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Page 1 of 1
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				Description for the S-SX				
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SUBSURFACE PHYSICAL CONDITIONS DESCRIPTION OF THE S-SX WASTE MANAGEMENT AREA

October 1999

Prepared for

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ACRONYMS AND ABBREVIATIONS

AEA	<i>Atomic Energy Act of 1954</i>
BHI	Bechtel Hanford Inc
CFR	Code of Federal Regulations
CRBG	Columbia River Basalt Group
CWM	Crib Waste Management (database)
DOE	U S Department of Energy
DOE/GJPO	U S Department of Energy, Grand Junction Project Office
DOE/RL	U S Department of Energy, Richland Operations Office
DQO	Data Quality Objective
Ecology	Washington State Department of Ecology
EPA	Environmental Protection Agency
ERDA	U S Energy Research and Development Agency
ERS	Environmental Release System (database)
ERT	Electrical Resistance Tomography
HEIS	Hanford Environmental Information System (database)
HWMA	<i>Hazardous Waste Management Act (RCW 70 105)</i>
Kd	Sorption Coefficient
MCL	Maximum Concentration Limit
MTU	Metric Ton of Uranium
PHMC	Project Hanford Management Contract
PNNL	Pacific Northwest National Laboratory
RCRA	<i>Resource Conservation and Recovery Act of 1976</i>
RCW	Revised Code of Washington
REDOX	Reduction Oxidation (S Plant)
SST	Single Shell Tank
TPA	Tri-Party Agreement (<i>Hanford Federal Facility and Consent Order</i>)
TWRS	Tank Waste Remediation System
UPR	Unplanned Releases
WAC	Washington Administrative Code
WMA	Waste Management Area

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1 0 INTRODUCTION

This document *Subsurface Physical Conditions Description of the S-SX Waste Management Area*, provides a discussion of the subsurface conditions relevant to the occurrence and migration of contaminants in the groundwater underlying the S-SX Tank Farm. These Tank Farms, located in the 200 West area of the Hanford Site, comprise the S-SX Waste Management Area (WMA). Included in this document are descriptions of the available environmental contamination data and a limited, qualitative interpretation of the data as it applies to contaminant behavior.

1 1 Background

Figure 1-1 shows the location of the S-SX Tank Farm, other Tank Farms and the surrounding facilities in Hanford Site 200 West Area. To facilitate *Resource Conservation and Recovery Act* (RCRA) groundwater monitoring programs, the S-SX Tank Farm were grouped into a WMA. The WMA boundary is shown in Figure 1-2. Key RCRA monitoring wells and facilities that received fluids generated by Tank Farm operations make up the S-SX WMA are also shown in Figure 1-2. Both the vadose zone and the unconfined aquifer are included in the S-SX WMA.

Groundwater samples from RCRA monitoring wells located upgradient and downgradient of the S-SX Tank Farm were taken periodically to monitor contamination with sources within the S-SX WMA. Waste constituents (technetium-99, chromium, nitrate) appearing in groundwater over the last decade are likely to have originated from S-SX Tank Farm wastes (Johnson and Chou, 1998).

Because of this conclusion, the Washington State Department of Ecology (Ecology), Environmental Protection Agency (EPA) and U.S. Department of Energy (DOE) negotiated Hanford Federal Facility Agreement and Consent Order (also known as Tri-Party Agreement or TPA) Change Control Form Number M-45-98-03 (Ecology et al., 1999). The proposed TPA milestones mandate a series of S-SX WMA evaluation activities. The ultimate goal of the activities is to determine the need for corrective action to mitigate the impact to single-shell tank (SST) contamination on the surrounding environment. One of the first significant efforts in this process is to complete additional characterization of current contamination conditions in the subsurface underlying the S-SX WMA. Characterization activities are underway (notably vadose zone soil extraction from Borehole 41-09-39 between and slightly south of Tanks 241-SX-108 and 241-SX-109, and a borehole near the tank wall and southwest of Tank 241-SX-115) and others are planned. The information generated by the characterization activities will support waste management decisions for interim corrective measures, SST waste retrieval and SST closure.

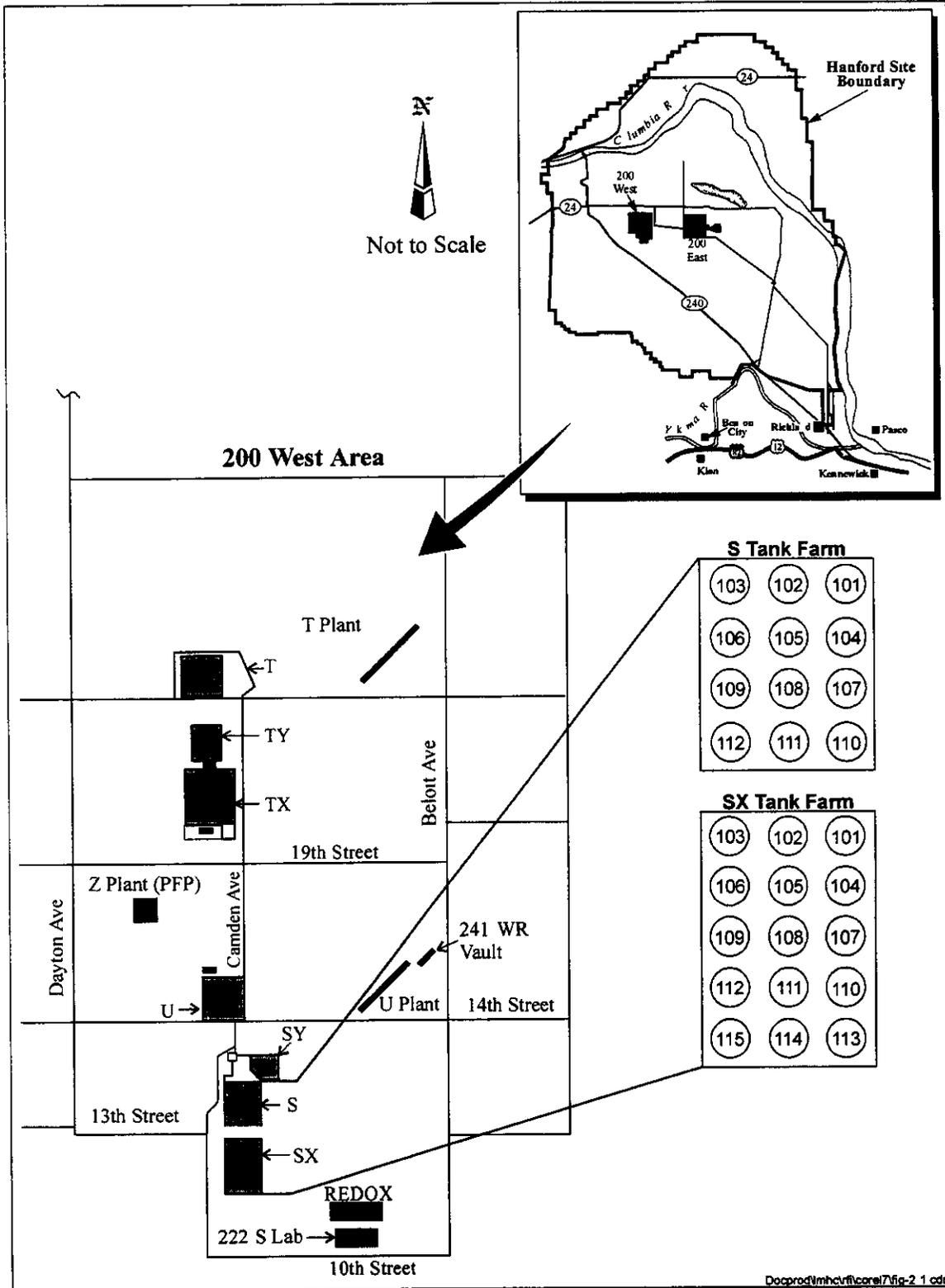


Figure 1-1 Location Map of the S-SX Tank Farm and Surrounding Facilities in the 200 West Area

