

GROUNDWATER PROTECTION PROGRAM  
CALENDAR YEAR 1999  
EVALUATION OF GROUNDWATER AND SURFACE WATER QUALITY DATA  
FOR THE  
BEAR CREEK HYDROGEOLOGIC REGIME  
AT THE  
U.S. DEPARTMENT OF ENERGY Y-12 PLANT,  
OAK RIDGE, TENNESSEE

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## List of Acronyms and Abbreviations

AGLLSF	Above Grade Low-Level Storage Facility
BCBG	Bear Creek Burial Grounds
BCV	Bear Creek Valley
BCK	Bear Creek kilometer
Bear Creek Regime	Bear Creek Hydrogeologic Regime
BG	Burial Ground
bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CE	counting error
CY	calendar year
DNAPL	dense nonaqueous phase liquids
DOE	U.S. Department of Energy
DQO	data quality objective
East Fork Regime	Upper East Fork Poplar Creek Hydrogeologic Regime
ft	feet
GWMR	Groundwater Monitoring Report
GWPP	Groundwater Protection Program
HCDA	Hazardous Chemical Disposal Area
IWQP	Integrated Water Quality Program
MCL	maximum contaminant level
MDA	minimum detectable activity
MIC	microbiologically induced corrosion
µg/L	micrograms per liter
mg/L	milligrams per liter
msl	mean sea level
NT	North Tributary (Bear Creek)
ORR	Oak Ridge Reservation
PCE	tetrachloroethene
pCi/L	picoCuries per liter
RCRA	Resource Conservation and Recovery Act
REDOX	oxidation-reduction potential
RI	Remedial Investigation
SDWA	Safe Drinking Water Act
SS	south side (Bear Creek)
TCE	trichloroethene
TDS	total dissolved solids
VC	vinyl chloride
VOC	volatile organic compound
WMA	Waste Management Area
111TCA	1,1,1-trichloroethane
11DCA	1,1-dichloroethane
11DCE	1,1-dichloroethene
12DCA	1,2-dichloroethane
12DCE	1,2-dichloroethene
c12DCE	cis-1,2-dichloroethene
t12DCE	trans-1,2-dichloroethene

## **List of Acronyms and Abbreviations (continued)**

Tc-99	technetium-99
U-234	uranium-234
U-238	uranium-238

## 1.0 INTRODUCTION

This report presents an evaluation of the water quality monitoring data obtained by the Y-12 Plant Groundwater Protection Program (GWPP) in the Bear Creek Hydrogeologic Regime (Bear Creek Regime) during calendar year (CY) 1999. The Bear Creek Regime contains many confirmed and potential sources of groundwater and surface water contamination associated with the U.S. Department of Energy (DOE) Oak Ridge Y-12 Plant. Applicable provisions of DOE Order 5400.1A - *General Environmental Protection Program* - require evaluation of groundwater and surface water quality near the Y-12 Plant to: (1) gauge groundwater quality in areas that are, or could be, affected by plant operations, (2) determine the quality of surface water and groundwater where contaminants are most likely to migrate beyond the DOE Oak Ridge Reservation (ORR) property line, and (3) identify and characterize long-term trends in groundwater quality.

The CY 1999 monitoring data that were evaluated for DOE Order 5400.1A purposes were collected by the Y-12 Plant GWPP managed by Lockheed Martin Energy Systems, Inc. and the Integrated Water Quality Program (IWQP) managed by Bechtel Jacobs Company LLC. The IWQP monitors groundwater and surface water quality for the purposes of: (1) Resource Conservation and Recovery Act (RCRA) post closure corrective action monitoring, as specified in the post closure permit for the Bear Creek Regime; and (2) Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial effectiveness monitoring, as specified in the applicable record of decision or decision documents pending final approval, and CERCLA pre-remediation baseline water quality monitoring (AJA Technical Services, Inc. 2000).

The following sections of this report contain relevant background information (Section 2.0); describe the results of the respective data evaluations required under DOE Order 5400.1A (Section 3.0); summarize significant findings of each evaluation (Section 4.0); and list the technical reports and regulatory documents cited for more detailed information (Section 5.0). All of the figures (maps and trend graphs) and data tables referenced in each section are presented in Appendix A and Appendix B, respectively.



## **2.0 BACKGROUND INFORMATION**

The Bear Creek Regime encompasses several confirmed and suspected sources of groundwater and surface water contamination within Bear Creek Valley (BCV) west of the DOE Y-12 Plant in Oak Ridge, Tennessee (Figure 1); unless otherwise noted, directions are in reference to the Y-12 Plant grid system. The following sections provide background information regarding sources of contamination, an overview of the groundwater flow and surface water drainage characteristics, and the extent of groundwater and surface water contamination in the regime.

### **2.1 CONTAMINANT SOURCE AREAS**

The Bear Creek Regime encompasses a portion of BCV used since the early 1950s for the treatment, storage, and disposal of various hazardous and nonhazardous wastes (Figure 2). Many of the sites are confirmed or suspected sources of groundwater and surface water contamination, with the primary sources being the S-3 Site (formerly the S-3 Ponds), the Oil Landfarm waste management area (WMA), which includes the Boneyard/Burnyard/Hazardous Chemical Disposal Area (HCDA), and the Bear Creek Burial Grounds (BCBG) WMA. All of the sites except the Above Grade Low-Level Storage Facility (AGLLSF) have undergone some level of engineered closure (e.g., installation of multilayer, low-permeability caps) and are currently regulated under RCRA, CERCLA, or both. The AGLLSF is an operating facility that is not regulated under either program (Table B.1). Contaminated receptor media in the regime (groundwater, surface water, and Bear Creek stream sediments and floodplain soils) are also regulated under CERCLA.

### **2.2 TOPOGRAPHY AND BEDROCK GEOLOGY**

The Bear Creek Regime is bound to the north by Pine Ridge and to the south by Chestnut Ridge and encompasses the portion of BCV extending from a surface water and shallow groundwater divide at the west end of the Y-12 Plant to the western boundary of the Bear Creek watershed. Surface elevations range from 900 feet (ft) above mean sea level (msl) in the Bear Creek channel along the floor of BCV to about 1,200 ft msl along the crests of Pine Ridge and Chestnut Ridge (Figure 3).

The geology of the Bear Creek Regime is characterized by alternating sequences of clastic and carbonate strata that form the distinctive topography of the Valley and Ridge Physiographic Province. On the ORR, shale and siltstone beds of the Rome Formation form Pine Ridge to the north, limestone and shale formations of the Conasauga Group form BCV, and the primarily dolostone formations of the Knox Group form Chestnut Ridge to the south (Figure 3). Strike and dip of bedding are generally N 55°E and 45°SE, respectively (as referenced to true north). Bedrock is overlain by up to 50 ft of several materials, including man-made fill, alluvium, colluvium, fine-grained residuum from the weathering of the bedrock, and saprolite (weathered bedrock which retains relict bedding and fractures).

### **2.3 HYDROGEOLOGIC FRAMEWORK**

The following overview of the groundwater and surface water systems in the Bear Creek Regime is based on the conceptual hydrogeologic model described in the CERCLA remedial investigation (RI) report for the Bear Creek Characterization Area (DOE 1997), which is hereafter referenced as the RI Report. This conceptual model incorporates (1) the general hydrologic framework and associated nomenclature described

in Solomon *et al.* (1992); (2) groundwater flow characteristics presented in Moore (1988 and 1989) and Moore and Toran (1992); (3) results of hydrologic studies and investigations in BCV, including Dreier *et al.* (1987), Shevenell (1994), and Turner *et al.* (1991); and (4) findings of sampling and analysis activities performed specifically for RI purposes. Key aspects of the conceptual model regarding the principal hydrogeologic units and respective groundwater flow characteristics and the general hydrology of Bear Creek are summarized in the following discussion.

### 2.3.1 Groundwater System

There are two basic hydrogeologic units in the Bear Creek Regime: the aquifer, consisting of the Maynardville Limestone (upper Conasauga Group) and Copper Ridge Dolomite (lower Knox Group); and the aquitard, consisting of the remaining Conasauga Group formations (Nolichucky Shale, Maryville Limestone, Rogersville Shale, Rutledge Limestone, and Pumpkin Valley Shale) and the Rome Formation (Figure 3). Components of the aquifer underlie the axis of BCV (Maynardville Limestone) and the steep flank and crest of Chestnut Ridge (Copper Ridge Dolomite). Formations comprising the aquitard form the northern slope of BCV (Conasauga Group) and Pine Ridge (Rome Formation). The aquitard, which underlies the primary contaminant source areas in the Bear Creek Regime, is hydraulically upgradient of the aquifer, which functions as a hydrologic drain in BCV. Fractures provide the principal groundwater flowpaths in both units, and dissolution of carbonates in the aquifer has enlarged fractures and produced solution cavities and conduits that greatly enhance its hydraulic conductivity relative to the aquitard. Flow through the porous rock matrix is minimal in both units, although matrix diffusion processes play an important role in contaminant migration.

Groundwater flow in the aquitard and the aquifer is primarily parallel to bedding (along strike and dip), which in the aquitard may or may not coincide with the direction of maximum hydraulic gradient inferred from water level isopleths. Flow across bedding occurs primarily along permeable zones formed by cross-cutting fractures or fracture zones (and possibly small faults). The northern tributaries of Bear Creek are possibly the surficial expression of these cross-cutting structures. Such structures provide preferred flowpaths that channel groundwater from the aquitard to the aquifer or act as barriers to lateral flow, causing groundwater from deeper intervals to upwell and discharge to the shallower flow system in each hydrogeologic unit.

In the aquitard most groundwater flow occurs in a highly conductive interval near the bedrock/residuum interface. Flow above the water table occurs in response to precipitation when flowpaths in the residual soils become saturated and rapidly transmit water laterally (stormflow) down slope toward springs and seeps and vertically (recharge) to the water table interval. Recharge to the water table interval promotes strike-parallel groundwater flow toward discharge areas in nearby northern tributaries of Bear Creek. Although the presence of contaminants in groundwater more than 200 ft below ground surface (bgs) in the Nolichucky Shale clearly indicates permeable flowpaths at depth, flow is most active at depths less than 100 ft bgs, and only a small percentage of total flow ultimately recharges the deeper bedrock, where upward hydraulic gradients predominate. Overall, about 94% of the available groundwater in the aquitard discharges to Bear Creek tributaries, about 5% flows along cross-cutting fractures into the aquifer, and about 1% flows through strike-parallel pathways in the deeper subsurface (DOE 1997).

Decreasing groundwater flux with depth in the aquitard also is reflected by distinct changes in groundwater geochemistry. Most water table interval and shallow (i.e., <100 ft bgs) bedrock wells monitor calcium-magnesium-bicarbonate groundwater. A fairly abrupt change to sodium-bicarbonate groundwater, which is interpreted to be a function of longer groundwater residence time related to reduced fracture aperture or

increased fracture spacing (Solomon *et al.* 1992), occurs at a depth of about 100 ft bgs. Further reduced groundwater flux is indicated by the transition from sodium-bicarbonate groundwater to sodium-chloride groundwater that usually occurs at a depth of about 400 ft bgs. The transition to the sodium-chloride groundwater is accompanied by a general increase in total dissolved solids (TDS).

Most groundwater flow in the aquifer occurs at shallow depths (i.e., <100 ft bgs) in an extensively interconnected network of solution conduits and cavities (karst network). Below the shallow karst network, fractures provide the primary flowpaths. Also, there are seven stratigraphic zones in the Maynardville Limestone (numbered from bottom to top) that are differentiated by distinct lithologic and hydrologic characteristics (Shevenell *et al.* 1995). The more permeable zones are at the bottom (Zone 2) and top (Zone 6) of the formation, but the uppermost zones are the most permeable and probably transmit the bulk of the groundwater in the Maynardville Limestone (Goldstrand 1995). Groundwater geochemistry is more homogeneous in the aquifer than in the aquitard; almost every monitoring well in the Maynardville Limestone, regardless of depth, monitors calcium-magnesium-bicarbonate groundwater. Some shallow wells monitor sulfate-enriched groundwater, which probably reflects dissolution of locally disseminated sulfides, including gypsum and anhydrite, and several deep wells monitor calcium-magnesium-sulfate groundwater with very high TDS.

Flow in the shallow karst network in the aquifer is relatively rapid and occurs as “quickflow” discharge to Bear Creek during rainfall. Active groundwater circulation in the aquifer occurs at greater depth than in the aquitard, and groundwater from the deeper flow system discharges along major gaining (influent) reaches of Bear Creek. These discharge areas are probably related to large-scale structural (e.g., cross-strike faults) or stratigraphic discontinuities in the Maynardville Limestone. Overall, about 81% of the available groundwater in the aquifer (Maynardville Limestone) discharges directly to Bear Creek, 16% flows into the creek from spring SS-5, and 3% follows strike-parallel flowpaths in the subsurface (DOE 1997).

Isopleths of seasonal groundwater surface elevations in the Bear Creek Regime during CY 1999 (Figure 4) indicate generally southwesterly flow in the aquitard toward the aquifer (Maynardville Limestone) and westerly (strike-parallel) flow in the aquifer toward the west end of BCV. Seasonal water level fluctuations, which were typically less than 10 ft in most water table interval and bedrock interval monitoring wells, influenced the magnitude of hydraulic gradients but did not significantly alter the overall groundwater flow patterns.

### **2.3.2 Surface Water System**

Surface water in the Bear Creek Regime is drained by Bear Creek and its tributaries (Figure 3). From its headwaters near the west end of the Y-12 Plant, Bear Creek flows southwest for approximately 4.5 miles, where it turns northward to flow into East Fork Poplar Creek. Monitoring locations along the main channel of Bear Creek are specified by the Bear Creek kilometer (BCK) value corresponding to the distance upstream from the confluence with East Fork Poplar Creek (e.g., BCK-09.40). Sections of the main channel are referenced as upper Bear Creek (upstream of BCK-11.97), middle Bear Creek (between BCK-11.97 and BCK-09.40), and lower Bear Creek (downstream of BCK-09.40). Tributaries are designated as north tributary (NT) or south tributary along with a value representing the tributary number counted downstream from the headwaters (e.g., NT-1). Major springs along the south side (SS) of Bear Creek are numbered in ascending order downstream from the headwaters (e.g., SS-1).

Approximately half of the annual precipitation in BCV exits via surface water flow in Bear Creek, and possibly higher proportions during winter and early spring (DOE 1997). Flow in the creek increases rapidly

during rainfall and afterward reflects the relative contributions of overland flow, stormflow, and groundwater discharge. Flow in the main channel and tributaries generally returns to pre-precipitation levels within one or two days. Major sections of upper and middle Bear Creek are seasonally dry, but flow is perennial in lower Bear Creek.

The main channel of Bear Creek functions as a major conduit of the shallow karst network within the Maynardville Limestone (DOE 1997). Discharge from numerous springs located along the Maynardville Limestone/Copper Ridge Dolomite boundary on the north slope of Chestnut Ridge dominate the hydrology of the creek, especially during droughts when they provide most of the flow in the main channel. Additionally, the main channel contains alternating gaining and losing reaches. Each gaining reach generally correlates with a major aquifer discharge area. Losing reaches in upper and middle Bear Creek, particularly a section of the main channel directly south of Sanitary Landfill I, play an important role in transferring contaminants from Bear Creek to the aquifer.

## **2.4 GROUNDWATER CONTAMINATION**

The following discussion is based on the contaminant transport models for the primary source areas in the Bear Creek Regime (the S-3 Site, the Oil Landfarm WMA, and the BCBG WMA) and the principal contaminant migration pathways (the Maynardville Limestone and Bear Creek) described in the RI Report. These models incorporate the bulk of the geologic, hydrologic, and water quality data available for the Y-12 Plant and essentially represent the culmination of hydrogeologic characterization and contamination assessment efforts performed since the mid-1980s.

### **2.4.1 S-3 Site**

Operation of the former S-3 Ponds emplaced a large reservoir of contamination in the aquitard (Nolichucky Shale) consisting of a heterogeneous mix of inorganic, organic, and radioactive constituents. The principal groundwater contaminants are nitrate, technetium-99 (Tc-99), uranium isotopes (primarily uranium-234 [U-234] and uranium-238 [U-238]), trace metals (e.g., cadmium), and volatile organic compounds (VOCs). Contaminant concentrations in the aquitard nearest the site have probably reached maximum levels, with the center of mass of the plume slowly moving westward. Westward, strike parallel migration of contaminants in the aquitard occurs until they encounter a cross-cutting structure that promotes upward discharge into the shallow flow system, or cross-strike flow into the aquifer.

The S-3 Site contaminant plume in the aquitard extends south toward the upper reach of Bear Creek and along strike in the water table interval and the deeper bedrock for over 3,000 ft to the west (Figure 5). Nitrate is a highly mobile and chemically stable contaminant that delineates the maximum extent of groundwater transport and effectively traces the principal migration pathways. Nitrate (as N) concentrations (hereafter synonymous with “nitrate” concentrations) within the plume exceed 10,000 milligrams per liter (mg/L) in the deep bedrock directly below the S-3 Site, 1,000 mg/L in the shallow groundwater near the site, and 10 mg/L near the plume boundaries.

Gross alpha activity and gross beta activity within the S-3 Site contaminant plume exceed 1,000 picoCuries per liter (pCi/L). Although a diverse population of radioisotopes is present in the groundwater closest to the site, elevated gross alpha and gross beta activity in the groundwater (Figure 5) probably delineate migration of uranium isotopes and Tc-99, respectively.

Other components of the S-3 Site contaminant plume are trace metals and VOCs. The distribution of trace metals is less extensive than that of nitrate and radioactivity, but the most mobile metals within the plume (e.g., barium) have been transported beyond the acidic groundwater (pH <5) nearest the site. Acetone and tetrachloroethene (PCE) are the principal VOCs within the plume. Concentrations of PCE exceed 5,000 micrograms per liter ( $\mu\text{g/L}$ ) in wells adjacent to the site, indicating the presence of dense nonaqueous phase liquids (DNAPL) in the subsurface, but decrease to less than 50  $\mu\text{g/L}$  about 500 ft downgradient of the site. Therefore, the suspected DNAPL emplaced during operation of the S-3 Ponds is the potential source of aqueous phase PCE observed in groundwater near the site, and the limited extent of PCE migration suggests substantial natural attenuation.

The S-3 Site contains varying amounts of sludge produced by denitrification of the waste water during closure of the former S-3 Ponds. Sludge within the saturated zone may release Tc-99 and uranium isotopes to the shallow groundwater flow system in the aquitard, which then may be transported westward through the water table interval toward discharge points in NT-1 (DOE 1997). Additionally, matrix diffusion and advective transport processes are slowly releasing contaminants (e.g., nitrate) from the deeper reservoir into the more active (shallow) aquitard flow system.

#### **2.4.2 Oil Landfarm WMA**

The primary sources of groundwater contaminants in the Oil Landfarm WMA (listed in order of importance) are the Boneyard/Burnyard/HCDA, the Oil Landfarm, and Sanitary Landfill I (Figure 2 and Table B.1). Each of these sites is a source of VOCs in the shallow groundwater, and the Boneyard/Burnyard/HCDA is a major source of elemental uranium and alpha radioactivity.

Uranium isotopes are the principal groundwater contaminants at the Boneyard/Burnyard. Contamination delineated by soil sampling and geophysical and radiological surveys indicate a major source area located immediately northwest of the HCDA cap. Wastes in the Boneyard/Burnyard are probably within the saturated zone during seasonally high groundwater levels, and uranium isotopes may be leached and transported with the shallow groundwater that discharges into NT-3 or recharges directly into the Maynardville Limestone. Gross alpha and gross beta activity exceed 1,000 pCi/L in the shallow groundwater along NT-3 from the northwest corner of the site to the confluence of NT-3 and Bear Creek (Figure 5).

The Boneyard/Burnyard/HCDA also is the source of a dissolved VOC plume in the shallow groundwater. Primary components of the plume are trichloroethene (TCE), cis-1,2-dichloroethene (c12DCE), and PCE. Concentrations of these VOCs are less than 1% of solubility, indicating that DNAPL are probably not present in the subsurface. Because the high gross alpha and beta levels in surface water at NT-3 characterize the plume originating from the Boneyard/Burnyard (Figure 5), the lack of VOCs in these samples indicate that the HCDA is most likely the principal source of these VOCs.

Groundwater contaminants at the Oil Landfarm are principally VOCs, and a commingled plume containing two distinct suites of VOCs are evident: one to the northeast dominated by 1,1,1-trichloroethane (111TCA), 1,1-dichloroethane (11DCA), and 1,1-dichloroethene (11DCE); and one to the south dominated by PCE, c12DCE, trans-1,2-dichloroethene (t12DCE), and TCE. The dissolved VOC plume appears to be restricted to the shallow flow system. Summed VOC concentrations exceed 1,000  $\mu\text{g/L}$  in the northeast part of the plume and 100  $\mu\text{g/L}$  in the southern part of the plume; maximum concentrations within the plume do not indicate the presence of DNAPL in the subsurface.

Sanitary Landfill I is a probable source of 11DCA, c12DCE, and t12DCE in the shallow groundwater (aquitard and aquifer) downgradient to the south of the site (Figure 5). Maximum VOC concentrations are typically less than 50 µg/L. In the aquifer (Maynardville Limestone), these constituents have intermingled with the VOC plume (primarily TCE and c12DCE) originating from upgradient sources. Sanitary Landfill I also may be a source of boron in the groundwater at several wells immediately downgradient (west) of the site.

### **2.4.3 Bear Creek Burial Grounds WMA**

Groundwater in the aquitard underlying the BCBG WMA is extensively contaminated with VOCs at both shallow (water table) and deep (bedrock) intervals (Figure 5). There are five primary source areas: Burial Ground (BG)-A (North and South), BG-C (East and West), and the Walk-In Pits (Figure 2 and Table B.1). Dissolved VOC plumes in the shallow groundwater at several of these source areas are probably related to widespread occurrence of DNAPL in the subsurface. Contamination in the deeper groundwater flow system reflects density-driven, downward migration of DNAPL.

The disposal trenches comprising BG-A (North and South) received almost two million gallons of waste oils and coolants, and DNAPL have been encountered at 260 ft and 330 ft bgs in monitoring wells down-dip of source trenches in BG-A South. Dissolved VOC plumes in the groundwater underlying both areas are dominated by PCE, TCE, and c12DCE. Other common plume constituents are 111TCA, 11DCA, and 1,2-dichloroethane (12DCA). Summed concentrations of these plume constituents exceed 100,000 µg/L. Groundwater in the water table interval transports the plume constituents along strike toward discharge areas in NT-7. Strike-parallel migration also occurs below the water table interval, as reflected by westward (strike-parallel) transport of PCE indicated by data obtained from deeper bedrock wells at BG-A South.

Separate plumes of dissolved VOCs apparently occur in the shallow groundwater at BG-C East and BG-C West (Figure 5), both dominated by c12DCE with lesser amounts of vinyl chloride (VC). Concentrations within the plume are generally less than 500 µg/L. Groundwater containing these VOCs discharges to the NT-8 catchment on the northwest side of the Burial Grounds WMA. Data for both source areas do not clearly indicate the presence of DNAPL in the subsurface (DOE 1997).

Groundwater near the Walk-In Pits contains a distinct plume of dissolved VOCs dominated by PCE. Concentrations exceed 2,000 µg/L, which is about 1% of the maximum PCE solubility and possibly indicates DNAPL in the subsurface (DOE 1997). Contaminants in the shallow groundwater flow system may not discharge extensively to surface water (DOE 1997).

Although large quantities of uranium wastes were disposed in the BCBG WMA, few monitoring wells in the area yield radioactive groundwater samples (Figure 5). However, RI data for soil samples and surface water samples collected from NT-6, NT-7, and NT-8 indicate that BG-A South and BG-C East (Figure 2) are probable sources of radioactivity. Maximum gross alpha and gross beta activities in the samples from these tributaries ranged from about 20 pCi/L to more than 100 pCi/L. The disparity with the groundwater sample data may be an artifact of the monitoring well network (few wells are screened within the shallowest water table interval where radioactive contamination likely occurs), but the relatively low levels of radioactivity in the groundwater also suggest that the bulk of the uranium wastes in BG-A South and BG-C East are not within the saturated zone (DOE 1997).

Boron is the primary trace metal contaminant in the groundwater at the BCBG WMA. Elevated boron concentrations occur primarily in the shallow groundwater near BG-A South and BG-C (East and West) and

probably resulted from disposal of borax wastewater from the Y-12 Plant. Boron is most likely present in the groundwater as borate  $[B(OH)_3]$ , which is chemically stable and relatively mobile, and is transported toward discharge points in Bear Creek tributaries NT-7 and NT-8.

#### **2.4.4 Maynardville Limestone Exit Pathway**

The principal groundwater contaminants in the Maynardville Limestone are nitrate, VOCs, radioactivity, and trace metals. These contaminants primarily originate from the S-3 Site (nitrate, trace metals, and radionuclides), the Boneyard/Burnyard/HCDA (uranium isotopes and VOCs), Sanitary Landfill I (VOCs), the BCBG WMA (VOCs and radionuclides), and the Rust Spoil Area (VOCs) or an unidentified (VOC) source area in the Bear Creek floodplain adjacent to the Rust Spoil Area. These contaminants enter the Maynardville Limestone through direct recharge, hydrologic communication with surface water in Bear Creek, and inflow of shallow groundwater from the aquitard. Relative contributions from the source areas and the geochemical characteristics of the contaminants have produced two primary plumes of contamination in the groundwater: one containing nitrate and radioactivity and another containing VOCs. Both occur in the shallow karst network and the deeper fracture flowpaths and are commingled downgradient of the Boneyard/Burnyard/HCDA. Trace metal contaminants are more sporadically distributed and chiefly occur in the shallow karst network near the primary source areas (S-3 Site, Boneyard/Burnyard/HCDA, and BCBG WMA).

The nitrate plume in the aquifer essentially delineates the maximum extent of contaminant transport and effectively traces the primary migration pathways in the Maynardville Limestone (Figure 5). The plume is continuous in the deeper bedrock from south of the S-3 Site for about 10,000 ft along strike to the west, whereas attenuation from more active recharge and groundwater flux has reduced nitrate levels and produced a more discontinuous plume in the shallow karst network. Nitrate concentrations within the plume exceed 500 mg/L south of the S-3 Site, but rapidly decrease to less than 50 mg/L south of the Oil Landfarm WMA, and are typically highest in the fracture-dominated groundwater flow system at depths greater than 100 ft bgs.

The distribution of VOCs in the Maynardville Limestone reflects the relative contributions of several source areas and commingling during downgradient transport (Figure 5). Plume constituents in the upper part of BCV are TCE, c12DCE, and PCE; probable source areas are Spoil Area I, the S-3 Site, and possibly the Fire Training Facility located in the Upper East Fork Poplar Creek Hydrogeologic Regime (East Fork Regime). The major inputs to the plume occur from the Rust Spoil Area (TCE) or a nearby source in the Bear Creek floodplain, the Boneyard/Burnyard/HCDA (TCE and c12DCE), Sanitary Landfill I (111TCA and 11DCA), and discharge from the Bear Creek tributary (NT-7) that traverses BG-A North and A South (c12DCE and 12DCA). The highest concentrations within the plume (i.e., >300  $\mu\text{g/L}$ ) occur in the deeper groundwater south (down dip) of the Boneyard/Burnyard. These high concentrations coincide with the downward vertical hydraulic gradients in the Maynardville Limestone in this area and the major losing reach of middle Bear Creek south of Sanitary Landfill I.

Radioactivity in the groundwater in the Maynardville Limestone is primarily from uranium isotopes and Tc-99. The extent of these radionuclides are generally delineated by gross alpha activity and gross beta activity, respectively. The distribution of gross beta activity mirrors that of nitrate, indicating both a common source of nitrate and Tc-99 (the S-3 Site) and migration along common flowpaths. Increased gross alpha activity in the groundwater downstream of the NT-3 catchment reflects inputs of uranium isotopes from sources in the Boneyard/Burnyard/HCDA.

Most trace metal contamination in the Maynardville Limestone occurs in the shallow groundwater near the S-3 Site and the Boneyard/Burnyard/HCDA. Near the S-3 Site, the principal trace metal contaminants are barium, boron, cadmium, copper, lead, mercury, strontium, and uranium. Some of these metals (e.g., cadmium) were entrained in the highly acidic wastes disposed at the site, and others (e.g., strontium) were dissolved from the underlying bedrock. Trace metal contamination is sporadic in the groundwater at the Boneyard/Burnyard/HCDA, and the principal contaminants are beryllium, manganese, mercury, nickel, and uranium. Boron and uranium are the most common trace metal contaminants in the aquifer downgradient of the S-3 Site and the Boneyard/Burnyard/ HCDA, which indicates that relatively mobile, ionic species of both metals are present in the groundwater.

## **2.5 SURFACE WATER CONTAMINATION**

Many of the principal components of the groundwater contaminant plumes in the Bear Creek Regime, including nitrate, Tc-99, uranium isotopes, several trace metals, and a few VOCs (PCE, TCE, and c12DCE), occur in Bear Creek upstream of BCK-09.40 and several of its northern tributaries. However, the quality of surface water in Bear Creek improved dramatically after waste disposal at the S-3 Site ceased in 1983. Nitrate concentrations in upper Bear Creek at BCK-12.46, for example, exceeded 1,000 mg/L in 1983, but were less than 200 mg/L in 1994. Currently, input from several northern tributaries (primarily NT-1, NT-2, NT-3, and NT-8) during seasonally high flow conditions contribute the bulk of the contamination to the creek. During dry periods, contaminant flux into Bear Creek is generally lower, but because of less dilution in the creek channel, concentrations are typically higher and are probably controlled by contaminant levels in the groundwater discharged from springs SS-1, SS-4, and SS-5 (DOE 1997).

### 3.0 MONITORING DATA EVALUATION

The following sections provide an evaluation of the monitoring data for the network of CY 1999 sampling locations in the Bear Creek Regime, as reported in the annual Groundwater Monitoring Report (GWMR) issued by the Y-12 Plant GWPP in March 2000 (AJA Technical Services, Inc. 2000). The discussion mirrors the applicable requirements of DOE Order 5400.1A. Section 3.1 contains an evaluation of groundwater quality in areas that are, or could be, affected by Y-12 Plant operations (hereafter referenced as Surveillance Monitoring). Section 3.2 contains an evaluation of surface water and groundwater quality where contaminants are most likely to migrate beyond the ORR boundaries (hereafter referenced as Exit Pathway/Perimeter Monitoring). Increasing long-term contaminant trends are described in Section 3.3.

The CY 1999 monitoring results reported for 58 monitoring wells, 7 springs, and 12 surface water stations in the Bear Creek Regime (see Figure 6) were evaluated for the purposes of DOE Order 5400.1A. As shown in Table 1, the CY 1999 data for the bulk of the monitoring wells were evaluated for Surveillance Monitoring (Section 3.1) purposes whereas results for four wells and all of the springs and surface water stations were evaluated for the purposes of Exit Pathway/Perimeter Monitoring (Section 3.2).

**Table 1. CY 1999 sampling locations in the Bear Creek Regime**

DOE Order 5400.1A Evaluation	Number of Sampling Locations		
	Monitoring Wells	Springs	Surface Water Stations
Surveillance Monitoring	53	.	.
Exit Pathway/Perimeter Monitoring	4	7	12
Increasing Long-Term Trends	6	1	.

Note that the long-term trend analysis is based on CY 1999 sampling locations that exhibit increasing contaminant concentration trends (Section 3.3).

Surveillance monitoring samples were collected during each quarter of CY 1999. Twenty-seven of the monitoring wells were sampled twice (semiannually) during CY 1999 (Table B.2), once during the first quarter of the year (seasonally high groundwater flow) and once during the third quarter of the year (seasonally low groundwater flow). Seven wells associated with the Environmental Management Waste Management Facility, which is currently under construction near the Oil Landfarm, were sampled quarterly during the year (Table B.2). The remaining wells were sampled only once during CY 1999, including each of the wells with the Westbay™ multiport sampling equipment (GW-132, GW-133, GW-134, GW-135, and GW-726), which enables collection of discreet groundwater samples from multiple depth intervals in each well (hereafter referenced as Westbay wells).

As discussed in Section 2.2 of the CY 1999 GWMR, groundwater samples were collected from each of the monitoring wells (except those with Westbay™ equipment) in accordance with the low-flow, minimal drawdown sampling method (hereafter referenced as low-flow sampling). The Westbay wells were sampled in accordance with the operating procedures and manufacturers instructions for the multiport sampling equipment. Low-flow sampling involves collecting the groundwater samples from each well immediately after field measurements of pH, conductivity, temperature, oxidation-reduction potential (REDOX), and dissolved oxygen show stable values (minimal variation over four consecutive readings) in the groundwater purged from the well at a rate low enough (<300 milliliters per minute) to ensure minimal drawdown of the water level in the well (<0.1 ft per 15 minutes). Initiated by the Y-12 Plant GWPP in October 1997, the low-

flow sampling method replaced the previous “conventional” sampling method, which involved purging at least three well volumes of groundwater (if the well did not purge dry) at a much higher pumping rate (1.0 to 1.8 gallons per minute) before collecting samples from each well (hereafter referenced as conventional sampling).

Evaluation of the monitoring data presented in the CY 1999 GWMR for the purposes of DOE Order 5400.1A focused on the primary components of the groundwater contaminant plumes in the Bear Creek Regime (see discussion in Section 2.4) as defined by: (1) nitrate concentrations that exceed the 10 mg/L maximum contaminant level (MCL) for drinking water, (2) total uranium concentrations that exceed the 0.02 mg/L proposed federal MCL (U.S. Environmental Protection Agency 2000), (3) individual VOC concentrations that exceed MCLs or summed VOC concentrations that exceed 5 µg/L, and (4) gross alpha radioactivity above the MCL (15 pCi/L) and/or gross beta radioactivity above the Safe Drinking Water Act (SDWA) screening level (50 pCi/L) for a 4 millirem per year dose equivalent (the MCL for gross beta). Each evaluation is based on historical and CY 1999 results that meet the applicable data quality objectives (DQO) defined in *Y-12 Plant Groundwater Protection Program Data Management Plan* (Science Applications International Corporation 2000). Detailed descriptions of the DQO criteria and associated data screening process, along with summaries of the CY 1999 data that do not meet applicable DQOs, are provided in Section 2.6 of the CY 1999 GWMR.

### **3.1 SURVEILLANCE MONITORING**

The CY 1999 monitoring results reported for a total of 53 monitoring wells in the Bear Creek Regime were evaluated for the purposes of DOE Order 5400.1A Surveillance Monitoring (Figure 6 and Table B.2). Thirty-two of these wells are completed in the geologic formations comprising the aquitard (Maryville Limestone, Nolichucky Shale, Rogersville Shale, Pumpkin Valley Shale, and Rome Formation), 20 of the wells are completed in the geologic formations comprising the aquifer (Maynardville Limestone and Copper Ridge Dolomite), and Westbay well GW-134 is constructed with sampling ports in both the aquifer and aquitard (Figure 7). The following sections present separate evaluations of the CY 1999 monitoring data for the wells in each hydrogeologic unit.

#### **3.1.1 Aquitard Wells**

As shown in the following summary (Table 2), elevated concentrations of one or more of the principal groundwater contaminants in the Bear Creek Regime were reported for 17 of the aquitard wells used for Surveillance Monitoring purposes during CY 1999. These sampling locations include one well located hydraulically downgradient (GW-276) of the S-3 Site; two Westbay wells located east (GW-133) and southeast (GW-134) of the S-3 Site; five wells (GW-085, GW-346, GW-526, GW-537, and GW-829) located along geologic strike between the S-3 Site and the Oil Landfarm WMA; one well located on the southwest side of the Boneyard/Burnyard/HCDA (GW-087); two wells (GW-006 and GW-008) located south of the Oil Landfarm disposal plots; and six wells (GW-046, GW-082, GW-242, GW-627, GW-653, and GW-726) located within the BCBG WMA (Figure 6).

