided in Sect. 5. The probes will be pushed to refusal (i.e., top of competent bedrock). Analyses will include uranium by kinetic phosphorescence analysis (KPA), nitrate by ion chromatography and field parameters using the various methods described in Sect. 6.

In addition to the analyses listed above, an assessment is currently being conducted to determine if *in situ* uranium assays on FRC sediment is possible by logging either core holes or wells with a 1-inch diameter NaI detector used to determine *in situ* gamma activity. This method offers two very attractive advantages beyond the laboratory methods discussed in other sections (Miller et al. 1994). First, well logging would avoid the necessity and cost of collecting and processing the sediment samples from FRC sampling site in the laboratory. Second, *in situ* well logging for uranium assay is non-destructive and, thus, could be repeated at intervals to determine if the activity in sediment surrounding the hole were changing with time or because of experimental manipulation during field trials by NABIR investigators. If it is determined that the *in situ* uranium logging tool is working and providing valuable information to the FRC, standard well-logging protocols, including well construction methods and materials specifications, would need to be developed prior to the initiation of Phase II investigations.

3.1.2 Phase II Investigation

Historical data and data from the Phase I investigation will be used to identify areas that warrant additional, more detailed investigation for use as contaminated FRC field plots. Phase II investigations will focus on obtaining geochemical and hydrogeologic data from one or two of the most promising contaminated field plots to minimize collection of data from unsuitable locations. Area 3 is one of the field plots targeted for additional studies (Fig. 3.1). Although the least characterized, Area 3 has the greatest potential for NABIR research in terms of spatial extent, proximity to the contaminant source, and minimal disturbance by previous remediation activities (e.g., reactive barriers).

The type and sequence of characterization activities proposed for each of the three research areas adjacent to the S-3 Ponds (identified as Areas 1, 2, and 3 on Fig. 2.11), is described below. The activities proposed for Phase II are dependent on the level of preexisting characterization data and instrumentation, as well as on the results of Phase I activities that are designed to better determine the distribution of uranium and nitrate in groundwater. The activities are sequenced such that each can benefit from the information obtained from the previous activities, thus allowing scope refinement along the way. In addition, the testing is structured in such

a way that the presence of multiple transport pathways can be discerned and their transport characteristics measured. These transport pathways are: 1) topographically driven flow through unstructured fill material; 2) preferential flow through alluvial deposits associated with a preexisting, now buried stream channel (Sutton and Field, 1995); and 3) preferential flow along fractures in the structured sediment (saprolite) and shallow bedrock.

3.1.2.1 Area 1 Location

Tasks to be performed at Area 1 include:

1. Coring – No new wells are planned at Area 1 during Phase II unless it is determined to be a more suitable location than Area 2 or 3 for locating the first FRC field plots. New piezometers could be installed in the coreholes at this site if needed. Although there is known groundwater contamination at this site, there is very little information on stratigraphy or the concentration of contaminants in sediment. Therefore, approximately five cores will be taken at locations where the presence of uranium was determined from Phase I and previous investigations (U.S. DOE 1997). Cores will be analyzed for stratigraphic and structural purposes (material type, location and spacing of apparent flow zones, etc.). Some cores will be taken within the area that has been impacted geochemically by the permeable reactive barrier to determine if guar gum and/or the iron treatment media is impacting the geochemistry and microbial communities at the site. Drilling logs will be prepared describing the material encountered, fractures, and water-bearing zones. Subsamples of the cores will be analyzed for contaminant concentrations and distributions, and for chemical characteristics that may impact or limit biological activity.

2. Groundwater Sampling – Due to the amount of existing data available for this site and because it is not likely to be one of the initial field plots, only one round of groundwater sampling will be conducted on the seven new wells installed in Phase I. Analyses will be conducted to determine contaminant concentrations and chemical characteristics that may impact or limit biological activity (Table 3.3).

3. Microbiological Characterization – Microbiological characterization, when performed, is the responsibility of individual NABIR investigators and is not conducted at the FRC, but on samples shipped to host institutions. The approach to collection of samples for microbial characterization of Area 1 will be the same as for Area 3.

4. Hydraulic testing – Slug tests and point dilution tests will be conducted on selected new and existing piezometers (five locations). Piezometers will be chosen based on results of coring and to ensure representation from all transport pathways (fill and weathered shales).

5. Water Level Monitoring – Several new and existing piezometers will be instrumented with continuous water level monitoring equipment (data loggers and transducers) to evaluate gradients and storm response, and provide a baseline prior to pumping tests. Monitoring wells will also be monitored every other week for 3 months to provide a snapshot of flow directions and to provide data to calibrate the transducers.

6. Field Parameter Monitoring – Multi-parameter YSI Sondes will also be installed in two wells to monitor temporal changes in field parameter measurements (dissolved oxygen, specific conductance, pH, Eh, temperature, and water levels) in response to recharge events.

3.1.2.2 Area 2 Location

Tasks to be performed at Area 2 include:

1. Coring – Due to the number of existing piezometers, no new wells are planned at Area 2 during Phase II. Although there is known groundwater contamination at this site, there is very little information on stratigraphy or the concentration of contaminants in sediment. Therefore, approximately four cores will be taken at locations where the presence of uranium was determined from Phase I and previous investigations (U.S. DOE 1997). Coring locations will be selected, if possible, within and outside of the presumed location of the old stream channel including shallow fill, saprolite, and transition zone or shallow bedrock. Cores will be analyzed for stratigraphic and structural characteristics (material type, location and spacing of apparent flow zones, etc.). Drilling logs will be prepared describing the material encountered, fractures, and water-bearing zones. Subsamples of the cores will be analyzed for contaminant concentrations and distributions, and for chemical characteristics that may impact or limit biological activity.

2. Groundwater Sampling – Due to the amount of existing data available for this site and because it is not likely to be one of the initial field plots, only one round of groundwater sampling will be conducted on the 4 new wells installed in Phase I. Analyses will be conducted to determine contaminant concentrations and chemical characteristics that may impact or limit biological activity (Table 3.3).

3. Microbiological Characterization – The approach to microbiological characterization, which will be conducted by individual NABIR investigators off-site at their host institutions, at Area 2 will be the same as for Area 3.

4. Hydraulic testing – Slug tests and/or point dilution tests will be conducted on several new and selected existing piezometers (five locations). Piezometers will be chosen based on results of coring to ensure representation from all transport pathways (stream channel, fill, and weathered shales).

5. Pumping Test – A pumping test using multiple monitoring wells will be conducted to identify connected pathways within a field plot size area (e.g., 30 m x 30 m). Wells will be instrumented for continuous water level monitoring for the duration of the test.

6. Water Level Monitoring – Monitoring wells will be monitored every other week for 3 months to provide a snapshot of flow directions and to provide data to calibrate the transducers.

3.1.2.3 Area 3 Location

Tasks to be performed at Area 3 include:

1. Coring/Well Installation – Cores will be collected and piezometers will be installed in approximately 10 coreholes in locations where the presence of uranium was determined in Phase I. Some of the piezometers will be constructed to have multiple ports for discrete vertical sampling. Locations will be selected if possible within and outside of the presumed location of the old stream channel, including shallow fill, saprolite, and transition zone or shallow bedrock. Cores will be analyzed for stratigraphic and structural characteristics (material type, location and spacing of apparent flow zones, etc.). Drilling logs will be prepared describing the material encountered, fractures, and water-bearing zones. Subsamples of the cores will be analyzed for contaminant distribution and concentrations, and for chemical and physical characteristics that may impact or limit biological activity (Table 3.2).

2. Groundwater Sampling – Two rounds of groundwater sampling on approximately 20 wells will be conducted to determine contaminant distribution and concentrations, and for chemical characteristics that may impact or limit biological activity (Table 3.3).

3. Microbiological Characterization – Microbial Characterization, when performed, is the responsibility of individual NABIR investigators and is not conducted at the FRC, but on samples shipped to host institutions. Subsamples of the cores will be obtained for characterizing the microbial community using the terminal restriction fragment length (T-RFLP) technique described by Liu et. al. (1997) and/or other characterization techniques such as phospholipid fatty acid (PLFA), denaturing gradient gel electrophoresis (DGGE), acridine orange direct counts (AODC). The final microbial sampling and analysis strategy was determined at the September NABIR FRC workshop (focusing on FRC sampling needs). Sediment samples will be frozen at -80 C and archived until the samples are analyzed. Samples for surplus community DNA (if generated) will also be frozen at -80 C and retained in the FRC sample archive for future use by NABIR investigators. Using archived sediment samples and DNA wherever possible offers several advantages including reduced sampling costs and a basis for comparing different analytical results. Sampling intervals will be determined based on stratigraphy and uranium distribution in the cores. Some samples may be obtained and stored under anaerobic conditions. Wherever possible, only half (lengthwise) of the core will be subsampled and the remainder archived for replicate or comparative analyses.

4. Additional Piezometer Installation (drive point) and Sampling –Approximately 5 piezometers (in addition to those described in task 1) will be installed and sampled to further define potential pathways on the western side of S-3 Ponds (topographic/along-dip, old stream channel, along-strike). Some of these piezometers will be constructed with multiple ports for discrete vertical sampling.

5. Hydraulic Testing – Slug tests and/or point dilution tests will be conducted on select new and existing piezometers (10 locations) for determination of hydraulic parameters (Table 3.4). Piezometers will be chosen based on results of coring and to ensure representation from all transport pathways (stream channel, fill, and weathered shales).

6. Water Level Monitoring –Several new and existing piezometers will be instrumented with continuous water level monitoring equipment (data loggers and transducers) to evaluate gradients and storm response, and provide a baseline prior to pumping tests. Monitoring wells will also be monitored every other week for 3 months to provide a snapshot of flow directions and to provide data to calibrate the transducers.

7. Field Parameter Monitoring –Multi-parameter YSI Sondes will be installed in three wells to monitor temporal changes in field parameter measurements (dissolved oxygen, specific conductance, pH, Eh, temperature, and water levels) in response to recharge events (Table 3.3).

8. Pumping Test – A pumping test will be conducted using multiple monitoring wells to identify connected pathways within a field plot size area (e.g., 30 m x 30 m). Wells will be instrumented for continuous water level monitoring for the duration of the test.

9. Natural Gradient Tracer Test – Multi-tracer tests will be conducted using multiple injection wells based on the results of the pumping tests. A combination of gas and anionic tracers will be injected using passive injection and sampling methods for the gases and flux-adjusted continuous injection methods for the anionic tracers. Sampling locations will include wells in potential pathways along the old stream channel, along-strike, and parallel to dip or topography.

3.1.2.4 Summary of Sampling and Analysis for Phase II

A summary of the number of samples and analyses that are planned on the core samples, and groundwater samples for each Area are provided on Tables 3.2 and 3.3. A summary of the hydraulic testing that is planned for each of the three Areas is provided on Table 3.4.

Table 3.2. Summary of Proposed Phase II Coring

Location	**Number of Coreholes**	**Analyses**		
		Uranium – kpa	Sediment Char. - particle size, bulk density, saturated water content, U sorption Isotherm, TOC/TIC, Fe and Mn Oxides, and metals	Microbiology (to be conducted off the FRC by individual NABIR investigators) - t-RFLP, AODC, DGGE, PLFA and/or other analytical methods as determined by NABIR investigators at the September workshop
Area 1	5 locations	25 samples (5/core) selected for analysis based on field screening results	5 samples from a representative core	5 samples selected for analysis based on location relative to reactive barrier site and contaminant concentration
Area 2	4 locations	20 samples (5/core) selected for analysis based on field screening results	5 samples from a representative core	5 samples selected for analysis based on location relative to reactive barrier site and contaminant concentration
Area 3	10 locations	50 samples (5/core) selected for analysis based on field screening results	10 samples from two representative cores	15 samples selected for analysis based on contaminant concentration and indications of reducing and oxidizing conditions

Techniques for sampling and analyzing the cores are described in greater detail in subsequent sections. Field screening of the cores will be conducted for gross radioactivity using Geiger-Mueller (GM) survey instruments. In addition, core holes will be logged with a down-hole 1-inch diameter NaI detector used to determine *in situ* gamma activity (if this is determined to be a viable method).

Table 3.3. Summary of Proposed Phase II Groundwater Sampling

Location	Number of Wells Sampled	Analyses		
		Geochemistry - Uranium (KPA), metals (ICP or ICP/MS), anions (IC), alkalinity, and TOC/TIC	Volatile Organic Compounds (GC or GC/MS)	Field Parameters - sulfide, ferrous iron, EC, pH, Eh, temp., and dissolved oxygen
Area 1	7 locations	7 samples selected for analysis based on Phase I results	3 samples	7 samples – Same as geochemistry analysis
Area 2	4 locations	4 samples selected for analysis based on Phase I results	No Samples	4 samples – Same as geochemistry analysis
Area 3	Round 1 - 20 locations	20 samples from select new and existing piezometers	5 samples	20 samples – Same as geochemistry analysis
	Round 2 - 20 locations	20 samples from select new and existing piezometers	No Samples	20 samples – Same as geochemistry analysis
QC Samples		1 in 20 field duplicates and blanks / round	1 blank and 1 duplicate / round	1 in 20 field duplicates and blanks

Techniques for sampling and analyzing groundwater samples are described in subsequent sections.

Table 3.4. Summary of Phase II Hydraulic Characterization

	Hydraulic Testing			
Location	**Water Level/ Field Parameter Monitoring**	**Slug Tests Or Point Dilution Test**	**Pumping Test**	**Natural Gradient Tracer Testing**
Area 1	Manual twice a month for 3 months, continuous at 4 locations, YSI Sonde at 2 locations	5 Locations	None	None
Area 2	Manual twice a month for 3 months	5 Locations	One short-term test (< 24 hours)	None
Area 3	Manual twice a month for 3 months, continuous at 4 locations, YSI Sonde at 3 locations	10 Locations	One short-term test (< 24 hours)	One test conducted with continuous injection of multiple tracers (e.g., bromide and noble gases) until break-through is observed at multiple locations.

Techniques for conducting hydraulic testing are described in subsequent sections.

3.1.2.5 Geophysical Surveys

Previous geophysical work conducted in the vicinity of the S-3 Ponds (Sect. 2.4.1) indicates that it may be possible to obtain valuable information on subsurface conditions and contaminant distribution by conducting geophysical studies. The two methods being considered for testing at the site include seismic refraction and direct current (DC) resistivity. A brief description of these methods and the work that will be conducted to assess their viability at the FRC contaminated field site is provided below.

Seismic Refraction Method - The seismic refraction method is commonly used to determine depth to bedrock, the water table, or some other geologic interface that separates media through which seismic waves propagate at different velocities. The interfaces need not be planar, and typically do not have a large dip, and the velocities of the layers are assumed to increase with depth. Conventional data analysis methods assume

that layers are laterally continuous and that the velocities that are assigned to each layer are constant within that layer. These assumptions can be proven by inspection of the data and by comparison of seismic refraction data with surface to borehole measurements known as vertical seismic profiles.

More recently, tomographic inversion routines are being marketed for processing of seismic refraction data. These routines require more shot points within the receiving array, but allow laterally discontinuous layers, vertical velocity gradients, and lateral changes in velocity. The tomographic methods can be used to map the seismic heterogeneity of the shallow subsurface.

Direct Current Resistivity Method - The principle behind DC resistivity measurements is simple. Metal stakes are driven into the ground and connected to a battery. Geologic structure and manmade buried objects influence the resulting underground flow of electrical current, and this can be measured by mapping the distribution of voltages at the surface.

Most rocks and sediment are insulators. The flow of electrical current in the ground is predominantly by electrolytic conduction; i.e., ions (contaminants) migrating through water in the pore spaces. Consequently, the electrical resistivity of geologic materials is controlled largely by the amount of porosity, degree of saturation, and ionic strength of the pore waters. A tight rock will be more resistive than a porous one; a dry rock will be more resistive than a wet one; a pore fluid with low ion concentrations will be more resistive than one with high ion concentrations. Man-made objects, particularly those containing metals, also reduce the electrical resistivity of the subsurface. The goal of resistivity surveys is to deduce information about rock and sediment types, porosity, saturation, ion/contaminant concentration of the pore water and the distribution of man-made objects by their effect on electrical current flow in the ground.

Multielectrode resistivity data can be acquired with a Sting/Swift resistivity system (and inverted with the program Res2Dinv). Twenty-eight or more electrodes are placed in the ground. A microprocessor in the Swift resistivity box controls the firing sequence of the electrodes according to the type of array selected, and logs all of the data, which are downloaded to a laptop computer in the field at the end of each sounding. Each measurement is made with four electrodes, two serving as current electrodes and two serving as potential electrodes. The firing sequence is designed so that measurements are taken with many combinations of electrode spacing and locations so that lateral and vertical changes in resistivity can be detected and measured. The inversion program is then used to determine resistivity as a function of depth and offset along the profile line.

Testing of Geophysical Methods - The two geophysical methods described above will be tested by running two to three arrays in Area 3 (Fig. 2.11). The lines will be oriented in a north to south direction parallel to the western side of the S-3 Ponds Parking lot. By conducting this test it will be determined if it is possible to discern geologic features such as the top of bedrock and the old Bear Creek Stream channel. The electrical method will also be used to determine if the high conductivity S-3 Ponds groundwater plume can be observed. Further geophysical studies will be considered based on the results of these initial studies

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3.2 MAYNARDVILLE LIMESTONE SAMPLING

Sampling in the Maynardville Limestone will consist of collecting samples from four bedrock wells (GW-706, GW-683 and GW-684) known to be located in the middle of the intermediate zone transport pathway. Core samples will not be collected from the Maynardville Limestone formation until this area is identified as a target for NABIR research. Analyses on these three wells will include TOC/TIC, field parameters (sulfide, ferrous iron, EC, pH, Eh, temperature, and dissolved oxygen), and microbiological analyses using t-RFLP, AODC, DGGE, PLFA and/or other analytical methods as determined by NABIR investigators at the September workshop. Past sampling under other programs should provide sufficient information on other geochemical characteristics of this groundwater. This sampling will coincide with other Phase II sampling activities.

3.3 BACKGROUND AREA SAMPLING

Sampling in the Background Area will consist of collecting six samples from two coreholes and conducting the same microbial analyses as for cores from the contaminated site. These data will be compared to the microbial communities identified for the contaminated areas. This sampling will coincide with other Phase II sampling activities.

4. SAMPLING PROCEDURES

A summary of the activities associated with field sampling is presented in the Quality Assurance Project Plan. A field log book suitable for quality assurance purposes will be maintained and used to describe all field activities. This section describes the specific sampling procedures that will be used in the site characterization work.

4.1 CORE SAMPLING

An Acker Drill Co. (TBD-ll), Holegator track drill will be the primary piece of onsite equipment used for drilling operations. A Mobile Drill Co. Surveyor trailer mounted drill is also available for shallow sediment work. Drilling support for field sampling activities is provided by ESD technical staff equipped to support most common drilling activities including: 1) hollow-stem & flight augers; 2) 94 mm wire-line system with sediment & coring attachments; 3) split spoons up to 3.5"; 4) driven wells up to 2" diameter; and 5) micro wells of various configurations. Cores can be collected in 6-foot lengths or less.

To extract a core, a 3" hollow barrel will be driven to the depth that coring is to begin. A pull-out point at the front-end of the barrel will be disconnected and extracted once the barrel is in position. The core sample will be collected inside a polyurethane sleeve (liner) (1-3/8" diameter and 6” long) that will be present inside the corer when it is driven through the sediment. After the cores are removed from the ground, the sleeves will be cut to size and small samples (about 30-40 g) collected for geochemical, mineralogical, and microbiological analysis. For excess material the open ends of the tube will then be packed with plastic bags or bubble rap (to stabilize the material) and sealed with plastic caps that will be securely taped to the tube. Hollow-stem augers and 2-inch diameter split spoon samplers (ASTM D1586-84) may also be used for collecting core samples, but since this method generates drill cutting wastes it is not the preferred method.

After sampling is finished at each coring point, either a well will be constructed (see subsequent section) or the hole will be filled with sand and the excess sediment that was removed during coring. Additionally, bentonite will be used to fill in the upper 3' of the hole to prevent surface water from flowing down the corehole. Drilling logs will be prepared for each corehole describing materials encountered, fractures, and water-bearing zones. ASTM method D2488-90 will be used to classify the sediment material extracted during coring.