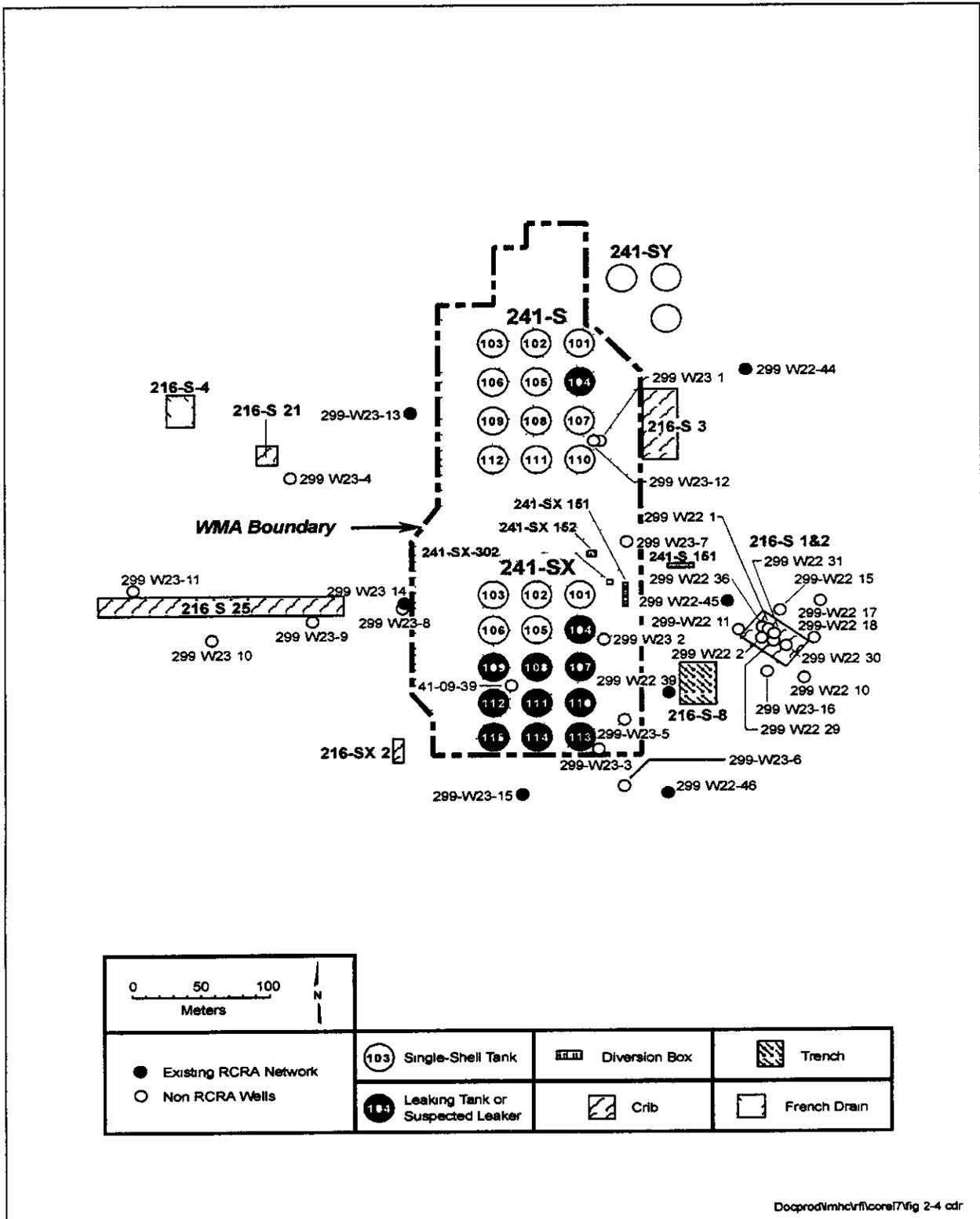


Figure 1-2 S-SX Waste Management Area and Surrounding Facilities

The need for additional characterization was also given impetus by the recommendations of an outside expert panel (first convened in 1996) to evaluate the potential for enhanced migration of radionuclides in the vadose zone underlying the S-SX WMA. The expert panel proposed specific characterization tasks to provide a more comprehensive evaluation (DOE/RL 1997)

1 2 Purpose

Within the context of the characterization and evaluation program, this document fulfills several purposes. In the very near term, a Data Quality Objective (DQO) process will be convened to plan additional characterization activities for the S-SX WMA, particularly the vadose zone. Given the large number of vadose zone and perhaps groundwater, contamination events that occurred in the S-SX WMA, it is clear that numerous characterization activities are plausible and an efficient characterization approach is needed to adequately evaluate the site. To aid this decision-making process, characterization is focused on site-specific data that defines the occurrence and migration of contaminants within the system to date. In order to describe the data effectively, a concise description and limited interpretation of critical data are provided.

Beyond the initial characterization efforts, a systematic description of the environmental conditions affecting contaminant migration is needed to identify data gaps, recognize significant relationships among different types of data, and organize data inputs to contaminant migration models. This document provides a framework for completing a systematic description as more data are collected, interpreted and integrated with currently available information.

1 3 Scope

The first part of this document describes the two primary components of the subsurface condition database: the physical setting of the S-SX WMA and the contaminants occurring therein. Chapter 2 is the physical setting, which includes the Tank Farm infrastructure, geology, hydrology/infiltration mechanisms, and geochemistry. In the Tank Farm infrastructure description, emphasis is placed on those parts of the system, which allowed fluids to discharge into the soil column and the time periods during which these parts were operational. In the geology description, emphasis is placed on those features, which are considered to most strongly influence fluid distribution. In the infiltration discussion, emphasis is placed on infiltration mechanisms, infiltration history (e.g., U-Pond operational effects on water movement over time). In the hydrology section, hydrologic properties of the geologic strata that control fluid movement are discussed. In the geochemistry section, emphasis is focused on the characteristics that control contaminant movement, particularly in relation to fluids.

The second component of the subsurface condition database is the description of contaminant occurrences and movement within the vadose zone and unconfined aquifer, which is presented in Chapter 3. First, a summary of contamination events is provided to orient the reader to historical sequence of events. This is important to describe because of the intermittent nature of fluid discharges in the S-SX WMA and occurrences of contamination currently observed in the unconfined aquifer underlying the S-SX WMA. Second, an overview of the historical and spectral gamma database is provided because the data are unique in their extent, both temporally and spatially. The overview demonstrates the observed spatial variability of contamination concentration and provides the most comprehensive indication of the diversity among various contaminating events. The remainder of the discussion in Chapter 3 is organized by specific sources or similar types of sources. The key data in this discussion includes tank waste inventory and chemistry information derived from process history, corroborating gamma logging data, and soil sample data, where available.

In Chapter 4, a brief qualitative integration of the data is provided and conceptualization of the contamination events. Due to the diversity of the different events, database interpretations are given for each of the specific contaminating occurrences or types of occurrences. Finally, key uncertainties and data gaps that are important to understanding potential future contamination of the unconfined aquifer. Chapter 5

Three appendices are also provided. Appendix A provides supporting geologic data. Appendix B provides supporting hydrologic data. Appendix C provides a summary of analyses of gamma logging data.

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2 0 PHYSICAL SETTING

The following section provides a description of the infrastructure, geology, hydrology infiltration characteristics, and geochemistry of the S-SX WMA

2 1 *Infrastructure and Operational History*

This section discusses the infrastructure and history of the S-SX Tank Farm and ancillary equipment, as well as, nearby cribs, ponds and ditches. A more detailed historical review is provided by Brevick et al (1996). Those elements of the infrastructure that are known or suspected to have discharged fluids to the vadose zone are identified along with parts that remain capable of future discharges.

2 1 1 S-SX WMA Infrastructure

The S-SX WMA consists of the S-SX Tank Farm, waste transfer lines, leak detection systems, and other miscellaneous equipment. Outside the WMA boundaries are additional facilities that were used during S and SX Tank Farm operations. These include numerous cribs, located to the east, south, and west of the S-SX WMA, 242-S Evaporator facility, located just north of the S Tank Farm, and U-10 pond, located approximately 300 meters west of the S-SX WMA. There are also a number of active or abandoned water lines crossing the WMA.

2 1 2 Operational History

The S Tank Farm was built in 1950-51 and consists of twelve 75-foot diameter tanks with nominal 750,000-gallon storage capacity. The basic tank structure is a cylindrical steel container enclosed in a concrete shell and capped by a concrete dome (see Hanlon 1999 for a schematic diagram). In 1951, the S Tank Farm began receiving Reduction and Oxidation (REDOX) wastes. In the summer of 1952, some tanks began to boil because of the radioactive decay heat load in the REDOX high-level wastes. A surface condenser was added to remove excess liquid from the tanks, and the collected liquids were piped to nearby cribs. After the REDOX plant was deactivated, the S farm tanks received solids from the 242-S Evaporator. Only one tank in the S Tank Farm (Tank 241-S-104) is assumed to have leaked. The S Tank Farm tanks were removed from service in the late 1970s and early 1980s.

The SX Tank Farm is made up of 15 SSTs, each with a nominal 1 million-gallon storage capacity. The SX Tank Farm was constructed in 1953 and 1954 and the first six SX tanks began receiving waste from the REDOX plant in 1954. In 1955 the remaining nine began to receive waste. Tanks 241-SX-105 and 241-SX-107 through 241-SX-115 were designed to handle REDOX high-level boiling wastes. Allowing supernates to evaporate and then return condensates, as required, to maintain desired liquid levels reduced heat loads within the tanks. According to Hanlon (1999) all nine of the SX tanks that operated as boiling waste tanks are confirmed or assumed leakers. Tanks 241-SX-101 through 241-SX-106 are at least half filled with solids (mostly saltcake and some sludge).

Each of the tanks in the S-SX Tank Farm have shallow (80 to 102 feet) radiation monitoring wells (drywells) installed around the tanks as a secondary leak detection system. With the exception of two wells drilled in 1996 and 1997 (41-09-39 and 41-12-01), all 170 drywells were installed from 1954 to 1978. In addition, the boiling waste tanks in the SX Tank Farm have laterals installed approximately 10 feet below the tank bottom for gamma logging. Gamma logging data from the drywells and laterals were used to ascertain the integrity of the tank.

As shown in Figure 1-2, there are a number of cribs around the S-SX WMA that received large volumes of slightly contaminated water and other waste streams. Historical records indicate that tank wastes were not cascaded directly from the tanks into cribs. Rather, the cribs received excess condensate from the boiling waste tanks and cooling water from the condensers. Liquids were transferred through a complex piping system that includes collection boxes (e.g., diversion boxes, valve pits) for routing liquids to various locations. Other additions to the cribs included discharges from the first cold REDOX start-up run and groundwater coming from the U-crib "pump and treat" operations in the mid-1980s. Discharge to cribs is discussed in more detail in Section 2.3.2. Developing an understanding of the range and quantities of chemicals and radionuclides added to the cribs may be required to fully understand the potential impacts to groundwater.

In addition, the U-10 pond received about 44 billions of gallons of slightly contaminated water, a fraction of which included fluids generated by S-SX Tank Farm operations. The large additions of water to the U-10 pond significantly impacted groundwater flow patterns under the S-SX WMA.

Finally, a number of raw and potable water lines are present in the S-SX WMA vicinity. Leaks from the lines could have contributed to tank waste migration in the vadose zone. It appears that leaks from the lines were not viewed as having adverse impacts to tank farm operations. Thus, historical records are likely to be incomplete.

2 2 Geology

This section summarizes the geologic setting and presents a revised geologic description of the S and SX Tank Farm vicinity. The information in this section provides the framework for subsequent consideration of stratigraphic and structural controls on moisture and waste movement through the vadose zone to groundwater. Geologic maps and stratigraphic cross sections supporting the following discussion are included in Appendix A.