**Table 2. Principal groundwater contaminants detected in aquitard wells used for CY 1999 Surveillance Monitoring**

Well Number	Monitored Interval Depth (ft bgs)	Inorganics		Summed VOCs (>5 µg/L)	Radioactivity	
		Nitrate (>10 mg/L)	Uranium (>0.02 mg/L)		Gross Alpha (>15 pCi/L)	Gross Beta (>50 pCi/L)
GW-006	15.3 - 46.8	.	.	°	.	.
GW-008	13.0 - 25.5	.	.	°	.	.
GW-046	5.0 - 20.3	.	.	°	.	.
GW-082	29.4 - 34.4	.	.	°	.	.
GW-085	48.4 - 58.8	°	.	°	.	°
GW-087	7.5 - 19.0	.	°	°	°	°
<b>GW-133</b>	55.0 - 599.0	°	.	°	°	°
<b>GW-134</b>	171.0 - 740.0	°	.	°	.	.
GW-242	9.0 - 17.0	.	°	°	°	°
GW-276	11.3 - 18.5	°	°	°	°	°
GW-346	51.5 - 64.9	°	.	.	.	.
GW-526	101.0 - 123.0	°	.	.	.	°
GW-537	4.8 - 23.3	°	.	°	.	°
GW-627	254.0 - 270.0	.	.	°	.	.
GW-653	26.3 - 39.0	.	°	°	.	.
<b>GW-726</b>	39.9 - 600.0	.	°	.	.	°
GW-829	102.9 - 114.6	°	.	.	.	°

**Note:** BOLD = Westbay well

The groundwater at these wells reflect migration of contaminants from the former S-3 Ponds (GW-085, GW-134, GW-276, GW-346, GW-526, GW-537, and GW-829); the Oil Landfarm (GW-006 and GW-008); the Boneyard/Burnyard/HCD A (GW-087); and the BCBG WMA (GW-046, GW-082, GW-627, and GW-653). Note that contaminants detected in samples from Westbay wells GW-133 and GW-726 potentially represent analytical artifacts or ambient concentrations at depths greater than 400 ft bgs (petroleum hydrocarbons at GW-133-08 and uranium at GW-726-04).

### 3.1.1.1 Inorganics

Elevated nitrate levels (>10 mg/L) and/or total uranium concentrations (>0.02 mg/L) were reported for at least one groundwater sample collected during CY 1999 from seven of the aquitard monitoring wells: GW-085, GW-134 (sampling ports 5, 11, 15, 18, 21, and 33), GW-276, GW-346, GW-526, GW-537, and GW-829. As shown in the following summary (Table 3), the CY 1999 nitrate results for these wells show that nitrate levels in the aquitard near the S-3 Site: (1) have decreased below 100 mg/L in the water table interval to the south (down-dip) of the site (GW-276) but exceed 3,000 mg/L along dip-parallel flowpaths more than 500 ft bgs (GW-134); (2) remain above 1,000 mg/L in the shallow (GW-346) and deeper (GW-526) bedrock intervals in the Nolichucky Shale along strike-parallel flowpaths more than 1,000 ft west of the site; (3) exceed 500 mg/L in the water table interval (GW-537) in the Nolichucky Shale west of NT-2; and (4) exceed 100 mg/L in the shallow bedrock interval (GW-085) in the Nolichucky Shale near the westernmost boundary of the nitrate plume.

**Table 3. Elevated nitrate and uranium concentrations in aquitard wells used for Surveillance Monitoring during 1999**

Well Location / Number	Distance and Direction from S-3 Site (Figure 6)	Nitrate (mg/L)		Uranium (mg/L)	
		1st Qtr. 1999	3rd Qtr. 1999	1st Qtr. 1999	3rd Qtr. 1999
S-3 Site GW-276	200 ft South	<b>86.3</b>	<b>68</b>	<b>0.706</b>	<b>0.98563</b>
Spoil Area I GW-134-21 GW-134-18 GW-134-15 GW-134-11 GW-134-05	350 ft South	NS	<b>818.2</b>	NS	0.00235
		NS	<b>2,333</b>	NS	0.00284
		NS	<b>3,987</b>	NS	0.0018
		NS	<b>237.4</b>	NS	0.00157
		NS	<b>1173</b>	NS	0.00154
S-3 Site GW-346 GW-526	1,300 ft West	<b>1,005</b>	NS	0.0039	NS
		<b>1,180</b>	NS	ND	NS
Oil Landfarm WMA GW-829 GW-537 GW-085	1,800 ft West	<b>3.17</b>	<b>23.97</b>	0.00124	0.00115
	2,500 ft West	<b>579</b>	<b>897.2</b>	0.00142	0.00127
	3,000 ft West	<b>103</b>	<b>133.9</b>	ND	ND
Boneyard/Burnyard GW-087	3,800 ft West	ND	NS	<b>0.0806</b>	NS

**Notes:** NS =Not sampled; ND = Not detected; **BOLD** = Exceeds current MCL for nitrate (10 mg/L) or the proposed MCL for uranium (0.02 mg/L).

The widespread occurrence of elevated nitrate levels reflect the high mobility of nitrate in the groundwater. Conversely, uranium is much less mobile than nitrate and the elevated concentrations of uranium are typically evident only close to the source areas, including the Boneyard/Burnyard (GW-087) and the S-3 Site (GW-276). In either case, the nitrate and total uranium results for the aquitard monitoring wells used for Surveillance Monitoring purposes during CY 1999 do not indicate any significant change in the extent or distribution of these contaminants.

Historical data show that well GW-276 yields moderately contaminated, calcium-magnesium-bicarbonate groundwater from the water table interval in the Nolichucky Shale about 200 ft directly south (across geologic strike) of the S-3 Site (Figure 6). Although the CY 1999 monitoring data show that nitrate levels in the well remain above 50 mg/L, these results reflect the decreasing long-term concentration trend (Figure 8) resulting from a combination of substantially reduced nitrate flux (and other contaminants) following closure of the S-3 Site and flushing of contaminated shallow groundwater during subsequent seasonal and episodic recharge/discharge cycles (Shevenell 1994). Moreover, the nitrate results obtained from low-flow sampling during CY 1998 and CY 1999 are consistent with previous conventional sampling data indicating that rate of concentration decrease has slowed since the mid-1990s, as illustrated by the nitrate results obtained in March 1988 (1,217 mg/L), March 1994 (147 mg/L), and March 1999 (86.3 mg/L). This suggests that the most highly contaminated groundwater in the more permeable flowpaths has been flushed from the shallow groundwater system in the aquitard near the S-3 Site.

As shown in Table 3, the CY 1999 monitoring results show that total uranium concentrations in well GW-276 remain substantially above the proposed MCL. Additionally, these uranium results, along with the initial low-flow sampling results obtained during CY 1998, indicate a moderately increasing short-term concentration trend from 0.63 mg/L in January 1998 to 0.9856 mg/L in July 1999. This potentially indicates increased flux of uranium (and uranium isotopes) in the shallow groundwater south of the S-3 Site. Similar short-term concentration increases also are indicated by the historical (conventional sampling) uranium data

for the well. For example, total uranium concentrations increased between March 1994 (1.16 mg/L) and July 1995 (2 mg/L), then subsequently decreased through January 1997 (0.78 mg/L).

Westbay well GW-134 is a former corehole located about 350 ft south-southeast (across geologic strike) of the S-3 Site (Figure 6). Groundwater samples were collected from a total of ten sampling ports in the well (Figure 7), seven of which yield groundwater from the aquitard (Nolichucky Shale and Maryville Limestone) at depths ranging from 171 ft bgs (sampling port 29) to 740 ft bgs (sampling port 5). Analytical results for these sampling ports show very high nitrate levels down-dip of the former S-3 Ponds, with concentrations above 1,000 mg/L evident at depths of 426 ft bgs (sampling port 18), 486 ft bgs (sampling port 15), and 740 ft bgs (sampling port 5). As shown in Table 4, these nitrate levels are substantially lower than the concentrations evident in when the sampling ports in this well were first sampled in January 1991 (Dreier *et. al.* 1993).

**Table 4. Nitrate results for selected sampling ports in well GW-134, January 1991 and September 1999**

Sampling Port No.	Depth (ft bgs)	Hydraulic Head (ft msl)	Nitrate (as N) (mg/L)		% Decrease
			January 1991	September 1999	
29	171	992.6	76	ND	100%
25	286	995.75	616	0.5	99%
21	371	1002.5	NS	818	.
18	426	1006.3	5,520	2,333	58%
15	486	1008.3	NS	3,987	.
11	578	1000.1	1,780	237	87%
05	740	987.47	NS	1,173	.

**Notes:** ND = Not detected; NS = Not sampled; Hydraulic head calculated from pressure measurements.

Very high nitrate concentrations occur at depth in the aquitard near the former S-3 Ponds because the higher hydraulic head maintained by operational waste water levels in the ponds, combined with the higher relative density of the waste water compared to ambient groundwater, created a strong driving force for downward (dip-parallel) migration of the waste constituents (DOE 1997). The volume of wastewater from the ponds in the groundwater system locally elevated the fluid pressure and the highest nitrate concentrations occur near the crest of the pressure bulge in the Nolichucky Shale as illustrated by hydraulic heads determined from pressure readings obtained from selected sampling ports in July 1991 (Table 4). It is possible that the highly contaminated zones may have been a source of nitrate contamination for other zones during the five-year period that the corehole stood open. The significant decrease in nitrate concentrations suggests that the source of nitrate emplaced during operation of the S-3 Ponds is being depleted.

Monitoring wells GW-345, GW-346, and GW-526 comprise a well cluster in the Nolichucky Shale next to NT-1 about 1,300 ft west (along geologic strike) of the S-3 Site (Figure 6). These wells intercept the contaminant plume from the S-3 Site with the historical monitoring results for each well reflecting contaminant concentrations in the water table (GW-345), shallow bedrock (GW-346), and deep bedrock (GW-526) intervals in the Nolichucky Shale (DOE 1997). As shown in the following data summary (Table 5), the CY 1999 data indicate that nitrate concentrations in the water table interval (GW-345) have decreased substantially since the late 1980s and are now less than 1 mg/L, whereas nitrate concentrations in the shallow and deep bedrock intervals (GW-346 and GW-526) exhibit relatively stable trends that have generally remained near 1,000 mg/L.

**Table 5. CY 1999 and selected historical nitrate data for wells GW-345, GW-346, and GW-526**

Well Number	Feb. 1989	Jan. 1990	Jan. 1991	March 1992	Feb. 1993	Feb. 1994	Feb. 1998	March 1999
GW-345	2,300	186	139	NS	7.7	1.9	NS	0.48
GW-346	1,000	811	NS	NS	NS	NS	NS	1,005
GW-526	574	732	1,390	928	826	NS	1,210	1,180

**Note:** NS = Not sampled

Low nitrate levels in the groundwater at well GW-345 indicates that the bulk of the contaminated groundwater has been flushed from the water table interval, and the very high nitrate levels in wells GW-346 and GW-526 reflect the extensive strike-parallel transport in the shallow and deep bedrock intervals in the Nolichucky Shale (DOE 1997). Additionally, the relatively stable nitrate concentration trends evident in wells GW-346 and GW-526 suggest that the nitrate from the deeper flow system does not extensively discharge upward into NT-1. This interpretation is supported by the vertical hydraulic gradients, shown in Table 6, which are typically upward from the deeper bedrock interval (GW-526) to the shallow bedrock interval (GW-346) and downward from the water table interval (GW-345) to the shallow bedrock interval.

**Table 6. Vertical hydraulic gradients in the aquitard at wells GW-345, GW-346, and GW-526**

Well Number	Monitored Interval Center-Point Elevation (ft above msl)	Water Level Elevation (ft above msl)		Upward (+)/Downward(-) Vertical Hydraulic Gradient	
		Jan. 1995	Mar. 1999	Jan.1995	Mar. 1999
GW-345	974.2	982.2	982.85	.	.
GW-346	936.9	978.5	981.86	- 0.10	- 0.03
GW-526	883.3	985.6	985.15	+ 0.13	+ 0.06

Historical data show that well GW-829 yields moderately contaminated sodium-bicarbonate groundwater from the shallow bedrock interval in the Nolichucky Shale about 500 ft west (along geologic strike) of the GW-345/GW-346/GW-526 well cluster (Figure 6). Monitoring results obtained during CY 1999 generally confirm the initial low-flow sampling results obtained during CY 1998, and show that nitrate levels in the well remain above the drinking water MCL (10 mg/L). However, these low-flow sampling results, including the anomalously low nitrate level reported for the sample collected from the well in March 1999 (3.17 mg/L), are at least 15% lower than nitrate levels previously evident in the well. Although historical conventional sampling results show a generally decreasing nitrate concentration trend (Figure 8), the recent concentration decrease indicated by the low-flow sampling results obtained since CY 1998 may be due to the change to the low-flow sampling method. Higher nitrate levels in samples collected using the conventional sampling method may be evident because the hydrologic response to purging the well may increase the flux of nitrate (and other contaminants) into the well and consequently “inflate” the nitrate concentrations compared to those obtained from low-flow sampling. In either case, the elevated nitrate levels in the groundwater at well GW-829 reflect strike-parallel migration of the nitrate plume in the shallow bedrock interval west of NT-1 (DOE 1997).

Data obtained during CY 1999 show that nitrate concentrations exceed 500 mg/L in the groundwater at well GW-537, which is completed in the water table interval (23 ft bgs) in the Nolichucky Shale about 700 ft west

(along geologic strike) of well GW-829 (Figure 6). High nitrate levels in the shallow groundwater at this well are believed to be maintained primarily via upward inflow of nitrate from the deeper flow system because, as noted in the previous discussion of monitoring results for wells GW-345 and GW-276, seasonal and episodic recharge/discharge cycles have flushed the most highly contaminated groundwater from the shallow flow system in the aquitard. Assuming that the center of mass of the nitrate plume in the aquitard is slowly migrating westward (along strike), upwelling of nitrate from the deeper bedrock should produce relatively stable or increasing long-term concentration trends in the shallow groundwater near well GW-537 (DOE 1997). Excluding the conspicuously low nitrate concentration in September 1994 (81 mg/L), historical (conventional sampling) data obtained since January 1990 show variable but relatively stable long-term nitrate levels (Figure 8).

Elevated nitrate concentrations in the calcium-magnesium-bicarbonate groundwater at well GW-085, which is completed at a depth of 55.2 ft bgs in the Nolichucky Shale about 500 ft west of well GW-537 (Figure 6), reflect strike parallel migration of the nitrate plume in the shallow bedrock west of NT-2 and indicate that the leading edge of the nitrate plume lies west of the well toward NT-3 (DOE 1997). As shown on Figure 9, historical (conventional sampling) data show that nitrate levels in well GW-085 generally increased between May 1991 (115 mg/L) and October 1993 (312.6 mg/L), subsequently decreased through March 1998 to the lowest level ever reported for the well (43 mg/L), and then appear to rebound above 100 mg/L in March 1999 (103 mg/L) and August 1999 (133.9 mg/L). This long-term nitrate concentration trend suggests westward, strike parallel migration of a “pulse” of nitrate in the shallow flow system in the aquitard west of the S-3 Site (Figure 9).

The Boneyard/Burnyard/HCDA is believed to be a primary source of elemental uranium in the aquifer to the south and west of the Oil Landfarm WMA (see Section 2.4.2). Uranium leached from the source(s) at this site, which may lie within the saturated zone during seasonally high flow conditions, recharges directly into the Maynardville Limestone or migrates westward (along geologic strike) in the aquitard toward NT-3 and enters the aquifer along the major losing reach of the Bear Creek south of the Sanitary Landfill I (DOE 1997). This migration pattern is consistent with the elevated uranium concentrations reported for the unfiltered (0.0806 mg/L) and filtered (0.104 mg/L) samples collected from aquitard well GW-087 in March 1999 (seasonally high flow conditions). This well, completed in the Nolichucky Shale near the contact with the Maynardville Limestone, is located on the southwest (hydraulically downgradient) side of the Boneyard/Burnyard/HCDA (Figure 6). Compared with historical data for the well, the uranium results obtained in March 1999 reflect a substantial decrease from uranium levels evident in the late 1980s (e.g., 0.552 mg/L in September 1987) and are similar to the results obtained during September 1997 (0.064 mg/L) and July 1998 (0.143 mg/L). Decreased concentrations of uranium in the shallow groundwater at this well probably reflect reduced flux of uranium after the Boneyard/Burnyard/HCDA was capped during closure of the Oil Landfarm.

### **3.1.1.2 Volatile Organic Compounds**

Excluding false-positive results, one or more chloroethenes (PCE, TCE, c12DCE, t12DCE, 11DCE, and VC), chloroethanes (111TCA, 12DCA, 11DCA, and chloroethane), chloromethanes (carbon tetrachloride, chloroform, and methylene chloride), petroleum hydrocarbons (benzene, toluene, ethylbenzene, and dimethylbenzene), or miscellaneous compounds (acetone, acrylonitrile, 2-butanone, carbon disulfide, dibromodichloromethane, 1,2-dichloropropane, 4-methyl-2-pentanone, and styrene) were detected in at least one groundwater sample collected during CY 1999 from the aquitard wells used for Surveillance Monitoring. Maximum summed VOC concentrations exceeded 5 µg/L in samples from 10 wells and range from 10 to 100 µg/L in wells GW-006, GW-008, GW-133-08, GW-276, and GW-653; exceed 100 µg/L in wells

GW-082, GW-087, GW-242, and GW-627; and exceed 10,000 µg/L in well GW-046. As shown in Table 7, maximum concentrations of PCE, TCE, cis-1,2-DCE, 1,1-DCE, VC, and benzene exceed respective MCLs for drinking water.

**Table 7. CY 1999 maximum VOC concentrations in aquitard wells that exceed MCLs**

Well Number	Concentration (µg/L)					
	PCE	TCE	c12DCE	11DCE	VC	Benzene
GW-008	10	(3)	17	(4)	.	(1)
GW-046	<b>3000 D</b>	<b>2100 D</b>	<b>4400 D</b>	<b>100 D</b>	<b>630 D</b>	<b>(42) D</b>
GW-082	.	.	<b>380 D</b>	<b>8</b>	<b>150</b>	<b>6</b>
GW-087	<b>31</b>	<b>43</b>	55	.	.	.
GW-242	.	(3)	<b>82</b>	.	<b>45</b>	.
GW-276	<b>14</b>	.	.	.	.	.
GW-627	<b>470 D</b>	<b>150</b>	8	<b>15</b>	<b>12</b>	.
MCL (µg/L)	5	5	70	7	2	5
<b>Notes:</b> ( ) = Estimated concentration below the reporting limit; D = diluted analysis; “.” = Not detected; Bold = Exceeds MCL						

Additionally, the VOC results for these monitoring wells do not indicate any significant changes in the extent or distribution of dissolved VOCs in the aquitard (Figure 5).

Historical data for several wells in the aquitard adjacent to the S-3 Site show dissolved PCE concentrations above 5,000 µg/L in the shallow groundwater and indicate the presence of DNAPL in the subsurface (DOE 1997). However, the PCE results for the samples collected in February (11 µg/L) and July (14 µg/L) 1999 from well GW-276, which is only 200 ft south of the S-3 Site (Figure 6), illustrate the substantial attenuation of VOCs in the aquitard. Both results exceed the MCL for PCE (5 µg/L) but are an order-of-magnitude lower than the levels reported for samples collected from the well in the late 1980s (e.g., 230 µg/L in March 1988). Additional evidence of the substantial attenuation of VOCs in the aquitard is shown by the absence of PCE (and other VOCs) in the samples from Westbay well GW-134 (directly downdip from the S-3 Site) and wells GW-346 and GW-526 (along strike from the S-3 Site), which have very high (> 1,000 mg/L) nitrate concentrations (see Section 3.1.1.1).

The CY 1999 monitoring results for well GW-008 are consistent with the initial low-flow sampling results obtained during CY 1998 (the well had not been previously sampled since the mid-1980s) and show that this well monitors the plume of dissolved chloroethenes (PCE, TCE, c12DCE, and 11DCE) in the shallow groundwater southwest of the Oil Landfarm (see discussion in Section 2.4.2). As shown in the preceding data summary (Table 7), PCE concentrations in the well remain above the drinking water MCL, although the maximum summed VOC concentrations evident during CY 1998 (56 µg/L) and CY 1999 (49 µg/L) are an order of magnitude lower than evident during the mid-1980s (>500 µg/L). Decreased concentrations of dissolved VOCs in the shallow groundwater at well GW-008 are probably the result of several factors, including closure of the Oil Landfarm, installation of the low permeability cap over this site, and natural attenuation in the aquitard. Seasonal and episodic recharge/discharge cycles also probably flush residual contamination from the shallow flow system. The unusually low TDS (57- 82 mg/L) reported for the groundwater samples collected from the well during CYs 1998 and 1999, which suggests short residence time and implies active groundwater recharge and discharge flowpaths, supports this interpretation.

As noted in Section 2.4.2, the HCDA is the suspected source of the dissolved VOC plume in the shallow groundwater near NT-3; this site is the most likely source of the dissolved chloroethenes detected in well GW-087. Similar to results for total uranium (see Section 3.1.1.1), the March 1999 VOC results for well GW-087 show a substantial decrease from the late 1980s and likewise probably reflect reduced flux of contaminants from the Boneyard/Burnyard/HCDA after this site was capped during the closure of the Oil Landfarm. For example, PCE concentrations exceeded 1,000 µg/L in 1987, have been less than 500 µg/L since 1988 and less than 100 µg/L since 1997. The overall decrease in VOC concentrations since 1990 is shown by the selected results shown below in Table 8.

**Table 8. CY 1999 and selected historical VOC data for well GW-087**

VOC	VOC Concentration (µg/L)				
	March 1990	Sept. 1995	Sept. 1997	July 1998	March 1999
PCE	240	220	100	61	31
TCE	330	410	180	140	43
Total 12DCE	98	120	470	350	55
Chloroform	26	18	9	6	.
Benzene	33	5	14	11	.
<b>Summed VOCs:</b>	<b>727</b>	<b>773</b>	<b>773</b>	<b>568</b>	<b>129</b>

**Note:** “.” = Not Detected; total 1,2-dichloroethene (12DCE) = c12DCE + t12DCE

The increasing 12DCE concentrations evident from 1990 through 1997 compared to the decreasing PCE concentrations suggests partial degradation of PCE. The March 1999 results show that c12DCE (55 µg/L) has the highest concentration of the chloroethenes, and that the concentration of all VOCs decreased from CY 1998.

Historical data show that wells GW-082 and GW-242, which are located in the NT-8 catchment near the northern portion of the BCBG WMA (Figure 6), yield calcium-magnesium-bicarbonate groundwater containing a suite of dissolved VOCs dominated by the degradation daughter products of PCE (12DCE and VC). Numerous areas within BG-C and BG-D are believed to be the source of the VOCs in these wells (DOE 1997) and the wells intercept separate, relatively small VOC plumes on the west (GW-082) and east (GW-242) sides of the WMA (Figure 5). As shown in the following data summary (Table 9), respective results reported for the groundwater samples collected from these wells in March 1999 show an increasing long-term trend in VOC concentrations in well GW-082 (see Section 3.3), but relatively stable VOC levels in well GW-242.

**Table 9. CY 1999 and selected historical VOC results for wells GW-082 and GW-242**

VOC	Concentration (µg/L)							
	GW-082					GW-242		
	Mar. 1991	Mar. 1992	Mar. 1993	April 1997	Mar. 1999	Apr. 1988	Feb. 1990	Mar. 1999
PCE	.	.	.	.	.	8	.	.
TCE	.	.	.	.	.	(3)	5	(3)
12DCE	72	19	42	200	380	NA	130	82
VC	.	13	30	53	150	39	27	45
11DCE	.	.	.	.	8	.	.	.
11DCA	.	.	.	(3)	410	.	.	.
Chloroethane	.	.	.	(7)	12	.	.	.
Benzene	.	.	.	.	6	.	.	.

**Note:** ( ) = Estimated value below the analytical reporting limit; “. ” = Not detected; NA = Not analyzed

The absence or low levels of PCE and TCE in these wells combined with the high concentrations of 12DCE isomers and VC potentially indicate reductive dechlorination of PCE. Under anaerobic conditions, reductive dechlorination of PCE occurs according to the following sequence (Hinchee *et al.* 1995):



Several factors influence this process, including the availability of electron donors (e.g., hydrogen), and the efficiency of the process differs under methanogenic, sulfate-reducing, iron-reducing, and nitrate-reducing conditions (Chapelle 1996). Also, as indicated by the preceding chemical equation, inorganic chloride accumulates throughout this process, which may account for the very high chloride levels evident in well GW-082 (147 mg/L in March 1999) and the comparatively lower but nevertheless elevated chloride level in well GW-242 (11.3 mg/L in March 1999).

Monitoring results obtained during CY 1999 show that well GW-046, which is completed at a depth of 20 ft bgs in the Nolichucky Shale at the southwest corner of BG-A South, contains a diverse mixture of dissolved chloroethenes, chloroethanes, chloromethanes, and petroleum hydrocarbons, with extremely high concentrations (i.e., >1,000 µg/L) of several compounds (e.g., PCE) possibly indicating the presence of DNAPL in the subsurface. Additionally, the summed concentration of VOCs detected in the sample collected from the well in July 1999 (10,137 µg/L) is substantially higher compared to the sample collected from the well in February 1999 (7,998 µg/L), which suggests seasonally variable dilution from uncontaminated recharge. Also, the seasonal concentration fluctuations are less clearly evident for the dissolved chloroethanes (primarily 111TCA and 11DCA) in the well. Assuming that the well monitors a commingled plume of chloroethenes and chloroethanes, it is unclear why the chloroethenes exhibit wide seasonal concentrations fluctuations and the chloroethanes do not. Perhaps these compounds migrate along different flowpaths in the aquitard, with dilution via seasonal recharge more prevalent in the flowpaths dominated by chloroethenes. Alternatively, the concentration of dissolved chloroethenes and chloroethanes may reflect seasonal changes in the biotic and/or abiotic degradation of these compounds. Natural biodegradation of PCE and/or abiotic degradation of 111TCA is strongly indicated by the proportionally high concentrations of respective intermediate degradation compounds (c12DCE and 11DCA), the presence

of respective biodegradation end products (VC and chloroethane), and the unusually high levels of chloride (>20 mg/L) in the groundwater at the well. Furthermore, the atypically low pH of the groundwater samples collected from the well during CY 1999 (field measurements = 4.39 and 5.08) and CY 1998 (field measurements = 5.12 and 5.01) may reflect abiotic degradation of 111TCA, whereby nearly 80% of the 111TCA is chemically transformed to acetic acid (McCarty 1996).

The CY 1999 VOC results for aquitard well GW-627, which is completed at a depth of 270 ft bgs in the Nolichucky Shale about 500 ft west of well GW-046 (Figure 6), are consistent with historical data and show that this well yields groundwater samples containing a mixture of dissolved chloroethenes (PCE, TCE, 11DCE, c12DCE, trans-1,2-DCE, and VC) and chloroethanes (11DCA and chloroethane). The monitoring results also reflect the steadily increasing PCE and TCE concentration trends evident since February 1990 (see Section 3.3). The detection of these VOCs in well GW-627 generally coincides with the January 1990 discovery of PCE and TCE DNAPL in the Nolichucky Shale 260 to 330 ft down dip of BG-A South (Haase and King 1990). The subsequent increasing concentration trend in well GW-627 clearly indicates migration of VOCs at depth in the aquitard, although fate and transport modeling suggest it will take as long as 600 years for the PCE to migrate as far west as NT-8 (DOE 1997).

Groundwater samples collected during CY 1999 from well GW-653, which is completed at a depth of 39 ft bgs in the Nolichucky Shale about 1,000 ft west (along geologic strike) of BG-A South (Figure 6), contained relatively low concentrations (2 - 32 µg/L) of PCE, TCE, c12DCE, and 11DCA, with higher summed VOC concentrations evident during March 1999 (41 µg/L) than in August 1999 (24 µg/L). These results are consistent with historical (conventional and low-flow sampling) data, which also show seasonal concentration fluctuations, with higher summed VOC concentrations evident during seasonally high flow conditions (winter and spring) and lower concentrations evident during seasonally low flow conditions (summer and fall). Although dominated by these seasonal fluctuations, the CY 1999 and historical VOC data for well GW-653 indicate an increasing long-term concentration trend (see Section 3.3).

### **3.1.1.3 Radioactivity**

Gross alpha and/or gross beta results reported for the bulk of the aquitard monitoring wells used for Surveillance Monitoring during CY 1999 do not exceed the associated minimum detectable activity (MDA). Results that exceed the MDA and the corresponding counting error (CE), which is a value that expresses the degree of analytical uncertainty, were reported only for the groundwater samples collected from 11 aquitard wells during CY 1999: GW-008, GW-046, GW-085, GW-087, GW-132, GW-133, GW-135, GW-242, GW-276, GW-537, and GW-829. Most of these gross alpha and gross beta results, however, just slightly exceed the associated MDA and are characterized by substantial analytical uncertainty (i.e., CE >50% of the gross alpha/gross beta value). As shown in the following data summary (Table 10), gross alpha activity above the 15 pCi/L MCL or gross beta activity above the 50 pCi/L SDWA screening level were reported only for the groundwater samples collected from six of these wells: GW-085, GW-087, GW-133 (sampling port 24), GW-276, GW-537, and GW-829.

**Table 10. Elevated gross alpha and gross beta results for aquitard wells used for CY 1999 Surveillance Monitoring**

Well	Date Sampled	Gross Alpha (pCi/L)		Gross Beta (pCi/L)	
		MDA	Activity ± CE	MDA	Activity ± CE
GW-085	03/17/99	3.2	<MDA	8.7	48 ± 8
	08/31/99	4	<MDA	9	<b>93</b> ± 10
GW-087	03/11/99	5.6	<b>36</b> ± 8.3	7.9	38 ± 7.4
GW-133-24	08/19/99	9.7	<b>270</b> ± 30	17	<b>56</b> ± 14
GW-276	02/04/99	3.73	<b>354.5</b> ± 15.16	2.35	<b>806.1</b> ± 9.79
	07/16/99	3.62	<b>514.9</b> ± 15.13	2.66	<b>473.9</b> ± 7.29
GW-537	03/18/99	1.3	4.3 ± 2.9	8.9	<MDA
	08/31/99	17	<MDA	15	<b>420</b> ± 28
GW-829	03/17/99	53	<MDA	86	<b>580</b> ± 86
	08/30/99	6	<MDA	7.2	<MDA

**Note:** BOLD = Exceeds MCL (gross alpha) or SDWA screening level (gross beta)

Elevated gross alpha and gross beta activity in the groundwater at these wells reflect the relatively limited extent of radiological contamination in the aquitard, which occurs primarily near the S-3 Site (GW-085, GW-537, and GW-276) and the Boneyard/Burnyard/HCDA (GW-087). However, the elevated gross alpha and gross beta results reported for Westbay well GW-133, which is a former corehole located only 100 ft east of the S-3 Site (Figure 6), are potentially analytical artifacts considering the lack of nitrate (<0.28 mg/L) in the well (nitrate is far more mobile than any of the alpha- and beta-emitting radionuclides in the Nolichucky Shale beneath the former S-3 Ponds). Analytical errors may likewise explain the unusually high gross beta activity reported for the groundwater sample collected from well GW-829 in March 1999 (results for this well have been below the MDA since 1996).

Shallow and deep groundwater at the S-3 Site contains a heterogeneous mixture of several alpha- and beta-emitting radionuclides, including Tc-99, U-234, and U-238. Each of these radionuclides were detected above MDAs in the groundwater samples collected from well GW-276, with the highest concentrations reported for Tc-99 (970 ± 19 pCi/L) and U-238 (240 ± 31 pCi/L). Although Tc-99 is volatilized during gross beta analyses (gross beta activity is typically less than the Tc-99 activity), elevated gross beta results generally correlate with elevated Tc-99 activity near the S-3 Site, and Tc-99 is often the only beta-emitting radionuclide detected in wells near the site. As with other contaminants in the groundwater at this well, historical data show that gross alpha and gross beta radioactivity have decreased substantially since the late 1980s, although gross beta activity has generally decreased at a faster rate. Alpha activity levels are probably maintained by the slow release of alpha-emitting isotopes adsorbed to sludges remaining in the S-3 Ponds and mineral surfaces in the aquitard, whereas more rapidly decreasing beta activity reflects the greater flushing of Tc-99 from the shallow flow system, which is more mobile and less readily adsorbed in the subsurface (DOE 1997).

The CY 1999 gross alpha and gross beta results for groundwater samples from wells GW-085 and GW-537 are generally consistent with respective historical data and clearly illustrate the differential retardation of radionuclides in the aquitard. The low gross alpha in the groundwater at each well reflects substantial attenuation of uranium isotopes (and other alpha-emitting radionuclides) in the aquitard west of the S-3 Site. The U-234 and U-238 activities reported for samples collected from these two wells in CY 1995 were either less than the associated MDAs or had proportionally high counting errors. In contrast, the much higher gross

beta in the shallow groundwater at each well reflects lesser retardation of Tc-99 and substantially greater strike-parallel transport from the S-3 Site. Respective Tc-99 activities above 100 and 1,000 pCi/L were reported for samples collected from wells GW-085 and GW-537 in CY 1995. Well GW-537 is completed in the water table interval about 2,500 ft west of the S-3 Site (near NT-2) and well GW-085 is completed in the shallow bedrock interval about 500 ft west of well GW-537 (Figure 6). Historical gross beta results for these wells show significant temporal fluctuations (some of which probably reflect analytical variability) but generally upward long-term trend for well GW-537 (see Section 3.3). Slow, westward migration of the center of mass of the S-3 Site contaminant plume in the bedrock interval and upwelling at NT-2 may explain the increasing gross beta activity in the shallow groundwater well GW-537. Historical (conventional and low-flow sampling) results show that gross beta activity (and nitrate concentrations) in well GW-085 generally increased between June 1991 and January 1994, generally decreased through March 1997, and appear to have slightly increased through August 1999 (Figure 9). These long term trends for well GW-085 potentially reflect westward, strike parallel migration of a “pulse” of nitrate and Tc-99 in the shallow bedrock interval of the aquitard west of NT-2.

Transport of uranium isotopes leached from the source(s) at the Boneyard/Burnyard/HCDA probably explains the radioactivity in the shallow groundwater at well GW-087 (DOE 1997). As noted in Section 3.1.1.1, the source(s) of elemental and isotopic uranium this site may lie within the saturated zone during seasonally high flow conditions and, consequently, uranium may recharge directly into the Maynardville Limestone or migrate westward (along geologic strike) in the aquitard toward well GW-087. Compared with historical data for the well, the gross alpha and gross beta results obtained in March 1999 (Table 10) reflect a decrease from respective levels evident in the well during late 1980s (>100 pCi/L) and are generally consistent with results for 1997 and 1998. Decreased levels of gross alpha and gross beta radioactivity in the shallow groundwater at this well probably reflect reduced flux of uranium isotopes after the Boneyard/Burnyard/HCDA was capped during closure of the Oil Landfarm.

### **3.1.2 Aquifer Wells**

Elevated concentrations of one or more of the principal groundwater contaminants in the Bear Creek Regime were reported for 19 of the aquifer (Maynardville Limestone or Knox Group) wells used for Surveillance Monitoring purposes. As shown in the following summary (Table 11), these wells include ten of the wells that comprise three Exit Pathway Pickets in the Bear Creek Regime: Picket A (GW-683 and GW-684), Picket B (GW-695, GW-703, GW-704, and GW-706), and Picket C (GW-724, GW-725, GW-738, and GW-740); wells in each Exit Pathway Picket are completed at various depths within different hydrostratigraphic zones along a strike-normal transect across the Maynardville Limestone and lower Knox Group.