Special Core Handling Procedures for Microbial Samples that will be Analyzed Off-site - Core specimens for microbial analysis will be obtained directly from the lined split spoon sampler or core barrel. The microbiological samples will be frozen in an -80ºC freezer to await shipping and future analysis. Caps will be placed on the ends of the core liner tube as soon as it is brought to the surface, slits cut into the caps and the sample purged with argon. The end caps are taped into place and the sample is then placed in a sealable PVC tube with valves on both ends. The PVC tube is purged with argon and pressurized to ensure that oxygen does not enter during transport. Samples will be kept on ice or refrigerated during transport. Chain of custody procedures described in the FRC QAP will be followed . All materials that come in direct contact with the sample (e.g., core barrel liners) will be sterilized and wrapped in clean plastic prior to use. A portable hot water/steam pressure washing system will be used to decontaminate downhole drilling equipment between sampling locations. Temperature of the downhole sampling equipment will be monitored to make sure high temperatures in the borehole do not impact analytic results.

4.2 PUSHPROBE PIEZOMETER INSTALLATION

Pushprobe piezometers will be installed by pushing/driving a 3-in hollow barrel to the depth that the piezometer is to be installed (typically bedrock refusal). The well screen and blank casing is installed inside the hollow barrel and inert quartz based sand pack is placed around the well screen as the hollow barrel is removed. The top 3' of the hole is sealed with bentonite. Typical construction details for a single well completion and a multi-port well completion are shown on Figs. 4.1 and 4.2, respectively. For stabilizing multilevel wells, a PVC pipe will extend the full length of the borehole. When a screened interval above the base of the borehole is desired, solid casing will be added below the screen (as shown). Well construction logs will be prepared for each piezometer installed.

Figure 4.1 Typical Piezometer Construction Detail

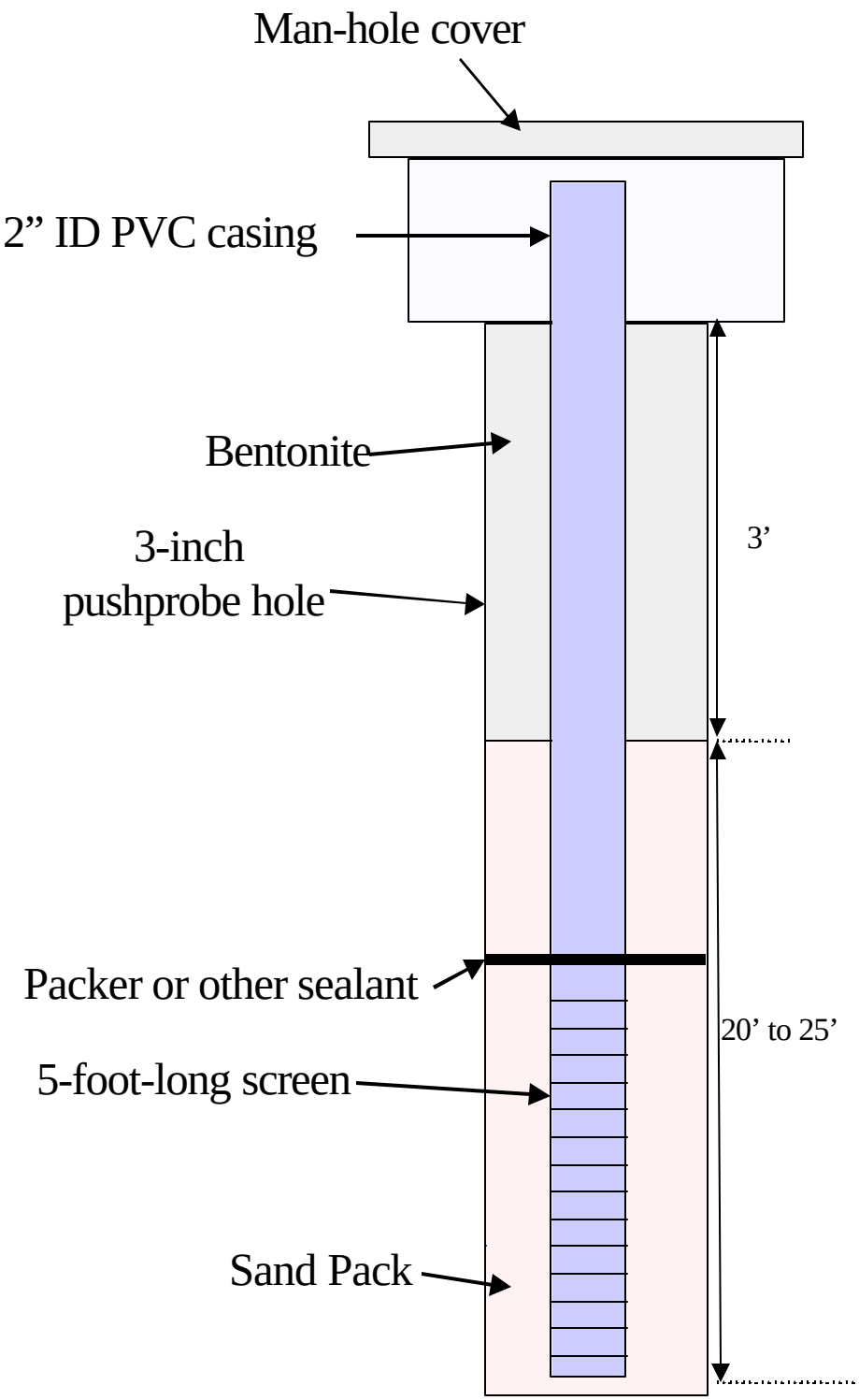
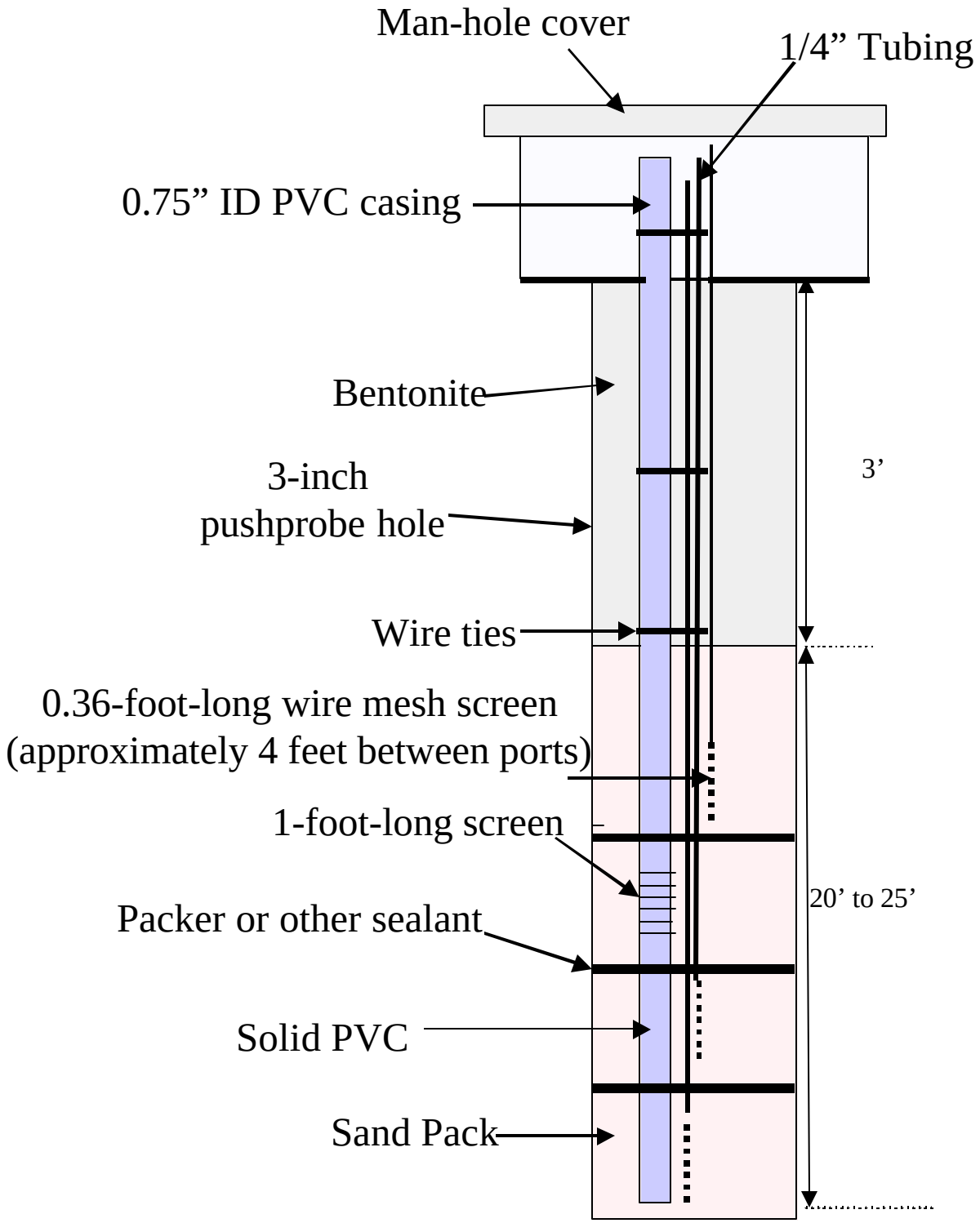


Figure 4.2 Typical Multi-port Piezometer Construction Details



4.3 GROUNDWATER SAMPLING

Groundwater will be sampled with a peristaltic pump using dedicated sampling tubes in each well. Minimal purge techniques (Kearl et al., 1992) (Puls et al., 1992) will be used in order to reduce the disturbance caused by removal of large volumes of water from the system. In most cases, the pump will be set on a low rate (no greater than 100 ml/minute) to minimize drawdown in the well and ensure that groundwater is being drawn through the well screen rather than from the standing column of water in the well casing. A higher pump rate may be used only if monitoring during pumping demonstrates that no drawdown is occurring, or for wells that are known to purge dry even at low rates.

For very small diameter wells that do not produce much groundwater, the well will be completely purged in the morning and sampled in the afternoon after sufficient groundwater has recovered in the well. Otherwise, field parameters will be monitored until stable groundwater chemistry (e.g. specific conductance, pH, Eh, temperature, dissolved oxygen) readings are obtained on the YSI Sonde. The YSI Sonde will be fitted with a flow-through cell to reduce exposure to the atmosphere. The purge water will be collected in 55-gal drums and removed by the environmental management contractor, Bechtel Jacobs Company. It may also be possible to discharge water back to the subsurface if approved by the regulators.

Samples will be handled and transported according to regulatory requirements and procedures outlined in the FRC Quality Assurance Plan. Samples will be preserved and stored as required by the analytical protocols (e.g. cooled, preservative added) and FRC health-physicists will check for exterior radioactivity. Storage on site may occur for short periods of time in ice chests containing “blue ice” or in the field trailer refrigerator but will be quickly transferred to refrigerator storage at the laboratory at the appropriate temperatures. All storage of contaminated samples will follow procedures and regulations relevant to radioactive materials (ESD Chemical Hygiene Plan). Any samples shipped offsite for analysis will follow chain of custody procedures described in the FRC Quality Assurance Plan.

5. HYDRAULIC CHARACTERIZATION

5.1 WATER LEVEL MEASUREMENTS

Continuous water levels will be measured using pressure transducers that feed into a Campbell or other data logging system. The system is programmable, stable, and can handle the entire monitoring network through the addition of multiplexers to expand the number of available channels. A data storage module will be added to increase the data storage capacity. As necessary, wells at further distances away from the primary characterization area will also be continuously monitored using pressure transducers and either single-channel or double-channel data loggers (e.g., Telog, or Hermit respectively) or Well Wizards or YSI Sondes. Data will be downloaded between each successive characterization activity. Calibration checks will be performed prior to and following each phase to ensure that the system is reading correctly and to measure any sensor drift for later corrections. In addition, manual water levels will be obtained periodically in every well using a water level probe with a sensor at the base that minimizes displacement of water in the well. These data will provide additional calibration checks.

Data will be downloaded from the data loggers to a PC and backed up on electronic media. Depth to water will be converted to water level elevations. Linear corrections will be made if necessary based on calibration checks. All field activities and field measurements will be noted in field logbooks and later transferred to electronic media.

5.2 SLUG TESTS

Slug injection tests (ASTM Method D4044-91) will be conducted in select piezometers at the three areas (Figs. 3.1 and 3.2) around the S-3 Ponds being investigated. These tests consist of instantaneous injection of a known volume of water into the casing (or the immersion of a cylinder of known volume), causing a rise in the water level in the casing either by the addition of water or by displacement. The drop in water level over time is then monitored until the initial water level is once again reached. This re-equilibration rate is related to the hydraulic conductivity (K) and storativity of the material immediately surrounding the wellbore, and can be determined through a straightforward analysis using type curves (Domenico and Schwartz, 1990). While these tests measure K over relatively short length scales (as compared to pumping tests), they are useful for establishing spatial variability in K and possibly delineating the geometry and extent of preferential flowpaths.

For a network of wells that is instrumented for continuous monitoring, multiple wells could be simultaneously tested as long as it was ascertained that testing in one well was not impacting water levels in the other wells being tested, thus saving time and effort.

5.3 SPECIFIC DISCHARGE MEASUREMENTS (POINT DILUTION TEST)

A borehole dilution or point-dilution method will be used to estimate the average specific discharge of groundwater in the formation as a function of depth (Halevy et. al., 1967; Drost et al., 1968; Hicks et al., 1992; Sanford and Moore, 1994; and Novakowski et al., 1995). For uncased wells, a dual packer apparatus isolating a 0.3 m section of borehole will be set in place for at least one day prior to the point-dilution test. For drivepoint wells targeting designated depths within the formation, the method will utilize a single packer apparatus to isolate the screened interval since the bottom of the well is already sealed.

Groundwater in the test interval will be slowly replaced with deionized water and the specific conductance and pressure-head monitored continuously. Distilled water will be added at a rate such that the pressure-head remains constant so that the system is not stressed. When the specific conductance of the interval becomes sufficiently low, the addition of distilled water will be terminated and the rise in specific conductance monitored. The rate at which the test interval re-equilibrates with the formation will be used to calculate the specific discharge through that zone (Freeze and Cherry, 1979; Sanford and Moore, 1994). For multiple measurements in uncased boreholes, point dilution measurements will overlap each depth interval by 0.15 m, ensuring that accurate measurements of specific discharge are assessed with depth in each borehole.

5.4 PUMPING TESTS

Pumping tests (ASTM Methods D4043-91, D4050-91, 4105-91, 4106-91) will be conducted by pumping a well at a constant rate and observing drawdown in the pumped well and nearby observation wells. A well with a high hydraulic conductivity will be utilized for the test (determined based on slug tests and point-dilution tests). Pumping rates will be measured periodically throughout the test to ensure that the rate remains constant or that any change in rate is captured. Each test will be initiated no sooner than 48 hours after a significant rain (more than 3 mm in a 24-hour period), or when water levels determined by continuous monitoring indicate that recovery following a storm has occurred, in order to avoid any influence from meteorological perturbations.

Continuous water level monitoring will be conducted in all monitoring wells in the network throughout the test. The measurement interval will be programmed for a logarithmic scale so that frequent measurements are made during the initial drawdown and again during the initial recovery phase.

Because the site is contaminated, water being pumped from these wells cannot be discharged back to the system without prior approval. Pumped water will be captured and containerized for analysis and disposal. Samples will occasionally be collected and analyzed during pumping to evaluate changes in water chemistry or contamination.

Data will be downloaded from the data loggers into a PC and backed up on electronic media. Depth to water will be converted to water level elevations, and linear corrections will be made if necessary based on calibration checks. All field activities and field measurements will be noted in field logbooks and later transferred to electronic media.

5.5 TRACER TESTS

Tracer tests will be conducted after completion of the pumping tests in order to maximize the information available for tracer test design. Tracer injection will not be initiated until after full recovery from the pumping test has occurred, as determined by water level monitoring in the observation wells, and until at least two baseline tracer samples have been obtained from each monitoring location. Multiple tracers will be injected at each injection location in order to evaluate the influence of matrix diffusion along each transport pathway. The suite of tracers will include gas tracers (e.g., He, Ne, Ar, SF6, Kr) and anionic tracers (e.g., Br^-, I^-), and will require a variety of injection, sampling, and analytical methods as described below.

5.5.1 Monitoring well network

The tracer test will utilize the same monitoring well network as is used for the pumping tests. One or more of the wells utilized in the previous tests will be used as injection wells for different tracers and injection will be done simultaneously in order to definitively measure connectivity and transport characteristics within specific transport pathways under identical conditions.

The piezometric monitoring system utilized for the pumping test will remain in place for the tracer test. However, data loggers will be reprogrammed to obtain hourly readings throughout the duration of the tracer test. This will allow the transport behavior to be correlated with gradients and to capture any perturbations that may affect transport, such as during storm events.

5.5.2 Tracer injection, sampling, and analysis methods

Anionic tracers - A constant concentration injection will be conducted for several days, depending on the results of the hydraulic testing. Sampling frequencies will be determined based on these results as well. Once detection has occurred in the nearest locations, then the more distant locations will be added to the sampling schedule. Following tracer shutoff, the wells will continue to be sampled three times weekly for an additional 30 days to measure the tailing behavior of the tracer concentrations. Actual times for the injection and recovery phases will depend on the transport dynamics observed during the test and may need to be adjusted accordingly.

Because of the potential for changes in groundwater flux through the injection well and the desire to maintain a constant source concentration, a continuous injection system will be used. The system has been tested and utilized successfully for long-term (years) tracer injection elsewhere at ORNL (Jardine et al. 1999).

The tracer injection system will consist of a double straddle packer design that will be used to isolate the screened interval in the injection well. A computational datalogger will automatically deliver small increments of a concentrated tracer stock solution through a solenoid valve in order to maintain a constant diluted injection concentration within the packed interval. The fluid in the injection interval will be continuously mixed by recirculating groundwater through a high-performance peristaltic pump and flow-through temperature-compensated conductivity cell. Copper refrigeration tubing will be used for the entire circulation system except for a 15-cm long piece of silicon tubing needed in the pump head. Copper tubing will eliminate the loss of dissolved gas tracers (e.g., He, Ne, Ar, SF_6, Kr) that will be co-injected into the same wells.

The pump rate will be set to mix the entire interval within 5-10 minutes. Flow through the conductivity cell will serve to trigger the automatic addition of tracer when the conductivity of the injection interval falls below a specified target value. Conductivity is checked every second and if tracer is needed, the solenoid valve will open for a designated time to dispense tracer stock solution from a constant head marriotte device. Using this approach, tracer addition will have a negligible affect on the total volume of the injection interval and this will be confirmed with continuous pressure head measurements within the interval.

Fifty-ml samples will be obtained from all sampling locations. Minimal purge techniques will be used to ensure that groundwater is being drawn through the well screen rather than from the standing column of water in the well casing.

In addition, high-frequency sampling (hourly) in the wells instrumented with Isco samplers will be conducted during at least two storm events in each of the injection and recovery phases. The purpose of these samples is

to ascertain differences in transport behavior, particularly fast fracture flow or dilution effects during storms. The inclusion of upgradient wells in the monitoring well network will allow a determination of changes in hydraulic gradient and subsequent changes in transport direction during these perturbations.

Samples will be labeled and refrigerated in an ice chest until they can be transported to the laboratory for analysis. Analysis will be done in ESD laboratories using ion chromatography methods in order to provide a lower detection limit and more stable and repeatable analyses. Samples will be centrifuged prior to analysis to minimize turbidity, but will not be filtered.

Dissolved gas tracers - As with the anionic tracers, a relatively constant concentration injection will be done over the same time period. The gas injection and sampling system utilizes molecular diffusion through gas-permeable tubing (Sanford and Solomon 1998; Sanford et al. 1996) and has the advantage of minimizing any impact on flow conditions. Gas is continuously pumped through a coil of Teflon tubing installed in the screened section of the well. The gas diffuses quickly into the surrounding groundwater, coming to a steady-state concentration based on the in situ temperature and pressure conditions, the solubility constant, and the average groundwater flux through the wellscreen.

Samples will be obtained using passive-diffusive samplers consisting of two parts—a length of gas-permeable silicon tubing, and a copper sample tube that is sealed on one end and valved on the other (Sanford et al. 1996). Dissolved gas diffuses through the silicon tubing and comes to equilibrium with the surrounding groundwater. A portion of the gas is trapped in the copper tube, which is open to the silicon tubing by way of a valve while the sampler is suspended in the well. When the sampler is removed from the well, the silicon tubing is immediately disconnected, closing the valve and sealing in the gas sample. The gas is then analyzed by direct injection into a gas chromatograph.

Alternatively, water samples may be obtained using methods similar to those used for sampling some VOCs. In that case, headspace samples would be analyzed for the gas tracers. While the passive-diffusive method allows a simple means for obtaining samples without the need for disposing of contaminated groundwater, it is limited by the need for equilibration time. The headspace method is slightly more complicated due to the care required to prevent loss of gases during sampling, but allows for instantaneous sampling where monitoring rapid changes is desired, such as during storm events.