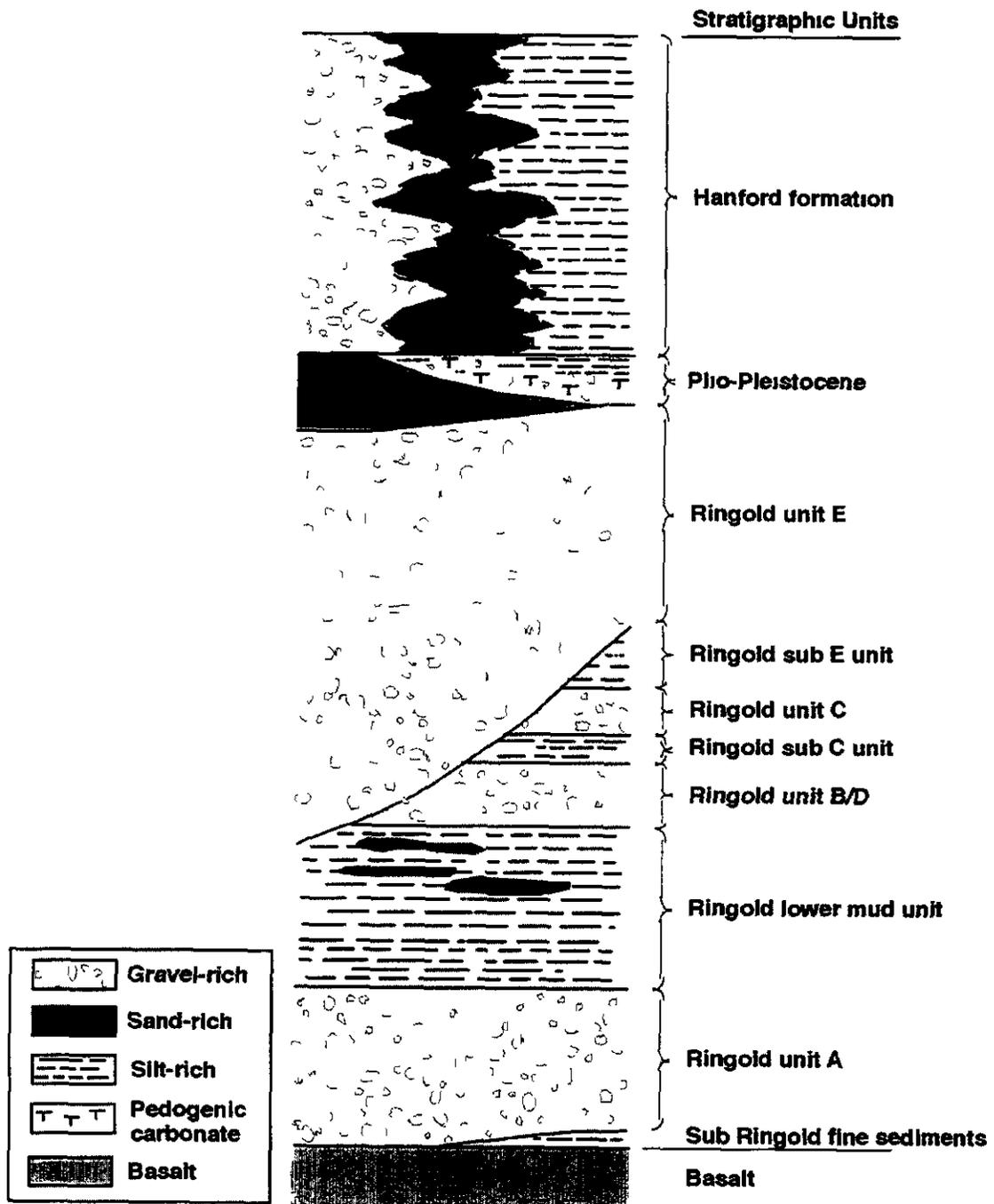
2 2 1 Geomorphology

The S-SX Tank Farm lie within a shallow, north-south oriented topographic depression. The depression formed within the southwestern extent of a flood bar deposit is known as the Cold Creek bar (DOE, 1988). This topographic feature in combination with construction disturbances is conducive to collecting surface runoff, especially along the south side of the SX Tank Farm and the east side of S Tank Farm.

2 2 2 General Stratigraphy

The S-SX Tank Farm was constructed in a sequence of sediments that overlie the Columbia River Basalt Group (CRBG) on the north limb of the Cold Creek syncline as depicted in Figure 2-1. The sediments include the upper Miocene to Pliocene Ringold Formation, the Plio-Pleistocene unit, Pleistocene cataclysmic flood gravels and slack water sediments of the Hanford formation, and Holocene eolian deposits.

The Ringold Formation consists of sediments deposited by the Columbia River and associated tributaries. The sediments were deposited between 8.5 and 3 million years ago and consist of clay, silt, fine- to coarse-grained sand, and granule to cobble gravel. The top of the unconfined aquifer under the Tank Farms is in Ringold fluvial gravels. The gravels are separated by fine-grained deposits typical of overbank flooding and lacustrine environments (DOE, 1988; Lindsey 1991). The lowermost of the fine-grained sediments is the "lower mud". The uppermost Ringold unit under the tank farms is called "unit E" and consists of sandy gravels to gravelly sands. In the saturated zone, Ringold gravels locally are cemented and intercalated with zones having no cementation. The result is highly variable permeability in the saturated zone.



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Figure 2-1 General Stratigraphy of the S-SX WMA

The vadose zone beneath the S-SX Tank Farm is as much as 65 meters (213 feet) thick and consists of the Pleistocene-aged Hanford formation, the Plio-Pleistocene unit, and the upper part of the Ringold Formation. At the Tank Farms, the Hanford formation and underlying Ringold Formation are separated by a thin sequence of sediments called the Plio-Pleistocene unit. The Plio-Pleistocene unit unconformably overlies a tilted and truncated Ringold Formation and consists of alluvium deposited by small streams flowing from the surrounding higher elevations.

The Hanford formation is the informal name given to all glaciofluvial cataclysmic flood sediments of the Pleistocene Epoch. It consists of pebble- to boulder-gravel, fine- to coarse-grained sand, silty sand, and silt to clayey-silt.

A three-dimensional representation of the vadose zone stratigraphy underlying the S-SX WMA and surrounding area is provided in Figure 2-2. This figure illustrates the primary stratigraphic units, sequence, and spatial variability in thickness and orientation.

2.2.3 Methodology

Borehole data consisting of drilling logs, archived samples, and geophysical logs are the principal data sets used to interpret the subsurface at the S-SX Tank Farm. Archived natural gamma geophysical logs from boreholes in the S-SX Tank Farm and surrounding area were located, and the logs were incorporated into the interpretations. The previously unused geophysical logs (see Appendix A, Section A.2.5) included data from surrounding waste disposal sites obtained prior to discharge of effluent and provide an invaluable source of information for stratigraphic correlations. In addition, numerous reports describing the geology of the S-SX Tank Farm area and vicinity are available and are a valuable source of information (e.g., Price and Fecht, 1976a, 1976b, 1976c; Tallman et al., 1979; DOE, 1988; Lindsey, 1991, 1995).

Initially, well-site geology or drilling logs were examined and compared to geophysical logs from the boreholes. The quality of drilling logs varies because many wells and boreholes were drilled without a geologist present at the site. In addition, well logs are constrained by the drilling method and sample recovery. Sample retrieval in the vadose zone is difficult and does not allow the exact depth of samples and contacts to be determined. Samples are archived in 5-foot intervals, thus, can induce as much as a 5-foot uncertainty in lithology in either direction. Changes in drilling-blow counts provide additional information regarding depth of lithology changes because of differing sediment resistance to drilling.

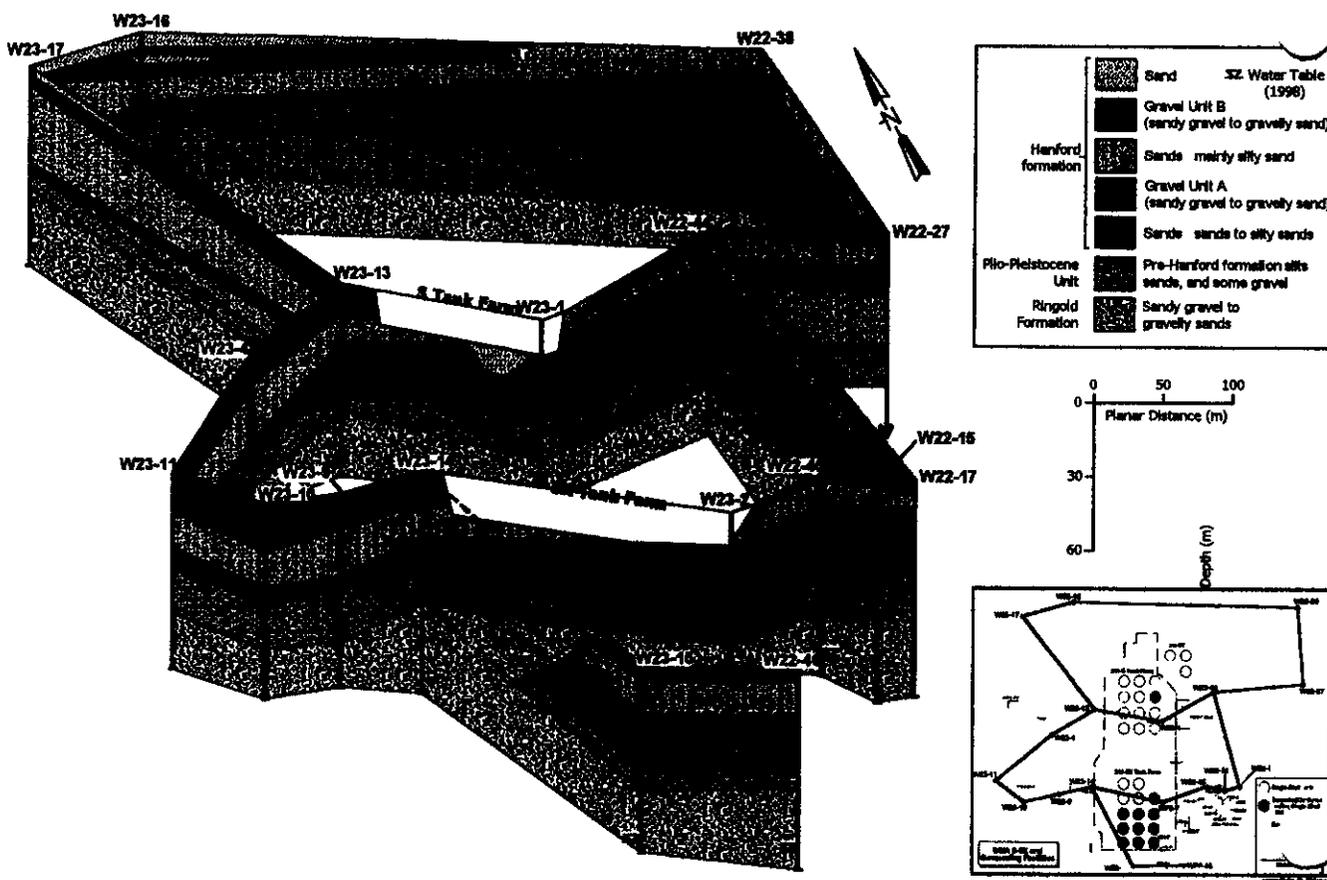


Figure 2-2 Fence Diagram of Vadose Zone Stratigraphy Underlying the S-SX Waste Management Area

Geophysical logs (e.g., gross gamma ray) provide a continuous record of the borehole and allow more precise placement of geologic contacts. Geophysical logs can show lithology differences because of differing amounts of natural gamma-ray emitters (most commonly, potassium-40). Gamma-ray logs are proportional to clay and silt abundance and record changes in grain size.