**Table 11. Principal groundwater contaminants detected in aquifer wells used for  
CY 1999 Surveillance Monitoring**

<b>Well Number</b>	<b>Monitored Interval Depth (ft bgs)</b>	<b>Nitrate (&gt;10 mg/L)</b>	<b>Uranium (&gt;0.02 mg/L)</b>	<b>Summed VOCs (&gt;5µg/L)</b>	<b>Radioactivity (Alpha&gt;15 pCi/L/ Beta&gt;50 pCi/L)</b>
GW-053	11.4 - 32.8	.	.	°	.
<b>GW-134</b>	41.0 - 106.0	°	.	°	°
<b>GW-135</b>	214.0 - 1,206.0	.	.	°	.
GW-226	45.0 - 55.0	°	.	°	.
GW-228	80.0 - 100.0	.	.	°	°
GW-236	10.0 - 18.5	°	.	°	°
GW-311	25.6 - 40.3	.	.	°	.
GW-315	90.0 - 104.0	°	.	°	.
GW-601	318.5 - 356.0	°	°	°	°
GW-683	133.9 - 196.8	.	.	.	°
GW-684	106.4 - 128.4	°	°	°	.
GW-695	50.6 - 62.6	°	.	°	.
GW-703	135.0 - 182.0	.	.	°	.
GW-704	246.0 - 256.0	°	°	°	°
GW-706	157.0 - 182.5	°	.	°	.
GW-724	289.6 - 301.6	°	.	°	.
GW-725	132.5 - 142.5	°	.	°	.
GW-738	63.5 - 88.0	°	.	°	.
GW-740	165.6 - 190.0	.	.	°	.

**Note:** BOLD = Westbay well

The contaminants detected in these monitoring wells originate from the S-3 Site (nitrate, uranium, and radioactivity), the Boneyard/Burnyard/HCDA (uranium, VOCs, and radioactivity), Sanitary Landfill I (VOCs), the BCBG WMA (VOCs and radioactivity), the Rust Spoil Area (VOCs), or an unidentified (VOC) source area in the Bear Creek floodplain adjacent to the Rust Spoil Area (DOE 1997).

### 3.1.2.1 Inorganics

Elevated nitrate levels (>10 mg/L) and/or total uranium concentrations (>0.02 mg/L) were reported for at least one groundwater sample collected during CY 1999 from 11 of the monitoring wells in the aquifer: GW-134 (sampling ports 33, 35, and 36), GW-226, GW-236, GW-601, GW-683, GW-684, GW-695, GW-704, GW-706, GW-724, GW-725, and GW-738. As illustrated in the following summary (Table 12), the CY 1999 results for these monitoring wells show that: (1) nitrate levels in the aquifer remain above 200 mg/L more than 100 ft bgs in the Maynardville Limestone directly south (across geologic strike) of the S-3 Site (GW-134; sampling ports 33 and 35), and the concentrations steadily decrease with westward (parallel with geologic strike) distance from the S-3 Site, and (2) elevated uranium concentrations in the aquifer occur in wells located downgradient of the Boneyard/Burnyard/HCDA.

**Table 12. Elevated nitrate and uranium concentrations in aquifer wells used for  
CY 1999 Surveillance Monitoring**

Well Location / Number	Distance and Direction from S-3 Site (Figure 6)	Nitrate (mg/L)		Uranium (mg/L)	
		1st Qtr. 1999	3rd Qtr. 1999	1st Qtr. 1999	3rd Qtr. 1999
Spoil Area I GW-134-36 GW-134-35 GW-134-33	350 ft South	NS	<b>72.98</b>	NS	ND
		NS	<b>290.5</b>	NS	ND
		NS	<b>214.5</b>	NS	ND
S-3 Site GW-236	1,800 ft West	NS	<b>47.73</b>	NS	0.00696
Exit Pathway Picket C GW-724 GW-725 GW-738	3,000 ft West	<b>30.6</b>	<b>24.96</b>	0.00056	0.00128
		<b>22.8</b>	<b>22.09</b>	0.0089	0.0078
		<b>19.3</b>	<b>10.31</b>	0.0022	0.00176
Oil Landfarm WMA GW-601 GW-226	4,400 ft West	<b>14</b>	NS	NS	ND
	4,500 ft West	<b>28.6</b>	7.06	0.0136	0.00765
Exit Pathway Picket B GW-695 GW-704 GW-706	7,000 ft West	<b>10.7</b>	9.144	0.0031	0.00323
		<b>14.7</b>	7.197	0.0039	0.00366
		<b>44.6</b>	<b>25.95</b>	<b>0.113</b>	<b>0.0942</b>
Exit Pathway Picket A GW-683 GW-684	10,000 ft West	4.88	1.69	<b>0.0446</b>	<b>0.0247</b>
		4.13	0.988	<b>0.0285</b>	0.0178

**Notes:** ND = Not detected; NS = Not sampled; **BOLD** = Exceeds MCL (proposed for uranium).

Also, the nitrate and total uranium results for these wells do not indicate any significant change in the overall extent or distribution of these contaminants in the aquifer.

As noted in section 3.1.1.1, well GW-134 is a former corehole equipped with Westbay™ multi-port sampling equipment that is located about 350 ft south (across geologic strike) of the S-3 Site (Figure 6). Three of the sampling ports in the well yield groundwater from the aquifer (Figure 7) at depths of 41 ft bgs (sampling port 36), 81 ft bgs (sampling port 35), and 106 ft bgs (sampling port 33). As shown in the preceding data summary, elevated nitrate levels were detected in the groundwater samples from each of these sampling ports, with the highest concentrations (>200 mg/L) evident in the deeper ports. Compared with available historical data, including a nitrate concentration of 1,340 mg/L in a sample collected from port 33 in January 1991 (Dreier *et. al.* 1993), the CY 1999 nitrate results reflect the substantial concentration decrease at shallow depths in the Maynardville Limestone. Nevertheless, these results probably reflect migration of nitrate from the Nolichucky Shale into the Maynardville Limestone directly south of the S-3 Site, possibly facilitated by fractures (or fracture zones) that cut across geologic-strike.

Historical data show that well GW-236, which is completed with a screened interval less than 20 ft bgs, yields (nitrate-enriched) calcium-magnesium-bicarbonate groundwater from the shallow karst network in the Maynardville Limestone near the confluence of NT-1 and Bear Creek (Figure 6). The nitrate result (47.73 mg/L) obtained from low-flow sampling in September 1999 (seasonally low flow) is slightly lower than the conventional sampling nitrate result (65 mg/L) obtained when this well was last sampled (September 1995). Both of these nitrate levels, however, are much lower than the concentrations evident in the well during the late-1980s (e.g., 805 mg/L in May 1989). These results show that nitrate levels in the well have decreased substantially since closure of the former S-3 Ponds, and that the rate of decrease has generally slowed. This suggests that the most highly contaminated groundwater has been flushed from shallow karst network in the aquifer.

Four of the monitoring wells that comprise Exit Pathway Picket C, which is located about 1,300 ft southwest (downgradient) of well GW-236 (Figure 6), were sampled during CY 1999: GW-724, GW-725, GW-738, and GW-740. Analytical results for these samples show that nitrate concentrations remain above the MCL in the groundwater at three of these wells (GW-724, GW-725, and GW-738), with the highest concentrations reported for the groundwater samples from the deepest well (GW-724; monitoring interval 289 - 301 ft bgs). These results also continue the decreasing long-term nitrate concentration trends evident for each of these wells (Figure 10), which probably reflect the long-term effects of reduced contaminant flux and greater attenuation (i.e., dilution) following closure of the S-3 Site (DOE 1997). As shown in Table 13, however, the average nitrate concentrations determined from CY 1998 and CY 1999 low-flow sampling results for wells GW-724 and GW-725 are substantially less than the average nitrate concentration determined from the most recent (CY 1996 and CY 1997) conventional sampling nitrate results for each well.

**Table 13. Comparison of conventional sampling and low-flow sampling results for nitrate in Exit Pathway Picket C wells GW-724 and GW-725**

Well	Nitrate (as N)									
	Conventional Sampling (mg/L)					Low-Flow Sampling (mg/L)				
	1996		1997		Avg.	1998		1999		Avg.
	Mar.	Aug.	Mar.	Sept.		Mar.	Sept.	Feb.	Aug.	
GW-724	38.8	35.1	35.7	36.3	36.5	20.6	7.73	30.6	24.9	20.9
GW-725	67.9	51	76.1	47.5	60.6	24.4	26.15	22.8	22.09	23.8

Therefore, the decreasing nitrate trends indicated by the historical data for these wells may be at least partially attributable to the change from conventional sampling to low-flow sampling.

Well GW-601 is located on the steep northern flank of Chestnut Ridge directly south of the Oil Landfarm WMA (Figure 6) and is a fairly deep well (356 ft bgs) completed with a 40-ft open-hole monitored interval in the upper Maynardville Limestone. The monitored interval in the well is directly down-dip of a losing reach of Bear Creek that plays an important role in the transfer of contaminants from the shallow karst network to the deeper flow system in the Maynardville Limestone, and this downward (dip-parallel) transport of nitrate (and other contaminants) probably explains the elevated nitrate levels in well GW-601 (DOE 1997). The nitrate result (14 mg/L) obtained from low-flow sampling in March 1999 indicates that nitrate levels in the well remain slightly above the MCL, but are about 50% lower than the nitrate concentrations indicated by historical (conventional sampling) results for the well. For example, nitrate concentrations of 30 mg/L or more were reported for each of the groundwater samples collected from the well in March 1992 (30 mg/L), March 1993 (32.1 mg/L), and March 1994 (31.9 mg/L). Based on these data, it is not clear if the nitrate concentrations in the well have decreased slightly as a result of natural attenuation and reduced flux of nitrate following closure of the former S-3 Ponds, or if the reduced nitrate level evident in March 1999 is an artifact of the change to the low-flow sampling procedure.

Nitrate concentrations reported for the groundwater samples collected from well GW-226 during CY 1999 are consistent with the initial low-flow sampling results obtained during CY 1998, and confirm the substantial increase in comparison to the historical (conventional sampling) nitrate data for the well (see Section 3.3). Located south of Sanitary Landfill I in the Oil Landfarm WMA (Figure 6), this well yields (nitrate-enriched) calcium-magnesium-bicarbonate groundwater from a depth of 55 ft bgs in the highly permeable basal portion (Zone 2) of the Maynardville Limestone. Elevated nitrate levels in the groundwater at well GW-226 probably reflect inflow of nitrate (and other mobile groundwater contaminants) into the

Maynardville Limestone along the losing reach of Bear Creek south of Sanitary Landfill I, and downgradient transport along the strike-parallel flowpaths intercepted by the well (DOE 1997). Additionally, seasonally variable flux of nitrate along these flowpaths is suggested by the much higher nitrate concentration (28.6 mg/L) and groundwater elevation (934.53 ft msl) evident in March 1999 (seasonally high flow) compared with the lower nitrate (7.06 mg/L) and groundwater (924.88 ft msl) levels evident during August 1999 (seasonally low flow).

All five of the monitoring wells that comprise Exit Pathway Picket B, which is located about 2,500 ft west (downgradient) of well GW-226 (Figure 6), were sampled during CY 1999. As shown in Table 12, nitrate concentrations that exceeded the MCL were reported for three of these wells (GW-695, GW-704, and GW-706), with the lowest concentrations above the MCL reported for the shallowest well (GW-695). This illustrates a key characteristic of the nitrate plume in the aquifer, in that nitrate concentrations in the shallow karst network (e.g., GW-695) are usually lower than nitrate levels in the deeper flow system (e.g., GW-706) because of the greater degree of attenuation (dilution) in the shallow flow system (DOE 1997). Additionally, the CY 1999 nitrate results for well GW-695 are generally consistent with historical (conventional sampling and low-flow-sampling) data, which indicate an increasing long-term concentration trend (see Section 3.3). Conversely, nitrate concentrations evident in wells GW-704 and GW-706 indicate fluctuating or relatively indeterminate long-term trends (Figure 11). For example, nitrate concentrations in well GW-706 increased from 10 mg/L in June 1991 to almost 50 mg/L in September 1992, steadily decreased below 20 mg/L through February 1997, and subsequently increased above 40 mg/L through February 1999. Nitrate levels in these wells are probably maintained via infiltration of nitrate-contaminated groundwater and surface water along the losing reach of Bear Creek south of the Oil Landfarm WMA (DOE 1997). As shown in Table 14, however, the most recent increase in the nitrate levels in well GW-706 generally coincides with the change from conventional sampling to low-flow sampling.

**Table 14. Comparison of conventional sampling and low-flow sampling results for nitrate in Exit Pathway Picket B well GW-706**

Well	Nitrate (as N)							
	Conventional Sampling (mg/L)				Low-Flow Sampling (mg/L)			
	1996		1997		1998		1999	
	Mar.	Aug.	Feb.	Sept.	Jan.	Aug.	Feb.	Aug.
GW-706	15.2	16.8	18.1	33.1	45.7	48.1	44.6	25.95

Thus, it is not clear if the recent increase in the nitrate concentration in well GW-706 is an artifact of the change from conventional sampling to low-flow sampling.

As shown in Table 12, the total uranium concentrations reported for Exit Pathway Picket B well GW-706 are the highest reported for any of the aquifer wells sampled during CY 1999. These results are consistent with the initial low-flow sampling results obtained during CY 1998 and the historical conventional sampling data. Aside from particularly low concentrations in June 1991 (0.002 mg/L), March 1993 (0.002 mg/L), and September 1993 (0.008 mg/L) and a conspicuous concentration “spike” in December 1993 (0.23 mg/L), the uranium data reflect a relatively stable long-term concentration trend (Figure 12). This is probably because influx of uranium from Boneyard/Burnyard helps maintain the elevated concentrations evident in downgradient wells (DOE 1997).

Four of the monitoring wells that comprise Exit Pathway Picket A were sampled during CY 1999. These wells are located just downstream of the confluence of NT-7 and Bear Creek, approximately 3,500 ft west (downgradient) of Exit Pathway Picket B (Figure 6). Analytical results for these wells are generally consistent with respective historical (conventional and low-flow sampling) data and show that nitrate levels remain below the MCL, with the highest concentrations evident in the samples collected from wells GW-683 (4.88 mg/L) and GW-684 (4.13 mg/L) in February 1999 (seasonally high groundwater flow). However, as shown on Table 12, groundwater samples collected from both of these wells contained elevated total uranium concentrations, with the highest concentration (0.0446 mg/L) reported for the sample collected from well GW-683 in February 1999. Elevated uranium concentrations in the groundwater at these wells probably reflect downgradient, strike-parallel transport of uranium from the Boneyard/Burnyard/HCCA, but may also be at least partially attributed to inflow of radiologically contaminated groundwater/surface water from the Bear Creek tributaries that drain the BCBG WMA (DOE 1997). In either case, the uranium results for both wells reflect widely variable but generally decreasing long-term concentration trends (Figure 12), with little if any difference evident between the conventional sampling (1996-1997) and low-flow sampling (1998-1999) results for either well.

### **3.1.2.2 Volatile Organic Compounds**

Excluding false-positive results, one or more chloroethenes (PCE, TCE, c12DCE, 11DCE, and VC), chloroethanes (111TCA, 12DCA, and 11DCA), chloromethanes (carbon tetrachloride and chloroform), petroleum hydrocarbons (benzene, toluene, ethylbenzene, and dimethylbenzene), or miscellaneous compounds (acetone, acrylonitrile, carbon disulfide, and styrene) were detected in at least one groundwater sample collected during CY 1999 from the aquifer wells used for Surveillance Monitoring. Maximum CY 1999 summed VOC concentrations exceeded 5 µg/L in samples from 16 wells and are less than 10 µg/L in wells GW-056, GW-135 (sampling ports 06 and 26), GW-236, GW-311; range from 10 to 100 µg/L in wells GW-053, GW-134 (ports 34 and 35), GW-135 (sampling ports 03, 11, and 23), GW-228, GW-315, GW-601, GW-695, GW-703, GW-704, GW-706, GW-725, GW-738, and GW-740; exceed 100 µg/L in wells GW-226 and GW-724. As shown in the following summary (Table 15), maximum concentrations of PCE, TCE, VC and benzene exceed respective MCLs for drinking water.

**Table 15. CY 1999 maximum VOC concentrations in aquifer wells that exceed MCLs**

Well Number	Concentration (µg/L)			
	PCE	TCE	VC	Benzene
GW-053	.	(3)	(5)	.
GW-134-33	<b>10</b>	<b>30</b>	.	.
GW-134-35	<b>11</b>	<b>19</b>	.	.
GW-135-03	.	.	.	<b>13</b>
GW-135-11	.	.	.	<b>34</b>
GW-135-23	.	.	.	<b>14</b>
GW-226	.	<b>210 D</b>	.	.
GW-228	.	<b>55</b>	.	.
GW-311	.	<b>7</b>	.	.
GW-315	<b>14</b>	<b>6</b>	.	.
GW-601	.	<b>96</b>	.	.
GW-695	.	<b>8</b>	.	.
GW-703	.	<b>20</b>	.	.
GW-704	.	<b>79</b>	.	.
GW-706	.	<b>20</b>	.	.
GW-724	(4)	<b>120</b>	.	.
GW-725	(3)	<b>29</b>	.	.
GW-738	.	<b>38</b>	.	.
GW-740	.	<b>65</b>	.	.
MCL (µg/L)	5	5	2	5
<p><b>Notes:</b> ( ) = Estimated concentration below the reporting limit; D = diluted analysis;            “. ” = Not detected; <b>Bold</b> = Exceeds MCL</p>				

These monitoring results do not indicate any significant changes from historical data in the extent or distribution of dissolved VOCs in the aquifer (Figure 5).

As shown in the preceding data summary, concentrations of PCE and TCE that exceed respective MCLs were detected in the samples collected from two of the sampling ports in well GW-134 that yield groundwater from the aquifer (Figure 7), one port at a depth of 81 ft bgs (sampling port 35) and one at a depth of 106 ft bgs (sampling port 33). Considering the elevated nitrate levels in the samples collected from these sampling ports, these VOC results likewise reflect migration of VOCs from the Nolichucky Shale into the Maynardville Limestone directly south of the S-3 Site, possibly facilitated by fractures (or fracture zones) that cut across geologic strike.

Westbay well GW-135 is a former corehole located on the northern flank of Chestnut Ridge about 600 ft southeast of Spoil Area I (Figure 6). Groundwater samples were collected in September 1999 from a total of ten sampling ports in the well (Figure 7), each of which yield groundwater from the Maynardville Limestone and or lower Knox Group at depths ranging from 214 ft bgs (sampling port 39) to 1,206 ft bgs (sampling port 3). As shown in the following summary (Table 16), several dissolved petroleum hydrocarbons were detected in the groundwater samples collected from five of these sampling ports, including the three deepest sampling ports in the well.

**Table 16. VOCs detected in well GW-135, September 1999**

VOC	Concentration (µg/L)				
	Port 3 (1,206 ft bgs)	Port 6 (1,142 ft bgs)	Port 11 (965 ft bgs)	Port 23 (609 ft bgs)	Port 26 (554 ft bgs)
Acrylonitrile	13	.	.	.	.
Benzene	13	(2)	34	14	(4)
Ethylbenzene	.	.	.	(3)	(3)
Toluene	.	.	.	(3)	.
Styrene	(3)	.	.	.	(1)

**Notes:** "." = Not detected; () = Estimated value below the analytical reporting limit

According to the manufacturer, the Westbay™ sampling equipment contains several components made with acrylonitrile, and detection of this compound is often an artifact from sampling ports in low permeability zones (Westbay Instruments, Inc. 1999). Thus, the presence of acrylonitrile in the sample collected from sampling port 3 suggests that this port is within a low-permeability interval in the Nolichucky Shale. However, this does not explain the detection of the petroleum hydrocarbons in samples from each of the sampling ports (note that the benzene concentrations in sampling ports 3, 11, and 23 exceed the MCL). Transport from potential surficial sources of petroleum hydrocarbons (e.g., the Fire Training Facility) seems unlikely considering the depth of these sampling ports, although the corehole remained open to the ground surface for about five years and circulation between shallow and deep zones in the corehole may have occurred before installation of the Westbay™ system (Dreier *et. al.* 1993). Residual traces of oil-based lubricants (if any) that may have been used on drilling rods when the corehole was drilled also seems an unlikely source of the petroleum hydrocarbons. Alternatively, these results may reflect natural hydrocarbon concentrations from petroliferous zones in the Maynardville Limestone and Knox Group.

Dissolved chloroethenes (PCE, TCE, and c12DCE) were detected in the groundwater samples from well GW-315 during CY 1999, which is completed at a depth of 104 ft bgs on the northern flank of Chestnut Ridge at the Spoil Area I (Figure 6). The summed concentration of the VOCs detected in each sample are dominated by PCE (13 - 14 µg/L) with lesser amounts of TCE (6 µg/L) and c12DCE (3 µg/L). These low-flow sampling results are consistent with historical (conventional and low-flow sampling) data for the well and reflect influx of dissolved chloroethenes from Spoil Area I or possibly the Fire Training Facility, which is a confirmed source of chloroethenes in the East Fork Regime about 1,000 ft east of the well (DOE 1997). As illustrated by PCE data, VOC concentrations in the groundwater at well GW-315 have decreased about 50% from the maximum concentration during CY 1991 (38 µg/L).

Monitoring results obtained during CY 1999 for well GW-311 are consistent with historical (conventional sampling and low-flow sampling) data and show relatively low levels of TCE (7 µg/L) in the shallow groundwater (40 ft bgs) near the Rust Spoil Area (Figure 6). The source of the TCE is either the Rust Spoil Area or an unidentified nearby source in the Bear Creek floodplain (DOE 1997). Compared with the TCE concentrations evident during the early 1990s (e.g., 30 µg/L in January 1991), the CY 1999 monitoring results show that the TCE levels have decreased substantially (>75%), although the TCE results obtained from low flow sampling in March 1998 (8 µg/L) and August 1998 (10 µg/L) suggest that the rate of decrease has slowed.

Several VOCs (PCE, TCE, c12DCE, 111TCA, and carbon tetrachloride) were detected in at least one of the groundwater samples collected from the Exit Pathway Picket C monitoring wells during CY 1999, with the

higher summed VOC concentrations in wells GW-724 (127 µg/L) and GW-740 (73 µg/L) compared to wells GW-725 (26 µg/L) and GW-738 (40 µg/L). These results support the initial low-flow sampling results obtained from each well during CY 1998, and as illustrated by the following summary of TCE data (Table 17), generally do not substantially differ from respective conventional sampling results for wells GW-738 and GW-740.

**Table 17. Comparison of conventional sampling and low-flow sampling results for TCE in Exit Pathway Picket C wells GW-724, GW-725, GW-738, and GW-740**

Well	TCE (µg/L)							
	Conventional Sampling				Low-Flow Sampling			
	1996		1997		1998		1999	
	Q1	Q3	Q1	Q3	Q1	Q3	Q1	Q3
GW-724	160	40	35	45	130	120	120	110
GW-725	17	12	7	16	42	20	19	29
GW-738	50	40	43	36	37	30	36	38
GW-740	72	31	36	73	72	59	65	64

The slightly higher low-flow sampling results for TCE in low-flow samples from wells GW-724 and GW-725 contrast with the previous discussion regarding the substantially lower low-flow sampling results for nitrate in these wells (see Section 3.2.1.1). It is unclear how or why changing the sampling method would differentially effect the concentrations of different types of contaminants in these wells. Nevertheless, the dissolved TCE in the groundwater at the Picket B wells reflects strike-parallel transport from the Rust Spoil Area, with the trace concentrations of the other VOCs (e.g., PCE and carbon tetrachloride) indicating migration from another upgradient source, possibly the S-3 Site (DOE 1997). Also, the CY 1999 results are generally consistent with the long-term TCE concentration trends defined by historical (conventional and low-flow sampling) data (Figure 13), with moderately decreasing trends evident in the shallower wells (GW-738 and GW-725) and indeterminate or slightly increasing trends evident in the deeper wells (GW-724 and GW-740).

As noted in Section 3.1.2.1, well GW-601 is directly down-dip of a major losing reach of Bear Creek south of the Oil Landfarm WMA that plays an important role in the transfer of contaminants from the shallow karst network into the deeper groundwater flow system in the Maynardville Limestone. This contaminant migration pattern explains the presence of dissolved VOCs in the groundwater at well GW-601. Historical (conventional sampling) data show that the groundwater samples from this well contained primarily TCE (>100 µg/L) along with trace levels (<5 µg/L) of PCE, 12DCE, 11 DCE, carbon tetrachloride, chloroform, and 111TCA. As shown in the following data summary (Table 18), TCE, PCE, and carbon tetrachloride were detected in each of the samples collected from the well in March 1992, March 1993, and March 1994 (i.e., during seasonally comparable flow conditions), but only TCE was detected in the sample collected from the well in March 1999.

**Table 18. CY 1999 and selected historical results for VOCs in well GW-601**

VOC	Concentration (µg/L)			
	Conventional Sampling			Low-Flow Sampling
	March 1992	March 1993	March 1994	March 1999
PCE	(1)	(1)	(1)	.
TCE	130	140	130	96
12DCE	(1)	(2)	.	.
Carbon Tetrachloride	(2)	(4)	(2)	.

**Notes:** “.” = Not detected; () = Estimated value below the analytical reporting limit

These results suggest a moderate decrease (about 25%) in the concentration of TCE in the well, although it is not clear from the available data to what extent, if any, this decrease is an artifact of the change from conventional sampling to low-flow sampling.

Historical data show that well GW-228, which is completed at a depth of 100 ft bgs in the lower Maynardville Limestone about 300 ft north-northeast (across geologic strike) of well GW-601 (Figure 6), yields calcium-magnesium-bicarbonate groundwater containing several dissolved chloroethenes, primarily TCE and 12DCE. As shown in the following data summary, the VOC results obtained from low-flow sampling in September 1999 do not clearly indicate any significant difference with conventional sampling data and reflect a relatively stable or indeterminate long-term concentration trend.

**Table 19. CY 1999 and selected historical results for VOCs in well GW-228**

VOC	Concentration (µg/L)					
	Conventional Sampling					Low-Flow Sampling
	Sep. 1986	Sep. 1987	Sep. 1988	Sep. 1989	Sep. 1995	September 1999
TCE	62	75	82	61	28	55
12DCE	NA	NA	NA	8	14	8

**Note:** NA = Not analyzed

Dissolved VOC concentrations in well GW-228 probably reflect inflow of contaminated groundwater from the Boneyard/Burnyard/HCDA, which is the primary source of TCE and c12DCE in shallow groundwater downgradient of the Oil Landfarm WMA (DOE 1997).

Inflow of TCE-contaminated groundwater from the Boneyard/Burnyard/HCDA may also explain the very high TCE concentrations (110 - 210 µg/L) reported for the samples collected from well GW-226 during CY 1999. This well yields VOC-contaminated calcium-magnesium-bicarbonate groundwater from the Maynardville Limestone about 300 ft west (hydraulically downgradient) of well GW-228 (Figure 6). The CY 1999 TCE results for well GW-226 are similar to the initial low-flow sampling results obtained during CY 1998, which differ substantially from historic (conventional sampling) results for TCE and reflect a significant concentration increase (see Section 3.3). Conversely, the concentrations of other VOCs detected in the groundwater samples collected from this well during CY 1999 suggest decreasing long-term concentration trends (Figure 14). Only trace levels of c12DCE were detected in the groundwater samples collected in CY 1999 (e.g., 4 µg/L in March 1999), whereas total 12DCE concentration above 30 µg/L were

previously evident in the well (e.g., 37 µg/L in August 1990). Moreover, the conventional sampling results obtained between November 1988 (14 µg/L) and May 1991 (29 µg/L) indicate an increasing concentration trend (Figure 14), but the low-flow sampling results suggest a decreasing concentration trend between February 1998 (7 µg/L) and August 1999 (3 µg/L).

Low concentrations of TCE, c12DCE, VC, and 11DCA were detected in the groundwater samples collected from well GW-053 during CY 1999, with c12DCE (13 - 15 µg/L) as the primary compound and, as noted on Table 15, concentrations of VC (5 µg/L) that remain above the MCL (2 µg/L). Dissolved VOCs in this well, which yields calcium-magnesium-bicarbonate groundwater from a depth of 33 ft bgs in the upper Maynardville Limestone about 500 ft south of the BCBG WMA (Figure 6), reflect inflow of contaminants from beneath BG-A South (DOE 1997). These CY 1999 (low-flow sampling) VOC results are consistent with historical (conventional sampling) data for the well and show indeterminate long-term concentration trends that generally decrease from 1990 through 1994, followed by fairly stable concentrations for each compound since CY 1995.

Dissolved chloroethenes (TCE, c12DCE, and 11DCE) were detected in each of the groundwater samples collected from Exit Pathway Picket B wells GW-695, GW-703, GW-704, and GW-706 during CY 1999, with the highest summed concentration of these compounds evident in the sample collected from well GW-704 in August 1999 (87 µg/L). These results, which show that TCE concentrations in each well remain above the MCL (see Table 15), reflect the TCE-dominated composition of the dissolved VOC plume in the aquifer downgradient of the Oil Landfarm WMA. Also, considering that the highest summed VOC concentrations occur in the groundwater at well GW-704, which is the deepest (256 ft bgs) well in Exit Pathway Picket B, the composition of the dissolved VOC plume reflects strike-parallel transport from source areas in the upper reaches of Bear Creek (i.e., the Rust Spoil Area) and vertical influx via the losing reach of Bear Creek south of Sanitary Landfill I (DOE 1997). In any case, the CY 1999 TCE results for each of the Picket C wells are generally consistent with respective historical data and, as shown in Table 20, do not reflect substantial concentration differences that are clearly attributable to the change from conventional sampling to low-flow sampling.

**Table 20. Comparison of conventional sampling and low-flow sampling results for TCE in Exit Pathway Picket B wells GW-695, GW-703, GW-704, and GW-706**

Well	TCE (µg/L)							
	Conventional Sampling				Low-Flow Sampling			
	1996		1997		1998		1999	
	Q1	Q3	Q1	Q3	Q1	Q3	Q1	Q3
GW-695	5	5	7	5	7	5	8	4
GW-703	13	9	FP	14	21	18	20	16
GW-704	97	70	FP	100	35	78	52	79
GW-706	8	7	FP	11	11	12	20	13

**Note:** FP = False positive result

Overall, the TCE results for these Picket B wells suggest indeterminate (GW-695, GW-706, and GW-704) or generally decreasing (GW-703) long-term concentration trends (Figure 15).

### 3.1.2.3 Radioactivity

Gross alpha and/or gross beta that exceed the associated MDA and corresponding CE was reported for the groundwater samples collected from 19 aquifer wells during CY 1999: GW-053, GW-056, GW-134, GW-135, GW-226, GW-236, GW-315, GW-621, GW-683, GW-684, GW-685, GW-695, GW-703, GW-704, GW-706, GW-724, GW-725, GW-738, and GW-740. The bulk of the gross alpha and gross beta results for these wells, however, reflect very low levels (<5 pCi/L) that just slightly exceed the associated MDA or have substantial analytical uncertainty. As shown in Table 21, only the gross alpha results reported for wells GW-683 and GW-706 exceed the 15 pCi/L MCL and the gross beta results reported for wells GW-134, GW-236, and GW-706 exceed the 50 pCi/L SDWA screening level.

**Table 21. Elevated gross alpha and gross beta radioactivity reported for aquifer wells used for Surveillance Monitoring during CY 1999**

Well	Date Sampled	Gross Alpha (pCi/L)			Gross Beta (pCi/L)		
		MDA	Activity ± CE		MDA	Activity ± CE	
GW-134-33	08/11/99	7.5	<MDA		9.5	<b>210</b>	± 16
GW-134-35	08/11/99	7.7	<MDA		9.4	<b>330</b>	± 19
GW-236	09/08/99	4	5.9	± 3.7	8.5	<b>85</b>	± 9.7
GW-683	02/11/99	3.7	<b>26</b>	± 6.8	8.3	20	± 6.2
	07/29/99	3.8	<b>16</b>	± 5.4	8.1	21	± 6.4
GW-706	02/17/99	4	<b>43</b>	± 8.9	8.7	<b>120</b>	± 11
	08/04/99	4	<b>38</b>	± 8.4	9.6	<b>86</b>	± 10

**Note:** BOLD = Exceeds MCL (gross alpha) or SDWA screening level (gross beta).

Extensive historical data show that elevated gross alpha and gross beta activity in the aquifer is primarily from uranium isotopes (U-234 and U-238) and Tc-99, respectively. Uranium isotopes enter the aquifer via inflow from the buried tributary of Bear Creek that extends beneath the S-3 Site, direct recharge from the Boneyard/Burnyard (and inflow from the NT-3 catchment), and inflow from tributary catchments to the east (NT-6) and west (NT-7 and NT-8) of BG-A North and BG-A South (DOE 1997).

Gross beta activity that exceed the SWDA screening level were reported for the samples collected from two of the sampling ports in well GW-134 that yield groundwater from the Maynardville Limestone (Figure 7). Considering the elevated nitrate and chloroethene levels in the samples collected from these sampling ports, these results likewise reflect migration of beta-emitting radionuclides (probably Tc-99) from the Nolichucky Shale into the Maynardville Limestone directly south of the S-3 Site, possibly facilitated by fractures (or fracture zones) that cut across geologic strike. Although Tc-99 is volatilized during gross beta analyses (gross beta activity is typically less than the Tc-99 activity), elevated gross beta results generally correlate with elevated Tc-99 activity near the S-3 Site, and Tc-99 is often the only beta-emitting radionuclide detected in wells near the site.

Elevated gross beta activity in the groundwater at well GW-236, as with nitrate in the well (see Section 3.1.2.1), reflects migration of Tc-99 from the reservoir of contamination emplaced in the Nolichucky Shale during operation of the former S-3 Ponds because, as noted in Section 2.4.1, nitrate and Tc-99 share similar groundwater transport/migration patterns (DOE 1997). The gross beta result obtained from low-flow sampling in September 1999 is slightly lower than the most recent gross beta result obtained from

conventional sampling in September 1995 (97.5 pCi/L), but both of these results are much lower than the gross beta levels evident in the well during the late 1980s (e.g., 180 pCi/L in May 1989). This suggests that beta radioactivity (and Tc-99 concentrations) in the well has decreased substantially since closure of the former S-3 Ponds, and that the rate of decrease has generally slowed.

As shown in the preceding data summary (Table 21), the CY 1999 gross alpha and gross beta results reported for well GW-706 were the highest levels reported for any of the aquifer wells that were sampled during CY 1999. Influx of uranium isotopes from the source(s) associated with the Boneyard/Burnyard probably explains the elevated radioactivity in the groundwater at this well (DOE 1997). This is supported by radiological results obtained during CY 1999, which indicate elevated levels of U-234 (18.07 pCi/L) and U-238 (33.46 pCi/L) in the groundwater samples from well GW-706. Historical data suggest that the gross beta activity at well GW-706 reflects commingling of uranium decay products (e.g., thorium-234) of the Boneyard/Burnyard plume with Tc-99 (and nitrate, see Section 3.2.1.1) of the S-3 Ponds plume; Tc-99 activity showed a decreasing trend in the data for the well from 1993 (>250 pCi/L), 1994 (100 - 200 pCi/L), and 1995 through 1996 (<100 pCi/L).

Results for gross alpha or beta activity that exceed associated MDA and the CE were reported for at least one groundwater sample collected from each of the Exit Pathway Picket A wells that were sampled during CY 1999. As shown in the preceding data summary (Table 21), only the gross alpha results for wells GW-683 exceed the MCL (15 pCi/L) and the CY 1999 gross beta results for all of the Picket A wells are below the SDWA screening level (50 pCi/L). Elevated gross alpha activity in the groundwater at well GW-683, which yields calcium-magnesium-bicarbonate groundwater from the lower Knox Group, may reflect transport of uranium isotopes from upgradient sources (e.g., the Boneyard/Burnyard) into successively higher hydrostratigraphic zones in the Maynardville Limestone and ultimately into the lower Copper Ridge Dolomite. However, considering attenuation during transport from this site, which is about a mile east of Exit Pathway Picket A, influx of uranium isotopes discharged from the Bear Creek tributaries that drain the BCBG WMA also seems to be a likely source of the radioactivity in the groundwater at this well.