The passive-diffusive gas tracer method has been successfully applied in several tracer studies on the Oak Ridge Reservation, some of them extending several months to over a year (e.g., Moline et al. 1998; Sanford and Solomon 1998; Jardine et al. 1999).

6. FIELD ANALYSIS PROCEDURES

Analyses of groundwater that will routinely be conducted in the field using Hach analytical methods (1998, Hach Co., Loveland, CO) include sulfide and ferrous iron. Additional field analyses (e.g., total iron, nitrate, and nitrite) may also be performed as needed using Hach analytical methods but will normally be analyzed using the IC laboratory methods (Sect 7.3). Field parameters (i.e., specific conductance, temperature, pH, Eh and dissolved oxygen) will be taken with a YSI multi-parameter water quality sonde installed in a flow-through cell. When greater accuracy is needed, dissolved oxygen will be determined using CHEMetric oxygen vacu-vials. Groundwater will be sampled and analyzed immediately for ferrous iron and sulfide. Estimated method detection limits are in accordance with USEPA definition in 40 CFR, Part 136, Appendix B (7/1/94 edition). If determined as necessary the accuracy of results may be confirmed using standard additions by adding small amounts of known standard solution to a sample and repeating the analysis. The field analysis procedures are summarized in Table 6.1.

Table 6.1. Field Analysis of Groundwater

Analysis	Method	Laboratory	Holding Time	Container	Quality Control (as needed)
Ferrous Iron	Hach 8146	Field Kit	Immediate analysis	20 mL glass vials	Standards Duplicates Std. Addition
Total Iron	Hach 8008	Field Kit	Immediate analysis	20 mL glass vials	Standards Duplicates Std. Addition
Nitrite	Hach 8057/8153	Field Kit	Immediate analysis	20 mL glass vials	Standards Duplicates Std. Addition
Nitrate	Hach 8039	Field Kit	Immediate analysis	20 mL glass vials	Standards Duplicates Std. Addition
Sulfide	Hach 8131	Field Kit	Immediate analysis	20 mL glass vials	Standards Duplicates Std. Addition
Dissolved Oxygen	Rhodazine D	Field Kit YSI Sonde	Immediate analysis	Flow-through cell	Standards Duplicates
Temperature	Thermistor	YSI Sonde	Immediate analysis	Flow-through cell	Standards Duplicates
pH	pH probe	YSI Sonde	Immediate analysis	Flow-through cell	Standards
Eh	Platinum redox probe	YSI Sonde	Immediate analysis	Flow-through cell	Instrument checks
Specific conductance	Conductivity probe	YSI Sonde	Immediate analysis	Flow-through cell	Standards

6.1 GROSS RADIOACTIVE SCREENING

Sediment will be screened in the field for gross radioactivity using Geiger-Mueller (GM) survey instruments. However, ratemeter-type GM survey instruments will not detect any above-background (50-100 cpm) gross beta-gamma activity which could include uranium up to about 500 ppm using routine survey times of less than 30 seconds per probe position. Cumulative or integral-type GM instruments may detect down to about 100-250 ppm but these instruments require longer counting times (several minutes) and would require background subtractions. Such lengthy surveys are more amenable to laboratory use rather than for field operation. Although alpha scintillation probes offer more sensitivity to uranium, it only measures alpha activity on the surface of sediment core or auger cuttings; sediment samples cannot be contained in liners or sleeves for such surveys as these will completely block all alpha particle emissions.

6.2 DOWNHOLE URANIUM ANALYSIS

An *in situ* assay for uranium in sediment using core holes, wells, or residual sampling holes, offers two very attractive advantages beyond the laboratory methods discussed in Sect. 7 (Miller et al. 1994). First, well logging would avoid the necessity and cost of collecting and processing samples in the laboratory. Second, *in situ* well logging for uranium assay is non-destructive and, thus, could be repeated at intervals to determine if the activity in sediment surrounding the hole was changing with time or because of experimental manipulation. It also has two significant disadvantages compared to sampling methods. First, *in situ* assay offers no information about the fraction of the uranium dissolved in groundwater, which could only be determined by water sampling and laboratory analyses. Second, its sensitivity is likely to be lower as “samples” cannot be shielded from each other within the hole and higher general backgrounds will be encountered which will raise the detection limit. However, in situ analyses via gamma spectroscopy can be very close in sensitivity to laboratory analyses (Benke and Kearfoot 1997) and can attain the sensitivity for proposed maximum allowable cleanup levels for uranium isotopes (Wood et al. 1999).

ESD has several 1-inch diameter sodium iodide detectors, which could be employed for *in situ* measurement of gamma activity. These detectors would be operated in well-logging mode and coupled with a field-portable PC-based, multi-channel analyzer, which ESD already has. The sensitivity of detectors would need to be checked in order to calculate the counting time needed to achieve a specified detection limit.

Sampling holes could be left open (uncased) for one-time depth logging. The probe would be lowered into the hole and assays conducted at various depth intervals (e.g., every 0.5 foot) with gamma-ray spectrums collected for fixed intervals (e.g., 30 minutes). Uncased holes would minimize shielding of the detector by any casing material; but these could not be expected to remain open for repeated logging over extended periods of time. Alternately, sample holes may be cased with minimum density materials (e.g., plastic pipe would be preferred over steel). In this case, counting assay intervals would need to be longer than for uncased holes but might attain the same detection limits. In situ assay holes could also be unscreened which would avoid the additional shielding effect of water filling the well column volume of a screened well. Gamma activity logging can continue beneath the water table although a significant decrease in sensitivity will be noted. A standard well-logging protocol, including well construction methods and materials specifications, will be developed. These specifications will be compatible with all other sampling and characterization plan needs.

6.3 IRON

Determination of ferrous iron [Fe(II)] will use the 1, 10-phenanthroline method (Hach method 8146). The 1, 10-phenanthroline indicator reacts with Fe(II) in solution to form an orange color that is analyzed with a field

spectrophotometer at 510 nm. The indicator does not react with ferric iron [Fe(III)]. The estimated lower detection limit is 0.018 mg/L with a precision of 0.006 mg/L. The method is linear to 3.0 mg /L. Standard solutions will be prepared using ferrous ammonium sulfate.

Determination of total iron will use the FerroVer method (Hach method 8008). The FerroVer reagent reacts with all soluble iron and most insoluble forms of iron in the sample to produce soluble ferrous iron. This then reacts with 1,10-phenanthroline indicator to form a orange color that is analyzed with a field spectrophotometer at 510 nm. The estimated lower detection limit for total iron is 0.018 mg/L with a precision of 0.006 mg/L. Standard solution will be prepared using atomic absorption grade analytical standards that consist of iron metal dissolved in an acidic aqueous solution. Ferric iron, Fe(III), will be determined by subtracting the ferrous iron concentration from the result of the total iron test.

6.4 NITRITE/NITRATE

Determination of nitrite will use two methods depending on its concentration in the groundwater. Low range analyses where concentrations do not exceed 0.3 mg/L NO_2^- will use the diazotization method (Hach method 8507). In this method, nitrite in the sample reacts with sulfanilic acid to form an intermediate diazonium salt that couples with chromotropic acid to produce a pink colored complex that is analyzed with a field spectrophotometer at 507 nm. Estimated lower detection limits are 0.001 mg/L with a precision of 0.0003 mg/L. Standard solutions will be prepared using a Hach nitrite stock solution. High range analyses, where NO_2^- concentrations are above 0.3 mg/L, will use the ferrous sulfate method (Hach method 8153). Ferrous sulfate is used in an acidic media to reduce nitrite to nitrous oxide. Ferrous ions complex the nitrous oxide to form a greenish-brown color that is analyzed with a field spectrophotometer at 585 nm. The method is linear to 150 mg/L with a precision of 2.2 mg/L. Standard solutions will be prepared using sodium nitrite.

Nitrate will be determined using the cadmium reduction method (Hach method 8039). Cadmium metal reduces nitrate to nitrite and the acidic media is reacted with sulfanilic acid to produce a diazonium salt. The salt couples to gentisic acid to form an amber colored solution that is analyzed with a field spectrophotometer at 500 nm. The method is linear to 30 mg/L with a precision of 2.3 mg/L. Standard solutions will be prepared from sodium nitrate.

6.5 SULFIDE

Determination of sulfide will use the methylene blue method (Hach method 8131). Groundwater hydrogen sulfide and acid-soluble metal sulfides react with N, N-dimethyl-p-phenylenediamine oxalate to form methylene blue. The blue-colored solution is analyzed with a field spectrophotometer at 665 nm. The estimated lower detection limit is 0.01 mg/L with a precision of 0.003 mg/L. The method is linear to 0.6 mg/L. Standard solutions will be prepared using a Hach sulfide stock solution.

6.6 DISSOLVED OXYGEN

YSI Multiparameter Water Quality Monitor - Dissolved oxygen (DO) is determined using a rapid pulse-Clark type, polarographic sensor with a range of 0 to 50 mg/L. The accuracy is 0.2 mg/L for 0 to 20 mg/L of DO, and 0.6 mg/L for 20 to 50 mg/L of DO.

Hach Kit – When lower detection limits are required, determination of DO will be conducted using Rhodazine D Method, which reacts with groundwater DO to form a deep rose color that is analyzed with a

field spectrophotometer at 555 nm. The spectrophotometer is calibrated with a CHEMetric dissolved oxygen ampule kit and a calibration table is formulated. The estimated lower detection limits for DO are 20 g/L and the method is linear to 800 ug/L. For groundwater DO analyses above 800 ug/L, visual colorimetric analyses are performed using a CHEMetric standard comparator, which has a linear range up to 12 mg/L DO.

6.7 pH/EH/SPECIFIC CONDUCTANCE/TEMPERATURE

6.7.1 YSI Muliparameter Water Quality Monitor

Groundwater pH will be measured using a pH probe with a saturated potassium chloride (KCl) junction. The probe will be calibrated using a two point buffer calibration curve. Groundwater specific conductance will be measured with a conductivity probe that has been calibrated with known conductivity standards of KCl. Standard curves and probe calibration will be checked every day sampling is conducted. Temperature will be measured with a thermistor. The operating range is -5 to 45°C with an accuracy of 0.15°C and resolution of 0.01°C.

6.7.2 Stand Alone Probes

Groundwater pH may also be measured using a pH probe with a saturated KCl junction. The probe will be calibrated with a field meter using a two point buffer calibration curve. A slope of 573 mV will ensure accurate calibration. Sample equilibration times will be based on the stability of the measurement, with 4 min being an appropriate cutoff time. Probe calibration will be checked every day sampling is conducted.

Groundwater Eh will be performed using a platinum redox probe with a fill solution of 4M KCl saturated with Ag/AgCl. Direct measure of the groundwater electrical potential (mV) will be performed. Measurements will be converted to values that are relative to the normal hydrogen electrode at any particular temperature.

Groundwater specific conductance will be measured with a conductivity probe that has been calibrated with known conductivity standards of KCl.

Standard curves and probe calibration will be checked every day sampling is conducted.

7. LABORATORY ANALYSES

This section describes the laboratory procedures that will be used during the site characterization. Table 7.1 provides a summary of these procedures. All laboratory analyses will be performed in ORNL laboratories unless otherwise indicated.

7.1 URANIUM

Uranium will be determined using time-resolved KPA. The excitation source is a dye laser pumped by a nitrogen laser, with photomultiplier tubes operating in photon counting mode as the detector. 1-2 mls of sample are required, with typical analysis time being 1-3 minutes. The instrument automatically mixes sample with reagent and injects the sample. Software control provides for sample cell rinsing and auto ranging of the detector. Intensity data are corrected for background, variations in laser power and coincidence. Intensity intercepts are calculated by linear least-squares regression. Results are quantified by external or internal calibration. The raw data, configuration settings, and operating preferences are stored electronically for later use.

The analytical range of KPA without matrix interferences is 0.01 µg/L to 5.0 mg/L. The relative standard deviation is typically 2-3% above 0.1 µg/L and 7-10% below 0.1µg/L. Several species can cause interferences including acid above 2 molar, alcohols, alkalinity and carbonate, aluminum, halides (not fluoride), chromate, chromium, copper, iron (II), lead, manganese (II), nickel (II), organics, silver, thallium, and zirconium. These species can interfere with the complexing of the uranium and quenching of the luminescence.

Groundwater will be analyzed for uranium using the ESD's KPA instrument (Chemchek Instrument Inc.). This uranium analytical method (Croatto et al. 1997) is the most sensitive method available, with a typical detection limit of 0.01 ug/L, which is relatively rapid, and requires only minimal sample preparation (filtration). The KPA analytical protocol can be easily integrated with other priority laboratory measurements of groundwater characterization (i.e., pH, alkalinity, dissolved anions and cations). It will be the primary screening method for selecting wells or areas of the FRC site for potential field experiments. It is much more sensitive than radioactivity measurements of water samples because of the low specific activity of natural uranium (i.e., 1.58 dpm/µg of uranium) although the radioactive methods are non-destructive. Although uranium could be analyzed in water by liquid scintillation spectroscopy using the alpha pulse analytical method, this method offers no advantage over KPA in either sensitivity or preparation.

Sediment samples will be assayed for uranium using KPA with sodium carbonate extracts (Francis et al. 1999). Although the sodium carbonate method does not extract all the background uranium within natural soil minerals, it is very effective in removing contaminated surfaces and has been tested on soil from the Y-12 Landfarm (Francis et al. 1999) and found to be effective on sediment from the DOE facility in Fernald, Ohio (Mason et al. 1997). The anthropogenic inputs of uranium to the contaminated FRC sediment are much more important for NABIR Projects to address and measure in selecting field demonstration sites. Total dissolutions (Hossner 1996) of sediment samples will be carried out for background information on all elements using ICP-MS and will include total uranium. Sediment samples will be dried, disaggregated and separated from inert coarse particles (> 2 mm), and subsamples weighed into secondary containers such as test tubes or beakers for extraction and/or total dissolutio

Table 7.1. Laboratory Analyses

Analysis	Matrix	Method	Lab	Preservation	Holding Time	Container
Uranium sorption isotherms	Sediment	KPA	ESD	None	None	Glass
Iron and manganese oxides	Sediment	Dithionite-citrate-bicarbonate method of Mehra and Jackson (1960)/AA	ESD	None	None	Polyethylene or glass
Particle size	Sediment	Bouyoucos hydrometer method	ESD	None	None	Polyethylene or glass
Bulk density	Sediment	Gravimetric	ESD	None	None	Polyethylene or glass
Water content	Sediment	Gravimetric	ESD	None	None	Polyethylene or glass
Anions	Groundwater	Ion chromatograph	ESD	Cool to 4° C until analysis	28 days except for nitrate, nitrite and phosphate which is 48 hours.	Polyethylene or glass
TOC,TIC	Groundwater	Shimadzu TOC analyzer	ESD	No acid/no headspace Cool to 4° C until analysis	Analyzed within one week	Glass vials
TOC,TIC	Sediment	Shimadzu TOC analyzer	ESD	Cool to 4° C until analysis	6 months	Polyethylene or glass
VOAs	Groundwater	GC or GC/MS	External and/or ESD	Cool to 4° C until analysis	14 days	40 ml glass vials with Teflon-lined septum
Metals	Groundwater	ICP, ICP/MS, or AA	External and/or ESD	HNO_3 to pH<2	6 months	Polyethylene or glass
Metals	Sediment	ICP, ICP/MS, or AA	External and/or ESD	Cool to 4° C until analysis	6 months	Polyethylene or glass
Total U	Groundwater	KPA	ESD	HNO_3 to pH<2	6 months	Glass vials
Technitium-99	Groundwater	Scintillation	ESD	None	None	Polyethylene or glass
Technitium-99	Sediment	Scintillation	ESD	None	None	Polyethylene or glass
Total U	Sediment	KPA	ESD	HNO_3 to pH<2	6 months	Glass vials
Alkalinity	Groundwater	Titration	ESD		24 hrs	Glass vials
Dissolved Gases	Groundwater	GC/hdsp injection	ESD		24 hrs	40 ml glass vials with Teflon-lined septum

Note: Quality control will include analysis of Standards, Blanks, duplicates, and instrument checks.

7.2 TECHNETIUM

Tc-99 is a beta-emitter with a half-life of about 2.13×10^5 years and a specific activity of ~17 µCi/mg. It is commonly determined by liquid scintillation analysis with a high accuracy because of its relatively high specific activity. The detection limit is approximately 1000 ρCi/L (or ~0.06 µg/L) if no preconcentration or pretreatment is performed (i.e., the groundwater is directly mixed with the scintillation cocktail and analyzed).

However, groundwater at many locations of the FRC (e.g., Pathway 2) contains less than 1000 ρCi/L Tc-99 (as pertechnetate, TcO_4^-). Sample preconcentration and pretreatment is thus necessary, particularly for groundwater containing a high salt concentration which may quench the radioactivity or interfere with the measurement of Tc-99 by the scintillation analysis.

The preconcentration of groundwater may be accomplished by evaporation and extraction on a hotplate. However, this procedure is relatively tedious and labor intensive. Alternatively, the groundwater is extracted with specific anion exchange resins such as the 3M resin disks and the bifunctional resins recently developed at ORNL for selective sorption of TcO_4^-. The TcO_4^- - loaded resins can then be directly counted by the liquid scintillation analyzer, and this procedure has been routinely used in our laboratory (Gu et al., 1998; Gu et al., 2000).

Depending on the objectives, about 0.1 to 5 L of groundwater may be processed so that the detection limit can be lowered by 2 to 3 orders of magnitude. (~0.2 to 10 ρCi/L).

Similar analytical protocols may be used for the analysis of Tc-99 in soil samples after extraction. Pertechnetate is poorly sorbed by soil clay minerals, particularly at a relatively high pH condition (pH > 10) (Gu and Dowlen, 1996). However, TcO_4^- can be strongly sorbed by minerals such as iron and aluminum oxides at a low pH condition. Therefore, a solution of 0.5M KCl (or sodium carbonate) at pH 10 is generally satisfactory for extracting TcO_4^- from the soil.

It is noted, however, that TcO_4^- is also readily reduced in soil and the reduced forms of Tc are relatively insoluble. Caution must be taken if soil is under reducing conditions. In this case, soil should be pretreated to convert the reduced forms of Tc-99 to TcO_4^-.

7.3 METALS

The analysis of metals for this project will be performed by Inductively Coupled Plasma (ICP), Inductively Coupled Plasma/Mass Spectrometry (ICP/MS), Cold Vapor Atomic Absorption (CVAA), Flame Atomic Absorption (FAA) or Graphite Furnace Atomic Absorption (GFAA). Background concentrations of metals and nonvolatile elements will be determined on total dissolution of sediment (Hossner 1996); "available" metals, in contrast to total, will be analyzed on dithionite-citrate-bicarbonate extracts of sediment (Loeppert and Inskeep 1996) and will be the characterization method for FRC contaminant availability used for more intensive sampling. The method used will depend on the interferants present in the sample and the detection limit needed for the specific metal. Samples may be analyzed using ESD's equipment or shipped to an outside analytical laboratory via a purchase order through the Oak Ridge Sample Management Office.

ESD has a Perkin Elmer Analyst 800, which is equipped with a transversely heated graphite furnace and longitudinal Zeeman-effect background corrector. Standards are obtained from JT Baker and matrix modifiers from Perkin Elmer. Data can be downloaded electronically. FRC staff members also have access to a Thermo-Jarrell Ash Polyscan Iris ICP.

7.4 ANIONS

The analysis of anions (i.e., chloride, nitrate, nitrite, sulfate) for this project will be performed by ion chromatography (IC) using EPA Method 300.0. The instrument to be used is a Dionex DX-120 Ion Chromatograph with an AS4A column and AS4G guard column. IC uses chromatographic separation and conductivity to measure concentration compared with a standardized curve. The instrument is highly sensitive, particularly when anion auto-suppression is added, allowing detection at ppb levels. Approximately 5 ml of filtered sample is required and is consumed in the analysis. The system is computerized for automated data analysis and digital data recording. Data can be downloaded into spreadsheet or comma delimited files. Typical analytes include chloride, fluoride, nitrate, nitrite, sulfate, bromide, and phosphate. Minimum detectable concentrations vary with sample size and the conductivity scale used.

Anionic tracer analysis will also be performed in ESD laboratories using ion chromatography methods. These samples will be centrifuged prior to analysis to minimize turbidity, but will not be filtered.

7.5 TOTAL ORGANIC AND INORGANIC CARBON

Both organic and inorganic carbon can be converted to CO_2 by either catalytic combustion of organic carbon or by acidification of inorganic carbon. The CO_2 is measured photometrically because of its strong absorption of infrared light. This method is highly sensitive and subject to little interference from other components in the groundwater.