When geophysical logs are compared to the well-site geology logs and archived samples, uncertainty in the depth of lithologic changes is greatly reduced. The newly located natural gamma-ray logs allowed older wells for which only drilling logs were previously available, to be reinterpreted and correlated with newer wells. This greatly increased the confidence in locating stratigraphic contacts, especially the Plio-Pleistocene-Hanford contact. In addition, the signature of the geophysical response from the borehole can provide an additional tool for correlating stratigraphy among boreholes.

2.2.4 Uncertainty

Sources of uncertainty for locating contacts between stratigraphic units in boreholes and correlations among boreholes include the following:

- Borehole-related uncertainties — drilling method, source and quality of the borehole logs, and borehole spacing
- Sampling related uncertainties — method of drilling and sampling, sampling frequency, and bias induced by the sampling techniques
- Geologic-related uncertainties — three-dimensional shape of the sedimentary features, lateral changes in relative proportion of sand, silt, and gravel, and bed-form properties of the sediment layers

A complete discussion of the sources of uncertainties and a geostatistical evaluation of the stratigraphic correlations described in this report are included in Appendix A.

2.2.5 Columbia River Basalt Group

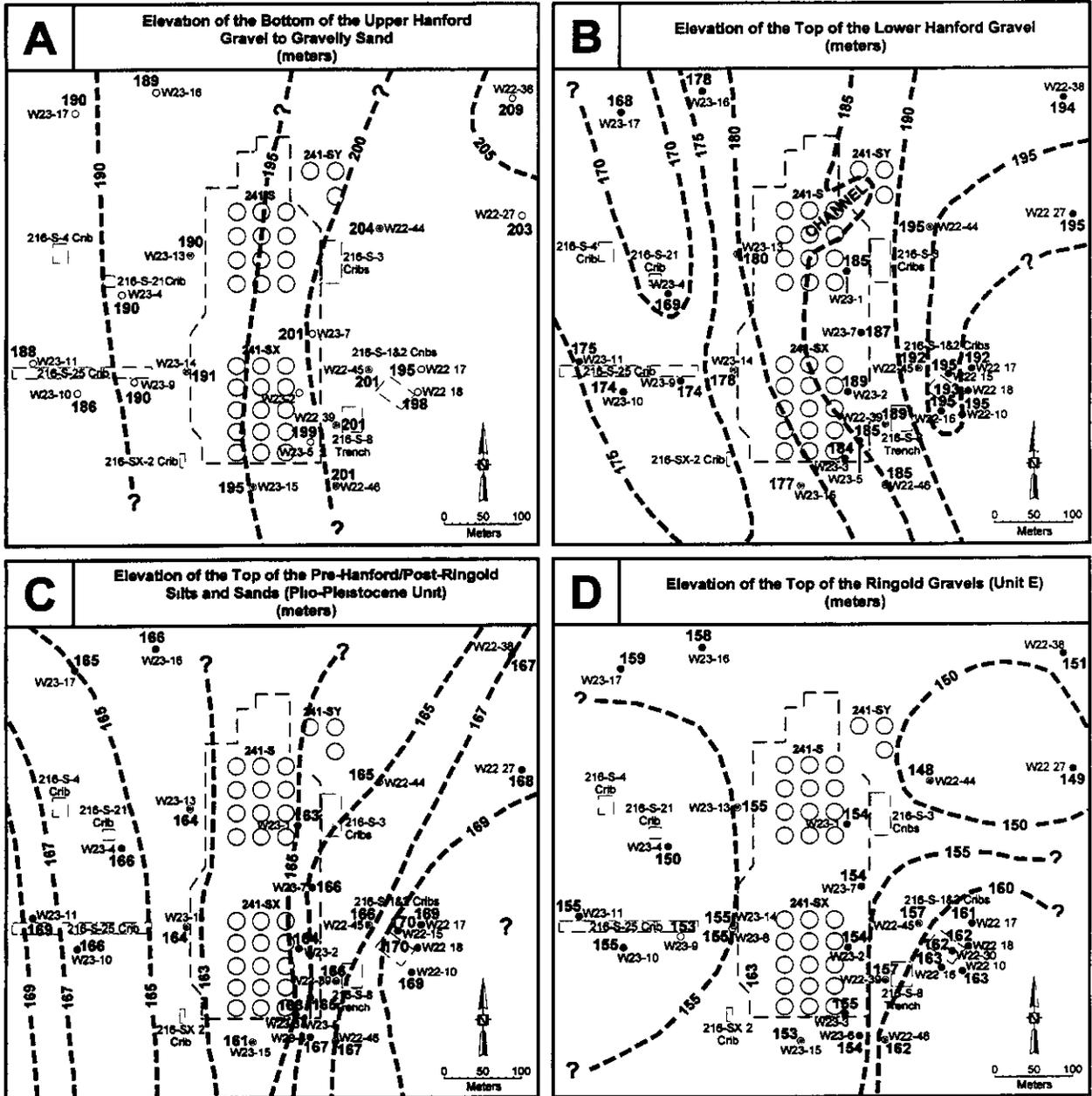
The surface of the CRBG forms the bedrock base of the unconfined aquifer under the S-SX Tank Farm. The Elephant Mountain Member of the Saddle Mountains Basalt is the youngest flow, approximately 560 feet below land surface, and dips southwest toward the axis of the Cold Creek syncline. Lavas of the Saddle Mountains Basalt and sediments of the Ringold Formation and Plio-Pleistocene unit thicken toward the axis of the Cold Creek syncline.

2 2 6 Ringold Formation

The Ringold Formation is up to 125 meters (410 feet) thick under the S-SX Tank Farm and thickens from east to west. The vadose zone portion thins from east to west (16 meters [50 feet] to about 13 meters [40 feet]) due to the continued influence of the former 216-U Pond. The part of Ringold Formation comprising the vadose zone and upper part of the unconfined aquifer consists of a slightly silty coarse- to medium-grained sandy gravel with intercalated gravelly sand (Ringold unit E). The upper Ringold is interpreted not to be present under the S-SX Tank Farm.

The lithologies and minerals present in the Ringold Formation are highly variable. This is because the Ringold Formation represents the ancestral Columbia River and tributaries that drained areas far beyond the CRBG terrain. Lithologies found include CRBG quartzites and other metamorphic rocks, granites and several other miscellaneous rock types from the areas surrounding the Columbia Basin. The sediments have varying degrees of calcium-carbonate (CaCO_3) and silica cementation. In Borehole 41-09-39 a zone of probable silica cementation was encountered at the water table. The sand fraction of Ringold Unit E typically consists of quartz, feldspar, and basalt. The silt size fractions consist of quartz, feldspar, mica, chlorite, and smectite (Tallman et al. 1979).

In the S-SX Tank Farm area, Slate (1996) interpreted the surface of the Ringold Formation as a southeast plunging trough parallel to the Cold Creek syncline. The trough contains two smaller troughs, one of which trends directly under the S-SX Tank Farm and one south of 200 West Area. Irregularities on the surface of the Ringold unit E gravels under the S-SX Tank Farm define another crude northeast-southwest trough with the lowest points east of the S Tank Farm (Figure 2-3D).



1999/DCL/S-SX/013

Figure 2-3 Elevation Maps of Stratigraphic Unit Tops Underlying the S-SX Waste Management Area

2 2 7 Plio-Pleistocene Unit

The Plio-Pleistocene unit is a compact, massive yellow brown silt and fine-grained sand with clay and some intercalated gravel. The Plio-Pleistocene unit is overlain by sands and silty sands of the Hanford formation that make it difficult to identify the contact in drilling and geology logs. The contact is consistently marked by an increase in the gross gamma-ray activity or signature seen in geophysical logs and is easily differentiated from the overlying Hanford formation. The Plio-Pleistocene unit is distinguished from the Hanford formation by having a greater calcium carbonate content and massive structure in core (DOE 1988)

The Plio-Pleistocene unit consists mainly of quartz and feldspar with less abundant basalt mica smectite, and chlorite (Tallman et al , 1979). It thins from southwest to northeast across the Tank Farms and varies in thickness from about 14 to 6 meters (45 to 20 feet). The Plio-Pleistocene unit contains a series of old buried soil zones (paleosols) with calcium carbonate development typical of an arid environment (caliche zones and pedogenic carbonate) (Slate 1996). Only one principal caliche zone is present under the Tank Farms but it varies from a discrete zone that lies directly on the Ringold Formation to a diffuse zone occurring a few meters above the Ringold. The caliche zones may have formed subareally during hiatuses in deposition.

The surface of the Plio-Pleistocene unit around the southern part of 200 West Area is a northwest-southeast trending trough (Slate, 1996). The trough resembles the surface of the underlying Ringold Formation and probably formed from erosion by Cold Creek and the later Missoula floods in the slowly subsiding Cold Creek syncline.

The new geophysical data coupled with the older drilling and geology logs allows greater refinement of the Plio-Pleistocene contact under the S-SX Tank Farm than was available in the past. The data show that under the Tank Farms a low amplitude north-south oriented trough is superimposed on the larger northwest-southeast trough (Figure 2-3C). Total relief across the trough in the Tank Farms and surrounding area is about 10 meters.

