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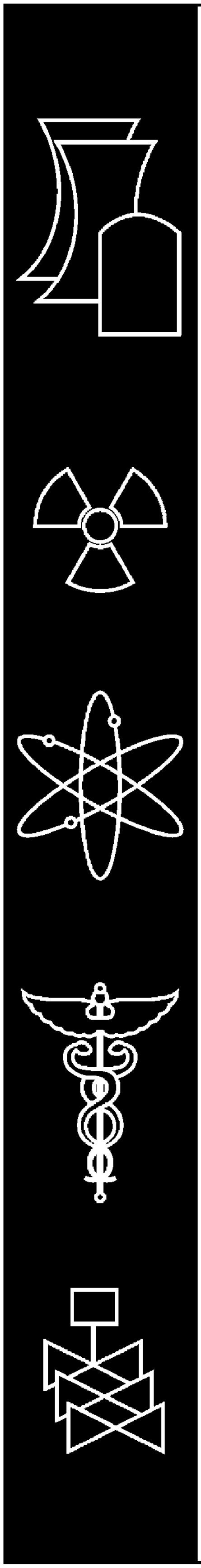

Soil and Groundwater Sample Characterization and Agricultural Practices for Assessing Food Chain Pathways in Biosphere Models

Pacific Northwest National Laboratory

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Abstract

This report describes work performed and summarizes observations to date on the U.S. Nuclear Regulatory Commission’s project *Assessment of Food Chain Pathway Parameters in Biosphere Models,* which was established to assess and evaluate a number of key parameters used in the food-chain models used in performance assessments of radioactive waste disposal facilities. Section 2 of this report describes activities undertaken to collect samples of soils and groundwater from three geographical regions of the United States, the Southeast, Northwest, and Southwest, and perform analyses to characterize their physical and chemical properties. Because the uptake and behavior of radionuclides in plant roots, plant leaves, and animal products depends on the chemistry of the water and soil coming in contact with plants and animals, water and soil samples collected from these regions on the United States are being used in ongoing experiments at Pacific Northwest National Laboratory to determine radionuclide soil-to-plant concentration ratios, leaf interception and translocation factors. Crops and forage used in the experiments are grown in the soils, and long-lived radionuclides introduced into the groundwater provide the contaminated water used to water the grown plants. The radionuclide uptake results from this research study are expected to show how regional variations in water quality and soil chemistry affect radionuclide uptake. Section 3 summarizes information gathered regarding agricultural practices and common and unusual crops grown in each of these three areas. This type of information is directly useful in formulating inputs to radioecological and food-chain models used in performance assessments and other kinds of environmental assessment. This food-chain pathway data may be used by the NRC staff to assess dose to persons in the reference biosphere (e.g., persons who live and work in an area potentially affected by radionuclide releases) of waste disposal facilities and decommissioning sites.

FOREWORD

The U.S. Nuclear Regulatory Commission (NRC) recognizes that the food chain pathway could significantly contribute to the potential dose received by members of the public as a result of the potential release of radionuclides to the environment from many NRC-licensed sites. To quantify the importance of this pathway, the NRC has developed performance assessment strategies involving biosphere computer codes to evaluate the potential resulting dose to humans. These biosphere codes incorporate parameters for radionuclide uptake in plant roots and leaves, as well as animal products, to aid in predicting the radionuclide concentrations that humans would ingest and inhale in the event of an environmental release.

This report documents an NRC-sponsored study of soil and groundwater characterization and agricultural practices for assessing food chain pathways in biosphere models. Chapter 2 describes the collection of soil and groundwater samples collected from the Southeast, Southwest, and Northwest geographical regions of the United States, and provides the physical and chemical results obtained by analyzing those samples. In addition, Chapter 3 summarizes data and information regarding agricultural practices and common and unusual crops grown in each of the three geographical regions.

Compared to the present study, past radionuclide uptake experiments tended to be more generic and did not consider the many regional variables (e.g., soil and groundwater chemistries) that could affect the uptake and behavior of radionuclides in plants and animals. However, the uptake and behavior of radionuclides depend on the chemical content of the soil and water coming in contact with plant roots, plant leaves, and animal products. Consequently, the NRC's Office of Nuclear Regulatory Research (RES) designed its study of food chain pathways in biosphere models to include soil and water samples collected from three distinct geographical regions of the United States. In so doing, the experiments sought to determine soil-to-plant radionuclide concentration ratios, leaf interception and translocation factors, and animal product transfer coefficients. Crops and forage used in the experiments are grown in the sampled soils, and long-lived radionuclides introduced into the groundwater contaminate the water used to irrigate the growing plants. Thus, the results from this study should be more realistic than those of past experiments because they are designed to show how regional variations in soil and water quality chemistry affect radionuclide uptake in plants and animals.

The NRC is currently using the results described in this report to interpret the results of ongoing experiments at Pacific Northwest National Laboratory to determine radionuclide uptake factors in plants and animals. For the future, the agency expects to use those uptake factors in biosphere codes to reduce uncertainties in food chain pathway dose assessments. In addition, the radionuclide uptake data and agricultural practices from this study provide a knowledge base for the NRC staff to use in evaluating biosphere data, analyses, and computer codes, and to quantify uncertainties in the biosphere-related technical basis for licensing.

Carl J. Paperiello, Director
Office of Nuclear Regulatory Research

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Acronyms

ASA	American Society of Agronomy
ASTM	American Society for Testing and Materials
CBP	Columbia Basin Project
CEC	cation exchange capacity
cps	counts per second
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ICP-MS	inductively coupled plasma-mass spectroscopy (spectrometer)
ICP-OES	inductively coupled plasma-optical emission spectroscopy (same as ICP-AES)
ICDD	International Center for Diffraction Data, Newtown Square, Pennsylvania
JCPDS	Joint Committee on Powder Diffraction Standards
LOI	loss on ignition
ND	not detected
PDF™	powder diffraction file
PNNL	Pacific Northwest National Laboratory
QA	quality assurance
USGS	U.S. Geological Survey
XRD	X-ray powder diffractometry analysis (commonly called X-ray diffraction)
XRF	X-ray fluorescence analysis

Units of Measure

Å	angstrom
g	gram
kV	kilovolt
L	liter
M	molarity, mol/L
mA	milliampere
mg	milligram
mL	milliliter
mS	millisiemens
N	Normality (of a solution), in number of gram equivalent weights of solute per liter of solution
I/I_o	relative intensity of an XRD peak to the most intense peak
wt%	weight percent
ºC	temperature in degrees Celsius [T(ºC) = T(K) – 273.15)]
λ	wavelength
µ	micro (prefix, 10^{-6})
µeq	microequivalent
µg	microgram
µm	micrometer
θ	angle of incidence (Bragg angle)

1.0 Introduction

The U.S. Nuclear Regulatory Commission's project *Assessment of Food Chain Pathway Parameters in Biosphere Models* has been established to assess and evaluate a number of key parameters used in the food-chain models used in performance assessments of radioactive waste disposal facilities. The objectives of the research program include:

- Provide data and information for the important features, events, and processes of the pathway models for use in biosphere computer codes. These codes calculate the total effective dose equivalent (TEDE) to the average member of the critical group and maximally exposed individual, for example, from radionuclides in the contaminated ground water release scenarios in NRC's performance assessments of waste disposal facilities and decommissioning sites,
- Reduce uncertainties in food-chain pathway analysis from the agriculture scenarios of biosphere models in performance assessment calculations,
- Provide better data and information for food-chain pathway analyses by:
  - Performing laboratory and field experiments, including integral and separate effect experiments, to evaluate the potential pathways and uptake mechanisms of plants and animals contaminated by long-lived radionuclides,
  - Presenting food-chain pathway data and information by regional and local geographical locations,
  - Quantifying uncertainties in the radioactive contamination of food crops and long-term build up of radionuclides in soils with contaminated ground water from water irrigation systems,
  - Determining data on factors affecting radionuclide uptake of food crops including irrigation water processes, soil physical and chemical properties, soil leaching and retention properties near crop roots, soil resuspension factors and other soil and plant characteristics.

The results of this research program will provide needed food-chain and animal product pathway data and information for important radionuclides that may be used by the NRC staff to assess dose to persons who live and work in areas potentially affected by radionuclide releases from waste disposal facilities and decommissioning sites.

Section 2 of this report describes activities undertaken to collect samples of soils and groundwater from three regions of the United States, the Southeast, Northwest, and Southwest, and perform analyses to characterize their physical and chemical properties. Because the uptake and behavior of radionuclides in plant roots, plant leaves, and animal products depends on the chemistry of the water and soil coming in contact with plants and animals, water and soil samples collected from these regions on the United States are being used in ongoing experiments at Pacific Northwest National Laboratory to determine radionuclide soil-to-plant concentration ratios, leaf interception and translocation factors. Crops and forage used in the experiments are grown in the soils, and long-lived radionuclides introduced into the groundwater provide the contaminated water used to water the grown plants. Radionuclides under consideration include ^{99}Tc, ^{129}I, ^{238}Pu, ^{237}Np, and ^{241}Am. Plant types include alfalfa, corn, onion, and potato. The radionuclide uptake results from this research study are expected to show how regional variations in water quality and soil chemistry affect radionuclide uptake.

Section 3 summarizes information gathered regarding agricultural practices and common and unusual crops grown in each of these three areas. Data from this research program are expected to be used in biosphere models to calculate the dose from groundwater release scenarios in performance assessment computer codes.

2.0 Sampling and Analysis of Groundwater and Soil Samples

Uncontaminated soil and groundwater samples were collected from four and three sites, respectively, that are in the vicinity of waste disposal facilities and unaffected by disposal activities at those sites. The soil and groundwater samples were collected for use in plant radionuclide uptake studies. The areas for sampling included agricultural sites and currently operating and proposed waste disposal facilities and decommissioning sites, including the commercial low-level radioactive waste (LLW) sites in the states of Washington and South Carolina.

2.1 Sampling Sites for Groundwater and Soil Samples

Three areas for soil and water samples were identified that met the objectives identified in the work plan for the "Assessment of Food Chain Pathway Parameters in Biosphere Models" project. These sites include the Hanford Site, Washington; Savannah River, South Carolina; and Nye County, Nevada. Together they provide a range of soil characteristics for radionuclide bio-uptake studies. After the plant uptake experiments were started, it was discovered that soil from the Savannah River Site in South Carolina would not support plant growth because the soil was allelopathic – that is, it contained natural toxins to plant growth as a result of its association with pine trees. A different nearby location was then identified to obtain a new soil sample for the plant studies. This soil sample (Section 2.1.3) was obtained from a research field operated by Clemson University in Blackville, South Carolina, in Barnwell County, located 15 mi. east-northeast of the Savannah River Plant. The Hanford location is about 15 km (9 miles) west of the U.S. Ecology low-level waste disposal site; the South Carolina location is about 22 km (14 miles) northeast of the Barnwell low-level waste disposal site (the original Savannah River Site location was about 5 miles west), and the Nevada location is about 80 km (50 miles) southeast of the Beatty low-level waste site and about 37 km (23 miles) downgradient from the proposed Yucca Mountain high-level waste repository.

The experimental design of the uptake experiments requires approximately 300 liters of water and 0.2 cubic meters of soil from each site. The latitude and longitude position of each sampling location was recorded by using a global positioning system (GPS) unit to provide traceability and the opportunity to provide duplicate samples if required. In addition, at the one privately owned site in Nye County, Nevada, it was arranged through an agreement with the landowner that the site would be available for re-sampling should any additional material be needed. No measurements were made at the well of parameters such as Eh, temperature, dissolved oxygen, etc., because in the anticipated use of spray irrigation, these parameters would rapidly change to match the terrestrial conditions.

2.1.1 Hanford Site, Washington

The sampling site for the Hanford soil and groundwater samples is located off Washington highway 240 near the area referred to as the “Yakima Barricade” at the western entrance to the U.S. Department of Energy Hanford Site in southeastern Washington State. Logistically, the sample site is easily accessible by road, and a pump is installed in the well used for groundwater sampling (Figure 2.1). The Hanford Site designation for the well is 699-49-100C, and the coordinates are North 46.577°, West 119.726°. The well has been used in the past for providing water to the guard shack at the Yakima Barricade (see structure in background at top of right photograph in Figure 2.1), and is still used to provide “up-gradient background” groundwater samples (i.e., water not affected by Hanford disposal activities) to the Hanford Site environmental programs. The water chemistry of the well has been well characterized, and the analyses are available through the Hanford Environmental Information System (HEIS 1994) data base.

The Hanford soil[1] sample was collected within 100 m of the well used for the groundwater sample, and the coordinates for the location of the soil sample are North 46.5757°, West 119.7259°. The soil sample is a silty, very fine sand that is referred to as the McGee Ranch soil. The soil in this area has been extensively characterized, because there are plans to use this sediment as a soil covering for surface barriers on waste-disposal areas at the Hanford Site (DOE 1999) (Figure 2.1).

Groundwater Sampling

Soil Sampling

Figure 2.1. Locations of Groundwater and Soil Samples from the Hanford Site

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[1] Because of its depositional history, the unconsolidated surface and near-surface geologic material at the Hanford Site is referred to as “sediment” in Hanford Site literature.

2.1.2 Nye County, Nevada

The sampling site (Figure 2.2) in Nye County is located in a desert valley approximately 110 miles west of Las Vegas in the Amargosa Valley, Nevada. The soil and groundwater samples were collected by agreement with the owner from private land. The site is located west of Las Vegas approximately 175 km (110) miles on Nevada highway 95. From the junction of highways 95 and 373, the site is 16 km (10 miles) south to Mecca Road, and then west 9 km (5.5 miles) to Van Patton Drive.

The groundwater was collected from an irrigation well that is used to flood irrigate pastureland. The coordinates for the well used for the groundwater sample are North 36 29' 24.4", West 116 30' 51.5". The pasture was used to grow alfalfa for about 14 years up until about 1996, when it was allowed to turn to pasture. According to the land owner, the soil was originally conditioned using approximately 0.225 kg/m^2 (10 tons/acre) of gypsum. No commercial fertilizer was used on the pasture.

The soil was approximately 75 cm (2.5 feet) thick at the sample site, and consists of a light brown silty sand. The coordinates for the site of the soil sample are North 36° 29' 23.7", West 116° 30' 52.0". Near the base, the occurrence of white streaks in the soil increased until the soil transitioned into broken-up calcrete.