### 3.2 EXIT PATHWAY/PERIMETER MONITORING

The CY 1999 monitoring results reported for the following aquifer wells, springs that discharge into Bear Creek, surface water stations located along the main channel of Bear Creek and several northern tributaries of Bear Creek were evaluated for the purposes of DOE Order 5400.1 Exit Pathway/Perimeter Monitoring.

**Table 22. Sampling locations used for Exit Pathway/Perimeter Monitoring during CY 1999**

Monitoring Wells		Springs	Surface Water Stations	
Number	Monitored Interval Depth (ft bgs)		Bear Creek Mainstem	Bear Creek Tributaries
GW-712	441.5 - 457.5	SS-1	BCK-00.63	NT-01
GW-713	305.0 - 315.2	SS-4	BCK-04.55	NT-02
GW-714	115.1 - 145.0	SS-5	BCK-07.87	NT-06
GW-715	32.0 - 44.0	SS-6	BCK-09.40	NT-07
		SS-6.6	BCK-09.47	NT-08
		SS-7	BCK-10.60	
		SS-8	BCK-11.97	

Groundwater or surface water samples were collected semiannually during CY 1999 from each of the monitoring wells and springs, and from all but three of the surface water sampling stations (BCK-10.60, NT-02, and NT-06), which were sampled only once during the year (Table B.2). Analytical results for each sampling location, along with available historical data, serve as the basis for the following evaluation of surface water and groundwater quality where contaminants from the Y-12 Plant are most likely to migrate beyond the boundaries of the Bear Creek Regime. For the purposes of this evaluation, the sampling locations used for Exit Pathway/Perimeter Monitoring during CY 1999 are assigned to one of three areas: Upper Bear Creek encompasses the sampling locations upstream (east) of BCK-11.97; Middle Bear Creek encompasses sampling locations between BCK-11.97 and BCK-09.40; and Lower Bear Creek encompasses the sampling locations downstream of BCK-09.40 (Figure 6). Additionally, evaluation of the CY 1999 monitoring data for each sampling location is focused on results for the principal components of the groundwater contaminant plumes in the Bear Creek Regime: inorganics (nitrate and uranium), VOCs, and radioactivity (gross alpha and gross beta).

### 3.2.1 Upper Bear Creek

The surface water quality in the upper reaches of Bear Creek primarily reflects discharge of contaminated groundwater from the water table interval in the aquitard and aquifer downgradient of the S-3 Site. As shown in the following data summary (Table 23), analytical results obtained during CY 1999 from the sampling locations in Upper Bear Creek show elevated concentrations of nitrate (>10 mg/L), total uranium (>0.02 mg/L), gross alpha (>15 pCi/L) and gross beta (>50 pCi/L), but only trace levels of VOCs (PCE), with the highest concentration of each contaminant evident in NT-01 and in the Bear Creek mainstem at BCK-11.97, which is just downstream of the confluence of NT-2 and Bear Creek (Figure 6).

**Table 23. CY 1999 maximum contaminant concentrations at Exit Pathway/Perimeter Monitoring sampling locations along Upper Bear Creek**

Sampling Point	Inorganics (mg/L)		Organics (µg/L)	Radioactivity (pCi/L)	
	Nitrate	Uranium	PCE	Gross Alpha	Gross Beta
NT-01	<b>500.2</b>	<b>0.0672</b>	5	<b>23</b>	<b>500</b>
SS-1	<b>18.5</b>	<b>0.0443</b>	.	<b>23</b>	42
NT-02	<b>16</b>	.	.	1.9	13
BCK-11.97	<b>62.5</b>	<b>0.207</b>	.	<b>56</b>	<b>130</b>

**Notes:** Results for each sampling point may be from more than one sampling date; “.” = not detected; **BOLD** = exceeds MCL (proposed for uranium) or SDWA screening level (gross beta).

These results are consistent with historical data with the overall quality of surface water evident in Bear Creek at BCK-11.97 reflecting inflow of contaminated groundwater discharged into NT-1 and NT-2 from the aquitard (Nolichucky Shale) west of the S-3 Site, as well as influx of contaminated groundwater in the aquifer (Maynardville Limestone) discharged from Spring SS-1. As indicated by the nitrate concentrations and gross alpha activities reported for BCK-11.97 since 1990, contaminant levels in Upper Bear Creek fluctuate seasonally, with the highest concentrations typically evident during the seasonally dry periods of the year (summer and fall) when the bulk of the flow in the creek is from groundwater discharge (DOE 1997). Along with these seasonal fluctuations, the nitrate and gross alpha results for BCK-11.97 also generally reflect decreasing long-term concentration trends (Figure 16).

### 3.2.2 Middle Bear Creek

Surface water quality in Bear Creek downstream of BCK-11.97 reflects contaminant transport from the upper reaches of the creek (nitrate, uranium, and radioactivity), from the Boneyard/Burnyard (uranium, TCE, and c12DCE), and from the Burial Grounds WMA (uranium, PCE, TCE, c12DCE, VC, and radioactivity). Much of this section of the creek loses flow to the aquifer, particularly the section of the channel immediately south of Sanitary Landfill I, which plays an important role in transferring contaminants from the creek to the groundwater (DOE 1997). As shown in the following data summary with sampling locations arranged from upstream to downstream (Table 24), the CY 1999 results for each of the locations in Middle Bear Creek show elevated concentrations of at least one of the principal components of groundwater contaminant plumes.

**Table 24. CY 1999 maximum concentrations of selected contaminants at Exit Pathway/Perimeter Monitoring sampling locations along Middle Bear Creek**

Sampling Point	Inorganics (mg/L)		Chloroethenes (µg/L)				Radioactivity (pCi/L)	
	Nitrate	Uranium	PCE	TCE	c12DCE	VC	Gross Alpha	Gross Beta
BCK-10.60	<b>12.2</b>	<b>0.201</b>	.	.	.	.	<b>89</b>	40
SS-4	<b>18.27</b>	<b>0.239</b>	.	<b>11</b>	.	<b>6</b>	<b>110</b>	<b>60</b>
NT-06	.	.0066	(3)	.	(3)	<b>(4)</b>	6.1	.
NT-07	0.27	<b>0.0269</b>	<b>28</b>	<b>21</b>	<b>82</b>	<b>(3)</b>	11	46
NT-08	0.54	<b>0.35</b>	<b>23</b>	<b>15</b>	<b>200</b>	<b>11</b>	<b>140</b>	44
BCK-09.47	8.8	<b>0.17</b>	(1)	(1)	15	.	<b>76.29</b>	44.09
SS-5	7.1	<b>0.0746</b>	.	.	.	.	<b>29</b>	29
BCK-09.40	<b>10.5</b>	<b>0.208</b>	(3)	(2)	17	.	<b>110</b>	<b>80</b>

**Notes:** Results for each sampling point may be from more than one sampling date. ( ) = Estimated value; “.” = not detected; **BOLD** = exceeds MCL (proposed for uranium) or SDWA screening level (gross beta).

As illustrated by the preceding data summary, concentrations of nitrate in Bear Creek generally decrease with distance downstream from the S-3 Site; for example, the maximum nitrate level at BCK-09.47 is about 25% lower than the maximum nitrate level at BCK-10.60. However, concentrations of other contaminants do not show a concurrent decrease with distance downstream because of influx of contaminants (e.g., uranium) from other sources. For example, maximum nitrate concentrations and gross beta activity at BCK-10.60 are significantly lower than the maximum levels reported for BCK-11.97, whereas the maximum uranium concentrations and gross alpha activity at BCK-10.60 are higher than evident at BCK-11.97. These results reflect input of uranium from the Boneyard/Burnyard, which lies between BCK-11.97 and BCK-10.60 (Figures 2 and 5).

Surface water in the Bear Creek tributaries that drain the BCBG WMA is radiologically contaminated (primarily U-234 and U-238), with the highest radioactivity evident in the southern branch of NT-8 (DOE 1997). As illustrated by the preceding data summary (Table 24), the surface water samples collected from NT-7 and NT-8 also contained surprisingly high levels of VOCs (considering the potential for volatilization), including concentrations of PCE, TCE, c12DCE, and VC that exceed respective MCLs. These results show that the plume of dissolved chloroethenes in the shallow groundwater near BG-C (East and West) discharges extensively into these tributaries (DOE 1997). Moreover, inflow of contaminated groundwater and surface water from the catchments of these tributaries, and discharge of contaminated groundwater from springs SS-4

and SS-5, probably accounts for the elevated nitrate and uranium concentrations, trace levels of VOCs, and elevated gross alpha and gross beta activity in Bear Creek at BCK-09.47 and BCK-09.40. Along with historical data, the CY 1999 results for BCK-09.40 show a generally decreasing the long-term trend for nitrate and a relatively steady long-term trend for gross alpha activity (Figure 16).

Discharge of groundwater from springs SS-4 and SS-5 sustains flow in the Bear Creek during seasonally low flow periods and contributes to surface water contamination downstream of BCK-11.97 (DOE 1997). As shown in Table 24, groundwater samples collected from each spring during CY 1999 contained elevated concentrations of nitrate, uranium, and gross alpha radioactivity; samples from spring SS-4 also contained TCE and VC concentrations that exceed respective MCLs, along with gross beta activity above 50 pCi/L. Note that the contaminant concentrations reported for SS-4 are higher than respective levels reported for spring SS-1, which is located about a mile closer to the S-3 Site (Figure 6). Higher concentrations in the groundwater discharged from spring SS-4 probably reflect transfer of contaminants from Bear Creek into the aquifer along the losing reach of the creek upgradient of the spring (DOE 1997).

### 3.2.3 Lower Bear Creek

As shown in the following summary of CY 1999 monitoring data (Table 25), few of the primary groundwater contaminants were detected at elevated concentrations in the samples collected from the monitoring wells at the westernmost Exit Pathway Picket in the Bear Creek Regime (Picket W) and from the springs in Lower Bear Creek (the elevated gross beta at GW-715 and the elevated nitrate at SS-8 are probable artifacts and not representative of actual groundwater quality).

**Table 25. CY 1999 maximum contaminant concentrations at Exit Pathway/Perimeter Monitoring sampling locations along Lower Bear Creek**

Sampling Point	Inorganics (mg/L)		Organics (µg/L)	Radioactivity (pCi/L)	
	Nitrate	Uranium		Gross Alpha	Gross Beta
GW-712	0.05	.	.	<MDA	20.7
GW-713	0.02	.	.	2.49	3.84
GW-714	1.8	.	.	1.39	5
GW-715	0.55	.	.	7.74	<b>[158]</b>
SS-6	0.93	.	.	5.5	.
SS-6.6	0.6	.	.	1.33	.
SS-7	0.58	.	.	4.62	4.42
SS-8	<b>[358]</b>	.	.	1.9	.
BCK-07.87	6.71	<b>0.115</b>	.	<b>52</b>	34
BCK-04.55	2.75	<b>0.053</b>	.	<b>21</b>	16
BCK-00.63	1.89	<b>0.0334</b>	.	<b>22</b>	11

**Note:** Results for each sampling point may be from more than one sampling date. “.” = not detected; **BOLD** = exceeds MCL (proposed for uranium) or SDWA screening level (gross beta); [ ] = probable artifact, spurious result unsupported by historic and subsequent monitoring results.

Surface water samples collected downstream of BCK-09.40 contained gross alpha activities that exceed the MCL (15 pCi/L) and total uranium concentrations that exceed the proposed MCL (0.02 mg/L). The February 1999 sample from BCK-07.87 (farthest upstream and had the highest gross alpha and gross beta in Lower Bear Creek) had relatively low Tc-99 activity (14.39 pCi/L) and higher U-234 (21.05 pCi/L) and U-238 (47.73 pCi/L) activities, which suggests transport from the S-3 Site (Tc-99) with inputs of uranium from the Boneyard/Burnyard and the BCBG WMA (U-234 and U-238). As illustrated by data for BCK-04.55, results

for each of these sampling locations indicate generally decreasing (nitrate) or relatively steady (gross alpha) long-term concentration trends (Figure 16). Nevertheless, results for BCK-00.63 show that elevated concentrations of total uranium and gross alpha radioactivity (presumably from uranium isotopes) occur in Bear Creek less than one kilometer from its confluence with East Fork Poplar Creek.

As shown in Table 25, the primary groundwater contaminants in the Bear Creek Regime were either not detected in the samples from these wells (e.g., uranium), were detected at very low levels (e.g., nitrate and gross alpha), or reflect analytical variability (e.g., gross beta). Overall, the monitoring results obtained during CY 1999 indicate that each of these Picket W wells continue to yield relatively uncontaminated groundwater downgradient of the commingled plume of inorganics, VOCs, and radioactivity in the Maynardville Limestone.

Groundwater samples collected from well GW-715 are characterized by elevated chromium and/or nickel concentrations. For example, the total nickel concentration (0.152 mg/L) reported for the sample collected from the well in July 1999 exceeds the MCL for nickel (0.1 mg/L). Rather than migration from potential sources of these metals in the Bear Creek Regime (e.g., the S-3 Site), elevated chromium and nickel concentrations in the well may be related to corrosion of the stainless steel well casing and screen. This well has type 304 stainless steel casing, which is comprised of 18-20% chromium, 8-12% nickel, and 64-70% iron (Sarouhan *et al.* 1998). Geochemical conditions known to be corrosive to stainless steel (e.g., dissolved oxygen >2 mg/L; Driscoll 1986) are often evident in the well. Additionally, the elevated chromium and nickel concentrations may reflect microbiologically induced corrosion (MIC). Preliminary sampling results obtained by the Y-12 Plant GWPP in February 2000 confirm the presence of slime-forming bacteria in the well (personal communication, Jones 2000), which may comprise the sessile (attached to the well casing) and planktonic (suspended in the water column) biomass that was observed in the well during a downhole video inspection in August 1999. Several different species of bacteria (including slime-forming bacteria) that are ubiquitous in groundwater may cause MIC of the well screen, particularly type 304 stainless steel, which is prone to crevice corrosion at badly executed welds (Oakley and Korte 1996). Moreover, as shown in the following data summary, both conventional and low-flow sampling results for several indicator parameters suggest that geochemical conditions in well GW-715 are within the optimum range for MIC of stainless steel.

**Table 26. Indicators of MIC in Exit Pathway Picket W well GW-715**

Indicator Parameter/Optimal Range (Cullimore 1993)	Conventional Sampling				Low-Flow Sampling			
	Jan. 96	July 96	Feb. 97	Aug. 97	Jan. 98	July 98	Feb. 99	July 99
Dissolved Oxygen (mg/L) >1	5.9	2.3	5.3	2.6	3.97	3.55	5.5	5.01
REDOX (millivolts) -50 to +150	222	135	127	10	84	41	174	131
pH 6.5 to 9.0	6.7	6.7	6.7	7.1	7.02	6.38	6.83	6.05

Thus, well GW-715 may not yield groundwater samples with representative concentrations of metals that are stainless steel corrosion products, particularly chromium and nickel.

### 3.3 CONTAMINANT CONCENTRATION TRENDS

Monitoring data obtained since the late 1980s and early 1990s show indeterminate or generally decreasing long-term contaminant concentration trends for the majority of sampling locations in the Bear Creek Regime, including most of the CY 1999 sampling locations (Table B.3). The decreasing concentration trends probably reflect a combination of several factors, including compliance with waste management regulations, waste minimization and source control measures, remedial actions, natural attenuation mechanisms (including biotic and/or abiotic degradation of VOCs), and, in some cases, changes in sampling procedures and analytical methods. For the purposes of DOE Order 5400.1A requirements, the following discussion is focused on CY 1999 sampling locations with elevated concentrations of the primary components of groundwater contaminant plumes that exhibit increasing long-term trends.

As shown in Table 27, increasing long-term contaminant concentration trends are indicated by the monitoring data for seven of the CY 1999 sampling locations in the Bear Creek Regime, including one well west of the S-3 Site near the Oil Landfarm WMA (GW-537), one well located south of the Oil Landfarm WMA (GW-226), three wells at the BCBG WMA (GW-082, GW-627, and GW-653), one well at Exit Pathway Picket B (GW-695), and spring SS-4.

**Table 27. CY 1999 sampling locations with increasing long-term contaminant concentration trends**

Sampling Location	Nitrate	Uranium	VOCs	Radioactivity
GW-082	.	.	o	.
GW-226	o	.	o	.
GW-537	.	.	o	o
GW-627	.	.	o	.
GW-653	o	.	o	.
GW-695	o	.	o	.
SS-4	.	.	o	.

The following trend evaluation is based on least-squares linear regression of the long-term data sets, which include both conventional sampling and low-flow sampling data, with the corresponding coefficient of determination ( $R^2$  value) used as an indicator of the relative significance (or goodness of fit) of the data with respect to each trend. A linear regression of short-term data for several of these wells also was used to evaluate concentration trends based on low-flow sampling data alone. Only data that meet applicable DQO criteria were used for trend analysis purposes.

Monitoring results for well aquitard well GW-082, located southwest (hydraulically downgradient) of BG-C West (Figure 6), show a substantial increase in VOC concentrations since 1993 (Figure 17). As noted in Section 3.1.2.2, the VOC plume intercepted by this well is dominated by chloroethene and chloroethane degradation products (c12DCE, VC, and 11DCA) which potentially indicates reductive dechlorination at the site. However, the clearly increasing concentration trends exhibited by c12DCE and VC indicate increased flux downgradient of the site toward discharge areas in NT-8.

As noted in Section 3.1.2.1, the CY 1999 monitoring data for well GW-226 indicate an overall increase in the concentration of nitrate in the well (Figure 18). However, the conventional sampling data show a decreasing trend between March 1987 (4.1 mg/L) and May 1991 (<0.2 mg/L), whereas the much higher concentrations indicated by the low-flow sampling results show an indeterminate trend dominated by wide (seasonal) concentration fluctuations (Figure 18). Thus, the apparent long-term increase in the concentration of nitrate in the well is a direct consequence of the large disparity between the conventional and low-flow

sampling results, which may be an artifact of one or both sampling methods. Aggressively purging the well using the conventional sampling method may have induced flow of uncontaminated groundwater into the well and thereby resulted in the collection of groundwater samples with “diluted” nitrate concentrations. This same rationale may likewise explain the substantial overall increase in the TCE concentration in the well (Figure 19). As with nitrate, the conventional sampling results for TCE show a strongly decreasing trend between March 1987 (32 µg/L) and May 1991 (3 µg/L), with the low-flow sampling results showing substantially higher TCE concentrations (>100 µg/L) and an indeterminate short-term trend (Figure 19). However, this explanation does not clearly reconcile why TCE (and nitrate) concentrations exhibit an increasing trend while the c12DCE concentrations in the well exhibit a decreasing trend (see Section 3.1.2.2), unless the “uncontaminated” groundwater that diluted the TCE (and nitrate) concentrations contained c12DCE from another source (e.g., the Oil Landfarm WMA).

The CY 1999 gross beta results for groundwater samples from aquitard well GW-537 are generally consistent with historical data (Figure 20), which show significant temporal fluctuations (some of which probably reflect analytical variability) but a moderately increasing long-term trend ( $R^2 = 0.34$ ). The long-term increase in the level of gross beta radioactivity in the shallow groundwater at this well potentially reflects the slow, westward migration of the center of mass of the S-3 Site contaminant plume (DOE 1997). In contrast, the low-flow sampling results for gross beta activity reflect an indeterminate ( $R^2 = 0.01$ ) short-term trend (Figure 20). Note, however, that the gross beta result reported for the sample collected from the well in March 1999 is less than the MDA (8.9 pCi/L) and is probably an analytical error.

Monitoring results obtained during CY 1999 show that the concentration of dissolved chloroethenes in aquitard well GW-627, as illustrated by the results for PCE, reflect a strongly increasing ( $R^2 = 0.60$ ) long-term trend following the initial detection of this compound in February 1990 (Figure 21). Moreover, not only are the low-flow sampling results for PCE substantially higher (>300%) than previously evident in the well, but these results suggest an even greater rate of concentration increase than the conventional sampling results. Well GW-627 is completed at a depth of 270 ft bgs about 500 ft west of BG-A South (Figure 6), and the detection of PCE and the subsequent concentration increase indicates migration of this and other VOCs at depth in the aquitard.

As noted in Section 3.1.1.2, the VOC results reported for the groundwater samples collected from well GW-653 during CY 1999 continue the increasing long-term trend evident since early 1993, as illustrated by results for 12DCE (Figure 22), which is the principal compound in the well. This well is completed at a depth of 39 ft bgs about 500 ft west of well GW-627. The conventional and low-flow sampling results, based on comparison with pre-sampling concentrations and groundwater elevations in the well, show that the 12DCE concentrations are often highest during winter and spring when water levels are highest (Figure 22). This pattern suggests seasonally variable flux of VOCs toward discharge areas in NT-8.

The CY 1999 monitoring results for well GW-695 reflect the strongly increasing long-term trend indicated by historical data, and show that nitrate levels in the well have increased from about 1 mg/L in the early 1990s to about 10 mg/L (the MCL for nitrate) in the late 1990s (Figure 23). Low-flow sampling results define an indeterminate short-term trend that is seemingly dominated by seasonal concentration fluctuations (Figure 23), with higher nitrate levels evident during seasonally high flow conditions (winter and spring). This suggests that the increasing concentrations of nitrate over the long term reflect a corresponding increase in the overall flux of nitrate in the shallow groundwater at Exit Pathway Picket B.

An increasing long-term TCE concentration trend also is indicated by the CY 1999 monitoring results for spring SS-4 (Figure 25), which is located about 500 ft west of well GW-695 (Figure 6). Samples have been collected from spring SS-4 since January 1991 on a quarterly (1991-1993) or semiannual (1994-1999) basis,

and review of the results for these samples show that the TCE concentrations increased from an average of 4 µg/L (i.e., <MCL) evident through July 1995 to an average of almost 8 µg/L (i.e., >MCL) through August 1999. The long-term increasing trend for SS-4 appears to have begun in 1995 (Figure 25). Historically, a slightly decreasing trend for the results from 1991 through 1995 was followed by a strongly increasing trend in the results from 1995 through 1999. Also, the TCE concentrations are typically higher in the samples collected from the spring during seasonally low-flow conditions (summer and fall); for example, the three highest TCE concentrations ever reported for spring SS-4 were detected in the samples collected in August 1997 (10 µg/L), August 1999 (11 µg/L), August 1998 (14 µg/L). This suggests that the TCE concentrations reflect variable degrees of dilution during seasonally high flow conditions (winter and spring), and that the increasing long-term trend reflects increased overall flux of TCE in the shallow karst network connected with spring SS-4.

#### 4.0 CONCLUSIONS AND RECOMMENDATIONS

The groundwater and surface water quality data obtained during CY 1999 are generally consistent with historical results regarding the sources of contamination in the Bear Creek Regime, the types of contaminants from each source area, the pattern and extent of contaminant transport, and long-term contaminant trends. This conclusion is based on evaluation of the data for the primary groundwater and surface water contaminants (nitrate, uranium, VOCs, and radioactivity). A summary of significant findings based on the evaluation of these CY 1999 results for the purposes of DOE Order 5400.1A is provided below.

The CY 1999 monitoring results reported for 53 monitoring wells, including 32 aquitard wells, 20 aquifer wells, and four Westbay™ wells (two with sampling ports in both hydrogeologic units), were evaluated for the purposes of DOE Order 5400.1 Surveillance Monitoring. These results indicate migration of contaminants from the S-3 Site and the BCBG WMA in the aquitard, and influx/transport of contaminants from the S-3 Site, Spoil Area I, Rust Spoil Area (or nearby source in the Bear Creek floodplain), the Oil Landfarm WMA, and the BCBG WMA in the aquifer. The CY 1999 monitoring results for most of the monitoring wells reflect historical data and do not indicate any significant change in the extent or distribution of groundwater contaminants in the Bear Creek Regime. Substantial natural attenuation of VOCs at depth in the aquitard may be indicated by the lack of PCE in samples from wells located downdip (Westbay well GW-134) and along strike (wells GW-346 and GW-526) from the S-3 Site, and by the elevated concentrations of degradation end products (e.g., VC) in samples from wells at the BCBG WMA (GW-046, GW-082, GW-242, and GW-627).

The CY 1999 monitoring results reported for 12 surface water stations (including 5 northern tributaries), seven springs that discharge into Bear Creek, and four aquifer wells at the westernmost Exit Pathway Picket (Picket W) were evaluated for the purposes of DOE Order 5400.1 Exit Pathway/Perimeter Monitoring. These results are generally consistent with historical data and show that contaminant concentrations generally decrease with distance from the S-3 Site, but localized segments of the Bear Creek show increases in the concentration of some contaminants with distance from the S-3 Site that reflects input of contaminated groundwater from other waste sites or from the aquifer. Moreover, the CY 1999 monitoring results for the surface water samples collected from Bear Creek at BCK-00.63, which is outside the boundaries of the Bear Creek Regime near the confluence between Bear Creek and East Fork Poplar Creek, show that total uranium concentrations and gross alpha activity exceed their respective proposed (0.02 mg/L) and current (15 pCi/L) MCLs.

Evaluation of the CY 1999 monitoring results with respect to contaminant concentration trends in the Bear Creek regime, as required under DOE Order 5400.1, indicates that increasing long-term concentration trends are evident for selected groundwater contaminants (primarily VOCs) in seven of the CY 1999 sampling locations, including four aquitard wells (GW-082, GW-537, GW-627, and GW-653), two aquifer wells (GW-226 and GW-695), and one spring that discharges into Bear Creek (SS-4). The increasing trends in the groundwater at the aquitard wells potentially represent westward contaminant migration along strike near the plume boundaries, while the increasing trends in the groundwater at the aquifer wells and spring SS-4 may reflect the hydrochemical dynamics within the groundwater plumes or increased flux of contaminants in the shallow karst system in the Maynardville Limestone. Monitoring results for the remaining CY 1999 sampling locations generally continue the decreasing (or indeterminate) concentration trends evident since the late 1980s and early 1990s.

Based on evaluation of the CY 1999 groundwater monitoring data,, the following actions are recommended:

- add aquitard well GW-082 to the Surveillance Monitoring network for the BCBG WMA. The CY 1999 data for this well supports a substantial increase in VOC concentrations from the early 1990s and suggests plume migration from BG-C West.
- Drop aquifer wells GW-056 and GW-685 at Exit Pathway Picket A and GW-621 at Exit Pathway Picket B from the Surveillance Monitoring network. These wells do not intercept groundwater with elevated concentrations of the primary components of the plumes in the Bear Creek Regime and have a substantial monitoring history.
- Collect samples twice during CY 2001 from the following six wells which have not been sampled in several years: aquitard well GW-098 and aquifer wells GW-225, GW-364, and GW-365 located downgradient of the Oil Landfarm WMA; and aquitard wells GW-124 and GW-616 located downdip of the S-3 Site.
- Replace BCK-10.60 with a surface water station in Bear Creek near Exit Pathway Picket B. The proposed sampling station should be located downstream of the losing reach of Bear Creek so that dry season samples can be collected. Samples have not been collected from BCK-10.60 during the third quarter sampling event for the last two calendar years because the creek was dry at this location.

## 5.0 REFERENCES

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**APPENDIX A**

**FIGURES**

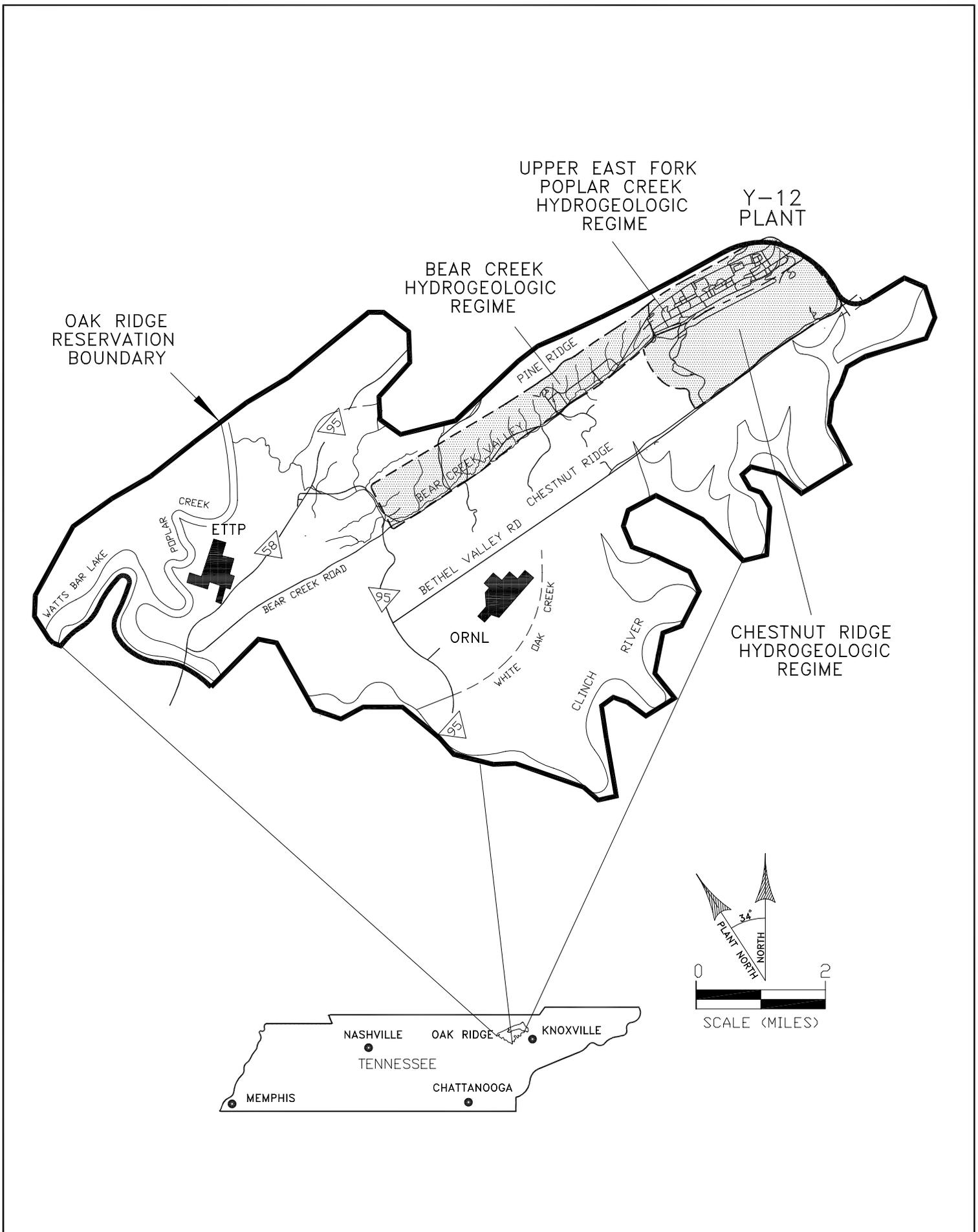
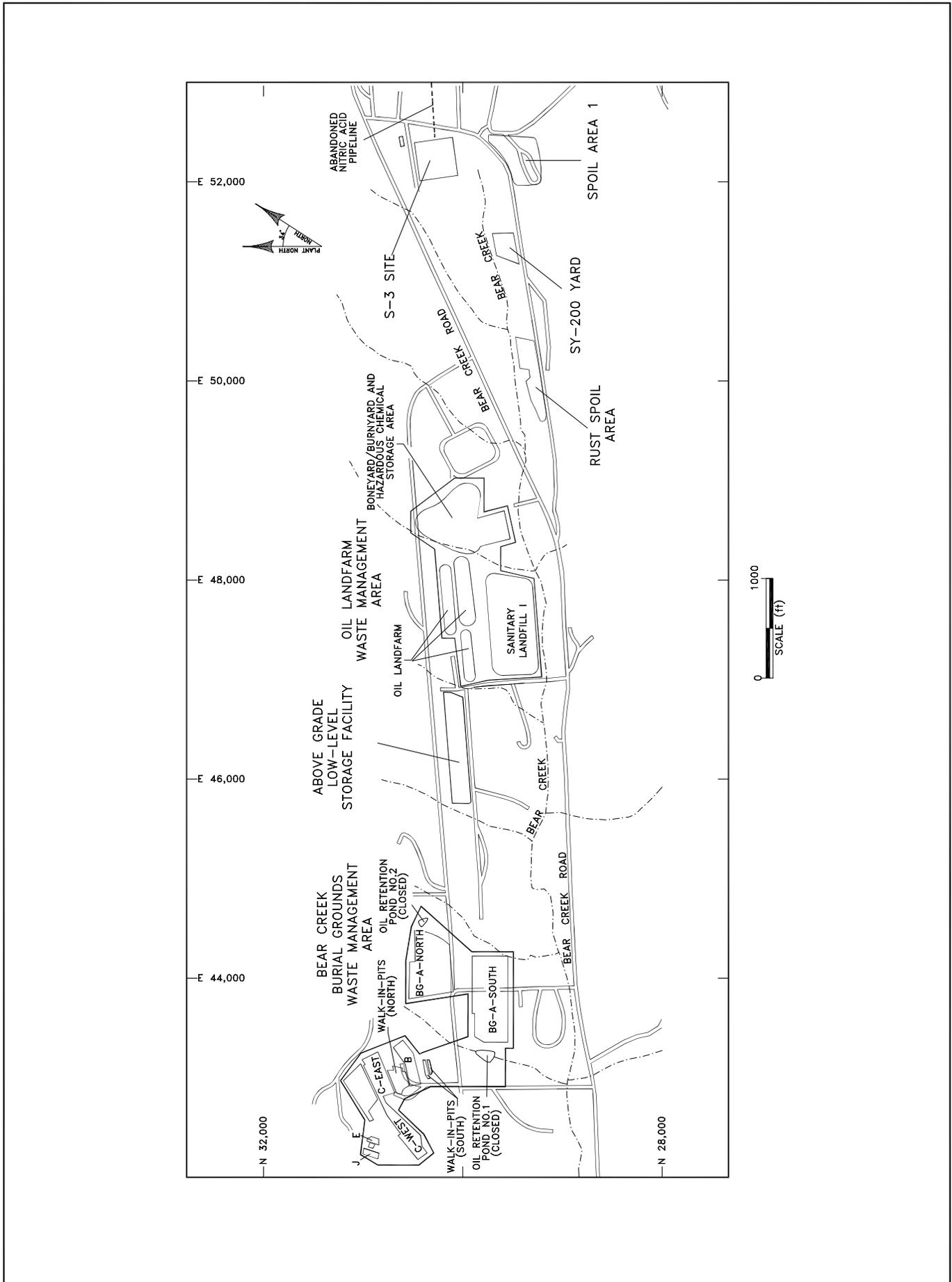
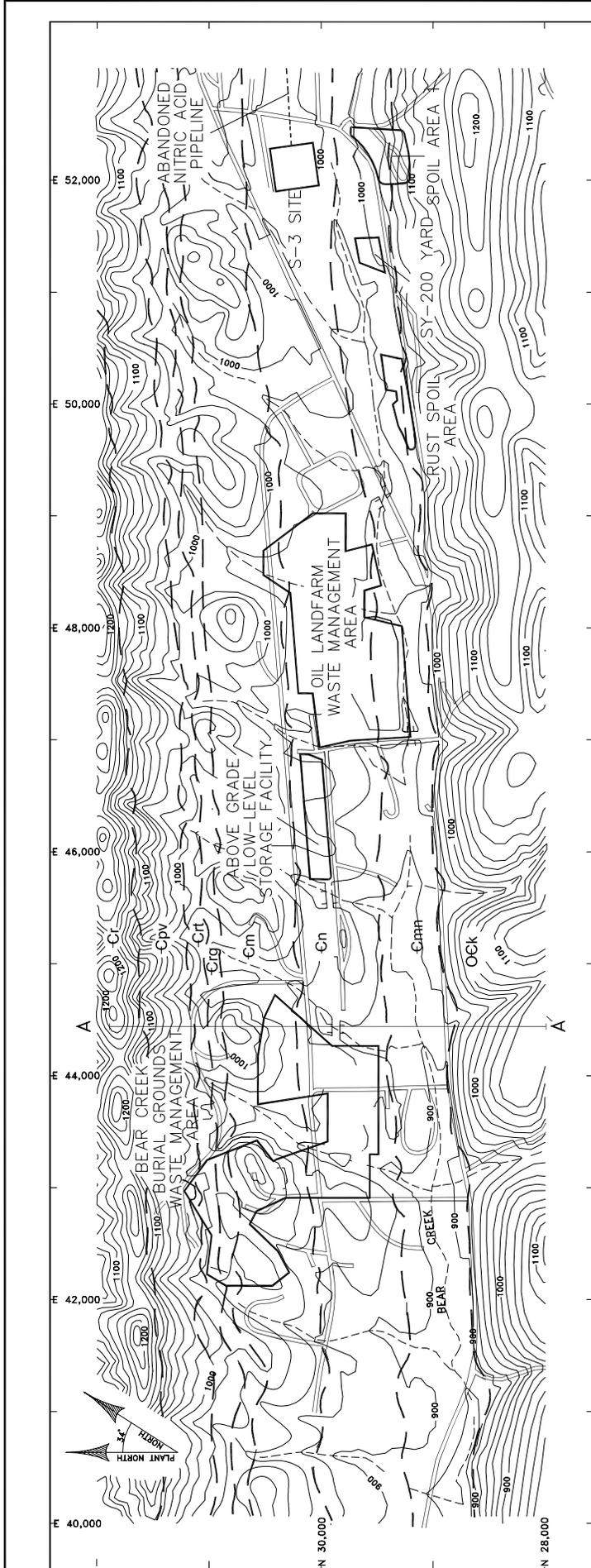


Fig. 1. Hydrogeologic regimes at the Y-12 Plant.