A sensitive Shimadzu TOC 5000 Total Organic Carbon Analyzer will be utilized for both organic and inorganic carbon analyses in groundwater samples. Groundwater samples will be collected in clean glass vials (with no acid and no headspace), and analyzed within a week. Inorganic carbon will be first analyzed by acidification of the sample (with phosphoric acid) and purging with high-purity oxygen. Inorganic carbon (as CO_2) is then released and detected as it flows through the infrared detector of the TOC analyzer.

Total carbon in groundwater sample is analyzed by directly injecting the unacidified sample into the combustion chamber of the TOC analyzer (with high-sensitive platinum catalysts) with oxygen as the carrier gas. Both organic and inorganic carbon are completely converted to CO_2 and detected as described above. The total organic carbon content is calculated by subtracting the inorganic carbon content from the total carbon content. The detection limit is approximately 10 µg/L carbon.

Solid phase total organic carbon will be determined using a Dohrmann DC-190 with an attached 183 Boat sampler. The instrument will be standardized using potassium hydrogen phthalate. Inorganic carbon will be removed by heating the sediment to near boiling for one hour with 1.5 M HCl. After the acid solution is removed, the sediment is rinsed with deionized water. The sediment is then dried and pulverized to obtain homogenous samples for analysis. The samples will be analyzed in triplicate. The linear range for the method is 15 - 2000 mg/L.

7.6 MICROBIOLOGY

Groundwater samples and subsamples of the cores will be obtained at the FRC for characterizing the microbial community at host institutions of individual NABIR investigators using the terminal restriction fragment length (T-RFLP) technique described by Liu et. al. (1997) and/or other characterization techniques such as phospholipid fatty acid (PLFA), denaturing gradient gel electrophoresis (DGGE), and acridine orange direct counts (AODC). Sediment samples will be frozen at -80 C and archived until the samples are analyzed. Surplus community DNA (if generated) will also be frozen at -80 C and retained in the FRC sample archive for future use by NABIR investigators. Using archived sediment samples and DNA wherever possible offers

several advantages including reduced sampling costs and a basis for comparing different analytical results. Sampling intervals will be determined based on stratigraphy and uranium distribution in the cores. Some samples may be obtained and stored under anaerobic conditions. Wherever possible, only half (lengthwise) of the core will be subsampled, and the remainder will be archived for replicate or comparative analyses.

7.7 ALKALINITY

Alkalinity will be determined by an automated titration of the sample to pH 4.3 using a Metroholm 719S titrino according to method 2320B from Standard Methods for the Examination of Water and Wastewater, 19th edition. The sample will be collected anaerobically in a pre-weighed 40 mL septa capped EPA vial and stored upside down submerged in water until analysis. Analysis will take place within 24 hours of sample collection. Hach digital titration conducted in the field may also be conducted to determine alkalinity.

7.8 DISSOLVED GASES

Dissolved gases (methane, ethane, and ethylene) in groundwater will be determined by headspace injection into a Hewlett Packard 590-series II gas chromatograph equipped with a chrompak coated Poraplot Q column (0.53 mm internal diameter x 25 m length) and flame ionization detector. The instrument will be calibrated using individual gas standards obtained from Scott Specialty Gases (1500 ppm each in a balance of nitrogen). The samples will be collected in argon purged 40 mL EPA septa capped vials and stored upside down submerged in water until analysis. The vials will be filled approximately halfway, and analyzed within 24 hours of collection. Sample and headspace volumes will be determined by weight.

Dissolved gas tracers will be analyzed by gas chromatography, using either a headspace method or direct injection from passive-diffusive gas samplers, depending on the sampling method chosen. Noble gases (He, Ne, Ar, Kr) will be analyzed using a Varian Star3400 gas chromatograph equipped with a thermal conductivity detector. SF6, if used, will be analyzed by the headspace method using a gas chromatograph equipped with an electron capture device. Because of the lower solubilities and greater tendency to partition into air, sample collection and preparation for headspace analysis will vary slightly from the procedure used for VOCs. EPA vials will be filled completely and capped immediately upon filling and kept cold in the field, and brought to the laboratory.

7.9 VOLATILE ORGANICS

Volatile organics will be determined by gas chromatograph/mass spectrometry (GC/MS) or by gas chromatography (GC). Samples may be analyzed using ESD's equipment or shipped to an outside analytical laboratory.

In ESD, volatile organics are determined on a Tekmar 3100 Purge and Trap coupled to a Hewlett Packard 5890 gas chromatograph with a photoionization detector that selectively detects aromatic and olefinic compounds. EPA Method 502.2 is the analytical protocol to be followed. The typical operating range is 5-40 ppb, although the high end can be extended to 1 ppm if needed. Standards are made from Supelco custom mix stock standards. Each analysis takes approximately 30 minutes.

7.10 SEDIMENT CHARACTERIZATION

7.10.1 Mineralogy

Mineralogy of sediment particles will be analyzed for a few background samples using X-ray diffraction techniques for estimating clay mineral species (Whittig and Allardice 1986).

7.10.2 Uranium Sorption Isotherms

Sediment samples will be moist sieved to <2 mm and 1.0 g samples will be added to 30 mL polycarbonate centrifuge tubes. Solutions of U(VI) from the nitrate salt will be prepared in a 5 mM $NaNO_3$ matrix with pH adjustment to the indigenous pH of the solid phase. Fifteen mL of eight U(VI) solutions from 0.01 to 5 mg/L will be added to each soil. The slurries will be agitated for 48 hours on a reciprocal shaker at which time they will be removed, centrifuged to separate solution and solid, and the supernatant saved for pH and U(VI) analyses. Sediment will be removed from the centrifuge tubes with a DDI water jet, and 0.1 M nitric acid will be added to desorb any uranium that may have been sorbed on the container walls. Uranyl analysis will use the kinetic phosphorescence analyzer which has detection low limits in the low part-per-trillion range; however, FRC sediment isotherm studies will not require dissolved uranium detection limits below 10 µg/L.

7.10.3 Iron and Manganese Oxides

The mass fractions of iron and manganese oxides on the solid phase materials will be determined using the dithionite-citrate-bicarbonate (DCB) method of Mehra and Jackson (1960) as revised by Loeppert and Inskeep (1996). Duplicate samples will be treated three times at 353ºK with the DCB treatment, using appropriate quantities of 0.3 M sodium citrate, 1 M $NaHCO_3$, and crystalline $Na_2S_2O_4$ to remove the iron and manganese oxides. Supernatant will be separated from the solid phase using centrifugation, with the supernatant saved in volumetric flasks. Iron and manganese will be analyzed by atomic absorption spectrophotometer with standards prepared in the DCB extraction solution. Because the DCB method extracts the hydrous iron and manganese oxide phase, and because these phases are responsible for most of the adsorption of heavy metal elements, this extraction method will also be used for routine assessment of “available” heavy metals in FRC sediment. A few FRC samples will be analyzed for heavy metals after total dissolution (see Sect. 7.2 Metals).

7.10.4 Particle Size

We will use the hydrometer method (Gee and Bauder 1986; ASTM 1990 Method D422-63) to determine the mass percentage of sand, silt, and clay in a sediment sample. Forty grams of air-dry sediment will be placed in a dispersing cup with 100 mL of a 5% Calgon solution and 400 mL of DDI water. The slurry will be agitated for about 10 minutes and then mixed in a mechanical blender for 5 minutes. The slurry will then be transferred to a 1000 mL cylinder using a stream of DDI water to assist in the transfer. DDI water will be added to bring the final volume to 1000 mL. The suspension will be allowed to equilibrate to room temperature. The temperature of the suspension will be recorded, and a plunger will be inserted and used to vigorously mix the suspension without spillage. The plunger will be removed and the time immediately recorded. A drop of amyl alcohol can be used if the surface is covered with foam. The hydrometer will be lowered into the suspension with minimal disturbance and the hydrometer read after 30 seconds from the point when mixing was terminated. With the hydrometer remaining in the suspension, a 1 minute reading will be taken as well. The hydrometer will be removed, rinsed, and wiped dry. The hydrometer will again be carefully inserted into the suspension after 3, 10, 30, 90, 270, and 930 minutes. The temperature should be recorded with each reading. A blank solution will also be prepared by adding 100 mL 5% Calgon to a cylinder with DDI water for a final volume of 1000 mL. Once the solution has reached room temperature, the hydrometer will be calibrated by insertion into the blank solution and reading the upper meniscus on the hydrometer stem. The percent sand, silt, and clay will be calculated based on Stoke’s Law.

If sieve analyses are conducted, ASTM Method C136-92 will be followed.

7.10.5 Bulk Density and Water Content

Duplicate undisturbed cores of sediment (8.5 cm diameter x 6 cm length) will be obtained using brass sleeves and sealed in tempi-cells. The sediment will be slowly saturated from the bottom with DI water and weighed. Sediment will be removed from the cylinders and oven dried at 105°C and weighed. Bulk density will be calculated from the total dry sediment weight and the total volume of the core area (American Society of Agronomy 1986). The water content (American Society of Agronomy 1986 and ASTM D4959-00) will be calculated from the total volume and the volume of water in the pore space of a known area of the sediment.

8. QUALITY CONTROL

8.1 FIELD QUALITY CONTROL

Duplicate analyses will be performed for approximately 1 in 20 samples to ensure repeatability.

Field blanks and equipment blanks will be taken as necessary.

Trip blanks will be prepared in the laboratory for the volatile organic analysis by filling a 40-ml bottle with distilled/deionized water. A trip blank will be included in each sample shipment for volatile organics.

Estimated method detection limit are in accordance with USEPA definition in 40 CFR, Part 136, Appendix B (7/1/94 edition). Accuracy of results will be confirmed using standard additions by adding small amounts of known standard solution to a sample and repeating the analysis.

8.2 LABORATORY QUALITY CONTROL

Check standards, instrument performance check solutions, laboratory duplicates, reagent blanks, instrument blanks, and performance evaluation samples will be analyzed as required by the applicable standard operating procedure, instrument manual, or analytical method.

9. HEALTH AND SAFETY

The FRC Manager and NABIR investigators are responsible for ensuring Environment, Safety, Health and Quality compliance at all stages of each project and the sample handling life cycle. The Oak Ridge National Laboratory Integrated Safety Management System (ISMS) is employed as the framework and overall approach to meeting all Environment, Safety, Health, and Quality (ESH&Q) requirements. An Oak Ridge National Laboratory ESH&Q checklist will be prepared and approved prior to conducting the site characterization activities. Work is also conducted under an approved FRC Health and Safety Plan. Penetration permits will be required for all subsurface drilling and a Radiological Work Permit will be required when conducting any coring work. See the FRC Management Plan and Health and Safety Plan for further information on the health and safety requirements and procedures that the FRC will follow.

10. WASTE MANAGEMENT

All project-related wastes generated by the FRC which require disposal will be characterized and certivied by UT-Battelle to waste stream profiles (waste acceptance criteria) managed by Bechtel Jacobs Company. After characterization and certification these wastes are turned over to Bechtel Jacobs Company for disposal. For most projects wastes will be contained in 55-gallon drums or other suitable containers for ultimate disposal by BJC.

To facilitate handling of these wastes, BWXT, as part of the site services it provides, furnishes industrial waste dumpsters at the locations of the field trailers at the FRC Contaminated Field Site to receive solid uncontaminated non-hazardous waste (e.g., disposable gloves and tyvek). Also, A Satellite Accumulation Area (SAA) for RCRA hazardous wastes generated from field analysis has been established at the FRC Contaminated Field Site. This SAA is managed by UT-Battelle and, consistent with waste operations at Y-12, bears a BWXT administrative identifier.

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Appendix A

DATA TABLES

Table A-1. Results of chemical analysis of wastes, soils, groundwater, and surface water at the S-3 Ponds Site FA

Analyte[d]	Wastes	Soils[a]				Groundwater[b]				Surface Water[c]			
	S-3 sludges	Results > detection limit	Maximum detect	Average result	Site Related Contami-nant	Freq. Of wells w. detects	Max detect	Mean of the medians[e]	Site Related Contami-nant	Freq. of detect	Avg.[f] result BCK 12.46	Avg.[f] result NT-1	Site Related Contami-nant
Inorganics (water - mg/L, soils - mg/kg)													
Aluminum	22134	40/ 40	29000	15600		23/ 23	800	81.05	Y	70/ 82	0.506	0.56	
Antimony		2/ 2	0.34	0.3		0/ 20	.	0.025					
Arsenic	1.12	40/ 40	20.5	3.5		1/ 9	0.009	0.003					
Barium	133.5	40/ 40	712	145	Y	24/ 24	380	19.137	Y	77/ 78	0.092	0.554	Y
Beryllium	2.74	36/ 40	1.8	1.0		11/ 22	0.11	0.0119	Y	3/ 78	0.0000	0.0002	
Boron	27.64	NA				24/ 24	4.40	0.29	Y	78/ 78	0.086	0.073	Y
Cadmium	4.9	2/ 40	2	0.2		10/ 25	4	0.174	Y	3/ 4		0.015	Y
Calcium	42215.6	39/ 39	318000	26700		26/ 26	10,000	1,665.6		78/ 78	164.5	228.3	
Chromium	133.2	40/ 40	69.6	30.8		13/ 25	0.31	0.017	Y				
Cobalt	3.47	40/ 40	31.1	16.6		11/ 23	2.3	0.268	Y	5/ 78	0.001	0.007	
Copper	92.45	38/ 40	50.8	22.3	Y	20/ 21	3.1	0.278	Y	4/ 78	0.005	0.002	
Cyanide	5.95	4/ 40	7.8	0.6	Y	0/	.	.		6/ 72	0.001		Y
Iron	3647	40/ 40	48300	25600		23/ 23	28	3.59		46/ 78	0.743	0.233	
Lead	35.79	40/ 40	82.3	15.5	Y	21/ 26	0.66	0.0106	Y	1/ 4		0.003	
Lithium	75.68					7/ 7	3.5	0.88	Y	33/ 72	0.015		
Magnesium	1941.32	40/ 40	60400	6930		26/ 26	2,500	263.3		78/ 78	23.4	29.8	
Manganese	99.67	40/ 40	2000	707		24/ 24	220	24.162	Y	78/ 78	0.046	3.0	
Mercury	2.28	26/ 39	82.9	7.8	Y	15/ 26	0.1100	0.0042	Y	18/ 72	0.0000		
Molybdenum	15.2	1/ 40	3.7	0.5		3/ 19	0.023	0.006					
Nickel	550.32	40/ 40	128	29.6	Y	22/ 24	20	2.07	Y	5/ 78	0.005	0.068	Y
Niobium	20.87					4/ 5	0.10	0.027	Y				
Phosphorous	952.9									41/ 72	0.058		Y
Potassium	1625.6	40/ 40	3990	2120		26/ 26	200	30.95		78/ 78	5.126	4.5	
Selenium	0.77	2/ 40	0.66	0.31		3/ 10	0.014	0.003		1/ 72	0.001		
Silicon						24/ 24	39	9.99					
Silver	1.87	26/ 40	4.3	1.8		0/ 6	.	.					
Sodium	2722.2	32/ 40	313	117		26/ 26	3,200	357.6		78/ 78	57.04	29.5	
Strontium	35.49					22/ 22	340	17.93	Y	78/ 78	0.42	0.692	Y
Thallium	0.33	2/ 40	0.75	0.22		1/ 8	0.01	0.005		2/ 72	0.001		

Analyte[d]	Wastes	Soils[a]				Groundwater[b]				Surface Water[c]			
	S-3 sludges	Results > detection limit	Maximum detect	Average result	Site Related Contami-nant	Freq. Of wells w. detects	Max detect	Mean of the medians[e]	Site Related Contami-nant	Freq. of detect	Avg.[f] result BCK 12.46	Avg.[f] result NT-1	Site Related Contami-nant
Thorium	195.1					1/ 20	0.28	0.109		2/ 72	0.006		
Tin	1.57	3/ 40	7.7	1.7		3/ 6	0.018	0.01					
Titanium	398.6					7/ 7	0.85	0.237	Y	3/ 72	0.009		
Total uranium (fluorometric)	991.71					22/ 26	44	2.90	Y	78/ 78	0.621	0.075	Y
Vanadium	7.1	40/ 40	91.9	24.4	Y	5/ 20	0.036	0.004	Y	1/ 72	0.003		
Zinc	58.27	40/ 40	163	50.1	Y	24/ 24	20	0.497	Y	30/ 78	0.013	0.014	
Zirconium	478.4					3/ 4	0.051	0.018		1/ 71	0.002		
Common Anions (water - mg/L, soils - mg/kg)													
Ammonia nitrogen						2/ 4	4.8	1.19					
Chloride						26/ 26	1,341	106.2	Y	6/ 6		27.4	Y
Fluoride						23/ 25	110	1.32	Y	6/ 6		1.0	Y
Kjeldahl nitrogen	460					4/ 4	1.8	0.73					
Nitrate - N	1130					19/ 26	13,400	1,659.	Y	77/ 77	38.83	166.6	Y
Nitrite						1/ 4	6.7	20.2					
Sulfate	220					23/ 23	2,204	204.7	Y	6/ 6		46.8	Y
Organics (water - mg/L, soils - mg/kg)													
Endrin aldehyde		1/ 13	5.4	2.3	Y								
Methoxychlor		1/ 13	5.9	9.8	Y								
PCB-1248	5666.8	4/ 39	3300	108	Y								
PCB-1254		15/ 39	370	59	Y								
PCB-1260		6/ 39	280	38.2	Y								
1,1,1-Trichloroethane						9/ 27	28	3.8	Y				
1,1,2-Trichloroethane	75.37					1/ 26	1	2.5					
1,1,2,2-Tetrachloroethane	383.5												
1,1,2-Trichloro-1,2,2-trifluoroethane	4.35												
1,1-Dichloroethene						3/ 26	5	2.5					
1,2-Dichloroethane						1/ 26	4	2.5					
1,2-Dichloroethene						3/ 25	100	5.0	Y				
2-Butoxyethanol	2289.6												

Analyte[d]	Wastes	Soils[a]				Groundwater[b]				Surface Water[c]			
	S-3 sludges	Results > detection limit	Maximum detect	Average result	Site Related Contami-nant	Freq. Of wells w. detects	Max detect	Mean of the medians[e]	Site Related Contami-nant	Freq. of detect	Avg.[f] result BCK 12.46	Avg.[f] result NT-1	Site Related Contami-nant
2-(2-Butoxyethoxy)-Ethanol	1908.0												
2,4-Dinitrophenol						1/ 3	77	20.8	Y				
2-Butanone						9/ 26	32	5.0	Y				
2-Chloroethylvinyl ether						1/ 10	4	5					
2-Hexanone		2/ 39	17	6.5	Y	3/ 26	4	5					
2-Hexanol	295.7												
2-Nitrophenol						1/ 3	71	20.3	Y				
3-(1,1-Dimethylethyl)-Phenol	6038.8												
4-Methyl-2-pentanone		5/ 40	28	6.4	Y	1/ 27	97	8.4					
4-Nitrophenol						1/ 3	120	30.3	Y				
Acetone	22.95	17/ 32	4200	275	Y	19/ 27	6,000	51.8	Y	1/ 5		5	Y
Benzene						4/ 26	3	2.5	Y				
Benzenemethanol						1/ 3	2	4.2					
Benzoic acid						2/ 3	58	25.0	Y				
Bis(2-ethylhexyl)phthalate						2/ 3	32	6.3	Y				
Bromodichloromethane						2/ 26	3	2.5					
Bromoform						1/ 26	2	2.5					
Butylbenzylphthalate						2/ 3	1	3.3					
Carbon disulfide						5/ 26	2	2.5					
Carbon tetrachloride						1/ 26	0.7	2.5					
Chlorobenzene						2/ 26	3	2.5					
Chloroform						14/ 27	69	7.0	Y				
Chloromethane						1/ 26	10	5					
Dibromochloromethane						1/ 26	1	2.5					
Diethylphthalate	522.8												
Di-n-butylphthalate						1/ 3	2	4.2					
Di-n-octylphthalate						2/ 3	3	3.5					
Dimethylbenzene						5/ 26	16	2.5	Y				
Ethylbenzene						3/ 26	4	2.5					