Figure 2.2. Location in Nye County, Nevada Where Groundwater and Soil Samples were Collected

2.1.3 Savannah River Site, South Carolina

This site was selected because this soil provides a good representation of forest soil from the southeastern United States. PNNL staff also had contacts at the U.S. Department of Energy Savannah River Site who could cost-effectively provide uncontaminated groundwater and soil samples from this location. This site receives considerably more infiltration from rainfall and snowmelt, and has a soil that was expected to have a higher organic carbon content than the soil samples from Hanford and Nye County. The water samples are from well HSB-85A (Figure 2.3) at coordinates North 33° 17' 6.548", West 81° 39' 17.7448". The soil samples were collected near well MSB 21 TA (Figure 2.4) at coordinates North 33° 19' 58.31", West 81° 44' 39.2". The groundwater and soil samples were provided by the Savannah River Technology Center in Aiken, South Carolina. The locations selected for the groundwater and soil samples represent "clean" groundwater and soil, which do not contain any radionuclide contamination at concentrations above natural background levels. Also, each sampling location has background data associated with it that was collected as part of the environmental monitoring program at the Savannah River Site. The soil from this site falls under the Restricted Shipping Regulations of the United States Department of Agriculture Animal Plant Health Inspection Service (USDA-APHIS). The reason given for this restriction is the potential for fire-ant contamination. Prior to be being distributed for characterization and use in the plant uptake experiments, the soil sample was therefore processed as follows:

Figure 2.3 Well Used for Groundwater Sample from Savannah River Site

Figure 2.4. Location Where Soil Sample was Collected from Savannah River Site [Soil was sampled from surface (bottom photograph) near the feet of the person standing in the trees in the top photograph.]

- The soil was considered contaminated until heat-treated and therefore handled using sterile technique. This meant that it was opened and handled only in an appropriate biosafety cabinet. These are within locked, negative air-pressure laboratories, with controlled access to authorized personnel only. At the minimum, safety apparel included a lab coat and two (2) pairs of disposable gloves that could be subsequently autoclaved.
- All soil residues were treated by either heating in a forced air oven at 110°-125°C for 16 h or autoclaving at temperatures ≥ 110°C and 15 pounds pressure for a minimum of 30 min.

2.1.4 Clemson University Site, South Carolina

This site was selected because this soil provides a good representation of an agricultural soil from the southeastern United States, and because it has been under cultivation for over 25 years, it is unlikely to suffer from the allelopathic nature of the forested Savannah River Site soil. Like the soil from the Savannah River Site, this site receives considerably more infiltration from rainfall and snowmelt than the soil samples from Hanford and Nye County. The soil sample was provided by a Professor of plant pathology and physiology at the Edisto Research and Education Center (664 Research Road, Blackville, South Carolina) at Clemson University. Blackville is 16 km (10 mi.) northeast of Barnwell on the junction of US 78 and US 321, and is approximately 50 km (30 mi.) east of Augusta, 15 mi. east-northeast of the Savannah River Plant, and 70 km (45 mi.) south-southwest of Columbia, South Carolina. Based on GPS, the soil sample was taken at coordinates North 33.2124°, West 81.18446°. Published soils maps indicate the soil is described as a Dothan Loamy Sand slope 0 to 2% or less. The soil sample is from a research field at The Edisto Research and Education Center. The field has been in agricultural production, primarily cotton and soybean, continuously for the last 25 years. The field was planted in soybeans in CY 2004, in cotton for one or two years before that, and then primarily in soybeans for the previous 10 or 12 years. Except for cleaning off plant debris, the location of the soil sample was undisturbed before digging of the soil sample. The soil was collected by scraping off the top 2 to 8 cm (1 to 3 inches) and collecting the sample at the 5 to 20 cm (2 to 8 inch) depth. The soil from the Clemson University Site also falls under USDA-APHIS because of the potential for fire-ant contamination. Therefore, prior to distribution for characterization and use in the plant uptake experiments, this soil sample was considered contaminated until heat-treated and handled using sterile technique as described in Section 2.1.3.

A separate groundwater sample was not taken at this site. Because of the similarities of the surface soils and general vicinity, the groundwater sample from the Savannah River location was considered to be representative of this location as well.

Figure 2.5. Research Field at the Edisto Research and Education Center Used for Soil from Clemson University Site

2.2 Methods for Analysis and Characterization of Groundwater and Soil Samples

The following method descriptions were taken, with the permission of the lead authors, from reports published by the PNNL Applied Geology and Geochemistry Group, such as Deutsch et al. (2004) and Serne et al. (2004).

2.2.1 Analysis of Groundwater Samples

2.2.1.1 pH and Conductivity

The pH values of the groundwater samples from the Hanford Site, Nye County, and Savannah River Site were measured using a solid-state pH electrode and a pH meter calibrated with buffers bracketing the expected range. This measurement is similar to *Test Methods for Evaluating Solid Wastes: Physical/Chemical Methods* SW-846 9040B (EPA 1995). Electrical conductivity was measured and compared to potassium chloride standards with a range of 0.001 M to 1.0 M. The pH and conductivity subsamples were filtered prior to analysis. The basic unit of conductivity is the siemens (S), formerly called the mho.

2.2.1.2 Alkalinity

The alkalinity of the groundwater samples from the Hanford Site, Nye County, and Savannah River Site were measured using standard titration. A volume of standardized sulfuric acid (H_2SO_4) was added to the sample to an endpoint of pH 8.3 and then an endpoint of pH 4.5. The volume of H_2SO_4 needed to achieve each endpoint is used to calculate the phenolphthalein ($OH^- + CO_3^{2-}$) and total ($OH^- + HCO_3^- + CO_3^{2-}$) alkalinity as calcium carbonate ($CaCO_3$). The alkalinity procedure is similar to Standard Method 2320 B (Clesceri et al. 1998).

2.2.1.3 Anions

Analyses of dissolved anions in groundwater samples from the Hanford Site, Nye County, and Savannah River Site were measured using an ion chromatograph. Bromide, carbonate, chloride, fluoride, nitrate, phosphate, and sulfate were separated on a Dionex AS17 column with a gradient elution technique from 1 mM to 35 mM KOH and measured using a conductivity detector. This methodology is similar to Method 9056 in *Test Methods for Evaluating Solid Wastes: Physical/Chemical Methods EPA SW-846* (1994b) with the exception of using gradient elution with NaOH.

2.2.1.4 Total Carbon

Total carbon contents of the groundwater samples from the Hanford Site, Nye County, and Savannah River Site were measured using a Shimadzu Carbon analyzer Model TOC-V csn that is equipped with an autosampler. The method used of measuring the carbon content of the groundwater samples is described in PNNL Technical Procedure AGG-TOC-001 (PNNL 2004),[2] and is similar to EPA Method 9060 (Total Organic Carbon) in *Test Methods for Evaluating Solid Wastes: Physical/Chemical Methods EPA SW-846* (EPA 1986). The adequacy of the system performance was confirmed by analyzing for known quantities of a liquid carbon standard.

2.2.1.5 Cations and Trace Metals

Analyses of major cations, such as Al, Ca, Fe, K, Mg, Mn, Na, and Si, dissolved in the groundwater samples from the Hanford Site, Nye County, and Savannah River Site were completed by inductively coupled plasma-optical emission spectroscopy (ICP-OES) (EPA Method 6010B, EPA 1996). Trace metals analyses, including Ag, As, Cd, Cr, Mo, Pb, Ru, Se, and U, were completed by inductively coupled plasma-mass spectroscopy (ICP-MS) using a method that is similar to EPA Method 6020 (EPA 1994a). For both

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[2] PNL. 2004. "PNNL Technical Procedure AGG-TOC-001 [Operating of Carbon Analyzer (TOC-V + SSM-5000A + ASI (Shimadzu))]." Procedure in review, Pacific Northwest National Laboratory, Richland, Washington.

ICP-OES and ICP-MS, high-purity calibration standards were used to generate calibration curves and to verify continuing calibration during the analysis. Multiple dilutions of selected samples were made and analyzed to investigate and correct for matrix interferences. The ICP-MS results are reported as total element concentration in terms of the specific isotope measured. The instrument software converts the concentration of an isotope of an element to the total concentration of the element based on the distribution of isotopes in the natural environment. For example, the total Cr concentration is reported from the raw count rates for both ^{52}Cr and ^{53}Cr isotopes based on taking the raw counts and dividing by the fraction of ^{52}Cr and ^{53}Cr found in nature to yield estimates of total Cr in the sample. (Note that these are stable isotopes of the elements).

2.2.2 Characterization and Analysis of Bulk Soil Samples

2.2.2.1 X-ray Diffraction

The primary crystalline minerals present in each bulk soil sample were identified using a Scintag X-ray powder diffraction (XRD) unit equipped with a Pelter thermoelectrically cooled detector and a copper X‑ray tube. The diffractometer was operated at 45 kV and 40 mA. Individual scans were obtained from 2 to 65° 2θ with a dwell time of 2 seconds. Scans were collected electronically and processed using the JADE® XRD pattern-processing software. Identification of the mineral phases in the background-subtracted patterns was based on a comparison of the XRD patterns measured for the sludge samples with the mineral powder diffraction files (PDF™) published by the Joint Committee on Powder Diffraction Standards (JCPDS) International Center for Diffraction Data (ICDD).

2.2.2.2 Elemental Analysis by X-ray Fluorescence

Elemental analysis of the bulk soil samples was determined by X-ray fluorescence (XRF). The XRF analyses were completed for PNNL by staff at the GeoAnalytical Laboratory in the Department of Geology at Washington State University (1228 Webster Physical Sciences Building, Pullman, Washington 99164-2812) using a Thermo-ARL Advant'XP+ automated spectrometer. The sequential, wavelength dispersive spectrometer contains a Rh-target X-ray tube operated at 60 kV, 60 mA. Samples were prepared for XRF analysis using a lithium tetraborate flux fusion method which includes double fusing (for homogeneity) in carbon crucibles at 1000°C. Preparation time and analytical time were both approximately one hour per sample. Except for now using diamond-impregnated metal disks to improve the lapping of specimen surfaces to flatness, the details of sample preparation are essentially those described in Johnson et al. (1999).

2.2.2.3 Particle Size Distribution

American Society for Testing and Materials (ASTM) procedures ASTM D1140-00 (ASTM 2000) (*Standard Test Methods for Amount of Material in Soils Finer Than the No. 200 [75 µm] Sieve*) and D422-63 (ASTM 2003) (*Standard Test Method for Particle-*

Size Analysis of Soils) were used for particle size analysis of the soil samples from the Hanford Site, Nye County, Savannah River Site, and Clemson University locations. In ASTM D422-63, a sedimentation process using a hydrometer is used to determine the distribution of particle sizes smaller than 75 µm, while sieving was used to measure the distribution of particle sizes larger than 53 µm (retained on a No. 270 sieve). A No. 10 sieve, which has sieve size openings of 2.00 mm, was first used to remove the fraction larger than "very coarse" prior to particle size analysis.

2.2.2.4 Moisture Content

Gravimetric water contents of the soil samples from the Hanford Site, Nye County, Savannah River Site, and Clemson University locations were determined using PNNL procedure PNL-MA-567-DO-1 (PNL 1990).[3] This procedure is based on the ASTM Method D2216-98 (*Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*) (ASTM 1998). One representative subsample of each soil sample was placed in tared containers, weighed, and dried in an oven at 105°C (221°C) until constant weight was achieved, which took at least 24 hours. The containers then were removed from the oven, sealed, cooled, and weighed. At least two weighings, each after a 24-hour heating, were performed to ensure that all moisture was removed. The gravimetric water content was computed as the percentage change in soil weight before and after oven drying.

2.2.2.5 Cation Exchange Capacity

The cation exchange capacity (CEC) of the soil samples from the Hanford Site, Nye County, Savannah River Site, and Clemson University locations were determined using the method described in ASA (1982). This method is particularly suited to arid land soils, including those containing carbonate, gypsum, and zeolites. This procedure involves two steps. The first step consists of saturation of the cation exchange sites with Na by reaction of the soil with pH 8.2, 60% ethanol solution of 0.4-*N* NaOAc–0.1 *N* NaCl. This is then followed by extraction of 0.5 *N* MgNO*3*. The concentrations of dissolved Na and Cl are then measured in the extracted solution so that the dissolved Na from the excess saturation solution, carried over from the saturation step to the extraction step, is deducted from the total Na. This provides amount of exchangeable Na, which is equivalent to the CEC.

2.2.2.6 Carbon Content

The total carbon and the inorganic carbon contents of the soil samples from the Hanford Site, Nye County, Savannah River Site, and Clemson University locations were measured using a Shimadzu Carbon Analyzer Model TOC-V csn. The method used to measure the carbon contents of the soil samples is similar to ASTM Method E1915-01 (*Test Methods*

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[3] PNL. 2000. "PNNL Technical Procedure SA-7. Water Content." Procedure approved in May 2000, in Procedures for Ground-Water Investigations, PNL-MA-567, Pacific Northwest National Laboratory, Richland, Washington.

for Analysis of Metal Bearing Ores and Related Materials by Combustion Infrared Absorption Spectrometry) (ASTM 2001). Known quantities of calcium carbonate standards were analyzed to verify that the instrumentation was operating properly. Inorganic carbon content was determined through calculations performed using the microgram per-sample output data and sample weights. The organic carbon content of the soil samples was calculated by subtracting the inorganic carbon contents from the respective total carbon contents for each sample.

2.2.2.7 1:1 Soil:Water Extracts

The water-soluble inorganic constituents in the soil samples from the Hanford Site, Nye County, Savannah River Site, and Clemson University locations were determined using a 1:1 soil:deionized-water extract method. The extracts were prepared by adding an exact weight of deionized water to approximately 60 to 80 g of soil subsample. The weight of deionized water needed was calculated based on the weight of the field-moist samples and their previously determined moisture contents. The sum of the existing moisture (porewater) and the deionized water was fixed at the mass of the dry soil. The appropriate amount of deionized water was added to screw cap jars containing the soil samples. The jars were sealed and briefly shaken by hand, then placed on a mechanical orbital shaker for one hour. The samples were allowed to settle until the supernatant liquid was fairly clear.

The supernatant was carefully decanted and filtered (passed through 0.45 µm membranes) for conductivity, pH, anion, carbon, and cation analyses. More details can be found in Rhoades (1996) and within *Methods of Soils Analysis - Part 3* (ASA 1996). The methods used for the pH, conductivity, anion, carbon, and cation analyses are the same as those described above for the analysis of the groundwater samples. The results for the analyses of the 1:1 soil:water extracts for the three soil samples are reported in terms of both units per gram of soil and units per milliliter of pore water. This conversion is based on a soil-to-water ratio of 1.0.