DER99B\_02 08/07/00

Fig. 2. Waste management sites and regulated units in the Bear Creek Hydrogeologic Regime.



SOURCE: King and Haase, 1987

SYSTEM GROUP	HYDRO UNIT	FORMATION	MAP SYMBOL	THICKNESS (ft)
CAMBRIAN	UPPER	COPPER RIDGE DOLOMITE	Ock	NOT DETERMINED
	MIDDLE	MAYNARDVILLE LIMESTONE	€mn	418-450
CONASAUGA	AQUITARD	NOLICHUCKY SHALE	Cn	422-550
		MARYVILLE LIMESTONE	Cm	346-445
		ROGERSVILLE SHALE	€rg	90-120
		RUTLEDGE LIMESTONE	€rt	90-120
		PUMPKIN VALLEY SHALE	€pv	260-320
LOWER		ROME	Cr	NOT DETERMINED

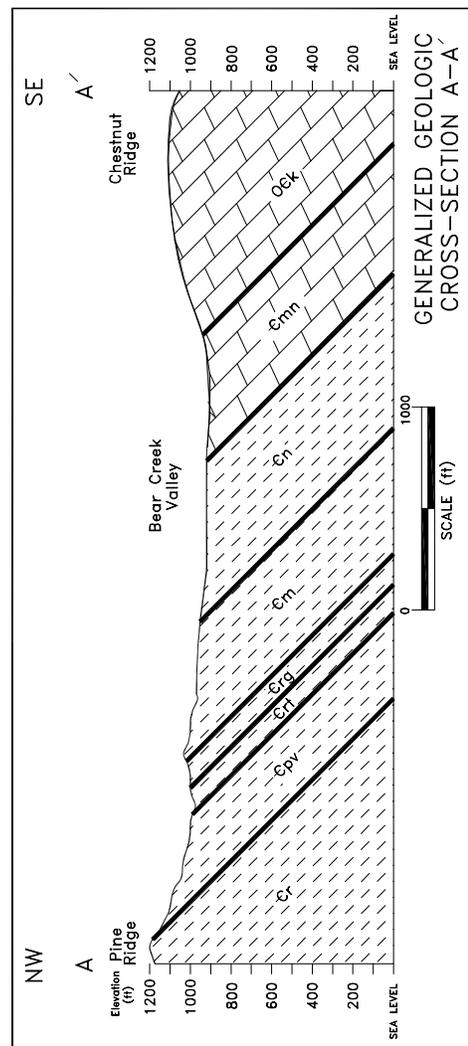
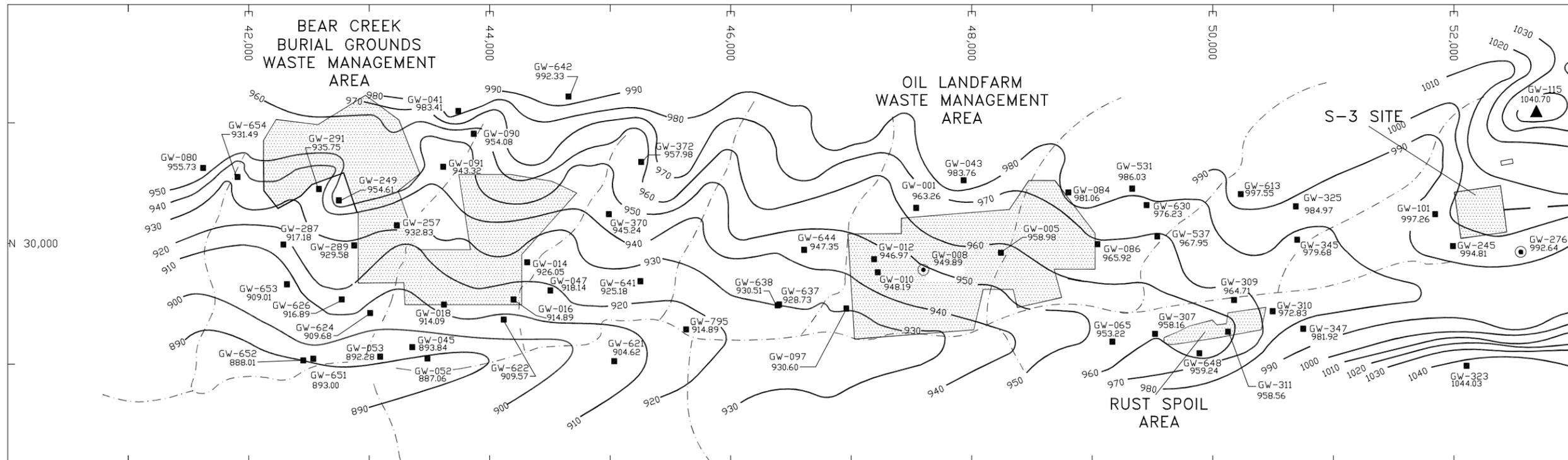
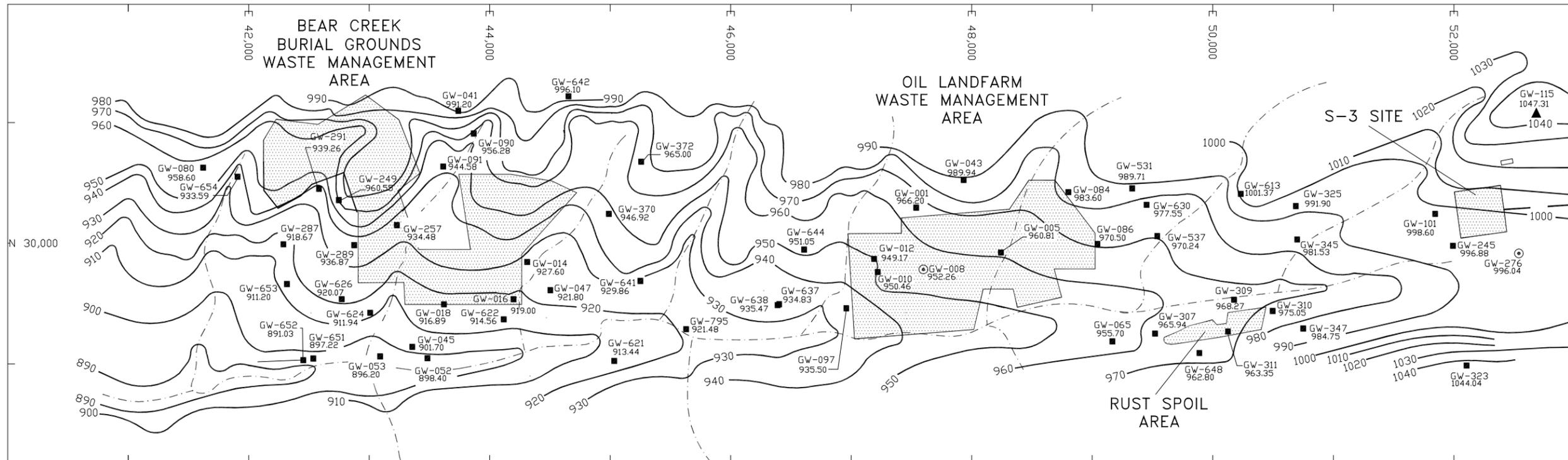


Fig. 3. Topography and bedrock geology in the Bear Creek Hydrogeologic Regime.



**EXPLANATION**

- WATER TABLE INTERVAL MONITORING WELL
- ▲ RCRA BACKGROUND / UPGRADIENT MONITORING WELL
- ⊙ RCRA POINT-OF-COMPLIANCE MONITORING WELL
- 920— WATER-LEVEL ISOPLETH (ft msl)
- - - SURFACE DRAINAGE FEATURE

Fig. 4. Seasonal groundwater elevations in the Bear Creek Hydrogeologic Regime, 1999.

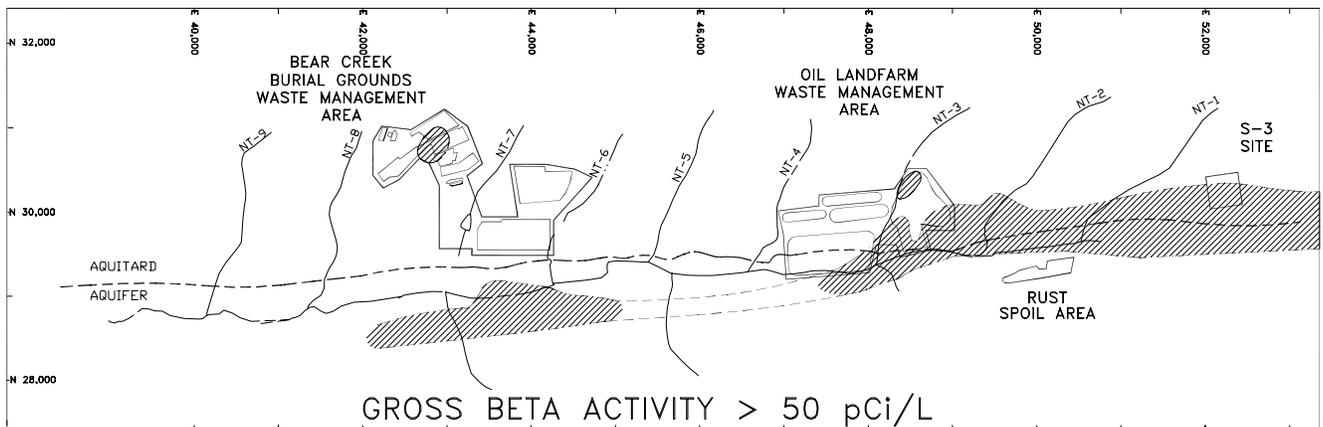
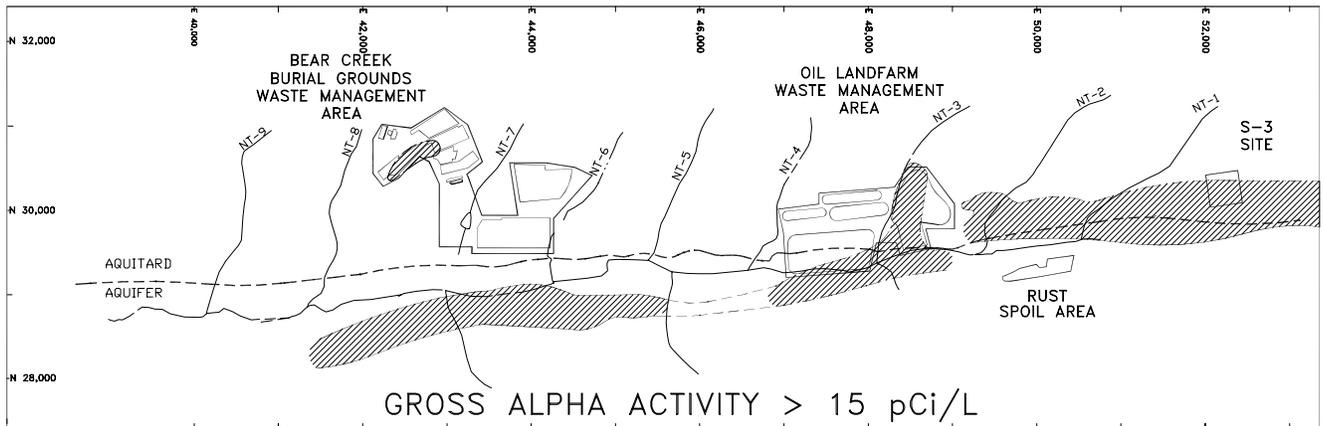
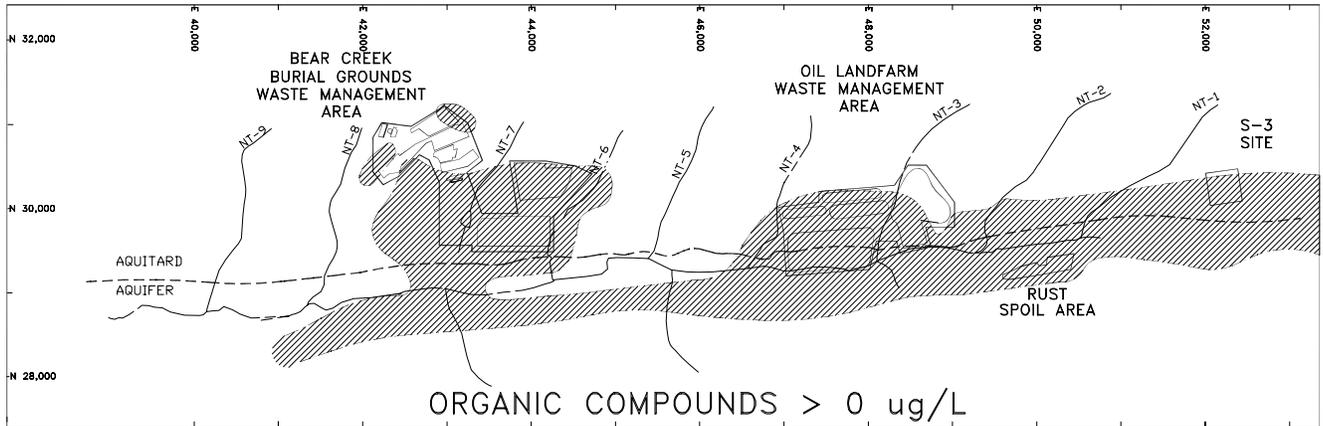
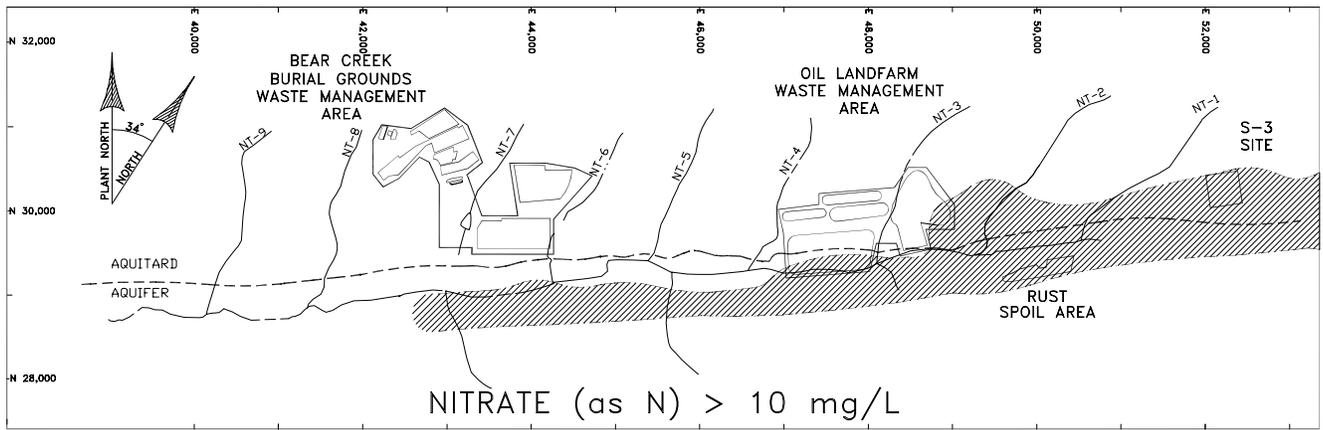
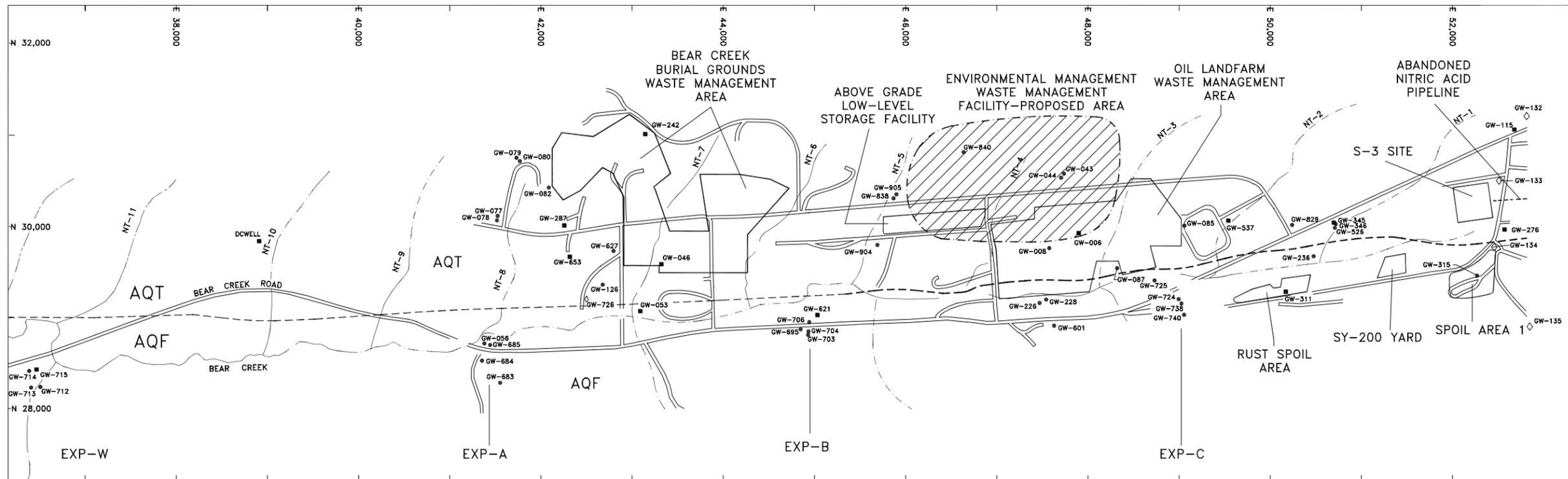
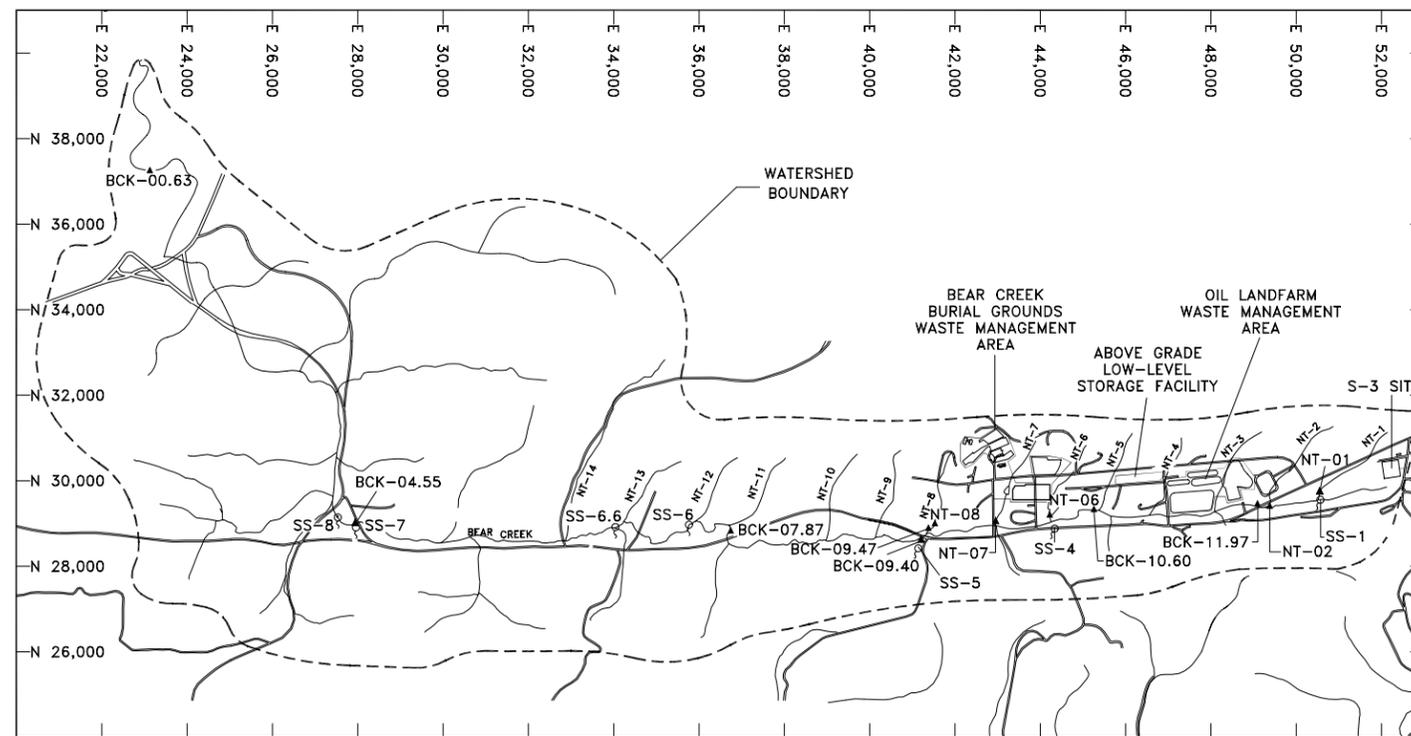


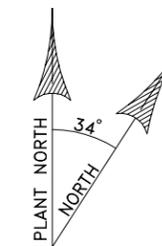
Fig. 5. Generalized extent of groundwater contamination in the Bear Creek Hydrogeologic Regime.



MONITORING WELL LOCATIONS



SPRINGS AND SURFACE WATER SAMPLING LOCATIONS



EXPLANATION

- — Water Table Monitoring Well
- — Bedrock Monitoring Well
- ◇ — Well With Westbay Multipoint Monitoring System
- ▲ — Surface Water Sampling Station
- ♀ — Spring Sampling Station
- EXP-C — Exit Pathway, Maynardville Limestone Picket
- — Surface Drainage Feature
- NT-5 — North Tributary
- AQT — Aquitard
- - - - - Approximate Nolichucky Shale\Maynardville Limestone Contact
- AQF — Aquifer

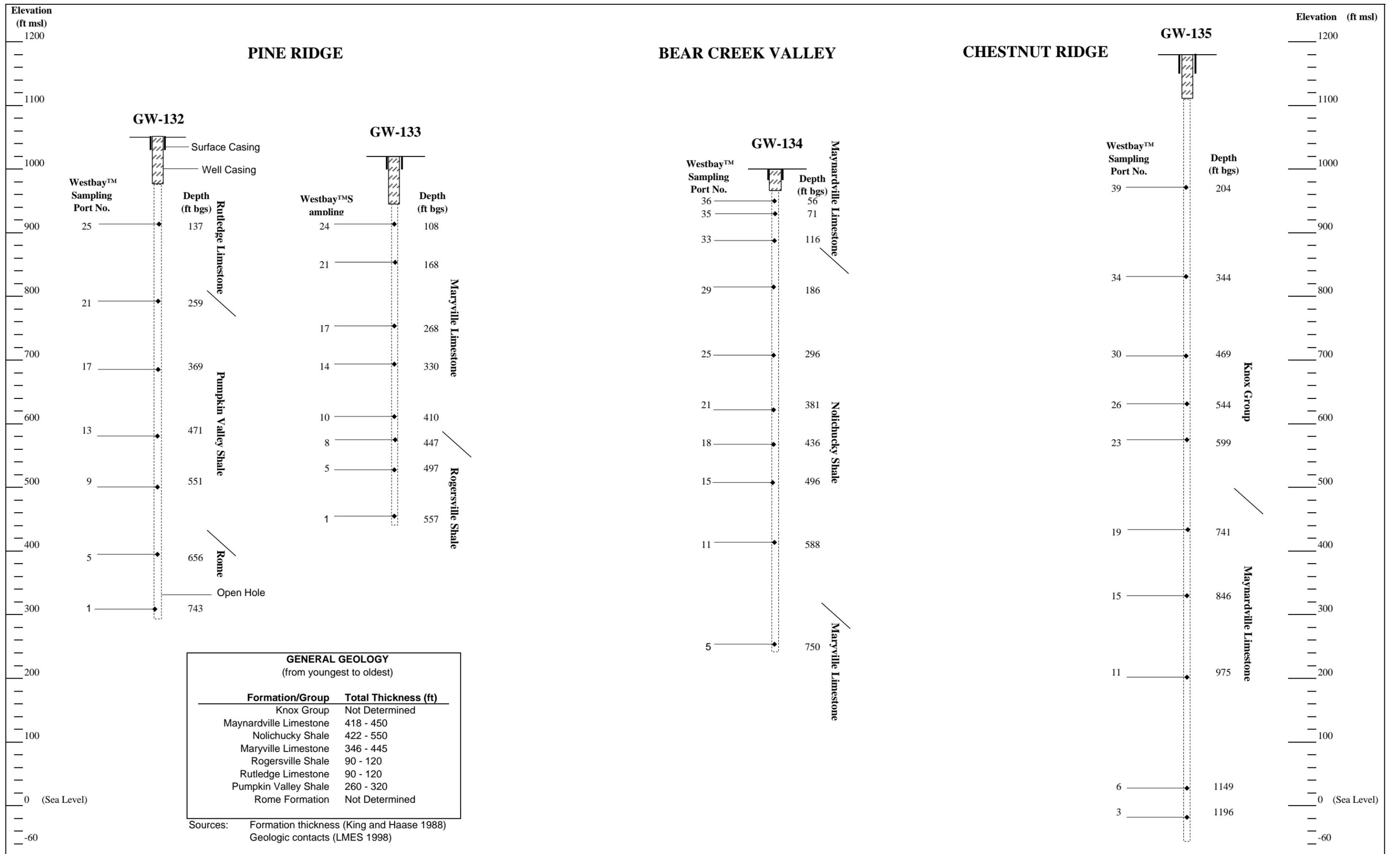
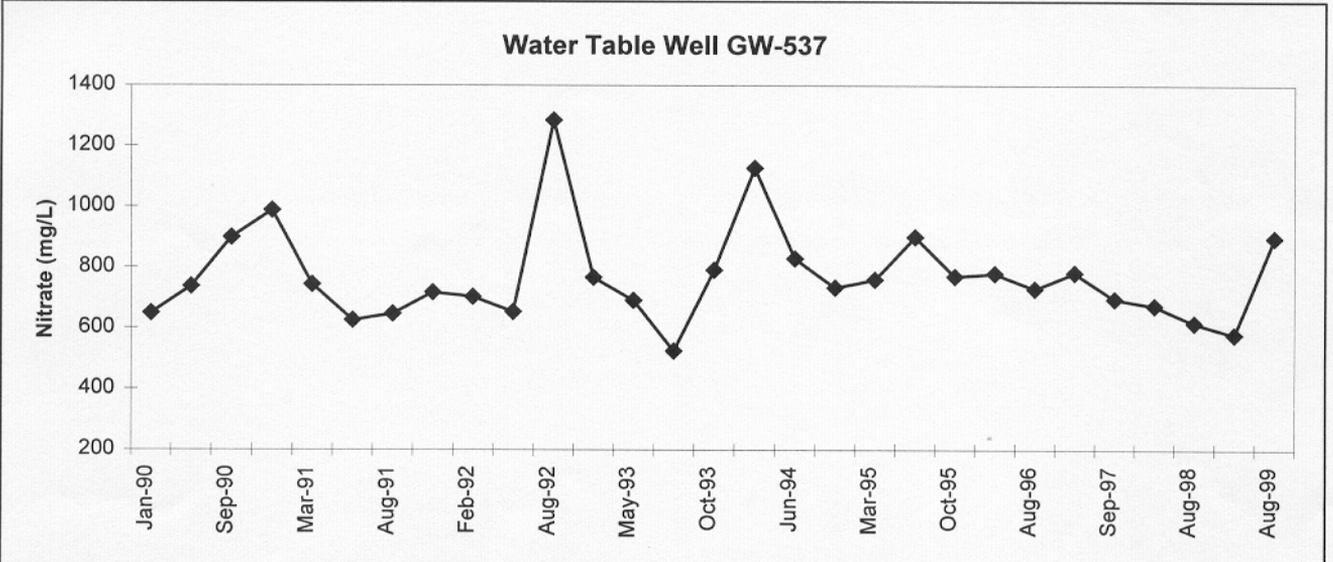
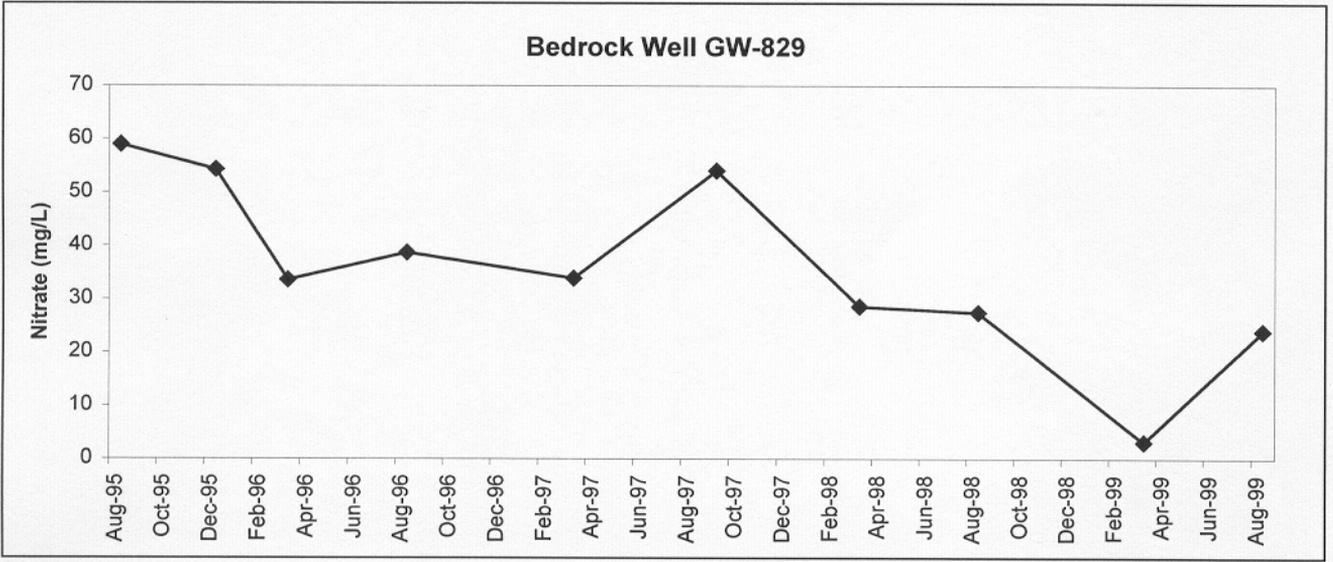
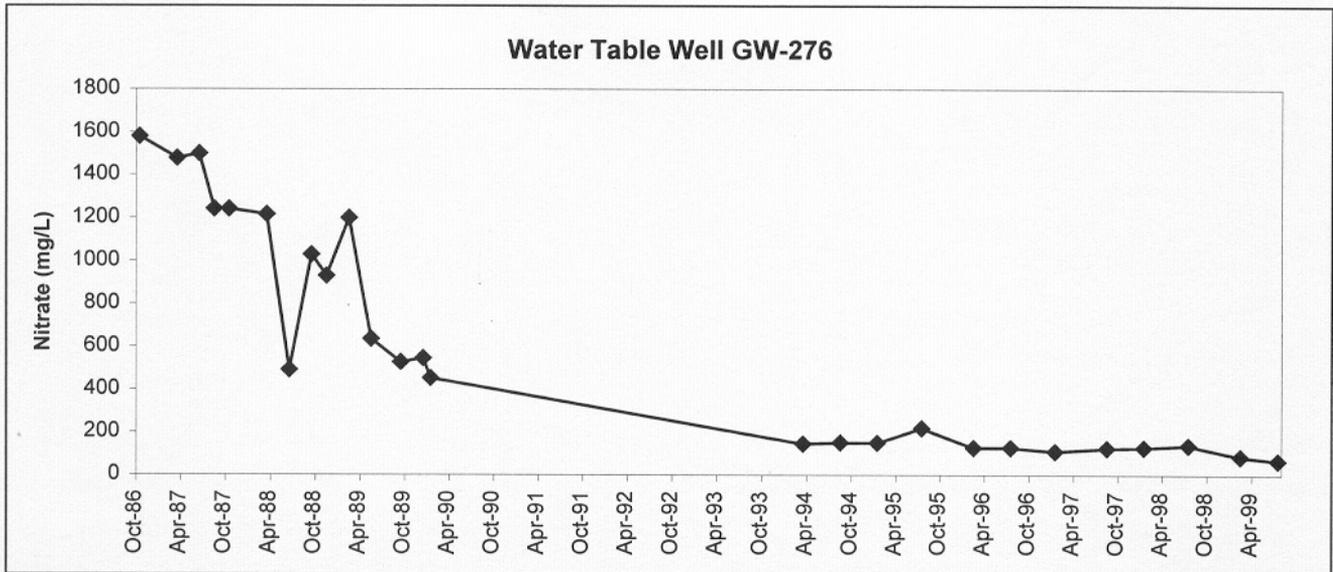


Fig.7. Westbay™ monitoring system sampling port depths in wells GW-132, GW-133, GW-134, and GW-135.



Note: Nitrate MCL = 10 mg/L

Fig. 8. Nitrate concentration trends in Aquitard wells GW-276, GW-537, and GW-829.