Analyte[d]	Wastes	Soils[a]				Groundwater[b]				Surface Water[c]			
	S-3 sludges	Results > detection limit	Maximum detect	Average result	Site Related Contami-nant	Freq. Of wells w. detects	Max detect	Mean of the medians[e]	Site Related Contami-nant	Freq. of detect	Avg.[f] result BCK 12.46	Avg.[f] result NT-1	Site Related Contami-nant
Methylene chloride	0.49	17/ 32	4200	275	Y	19/ 27	560	17.3	Y				
Naphthalene						1/ 3	1	3.7					
Phenols (mg/L or mg/kg)	7345.8					2/ 7	0.002	0.003	Y	54/ 72	0.0018		Y
Tetrachloroethene	793.0	10/ 40	24	3.9	Y	12/ 27	9,000	269.9	Y	6/ 6		3	Y
Toluene	0.27	19/ 39	120	9.9	Y	11/ 27	35	3.2	Y				
trans-1,2-Dichloroethene						2/ 13	2	2.8					
Trichloroethene	0.28					6/ 27	16	2.9	Y				
Trichlorofluoromethane	0.38												
Vinyl acetate						1/ 26	1	5					
Radioactivity (water - pCi/L, soils pCi/g)													
Alpha activity	925.1	22/ 40	92	10.9		14/ 18	24,400	615.7	Y	75/ 78	270.5	26.3	Y
Americium-241	0.01	3/ 40	0.12	0.01	Y	1/ 4	38	7.5	Y				
Beta activity	1903.2	27/ 40	180	21.6		17/ 18	75,000	2,620.8	Y	78/ 78	164.1	226.7	Y
Cesium-137	4.8					2/ 4	9.7	5.3	Y				
Neptunium-237	9.9	9/ 40	0.27	0.03		1/ 4	1,090	106.3	Y				
Plutonium-238	25.3	2/ 40	0.36	0.02	Y	./ 3	.	.					
Plutonium-239/240	2.5	1/ 38	0.015	0.005		./ 4	.	.					
Total Radium						1/ 1	35.14	35.14	Y				
Ruthenium-106	33.3												
Strontium-90	12.9					3/ 4	254	194	Y				
Technetium-99	7520.3	4/ 40	36	2.82	Y	3/ 4	80,400	17,538	Y	2/ 2h		206h	Yh
Thorium-228	267.3	34/ 40	3.5	0.8		1/ 4	3.2	1.0	Y	1/ 1i	0.1030i		Yi
Thorium-230	544.1	35/ 40	3.4	0.7	Y	2/ 4	0.59	0.36	Y				
Thorium-232	87.5	32/ 40	3.6	0.6		./ 3	.	.					
Tritium						9/ 12	5406	1245	Y				
Uranium-233/234	124.1	40/ 40	17	2.1	Y	3/ 4	4,650	660	Y	1/ 1i	52.8i		Yi
Uranium-235	8.1	22/ 40	0.99	0.12	Y	2/ 4	547	68.8	Y	1/ 1i	4.7i		Yi
Uranium-238	332.3	40/ 40	43	4.6	Y	3/ 4	13,600	1,601	Y	1/ 1i	127.0i		Yi

a Soil data are combined results for shallow and deep intervals for both soil aggregates at the S-3 site.
b Groundwater data are the results for the S-3 site groundwater aggregate.

c Surface water data are the results for the BCK 12.46 NT-1 aggregate.
d Analytes detected at least once are summarized. Results reflect data validation and data usability screens.
e The mean of the medians is the arithmetic mean of the median concentration of an analyte for each well. In calculating the mean of the medians it was assumed that non-detects are equal to one-half the detection limit for chemicals. Radionuclide data qualified as non-detect based on comparison to minimal detectable activities or counting errors are set equal to the reported value.
f ^{99}Tc is not an SRC in the Bear Creek BCK 12.46 and NT-1 surface water aggregates; however this analyte is an SRC in the NT-2 surface water aggregate and is only excluded from the NT-1 and BCK 12.46 aggregates becasue of poor data quality (no MDAs).
g These radionuclides are not SRCs in the Bear Creek BCK 12.46 and NT-1 surface water aggregates; however they are SRCs in the BCK 12.71 surface water sample and are only excluded from the NT-1 and BCK 12.46 aggregates becasue of poor data quality (no MDAs).

SRC—site-related contaminant.

Table A-2. Results of chemical analysis of groundwater in the Maynardville Limestone and Bear Creek FA and of surface water at SS-4, SS-5, and BCK 9.47

Analyte[b]	Groundwater				SS-4[a]				SS-5[a]				Bear Creek at BCK 9.47[a]			
	Freq. of wells w. detects	Max detect	Mean of the medi ans[c]	Site Related Contami nant	Freq. of detect	Max detect	Avg.[c] result	Site Related Contami nant	Freq. of detect	Max detect	Avg.[c] result	SRC?	Freq. of detect	Max detect	Avg.[c] result	Site Related Contami nant
Inorganics (mg/L)																
Aluminum	78/ 78	68	0.3		19/ 27	2.98	0.34		17/ 27	0.813	0.098		26/ 35	29.8	1.68	Y
Antimony	1/ 78	0.13	0.027		1/ 13	0.0028	0.001		1/ 13	0.003	0.001		4/ 22	0.003	0.001	
Arsenic	1/ 17	0.005	0.0025										5/ 22	0.023	0.003	
Barium	78/ 78	10	0.23		27/ 27	0.24	0.15		27/ 27	0.12	0.083		33/ 35	0.204	0.099	
Beryllium	40/ 78	0.0039	0.0002						1/ 27	0.0003	0.0002		1/ 35	0.0015	0.0002	
Boron	78/ 78	3	0.16	Y	14/ 14	0.26	0.11	Y	13/ 14	0.18	0.075	Y	13/ 13	4.1	0.80	Y
Cadmium	21/ 82	1.0200	0.008													
Calcium	82/ 82	880	119.52		27/ 27	140	100.2		27/ 27	87	62.73		35/ 35	101	64.67	
Chromium	39/ 82	0.71	0.007										1/ 11	0.01	0.006	
Cobalt	17/ 78	0.140	0.003										3/ 35	0.014	0.002	
Copper	70/ 78	0.19	0.005	Y	4/ 27	0.007	0.002		2/ 27	0.007	0.002		1/ 35	0.005	0.003	
Iron	78/ 78	170	1.82		23/ 27	3.72	0.46		20/ 26	1.13	0.111		34/ 35	38	2.39	
Lead	61/ 82	0.23	0.0046	Y	1/ 12	0.005	0.002		1/ 12	0.012	0.003					
Lithium	5/ 6	0.085	0.029	Y	7/ 7	0.036	0.029		7/ 7	0.014	0.010		7/ 7	0.091	0.060	Y
Magnesium	82/ 82	250	28.58		27/ 27	26	20.27		27/ 27	20	15.34		35/ 35	18.1	11.44	
Manganese	78/ 78	16	0.37	Y	26/ 27	0.809	0.14	Y	21/ 27	0.048	0.007		34/ 35	0.708	0.126	
Mercury	11/ 79	0.0019	0.0001		3/ 24	0.0002	0.0001						3/ 32	0.0002	0.0001	
Molybdenum	6/ 78	3.5	0.0052													
Nickel	57/ 78	0.23	0.0087		3/ 27	0.022	0.005		1/ 27	0.01	0.004		6/ 35	0.021	0.005	Y
Niobium	3/ 6	0.029	0.0073													
Potassium	82/ 82	44	4.0		26/ 27	5.4	3.0		26/ 27	3.2	1.767		35/ 35	12.2	4.16	
Selenium	2/ 20	0.005	0.0025										1/ 22	0.003	0.001	
Silicon	63/ 63	18	5.12		3/ 3	4.1	3.9		3/ 3	3.6	3.5		3/ 3	3.7	3.5	
Silver	0/ 19	0	0.005		1/ 27	0.007	0.003									
Sodium	82/ 82	1,300	33.4		27/ 27	25	15.79		27/ 27	14	7.8		34/ 35	17.1	9.5	
Strontium	77/ 77	23	0.91	Y	14/ 14	0.42	0.23	Y	14/ 14	0.2	0.11	Y	13/ 13	0.22	0.16	Y
Thallium	0/ 15	0	0.005													
Thorium	0/ 78	0	0.105													

Analyte[b]	Groundwater				SS-4[a]				SS-5[a]				Bear Creek at BCK 9.47[a]			
	Freq. of wells w. detects	Max detect	Mean of the medi ans[c]	Site Related Contami nant	Freq. of detect	Max detect	Avg.[c] result	Site Related Contami nant	Freq. of detect	Max detect	Avg.[c] result	SRC?	Freq. of detect	Max detect	Avg.[c] result	Site Related Contami nant
Tin	0/ 1	0	0.005													
Titanium	5/ 6	0.052	0.0183													
Total uranium (fluorometric)	71/ 82	0.30	0.0092	Y	14/ 14	0.285	0.136	Y	14/ 14	0.117	0.058	Y	13/ 13	0.152	0.103	Y
Vanadium	20/ 78	0.13	0.0026		1/ 27	0.004	0.002		1/ 27	0.0037	0.0019		6/ 35	0.058	0.005	Y
Zinc	78/ 78	5.1	0.0452	Y	12/ 27	0.02	0.006		13/ 27	0.02	0.005		19/ 35	0.223	0.018	Y
Zirconium	2/ 6	0.0081	0.003													
Common Anions (mg/L)																
Ammonia nitrogen	1/ 4	2.9	0.1													
Chloride	81/ 82	2,180	49.4	Y	26/ 26	41.5	25.91	Y	26/ 26	23.9	13.5	Y	34/ 34	34.4	17.1	Y
Fluoride	70/ 80	1.9	0.234		26/ 27	0.6	0.362	Y	24/ 27	0.44	0.205		35/ 35	0.4	0.26	Y
Kjeldahl nitrogen	3/ 4	4.9	1.4													
Nitrate	64/ 82	918	29.5	Y	26/ 27	67.6	31.58	Y	26/ 27	27	11.04	Y	35/ 35	46.2	14.47	Y
Nitrite	0/ 4	0	1.625													
Sulfate	82/ 82	2,833	95.9		26/ 27	45	27.7	Y	27/ 27	29	16.75	Y	33/ 35	29.6	21.24	
Organics (µg/L)																
1,1,1-Trichloroethane	25/ 83	43	2.7	Y	2/ 27	1	2.5	Y					1/ 35	0.4	2.5	
1,1-Dichloroethane	16/ 83	21	2.8	Y									3/ 35	2	2.5	Y
1,1-Dichloroethene	18/ 83	36	2.7	Y	3/ 27	3	2.6	Y								
1,2-Dichloroethane	4/ 83	2	2.5										7/ 35	20	5.1	Y
1,2-Dichloroethene	44/ 83	140	5.7	Y	21/ 27	21	7.7	Y	8/ 27	2	2.3	Y	34/ 35	28	7.1	Y
2-Butanone	15/ 83	16	5.1										2/ 35	24	4.2	Y
2-Hexanone	5/ 83	5	5.1													
4-Methyl-2-pentanone	9/ 83	8	5.1						1/ 27	4	3.3		1/ 35	86	5.4	
Acetone	44/ 83	180	5.1	Y					2/ 27	6	3.6	Y	6/ 35	23	6.7	Y
Benzene	17/ 83	10	2.5													
Bromodichloromethane	1/ 83	4	2.5													
Bromoform	2/ 83	1	2.5													
Carbon tetrachloride	25/ 83	9	2.6	Y												
Carbon disulfide	6/ 83	2	2.5		1/ 27	2	2.6		1/ 27	1	2.5					
Chlorobenzene	4/ 83	8	2.5													

Analyte[b]	Groundwater				SS-4[a]				SS-5[a]				Bear Creek at BCK 9.47[a]			
	Freq. of wells w. detects	Max detect	Mean of the medi ans[c]	Site Related Contami nant	Freq. of detect	Max detect	Avg.[c] result	Site Related Contami nant	Freq. of detect	Max detect	Avg.[c] result	SRC?	Freq. of detect	Max detect	Avg.[c] result	Site Related Contami nant
Chloroethane	5/ 83	8	5.1													
Chloromethane													6/ 35	7	3.9	Y
Chloroform	34/ 83	11	2.5	Y												
Dimethylbenzene	4/ 83	8	2.5													
Ethylbenzene	7/ 83	2	2.5													
Methylene chloride	32/ 83	23	2.5	Y					2/ 27	4	2.7	Y	3/ 35	4	2.4	Y
Phenols	4/ 21	0.006	0.008													
Styrene	3/ 83	1	2.5													
Tetrachloroethene	35/ 83	55	3.1	Y									14/ 35	4	2.1	Y
Toluene	19/ 83	1	2.5										1/ 35	1	2.5	
Trichloroethene	57/ 83	460	21.9	Y	26/ 27	23	8.8	Y	6/ 27	2	2.4	Y	7/ 35	2	2.2	Y
Trans-1,2-Dichloroethene	5/ 16	86	7.8	Y												
Vinyl acetate	15/ 83	10	5.1													
Vinyl Chloride	4/ 83	35	5.3													
Radioactivity (pCi/L)																
Alpha activity	43/ 73	108	4.69	Y	27/ 27	130	52.94	Y	22/ 27	75.8	29.35	Y	32/ 32	138	54.64	Y
Beta activity	53/ 73	197	16.7	Y	26/ 26	143	82.29	Y	24/ 26	81.75	37.83	Y	34/ 34	119.8	59.62	Y
Cesium-137	3/ 7	8.8	4.3													
Radium-228	2/ 7	7.8	1.46													
Technetium-99	3/ 8	39	9.38		2/ 3	220	136.6	Y					1/ 7	110	43.86	Y
Thorium-228	2/ 8	0.92	0.24										1/ 3	0.13	0.05	Y
Thorium-230	6/ 8	0.65	0.35		1/ 3	0.11	0.6	Y	1/3	0.21	0.14	Y	1/ 3	0.2	0.1	Y
Uranium-234	5/ 8	22	4.06		13/ 13	37.3	27.26	Y	13/ 13	26.6	13.97	Y	21/ 21	29.2	18.74	Y
Uranium-235	1/ 7	0.89	0.16		10/ 13	3.62	1.57	Y	3/ 13	2.98	0.84	Y	6/ 21	1.69	0.9	Y
Uranium-238	4/ 8	42	7.24		13/ 13	82.6	57.59	Y	13/ 13	58.4	26.71	Y	21/ 21	64.5	40.29	Y

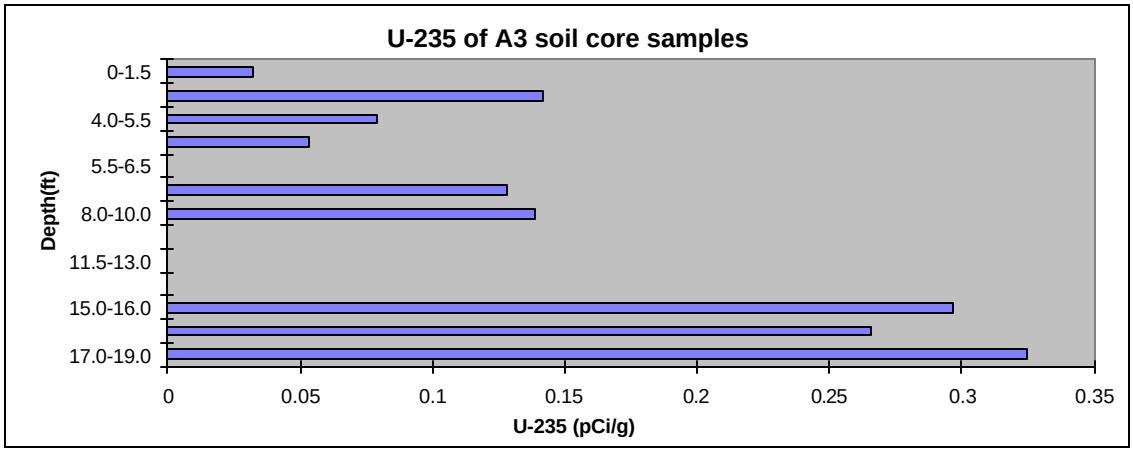
[a]Groundwater data are the results for the SS-4, SS-5, and BC at BCK 9.47. These data are presented in Table D.112, D.114, and D.106 in Appendix D.

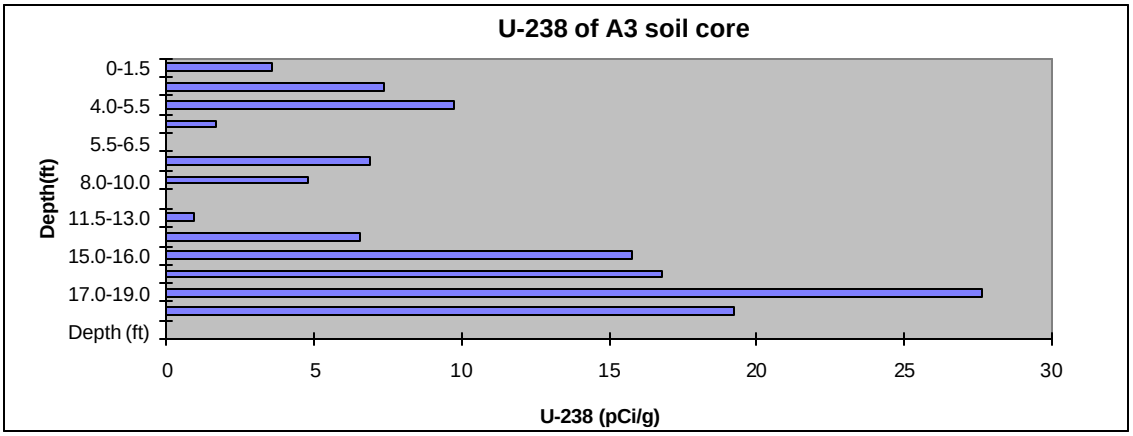
[b]Analytes detected at least once are summarized. Results reflect data validation and data usability screens.

[c]The mean of the medians is the arithmetic mean of the median concentration of an analyte for each well. In calculating the mean of the medians it was assumed that non-detects are equal to one-half the detection limit for chemicals. Radionuclide data qualified as non-detect based on comparison to minimal detectable activities or counting errors are set equal to the reported value.