2.3 Results of Analyses and Characterization of Groundwater and Soil Samples

Table 2.1 lists the tables and figures that contain the results of the analyses and characterization studies of the groundwater, soil, and 1:1 soil:water extract samples from the Hanford Site, Nye County, Savannah River Site, and Clemson University locations.

In the following tables, analyses are listed for primary and duplicate samples of one of the three groundwater, soil, and 1:1 soil:water extract samples. A duplicate sample is selected at random when a set of samples is submitted for analyses as part of the standard laboratory quality-assurance operating procedures used by the analytical laboratories in the PNNL Applied Geology and Geochemistry Group.

The background-subtracted XRD patterns for the soil samples from the Hanford Site, Nye County, Savannah River Site, and Clemson University Site are shown in Figure 2.6, Figure 2.7, Figure 2.8, and Figure 2.9, respectively. Each XRD pattern is shown as a function of degrees 2θ based on Cu K_α radiation (λ=1.5406 Å). The vertical axis in each pattern represents the intensity in counts per second (cps) of the XRD peaks. In order to conveniently scale the XRD patterns on the vertical axes and visualize the minor XRD peaks, it was necessary to cutoff the intensity of the most intense XRD peak in each pattern. These intensity cutoffs are labeled on each XRD pattern, and correspond to the largest XRD peak for feldspar for the Hanford Site soil sample, and for quartz for the Nye County, Savannah River Site, and Clemson University Site soil samples.

At the bottom of each XRD pattern, one or more schematic database (PDF) patterns considered for phase identification are also shown for comparison purposes. The height of each line in the schematic PDF patterns represents the relative intensity of an XRD peak (i.e., the most intense [the highest] peak has a relative intensity [I/I_o] of 100%). As noted previously, a crystalline phase typically must be present at greater than 5 wt% of the total sample mass (greater than 1 wt% under optimum conditions) to be readily detected by XRD.

The following minerals were identified in the soil samples (see Figure 2.6, Figure 2.7, Figure 2.8, and Figure 2.9):

- Hanford Site soil – quartz, plagioclase feldspar, microcline feldspar, amphibole, chlorite, and mica
- Nye County soil – quartz, plagioclase feldspar, microcline feldspar, amphibole, zeolite, and mica
- Savannah River Site soil – quartz
- Clemson University Site soil – quartz

More detailed analyses would be required to refine the identities of the general mineral identifications (e.g., plagioclase, amphibole, zeolite, mica, etc.) to specific compositions. The soil sample from Nye County appears to contain a zeolite mineral. Although the pattern for this soil sample (Figure 2.7) was a good match to the database pattern for clinoptilolite (PDF 47-1870), other compositions of zeolites may also match this pattern. Several reflections in the XRD patterns for soil samples from the Savannah River Site (i.e., 16.62, 25.50, and 33.44 °2θ) and Clemson University Site (i.e., 19.96, 23.99, 25.48, 25.67, 34.95, 37.74, 38.54 °2θ) could not be identified. Additional XRD patterns measured at slower scanning rates would be needed to identify the minerals associated with these reflections. Some of the unassigned reflections in the XRD pattern for the Clemson University soil appear to match anthropogenic organic compounds, but this identification is problematic. To test this possibility, a sample of the Clemson University soil was heated for approximately 5 hours at 500°C in an attempt to decompose any organic solids present in the sample, and then re-analyzed by X-ray diffraction. The results however were inconclusive because there were no differences in the XRD patterns for the Clemson University soil before and after heating at 500°C.

Table 2.1. Tables and Figures Containing the Results of the Analyses and Characterization Studies of the Groundwater, Soil, and 1:1 Soil:Water Extract Samples from the Hanford Site, Nye County, Savannah River Site, and Clemson University locations.

Type of Sample	Table or Figure Numbers	Results Reported
Groundwater Samples	Table 2.2	pH and Conductivity
	Table 2.3	Alkalinity at pH 8.3 and 4.5 Endpoints
	Table 2.4	Dissolved Anions by IC
	Table 2.5	Total Dissolved Carbon
	Table 2.6	Dissolved Macro and Trace Elements by ICP-OES
	Table 2.7 and Table 2.8	Dissolved Trace Metals by ICP-MS
Soil Samples	Figure 2.6, Figure 2.7, Figure 2.8, and Figure 2.9	XRD patterns for soil samples from Hanford, Nye County, Savannah River, and Clemson University Sites, respectively
	Table 2.9 and Table 2.10	Elemental analyses of bulk soil samples by XRF
	Table 2.11	Particle Size of Bulk Solid
	Table 2.12	Moisture Content
	Table 2.13	Cation Exchange Capacity (CEC)
	Table 2.14	Contents of Total, Inorganic, and Organic Carbon
1:1 Soil:Water Extracts	Table 2.15	pH and Conductivity
	Table 2.16	Alkalinity at pH 8.3 and 4.5 Endpoints
	Table 2.17	Dissolved Anions by IC
	Table 2.18 and Table 2.19	Dissolved Macro and Trace Elements by ICP-OES
	Table 2.20 and Table 2.21	Dissolved Trace Metals by ICP-MS

Table 2.2. pH and Conductivity Values for the Groundwater Samples

Groundwater Samples	pH	Conductivity[*] (mS/cm)
Hanford Site	8.43	0.544
Hanford Site (duplicate)	8.35	0.543
Nye County	8.42	0.197
Savannah River Site	8.75	1.052

[*] The basic unit of conductivity is the siemens (S), formerly called the mho.

Table 2.3. Alkalinity Values for the Groundwater Samples

Groundwater Samples	Alkalinity at pH 8.3 Endpoint	Total Alkalinity at pH 4.5 Endpoint
	(mg $CaCO_3$/L)	
Hanford Site	0.0*	168.36
Hanford Site (duplicate)	0.0	167.63
Nye County	15.372	290.60
Savannah River Site	0.0	81.984

* Alkalinity values of 0.0 mg $CaCO_3$/L at the pH 8.3 endpoint indicate that the starting pH values of the respective groundwater samples were near or less than pH 8.3.

Table 2.4. Concentrations of Dissolved Anions in the Groundwater Samples

Groundwater Samples	Br^-	CO_3^{2-}	Cl^-	F^-	NO_3^-	PO_4^{3-}	SO_4^{2-}
	(µg/mL)						
Hanford Site	<0.48	222.7	20.07	0.42	13.76	<0.51	79.75
Hanford Site (duplicate)	<0.48	220.9	20.00	0.42	13.66	<0.51	79.49
Nye County	<0.48	389.1	44.96	5.91	2.47	<0.51	187.0
Savannah River Site	<0.48	59.38	2.60	0.09	<0.43	<0.51	5.29

Table 2.5. Concentrations of Total Dissolved Carbon in the Groundwater Samples

Groundwater Samples	Total Dissolved Carbon		
	#1	#2	Average
	(mg/L)		
Hanford Site	39.85	40.14	40.00
Nye County	68.40	68.33	68.37
Savannah River Site	17.83	17.74	17.79

Table 2.6. Concentrations of Dissolved Macro and Trace Metals in the Groundwater Samples as Determined by ICP-OES

Groundwater Samples	Al	As	B	Ba	Be	Bi	Ca	Cd	Co	Cr
	(μg/L)									
Hanford Site	ND	<1.3E+02	<1.3E+02	1.8E+02	<6.3E+01	ND	5.8E+04	ND	<2.5E+01	<6.3E+01
Hanford Site (duplicate)	ND	<1.3E+02	<1.3E+02	1.5E+02	<6.3E+01	ND	5.9E+04	ND	<2.5E+01	<6.3E+01
Nye County	ND	<1.3E+02	8.8E+02	8.1E+01	<6.3E+01	ND	1.9E+04	ND	<2.5E+01	<6.3E+01
Savannah River Site	ND	<1.3E+02	<1.3E+02	6.3E+01	<6.3E+01	ND	3.3E+04	ND	ND	<6.3E+01

	Cu	Fe	K	Li	Mg	Mn	Mo	Na	Ni	P
	(μg/L)									
Hanford Site	<2.5E+02	<2.5E+01	7.6E+03	<2.5E+03	2.2E+04	ND	<2.5E+01	2.4E+04	<2.5E+01	<3.1E+02
Hanford Site (duplicate)	<2.5E+02	<2.5E+01	7.7E+03	<2.5E+03	2.2E+04	ND	ND	2.4E+04	<2.5E+01	<3.1E+02
Nye County	<2.5E+02	<2.5E+01	1.4E+04	<2.5E+03	1.7E+04	ND	<2.5E+01	2.1E+05	<2.5E+01	<3.1E+02
Savannah River Site	<2.5E+02	<2.5E+01	<1.3E+03	<2.5E+03	8.2E+02	ND	<2.5E+01	1.7E+03	<2.5E+01	<3.1E+02

	Pb	S	Se	Si	Sr	Ti	Tl	V	Zn	Zr
	(μg/L)									
Hanford Site	ND	ND	<5.0E+02	2.9E+04	2.3E+02	ND	ND	<2.5E+02	3.7E+02	<2.5E+01
Hanford Site (duplicate)	ND	ND	<5.0E+02	2.9E+04	2.3E+02	ND	ND	<2.5E+02	3.5E+02	ND
Nye County	ND	ND	<5.0E+02	2.2E+04	5.3E+02	ND	ND	ND	<6.3E+01	ND
Savannah River Site	ND	ND	<5.0E+02	1.3E+04	8.5E+01	ND	ND	<2.5E+02	<6.3E+01	<2.5E+01

Table 2.7. Concentrations of Dissolved Trace Metals in the Groundwater Samples as Determined by ICP-MS

Groundwater Samples	**Ag – total based on**		**As – total based on**	**Cd – total based on**		**Cr – total based on**	
	^{107}Ag*	**^{109}Ag**	**^{75}As**	**^{111}Cd**	**^{114}Cd**	**^{52}Cr**	**^{53}Cr**
	(μg/L)						
Hanford Site	<1.25E-01	<1.25E-01	2.51E+00	<5.00E-01	<5.00E-02	2.05E+00	2.24E+00
Hanford Site (duplicate)	<1.25E-01	<1.25E-01	2.85E+00	<5.00E-01	<5.00E-02	1.99E+00	2.55E+00
Nye County	<1.25E-01	<1.25E-01	4.02E+01	<5.00E-01	<5.00E-02	<1.25E+00	1.53E+00
Savannah River Site	<1.25E-01	<1.25E-01	<2.50E+00	<5.00E-01	<5.00E-02	<1.25E+00	1.28E+00
* Note that all isotopes indicated are non-radioactive.							

Table 2.8. Concentrations of Dissolved Trace Metals in the Groundwater Samples as Determined by ICP-MS (Continued)

Groundwater Samples	**Mo – total based on**		**Pb – total based on**		**Ru – total based on**		**Se – total based on**	**U – total based on**
	^{95}Mo**	**^{98}Mo**	**^{206}Pb**	**^{208}Pb**	**^{101}Ru**	**^{102}Ru**	**^{82}Se**	**^{238}U**
	(μg/L)							
Hanford Site	<2.50E+00	1.26E+00	<1.25E+00	<1.25E+00	<1.25E+00	<1.25E+00	<2.50E+01	2.32E+00
Hanford Site (duplicate)	<2.50E+00	<1.25E+00	<1.25E+00	<1.25E+00	<1.25E+00	<1.25E+00	<2.50E+01	2.30E+00
Nye County	1.34E+01	1.24E+01	<1.25E+00	<1.25E+00	<1.25E+00	<1.25E+00	<2.50E+01	3.78E+00
Savannah River Site	<2.50E+00	<1.25E+00	<1.25E+00	1.32E+00	<1.25E+00	<1.25E+00	<2.50E+01	<5.00E-02
* Note that all isotopes indicated are non-radioactive.								