2 2 8 Hanford Formation

The Hanford formation is about 38 to 40 meters (125 to 135 feet) thick at the S-SX Tank Farm and consists of massive sands and silty sands intercalated with beds of coarse sand and gravel and thin lens of silts and clayey silts. Cementation is very minor or absent. Five relatively laterally continuous sedimentary layers were identified - two gravelly units and three sandy units (Figures 2-2, 2-3A and 2-3B). The top four layers - the two sand layers and gravel units A and B - are equivalent to the Hanford formation subunit designation, H1 (Lindsey, 1995). The further

breakdown into four units is shown here because of the continuity of the layers in this location (with the exception of the surface sandy layer) The bottom sandy layer below Gravel Unit A is equivalent to Hanford subunit designation, H2 In addition, as summarized in Johnson and Chou (1998), sands overlying gravels can influence lateral spreading and downward migration of moisture Therefore the distribution and depth of the sand/gravel layers may be important to understanding contaminant movement at the Tank Farms, particularly in the contaminated region near Tanks 241-SX-108 and 241-SX-109

The five stratigraphic layers (gravelly units A and B and three sandy units) that define the Hanford formation show west to east variations in the proportion of sand silt, and gravel For example the sandy gravels on the west side of the Tank Farms transition to gravelly sands to slightly gravelly coarse sands on the east side The transitions reflect a response to changing depositional conditions resulting from higher to lower energy floodwaters

The Hanford formation consists of about 50% basalt and 50% felsic material (Tallman et al 1979) The felsic component is composed of quartz and feldspar with some samples containing greater than 10% pyroxene amphibole mica chlorite, ilmenite, and magnetite The silt and clay sized fractions consist of quartz feldspar mica, and smectite

Bed forms in the flood sediments vary but can only be observed in surface exposures Cores can provide data on fine-scale bedding, however no core was collected from the S-SX Tank Farm area However, construction at the SY Tank Farm provided an opportunity to record typical bed forms in the upper 20 meters (60 feet) In the pit wall, Price and Fecht (1976c) observed finely bedded sand and sandy gravels with foreset bedding (Tallman et al 1979, Price and Fecht, 1976c) In addition, Price and Fecht (1976c) mapped the graded bedding, channel cut and fill structures and cross-cutting clastic dikes

Tallman et al (1979) recognized a flood channel that forms a topographic low through the 200 West Area The channel included topographic low that encloses the S-SX Tank Farm and is defined by silty sandy gravel New data available shows that the S-SX Tank Farm are located on the east side of a large northwest-southeast oriented flood channel that extends west of the 216-S-10 crbs (see Figures 2-2, 2-3A and 2-3B, and Appendix A Figures A1-2 and A1-3) The axis of the flood channel extends along the west side of the S-SX Tank Farm The channel recognized by Tallman et al (1979) that forms the topographic depression is superimposed on this larger channel A second smaller flood channel mapped by Price and Fecht (1976c) in the SY Tank Farm appears to trend Southwest across the S Tank Farm (Figures 2-2 and 2-3B) This late stage channel cuts into the upper most layers but does not appear to penetrate deeper than 25 meters

The two Hanford formation gravelly units provide the best definition of the geometry and sedimentation in the large flood channels where the study area is located (see Figure 2-2). The lower gravelly unit (Figure 2-2 gravel unit A, and Figure 2-3B) is a sandy gravel that varies in thickness from about 3 to 7 meters (10 to 25 feet). Gravelly unit A becomes progressively deeper from east to west defining the axis of the trough. The gravel almost directly overlies the Plio-Pleistocene unit along the west side of the Tank Farms. In the S Tank Farm (Figure 2-2 Figure A1-2 in Appendix A) and SX Tank Farm (Figure 2-2 Figure A1-3 in Appendix A) the gravel sequence was intersected during excavation for the tanks and is now in contact with the backfill.

The sand unit underlying gravelly unit A is medium- to fine-grained sand to silty sand. It is thickest on the east side of the Tank Farms but thins and pinches out on the west side as gravelly unit A deepens (Figure 2-3A and Appendix A). Thinning of the sands and silty sands may be the result of later scouring that produced the larger flood channel. A prominent silty clay bed is found at the same relative stratigraphic position on both the west and east sides of the SX Tank Farm (Johnson and Chou 1998). It is not presently known how far the bed extends under the Tank Farm or if it is continuous.

Upper gravelly unit B is sandy gravel with intercalated gravelly sand on the west side of the Tank Farms. It thins and grades into gravelly sand to coarse sand by the east side. The gravelly unit was intersected during Tank Farm construction and lies above the base of the tanks.

Between the two gravelly units lies an upper sand to silty-sand. The sediment thins to the east and thickens into the trough (Figure 2-2). A thin sandy silt 1 to 1.5 meters (3 to 5 feet) thick directly overlies gravelly unit A forming the base of the sands on the east and north side of the Tank Farms.

2.2.9 Clastic Dikes

Clastic dikes are vertical to subvertical sedimentary structures that crosscut normal sedimentary layering. Clastic dikes are a common geologic feature of the Hanford formation in the 200 Areas. Price and Fecht (1976c) mapped four clastic dikes in pit walls during excavation of the SY Tank Farm. Clastic dikes occurred in the 216-S-10 pond area southwest of the S-SX Tank Farm suggesting that clastic dikes might also be present in the S-SX Tank Farm area.

Clastic dikes occur in swarms and form four types of networks: 1) regular-shaped polygonal-patterns, 2) irregular-shaped, polygonal-patterns, 3) pre-existing fissure fillings, and 4) random occurrences (Fecht et al., 1998). Clastic dikes in the S-SX Tank Farm area probably occur as regular-shaped polygons based on observations southeast of the Tank Farms. Regular polygonal networks

resemble 4- to 8-sided polygons. Clastic dikes typically range from 3 centimeters to 1 meter in width, from 2 meters to greater than 20 meters in depth, and from 1.5 to 100 meters in length. Smaller dikelets, sills, and small-scale faults and shears are commonly associated with master dikes that form the polygons.

In general, a clastic dike has an outer skin of clay with coarser infilling material. Clay linings are commonly 0.03 millimeters to 1.0 millimeters in thickness, but may be up to as thick as 10 millimeters. The width of individual infilling layers range from 0.01 millimeter to more than 30 centimeters, and the length can vary from about 0.2 meters to more than 20 meters. Infilling sediments are typically poor- to well-sorted sand but may contain clay, silt, and gravel.

Figure 2-4 shows a projection of clastic dikes onto the S-SX Tank Farm. The projection is based on clastic dikes that were mapped between Army Loop Road and Highway 240 southeast of the S-SX Tank Farm. The projection was then scaled to using the best estimate of cell sizes based on Fecht et al. (1999). Figure 2-4 illustrates the maximum clastic dike width and indicates plausible frequency and pattern of clastic dikes in the S-SX WMA. The Figure does not indicate probable location of clastic dikes, but it does suggest that there is a high probability that clastic dikes intersect the Tank Farms and that the clastic dikes could be present where known leaks have occurred.

2.3 Recharge Sources and Events

The facility infrastructure, infiltration of water from natural and tank operation sources, and hydrologic properties of the stratigraphic units beneath the study area control the moisture and waste movement through the vadose zone to groundwater. An understanding of the interactive factors is needed to evaluate the overall nature and extent of subsurface contamination within the S-SX WMA. Available information, data gaps, and uncertainties concerning the above factors are summarized in Section 2.3 *Recharge Sources and Events* and Section 2.4 *Hydrologic Properties*. Supporting data tables and figures are provided in Appendix B.

Fluid infiltration into the soil column from natural and tank operation sources, which are discussed in Sections 2.3.1 and 2.3.2, respectively, had a substantial effect on current environmental contamination conditions in the S-SX WMA. Changes in vadose zone moisture distribution and water table elevation, in response to historical variations in natural and artificial recharge (Section 2.3.3), combined with aquifer properties account for the rate and direction of contaminant dispersal in the aquifer.

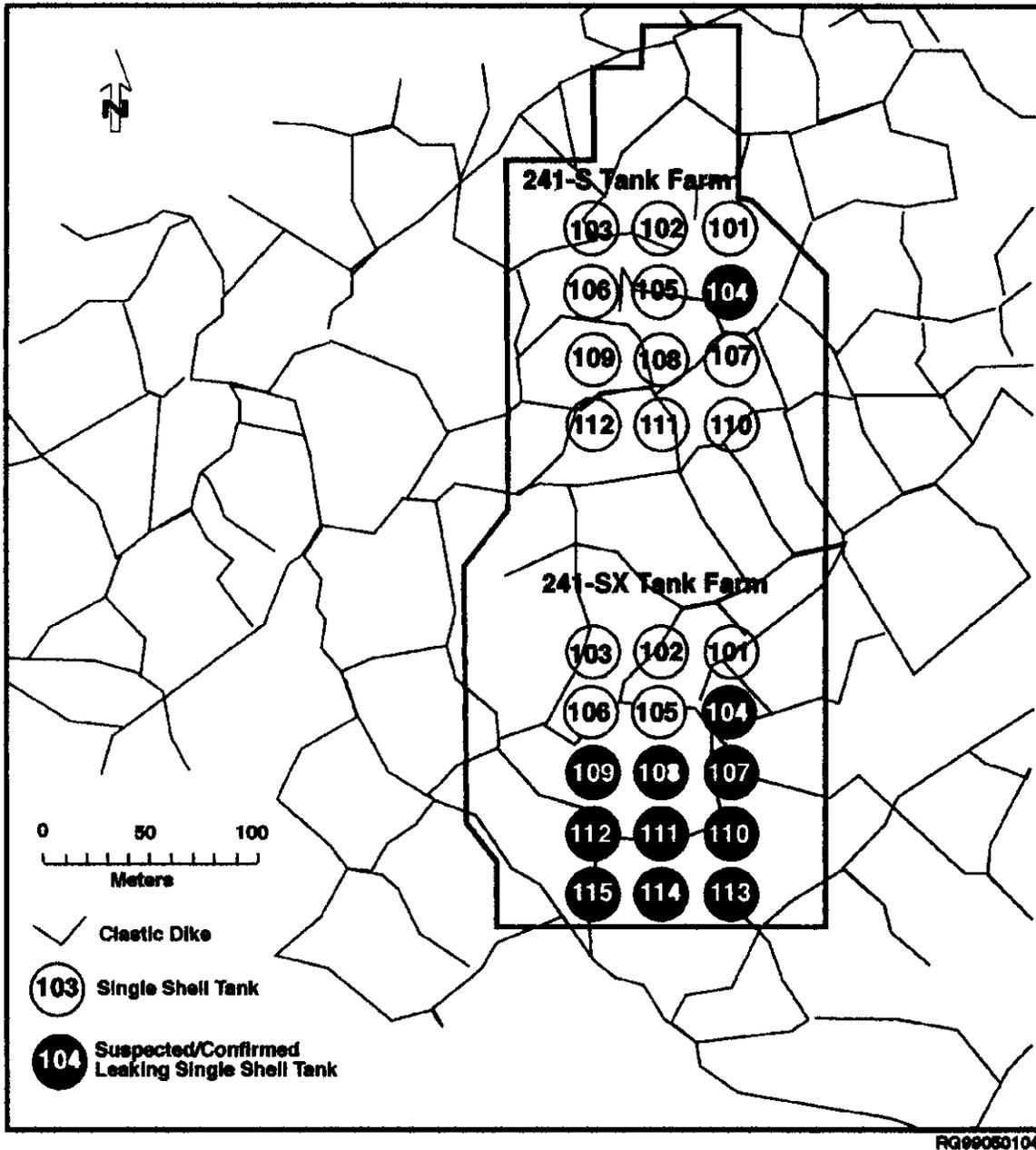


Figure 2-4 Projection of Clastic Dikes onto the S-SX Waste Management Area

2 3 1 Infiltration from Natural Sources

The Tank Farm surface characteristics and infrastructure create an environment conducive to enhanced general recharge and transient high intensity events. Infiltration, run-off events, and rapid snowmelt are discussed below.