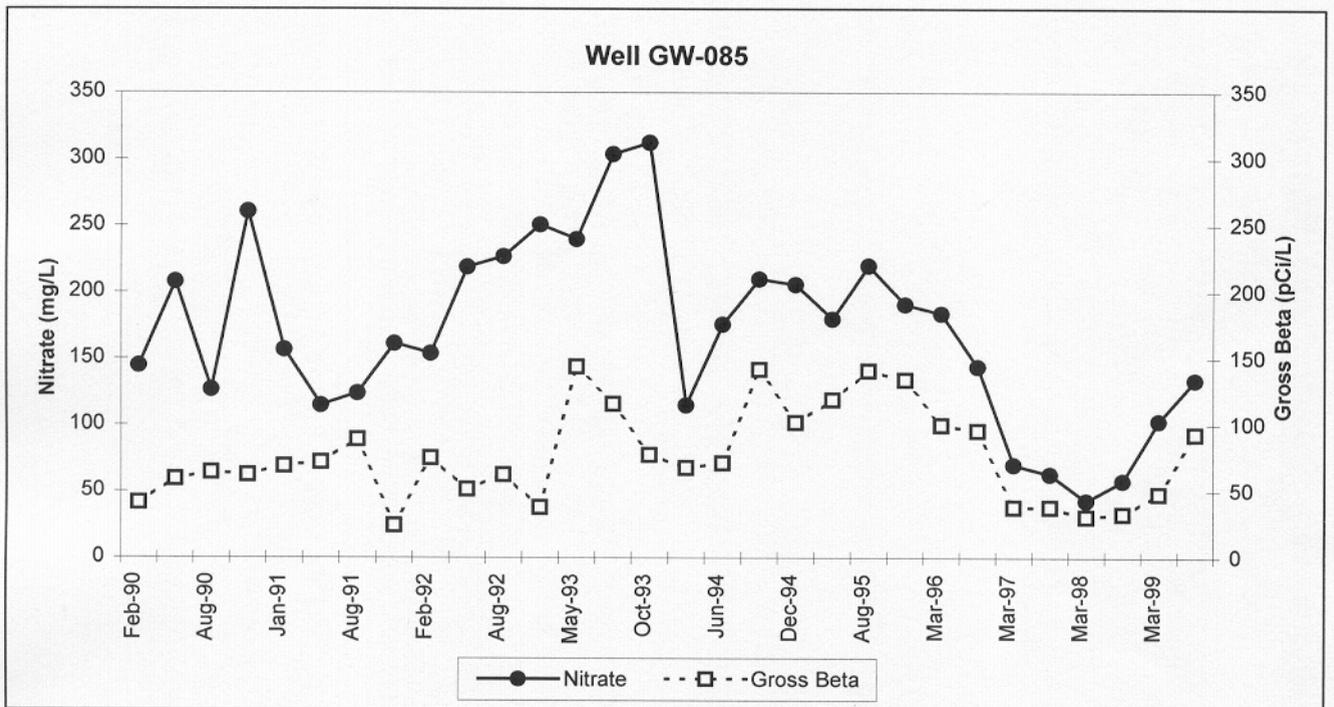


Fig. 9. Nitrate and gross beta concentration trends in well Aquitard GW-085.

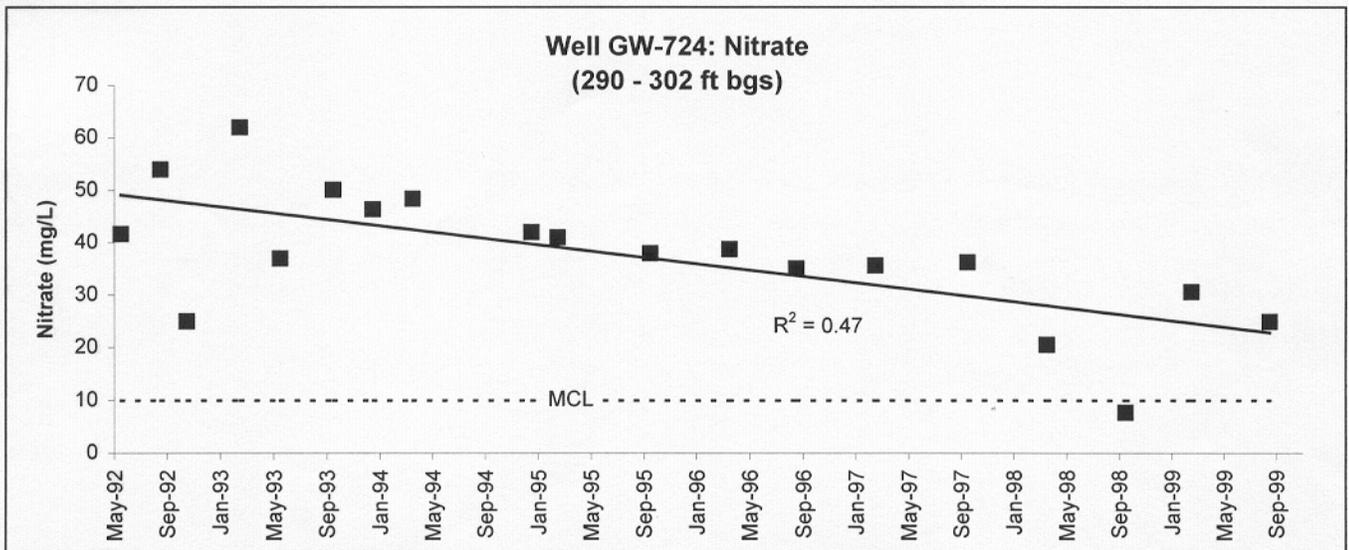
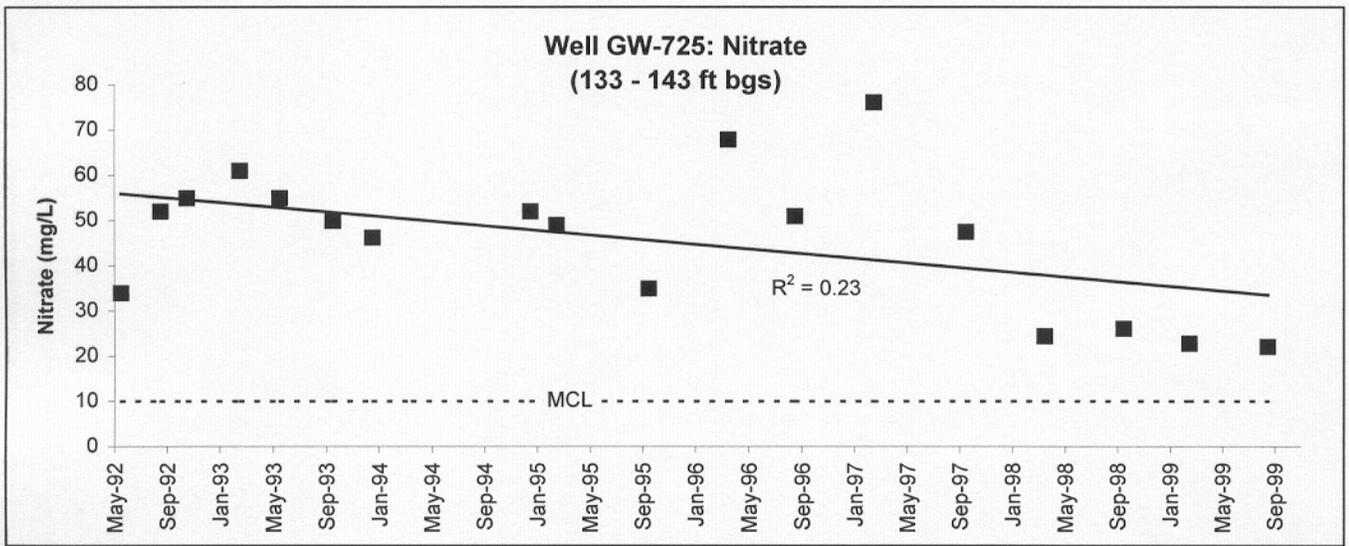
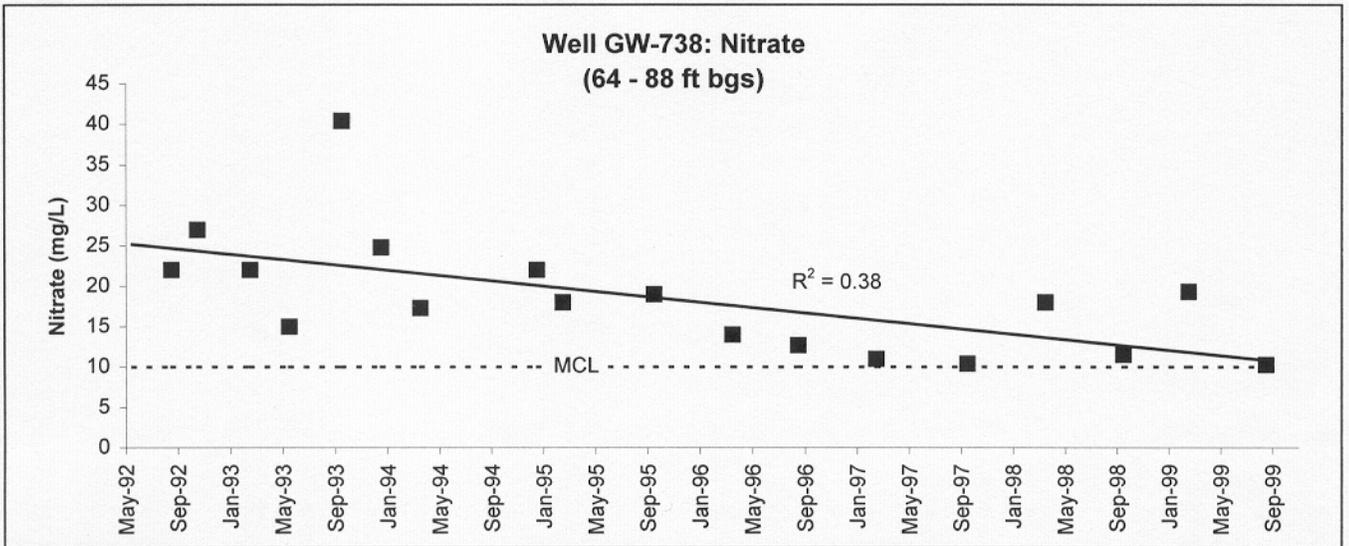


Fig. 10. Nitrate concentration trends in Aquifer wells GW-724, GW-725, and GW-738.

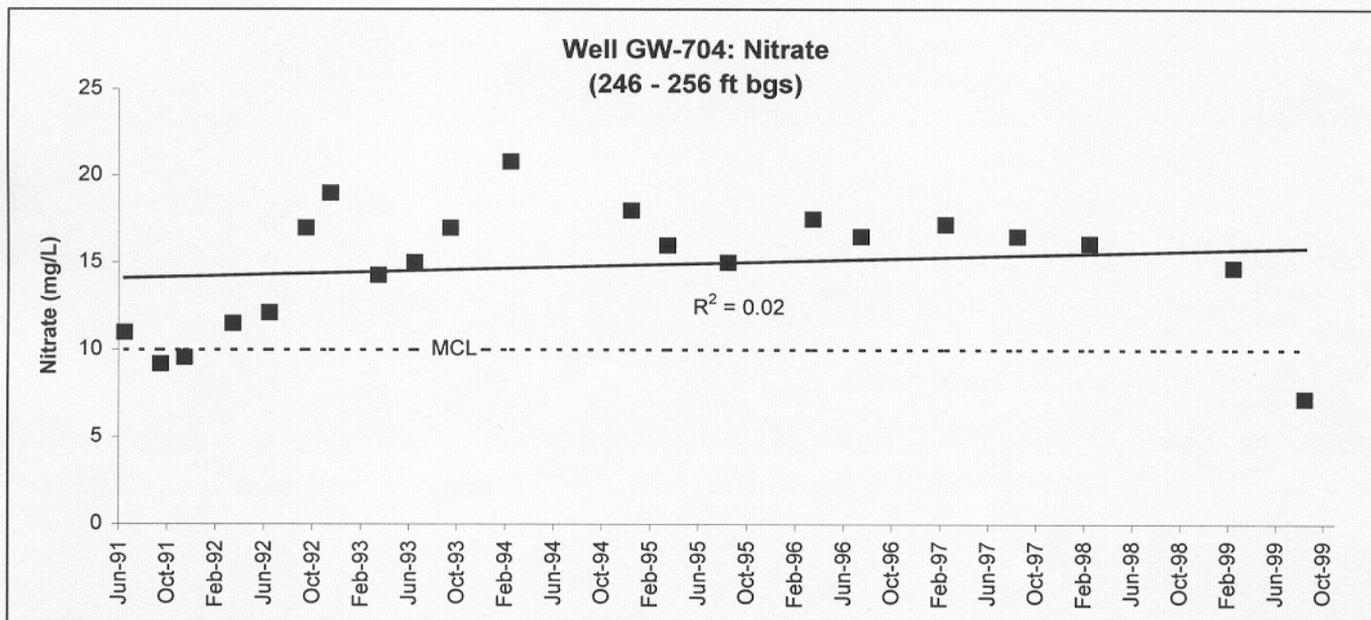
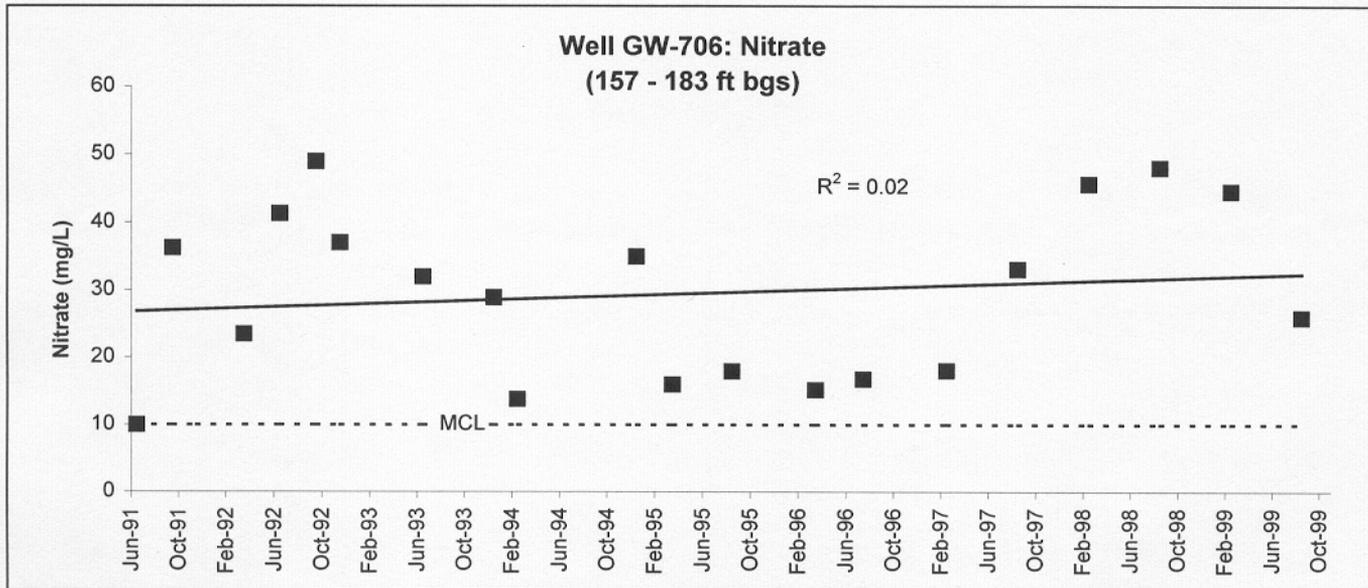


Fig. 11. Nitrate concentration trends in Aquifer wells GW-704 and GW-706.

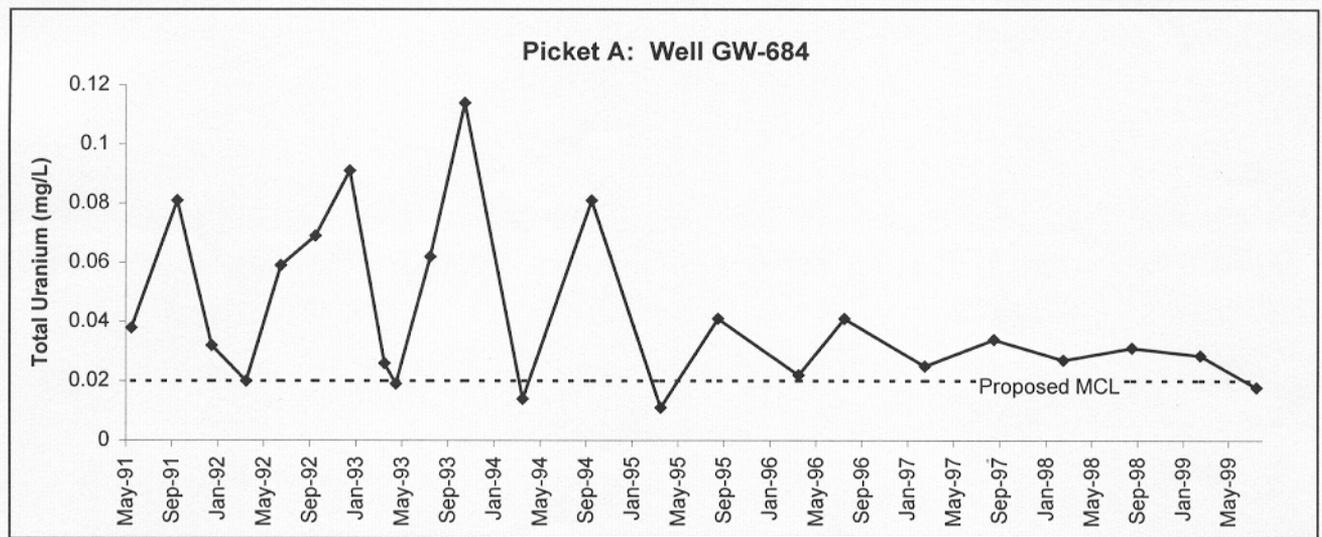
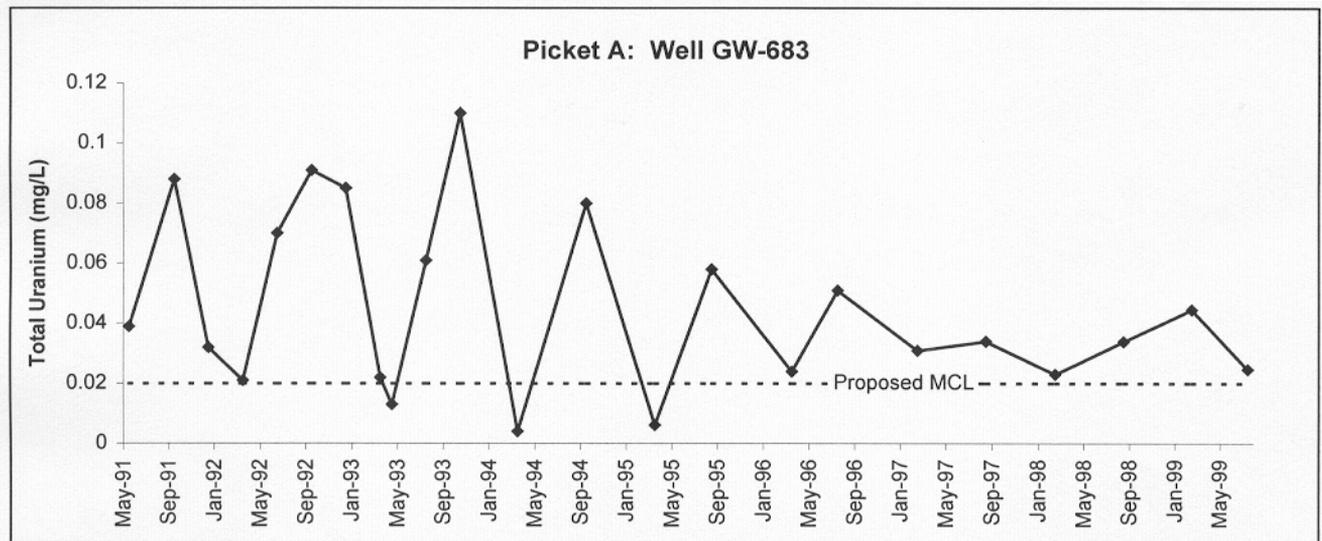
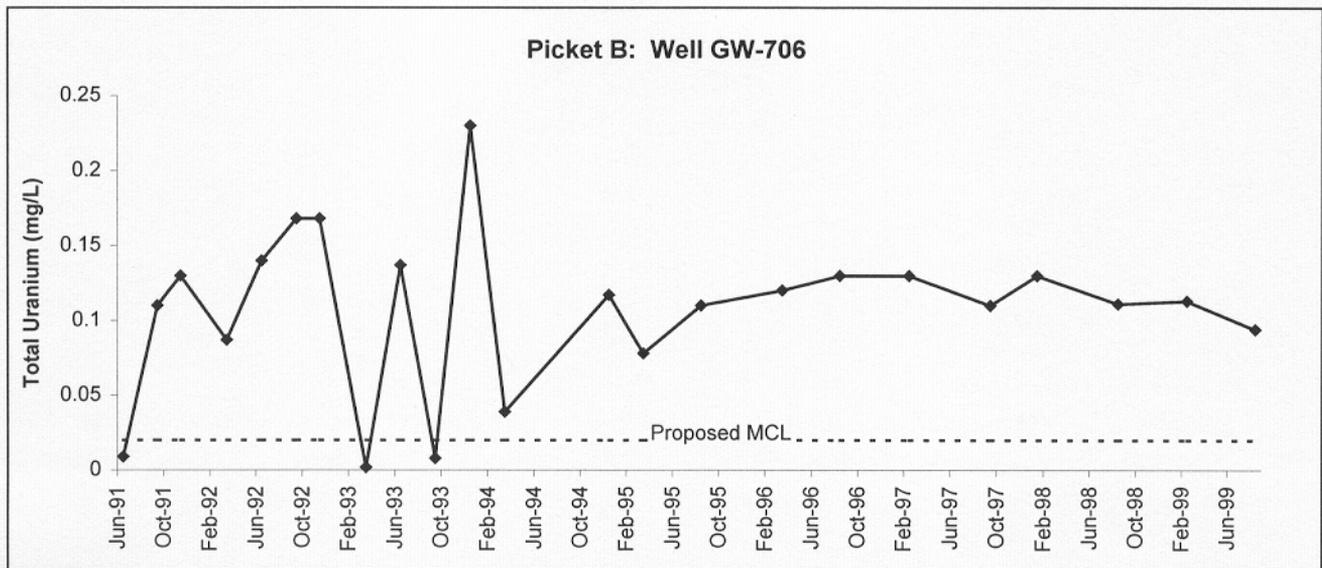


Fig. 12. Uranium concentration trends in Aquifer wells GW-683, GW-684, and GW-706.

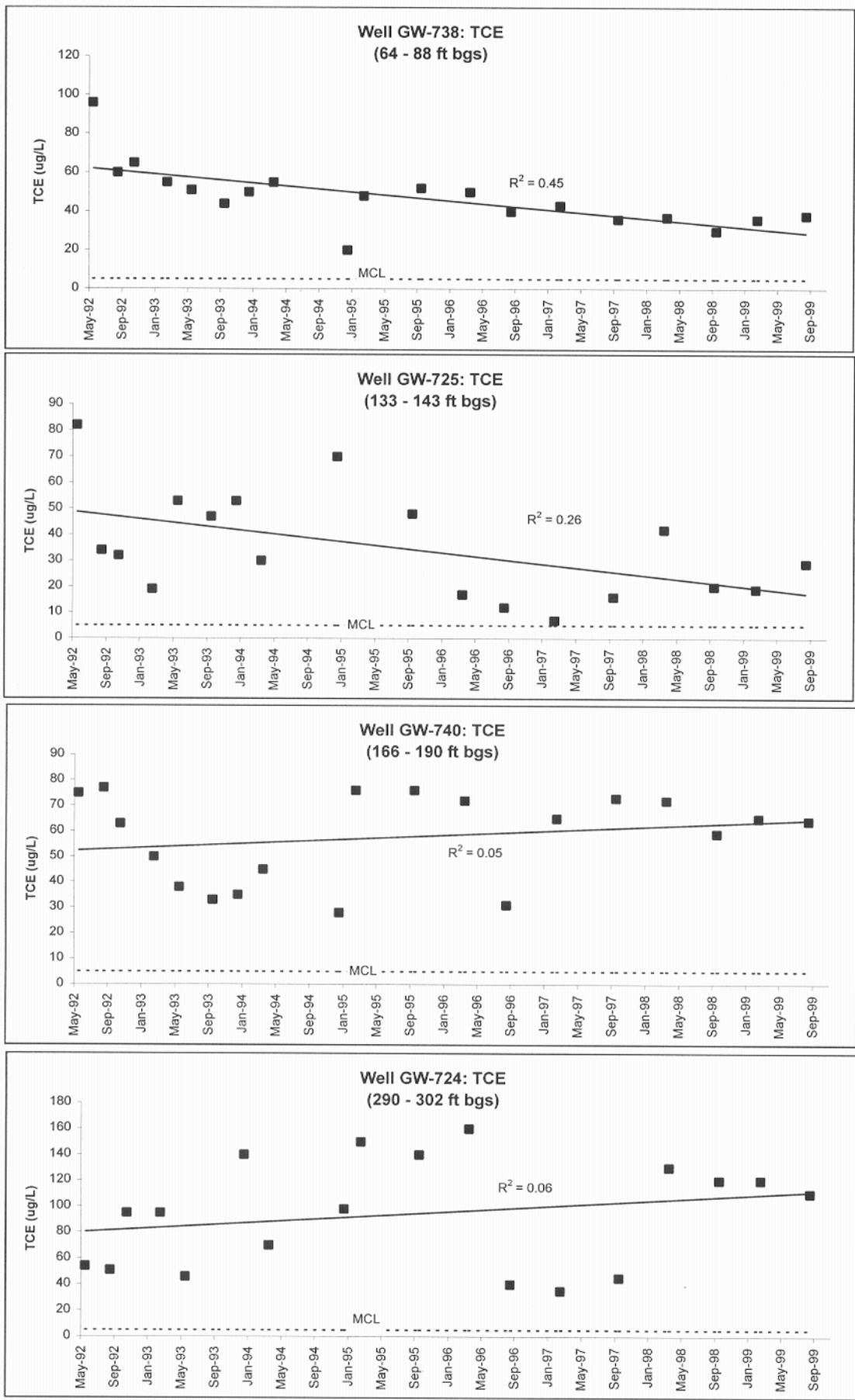


Fig. 13. TCE concentration trends in Aquifer wells GW-724, GW-725, GW-738, and GW-740.

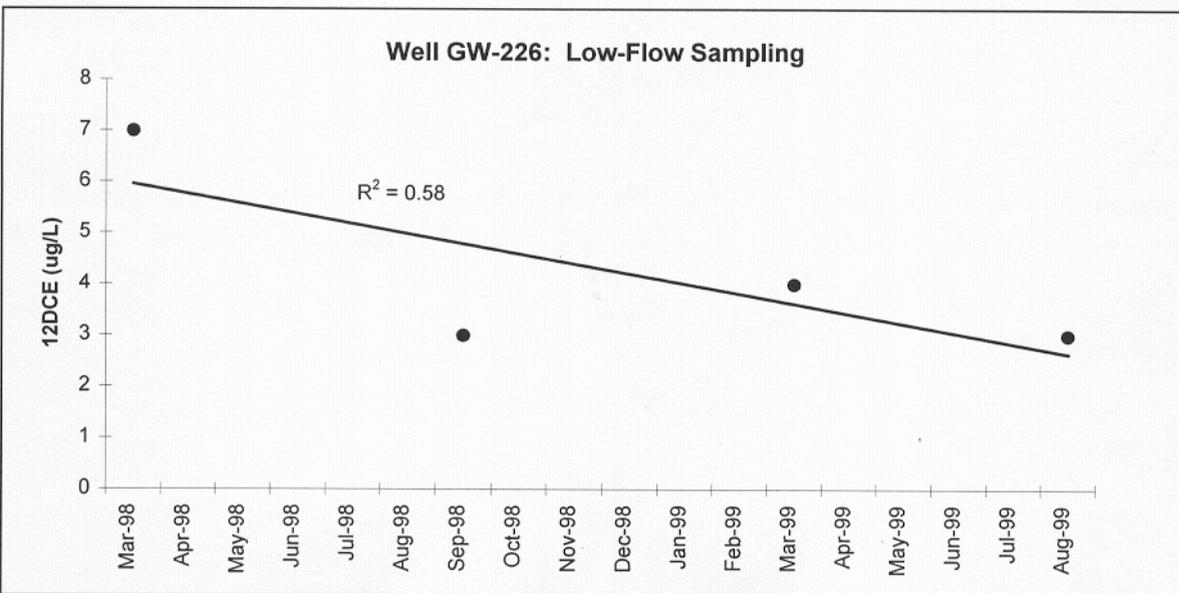
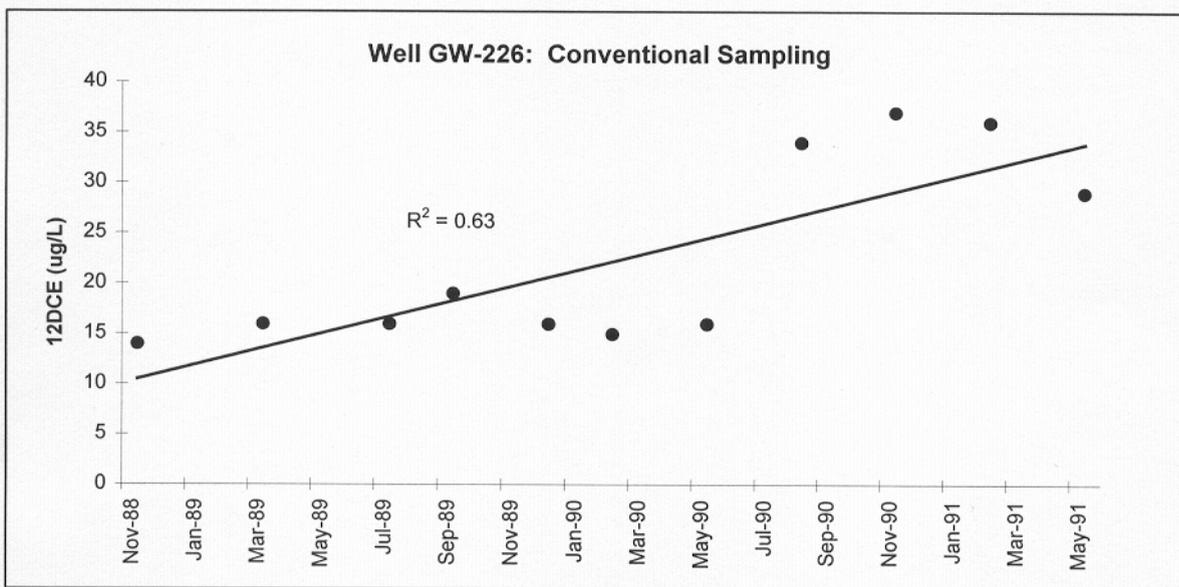
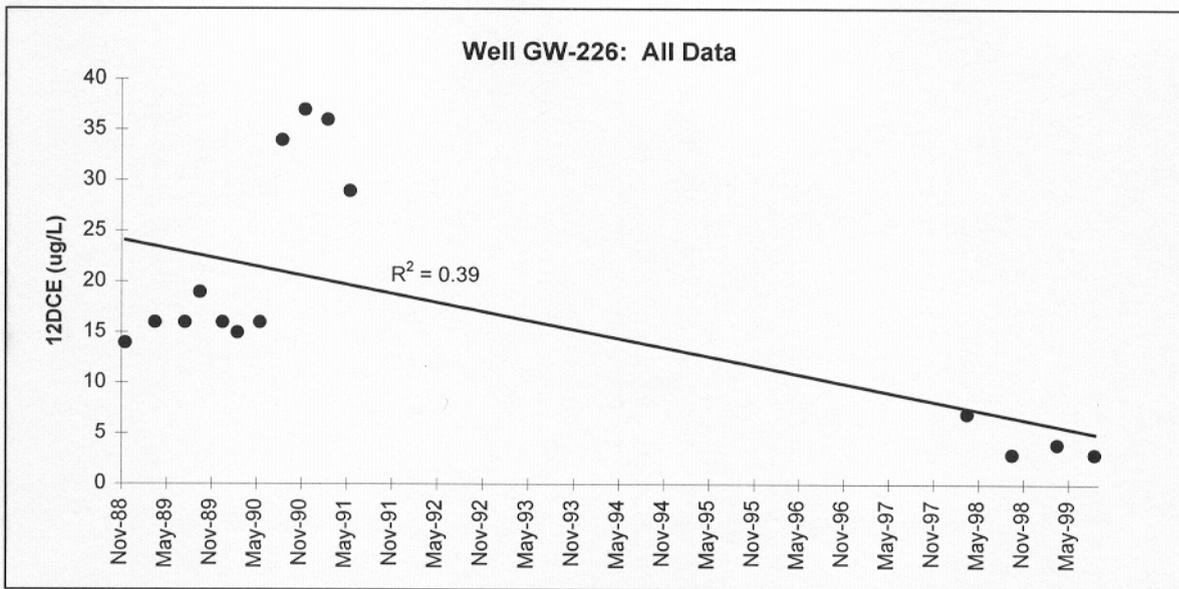


Fig. 14. Total 12DCE concentration trends in Aquifer well GW-226.