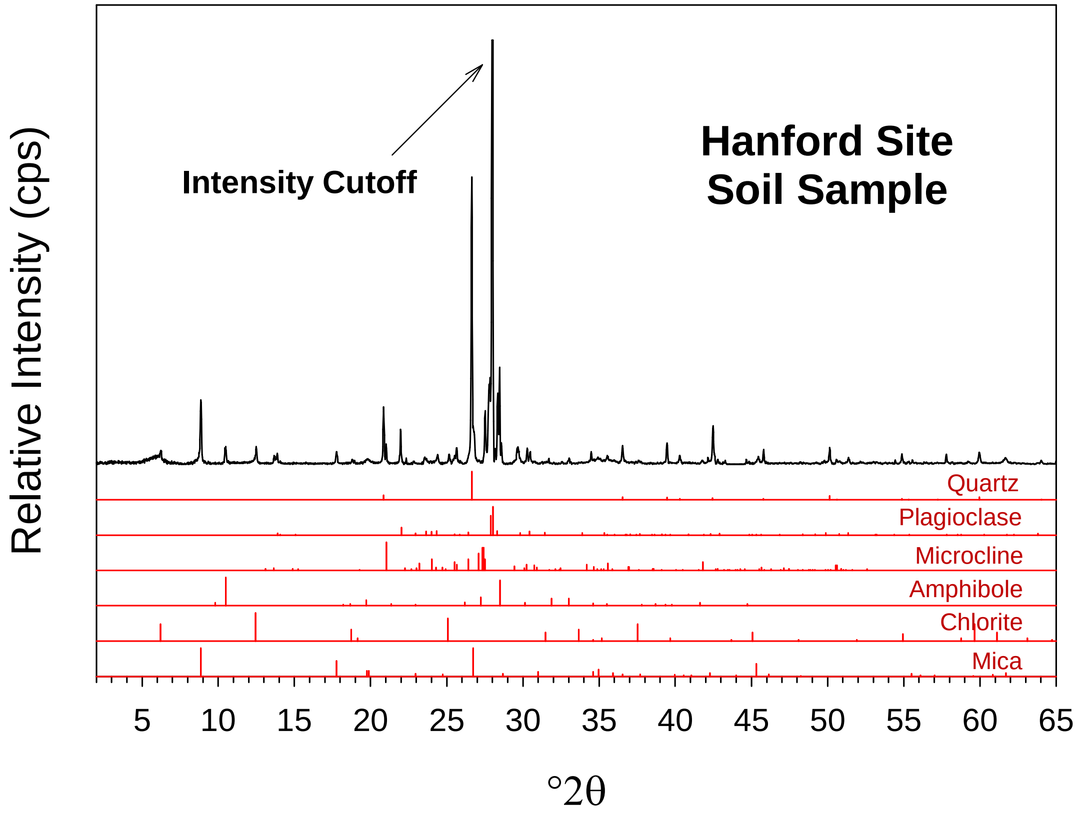

Figure 2.6. Background-Subtracted XRD Pattern for Hanford Site Soil Sample

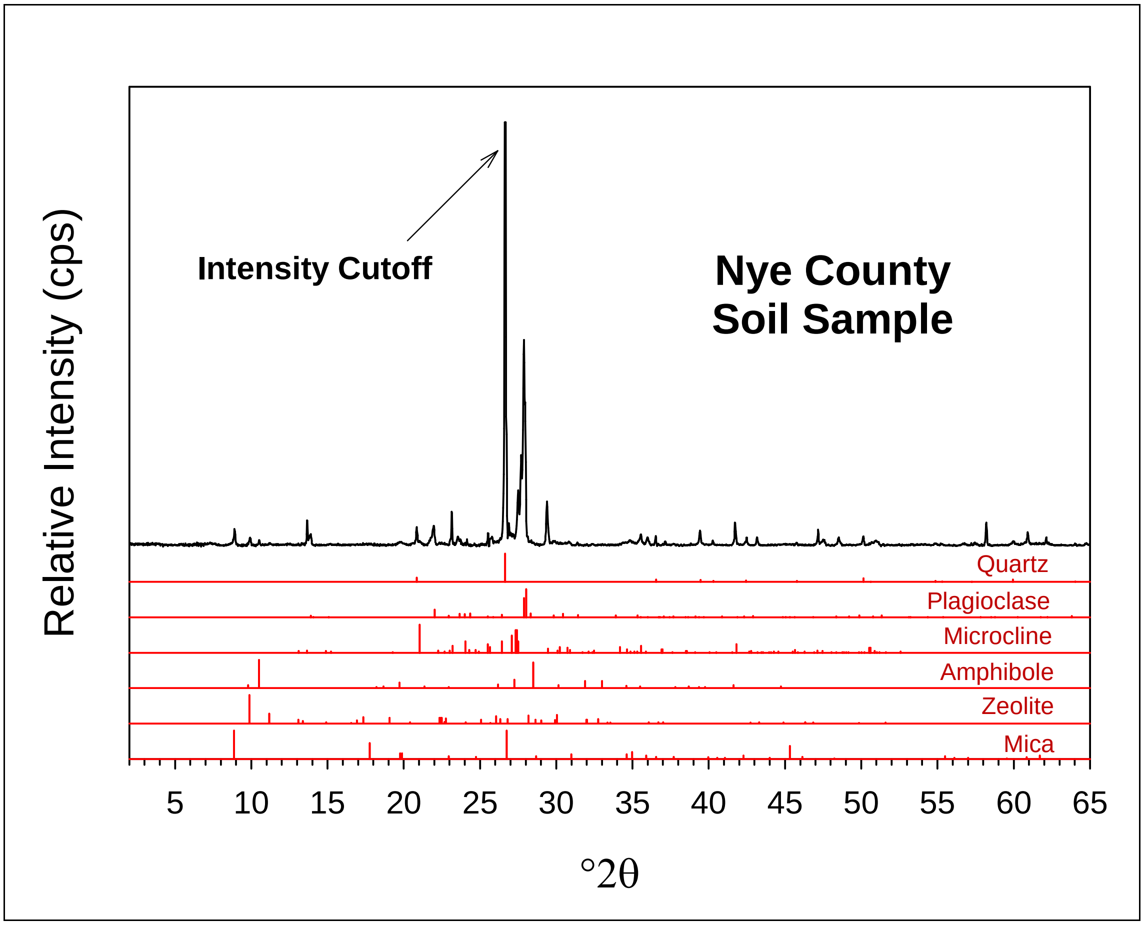

Figure 2.7. Background-Subtracted XRD Pattern for Nye County Soil Sample

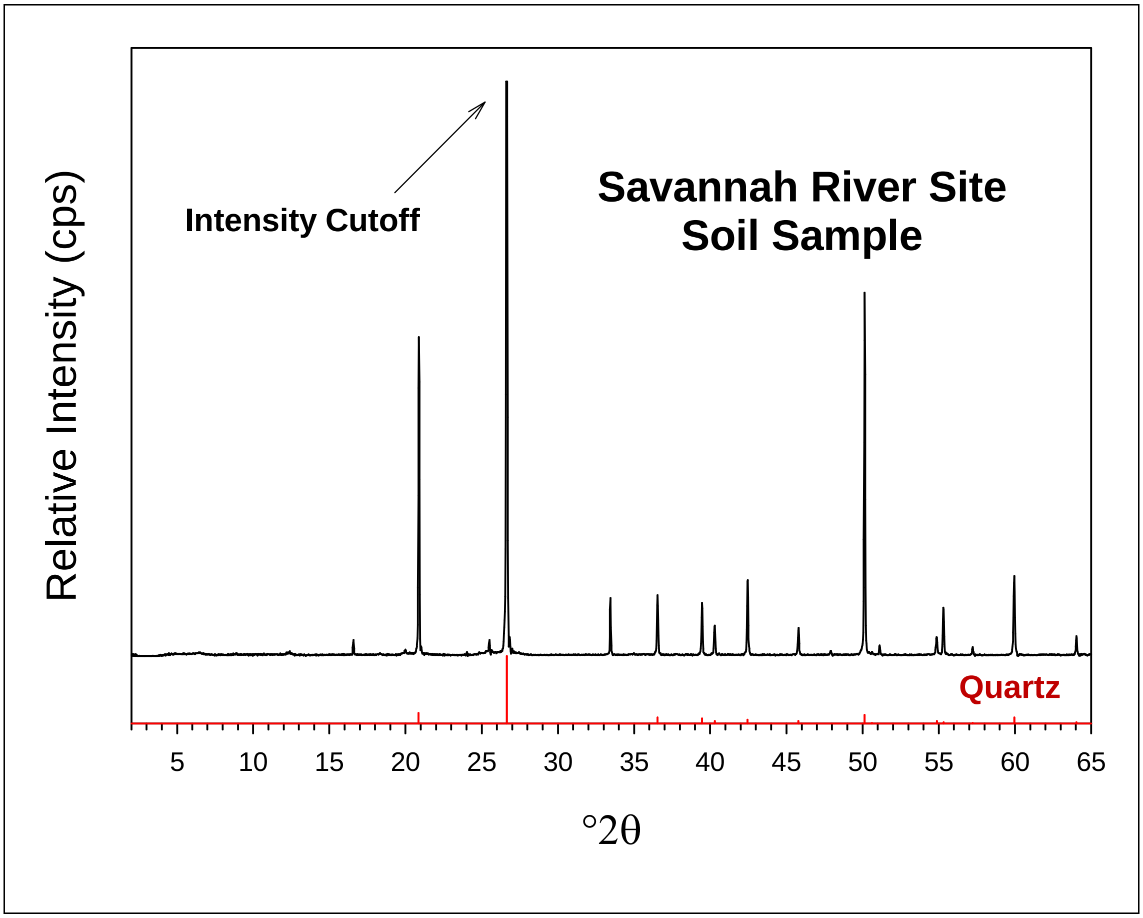

Figure 2.8. Background-Subtracted XRD Pattern for Savannah River Site Soil Sample

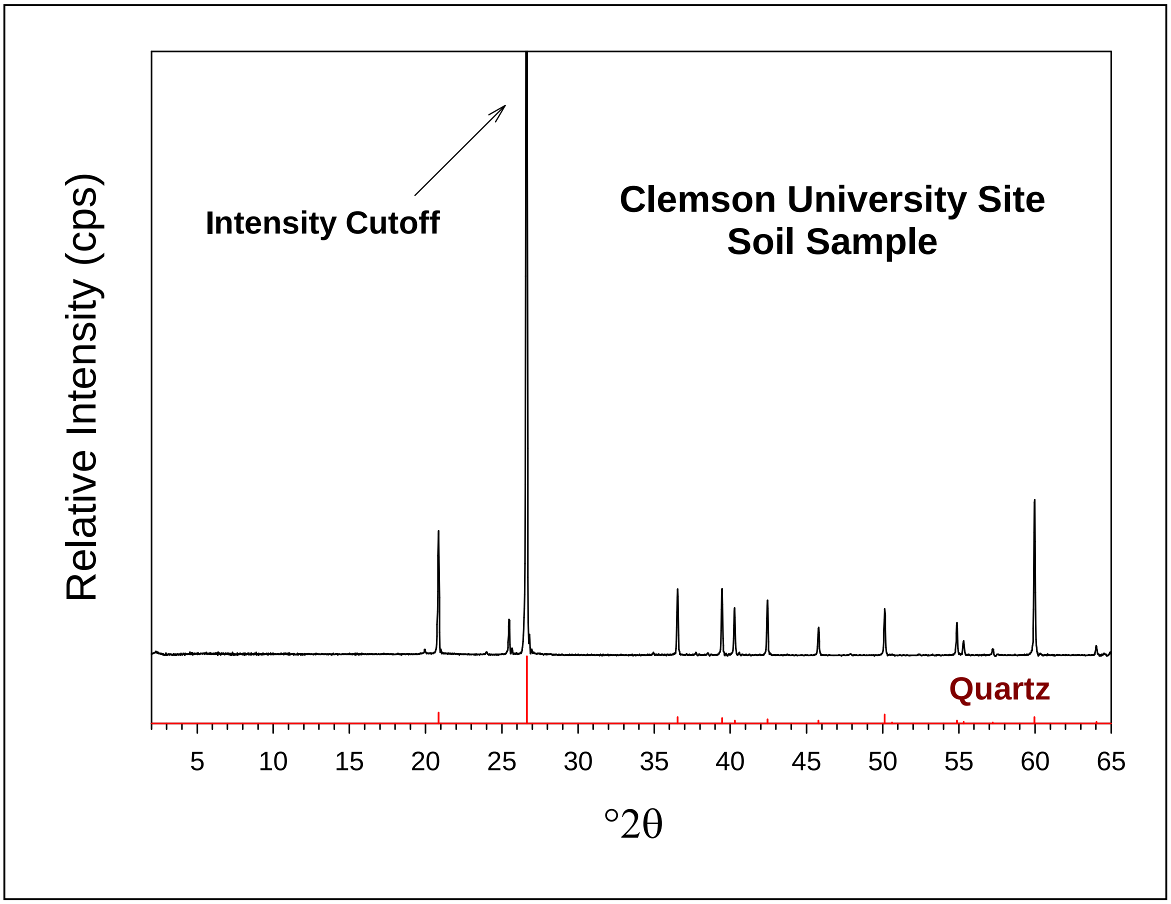

Figure 2.9. Background-Subtracted XRD Pattern for Clemson University Site Soil Sample

Table 2.9. Concentrations of Major Elements in Bulk Soil Samples as Determined by XRF

	Al_2O_3	**CaO**	**FeO***	**K_2O**	**MgO**	**MnO****	**Na_2O**	**P_2O_5**	**SiO_2**	**TiO_2**	**Total**
	(wt% – dry basis, normalized to 100%)										
Hanford Site	13.91	3.78	6.40	2.13	2.24	0.108	2.40	0.182	67.70	1.147	100.00
Nye County	13.44	6.23	2.04	4.31	1.55	0.064	3.00	0.071	68.95	0.347	100.00
Savannah River Site	1.79	0.03	0.43	0.07	0.06	0.026	0.02	0.037	97.05	0.495	100.00
Clemson University Site	0.90	0.02	0.28	0.04	0.03	0.007	0.00	0.047	98.27	0.328	99.93

	LOI***	**Al_2O_3**	**CaO**	**FeO***	**K_2O**	**MgO**	**MnO****	**Na_2O**	**P_2O_5**	**SiO_2**	**TiO_2**	**Total**
	(%)	**(wt% – normalized to 100% minus LOI)**										
Hanford Site	4.82	13.21	3.59	6.08	2.03	2.12	0.103	2.28	0.173	64.32	1.090	95.00
Nye County	7.91	12.35	5.73	1.88	3.97	1.42	0.059	2.75	0.065	63.37	0.319	91.91
Savannah River Site	1.79	1.76	0.03	0.42	0.07	0.06	0.026	0.02	0.036	95.22	0.486	98.12
Clemson University	1.04	0.89	0.02	0.27	0.04	0.03	0.007	0.00	0.047	97.19	0.325	98.90

[*] Concentrations of total iron are normalized to FeO. XRF determines the concentrations of total iron and manganese, but does not provide any data regarding the oxidation states of such redox sensitive elements present in the sample.

[**] Concentrations of total manganese are normalized to MnO.

[***] LOI = Loss on ignition

Table 2.10. Concentrations of Trace Elements in Bulk Soil Samples as Determined by XRF

	Ba	**Ce**	**Cr**	**Cu**	**Ga**	**La**	**Nb**	**Nd**	**Ni**
	(ppm)								
Hanford Site	648	70	44	20	17	35	13	31	23
Nye County	694	95	13	9	17	53	19	36	10
Savannah River Site	45	86	17	7	1	25	10	28	11
Clemson University Site	24	46	17	4	2	18	6	15	3

	Pb	**Rb**	**Sc**	**Sr**	**Th**	**V**	**Y**	**Zn**	**Zr**
	(ppm)								
Hanford Site	16	69	15	311	10	138	30	70	254
Nye County	24	136	6	413	19	24	27	53	256
Savannah River Site	8	10	2	6	8	16	24	13	675
Clemson University Site	7	4	0	3	7	10	13	21	445

Table 2.11. Particle Size Analysis of the Bulk Soil Samples

Soil Samples	Gravel (x > 2 mm)	Sand (2 > x > 0.050 mm)	Silt/Clay (x < 0.050 mm)
	(wt%)		
Hanford Site	0.0	82.92	17.08
Nye County	0.0	98.99	1.01
Savannah River Site	0.0	97.01	2.99
Clemson University Site	0.0	97.50	2.50

Table 2.12. Moisture Contents of the Bulk Soil Samples

Soils	Moisture (wt%)	
	First Weighing	Second Weighing
Hanford Site	2.49	2.39
Nye County	2.51	2.30
Nye County (duplicate)	2.57	2.38
Savannah River Site	0.25*	0.21*
Clemson University Site	0.16*	0.13*

* Soils from these two sites fall under USDA-APHIS because of the potential for fire-ant contamination. Prior to distribution for characterization, these soils had therefore been heat treated by either heating in a forced air oven at 110°-125°C for 16 to 48 h, or autoclaving at temperatures 110°C and 15 pounds pressure for a minimum of 30 min.