Gamma-spectroscopy analysis of A3 core samples

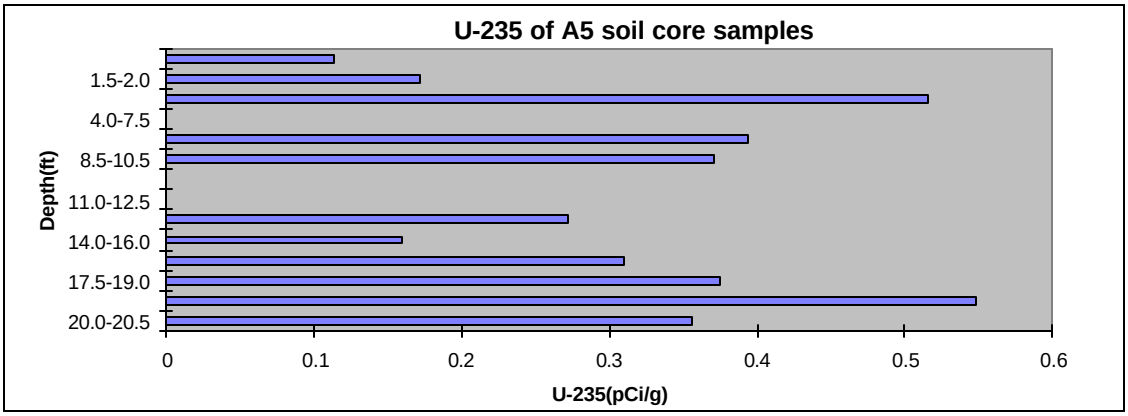
Sample #	Depth (ft)	U-235(pCi/g)	U-238(pCi/g)	235/238
A3-1	0-1.5	0.03	3.56	0.01
A3-2	1.5-2.5	0.14	7.36	0.02
A3-3	2.5-4.0	0.08	9.72	0.01
A3-4	4.0-5.5	0.05	1.69	0.03
A3-5	5.5-6.5	BD	BD	
A3-6	6.5-7.5	0.13	6.91	0.02
A3-7	8.0-10.0	0.14	4.80	0.03
A3-8	10.0-11.5	BD	BD	
A3-9	11.5-13.0	BD	0.93	
A3-10	13.0-15.0	BD	6.56	
A3-11	15.0-16.0	0.30	15.75	0.02
A3-12	16.5-17.0	0.27	16.80	0.02
A3-13	17.0-19.0	0.33	27.64	0.01
A3-14	19.0-20.0	0.36	19.19	0.02

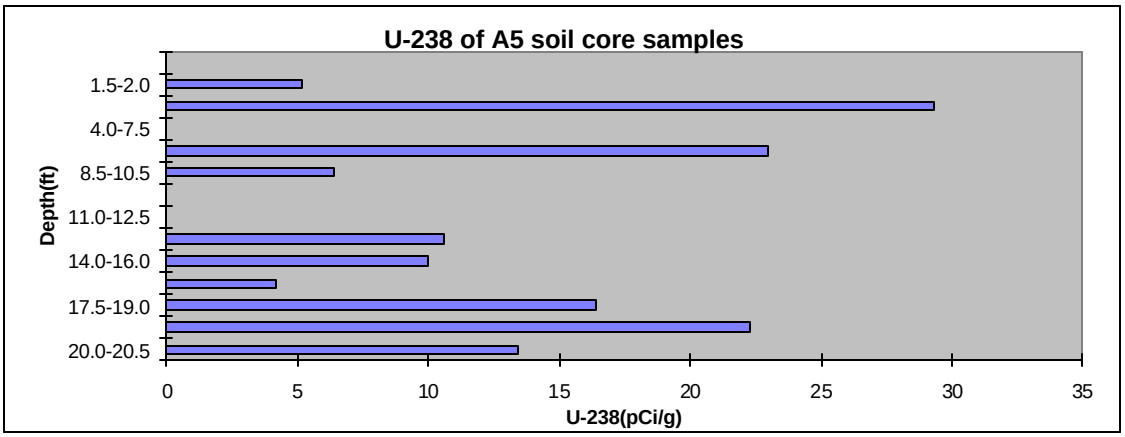




Gamma-spectroscopy analysis of A5 soil core samples

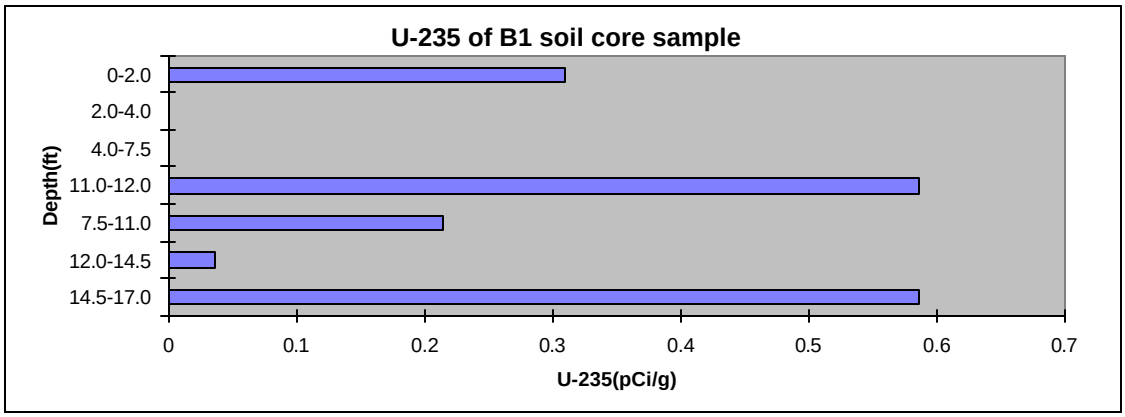
Sample #	Depth (ft)	U-235(pCi/g)	U-238(pCi/g)	235/238
A5-1	0-1.5	0.11	BD	
A5-2	1.5-2.0	0.17	5.13	0.03
A5-3	2.0-4.0	0.52	29.34	0.02
A5-4	4.0-7.5	BD	BD	
A5-5	7.5-8.5	0.39	22.97	0.02
A5-6	8.5-10.5	0.37	6.38	0.06
A5-7	10.5-11.0	BD	BD	
A5-8	11.0-12.5	BD	BD	
A5-9	12.5-14.0	0.27	10.59	0.03
A5-10	14.0-16.0	0.16	9.98	0.02
A5-11	16.0-17.5	0.31	4.13	0.07
A5-12	17.5-19.0	0.37	16.36	0.02
A5-13	19.0-20.0	0.55	22.30	0.02
A5-14	20.0-20.5	0.36	13.41	0.03
A5-15	20.5-22.2	0.06	10.33	0.01

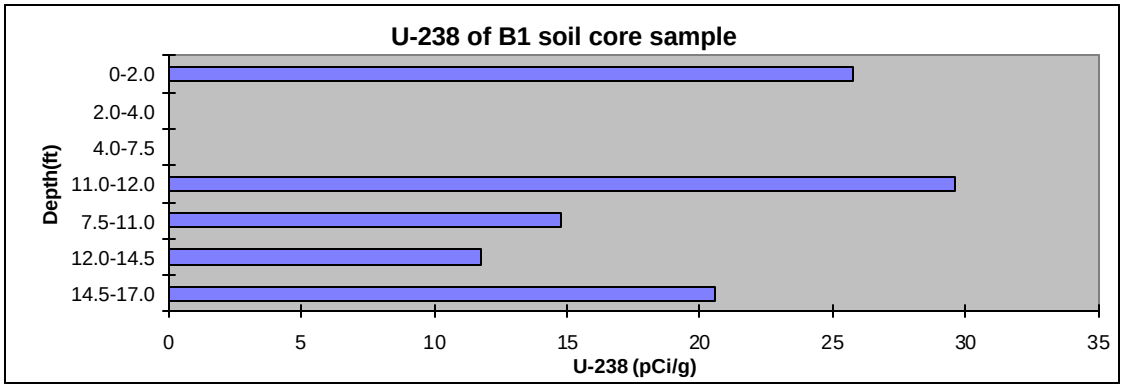




Gamma-spectroscopy analysis of B1 core samples

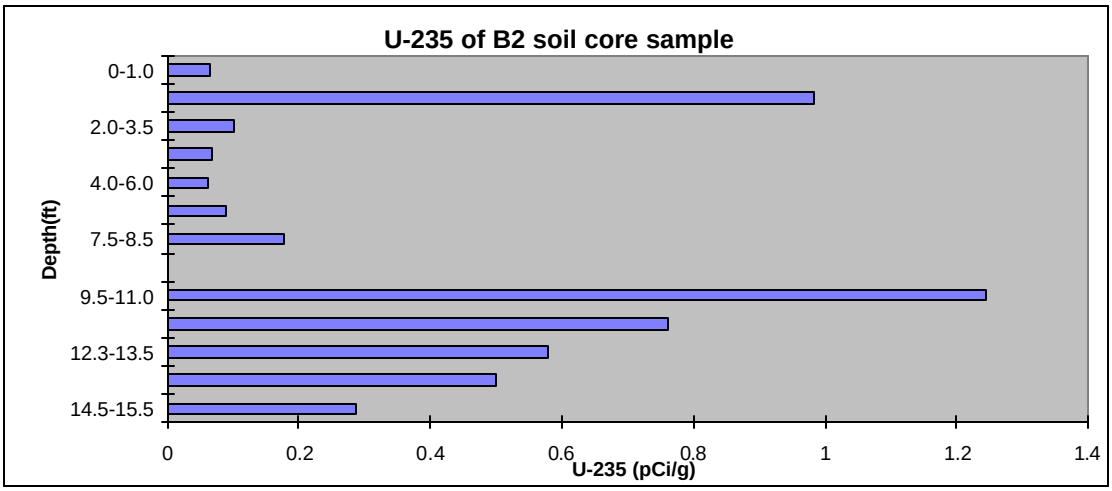
Sample #	Depth (ft)	U-235(pCi/g)	U-238(pCi/g)	235/238
B1-1	0-2.0	0.31	25.74	0.01
B1-2	2.0-4.0	BD	BD	
B1-3	4.0-7.5	BD	BD	
B1-4	7.5-11.0	0.22	14.76	0.01
B1-5	11.0-12.0	0.59	29.61	0.02
B1-6	12-14.5	0.04	11.75	0.00
B1-7	14.5-17.0	0.59	20.58	0.03
B1-8	17.0-17.5	BD	BD	

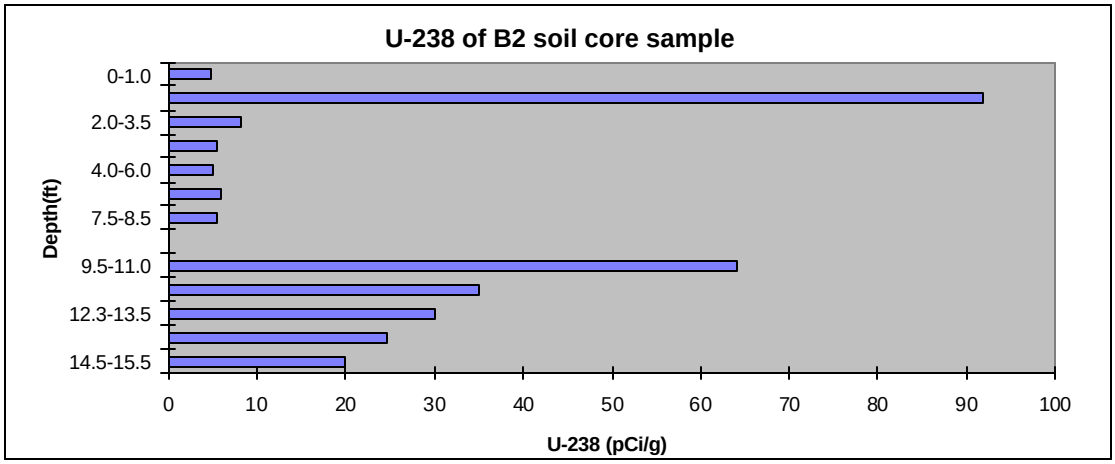




Gamma-spectroscopy analysis of B2 core samples

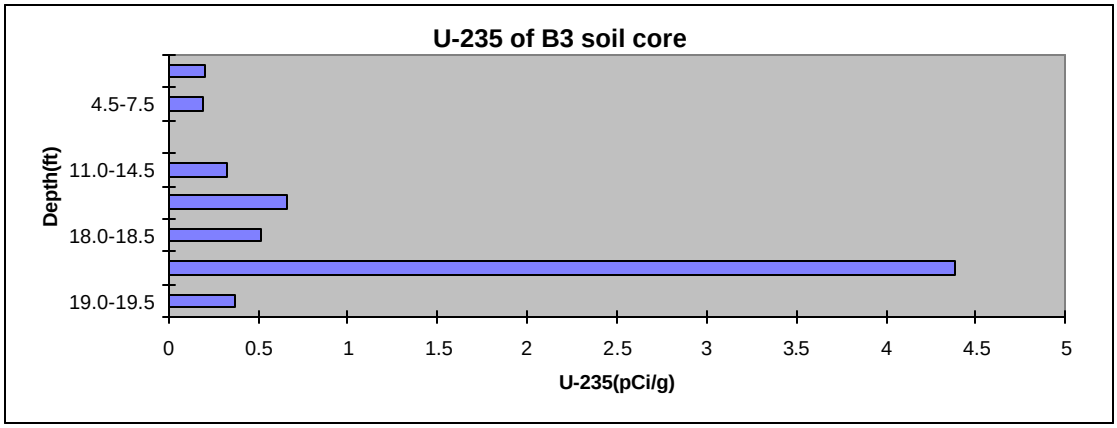
Sample #	Depth (ft)	U-235(pCi/g)	U-238(pCi/g)	235/238
B2-1	0-1.0	0.06	4.94	0.01
B2-2	1.0-2.0	0.98	91.78	0.01
B2-3	2.0-3.5	0.10	8.19	0.01
B2-4	3.5-4.0	0.07	5.61	0.01
B2-5	4.0-6.0	0.06	5.07	0.01
B2-6	6.0-7.5	0.09	5.89	0.02
B2-7	7.5-8.5	0.18	5.44	0.03
B2-8	8.5-9.5	BD	BD	
B2-9	9.5-11.0	1.24	64.19	0.02
B2-10	11.0-12.3	0.76	35.06	0.02
B2-11	12.3-13.5	0.58	30.12	0.02
B2-12	13.5-14.5	0.50	24.71	0.02
B2-13	14.5-15.5	0.29	20.04	0.01
B2-14	15.5-17.0	0.08	23.21	0.00

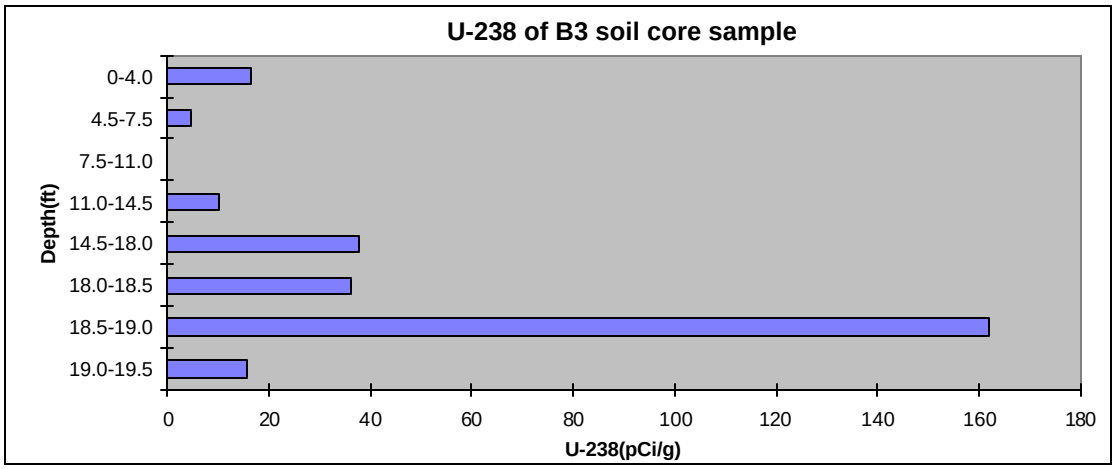




Gamma-spectroscopy analysis of B3 core samples

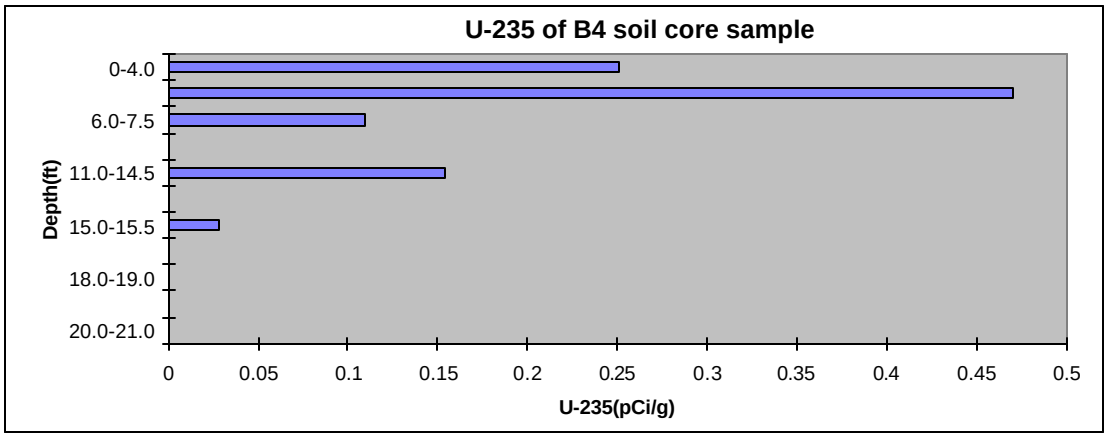
Sample #	Depth (ft)	U-235(pCi/g)	U-238(pCi/g)	235/238
B3-1	0-4.0	0.21	16.45	0.01
B3-2	4.5-7.5	0.20	4.49	0.04
B3-3	7.5-11.0	BD	BD	
B3-4	11.0-14.5	0.33	10.03	0.03
B3-5	14.5-18.0	0.67	37.80	0.02
B3-6	18.0-18.5	0.52	36.23	0.01
B3-7	18.5-19.0	4.39	162.10	0.03
B3-8	19.0-19.5	0.37	15.84	0.02
B3-9	19.5-20	0.29	15.82	0.02

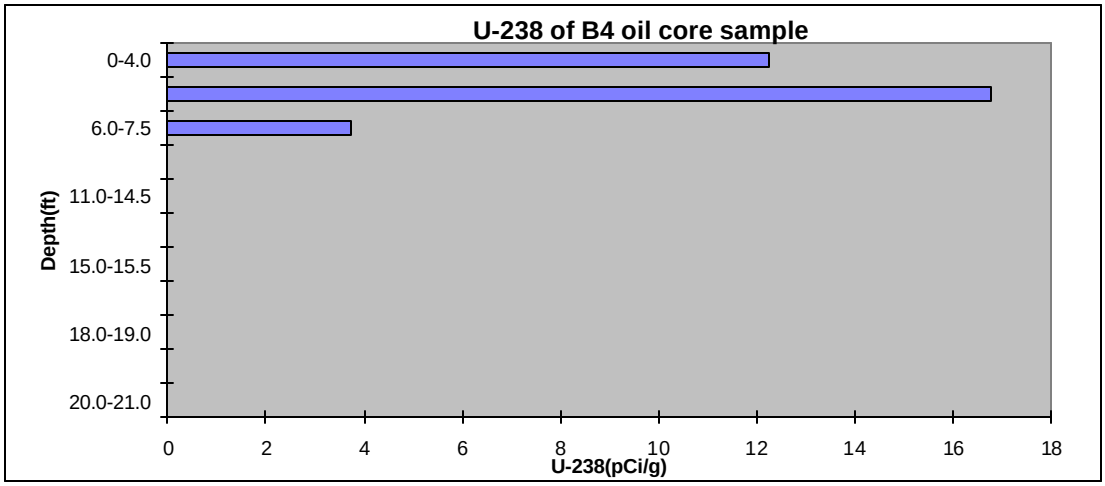




Gamma-spectroscopy analysis of B4 core samples

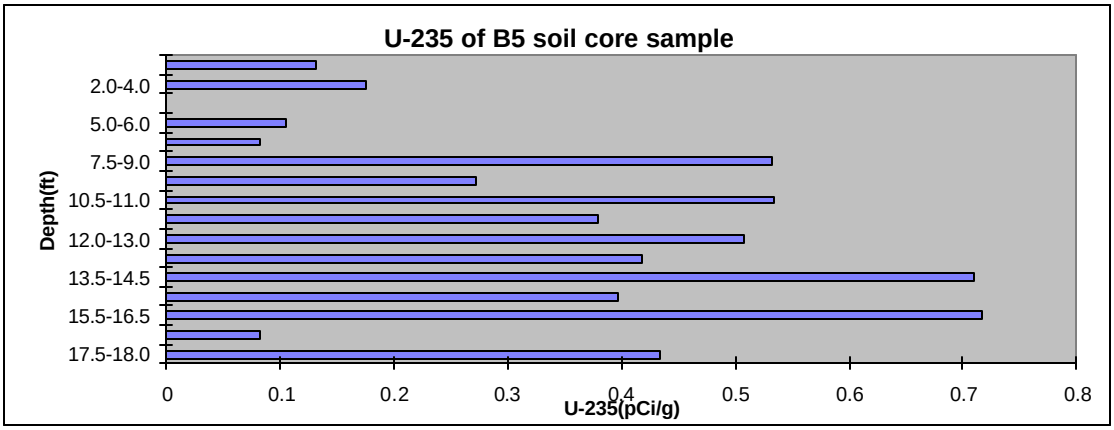
Sample #	Depth (ft)	U-235(pCi/g)	U-238(pCi/g)	235/238
B4-1	0-4.0	0.25	12.26	0.02
B4-2	4.0-6.0	0.47	16.77	0.03
B4-3	6.0-7.5	0.11	3.75	0.03
B4-4	7.5-11.0	BD	BD	
B4-5	11.0-14.5	0.15	BD	
B4-6	14.5-15.0	BD	BD	
B4-7	15.0-15.5	0.03	BD	
B4-8	15.5-18.0	BD	BD	
B4-9	18.0-19.0	BD	BD	
B4-10	19.0-20.0	BD	BD	
B4-11	20.0-21.0	BD	BD	