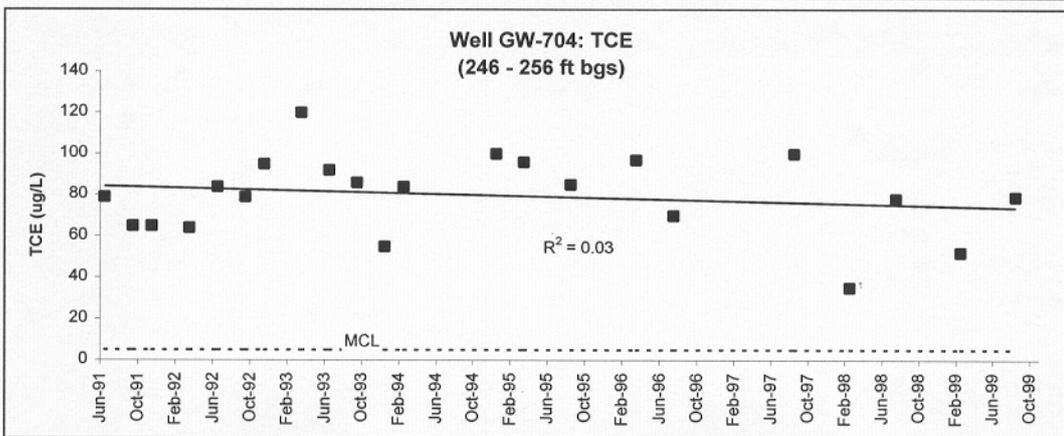
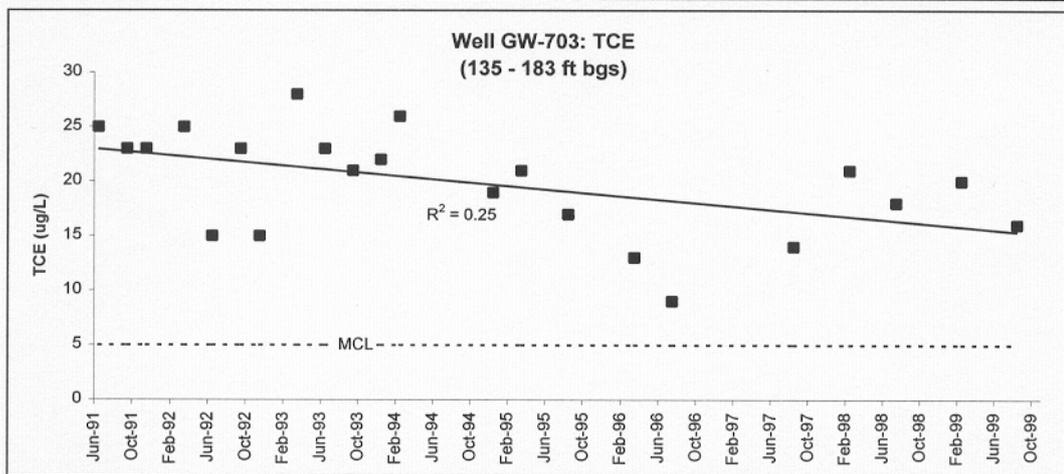
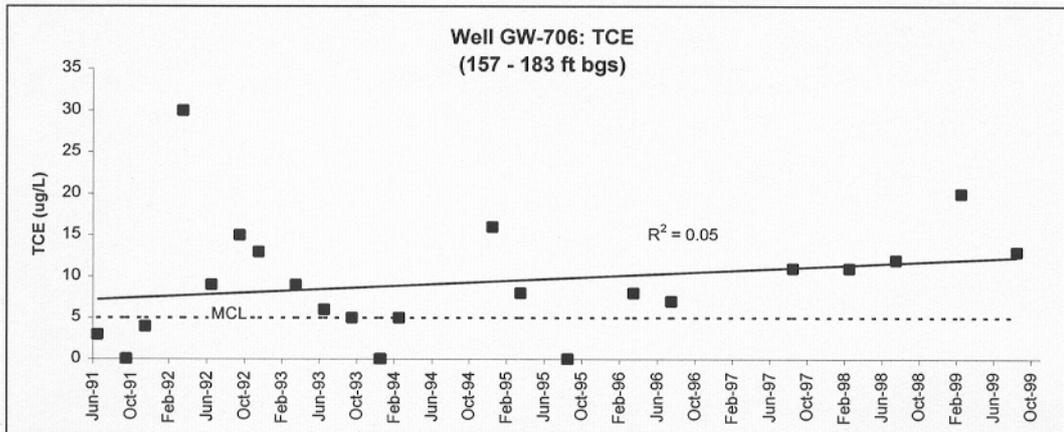
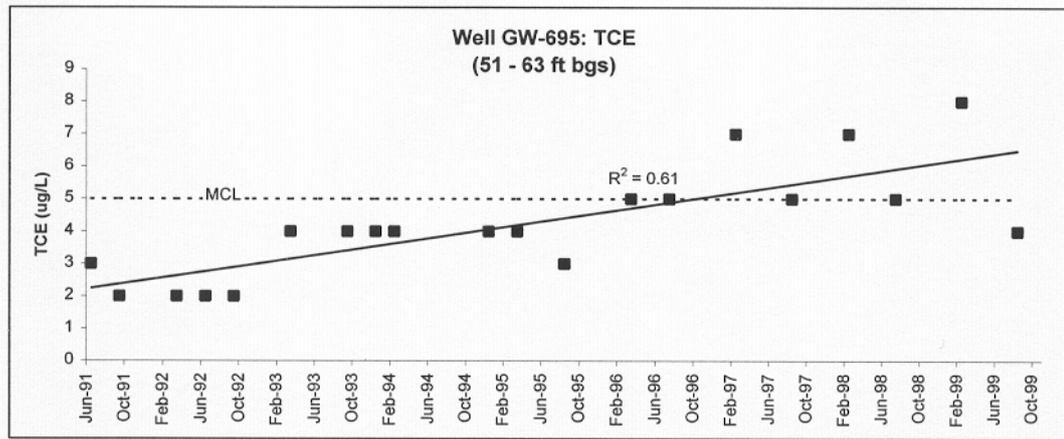
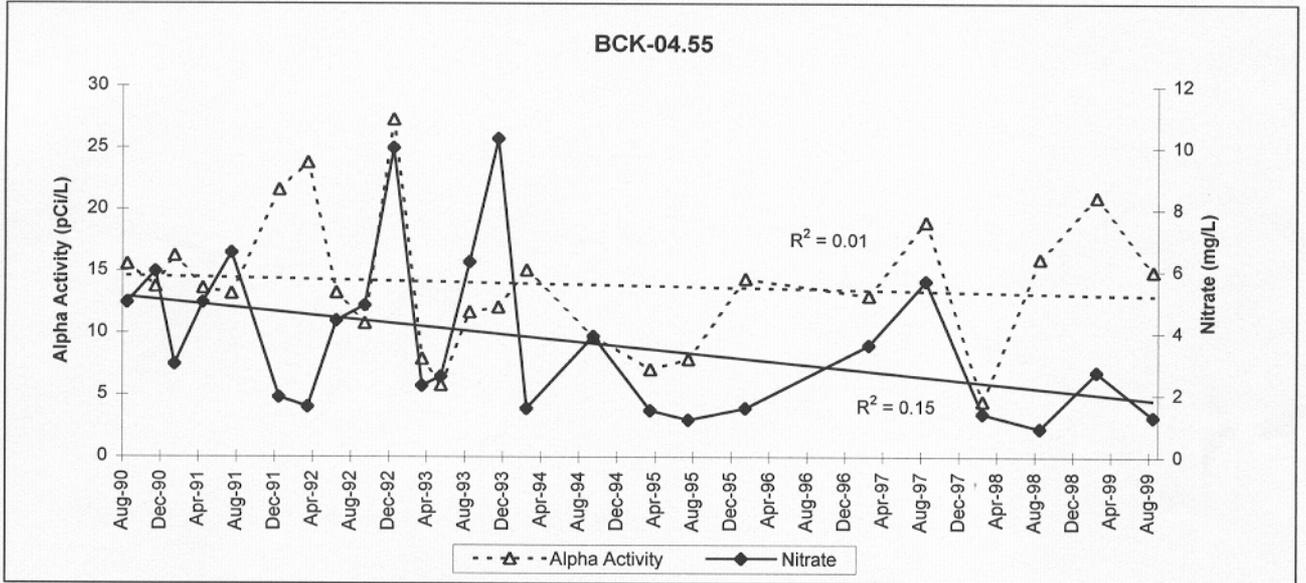
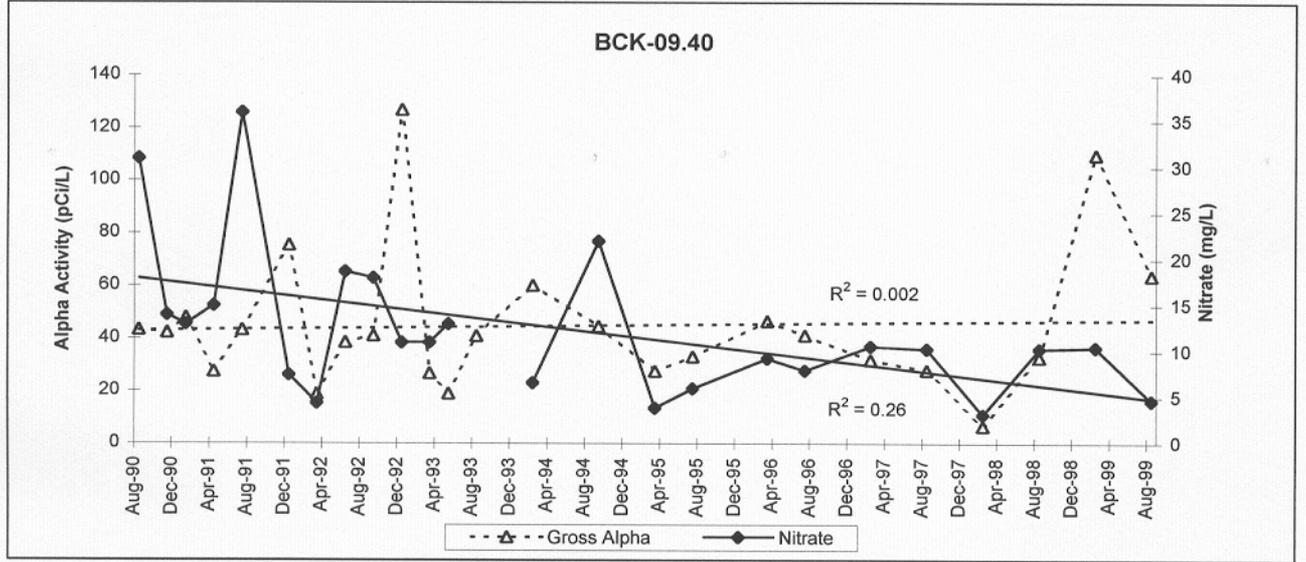
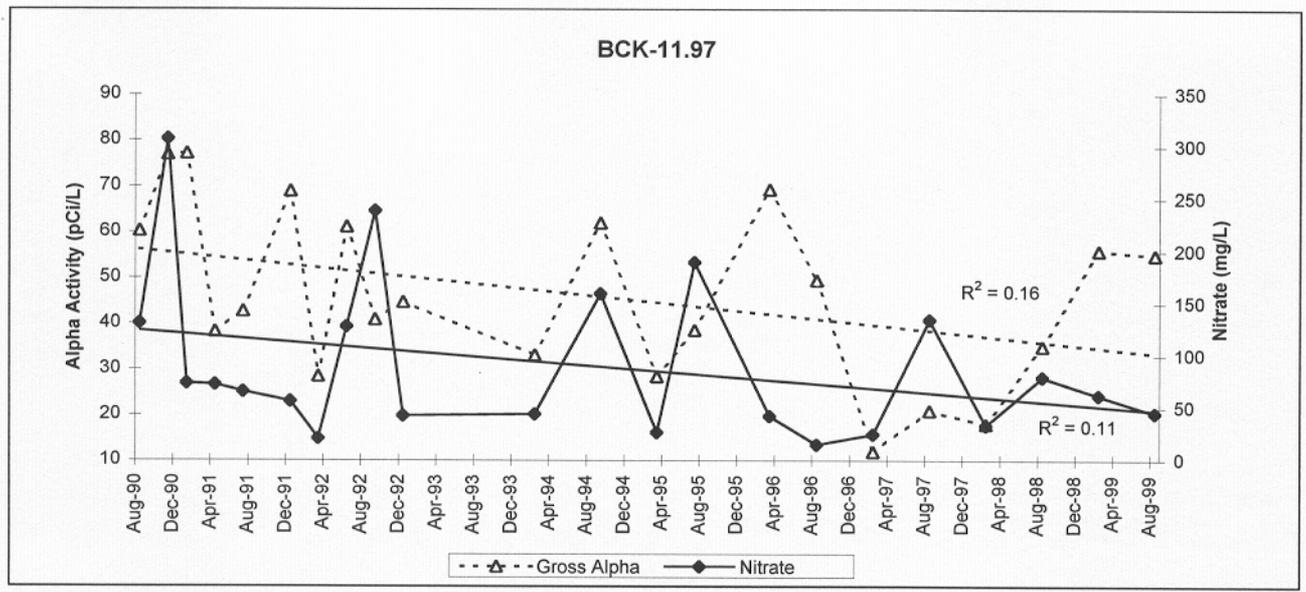


Fig. 15. TCE concentration trends in Aquifer wells GW-695, GW-703, GW-704, and GW-706.



Notes: Nondetected and anomalously high results are not plotted.  
 Gross Alpha MCL = 15 pCi/L; Nitrate MCL = 10 mg/L.

Fig. 16. Nitrate and gross alpha concentration trends in Bear Creek.

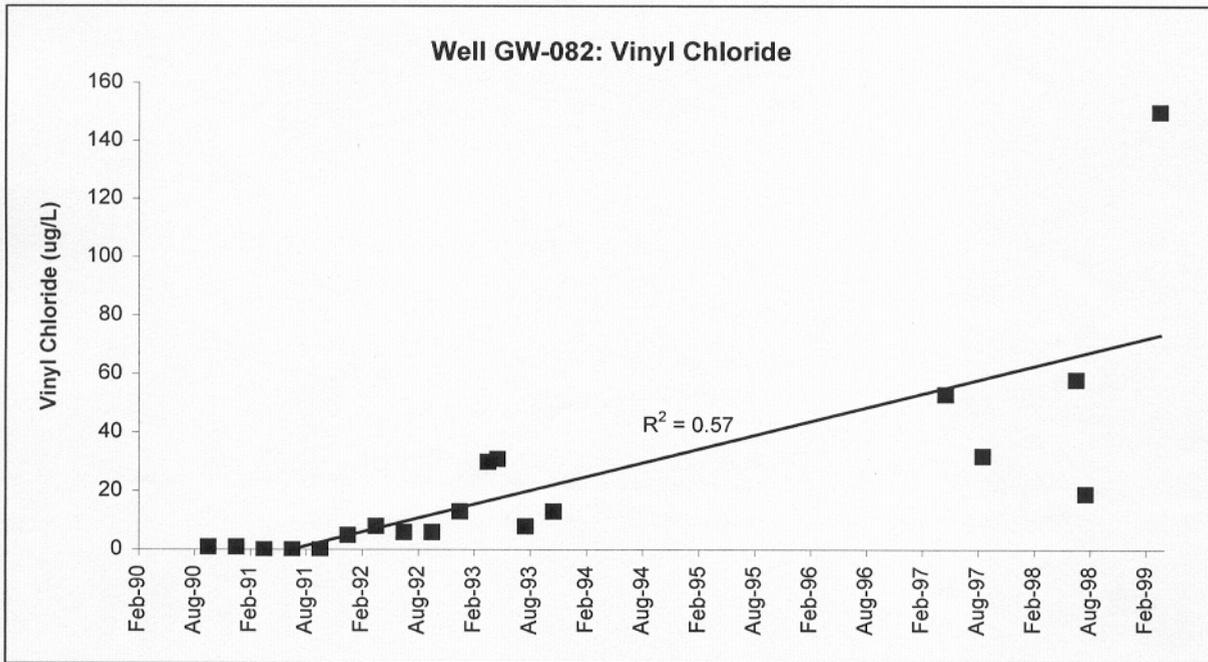
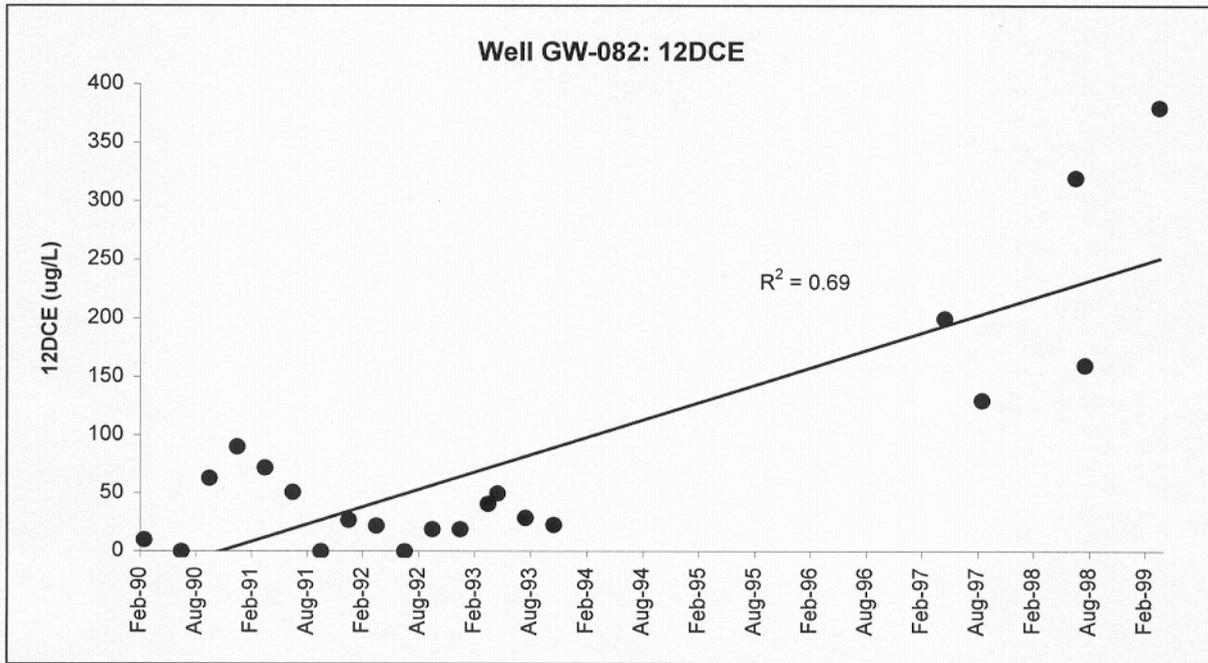


Fig. 17. Total 12DCE and vinyl chloride concentration trends in Aquitard well GW-082.



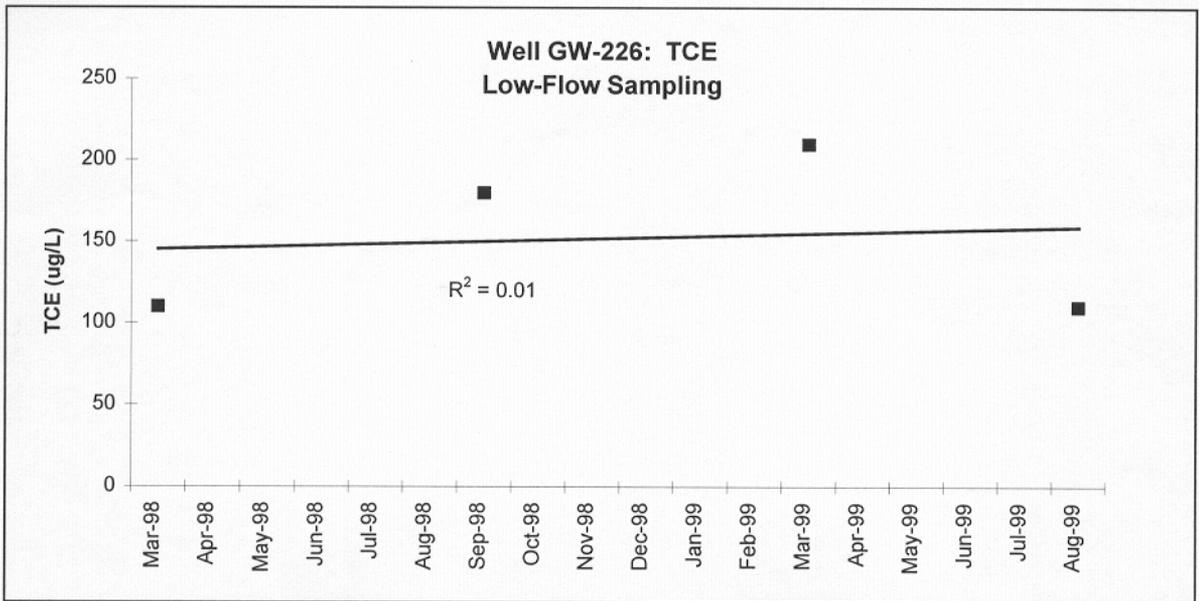
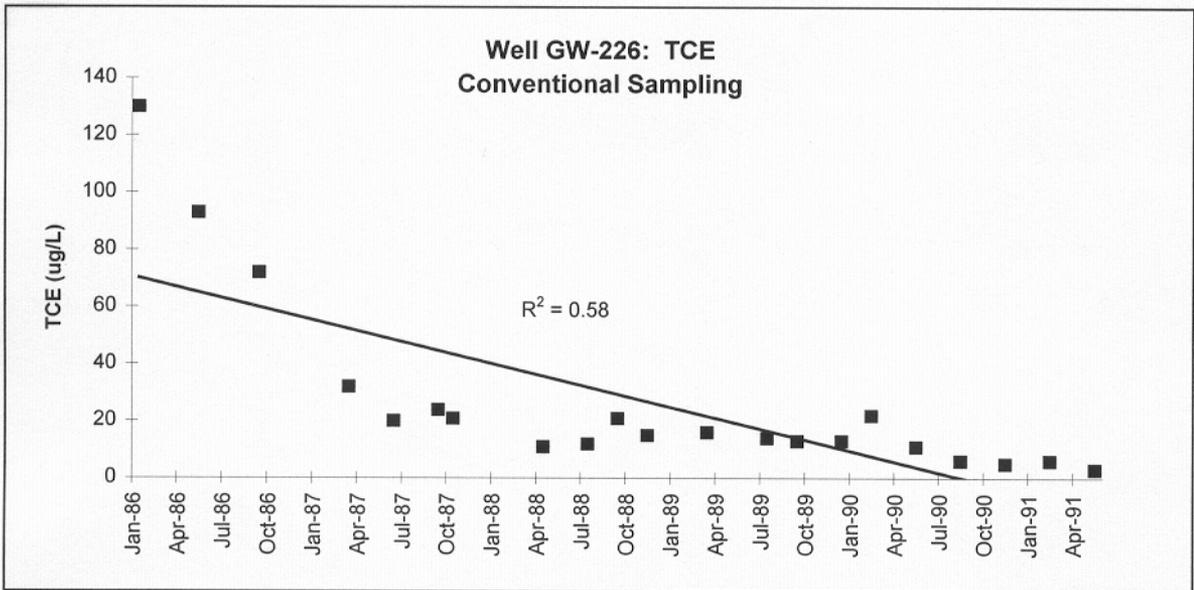
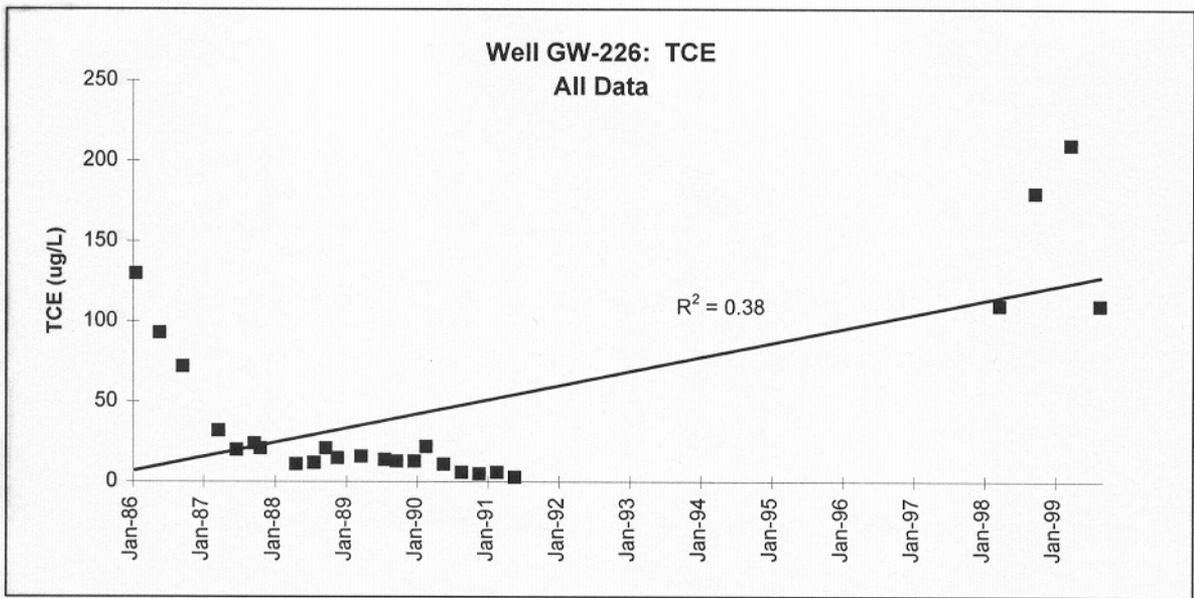


Fig. 19. TCE concentration trends in Aquifer well GW-226.

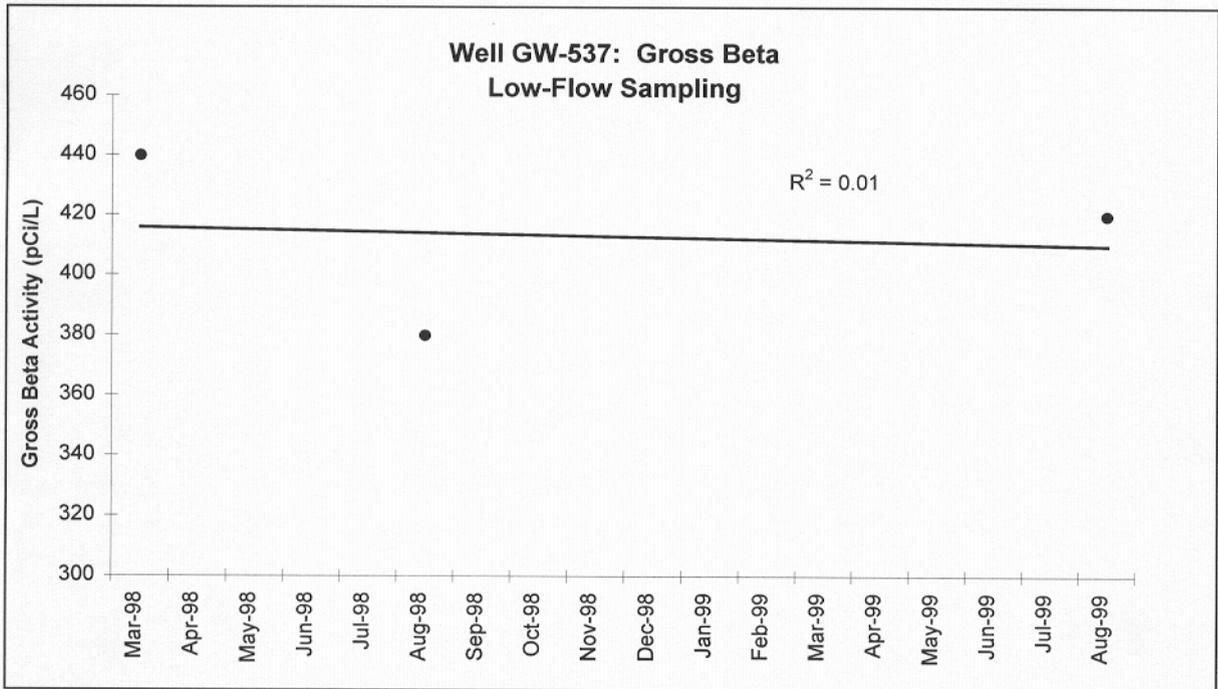
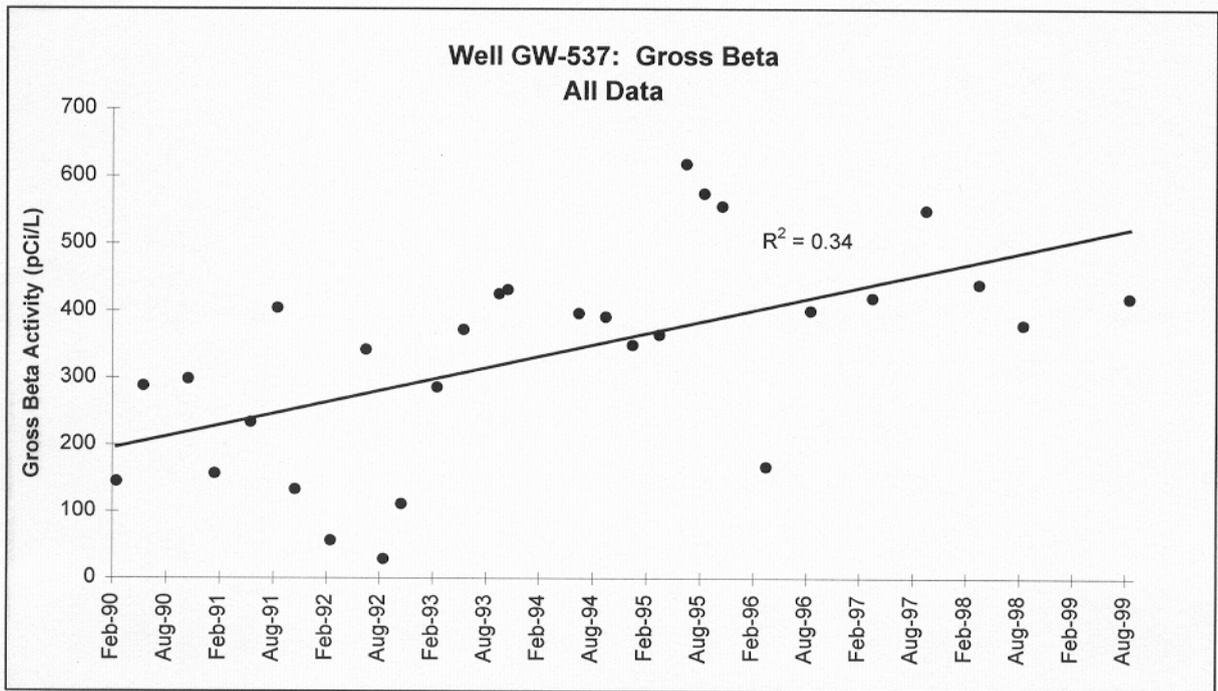


Fig. 20. Gross beta concentration trends in Aquitard well GW-537.

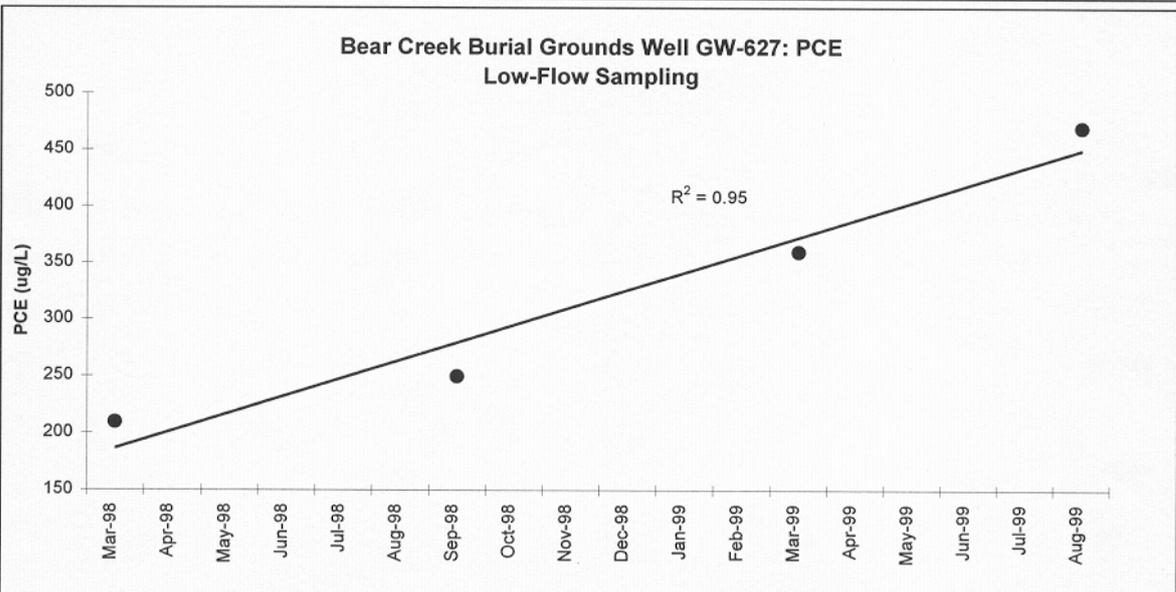
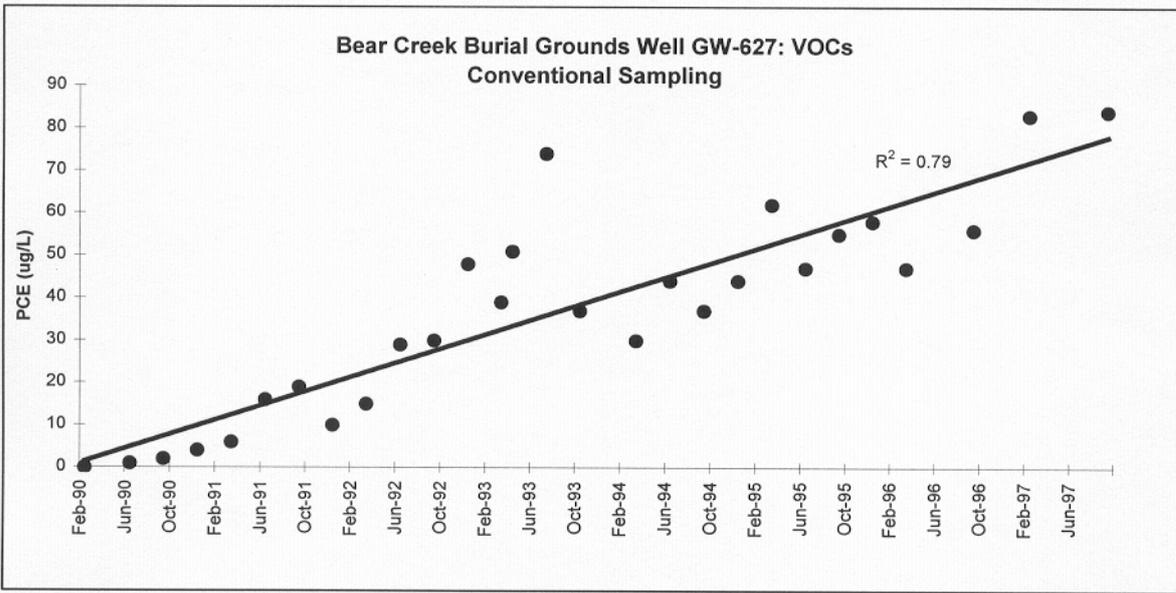
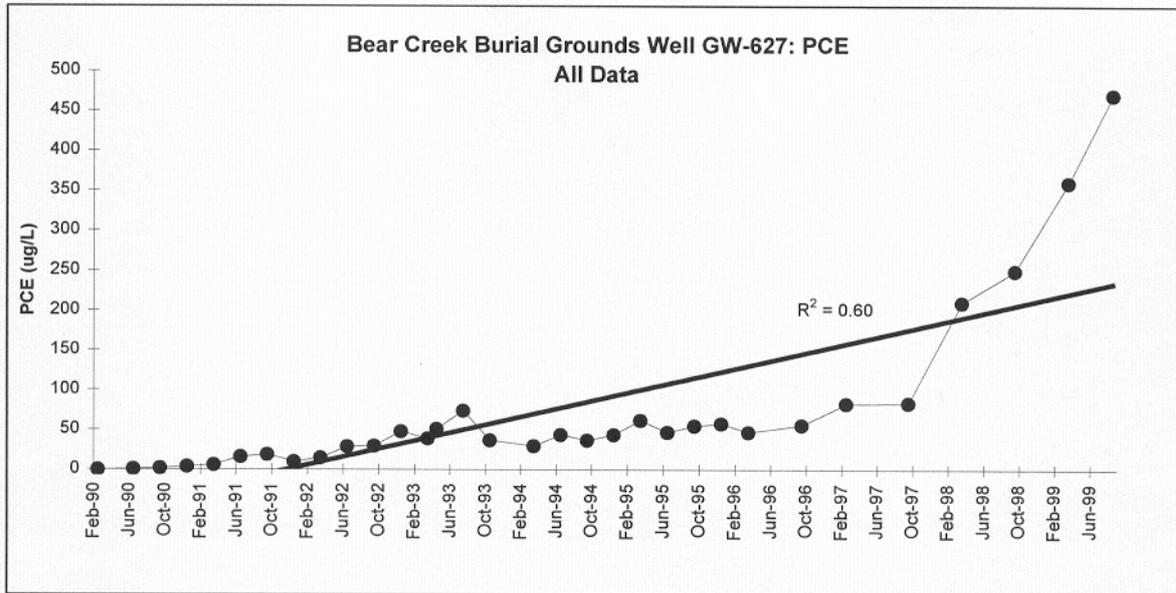


Fig. 21. PCE concentration trends in Aquitard well GW-627.