Table 2.13. Cation Exchange Capacity (CEC) Values for the Soil Samples

Soils	CEC (meq/100 g)			
	#1	#2	#3	Average
Hanford Site	38.2	35.1	ND*	36.7
Nye County	27.3	28.5	29.3	28.4
Savannah River Site	26.8	22.4	ND*	24.6
Clemson University Site	27.8	23.6	ND*	25.7

* ND – Third analysis of CEC not determined for these soil samples.

Table 2.14. Carbon Contents of the Soil Samples

Soil	Total Carbon			Total Inorganic Carbon			Total Inorganic Carbon As $CaCO_3$	Total Organic Carbon (by difference)
	#1	#2	Ave	#1	#2	Ave	Ave	Ave
	(wt%)							
Hanford Site	0.36	0.36	0.36	0.09	0.09	0.09	0.72	0.27
Nye County	1.10	1.08	1.09	0.97	0.98	0.97	8.11	0.12
Nye County (duplicate)	1.38	1.38	1.38	1.26	1.22	1.24	10.31	0.14
Savannah River Site	0.63	0.63	0.63	0.0	0.0	0.0	0.0	0.63
Clemson University Site	0.38	0.38	0.38	0.0	0.0	0.0	0.0	0.38

Table 2.15. pH and Conductivity Values for the 1:1 Soil:Water Extracts

1:1 Soil:Water Extracts	pH	Conductivity (mS/cm)	Conductivity (mS/cm) Dilution Corrected (in Pore Water)
Hanford Site	7.48	0.184	7.38
Nye County	8.07	0.400	15.94
Nye County (duplicate)	8.14	0.407	15.85
Savannah River Site	4.46	0.303	120.90
Clemson University Site	4.92	0.158	96.51
Clemson University Site (duplicate)	4.87	0.149	91.06

Table 2.16. Alkalinity Values for the 1:1 Soil:Water Extracts

1:1 Soil:Water Extracts	**Akalinity at pH 8.3 Endpoint**	**Total Alkalinity at pH 4.5 Endpoint**	**Porewater Total Alkalinity at pH 4.5 Endpoint Dilution Corrected (in Pore Water)**
	(mg $CaCO_3$/L)		
Hanford Site	0.0*	85.644	3,436.0
Nye County	6.588	137.61	5,485.7
Nye County (duplicate)	5.124	142.74	5,557.3
Savannah River Site	0.0*	10.248	4,088.9**
Clemson University Site	0.0*	19.764	12,070**
Clemson University Site (duplicate)	0.0*	19.032	11,630**

* Alkalinity values of 0.0 mg $CaCO_3$/L at the pH 8.3 endpoint indicate that the starting pH values of the respective extract samples were near or less than pH 8.3.

** Indicated dilution-corrected, porewater alkalinity values are likely in error by a considerable, but unknown, amount. Because these soil samples fell under USDA-APHIS and had been heat treated before submission characterization and analysis, calculations based on their low (essentially zero) moisture contents resulted in error in the calculated, dilution-corrected, porewater alkalinity values.

Table 2.17. Concentrations of Dissolved Anions in 1:1 Soil:Water Extract

1:1 Soil:Water Extracts[*]	**Br^-**	**CO_3^{2-}**	**Cl^-**	**F^-**	**NO_3^-**	**PO_4^{3-}**	**SO_4^{2-}**
	(µg/g soil)						
Hanford Site	<0.48	70.36	<0.236	0.16	2.50	NR[**]	1.36
Nye County	<0.48	161.8	6.86	7.03	5.57	NR[**]	30.81
Nye County (duplicate)	<0.48	162.0	6.92	7.07	5.20	NR[**]	30.69
Savannah River Site	<0.48	<50.00	2.85	5.53	2.22	NR[**]	29.22
Clemson University Site	<0.46	<48.19	0.39	1.05	1.68	7.37	18.11
Clemson University Site (duplicate)	<0.46	<48.21	0.40	2.65	1.76	7.90	19.04
	(µg/mL pore water)						
Hanford Site	<19.30	2,823	<9.452	6.62	100.3	NR[**]	54.63
Nye County	<19.17	6,446	273.5	280.4	222.0	NR[**]	1,228
Nye County (duplicate)	<18.73	6,307	269.5	275.2	202.3	NR[**]	1,195
Savannah River Site	<191.9	<19,950	1,136	2,205	886.8	NR[**]	11,660
Clemson University Site	<293.8	<30,540	246.5	665.0	1,066	4,671	11,480
Clemson University Site (duplicate)	<294.0	<30,560	254.5	1678	1,115	5,006	12,070

[*] Pore water dilution factors were 40.12, 39.86, 38.93, 399.00, 610.81, and 611.12, respectively.
Dilution factor corrected - µg in water extract per mL pore water.

[**] NR = Values not reported because analyses of PO_4^{3-} standard were outside the control limits.

[***] NA = Not applicable. Values could be calculated based on the measured values of 0.0 µg/g soil.

Table 2.18. Concentrations (µg/g soil) of Dissolved Macro and Trace Metals in the 1:1 Water Extracts as Determined by ICP-OES

1:1 Soil:Water Extracts	Al	As	B	Ba	Be	Bi	Ca	Cd	Co	Cr
	(µg/g soil)									
Hanford Site	ND	ND	<2.5E+02	<1.2E-01	<2.5E-01	<1.2E+00	2.10E+01	ND	<6.2E-01	<1.2E-01
Nye County	<5.0E-01	ND	<2.5E+02	<1.3E-01	<2.5E-01	<1.3E+00	5.40E+00	ND	<6.3E-01	<1.3E-01
Nye County (duplicate)	<5.0E-01	<5.0E+00	<2.5E+02	<1.3E-01	<2.5E-01	<1.3E+00	5.64E+00	ND	<6.3E-01	<1.3E-01
Savannah River Site	1.23E+01	ND	<2.5E+02	4.20E-01	<2.5E-01	<1.2E+00	1.98E+01	ND	<6.2E-01	<1.2E-01
Clemson University Site	2.95E+00	ND	<9.6E-02	9.51E-02	<9.6E-03	<1.9E-01	1.29E+01	<9.6E-03	<1.9E-02	<9.6E-03
Clemson Univ Site (duplicate)	3.20E+00	ND	<9.6E-02	7.40E-02	<9.6E-03	ND	1.38E+01	<9.6E-03	<1.9E-02	<9.6E-03

	Cu	Fe	K	Li	Mg	Mn	Mo	Na	Ni	P
	(µg/g soil)									
Hanford Site	<2.5E+00	<5.0E-01	<6.2E+01	<1.2E+00	5.19E+00	ND	<2.5E-01	<2.5E+00	<1.2E+00	<6.2E+00
Nye County	<2.5E+00	<5.0E-01	<6.3E+01	<1.3E+00	2.44E+00	ND	ND	8.20E+01	<1.3E+00	<6.3E+00
Nye County (duplicate)	<2.5E+00	<5.0E-01	<6.3E+01	<1.3E+00	2.38E+00	ND	<2.5E-01	8.36E+01	<1.3E+00	<6.3E+00
Savannah River Site	<2.5E+00	1.70E+00	<6.2E+01	<1.2E+00	3.31E+00	2.71E+01	ND	<2.5E+00	<1.2E+00	<6.2E+00
Clemson University Site	<9.6E-02	6.85E-01	9.24E+00	<9.6E-02	4.74E+00	2.76E+00	<3.8E-02	5.09E-01	<1.9E-02	3.69E+00
Clemson Univ Site (duplicate)	<9.6E-02	7.26E-01	9.78E+00	<9.6E-02	5.04E+00	2.92E+00	ND	5.53E-01	<1.9E-02	3.91E+00

	Pb	S	Se	Si	Sr	Ti	Tl	V	Zn	Zr
	(µg/g soil)									
Hanford Site	ND	<1.0E+01	ND	<2.5E+01	7.89E-02	<2.5E-01	ND	ND	<1.2E-01	ND
Nye County	<1.3E+00	1.15E+01	ND	<2.5E+01	5.79E-02	<2.5E-01	ND	<2.5E+00	1.65E-01	<2.5E-01
Nye County (duplicate)	ND	1.11E+01	ND	<2.5E+01	5.99E-02	ND	ND	<2.5E+00	<1.3E-01	ND
Savannah River Site	<1.2E+00	1.26E+01	<5.0E+00	<2.5E+01	1.23E-01	<2.5E-01	ND	<2.5E+00	2.68E-01	<2.5E-01
Clemson University Site	<9.6E-02	8.36E+00	<3.9E-01	<1.9E+00	<1.9E-02	<4.8E-02	<1.9E-01	<9.6E-02	9.57E-02	<1.9E-02
Clemson Univ Site (duplicate)	<9.6E-02	8.89E+00	<3.9E-01	<1.9E+00	<1.9E-02	<4.8E-02	<1.9E-01	<9.6E-02	7.87E-02	<1.9E-02

Table 2.19. Concentrations (µg/L pore water) of Dissolved Macro and Trace Metals in the 1:1 Water Extracts as Determined by ICP-OES

1:1 Soil:Water Extracts	**Al**	**As**	**B**	**Ba**	**Be**	**Bi**	**Ca**	**Cd**	**Co**	**Cr**
	(µg/L pore water)									
Hanford Site	ND	ND	<1.0E+07	<5.0E+03	<1.0E+04	<5.0E+04	8.44E+05	ND	<2.5E+04	<5.0E+03
Nye County	<2.0E+04	ND	<1.0E+07	<5.0E+03	<1.0E+04	<5.0E+04	2.15E+05	ND	<2.5E+04	<5.0E+03
Nye County (duplicate)	<1.9E+04	<1.9E+05	<9.7E+06	<4.9E+03	<9.7E+03	<4.9E+04	2.20E+05	ND	<2.4E+04	<4.9E+03
Savannah River Site	4.92E+06	ND	<1.0E+08	1.68E+05	<1.0E+05	<5.0E+05	7.91E+06	ND	<2.5E+05	<5.0E+04
Clemson University Site	1.87E+06	ND	<6.1E+04	6.03E+04	<6.1E+03	<1.2E+05	8.17E+06	<6.1E+03	<1.2E+04	<6.1E+03
Clemson Univ Site (duplicate)	2.03E+06	ND	<6.1E+04	4.69E+04	<6.1E+03	ND	8.74E+06	<6.1E+03	<1.2E+04	<6.1E+03

	Cu	**Fe**	**K**	**Li**	**Mg**	**Mn**	**Mo**	**Na**	**Ni**	**P**
	(µg/L pore water)									
Hanford Site	<1.0E+05	<2.0E+04	<2.5E+06	<5.0E+04	2.08E+05	ND	<1.0E+04	<1.0E+05	<5.0E+04	<2.5E+05
Nye County	<1.0E+05	<2.0E+04	<2.5E+06	<5.0E+04	9.74E+04	ND	ND	3.27E+06	<5.0E+04	<2.5E+05
Nye County (duplicate)	<9.7E+04	<1.9E+04	<2.4E+06	<4.9E+04	9.25E+04	ND	<9.7E+03	3.26E+06	<4.9E+04	<2.4E+05
Savannah River Site	<1.0E+06	6.78E+05	<2.5E+07	<5.0E+05	1.32E+06	1.08E+07	ND	<1.0E+06	<5.0E+05	<2.5E+06
Clemson University Site	<6.1E+04	4.34E+05	5.85E+06	<6.1E+04	3.00E+06	1.75E+06	<2.4E+04	3.22E+05	<1.2E+04	2.34E+06
Clemson Univ Site (duplicate)	<6.1E+04	4.60E+05	6.20E+06	<6.1E+04	3.19E+06	1.85E+06	ND	3.51E+05	<1.2E+04	2.48E+06

	Pb	**S**	**Se**	**Si**	**Sr**	**Ti**	**Tl**	**V**	**Zn**	**Zr**
	(µg/L pore water)									
Hanford Site	ND	<4.0E+05	ND	<1.0E+06	3.17E+03	<1.0E+04	ND	ND	<5.0E+03	ND
Nye County	<5.0E+04	4.56E+05	ND	<1.0E+06	2.31E+03	<1.0E+04	ND	<1.0E+05	6.57E+03	<1.0E+04
Nye County (duplicate)	ND	4.34E+05	ND	<9.7E+05	2.33E+03	ND	ND	<9.7E+04	<4.9E+03	ND
Savannah River Site	<5.0E+05	5.03E+06	<2.0E+06	<1.0E+07	4.90E+04	<1.0E+05	ND	<1.0E+06	1.07E+05	<1.0E+05
Clemson University Site	<6.1E+04	5.30E+06	<2.4E+05	<1.2E+06	<1.2E+04	<3.1E+04	<1.2E+05	<6.1E+04	6.06E+04	<1.2E+04
Clemson Univ Site (duplicate)	<6.1E+04	5.63E+06	<2.4E+05	<1.2E+06	<1.2E+04	<3.1E+04	<1.2E+05	<6.1E+04	4.99E+04	<1.2E+04

Table 2.20. Concentrations of Dissolved Macro and Trace Metals in 1:1 Water Extracts as Determined by ICP-MS

1:1 Soil:Water Extracts	**Ag – total based on**	**As – total based on**	**Cd – total based on**		**Cr – total based on**		**Mo – total based on**	
	^{109}Ag**	**^{75}As**	**^{111}Cd**	**^{114}Cd**	**^{52}Cr**	**^{53}Cr**	**^{97}Mo**	**^{98}Mo**
	(µg/g soil)							
Hanford Site	2.09E-04	7.02E-03	<1.25E-04	<1.25E-04	<2.50E-03	<5.00E-03	2.35E-03	2.35E-03
Nye County	8.07E-05	3.94E-02	1.63E-04*	1.41E-04*	<2.50E-03	<5.00E-03	1.31E-02	1.33E-02
Nye County (duplicate)	6.12E-05	3.89E-02	<1.25E-04*	<1.25E-04*	<2.50E-03	<5.00E-03	1.37E-02	1.39E-02
Savannah River Site	<5.00E-05	1.21E-03	5.98E-04	5.41E-04	<2.50E-03	<5.00E-03	<5.00E-04	<5.00E-04
Clemson University Site	<1.20E-04	5.88E-03	3.14E-04	3.16E-04	7.43E-03	6.80E-03	<1.20E-03	<1.20E-03
Clemson University Site (duplicate)	<1.21E-04	6.30E-03	3.33E-04	3.57E-04	8.32E-03	7.48E-03	<1.21E-03	<1.21E-03
	(µg/L pore water)							
Hanford Site	8.40E+00	2.82E+02	<5.01E+00	<5.01E+00	<1.00E+02	<2.01E+02	9.42E+01	9.42E+01
Nye County	3.22E+00	1.57E+03	6.50E+00*	5.62E+00*	<9.97E+01	<1.99E+02	5.24E+02	5.31E+02
Nye County (duplicate)	2.38E+00	1.51E+03	<4.87E+00*	<4.87E+00*	<9.73E+01	<1.95E+02	5.34E+02	5.43E+02
Savannah River Site	<1.99E+01	4.84E+02	2.39E+02	2.16E+02	<9.97E+02	<1.99E+03	<1.99E+02	<1.99E+02
Clemson University Site	<7.64E+01	3.72E+03	1.99E+02	2.00E+02	4.71E+03	4.31E+03	<7.64E+02	<7.64E+02
Clemson University Site (duplicate)	<7.64E+01	4.00E+03	2.11E+02	2.26E+02	5.27E+03	4.74E+03	<7.64E+02	<7.64E+02

* Indicated values for each respective cadmium isotope are suspect because the values for the primary and duplicate extract samples are too dissimilar.