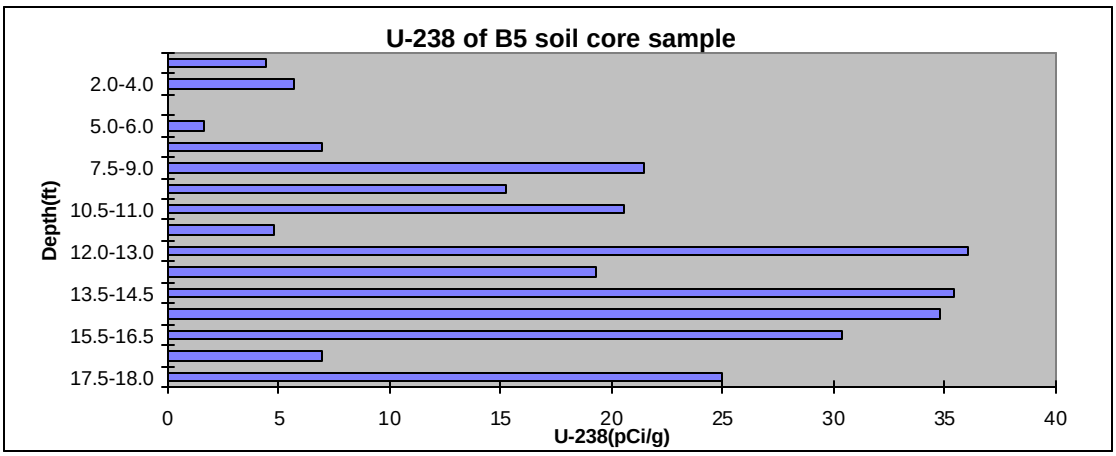




Gamma-spectroscopy analysis of B5 soil core samples

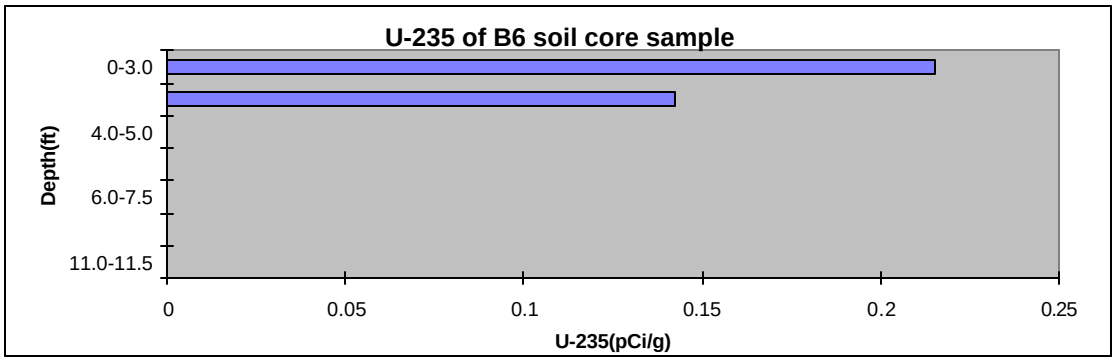
Sample #	Depth (ft)	U-235(pCi/g)	U-238(pCi/g)	235/238
B5-1	0-2.0	0.13	4.42	0.03
B5-2	2.0-4.0	0.18	5.72	0.03
B5-3	4.0-5.0	BD	BD	
B5-4	5.0-6.0	0.11	1.67	0.06
B5-5	6.0-7.5	0.08	6.98	0.01
B5-6	7.5-9.0	0.53	21.49	0.02
B5-7	9.0-10.5	0.27	15.22	0.02
B5-8	10.5-11.0	0.53	20.54	0.03
B5-9	11.0-12.0	0.38	4.78	0.08
B5-10	12.0-13.0	0.51	36.04	0.01
B5-11	13.0-13.5	0.42	19.31	0.02
B5-12	13.5-14.5	0.71	35.42	0.02
B5-13	14.5-15.5	0.40	34.80	0.01
B5-14	15.5-16.5	0.72	30.37	0.02
B5-15	16.5-17.5	0.08	6.98	0.01
B5-16	17.5-18.0	0.43	23.96	0.02

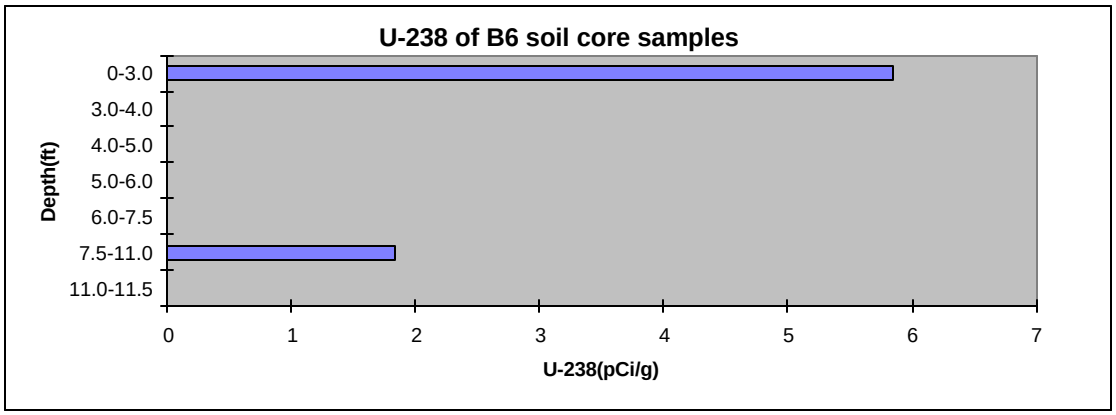




Gamma-spectroscopy analysis of B6 core samples

Sample #	Depth (ft)	U-235(pCi/g)	U-238(pCi/g)	235/238
B6-1	0-3.0	0.22	5.86	0.04
B6-2	3.0-4.0	0.14	BD	
B6-3	4.0-5.0	BD	BD	
B6-4	5.0-6.0	BD	BD	
B6-5	6.0-7.5	BD	BD	
B6-6	7.5-11.0	BD	1.83	
B6-7	11.0-11.5	BD	BD	





Appendix B

LITHOLOGIC LOGS FROM BEAR CREEK VALLEY REMEDIAL INVESTIGATION

B13-3

SAIC®

SHEET 1 OF 2

LOCATION BCV OU 1 TOTAL DEPTH 26.00 ft bgs

BOREHOLE NUMBER LITHKEY

COORDINATES BOREHOLE DIAMETER in. SAMPLING DEVICE

ELEVATION ft above MSL LOGGED BY

SAMPLE INFORMATION					STRATA	LITHOLOGIC DESCRIPTION	ELEVATION FEET
DEPTH FEET	SAMPLE ID	U-238 (pCi/g)	beta/ gamma (cpm)	water			
						Gravel, gravel zones	
						Clayey gravel	
						Gravelly clay	
5						Gravel, silt/sand, clay mixture, Zone A soils	
						Sands	
						Silts	
10						Sandy clays, clayey sands	
						Silty clays, clayey silts	
						Clays, minor gravel, silt, sand (<10%)	

DRILLING CONTRACTOR

DRILLING METHOD

DRILLING EQUIPMENT

DRILLING STARTED ENDED

REMARKS

Coordinates are reported in Y-12 Grid
See key sheet for symbols and abbreviations used above.

B13-4

SAIC®

SHEET 2 OF 2

LOCATION BCV OU 1 TOTAL DEPTH 26.00 ft bgs

BOREHOLE NUMBER LITHKEY

COORDINATES

BOREHOLE DIAMETER in. SAMPLING DEVICE

ELEVATION ft above MSL LOGGED BY

SAMPLE INFORMATION					STRATA	LITHOLOGIC DESCRIPTION	ELEVATION FEET
DEPTH FEET	SAMPLE ID	U-238 (pCi/g)	beta/ gamma (cpm)	water			
						Weathered shale	
						Chert	
						Clay with rock fragments	
20						No Recovery	
						Clay with chert fragments	
						Fill	
25						Limestone	

SAIC

SHEET 1 OF 1

LOCATION BCV OU I
BOREHOLE NUMBER S3-01
BOREHOLE DIAMETER 8 in.
LOGGED BY S.L. ABSTON

TOTAL DEPTH 11.50 ft bgs
SAMPLING DEVICE S-3IN

COORDINATES N 30,427.20 E 52,537.40
ELEVATION 1010.80 ft above MSL

SAMPLE INFORMATION					STRATA	LITHOLOGIC DESCRIPTION	ELEVATION FEET
DEPTH FEET	SAMPLE ID	U-238 (pCi/g)	beta/gamma (cpm)	water			
			150/80			(0.0-1.0) Moderate yellowish brown (10YR5/4) clay-CL, contains some rootlets and some iron staining, very few small frag of olive grey (5Y 4/1) shale.	1010
						(1.0-1.5) Light brown (5YR5/6) clay-CL mottled w/ dark yellowish orange (10YR6/6) completely weathered chert, dry and brittle.	
						(1.5-2.0) No recovery.	
	S01011	11.0	150/80	MOIST		(2.0-4.0) Light brown (5YR5/6) clay CL w/ approx 75% weathered (5Y4/1) olive grey to a dark yellowish brown (10YR4/2) shale. Moist shale has a moderate reddish brown (10R4/6) staining. Some shale has completely weathered to a very light grey (N8) clay. Shale is thinly laminated and micaceous.	
			120/80			(4.0-5.5) Same as above.	
5							
	S01012	10.0				(5.5-6.0) Light olive grey (5Y5/2) slightly weathered micaceous shale. Some bedding planes exhibit light brown (5YR5/6) staining, dry, brittle.	1005
						(6.0-7.4) Same as bottom of last spoon.	
			150/80				
						(7.4-8.0) Same as above but slightly moist and exhibiting some black organic staining on bedding planes breaks up in larger frag. than top of spoon.	
						(8.0-10.0) Same as above but large lenses of more silty shale (approx 10mm in width) also approx 5 mm in width layers of completely weathered very light grey (N8) shale-clay. Shale is more weathered and brittle, dry shale layers also exhibit undulating pattern.	
			80/80	MOIST			
10	S01013	7.9				(10.0-11.5) Split spoon refusal at 11.5 ft BGS on light olive grey (5Y5/2) only slightly weathered stained micaceous shale. Bedrock-cuttings from 11.5 TO 24 = Same as above.	
			80/80				1000

DRILLING CONTRACTOR OGDEN
DRILLING METHOD HOLLOW STEM AUGER
DRILLING EQUIPMENT CME-75
DRILLING STARTED 11/16/94 ENDED 11/16/94

REMARKS S-3IN=SPLIT SPOON (3in.)

Coordinates are reported in Y-12 Grid
See key sheet for symbols and abbreviations used above.

SAIC®

SHEET 1 OF 2

LOCATION BCV OU 1 TOTAL DEPTH 15.40 ft bgs

BOREHOLE NUMBER S3-02

BOREHOLE DIAMETER 8 in. SAMPLING DEVICE S-3IN

LOGGED BY S.L. ABSTON

ORDINATES N 30,062.00 E 52,391.80

VATION 1001.80 ft above MSL

AMPLE INFORMATION					STRATA	LITHOLOGIC DESCRIPTION	ELEVATION FEET
TH T	SAMPLE ID	U-238 (pCi/g)	beta/ gamma (cpm)	water			
						(0.0-1.0) Gravel.	
			60/60			(1.0-1.5) Silty clay -CL- moderate brown (5YR4/4) containing approx. 30% dark yellowish brown (10YR4/2) to light grey (N7) thinly laminated shale fragments dry.	
	S02011	4.2				(1.5-2.0) No recovery.	1000
			60/60			(2.0-3.5) Silty clay - CL dark yellowish brown (10YR4/2) clay w/ approx. 80% olive grey (5YR4/1) thinly laminated / micaceous shale exhibiting moderate brown (5YR4/4) weather staining. Some shale frag are a med. dark grey (N3 in color). The bottom 0.3 ft of the spoon contained large light grey (N7) limestone frag - fine grained micrite, dry.	
						(3.5-4.0) No recovery.	
						(4.0-5.2) Same as above.	
5			60/60			(5.2-6.0) Fine clay -CL moderate yellowish brown (10YR5/4). At transition to clay shale is a dark greenish grey (5GY4/1) to a medium bluish grey (5B5/1) in color still micaceous. Bottom of clay is rather homogeneous except for occasional small pocket of organics (black clay). Bottom clay getting slightly moist.	
	S02012					(6.0-7.0) Same as bottom of last spoon w/ occasional iron streak.	
			60/60	MOIST		(7.0-8.0) Becomes 50% mottled w/light grey (N7) clay becomes more firm w/increased grey clay content slightly moist.	995
						(8.0-9.2) Clay (CL) moderate yellowish brown (10YR5/4) clay w/ 80% moderate brown (5YR3/4) to light grey (N7) thinly laminated micaceous weathered shale w/ moderate brown (5YR4/4) weathered staining (iron).	
			60/60			(9.2-10.0) Moderate brown (5YR4/4) clay (CL) mottled w/ > 60% light grey (N7) clay, slightly firm and slightly moist not as firm as bottom of last spoon.	
0	S02013	NA		MOIST			
			60/60			(10.0-11.3) Silty clay -CL- dark yellowish brown (10YR4/2) thinly laminated micaceous shale (approx 80%) breaks into small pieces, crumbles dry.	
						(11.3-11.5) Contains approx 60% clay and it is mottled w/ grey (N7) clay.	
						(11.5-12.0) No recovery.	990
			60/60			(12.0-14.0) Same as bottom of last spoon w/ bottom 0.4 ft (13.6-14.0) becoming slightly lighter in color - pale brown (5YR5/2).	
	S02014						
			60/60			(14.0-15.4) Same as bottom of last spoon but only slightly weathered. Refusal - shale bedrock at 15.4 ft BGS.	

LING CONTRACTOR OGDEN

LING METHOD HOLLOW STEM AUGER

LING EQUIPMENT CME-75

LING STARTED 11/15/94 ENDED 11/15/94

REMARKS S-3IN=SPLIT SPOON(3in.)

Coordinates are reported in Y-12 Grid
See key sheet for symbols and abbreviations used above.

SAIC®

SHEET 2 OF 2

LOCATION BCV OU 1 TOTAL DEPTH 15.40 ft bgs

BOREHOLE NUMBER S3-02

COORDINATES N 30,062.00 E 52,391.80 BOREHOLE DIAMETER 8 in. SAMPLING DEVICE S-3IN

ELEVATION 1001.80 ft above MSL LOGGED BY S.L. ABSTON

SAMPLE INFORMATION					STRATA	LITHOLOGIC DESCRIPTION	ELEVATION FEET
DEPTH FEET	SAMPLE ID	U-238 (pCi/g)	beta/ gamma (cpm)	water			

SAIC®

SHEET 1 OF 1

LOCATION BCV OU 1 TOTAL DEPTH 7.50 ft bgs

BOREHOLE NUMBER S3-03

COORDINATES N 30,069.40 E 52,118.40 BOREHOLE DIAMETER 8 in. SAMPLING DEVICE S-3IN

ELEVATION 1006.50 ft above MSL LOGGED BY S.L.ABSTON

SAMPLE INFORMATION					STRATA	LITHOLOGIC DESCRIPTION	ELEVATION FEET
DEPTH FEET	SAMPLE ID	U-238 (pCi/g)	beta/ gamma (cpm)	water			
			80/60			(0.0-0.6) Gravel and crushed gravel.	
	S03011	2.8	60/60			(0.6-2.0) (10YR4/4) dark yellowish brown hard packed clay (CL w/ (N4) medium dark grey shale. Small gravel frag, greyish red (10R4/2) shale frag, brick frag concrete frag, dry, fill. (2.0-3.6) Same as bottom of last spoon.	1005
5	S03012	NA	60/60	MOIST		(3.6-4.0) (10YR5/6) yellowish brown (7.5YR4/6) strong brown mottled clay (CL) w/ frag of weathered (5Y5/2) olive shale, (2.5Y6/1) grey completely weathered shale (N6) med. light grey, large frag of shale, large wood frag. Moist toward bottom. Crystalline limestone frag also at bottom, fill. (4.0-5.8) Same as above w/ a limestone gravel layer at 5 ft and 5.7 ft BGS. (5.8-6.0) Same as above but also contains (5YR5/6) yellowish red clay (approx. 50%) also spoon containing asphalt frag. and white chert frag slightly moist, fill. (6.0-7.5) Shelby tube. Auger refusal at 7.5 ft BGS.	1000

DRILLING CONTRACTOR OGDEN

DRILLING METHOD HOLLOW STEM AUGER

DRILLING EQUIPMENT CME-75

DRILLING STARTED 11/22/94 ENDED 11/22/94

REMARKS S-3IN=SPLIT SPOON(3in.)

Coordinates are reported in Y-12 Grid
See key sheet for symbols and abbreviations used above.

SAIC®

SHEET 1 OF 2

LOCATION BCV OU 1 TOTAL DEPTH 22.90 ft bgs

BOREHOLE NUMBER S3-04

COORDINATES N 30,136.50 E 51,853.40 BOREHOLE DIAMETER 8 in. SAMPLING DEVICE S-3IN

ELEVATION 1004.50 ft above MSL LOGGED BY S.L. ABSTON

SAMPLE INFORMATION					STRATA	LITHOLOGIC DESCRIPTION	ELEVATION FEET
DEPTH FEET	SAMPLE ID	U-238 (pCi/g)	beta/ gamma (cpm)	Water			
				MOIST		(0.0-0.2) Small limestone gravel in 80% lime - moist sand. (0.2-0.4) Crusher run w/ larger limestone gravel frag.	
			80/80			(0.4-2.0) (7.5YR4/4) brown clay w/75% brownish grey (5YR4/1) to medium grey (N5) micaceous thinly to medium bedded shale frag. Some shale exhibits moderate reddish brown (10R4/6) staining and (5YR4/4) moderate brown staining - dry.	
	S04011					(2.0-3.0) Same as bottom of last spoon but w/ increasing amounts of olive grey (5Y4/1) shale.	
			80/80			(3.0-4.0) Asphalt (approx. 10%) bottom of spoon has a large concrete fragment approx. 3" in length w/pebbles in it, dry.	
						(4.0-6.0) Top .9 ft same as above w/transition into a moist dark greyish brown to a olive grey (5Y4/2) clay mottled w/ (10YR6/6) brownish yellow clay-turning into a more brittle, dry (10YR4/3) brown clay mottled w/some yellowish brown (10YR5/8) clay w/roots w/some small shale frag. brownish grey (5YR4/1).	1000
5				MOIST			
	S04012	NA				(6.0-6.2) Same as bottom of last spoon.	
			80/80			(6.2-7.1) Very weathered, brittle, dry, greyish red (10R4/2) shale micaceous exhibiting (10YR6/6) dark yellowish orange (10GY5/2) staining.	
						(7.1-8.0) Slightly weathered greyish red (10R4/2) micaceous shale w/ dark yellowish orange (10YR6/6) and black staining dry. Some bedding planes exhibit a greenish grey surface.	
			80/80	MOIST		(8.0-10.0) Top 1.7 ft same as above grading into a more moist shale - greyish red (10R4/2) thinly bedded, micaceous w/some layers being light grey (N7) in color and completely weathered. Some surfaces have a (10R4/8) red color.	995
10	S04013					(10.0-10.3) Same as bottom of last spoon.	
			80/80			(10.3-12.0) (7.5YR4/8) silty clay (CL) strong brown weathered shale w/60-70% (7.5YR6/1) grey clay- completely weathered shale layers. Some bedding planes exhibit (7.5YR6/8) reddish yellow staining, dry.	
						(12.0-13.0) Same as above.	
			80/80			(13.0-14.0) Same as above, becoming more competent, still brittle but only moderately weathered dry. Some bedding planes also exhibit black staining shale is micaceous. Only about <5% of the grey completely weathered shale.	
	S04014					(14.0-16.0) Light brown (5YR5/6) weathered massive shale/siltstone w/ some layers (N7) light grey completely weathered shale. Black and dark yellowish orange (10YR6/6) staining predominant, dry.	990

DRILLING CONTRACTOR OGDEN

DRILLING METHOD HOLLOW STEM AUGER

DRILLING EQUIPMENT CME-75

DRILLING STARTED 11/21/94 ENDED 11/22/94

REMARKS S-3IN=SPLIT SPOON(3in.)

Coordinates are reported in Y-12 Grid

See key sheet for symbols and abbreviations used above.

SAIC

SHEET 2 OF 2

LOCATION BCV OU 1 TOTAL DEPTH 22.90 ft bgs

BOREHOLE NUMBER S3-04

COORDINATES N 30,136.50 E 51,853.40 BOREHOLE DIAMETER 8 in. SAMPLING DEVICE S-3IN

ELEVATION 1004.50 ft above MSL LOGGED BY S.L. ABSTON

SAMPLE INFORMATION					STRATA	LITHOLOGIC DESCRIPTION	ELEVATION FEET
DEPTH FEET	SAMPLE ID	U-238 (pCi/g)	total/ gamma (cpm)	water			
			80/80				
			80/80	MOIST		(16.0-17.3) Same as last spoon w/grey clay being moist.	
	S04015	NA	80/80			(17.3-17.7) Very thinly laminated avulsing dark yellowish brown (10YR4/2) shale with some layers of the (N7) light grey (completely weathered) shale clay. (17.7-18.0) Greyish red (10R4/2) thinly laminated brittle weathered shale. (18.0-20.0) Spoon wet - split spoon sample not same as above. Alternating w/10mm thick beds of very weathered (10YR5/4) moderate yellowish brown siltstone. .2mm thick layers of thinly laminated brittle weathered (10R4/2) shale.	(K)
			80/80	WET			985
20						(20.0-21.5) Sample is saturated at the top greyish brown (5YR3/2) siliceous thinly laminated, moderately weathered shale, brittle, moist.	
	S04016		80/80				
						(21.5-22.0) No recovery.	
			80/80			(22.0-22.9) Split spoon refusal at 22.9 ft BGS. Same as above w/light brown (5YR5/6) and black weather staining less weathered only slightly dry.	