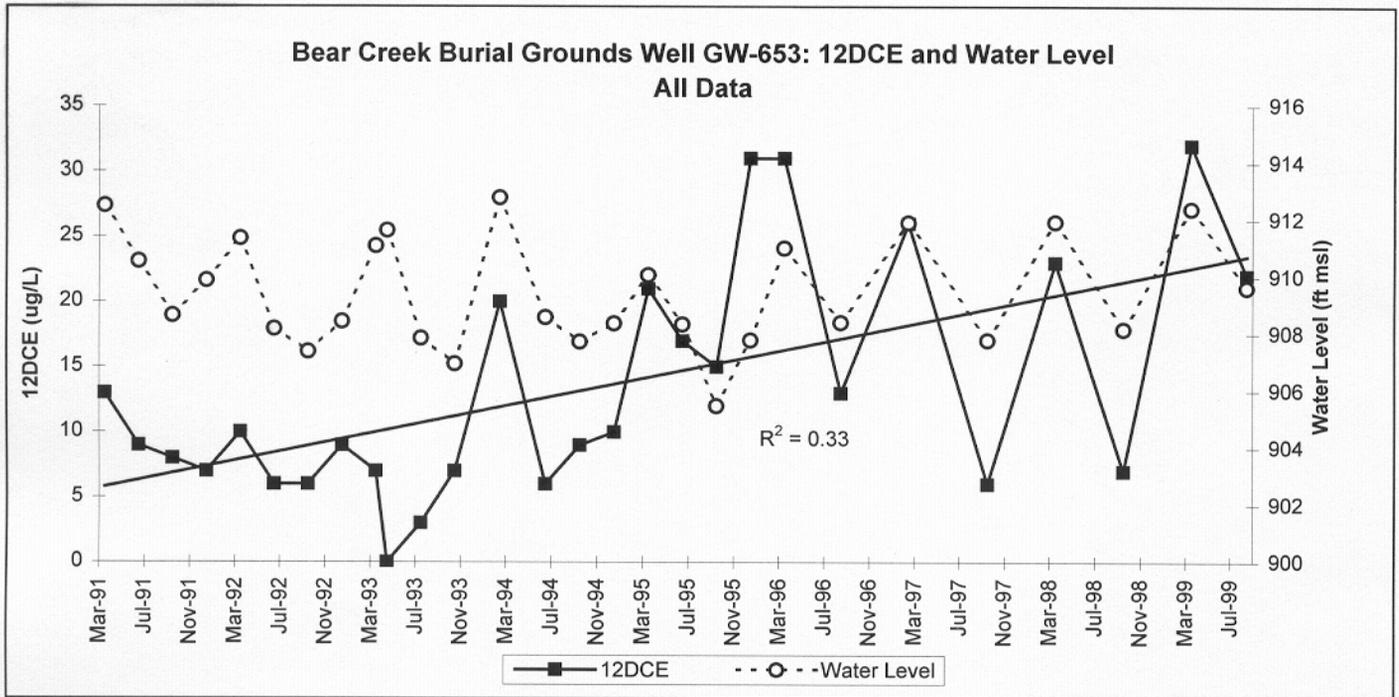


Fig. 22. Total 12DCE concentration trend in Aquitard well GW-653.

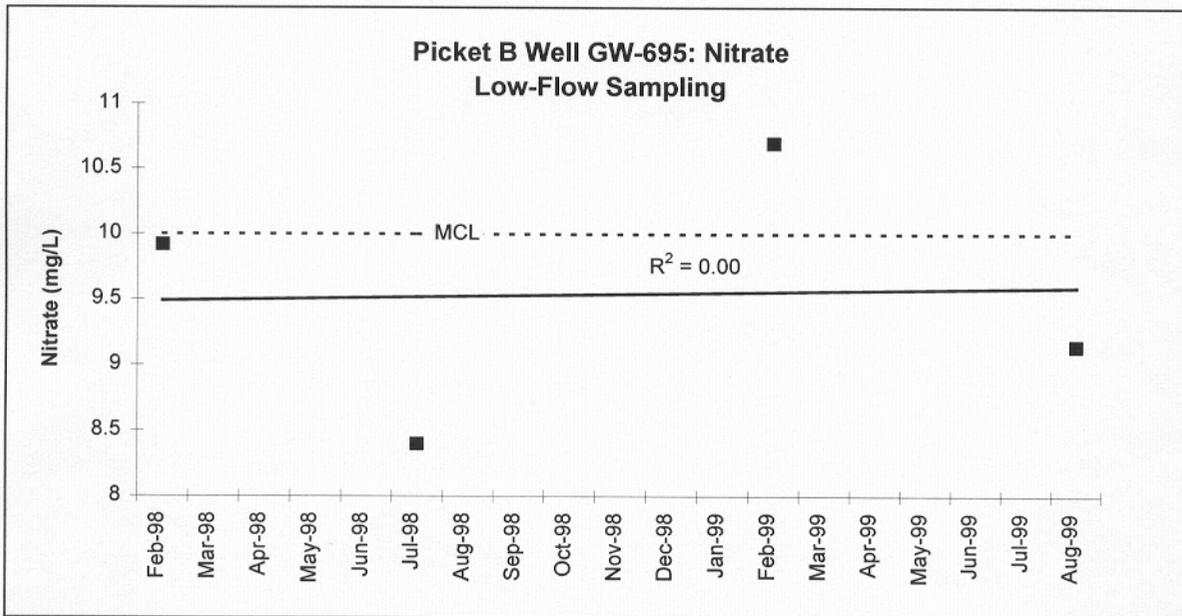
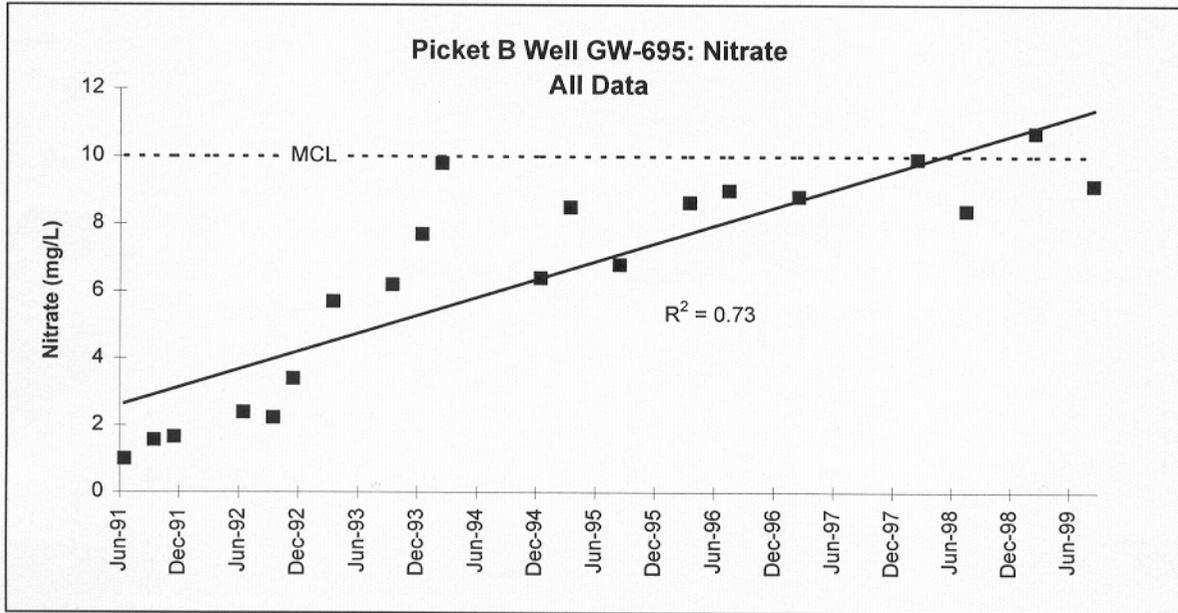


Fig. 23. Nitrate concentration trends in Aquifer well GW-695.

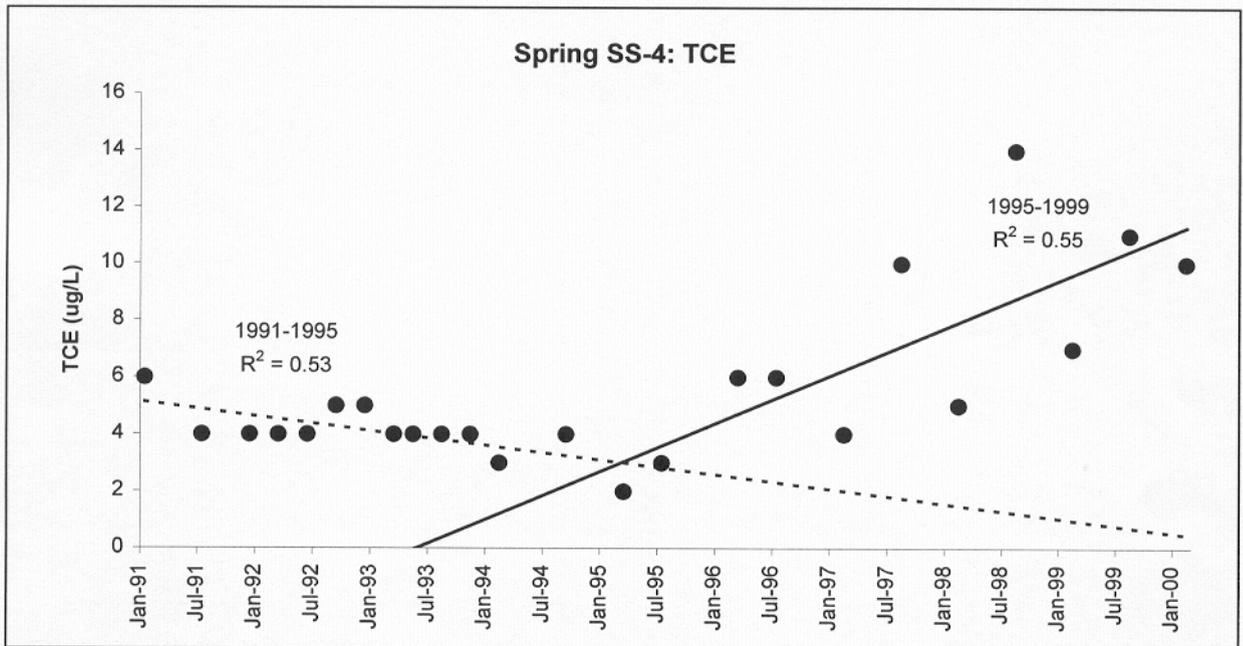
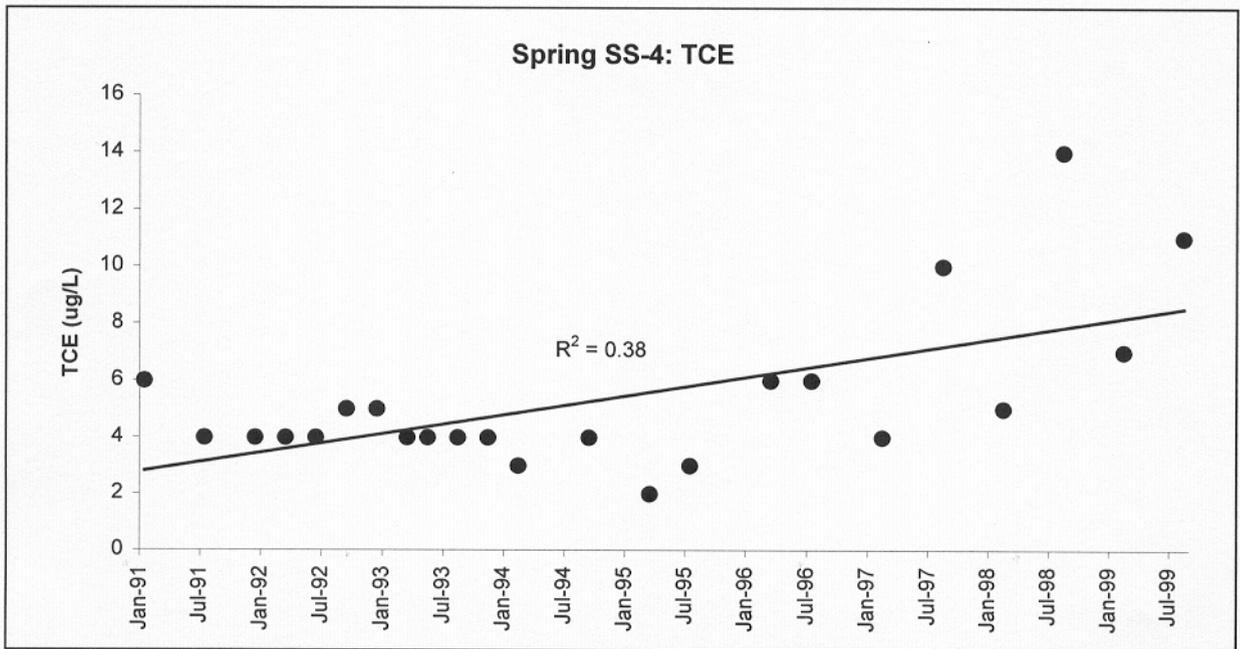


Fig. 24. TCE concentration trends in spring SS-4.

## **APPENDIX B**

### **TABLES**

**Table B.1. Waste management sites and regulated units in the Bear Creek Hydrogeologic Regime.**

Waste Management Site/ Regulated Unit	Regulatory Classification <sup>1</sup>	General Waste Inventory	Operational Status	
			Closed	Active
Above Grade Low-Level Storage Facility	NR	Low-level radioactive construction and demolition wastes.		•
Boneyard, Burnyard, and Hazardous Chemical Disposal Area	CERCLA	Magnesium chips, construction debris, pesticide containers, metal shavings, solvents, oils, laboratory chemicals, acids, bases, organics, water-reactive compounds, and shock sensitive compounds.	•	
Burial Grounds A (North and South)	RCRA/ CERCLA	Waste oils, coolants, and spent solvents.	•	
Burial Grounds C (West)	RCRA/ CERCLA	Waste oils, coolants, and spent solvents.	•	
Burial Grounds B, D, E, and J	CERCLA	Solid wastes including salts, metals (beryllium and uranium) and metal oxides, metal saw fines, and asbestos.	•	
Oil Landfarm	RCRA/ CERCLA	Waste oils and coolants containing beryllium compounds, depleted uranium, polychlorinated biphenyls, and spent solvents.	•	
Oil Retention Pond No. 1	CERCLA	Oil seepage from Burial Ground A South.	•	
Oil Retention Pond No. 2	CERCLA	Oil seepage from Burial Ground A North.	•	
Receptor Media	CERCLA	Contaminated groundwater, surface water, Bear Creek stream sediments, and Bear Creek floodplain soils.	Not Applicable	
Rust Spoil Area	CERCLA	Nonradioactive construction debris.	•	
Sanitary Landfill I	CERCLA	Nonhazardous solid wastes.	•	
Spoil Area I	CERCLA	Nonradioactive construction debris.	•	
SY-200 Yard	CERCLA	Temporary storage of equipment, machinery, and miscellaneous items.	•	
S-3 Site	RCRA/ CERCLA	Liquid, radioactive, nitric acid wastes and denitrification products.	•	
Walk-In Pits	RCRA/ CERCLA	Chemical wastes, shock-sensitive reagents, and uranium metal saw fines.	•	

**Table B.1 (continued)**

**Notes:**

1 From: U.S. Department of Energy. 1995. *Oak Ridge Reservation Site Management Plan for the Environmental Restoration Program*. U.S. Department of Energy Oak Ridge Field Office (DOE/OR-1001/R4). This classification applies only to CERCLA and RCRA regulations and may not reflect other applicable regulations (e.g., solid waste regulations at Spoil Area I).

CERCLA - Comprehensive Environmental Response, Compensation, and Liability Act

RCRA - Resource Conservation and Recovery Act

NR - Not regulated under RCRA or CERCLA.

**Table B.2. CY 1999 groundwater and surface water sampling locations and dates**

Evaluation Purpose <sup>1</sup>		DOE Order 5400.1 Exit Pathway/Perimeter Monitoring					
		DOE Order 5400.1 Surveillance Monitoring					
Sampling Point <sup>2</sup>	Sampling Location <sup>3</sup>	CY 1999 Sampling Date <sup>4</sup>					
		1st Quarter	2nd Quarter	3rd Quarter	4th Quarter		
BCK-00.63	EXP-SW	02/23/99	.	08/10/99	.		*
BCK-04.55	EXP-SW	02/23/99	.	08/10/99	.		*
BCK-07.87	EXP-SW	<b>02/23/99 D</b>	.	08/10/99	.		*
BCK-09.40	EXP-SW	02/24/99	.	08/11/99	.		*
BCK-09.47	EXP-SW	02/03/99	.	07/29/99	.		*
BCK-10.60	EXP-SW	02/24/99	.	DRY	.		*
BCK-11.97	EXP-SW	02/25/99	.	08/10/99	.		*
DC WELL	DCHAPCEM	03/24/99	.	.	.	*	
GW-006	EMWMF	03/30/99	<b>05/25/99 D</b>	<b>08/03/99 D</b>	10/20/99	*	
GW-008	OLF	02/08/99	.	07/15/99	.	*	
GW-043	EMWMF	03/11/99	05/17/99	07/27/99	10/18/99	*	
GW-044	EMWMF	03/18/99	05/18/99	07/28/99	10/19/99	*	
GW-046	BG	<b>02/08/99 D</b>	.	07/15/99	.	*	
GW-053	BG	03/24/99	.	08/26/99	.	*	
GW-056	EXP-A	02/09/99	.	07/28/99	.	*	
GW-077	BG	02/03/99	.	08/17/99	.	*	
GW-078	BG	<b>02/02/99 D</b>	.	08/17/99	.	*	
GW-079	BG	02/02/99	.	08/12/99	.	*	
GW-080	BG	02/03/99	.	<b>08/12/99D</b>	.	*	
GW-082	BG	03/04/99	.	.	.	*	
GW-085	OLF	03/17/99	.	08/31/99	.	*	
GW-087	OLF	03/11/99	.	.	.	*	
GW-115	S3	01/25/99	.	07/01/99	.	*	
GW-126	BG	03/02/99	.	.	.	*	
GW-132-01	S3	.	.	09/23/99	.	*	
GW-132-05	S3	.	.	09/27/99	.	*	
GW-132-09	S3	.	.	<b>09/27/99 D</b>	.	*	
GW-132-13	S3	.	.	09/28/99	.	*	
GW-132-17	S3	.	.	09/28/99	.	*	
GW-132-21	S3	.	.	09/28/99	.	*	
GW-132-25	S3	.	.	09/28/99	.	*	

Table B.2 (continued)

Evaluation Purpose <sup>1</sup>		DOE Order 5400.1 Exit Pathway/Perimeter Monitoring					
		DOE Order 5400.1 Surveillance Monitoring					
		CY 1999 Sampling Date <sup>4</sup>					
Sampling Point <sup>2</sup>	Sampling Location <sup>3</sup>	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter		
GW-133-01	S3	.	.	08/16/99	.	.	.
GW-133-05	S3	.	.	08/17/99	.	.	.
GW-133-08	S3	.	.	08/17/99	.	.	.
GW-133-10	S3	.	.	<b>08/18/99 D</b>	.	.	.
GW-133-14	S3	.	.	08/18/99	.	.	.
GW-133-17	S3	.	.	08/18/99	.	.	.
GW-133-21	S3	.	.	08/19/99	.	.	.
GW-133-24	S3	.	.	08/19/99	.	.	.
GW-134-05	S3	.	.	08/03/99 *	.	.	.
GW-134-11	S3	.	.	08/04/99 *	.	.	.
GW-134-15	S3	.	.	08/04/99 *	.	.	.
GW-134-18	S3	.	.	08/04/99 *	.	.	.
GW-134-21	S3	.	.	08/05/99 *	.	.	.
GW-134-25	S3	.	.	<b>08/10/99 D</b>	.	.	.
GW-134-29	S3	.	.	08/11/99	.	.	.
GW-134-33	S3	.	.	08/11/99	.	.	.
GW-134-35	S3	.	.	08/11/99	.	.	.
GW-134-36	S3	.	.	08/11/99	.	.	.
GW-135-03	S3	.	.	09/08/99	.	.	.
GW-135-06	S3	.	.	09/13/99	.	.	.
GW-135-11	S3	.	.	09/13/99	.	.	.
GW-135-15	S3	.	.	09/14/99	.	.	.
GW-135-19	S3	.	.	09/14/99	.	.	.
GW-135-23	S3	.	.	09/15/99	.	.	.
GW-135-26	S3	.	.	09/15/99	.	.	.
GW-135-30	S3	.	.	<b>09/15/99 D</b>	.	.	.
GW-135-34	S3	.	.	09/16/99	.	.	.
GW-135-39	S3	.	.	09/16/99	.	.	.
GW-226	OLF	03/18/99	.	<b>08/31/99 D</b>	.	.	.
GW-228	OLF	.	.	09/09/99	.	.	.
GW-236	S3	.	.	09/08/99	.	.	.
GW-242	BG	03/08/99	.	.	.	.	.
GW-276	S3	02/04/99	.	07/16/99	.	.	.
GW-287	BG	03/23/99	.	08/19/99	.	.	.
GW-311	RS	03/16/99	.	08/30/99	.	.	.

Table B.2 (continued)

Evaluation Purpose <sup>1</sup>		DOE Order 5400.1 Exit Pathway/Perimeter Monitoring					
		DOE Order 5400.1 Surveillance Monitoring					
		CY 1999 Sampling Date <sup>4</sup>					
Sampling Point <sup>2</sup>	Sampling Location <sup>3</sup>	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter		
GW-315	SPI	03/16/99	.	08/30/99	.	.	.
GW-345	S3	03/09/99	.	.	.	.	.
GW-346	S3	03/09/99	.	.	.	.	.
GW-526	S3	<b>03/11/99</b>	.	.	.	.	.
GW-537	OLF	03/18/99	.	08/31/99	.	.	.
GW-601	OLF	03/08/99	.	.	.	.	.
GW-621	EXP-B	02/15/99	.	08/02/99	.	.	.
GW-627	BG	<b>03/24/99 D</b>	.	08/26/99	.	.	.
GW-653	BG	03/23/99	.	08/19/99	.	.	.
GW-683	EXP-A	02/11/99	.	07/29/99	.	.	.
GW-684	EXP-A	02/10/99	.	07/29/99	.	.	.
GW-685	EXP-A	02/09/99	.	07/28/99	.	.	.
GW-695	EXP-B	02/15/99	.	08/02/99	.	.	.
GW-703	EXP-B	02/16/99	.	08/03/99	.	.	.
GW-704	EXP-B	02/16/99	.	08/04/99 *	.	.	.
GW-706	EXP-B	<b>02/17/99 D</b>	.	08/04/99 *	.	.	.
GW-712	EXP-W	01/25/99	.	07/01/99	.	.	.
GW-713	EXP-W	01/26/99	.	07/19/99	.	.	.
GW-714	EXP-W	01/26/99	.	07/15/99	.	.	.
GW-715	EXP-W	02/04/99	.	<b>07/15/99 D</b>	.	.	.
GW-724	EXP-C	02/22/99	.	08/09/99	.	.	.
GW-725	EXP-C	02/22/99	.	<b>08/09/99 D</b>	.	.	.
GW-726-02	BG	.	06/01/99	.	.	.	.
GW-726-04	BG	.	06/08/99	.	.	.	.
GW-726-06	BG	.	06/08/99	.	.	.	.
GW-726-09	BG	.	<b>06/09/99 D</b>	.	.	.	.
GW-726-12	BG	.	06/09/99	.	.	.	.
GW-726-16	BG	.	06/10/99	.	.	.	.
GW-726-20	BG	.	06/10/99	.	.	.	.
GW-726-23	BG	.	06/10/99	.	.	.	.
GW-738	EXP-C	02/18/99	.	08/05/99 *	.	.	.
GW-740	EXP-C	02/18/99	.	08/05/99 *	.	.	.
GW-829	OLF	03/17/99	.	08/30/99	.	.	.
GW-838	EMWMF	03/22/99	05/19/99	07/28/99	10/21/99	.	.
GW-840	EMWMF	.	05/20/99	07/29/99	10/19/99	.	.
GW-904	EMWMF	03/29/99	05/24/99	08/02/99	10/20/99	.	.
GW-905	EMWMF	03/25/99	05/24/99	08/02/99	10/21/99	.	.
NT-01	EXP-SW	02/25/99	.	08/11/99	.	.	.

**Table B.2 (continued)**

Evaluation Purpose <sup>1</sup>		DOE Order 5400.1 Exit Pathway/Perimeter Monitoring					
		DOE Order 5400.1 Surveillance Monitoring					
Sampling Point <sup>2</sup>	Sampling Location <sup>3</sup>	CY 1999 Sampling Date <sup>4</sup>					
		1st Quarter	2nd Quarter	3rd Quarter	4th Quarter		
NT-02	EXP-SW	03/02/99	.	.	.		•
NT-06	EXP-SW	03/02/99	.	.	.		•
NT-07	EXP-SW	03/02/99	.	.	.		•
NT-07	EXP-SW	02/02/99	.	07/29/99	.		•
NT-08	EXP-SW	03/02/99	.	.	.		•
NT-08	EXP-SW	02/02/99	.	07/29/99	.		•
SS-1	EXP-SW	02/25/99	.	08/11/99	.		•
SS-4	EXP-SW	02/24/99	.	<b>08/11/99 D</b>	.		•
SS-4	EXP-SW	02/02/99	.	<b>08/11/99 D</b>	.		•
SS-5	EXP-SW	02/23/99	.	08/11/99	.		•
SS-5	EXP-SW	02/02/99	.	08/11/99	.		•
SS-6	EXP-SW	02/23/99	.	08/10/99	.		•
SS-6	EXP-SW	02/03/99	.	08/10/99	.		•
SS-6.6	EXP-SW	02/03/99	.	<b>07/29/99 D</b>	.		•
SS-7	EXP-SW	02/02/99	.	07/29/99	.		•
SS-8	EXP-SW	02/03/99	.	07/29/99	.		•

**Notes:**

- 1 Although samples were collected from the sampling locations for a variety of monitoring purposes (e.g., RCRA), this report uses all of the monitoring results for DOE Order 5400.1A data evaluation purposes. The monitoring program for each location is provided in the CY 1999 GWMR (AJA Technical Services, Inc. 2000).
  
- 2
  - BCK - Bear Creek Kilometer
  - GW - Groundwater Monitoring Well; Westbay wells are GW-132, GW-133, GW-134, GW-135, and GW-726.
  - NT - Northern Tributary (to Bear Creek)
  - SS - Spring sampling location (south side of Bear Creek)

**Table B.2 (continued)**

**Notes:** (continued)

- 3           BG - Bear Creek Burial Grounds Waste Management Area
- DCHAPCEM - Douglas Chapel Cemetery
- EMWMF - Environmental Management Waste Management Facility
- EXP-A - Exit Pathway (Maynardville Limestone) Picket A
- EXP-B - Exit Pathway Picket B
- EXP-C - Exit Pathway Picket C
- EXP-W - Exit Pathway Picket W
- EXP-SW - Exit Pathway (Bear Creek) Surface Water
- OLF - Oil Landfarm Waste Management Area
- RS - Rust Spoil Area
- SPI - Spoil Area I
- S3 - S-3 Site
  
- 4           . - Not sampled
- D - Duplicate sample was collected (shown in bold typeface)
- \* - Additional sample was collected on August 24, 1999 for organics analysis because the holding time was missed.



**Table B.3. Principal contaminants and long-term concentration trends for the  
CY 1999 monitoring locations**

CY 1999 Sampling Location <sup>1</sup>	Unit <sup>2</sup>		Contaminant Type and Long-Term Trend <sup>3</sup>						
			Inorganics <sup>4</sup>		VOCs <sup>5</sup>			Radioactivity <sup>6</sup>	
	AQT	AQF	Nitrate	Uranium	Chloro-ethenes	Chloro-ethanes	Chloro-methanes	Gross Alpha	Gross Beta
BCK-00.63			.	"	.	.	.	"	.
BCK-04.55			.	"	.	.	.	"	.
BCK-07.87			.	"	.	.	.	"	.
BCK-09.40			CE	CE	"			"	CE
BCK-09.47			.		"			"	.
BCK-10.60			"	"	.	.	.	"	.
BCK-11.97			CE	CE	.	.	.	CE	CE
DC WELL	°		.	.	.	.	.	.	.
GW-006	°		.	.	"	"	.	.	.
GW-008	°		.	.	"	"	.	.	.
GW-043	°		.	.	.	.	.	.	.
GW-044	°		.	.	.	.	.	.	.
GW-046	°		.	.	"	"	.	.	.
GW-053		°	.	.	"	"	.	.	.
GW-056		°	.	.	.	.	.	.	.
GW-077	°		.	.	.	.	.	.	.
GW-078	°		.	.	.	.	.	.	.
GW-079	°		.	.	.	.	.	.	.
GW-080	°		.	.	.	.	.	.	.
GW-082	°		.	.	O	O	.	.	.
GW-085	°		CE	.	.	.	.	.	"
GW-087	°		.	CE	CE	.	.	CE	.
GW-115	°		.	.	.	.	.	.	.
GW-126	°		.	.	.	.	.	.	.
GW-132-01	°		.	.	.	.	.	.	.
GW-132-05	°		.	.	.	.	.	.	.
GW-132-09	°		.	.	.	.	.	.	.
GW-132-13	°		.	.	.	.	.	.	.
GW-132-17	°		.	.	.	.	.	.	.
GW-132-21	°		.	.	.	.	.	.	.
GW-132-25	°		.	.	.	.	.	.	.
GW-133-01	°		.	.	.	.	.	.	.
GW-133-05	°		.	.	.	.	.	.	.
GW-133-08	°		.	.	.	.	.	.	.
GW-133-10	°		.	.	.	.	.	.	.
GW-133-14	°		.	.	.	.	.	.	.
GW-133-17	°		.	.	.	.	.	.	.
GW-133-21	°		.	.	.	.	.	.	.
GW-133-24	°		.	.	.	.	.	"	"

Table B.3 (continued)

CY 1999 Sampling Location <sup>1</sup>	Unit <sup>2</sup>		Contaminant Type and Long-Term Trend <sup>3</sup>						
			Inorganics <sup>4</sup>		VOCs <sup>5</sup>			Radioactivity <sup>6</sup>	
	AQT	AQF	Nitrate	Uranium	Chloro-ethenes	Chloro-ethanes	Chloro-methanes	Gross Alpha	Gross Beta
GW-134-05	°		"	.	.	.	.	.	.
GW-134-11	°		"	.	.	.	.	.	.
GW-134-15	°		"	.	.	.	.	.	.
GW-134-18	°		"	.	.	.	.	.	.
GW-134-21	°		"	.	.	.	.	.	.
GW-134-25	°		.	.	.	.	.	.	.
GW-134-29	°		.	.	.	.	.	.	.
GW-134-33		°	"	.	"	.	.	.	"
GW-134-35		°	"	.	"	.	.	.	"
GW-134-36		°	"	.	.	.	.	.	.
GW-135-03		°	.	.	.	.	.	.	.
GW-135-06		°	.	.	.	.	.	.	.
GW-135-11		°	.	.	.	.	.	.	.
GW-135-15		°	.	.	.	.	.	.	.
GW-135-19		°	.	.	.	.	.	.	.
GW-135-23	°		.	.	.	.	.	.	.
GW-135-26	°		.	.	.	.	.	.	.
GW-135-30	°		.	.	.	.	.	.	.
GW-135-34	°		.	.	.	.	.	.	.
GW-135-39	°		.	.	.	.	.	.	.
GW-226		°	O	.	OE	.	.	.	.
GW-228		°	.	.	CE	.	.	.	.
GW-236		°	CE	.	.	.	.	.	CE
GW-242	°		.	.	"	"	.	.	.
GW-276	°		CE	CE	CE	.	.	CE	"
GW-287	°		.	.	.	.	.	.	.
GW-311		°	.	.	CE	.	.	.	.
GW-315		°	.	.	CE	.	.	.	.
GW-345	°		.	.	.	.	.	.	.
GW-346	°		"	.	.	.	.	.	.
GW-526	°		"	.	.	.	.	.	.
GW-537	°		"	.	.	.	.	.	O
GW-601		°	CE	.	CE	.	.	.	.
GW-621		°	.	.	.	.	.	.	.
GW-627	°		.	.	O	O	.	.	.
GW-653	°		.	.	O	.	.	.	.
GW-683		°	.	CE	.	.	.	"	.
GW-684		°	.	CE	.	.	.	.	.
GW-685		°	.	.	.	.	.	.	.
GW-695		°	O	.	"	.	.	.	.

Table B.3 (continued)

CY 1999 Sampling Location <sup>1</sup>	Unit <sup>2</sup>		Contaminant Type and Long-Term Trend <sup>3</sup>						
			Inorganics <sup>4</sup>		VOCs <sup>5</sup>			Radioactivity <sup>6</sup>	
	AQT	AQF	Nitrate	Uranium	Chloro-ethenes	Chloro-ethanes	Chloro-methanes	Gross Alpha	Gross Beta
GW-703		°	.	.	CE	.	.	.	.
GW-704		°	CE	.	"	.	.	.	.
GW-706		°	"	"	"	.	.	"	"
<b>GW-712</b>		°	.	.	.	.	.	.	.
<b>GW-713</b>		°	.	.	.	.	.	.	.
<b>GW-714</b>		°	.	.	.	.	.	.	.
<b>GW-715</b>		°	.	.	.	.	.	.	.
GW-724		°	CE	.	"	.	.	.	.
GW-725		°	CE	.	CE	.	.	.	.
GW-726-02	°		.	.	.	.	.	.	.
GW-726-04	°		.	"	.	.	.	.	.
GW-726-06	°		.	.	.	.	.	.	.
GW-726-09	°		.	.	.	.	.	.	.
GW-726-12	°		.	.	.	.	.	.	.
GW-726-16	°		.	.	.	.	.	.	.
GW-726-20	°		.	.	.	.	.	.	.
GW-726-23	°		.	.	.	.	.	.	.
GW-738		°	CE	.	CE	.	.	.	"
GW-740		°	.	.	"	.	.	.	.
GW-829	°		CE	.	.	.	.	.	.
GW-838	°		.	.	.	.	.	.	.
GW-840	°		.	.	.	.	.	.	.
GW-904	°		.	.	.	.	.	.	.
GW-905	°		.	.	.	.	.	.	.
<b>NT-01</b>			"	"	"	.	.	"	"
<b>NT-02</b>			"	.	.	.	.	.	.
<b>NT-06</b>			.	.	"	.	.	.	.
<b>NT-07</b>			.	"	"	"	.	.	.
<b>NT-08</b>			.	"	"	"	.	"	.
<b>SS-1</b>			CE	"	.	.	.	"	.
<b>SS-4</b>			"	"	O	.	.	"	.
<b>SS-5</b>			.	"	.	.	.	"	.
<b>SS-6</b>			.	.	.	.	.	.	.
<b>SS-6.6</b>			.	.	.	.	.	.	.
<b>SS-7</b>			.	.	.	.	.	.	.
<b>SS-8</b>			.	.	.	.	.	.	.

**Notes:**

- 1 All CY 1999 sampling locations are included on the table. The exit pathway/perimeter monitoring locations are in bold typeface.

### Table B.3 (continued)

#### Notes (continued):

2 Hydrostratigraphic unit.

AQT - Aquitard: Conasauga Group, excluding the Maynardville Limestone.

AQF - Aquifer: Maynardville Limestone and Knox Group.

3 Trend types were interpreted from data tables or plots of concentration changes over time.

. - Not a contaminant (criteria defined below).

" - Indeterminate trend: insufficient data, fairly stable trend, affected by sampling methods or highly fluctuating with no clear upward or downward trend.

∩ - Generally decreasing trend.

○ - Generally increasing trend.

Note that different VOCs have different long-term concentration trends at well GW-226: TCE shows an increasing trend and 12DCE shows a decreasing trend (see Figures 14 and 19).

4 CY 1999 nitrate concentration greater than or equal to 10 mg/L.

Total uranium concentration greater than or equal to 0.02 mg/L.

5 Summed CY 1999 concentration of a solvent group greater than or equal to 5 . g/L.

Ethenes = Summed chloroethenes (PCE, TCE, 12DCE, 11DCE, 11DCE, vinyl chloride)

Ethanes = Summed chloroethanes (111TCA, 11DCA, chloroethane)

Methanes = Summed chloromethanes (carbon tetrachloride, chloroform, methylene chloride)

6 Maximum CY 1999 gross alpha activity greater than or equal to 15 pCi/L.

Maximum CY 1999 gross beta activity greater than or equal to 50 pCi/L.

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