** Note that all isotopes indicated are non-radioactive.

Table 2.21. Concentrations of Dissolved Trace Elements in 1:1 Water Extracts as Determined by ICP-MS (Continued)

1:1 Soil:Water Extracts	**Pb – total based on**		**Ru – total based on**		**Se – total based on**	**U – total based on**
	^{206}Pb**	**^{208}Pb**	**^{101}Ru**	**^{102}Ru**	**^{82}Se**	**^{238}U**
	(µg/g soil)					
Hanford Site	<1.25E-03	<2.50E-03	<5.00E-05	<5.00E-05	<5.00E-03	1.93E-04
Nye County	<1.25E-03	<2.50E-03	<5.00E-05	<5.00E-05	<5.00E-03	1.92E-03
Nye County (duplicate)	<1.25E-03	<2.50E-03	<5.00E-05	<5.00E-05	<5.00E-03	2.07E-03
Savannah River Site	5.66E-03	6.07E-03	<5.00E-05	<5.00E-05	<5.00E-03	4.27E-03
Clemson University Site	5.43E-03	5.32E-03	<2.41E-04	<2.41E-04	1.29E-03	2.97E-03
Clemson University Site (duplicate)	6.16E-03	6.06E-03	<2.41E-04	<2.41E-04	1.41E-03	3.10E-03
	(µg/L pore water)					
Hanford Site	<5.01E+01	<1.00E+02	<2.01E+00	<2.01E+00	<2.01E+02	7.73E+00
Nye County	<4.98E+01	<9.97E+01	<1.99E+00	<1.99E+00	<1.99E+02	7.65E+01
Nye County (duplicate)	<4.87E+01	<9.73E+01	<1.95E+00	<1.95E+00	<1.95E+02	8.05E+01
Savannah River Site	2.26E+03	2.42E+03	<1.99E+01	<1.99E+01	<1.99E+03	1.70E+03
Clemson University Site	3.44E+03	3.37E+03	<1.53E+02	<1.53E+02	8.20E+02	1.88E+03
Clemson University Site (duplicate)	3.90E+03	3.84E+03	<1.53E+02	<1.53E+02	8.96E+02	1.96E+03
* Note that all isotopes indicated are non-radioactive.						

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3.0 Agricultural Practices at the Three Locations

A review has been conducted of site-specific characteristics and information on agricultural and gardening practices in the area of each of the soil and groundwater sampling sites. This information has been summarized from information gleaned from literature surveys, environmental impact statements, recent census data, area agricultural extension agencies, and site visits.

3.1 Washington

Agricultural practice information is based on current conditions in the south central part of eastern Washington, encompassing the Columbia Basin and Yakima Valley. Most of the following information is derived from the 2002 Census of Agriculture data for Benton, Franklin, Grant, and Yakima Counties (NASS 2002b; 2002c; 2002d; 2002e), monitoring and analysis information from the Department of Energy's Hanford Site (Schreckhise et al. 1993; Rittmann 2004), and a Land Use Census prepared for the Washington Public Power Supply System (now called Energy Northwest) (McDonald 1989). The information was compiled by Department of Energy (DOE) contractors by combining historical information with available government statistics. No surveys of farming practices or individual consumption patterns have been performed by DOE contractors for this region in several decades.

This area is one of the most productive farming regions in the United States. The area ranks first in the nation in production of apples and hops, and is in the top 10 for production of potatoes, grapes, hay, fruits and berries, sweet corn, and pigeons. The climate is semi-arid; the overall population density is moderate. Non-dryland agriculture, commercial and private gardens, relies on irrigation from surface water (the Columbia River via the Columbia Basin Irrigation District, with withdrawals at Grand Coulee Dam) or various smaller irrigation districts formed from the Yakima River. Some areas not served by the irrigation districts use available groundwater. Large areas far from rivers also rely on rainfall; these areas tend to lay fallow on alternate years to collect moisture. This dryland farming is primarily cattle grazing or winter wheat.

The climate of eastern Washington is semi-arid, with approximately 15 cm of precipitation per year, primarily in the winter months of November through January. Summers are hot (July monthly temperatures can average up to 30° C, a typical July averages about 25° C); winters can be cold (the coldest January average is -11° C, a typical January average is -1° C) (Stone et al. 1983).

The wide variety of agricultural products produced in eastern Washington is illustrated in Table 3.1. This information is summarized from NASS (2002b; c; d; and e) and McDonald (1989). The agricultural balance in the region is quite dynamic, and the acreage of all crops changes from year to year, but the productive nature of the region is apparent in this Table. Although the largest area is occupied by unirrigated cattle grazing and a rotating cycle of fallow land and winter wheat, the irrigated portions of the area produce a highly profitable range of products. Alfalfa hay is exported from the area to dairies in the more populated regions of Washington and Oregon. Apples and other soft tree fruits such as cherries, plums, apricots, and peaches are grown. While apples are the primary cash crop, their influence is decreasing in recent years as Red Delicious apple orchards are replaced with other crops. The region is host to the second-largest production of wine grapes in the United States; nearly 300 wineries now produce many varieties of *vitis vinifera* wines (and Concord grape production for juices and jellies is also large). A number of unusual crops are also produced. The production of the spice hops, used in beer making, is the largest in the United States, and over one-quarter of the world's output is grown in the area (hops production is also decreasing slightly, as the participants in the hops marketing association voluntarily reduce production to raise prices). Another specialty crop is mint oil (spearmint and peppermint). A wide range of vegetables is commercially grown, including sweet corn, onions, peppers, squash, beans, asparagus, and lettuce. Until recently, the region was one of the largest producers of asparagus in the United States; however, competition from South American countries is resulting in elimination of many local asparagus fields (they are largely being replaced with potatoes). Some crops are grown also for seed, such as carrot, onion, turnip, corn, radish, clover, and peas, as well as grass seed. Sugar beets have been an important crop historically; however in recent years production has been greatly curtailed because of low sugar prices. The only major commercial poultry operation is in Yakima County. Beef cattle are grazed in dryland areas throughout the region, and a number of major feed lots are also present. The dairy industry is growing through development of large commercial feeding and milking companies. Because of the productive fruit tree farming, bee keeping is also a surprisingly large activity. Franklin County is the 7th largest producer of pigeons in the United States.

The predominant method of irrigation is use of overhead sprinklers. Furrow or rill irrigation was the most common method of irrigating many Columbia Basin crops until about 1985 when sprinkler irrigation began to increase dramatically. Center-pivot

Table 3.1 Agricultural Activities in Washington Counties of Benton, Franklin, Grant, and Yakima within 80 km of the Columbia Generating Station, Hanford, Washington.

Crop	*Hectares*	*(Acres)*	*Livestock*	*Head*
Dryland grazing	104054	257122	Poultry	687500
Winter Wheat	86618	214037	Cattle	459532
Annual Fallow	76183	188253	Dairy Cows	49971
Alfalfa	52737	130317	Bee Colonies	28113
Corn	27628	68271	Sheep	17748
Vegetables	25305	62531	Pigeons	10400
Potatoes	23974	59242		
Apples	16307	40296		
Irrigated Grazing	16238	40124		
Grapes	13926	34413		
Seed Production	11481	28370		
Sweet Corn	10762	26593		
Hops	8470	20929		
Mint	7971	19696		
Tree Fruit (Cherry/Apple)	5212	12880		
Melons	303	749		

sprinkler systems allowed higher planting density, reduced the amount of irrigation labor needed, and allowed more economical production. It is estimated that about 60% of the onions grown in the Columbia Basin are now irrigated by center-pivot systems. More recently, drip irrigation has gained popularity, with about 20 percent of today's crops irrigated by this method. Irrigation water is available from most canal-supplied systems roughly from mid-April through October. In order to conserve pumping energy, most overhead systems are now designed to use minimal pressure on movable booms. However, for fixed systems, such as those in orchards, higher pressures are needed. In many areas, the irrigation systems are also used in early spring as a form of frost protection. In these systems, water is sprayed directly onto the flowers and buds of the fruit trees, to keep the temperature of the booms and fruits above a critical damage temperature (which may be slightly below freezing). As a result, the tree fruit irrigation systems are intentionally designed to wet the fruits when operating. According to the 1998 Washington Census of Agriculture, 6290 km^2 (1,554,813 acres) were irrigated, of which 81% was sprinkler, 16% was gravity feed (furrow or rill), and 3% was drip.

Although the winters are relatively cold, spring planting and orchard growth begins often in March or Aril, so the growing season is relatively long. Historically grown in the region commercially, lettuce or spinach give two crops per year. Up to four harvests per year may be obtained from alfalfa. Most crops require irrigation for essentially the entire growing season, the exception being dryland wheat, which as noted uses a two-year water cycle. Growing and irrigation seasons for the crops currently commercially grown, and a few that may be prevalent in private gardens, are presented in Table 3.2. The lengths of the growing season are derived from information of (Schreckhise et al. 1993) and McDonald (1989).

The irrigation requirements for essentially all crops are determined by the total evapotranspiration of the growing crop plus an overwatering term. Overwatering is required to avoid accumulation of salts in the surface soil. In arid regions, the overwatering rate usually is determined by calculating the amount of water required to flush accumulated salts out of the surface soil to maintain productivity. The value of this parameter is a function of the total water requirement of the crop, and is usually on the order of 100 mm/yr (BSC 2003). The average on-farm delivery is about 1130 mm to all crops in the Columbia Basin Project. Average annual crop irrigation requirements are estimated at 830 mm. This is a difference of about 300 mm in losses, but the percentage of this approximate value that is runoff compared to deep percolation (recharge) is not known since much of the surface runoff is captured and reused (http://www.sidney.ars.usda.gov/personnel/pdfs/Irrigation%20Technologies%20Comparisons.pdf). The acreage irrigated in the Columbia Basin Project (CBP) has steadily increased since the first water deliveries in the early 1950's. In the period of 1969 to 1996, the irrigated acreage increased from 1945 km^2 to 2517 km^2 (480,600 acres to 622,053 acres). In 1993, the issuance of additional water service contracts and groundwater licenses was suspended by the Bureau of Reclamation. That action was taken in response to the Northwest Power Planning Council and National Marine Fisheries Service requests to halt new irrigation diversions.

Table 3.2. Growing and Irrigation Seasons for Eastern Washington Crops

Crop (Planting – Harvest Dates)		*Days*
Lawn Grass (March-October)		240
Leafy Vegetables (April - September)		
	Mint (April -July/August)	90
	Spinach (2 crops)	90
	Asparagus (March - June)	60
	Hops (May-September)	150
Other Vegetables (March – October)		
	Potatoes (March/April-August/October)	120-140
	Corn (April/May –August/September)	120-180
	Onion (March -July/September)	150-200
	Carrot (April -September)	200
Fruits (April – October)		
	Apples (April -September)	200
	Pears (April -September)	180
	Soft tree fruit (Apricot/Peach) (April -June/August)	90-150
	Grapes (April – September/October)	180
Grains (October – July)		
	Winter Wheat (October-July)	270
Forage (March – October)		
	Alfalfa (4 harvests)	240

While this Bureau of Reclamation moratorium is in place, CBP's irrigated acreage will remain at present levels. The volume of water delivered on a project-wide basis to farms has decreased from about 1250 L/m^2 to 1180 L/m^2 (4.1 to 3.7 acre-feet/acre) in the period of 1969-1996. (For only the Columbia Basin Project, this is an annual total of 2.8x10^9 m^3 [2.3 million acre-feet or about 750 billion gallons]. The Washington statewide total is around 4.2x10^9 m^3 [1.1 trillion gallons].) The decrease in farm deliveries over time is primarily due to a change in irrigation practices by farmers. Farmers have converted from less efficient gravity or surface methods of applying water to more efficient pressurized methods such as center-pivot sprinklers. The conversion from gravity application of water to the use of center-pivot sprinklers and other pressurized irrigation systems has increased substantially since the early 1970's.

Irrigation requirements for the crops commercially raised in eastern Washington, plus some additional crops likely to be grown in private gardens, are presented in Table 3.3. The generic annual irrigation requirements in Table 3.3 are from Schreckhise et al. (1993), and the specific ones are developed from Washington State data taken from the 1998 Census of Agriculture (http://www.nass.usda.gov/census/census97/fris/fris.htm).

The productive yield of crops is a function of weather, water supply, soil type, and amounts of fertilizer added. The average yield of several commercial and garden crops for the eastern Washington region has been estimated based on production levels presented in McDonald (1989) or on values reported by Rittmann (2004). These values are presented in Table 3.4. Generic values are also presented; these are taken from Schreckhise et al. (1993).