Infiltration No direct measurements of the infiltration rate in the S-SX WMA were made. However, observations from similar disturbed, gravel-covered sites at Hanford indicate that as much as 10 centimeter per year can infiltrate a coarse gravel surface free of vegetation (Gee et al. 1992, Fayer and Walters 1995 and Fayer et al. 1996). This represents ~60% of the average annual meteoric precipitation (rainfall plus snowmelt).

Site-specific conditions within the S-SX Tank Farm could alter the average estimates of infiltration rates, especially near the single shell tanks. Recharge infiltrating through the gravel cover is intercepted and shed by the tank domes. Thus, infiltration rates near tank edges and between rows of tanks, may be many-fold higher than average area infiltration rates. Heat from the SSTs could offset the enhanced recharge. For example, moisture profiles from Borehole 41-09-39 (located near tank SX-109) suggested moisture content from the surface down to the Plio-Pleistocene contact (approximately 40 meters below surface) was not significantly different than at nearby locations outside the excavated area for the Tank Farm (Johnson and Chou 1998). Very few quantitative neutron moisture logs were run in the Tank Farms; therefore, it is difficult to fully evaluate the reliability of this single observation.

Runoff Events Transient saturation due to collection of runoff in low spots may be more significant than average annual area infiltration. For example, rapidly melting snow is one natural event that can lead to surface flooding. This type of occurrence was documented at other Tank Farms (e.g., at T farm - Hodges, 1998) but no similar record is available for the S-SX Tank Farm. However, a water line rupture in September 1996 demonstrated that surface water could enter and collect in low spots along the east side of the S Tank Farm (Johnson and Chou 1998). Approximately 2 million liters of water flowed into the north end of the farm in about a one-hour period following separation of a nearby 14-inch (36 centimeters) water main. The topographical low in which the WMA is located and the excavation pit at the south end of the SX Tank Farm provide potential locations for collection of water during unusual runoff events.

Rapid Snow Melt Since 1981, the Hanford Site meteorological station (located between the 200 West and 200 East areas) measures snowmelt. Figure 2-5 summarizes the total inches of snow (per month) that melted within a 24-hour period. The records indicate likely periods when unusual accumulations or ponding of water may have resulted in transient saturation events that could have led to transport of contaminants through the vadose zone to groundwater. The snowmelt events, as well as, maximum monthly precipitation since 1946 (Appendix B, Table B-1) are correlated with groundwater contamination occurrences in the following chapter.

Monthly Summaries of Rapid Snow Melt 1981 - 1997

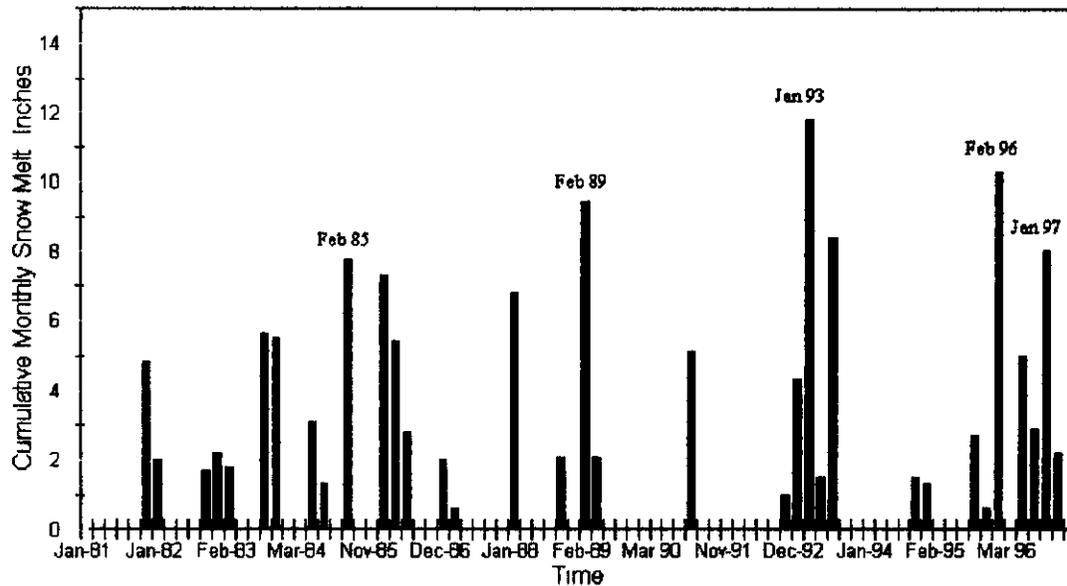


Figure 2-5 Monthly Summaries of Rapid Snowmelt Events, 1981 - 1997

2.3.2 Fluid Discharges from Tank Farm Operations

Throughout the operational history of the S-SX Tank Farm, fluids were discharged both deliberately and inadvertently. To understand the current state of environmental contamination in the S-SX WMA and plausible contaminant driving forces, it is necessary to evaluate available information on the history of fluid discharges that occurred. Key characteristics include the location and time, volume, and contaminant inventory of these discharges. As shown below, quantifiable characteristics are not available for all discharge events and sites. Much of the discharge history and characteristics data described below were collected by Brevick et al. (1996).

A summary of discharge events is provided in Table 2-1. Three types of fluid discharges associated with S-SX Tank Farm operations occurred numerous times in and around the S-SX WMA. These include: 1) deliberate collection and routing of cooling water and tank condensate to cribs; 2) mechanical failure of tanks and leakage into the underlying soil column; and 3) periodic failure of ancillary equipment (primarily diversion boxes and valve pits) used to transfer liquids between tanks.

Most of the S-SX cribs operated from the beginning of Tank Farm operations in 1952 until the early 1970s. During this time, the cribs received excess tank fluids, mostly in the form of steam or process condensates. In 1973, with the start-up of the 242-S Evaporator, all cribs except 216-S-25 were deactivated. At that time, crib 216-S-25 was activated and received condensate from the 242-S Evaporator.

Leaks from ancillary equipment were observed and recorded when sufficient fluid reached the surface from the buried, but near-surface, sources. The primary parts of the ancillary equipment system responsible for the surface spills appear to be the collection points for fluids being transferred around the Tank Farm (e.g., diversion boxes, valve pits, and catch tanks). Numerous pipes feed into the collection boxes that were frequently attached, detached, and reattached as part of normal operations. One diversion box, 241-S-151, appears repeatedly as a probable source of leaks.

Surface spills (also referred to as Unplanned Releases [UPRs]) were recorded in two time periods: the first from 1953 to 1958, and the second in the early 1970s to the early 1980s. The latter time period coincides with startup and operation of the 242-S Evaporator, a period when large amounts of tank fluids were transferred back and forth between the evaporator and the tanks through the ancillary equipment.

Table 2-1 Fluid Discharge History in the S-SX WMA and Surrounding Area

Site	Site Type	Location	Source	Waste Type	Operation/ Leak Time	Volume (gal)	Comments
207 S (b)	Retention Basin	S of SX	REDOX REDOX process coil failures	cooling water steam condensate	1951 1954 1952		S Farm constructed in 1950 1951 Referred to as UPR 200 W 15 &13 & 95
216 S 17 (b)	Pond	S of SX	207 S	cooling water steam condensate			
216 S 8 (d)	trench	E of SX	REDOX	unirradiated uranium	1951-1952	2 60E+06	
216 S 1 (d)	crib	E of SX	Tank D 1 and D 2	drainage redistilled process condensate	1952 1956	4 20E+07	
216 S 2 (c)	crib	E of SX	216 S 1	drainage redistilled process condensate	1952 1956		
216 S 13 (b)	crib	SE of SX	203 S metal decon storage UNH lag storage 276 S hexone storage		1952 1972		
216 U 10 (a)	pond	W of S	SX tanks and sources outside S SX	laundry & powerhouse waste cooling water	1952 1954		
216 S 15 (a) (UN 216-W 3)	pond	E of S	S 110 boiling	cooling water	1952		
pre 216 S-4 (a)	pond	W of S	216 S 15		1952		
241 S 151(a) (UPR 200 W 20)	diversion box	NE of SX			1953	(d)	cascading stopped in 1953 241 S 107 and S 104 boiling in 1953
216 S 3 (a)	crib	E of S	S tanks	steam condensate	1953 1956	1 10E+06	
216 S-4 (a)	crib	W of S	S tanks	cooling water	1953-1956		SX Tank Farms built in 1953 and 1954
216 S 5 (b)	crib	SW of SX		steam condensate	1954-1957	1 10E+09	SX 113 buckled in 1958
216 S 6 (b)	crib	SW of SX	REDOX	steam condensate	1954-1957	1 20E+09	
216 S 21(a)	crib	W of S	241 SX-401	steam condensate	1954 1970	2 30E+07	

Table 2-1 Fluid Discharge History in the S-SX WMA and Surrounding Area

					Operation/	Volume	
UPR-200 W 104 (a) UPR-200 W 106 (a) UPR 200-W 105 (a)	overflow	N of S	216 U 10	cooling water	1955		
299 W22 3 (a) (UPR-200 W-36)	failed well	E of S	216 S 2		1955		S 7 reached radiological limit in 1965
216 S 7 (b)	crib	E of SX	REDOX H-6 condenser		1956 1965	8 20E+07	
UPR-200 W-49 (a)	surface	SE of SX			1958	(e)	
UPR 200 W 50 (a)	surface	E of SX			1958	(f)	
UPR 200 W 51(a)	surface	E of SX	241 S-151 Diversion Box		1958		
UPR 200 W 52 (a)	surface	E of SX	241-S-151 Diversion Box		1958	(g)	
241 SX 113 (a) (UPR 200 W 145)	tank	SX	REDOX		1958	15000	
241 SX 108 (a) (UPR 200 W 141)	tank	SX	REDOX	high salt high Si/Al high T	1962	2400	
241-SX 107 (a) (UPR 200 W-140)	tank	SX	REDOX		1962	5000	
241-SX-109 (a) (UPR-200 W-142)	tank	SX	REDOX	high salt high Si/Al high T	1965	5000	
241 SX 115 (a) (UPR-200 W-141)	tank	SX	REDOX		1965	115000	more groundwater monitoring of failed well
241 S-104	tank		REDOX		1965	6000	REDOX shut down in 1967
216 S-9 (b)	crib	E of S	Tank D-2	redistilled process condensate	1965 1975	1 30E+07	S 9 replaces S 7 in 1965
216-S-23 (b)	trench	NE of S	Tank D 2	redistilled process condensate	1969 1972	9 00E+06	S 9 reached radiological limit in 1969
UPR 200 W 108 (b)	pipng	E of S	Tank D-2	redistilled process condensate	1969		216 S 23 replaced S 9 in 1969
UPR 200-W 109 (b)	pipng	E of SX			1969		
241 SX 112 (a) (UPR 200 W-144)	tank	SX			1969	30000	
216 S-25 (a)	crib	W of S	242 S Evaporator	evaporator condensate	1973 1995	7 60E+07	REDOX concentrator shutdown in 1967
Unnamed	tank flange	S Farm	241-S-107 to 241-S 102		1973		242-S evaporator startup in 1973
241 SX 111 (a) (UPR-200-W 143)	tank	SX			1974	2000	
UPR-200 W-80 (a)	surface	Between S & SX			1978		