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SAIC®

SHEET 1 OF 1

LOCATION BCV OU 1 TOTAL DEPTH 8.80 ft bgs

BOREHOLE NUMBER S3-05

COORDINATES N 30,380.70 E 51,801.90 BOREHOLE DIAMETER 8 in. SAMPLING DEVICE S-3IN

ELEVATION 1005.00 ft above MSL LOGGED BY S.L. ABSTON

SAMPLE INFORMATION					STRATA	LITHOLOGIC DESCRIPTION	ELEVATION FEET
DEPTH FEET	SAMPLE ID	U-238 (pCi/g)	beta/ gamma (cpm)	water			
						(0.0-0.2) Crushed limestone gravel and asphalt.	1005
						(0.2-2.0) Crushed limestone gravel, crusher run -fill, dry.	
			80/80				
	S05011					(2.0-4.0) Crusher run limestone gravel and crushed limestone fill, dry.	
			80/80				
						(4.0-4.6) Same as above but wet.	
		NA		WET			
5			80/80			(4.6-6.0) No recovery.	1000
	S05012					(6.0-7.0) Same as above - more gravel size limestone toward the bottom, very wet.	
				WET			
			80/80			(7.0-8.0) No recovery.	
						(8.0-8.2) Lime sand.	
	S05013		80/80			(8.2-8.7) Coarse grainsize limestone w/some dolostone frag.	
				WET		(8.7-8.8) Very compacted dense crusher run w/ gravel wet. Split spoon refusal at 8.8 ft BGS.	

DRILLING CONTRACTOR OGDEN

DRILLING METHOD HOLLOW STEM AUGER

DRILLING EQUIPMENT CME-75

DRILLING STARTED 11/21/94 ENDED 11/21/94

REMARKS S=SPLIT SPOON

Coordinates are reported in Y-12 Grid.
See key sheet for symbols and abbreviations used above.

SAIC®

SHEET 1 OF 2

LOCATION BCV OU 1 TOTAL DEPTH 18.80 ft bgs

BOREHOLE NUMBER S3-06

COORDINATES N 30,424.60 E 51,936.50 BOREHOLE DIAMETER 8 in. SAMPLING DEVICE S-3IN

ELEVATION 1011.60 ft above MSL LOGGED BY S.L. Abston

SAMPLE INFORMATION					STRATA	LITHOLOGIC DESCRIPTION	ELEVATION FEET
DEPTH FEET	SAMPLE ID	U-238 (pCi/g)	beta/ gamma (cpm)	water			
	S06011	NA	80/80	MOIST		(0.0-1.6) (5YR5/6) yellowish red clay -CL- slightly moist w/ (N7) light grey weathered chert frag., nodules throughout, slightly brittle to hard, some magnesium nodules - black - fill.	
						(1.6-2.0) No recovery.	1010
			80/80			(2.0-4.0) Same as above. Some chert completely weathered. Some fragments of coal. Bottom .2 ft limestone gravel (~80%) in a (10YR4/3) brown brittle, dry, clay - CL, fill.	
5	S06012		80/80	MOIST		(4.0-6.0) Same as bottom of last spoon w/ ~60% gravel and some brick frags. The bottom of spoon has large concrete frags. (concrete w/ gravel filler), slightly moist.	
			80/80			(6.0-7.3) All red brick frag. and light grey (5YR7/1) brick mortar - does not fizz w/HCL but is attached to the bricks. The bottom .05 ft. of the spoon had (10YR4/3) brown clay.	1005
						(7.3-8.0) No recovery.	
						(8.0-8.3) Same as bottom .05 ft of above spoon w/ smell, brick frag., brittle, dry.	
	S06013		80/80	MOIST		(8.3-9.5) (10YR6/6) brownish yellow clay mottled w/ traces of (10YR5/6) yellowish brown clay and black streaks of weathered chert, slightly moist.	
10						(9.5-10.0) Darker (10YR4/2) dark greyish brown clay mottled w/ (10YR5/6) yellowish brown clay - slightly moist, grey clay are soft - CL. (10.0-10.3) Same as above.	
			80/80			(10.3-12.0) Same as above w/ the grey clay becoming (10YR6/2) light brownish grey weathered shale w/ alot of black staining on bedding planes, slightly moist. Some shale layers are (N7) light grey completely weathered shale (clay), soft.	1000
	S06014		80/80			(12.0-14.0) Same as bottom of last spoon. Top .4 ft was 80% black weather stained. Increasing amounts of the grey (N7) chert frag. large, inside of chert is black w/ small reddish brown zone between the grey outside and black inside. Bottom .4 ft of spoon is a light olive brown (5Y5/6) slightly weathered shale - dry.	
						(14.0-15.8) Same as bottom of last spoon. Many bedding planes exhibit black weathered staining.	

DRILLING CONTRACTOR OGDEN

DRILLING METHOD HOLLOW STEM AUGER

DRILLING EQUIPMENT CME-75

DRILLING STARTED 11/28/94 ENDED 11/28/94

REMARKS S=SPLIT SPOON

Coordinates are reported in Y-12 Grid
See key sheet for symbols and abbreviations used above.

B13-13

SAIC®

SHEET 2 OF 2

LOCATION BCV OU 1 TOTAL DEPTH 18.80 ft bgs

BOREHOLE NUMBER S3-06

COORDINATES N 30,424.60 E 51,936.50 BOREHOLE DIAMETER 8 in. SAMPLING DEVICE S-3IN

ELEVATION 1011.60 ft above MSL LOGGED BY S.L. Abston

SAMPLE INFORMATION					STRATA	LITHOLOGIC DESCRIPTION	ELEVATION FEET
DEPTH FEET	SAMPLE ID	U-238 (pCi/g)	beta/ gamma (cpm)	water			
			80/80			(15.8-16.0) (10R4/2) greyish red, thinly bedded micaceous shale, only very slighaly weathered, dry. (16.0-17.0) Same as bottom of last spoon.	
							995
	S06015	NA	80/80	WET WET		(17.0-17.4) (7.5YR5/6) strong brown clay mottled w/ (7.5YR6/1) grey clay. Wet zone at 17.0-17.05 ft BGS and at 17.35 ft BGS.	
			80/80			(17.4-18.0) Medium grey (N5) thinly laminated weathered shale. Bed planes exhibit black staining, brittle, dry. (18.0-18.8) Medium grey (N5) thinly laminated shale fragments w/ some exhibiting black staining on bedding planes, dry, (outside of spoon wet). Refusal at 18.8 ft BGS.	

SAIC

SHEET 1 OF 2

LOCATION BCV OU 1 TOTAL DEPTH 27.90 ft bgs

BOREHOLE NUMBER S3-07

COORDINATES N 30,178.90 E 51,991.30 BOREHOLE DIAMETER 8 in. SAMPLING DEVICE S-3IN

ELEVATION 1008.10 ft above MSL LOGGED BY S.L. ABSTON

SAMPLE INFORMATION					STRATA	LITHOLOGIC DESCRIPTION	ELEVATION FEET
DEPTH FEET	SAMPLE ID	U-238 (pCi/g)	beta/ gamma (cpm)	water			
			60/60			(0.0-1.7) (5YR5/6) yellowish red clay - CL with rootlets some (2.5Y7/4) pale yellow clay and contains (7.5YR8/2) pinkish white weathered chert and medium dark grey (N4) limestone fragments.	
	S07011	8.6		MOIST		(1.7-2.0) Limestone gravel and crushed gravel (crusher run) slightly moist.	
				WET		(2.0-2.2) Crusher run, saturated.	
				MOIST		(2.2-2.7) (5YR5/6) yellow red, moist clay (CL) with (10YR8/4) very pale brown weathered chert.	
			400/60			(2.7-3.3) (N4) medium dark grey shale.	
						(3.3-4.0) (10YR 4/3) brown clay with 50% limestone gravel fragments (this section is the 400 cpm b/gamma), wet.	1005
				WET		(4.0-4.6) Split spoon refusal at 4.6 ft BGS on concrete - same as bottom of last spoon, saturated (some asphalt).	
5			200/60			(4.6-6.0) No recovery.	
	S07012	2.9				(6.0-7.0) Same as above, saturated.	
				WET			
			600/60			(7.0-7.2) Concrete. Top section had large asphalt fragments composite b/gamma 400 cpm.	
				MOIST		(7.2-8.0) (10YR5/6) yellowish brown silty clay - CL w/ weathered chert frag, olive green shale frag, asphalt, small limestone gravel, wood, slightly moist. 600 cpm.	
						(8.0-8.6) (5YR5/6) yellowish red clay - CL with limestone gravel fragments.	1000
			2000/60	MOIST		(8.6-8.8) (10YR4/3) brown clay with rootlets (highest with b/gamma meter). Traces of (5YR4/6) yellowish red (orange) fibrous material - very small probably plant material.	
10	S07013	4.1				(8.8-9.0) (5YR5/8) yellowish red clay mottled w/ (7.5YR5/4) brown clay, rootlets. Brown clay more moist than yellowish red clay.	
						(9.0-10.0) (10YR5/4) moderate yellowish brown thinly laminated shale, brittle, dry with moderate reddish brown (10YR4/6) staining. Spoons are wet on outside.	
						(10.0-10.8) Same as bottom of last spoon.	
			150/60			(10.8-12.0) (5YR5/6) yellowish red clay layered with (7.5YR7/2) pinkish gray clay - CL completely weathered shale exhibiting bedding plane fabric - moist.	
				MOIST		(12.0-14.0) Same as bottom of last spoon with yellowish red becoming less weathered and having black staining on the bedding planes, slightly moist solvent odor.	
			100/60				995
	S07014	35.0				(14.0-14.4) Same as above.	
						(14.4-15.2) (5YR4/1) brownish grey thinly bedded with black weather stain on bedding planes shale.	

DRILLING CONTRACTOR OGDEN

DRILLING METHOD HOLLOW STEM AUGER

DRILLING EQUIPMENT CME-75

DRILLING STARTED 11/29/94 ENDED 11/29/94

REMARKS S=SPLIT SPOON

Coordinates are reported in Y-12 Grid
See key sheet for symbols and abbreviations used above.

B13-15

SAIC

SHEET 2 OF 2

LOCATION BCV OU 1 TOTAL DEPTH 27.90 ft bgs

BOREHOLE NUMBER S3-07

COORDINATES N 30,178.90 E 51,991.30 BOREHOLE DIAMETER 8 in. SAMPLING DEVICE S-3IN

ELEVATION 1008.10 ft above MSL LOGGED BY S.L. ABSTON

SAMPLE INFORMATION					STRATA	LITHOLOGIC DESCRIPTION	ELEVATION FEET
DEPTH FEET	SAMPLE ID	U-238 (pCi/g)	beta/ gamma (cpm)	water			
			150/60	MOIST		(15.2-16.0) Almost completely weathered (N8) light grey and light brown (5YR5/6) shale with black staining on bedding planes. Slightly moist about 70% grey and 30% brown.	
						(16.0-16.3) (5YR5/2) reddish gray silty, dry brittle clay -CL	
			200/60			(16.3-16.7) (10YR5/6) yellowish brown clay mottled with (7.5YR3/3) dark brown clay and (7.5YR8/2) pinkish white clay. (16.7-18.0) Same as bottom of last spoon, solvent odor.	
	S07015	6.9	200/60			(18.0-20.0) Same as bottom of last spoon - moist solvent smell-odor.	990
20						(20.0-20.6) (7.5YR4/3) brown silty clay.	
			200/60	MOIST		(20.6-22.0) Moderate brown (5YR3/4) shale interbedded with moderate (5YR4/4) siltstone slightly weathered moist, solvent odor.	
	S07016	43.0	200/60			(22.0-24.0) Same as bottom of last spoon, brittle, slightly moist. Strong nitric odor.	985
						(24.0-25.8) Same as above. Not as strong of an odor. Very wet zone at 24.9 ft BGS.	
25			150/60	WET			
	S07017	4.6	100/60			(25.8-26.0) (5YR5/2) pale brown thinly bedded, slightly weathered shale. (26.0-26.4) Same as bottom of last spoon. (26.4-27.9) Split spoon refusal at 27.9 ft BGS. Dark yellowish brown (10YR4/2) thinly bedded only slightly weathered black on bedding planes shale.	

SAIC

SHEET 1 OF 1

LOCATION BCV OU I

BOREHOLE NUMBER S3-08

BOREHOLE DIAMETER 8 in.

LOGGED BY S.L. ABSTON

TOTAL DEPTH 12.00 ft bgs

SAMPLING DEVICE S-3IN

COORDINATES N 30,173.30 E 52,368.30

ELEVATION 1006.00 ft above MSL

SAMPLE INFORMATION					STRATA	LITHOLOGIC DESCRIPTION	ELEVATION FEET
DEPTH FEET	SAMPLE ID	U-238 (pCi/g)	beta/ gamma (cpm)	water			
	S08011	4.7	80/80			(0.0-1.2) (10YR4/4) dark yellowish brown silty clay -CL- with rootlets, concrete fragments, limestone fragments (7.5YR4/3) shale fragments.	1005
						(1.2-1.5) Coal fragments and gravel layer.	
						(1.5-2.0) Dark reddish grey shale - slightly weathered, dry.	
			80/80			(2.0-3.7) Same as bottom of last spoon.	
5	S08012	18.0	100/20	MOIST		(3.7-4.0) (10YR5/6) yellowish brown clay mottled w/ (2.5YR4/8) red and (10YR6/2) light brownish gray clay. Occasional layers of very weathered (10YR6/3) shale w/ black weather staining, plastic, slightly moist. (4.0-5.5) Same as above.	
						(5.5-5.8) Same as above with > 80% grey clay.	
						(5.8-6.0) Same as above with > 50% grey clay, more plastic (completely weathered shale beds) slightly moist.	1000
						(6.0-8.0) Geotechnical sample.	
	S08013		80/80			(8.0-9.2) Greyish red (10YR4/2), weathered, thinly laminated, brittle, shale w/ layers of (10YR6/2) light brownish grey, completely weathered shale - clay.	
						(9.2-9.5) Brownish grey (5YR4/1) thinly laminated, micaceous, slightly brittle to hard shale. Some bedding planes exhibit (5YR5/6) light brown to orange iron staining, dry. Split spoon refusal at 9.5 ft BGS.	

DRILLING CONTRACTOR OGDEN

DRILLING METHOD HOLLOW STEM AUGER

DRILLING EQUIPMENT CME-75

DRILLING STARTED 11/17/94 ENDED 11/17/94

REMARKS S=SPLIT SPOON

Coordinates are reported in Y-12 Grid
See key sheet for symbols and abbreviations used above.

SAIC®

SHEET 1 OF 1

LOCATION BCV OU 1 TOTAL DEPTH 16.00 ft bgs

BOREHOLE NUMBER S3-09

COORDINATES N 30,656.50 E 52,080.10 BOREHOLE DIAMETER 8 in. SAMPLING DEVICE S-3IN

ELEVATION 1018.00 ft above MSL LOGGED BY S.L. ABSTON

SAMPLE INFORMATION					STRATA	LITHOLOGIC DESCRIPTION	ELEVATION FEET
DEPTH FEET	SAMPLE ID	U-238 (pCi/g)	beta/gamma (cpm)	water			
			60/60			(0.0-2.0) Silty clay (CL) light brown (5YR5/6) with rocklets, medium light gray (N6) limestone gravel fragments, moderate reddish brown (10Y4/6) weathered chert fragments and dark yellowish orange (10YR6/6) weathered shale, thinly laminated (~60-75% shale, bottom .5 ft), dry.	
	S09011		60/60			(2.0-4.0) Completely to moderately weathered shale light brown (5YR5/6) to pale yellowish brown (10YR6/2) mottled with organic shale layers. Shale almost weathered to clay, dry.	1015
5	S09012	NA	60/60	MOIST		(4.0-5.5) Same as above but moist and becoming more complete.	
						(5.5-6.0) No recovery.	
				MOIST		(6.0-6.4) Same as above. (6.4-7.4) Split spoon refusal at 7.4 ft BGS. Bottom of spoon light olive gray (5Y6/1) shale exhibiting (10YR5/4) moderate yellowish brown weathering staining. The shale is thinly bedded and micaceous, dry, brittle.	
						(7.4-8.0) No recovery.	1010
	S09013		60/60			(8.0-9.2) Same as above, brittle. (9.2-9.5) Split spoon refusal at 9.5 ft BGS. Bottom of spoon is a light grey micaceous shale, much more resistant and only showing traces of weathering.	
10						(9.5-10.0) No recovery.	
			60/60	WET		(10.0-10.4) Same as above. (10.4-11.2) Very thinly bedded (N5) medium grey shale beds with staining (5YR5/6) light brown- occurring between bedding planes - bedding planes avulsate and some exhibit black organic staining and appear to be at a high angle to the spoon. (11.2-11.5) Exhibits a high angle of frac. in the split spoon core and having water it is a greyish brown (5YR3/2) highly silty clay-wet.	
	S09014		60/60	WET		(11.5-12.0) Resistant greyish brown (5YR3/2) shale exhibiting moderate brown (5YR4/4) and black weathering. Shale will break but not crumble. (12.0-13.4) Split spoon refusal at 13.4 ft BGS on a greyish brown (5YR3/2) shale exhibiting moderate brown (5 YR 4/4) and black weathering, wet. Refusal - only recovering shale and lab will not be able to run it.	1005

DRILLING CONTRACTOR OGDEN

DRILLING METHOD HOLLOW STEM AUGER

DRILLING EQUIPMENT CME-75

DRILLING STARTED 11/15/94 ENDED 11/15/94

REMARKS S=SPLIT SPOON

Coordinates are reported in Y-12 Grid

See key sheet for symbols and abbreviations used above.

B13-18

SAIC®

SHEET 1 OF 1

LOCATION BCV OU 1 TOTAL DEPTH 12.00 ft bgs

BOREHOLE NUMBER S3-10

COORDINATES N 29,781.00 E 50,793.00 BOREHOLE DIAMETER 8 in. SAMPLING DEVICE 8-3IN

ELEVATION 981.00 ft above MSL LOGGED BY S.L. ABSTON

SAMPLE INFORMATION					STRATA	LITHOLOGIC DESCRIPTION	ELEVATION FEET
DEPTH FEET	SAMPLE ID	U-238 (pCi/g)	beta/ gamma (cpm)	water			
	S10011	2.9	60/60			(0.0-2.0) Top .05 ft top soil- (10YR2/2) dusky brown silty clay CL-dark yellowish brown (10YR4/2) with (N6) (medium light gray) limestone fragments and siltstone - moderate brown (5YR4/4) -fill dry.	980
			60/60			(2.0-4.0) Silty clay -CL- (10YR4/2) dark yellowish brown with (N6) medium light gray limestone fragments and (5YR4/1) brownish grey thinly laminated shale fragments -fill, dry.	
5	S10012	NA	60/60			(4.0-5.5) Same as above with some fragments (N3) dark grey calcareous thinly laminated shale fragments -fill, dry.	
						(5.5-6.0) No recovery.	
			60/60			(6.0-8.0) Same as above- some shale appears micaceous- fill.	975
						(8.0-8.3) Same as above but softer.	
	S10013	NA	60/60	MOIST		(8.3-9.1) Silty clay- moderate yellowish brown (10YR5/4) with large medium grey (N5) crystalline limestone fragments, dry and hard.	
						(9.1-9.5) (5YR3/4) moderate brown clay, moist soft with plant rootlets, brick fragments, small thinly laminated micaceous (N3) dark grey shale fragments.	
10						(9.5-10.0) No recovery.	
			60/60	MOIST		(10.0-11.3) Split spoon refusal @ 11.3 ft BGS. Same as above (bottom). Top very moist getting dry downward. Bottom contained concrete, coal, bricks, stems piece of wood, asphalt, and some grayish red (10R4/2) limestone fragments some (N3) dark grey thinly laminated shale fragments and some dark greenish grey (5 GY 4/1) shale fragments. Refusal at 11.8 ft BGS.	970

DRILLING CONTRACTOR OGDEN

DRILLING METHOD HOLLOW STEM AUGER

DRILLING EQUIPMENT CME-75

DRILLING STARTED 11/14/94 ENDED 11/14/94

REMARKS S=SPLIT SPOON

Coordinates are reported in Y-12 Grid
See key sheet for symbols and abbreviations used above.