Table 3.3. Annual Irrigation Requirements for Selected Crops in Eastern Washington

Crop		*Irrigation mm/year*
Lawn Grass		1000
Leafy Vegetables		900
	Mint	760-860
	Spinach (2 crops)	640
	Asparagus	880
	Hops	760
Other Vegetables		1000
	Potatoes	640
	Sweet Corn	640
	Onion	510-610
	Carrot	560
Fruits		900
	Apples	1070
	Pears	820
	Soft tree fruit (Apricot, Peach)	820
	Grapes	380
Grains		0
	Winter Wheat	0-490
	Corn	730
Forage		1200
	Alfalfa (4 harvests)	700

3.2 Nevada

Agricultural practice information is based on current conditions in the southern portions of Nye County, Nevada, (primarily the general areas of Beatty, Amargosa Valley, and Pahrump), with additional general information from adjacent portions of California (YMP 1997; BSC 2003). Most of the following information is derived from the 1997 “Biosphere” survey conducted for the Department of Energy’s Yucca Mountain Project (DOE 1997) or ongoing DOE monitoring programs in the area (e.g., YMP 1997; 1999). The information is consistent with, but somewhat more specific than, the 2002 Census of Agriculture data for all of Nye County (NASS 2002a). The information was compiled by DOE contractors by combining historical information, color aerial photographs of the region, and the results of field trips to the area with verification with landowners and other people knowledgeable with conditions in the region (YMP 1997).

This area is mountainous and arid; the overall population density is low and commercial agricultural activities are limited. Essentially all agriculture, commercial and private gardens, relies on irrigation from groundwater. Because of the relatively small scale of agricultural activities, the distribution of crop types varies from year to year. Overall agricultural production has been increasing over the past several years; however, the total productivity of the area is limited by the availability of groundwater.

Table 3.4. Estimated Average Harvested Yield of Crops for Eastern Washington

Crop		*Yield kg/m^2*
Leafy Vegetables		1.5
	Mint oil	0.01*
	Asparagus	0.4
	Hops	0.2
	Lettuce	2.4
Other Vegetables		4
	Potatoes	4.8
	Sweet Corn	1.8
	Onion	4.0
	Carrot	4.3
Fruits		2
	Apples	2.7
	Pears	2.8
	Soft tree fruit (Apricot, Peach)	1.4
	Grapes	2.4
Grains		0.8
	Winter Wheat	0.7
	Corn	1.1
Forage		2
	Alfalfa (4 harvests)	1.4

*Mint oil is pressed from the mint leaves, and is a small fraction of the harvested mass.

The climate of southern Nevada is dry, with approximately 10 cm of precipitation per year, primarily in the winter months of December through March. Summers are very hot (July monthly temperatures can average up to 40° C); winters are mild (the coolest averages are still above 0° C) (BSC 2003).

Agriculture mainly involves growing feed (e.g., alfalfa) for farm animals; however, small-scale gardening and animal husbandry are common (YMP 1997). Commercial agriculture in the Amargosa Valley farming triangle includes a dairy (approximately 5,000 cows). A fish farm operated briefly in the area (approximately 15,000 catfish and bass; YMP 1999), but it has since ceased operations. There are approximately 900 hectares (2,200 acres) planted in alfalfa, 120 hectares (300 acres) in other hay, 30 hectares (80 acres) in pistachios, 3.5 hectares (9 acres) in fruit trees, 4 hectares (10 acres) in grapes, and 2 hectares (5 acres) each in onions and garlic. The dairy is the primary livestock operation, but numerous individuals keep other small animals, including recent additions such as ostriches. These and other characteristics of commercial production within an 84-km radius of Yucca Mountain are summarized in Table 3.5 (adapted from data presented in BSC 2003). Agriculture depends entirely on irrigation, and local wells provide water for household, agriculture, horticulture, and animal husbandry. There are no naturally occurring surface waters (i.e., perennial lakes and streams) in the area.

The proportions of various types of irrigation are presented in Table 3.6. In this region, alfalfa and other hays are the most common crops (YMP 1997, NASS 2002a), and dry hay used for livestock feed is produced locally and imported from outside the area (Horak and Carns 1997). Water is added to locally grown alfalfa hay and commercial feed before feeding it to animals (Horak and Carns 1997).

Table 3.5. Agricultural Activities within a 22,000 km^2 Region of Southern Nevada and Southeastern California (adapted from BSC 2003)

Crop	*Hectares*	*Acreage*	*Livestock*	*Head*
Alfalfa hay	910	2248	Cattle	275
Other hay	93	229	Milk cows	6731
Barley	51	127	Pigs	52
Oats	13	32	Sheep	3
Pistachios	32	80	Goats	38
Other tree fruit	4	9	Ostriches	157
Grapes	4	10	Poultry	74
Onions	2	5	Catfish	15,000
Garlic	2	5		

Table 3.6. Types of Irrigation in Southern Nevada

Crop Type	*Sprinkler*	*Drip*	*Surface*	*No Data*	*Total*
Grains and Forage	56%		7%	1%	64%
Fruits and Nuts		1%	0.07%	3%	4%
Leafy and Other Vegetables				0.01%	0.01%
To be planted	2%		3%		5%
Fallow (Land not planted)	14%			7%	21%
Sod	4%			2%	6%
Total	76%	1%	10%	13%	100%

Irrigation methods differ among crop types. Drip irrigation often is used on orchard and gardens, and overhead sprinklers and surface irrigation often are used on fields, especially the larger commercial operations (BSC 2003). In the Amargosa Valley in 1997, about 85 percent of field crops were irrigated with overhead sprinklers and all of the fruit and nut crops were irrigated with drip systems that cause little foliar deposition (BSC 2003). This ratio differs from the Nevada statewide averages, for which about 26% is sprinklers, and 73% is rill or furrow. There is little information about the preferred methods of irrigating gardens in the Amargosa Valley, but it may be assumed that sprinkler irrigation is common.

There is no evidence to suggest the widespread use of water treatment in this region and there is only a small quasi-municipal system where a water standard could be enforced (State of Nevada 1997).

Because of the hot summers and mild winters, the growing season is relatively long. Although not grown commercially, it would be possible to obtain 2 crops per year of vegetables such as lettuce or spinach. Up to six harvests per year may be obtained from alfalfa. All crops require irrigation for essentially the entire growing season. Growing and irrigation seasons for the crops currently commercially grown, and a few that may be prevalent in private gardens, are presented in Table 3.7. The lengths of the growing

Table 3.7. Growing and Irrigation Seasons for Southern Nevada Crops

Crop (Planting – Harvest Dates)		*Days*
Lawn Grass (All year)		365
Leafy Vegetables (February – November)		
	Lettuce (2 crops)	40-80
	Spinach (2 crops)	40-80
Other Vegetables (March – December)		
	Potatoes	100-120
	Carrots (2 crops)	70-80
	Onions (2 crops)	100-120
Fruits and Nuts (March – October)		
	Pistachios	220 (April-October)
	Other tree fruits (apples)	240
	Grapes	183
Grains (November – July)		
	Oats	160
	Barley	210-270
	Winter Wheat	210-270
Forage (January – December)		
	Alfalfa (6 harvests)	335
	Oat hay	75

season are derived from data of (BSC 2003), with the addition of information about pistachio trees from the University of California extension service (http://cekern.ucdavis.edu/Custom_Program143/Adequate_Irrigation_in_August_Important_for_Shell_Splitting.htm).

The irrigation requirements for essentially all crops are determined by the total evapotranspiration of the growing crop plus an overwatering term. Overwatering is required to avoid accumulation of salts in the surface soil. In arid regions, the overwatering rate usually is determined by calculating the amount of water required to flush accumulated salts out of the surface soil to maintain productivity. The value of this parameter is a function of the total water requirement of the crop, and is usually on the order of 10 cm/yr (BSC 2003). Irrigation requirements for the crops commercially raised, plus some additional crops likely to be grown in private gardens, are presented in Table 3.8. The annual irrigation requirements in Table 3.8 are derived from data of (BSC 2003), with the addition of information about pistachio trees from the University of California extension service (http://cekern.ucdavis.edu/Custom_Program143/Adequate_Irrigation_in_August_Important_for_Shell_Splitting.htm). The total pistachio irrigation is approximated as the total evapotranspiration for pistachios plus the overwatering amount applied to apples by (BSC 2003).

The productive yield of crops is a function of weather, water supply, soil type, and amounts of fertilizer added. The average yield of several commercial and garden crops for the southern Nevada/southeastern California region has been estimated by BSC (2003). These values are presented in Table 3.9. The range for pistachio yield is based on generic pistachio harvests as reported at http://www.uga.edu/fruit/pistacio.htm.

Table 3.8. Annual Irrigation Requirements for Selected Crops in Southern Nevada

Crop		*Irrigation mm/year*
Lawn Grass		1610
Leafy Vegetables		
	Lettuce (per crop for 2 crops)	320-340
	Spinach (per crop for 2 crops)	240-270
Other Vegetables		
	Potatoes	840
	Carrots (per crop for 2 crops)	470-530
	Onions (per crop for 2 crops)	410-920
Fruits and Nuts		
	Pistachios	1100
	Other tree fruits (apples)	1820
	Grapes	980
Grains		
	Oats	570
	Barley	840
	Winter Wheat	940
Forage		
	Alfalfa (6 harvests)	1950
	Oat hay	460

Table 3.9. Estimated Average Harvested Yield of Crops for Southern Nevada (adapted from BSC 2003).

Crop		*Yield kg/m^2*
Leafy Vegetables		
	Lettuce (per crop for 2 crops)	3.25
	Spinach (per crop for 2 crops)	1.78
Other Vegetables		
	Potatoes	5.15
	Carrots (per crop for 2 crops)	3.64
	Onions (per crop for 2 crops)	4.92
Fruits and Nuts		
	Pistachios	0.17-0.28
	Other tree fruits (apples)	2.67
	Grapes	1.51
Grains		
	Oats	0.28
	Barley	0.44
	Winter Wheat	0.54
Forage		
	Alfalfa (per harvest for 6 harvests)	1.02
	Oat hay	1.87

3.3 South Carolina

Agricultural practice information is based on current conditions in the coastal plain (Low Country) areas of South Carolina as reported by the South Carolina Department of Agriculture and the Clemson University Extension Service. The information is consistent with, but somewhat more specific than, the 2002 Census of Agriculture data for Aiken and Barnwell Counties (NASS 2002f; 2002g). Local Department of Energy analyses (e.g., DOE 2000) generally use information from a land and water use survey by Hamby (1991); this information is summarized in Simpkins and Hamby (2002). Much of this information used by DOE is actually default values from NRC Regulatory Guide 1.109.

This area is relatively flat, with abundant forests. The number of farms in South Carolina is estimated at 24,000, and the average farm size in the state is 80 hectares (196 acres). Total cash receipts for crops and livestock in South Carolina average $1.5 billion a year. The top ten commodities in the state for cash receipts are broilers; greenhouse, nursery, and floriculture; turkeys; tobacco; cattle and calves; cotton lint and seed; eggs; milk; soybeans; and hogs. In the year 2003, the national ranks of some South Carolina crops were:

2nd in flue-cured tobacco production
3rd in peach production
6th in turkeys raised
7th in sweet potato production
7th in cantaloupes
8th in watermelon production

Production of peanuts is greatly increasing. South Carolina acreage increased nearly 4900 hectares (12,000 acres) in 2004. Most of the increase is coming in the newer areas of peanut production, specifically, Calhoun and Orangeburg counties. Peanut production is shifting from Virginia and North Carolina to South Carolina. South Carolina farmers planted about 7500 hectares (18,500 acres) of peanuts in 2003, increasing to 12,100 hectares (30,000 acres) in 2004 (Southeast Farm Press 2004).

The growing season in all of South Carolina ranges from more than 290 days in the south to less than 190 days in the northwestern mountains. The climate of South Carolina is classified as humid subtropical except in the Blue Ridge Mountains, where it is humid continental. The state's annual average temperature varies from the mid-50's in the mountains to the low-60's along the coast. During the winter, average temperatures range from the mid-30's in the mountains to low-50's in the Lowcountry. During summer, average temperatures range from the upper 60's in the mountains to the mid-70's in the Lowcountry. South Carolina has four distinct seasons. The mountains tend to block many of the cold air masses arriving from the northwest, thus making the winters somewhat milder. Measurable snowfall may occur from 1 to 3 times in a winter in all areas except the Lowcountry, where snowfall occurs on average once every three years. Accumulations seldom remain very long on the ground except in the mountains. Tropical cyclones affect the South Carolina coast on an infrequent basis, but do provide significant influence annually through enhanced rainfall inland during the summer and fall months. Hurricanes are the most intense warm season coastal storms and are characterized by storm surge, winds, precipitation, and tornadoes. The average annual precipitation is approximately 48 inches, with an annual total in the mountains of 1800 to 2000 mm (70 to 80 inches), an annual total in the Midlands of 1060 to 1200 mm (42 to 47 inches) and an annual total along the coast of 1270 to 1320 mm (50 to 52 inches).

The climate is such that most agriculture does not require irrigation, except as a supplement to natural precipitation. Annual rainfall at various South Carolina cities is shown in Table 3.10.

As a result of the moister climate, irrigation is not as significant a use of water resources as it is in the western states. Irrigated land, and overall surface water and groundwater usage for irrigation in selected South Carolina counties, is shown in Table 3.11. Water withdrawal for irrigation use from 203 reporting entities totaled 102,687,000 m^3 (27,121,140,000 gallons), with 116 surface water systems accounting for 40,540,000 m^3 (10,707,640,000 gallons) and 128 groundwater systems accounting for 62,150,000 m^3 (16,413,500,000 gallons) (http://www.scdhec.net/eqc/water/pubs/wtruse2001.pdf). Compare this statewide total of $1x10^8$ m^3 (27 billion gallons) with the Columbia Basin Project in Washington State, which annually uses about $2.8x10^9$ m^3 (750 billion gallons).

Many crops can be grown in the South Carolina environment. South Carolina has a "certified roadside market program" for truck farms. Crops commonly available include apples, beets, berries, cabbage, cantaloupe, cucumbers, eggplant, greens (including collard, turnip, and mustard), nectarines, okra, peaches, peanuts, pecans, peppers, plums, sweet potatoes, tomatoes, and watermelons (www.scda.state.sc.us/consumerinformation/scroadsidemarket/scroadsidemarket.htm).