Table 2-1 Fluid Discharge History in the S-SX WMA and Surrounding Area

					Operation/	Volume	
UPR 200 W 81(a)	surface	Between S & SX			1979		
UPR 200 W 82 (a)	surface	E of SX	241 S-151 241 302A		1980		
UPR 200 W 127 (a)	surface	E of 242 S			1980		
UPR 200 W 114 (a)	surface	S 1 & S 2			1980		
UPR 200 W 115 (b)	surface	N of 242 S			1980		242 S closed in 1981
UPR 200-W 165 (b)	Surface	NE of SY-102			1985	(h)	216 U Pond closed in 1985

(a) upgradient of RCRA monitoring wells

(b) downgradient of RCRA monitoring wells

(c) up or downgradient with respect to RCRA monitoring wells is uncertain

(d) spill is reported to have covered 1000 sq ft

(e) spill is reported to have covered 500 sq ft

(f) spill is reported to have covered 2 acres

(g) spill is reported to have covered an oval 300 ft diameter

(h) spill is reported to have covered 300 000 sq ft

2 3 3 Subsurface Response to Recharge Events

This Section provides a discussion of subsurface response to infiltration events for the vadose zone and the unconfined aquifer

Vadose Zone Moisture Distribution Water sources from cribs adjacent to the S-SX Tank Farm that received Tank Farm process condensates and other wastewater (e g cribs 216-S-3 -S-8 and -S-25) are potential sources of water that could have migrated beneath the Tank Farms in the past Fine sediment layers were identified at about 10 meters below ground surface on the east side of the SX Tank Farm (well 299-W22-39) and at about 40 meters below ground surface on the west side of SX farm at well 299-W23-14 (Johnson and Chou 1998) The fine sediments may have served as localized "perching" layers for lateral spreading of wastewater into the Tank Farm The proximity of the 216-S-3 crib to the S Tank Farm and the dip of sedimentary units to the southwest favor lateral movement into the S Tank Farm near the east fenceline

The 216-S-25 crib received water in much larger volumes and more recently than any of the other cribs located adjacent to WMA S-SX (Appendix B, Figure B-2) Most of the discharge occurred in the mid 1970 s The stratigraphy (see Figure 2-2) beneath this crib suggests large volumes of water could have migrated along the top of the Plio-Pleistocene especially if fine sediment layers exist such as those that were encountered in well 299-W23-14 The west to east cross-section (Appendix A Figure A1-3) through this area indicates that the Plio-Pleistocene dips eastward and toward a trough that appears to center beneath the Tank Farm (see Figure 2-2) Thus it is possible that water from this crib migrated laterally into the Tank Farm at a depth of approximately 40 meters below ground surface during the high wastewater discharge period in the 1970 s

Smaller volumes of wastewater were received in the 1980 s and more recently from the 242-S Evaporator. All discharges to this crib were terminated in 1995. Operating histories of the above cribs as well as other ancillary Tank Farm waste systems and facilities are provided in Table 2-1.

A non-radioactive, non-hazardous wastewater source (216-SX-2 Crib or Sanitary Crib) is located at the southwest corner of SX farm. The active sanitary waste disposal drain field receives approximately 20,000 Liters per day of wastewater. Whether or not water from this small, nearby source could spread into the Tank Farm is uncertain. Stratigraphic detail in this area is limited. If a shallow, fine sediment layer that dips toward the farm exists, then perhaps it is likely. Judging from the general dip of sedimentary units based on the larger scale cross sections (Appendix A, Figure A1-3) it seems more likely that lateral movement would occur away from the Tank Farm rather than toward it. However, if infiltrating wastewater broke through to the top of the Plio-Pleistocene, the dip of the beds would favor movement to the east beneath the south end of the SX Tank Farm in the vicinity of tank SX-115.

One important consideration to note concerning the possible role of past-practice, subsurface water sources is that crib operations were for extended time periods. If water migrated beneath the Tank Farms and mobilized waste constituents that eventually reached groundwater, the groundwater contamination event should have been over an extended period as compared to transient saturation events (e.g., rapid snow melt or water line rupture).

Water Table and Artificial Recharge The water table has changed dramatically since Tank Farm operations began in the early 1950 s. The shift in discharge of large volumes of wastewater from the T Pond at the north end of 200 West to U Pond (or 216-U-10 Pond) located approximately 400 meters west of the S-SX Tank Farm, in the early 1950's raised the water table in the vicinity of the study area to > 10 meters above pre-Hanford conditions (Figure 2-6).

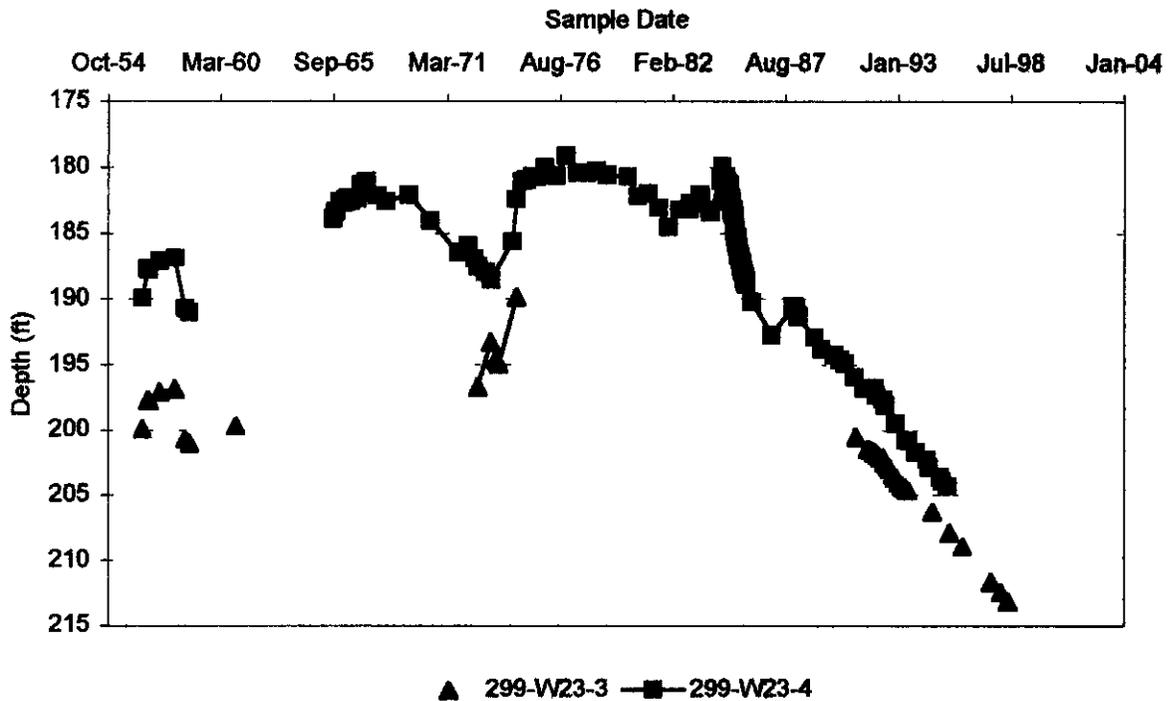


Figure 2-6 Historical Depth to Water Near SX Tank Farm
(Johnson and Chou 1999b)

When T Pond was in operation, the large groundwater mound at the north end of 200 West caused an inferred flow direction to the south in the vicinity of WMA S-SX (Appendix B, Figure B-1). As the mound shifted to the south in response to U Pond (about 1955) groundwater flow became more southwesterly through the study area. Discharges were terminated to U Pond in 1985. However, discharges were continued to both the 216-U-14 ditch near the north end of WMA S-SX and to the 216-Z-20 Crib south of the Plutonium Finishing Plant. The two large wastewater sources caused a shift in the groundwater mound back toward the north, which in turn resulted in a south-southeasterly flow beneath the WMA. With continued reduction in wastewater disposal, the water table declined. The inferred flow direction is currently shifting slowly back to a more easterly flow direction (pre-Hanford condition). The recent water table elevations for key wells in the vicinity of the WMA are shown in Figures 2-7 and 2-8.

As shown in Figures 2-7 and 2-8, water table elevations declined rapidly since 1995. A linear regression of water level versus time for the periods shown in Figures 2-7 and 2-8 indicates a decline of ~2 feet (0.6 meters) per year. As a result, several of the groundwater monitoring wells are going dry and must be replaced. For this reason, and to extend spatial coverage, several new wells are scheduled for installation over the next few years. The decreasing trend in water

table levels will cease once pre-Hanford levels are reached (approximately 20-25 feet below current levels per V G Johnson personal communication)

The water table elevation declined more rapidly for RCRA well 299-W22-44 located on the northeast side of S farm, than for the other wells in the network for WMA S-SX. The hydrograph (Figure 2-8) shows that water table elevation in 299-W22-44 declined relative to well 299-W22-45 which is located 180 meters to the south. This change in local water table gradient indicates there should be a shift from a southeasterly to a more easterly flow direction since termination of all wastewater discharges in 1995. As previously indicated, the 216-U-14 Ditch passed near the north end of S and SY Tank Farms. The ditch was dammed in 1985 when discharges to U-Pond were terminated which created a small localized mound near the north end of S farm.