Table 3.10. Monthly Rainfall in Selected South Carolina Cities (mm) (adapted from http://www.clemson.edu/irrig/Managmnt/Precip.htm)

Month	*Augusta*	*Columbus*	*Macon*	*Savannah*	*Charleston*	*Columbia*	*Greenville/ Spartanburg*
Jan	103	117	116	91	88	112	104
Feb	108	123	120	82	84	105	112
Mar	118	147	122	96	110	122	137
Apr	84	109	88	77	68	83	98
May	96	106	91	104	102	93	112
Jun	105	103	91	144	163	122	121
Jul	108	141	109	162	174	140	118
Aug	114	95	92	189	183	155	100
Sep	77	82	71	114	120	93	101
Oct	72	56	55	61	74	77	101
Nov	63	90	69	56	63	74	93
Dec	86	126	109	75	80	91	105
Annual	1134	1295	1134	1250	1309	1268	1302

Broiler chickens are the top animal product cash commodity in South Carolina. Poultry is raised in large commercial operations. Beef cattle and dairy cows are also common. South Carolina is the 8th largest producer of turkeys in the United States.

In South Carolina, cotton has the largest percentage of irrigated acreage followed by corn, land in vegetables, land in orchards, and soybeans. (Note that while 186,000 hectares [460,000 acres] of soybeans are grown in the state, only 3500 hectares [8650 acres] of those are irrigated – less than 2%). Total land area of various irrigated crops in South Carolina are listed in Table 3.12. Of the total irrigated acreage in South Carolina, 85% is sprinkler systems, 11% is drip or trickle systems, and 4% is flood or gravity systems. (South Carolina 2000 irrigation survey, http://www.clemson.edu/irrig/Survey/SURVEY00.PDF).

Most crops are only irrigated during periods of drought or during the hotter summer months. The average water application on irrigated areas is 200 mm/year. Average rates of irrigation for selected crops are given in Table 3.13. Specific values are derived from information from the 1998 Census of Agriculture (www.nass.usda.gov/census/census97/fris/fris.htm), and generic information is from Simpkins and Hamby (2002).

Because South Carolina is subtropical, the growing season for most crops is quite long. The South Carolina crop availability calendar is illustrated in Figure 3.1. As is evident, some crops are grown year around. Others have distinct harvest seasons, but the plants themselves have much longer growth periods, many approaching year round.

Productivity of various crops is presented in Table 3.14 (South Carolina Agricultural Statistics Service1997). The normalized yield is presented in Table 3.15.

Figure 3.1. Crop availability in South Carolina by Month (from http://www.scda.state.sc.us/consumerinformation/agfacts/agfacts.htm)

Commodity	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Apples									■	■	■	■
Butter Beans							■	■	■	■	■	
Cabbage				■	■	■						
Cantaloupes					■	■	■	■				
Cucumbers					■	■			■	■	■	
Green Onions			■	■	■	■	■	■	■	■	■	
Mixed Greens	■	■	■	■	■	■	■	■	■	■	■	■
Peaches					■	■	■	■	■			
Peanuts								■	■			
Peppers						■	■	■	■	■	■	
Tomatoes						■	■		■	■	■	
Squash (Yellow)					■	■	■	■	■	■		
Sweet Corn					■	■	■	■				
Sweet Potatoes								■	■	■	■	■
Watermelons						■	■	■				

Table 3.11. Surface Water and Groundwater Use for Irrigation in South Carolina (adapted from DHEC 2002). Water Use in Thousands of m^3.

County	*Surface Water*	*Groundwater*	*Total*	*Irrigated Area*
	Thousands of m^3			Hectares
Aiken	0	784	784	542
Allendale	2726	14041	16767	3784
Bamberg	2059	1995	4053	4688
Barnwell	330	204	534	2054
Beaufort	128	2779	2907	789
Berkeley	4922	83	5005	0
Calhoun	3175	5904	9078	4927
Charleston	217	0	217	384
Chester	7	0	7	136
Chesterfield	0	854	854	364
Clarendon	583	1763	2346	3045
Colleton	3186	7311	10497	307
Darlington	894	110	1003	1022
Dillon	0	132	132	123
Edgefield	1605	164	1769	2726
Florence	79	297	376	2064
Georgetown	2456	0	2456	399
Greenville	334	0	334	41
Greenwood	0	5	5	11
Hampton	339	5335	5674	1908
Horry	208	286	494	2040
Jasper	0	1413	1413	726
Lee	34	136	170	1422
Lexington	806	2623	3428	4789
Marion	0	94	94	4289
Marlboro	798	972	1770	611
Newberry	510	144	654	198
Oconee	1203	0	1203	1
Orangeburg	5667	10255	15922	11934
Pickens	41	0	41	101
Richland	89	0	89	409
Saluda	3577	0	3577	1801
Spartanburg	1207	0	1207	1226
Sumter	3289	4405	7694	4101
Williamsburg	11	0	11	81
York	61	59	119	115
Total	40542	62145	102687	65182

Table 3.12. Total Irrigated Crop Acreage in South Carolina in Year 2000.

Crop	*Irrigated (Hectares)*	*Irrigated (Acres)*	*Percentage*
Alfalfa	32	80	0.1%
Apples	26	64	0.0%
Beans&peas	338	836	0.6%
Berries	102	252.5	0.2%
Corn	15882	39245	27.0%
Cotton	17968	44400	30.6%
Grass seeds	405	1000	0.7%
Grains	324	800	0.6%
Grapes	44	109.2	0.1%
Lettuce	6	16	0.0%
Melons	3358	8298	5.7%
Nursery	1083	2676	1.8%
Nuts	117	290	0.2%
Pasture/Hay	1857	4589	3.2%
Potatoes	20	50	0.0%
Rice	36	90	0.1%
Small fruits	134	331	0.2%
Sorghum	40	100	0.1%
Soybeans	3501	8650	6.0%
Tobacco	2102	5195	3.6%
Tree fruits	4946	12222	8.4%
Vegetables	4509	11141	7.7%
Wheat	1740	4300	3.0%
Other	240	594	0.4%

Table 3.13. Irrigation Requirements for Selected Crops in South Carolina

Crop		*Irrigation mm/year*
Leafy Vegetables		
	Land in vegetables	275
Other Vegetables		
	Potatoes	180
	Sweet Corn	60
	Tomatoes	240
Fruits and Nuts		
	Tree fruits	460
	Peanuts	550
Grains		
	Corn	210
	Wheat	90
Forage		
	Alfalfa	0
	Pasture Grass	305

Table 3.14. Total Production of Various Crops in South Carolina

	Cotton (Bales)	*Soybeans* (Bushels)	*Oat hay* (Tons)	*Oats* (Bushels)	*Tobacco* (Lbx1000)	*Corn* (Bushels)	*Wheat* (Bushels)
Abbeville	(1)	7,500	17,400	(1)	-	(1)	22,300
Aiken	9,400	198,000	25,900	12,000	-	337,600	103,900
Allendale	6,400	379,700	2,000	27,900	-	1,178,300	550,200
Anderson	1,100	62,200	44,300	81,000	-	88,900	173,000
Bamberg	11,700	240,300	7,100	116,000	-	1,111,850	220,000
Barnwell	11,100	198,000	5,000	13,800	-	598,600	158,800
Beaufort	-	9,100	1,000	(1)	-	96,200	(1)
Berkeley	1,000	51,000	3,900	(1)	598	380,100	29,000
Calhoun	40,500	199,200	4,400	66,700	-	990,600	311,700
Charleston	-	15,600	2,100	(1)	-	122,900	(1)
Cherokee	(1)	19,500	13,100	(1)	-	(1)	20,000
Chester	3,000	(1)	13,000	19,800	-	58,100	31,300
Chesterfield	800	226,600	16,800	(1)	834	302,600	147,800
Clarendon	17,500	1,006,700	5,100	24,000	6,439	3,108,500	1,142,100
Colleton	2,400	215,600	11,100	69,600	698	1,330,000	129,500
Darlington	38,400	1,330,000	10,100	58,500	9,513	1,033,500	1,345,500
Dillon	25,100	1,018,800	1,800	26,000	10,362	582,600	1,101,600
Dorchester	9,000	230,100	5,300	77,600	1,260	993,300	94,500
Edgefield	4,500	42,000	8,000	(1)	-	26,300	18,800
Fairfield	-	(1)	7,100	(1)	-	24,600	12,000
Florence	17,700	1,352,700	3,100	41,800	21,346	1,582,400	774,000
Georgetown	1,400	72,800	3,500	(1)	3,126	263,100	27,600
Greenville	(1)	9,900	18,800	(1)	-	63,300	28,900
Greenwood	(1)	(1)	16,400	(1)	-	21,100	(1)
Hampton	22,500	244,100	4,000	24,700	-	1,097,900	369,700
Horry	1,900	1,044,500	4,800	130,000	31,195	1,800,300	632,700
Jasper	(1)	12,500	3,000	(1)	-	176,000	15,400
Kershaw	1,500	96,600	10,800	(1)	-	118,800	57,600
Lancaster	(1)	29,700	16,000	(1)	-	46,900	9,500
Laurens	(1)	13,000	24,400	21,600	-	49,200	38,400
Lee	40,700	893,100	4,200	(1)	1,833	951,350	705,600
Lexington	4,100	227,700	24,700	59,400	-	523,600	112,500
McCormick	-	-	2,800	(1)	-	(1)	(1)
Marion	5,600	577,100	3,300	38,000	10,244	480,400	388,000
Marlboro	48,400	687,700	5,900	42,300	1,634	248,300	493,500
Newberry	500	109,500	28,400	56,300	-	199,900	175,500
Oconee	-	35,000	26,600	(1)	-	63,900	43,800
Orangeburg	54,800	732,600	19,900	257,000	-	4,293,000	988,700
Pickens	-	(1)	19,500	(1)	-	40,400	(1)
Richland	600	276,000	7,900	(1)	-	432,300	211,000
Saluda	2,100	63,600	27,400	25,600	-	74,200	114,600
Spartanburg	-	39,000	33,300	51,300	-	115,700	45,000
Sumter	14,100	1,098,700	6,300	47,600	2,795	3,063,900	973,400
Union	-	(1)	9,000	(1)	-	(1)	(1)
Williamsburg	50,600	374,800	4,400	52,300	15,487	1,873,700	244,300
York	4,700	36,400	27,100	32,600	-	33,500	41,600
Other	1,900	23,100	-	146,600	446	42,300	46,700
State Total	455,000	13,500,000	560,000	1,620,000	117,810	30,020,000	12,150,000

(1) Included in other counties.

Table 3.15. Estimated Average Harvested Yield of Crops for South Carolina

Crop	*Yield kg/m^2*
Corn	0.59
Sorghum	0.27
Wheat	0.32
Barley	0.31
Oats	0.20
Soybeans	0.15
Peas	0.14
Hay	0.46
Alfalfa	0.58
Potatoes	2.52
Sweet Potatoes	1.18
Peanuts	0.31
Cotton	0.07
Tobacco	0.26

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4.0 Discussion

Physical and chemical characteristics are presented for four samples of soil and three associated groundwaters (the two South Carolina soils significantly differ only in allelopathy, and the one South Carolina groundwater sample is assumed to be applicable to either sampling location). These soil/groundwater combinations are being used in radionuclide uptake studies within the U.S. Nuclear Regulatory Commission's project *Assessment of Food Chain Pathway Parameters in Biosphere Model.* The differences in composition of the soils and waters from the three locations are expected to result in measurable differences in soil-to-plant transfer of the investigated radionuclides.

Because the uptake and behavior of radionuclides in plant roots, plant leaves, and animal products depends on the chemistry of the water and soil coming in contact with plants and animals, water and soil samples collected from these regions on the United States are being used in ongoing experiments at Pacific Northwest National Laboratory to determine radionuclide soil-to-plant concentration ratios, leaf interception and translocation factors. Crops and forage used in the experiments are grown in the soils, and long-lived radionuclides introduced into the groundwater provide the contaminated water used to water the grown plants. Radionuclides under consideration include ^{99}Tc, ^{129}I, ^{238}Pu, ^{237}Np, and ^{241}Am. Plant types include alfalfa, corn, onion, and potato. The radionuclide uptake results from this research study are expected to show how regional variations in water quality and soil chemistry affect radionuclide uptake.

The groundwater samples showed some differences. The groundwater from Nevada was the most alkaline. The waters from both western sites, Nevada and Washington, had more carbonates than the eastern sample. The Nevada groundwater sample had somewhat lower nitrate concentrations than might be expected from the literature, but the sample location is at the edge of an agricultural area.

Differences are apparent in the soils from the three geographic locations. The major difference is prevalence of silica (quartz) sand in both of the South Carolina samples. Soils from this region were originally anticipated to be rich in organic materials, but both were lower in organic carbon and most other minerals than either of the western soil samples. All sites were low in organic carbon. The Hanford location soil has the highest concentrations of silt and clay, possibly because of the history of glacial flooding in the Hanford region. The Nevada soil was lowest in clay, although the South Carolina samples were only slightly higher. Differences were also noted in the soil pore water concentrations of dissolved minerals; these differences may be the most predictive in determining plant uptake.

The presentation of agricultural practices in the three locations also highlights differences. Agriculture in the two Western locations is dependent upon irrigation, although the sources of irrigation water in Nevada are essentially entirely derived from groundwater while the sources of irrigation water in Southeastern Washington State are primarily derived surface water, with groundwater only used in areas where surface water canals are not economically available. Irrigation is used to a much lesser extent in South Carolina, and only for supplementing rainfall for brief periods. The types of crops, their growing periods, and overall yields also differ among the three locations.

This type of information is directly useful in formulating inputs to radioecological and food-chain models used in performance assessments and other kinds of environmental assessment. This food-chain pathway data may be used by the NRC staff to assess dose to persons who live and work in areas potentially affected by radionuclide releases from waste disposal facilities and decommissioning sites. These data are expected to be used in biosphere models to calculate the dose from ground water release scenarios in performance assessment computer codes.

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10. SUPPLEMENTARY NOTES
P. R. Reed, NRC Project Manager

11. ABSTRACT *(200 words or less)*

This report describes the work performed and summarizes the key observations to date on the U.S. Nuclear Regulatory Commission's project Assessment of Food Chain Pathway Parameters in Biosphere Models, which was established to assess and evaluate a number of key parameters used in the food-chain models used in performance assessments of radioactive waste disposal facilities. Section 2 of this report describes activities undertaken to collect samples of soils and groundwater from three regions of the United States, the Southeast, Northwest, and Southwest, and perform analyses to characterize their physical and chemical properties. Section 3 summarizes information gathered regarding agricultural practices and common and unusual crops grown in each of these three areas. This type of information is directly useful in formulating inputs to radioecological and food-chain models used in performance assessments and other kinds of environmental assessment. This food-chain pathway data may be used by the NRC staff to assess dose to persons in the reference biosphere (e.g., persons who live and work in an area potentially affected by radionuclide releases) of waste disposal facilities and decommissioning sites.

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