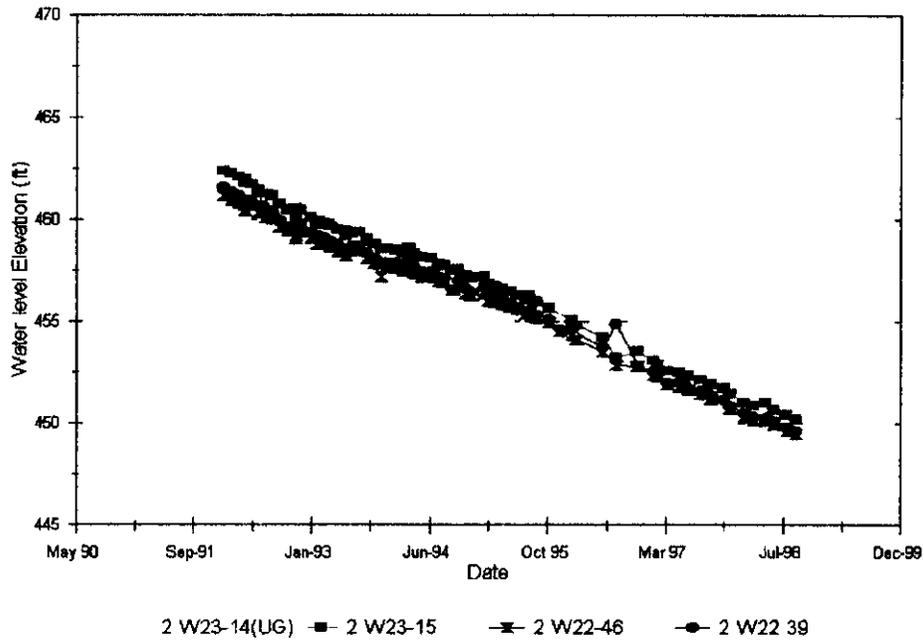


Figure 2-7 Hydrographs for the SX WMA

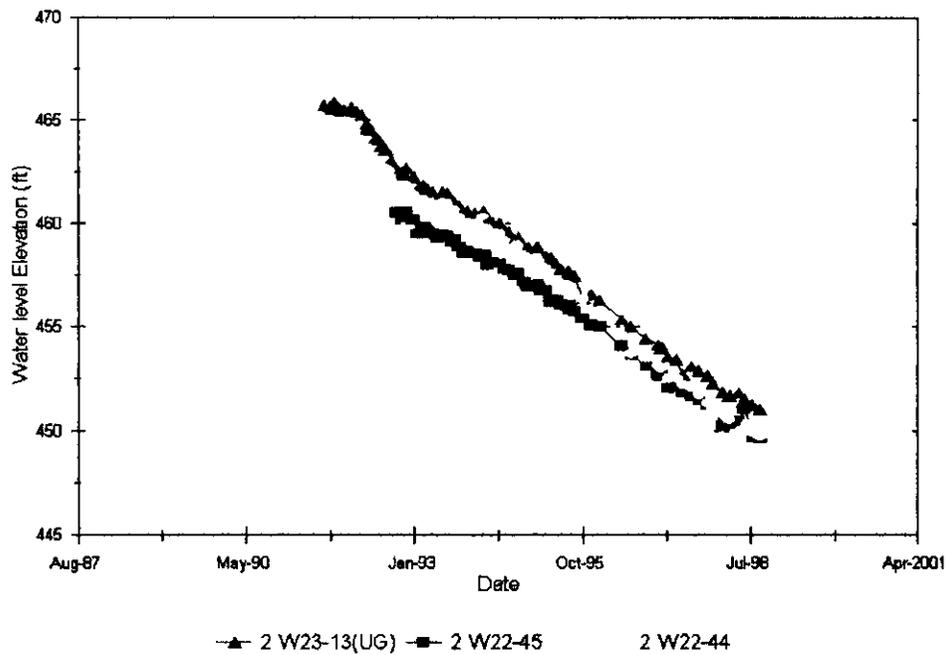


Figure 2-8 Hydrographs for the S WMA

2.4 Hydrologic Properties

This section includes a review of the Vadose zone and aquifer hydrologic. Also included are the effects of transient discharge events, both natural and Tank Farm-operation related, that occurred in the S-SX WMA since the inception of Tank Farm operations and the effects on fluid migration (i.e., fluxes, direction of movement, and distribution in the subsurface).

2.4.1 Vadose Zone Properties

A summary of vadose zone hydrologic properties is provided (Khaleel and Freeman (1995)). In Jones et al., aspects of vadose zone characteristics affecting moisture movement are described in detail. An abbreviated discussion of that summary is provided here.

Two aspects of the hydrologic properties of the S-SX WMA vadose zone are significant and likely to be synergistic. First, fluid flux rates through the vadose zone are sensitive to the intrinsic hydrologic properties of the soil materials. As shown in the geology description (Section 2.2), substantial variability in soil types exist among the vadose zone soils. The associated hydrologic properties are also different. Second, variability in the kinds of fluid discharge that occurred (e.g., surface spills versus general infiltration due to precipitation) creates temporal and spatial changes in recharge conditions and appears to affect the orientation of fluid movement.

Soil Property Variability Among the major stratigraphic units, all units of the Hanford formation are substantially more permeable than the Plio-Pleistocene. This observation is not based on S-SX WMA site-specific measurements. Instead, a set of measurements was made on hydrologic property values for soils collected from boreholes across the Hanford Site. The data, which were collected and evaluated by Khaleel and Freeman (1995), are used to estimate the hydrologic properties of the major stratigraphic units. Included in the database are location of the sample, depth at which the sample was collected, particle size distribution, moisture retention curve data, and saturated hydraulic conductivity values.

On a small scale within the Hanford formation, alternating horizontally-oriented lenses of soils with differing particle size distribution (sand-versus gravel-dominated) exist. The soils have different hydraulic conductivity values (inferred from the general database described above). Under normally low recharge conditions, horizontal movement of fluid in the fine-grained sediments, rather than vertical movement in the coarse-grained soils, is encouraged. While there are no site-specific hydrologic property values available, the range of the values

is expected to be similar to the measured range of values for the appropriate particle size distribution

An additional set of small-scale features is clastic dikes. Given the variability in particle size distribution frequently within a single dike, a wide range of hydrologic property values can be expected. A limited hydrologic properties database exists for clastic dike materials. Physical and hydrologic properties (e.g. bulk density, particle-size distribution, moisture retention, saturated and unsaturated hydraulic conductivities) for clastic dike infilling materials are included in Khaleel (1999) and Fayer and Ritter (1999). Other data (Fecht et al 1999) are available that present saturated hydraulic conductivity and UFA-based unsaturated conductivity measurements for clastic dike infilling materials.

Effects of Fluid Discharge Variability on Hydrologic Properties Numerous transient infiltration events related to both natural (see Section 2.3) and Tank Farm operations (see Section 3.1) occurred in the S-SX WMA. At the low end, normal precipitation events produce rather low infiltration rates. At the high end, crib discharges were sufficiently high to create near saturation to fully saturated conditions in the vadose zone. The immediate effect of enhanced discharge events is a rapid increase in moisture content in the region of discharge. Hydraulic conductivity values increase rapidly in a nonlinear fashion with increased moisture content until a maximum value is reached at full saturation. Consequently, more rapid fluid flux occurs in areas of large discharge as long as high moisture content can be maintained. Measurements of the fluxes in the S-SX WMA were not performed.

Synergistic Effects Field observations and some controlled testing suggest that the fluid migration characteristics are influenced by a complex interaction between flux rates and stratigraphic controls. At normal low infiltration rates, the geologic controls appear to be strongest. Moisture content profiles from gamma profiles of boreholes within the S-SX WMA identify high values in the soils dominated by smaller particle size soils (sand-dominated and the Plio-Pleistocene). This is expected because experimental data establishes that hydraulic conductivity values of fine-grained soils are relatively high compared to coarse-grained soils at low moisture contents typical of low infiltration rates. Therefore, fluids should migrate preferentially in these materials. Given the predominantly horizontal layering of the stratigraphic units including fine-grained units, lateral spreading should be a significant direction of movement. As moisture content and fluid fluxes increase, relative hydraulic conductivities become larger in coarse-grained soils and stratigraphic controls become less significant, the result being significantly vertical as well as, horizontal flow.

Other than the moisture profile signatures of boreholes within the S-SX WMA, two other examples of fluid movement in the vadose zone are available. Both of the examples are inferred from contaminant distribution data. The first example is based on the shape of the gamma plume underlying Tanks 241-SX-108 and

241-SX-109 5-8 meters below the tank bottom. The plume appears to have migrated in a southwesterly direction at a slight dip to the southwest. The depth, thickness of the high gamma zone, and orientation is consistent with the projection of gravel unit A in this region, suggesting some type of stratigraphic control.

In the second example, fluid movement is inferred from contamination underlying the 216-S-1 and 216-S-2 cribs, which was measured in 1956 and 1966 (ERDA, 1975). Located just east of the S-SX WMA, the 216-S-1 and -2 cribs are timbered structures placed in a 12 x 30-meter excavation. About 1.6×10^8 L of contaminated fluids were discharged into this facility over a four-year period from 1952 to 1956. The ruthenium gamma readings from 1956 indicate vertical distribution down to the bottom of the drywells (50 meters deep or more) and horizontal distribution across about 40 meters. Cesium-137 and strontium-90 were distributed in discrete horizontal layers down to the water table. Comparison of 1956 and 1966 data indicates lateral and vertical spreading of both the isotopes occurred.

2.4.2 Aquifer Properties

As previously discussed, the upper aquifer occurs in partially cemented Ringold sands and gravels. The extent of the cementing is not well known. Based on core data from 41-09-39 and 299-W19-10, much of the upper aquifer (0-5 meters) appears to occur in cemented Ringold (sandy gravel). At greater depths, the cementing is not present. This may result in a more transmissive aquifer as the water table declines. This is also an important consideration (and uncertainty) when installing new groundwater monitoring wells with long screened intervals designed to allow for the declining water level.

Hydraulic conductivities based on slug tests, conducted near the time the RCRA wells were installed (about 1992, see Appendix B - Table B-2), are generally very low, but they cover a wide range (0.4 to 27 meters per day) indicating a high degree of uncertainty. The corresponding Darcy flow rates based on a June 1998 water table gradient of 0.0015 and effective porosity of 0.1 to 0.3 are 0.002 to 0.4 meters per day (Hartman and Dresel, 1999). The wide range in calculated Darcy velocities is attributed to the wide range in hydraulic conductivities (probably due to variable cementing) and assumptions about effective porosity.

There are also uncertainties related to the overall groundwater flow direction. Inferred flow directions based on water table elevation rely on the assumption that the aquifer has uniform porosity (isotropic). However, the variability in hydraulic conductivity, which was noted above, and the physical examination of a few core samples suggest a very non-homogeneous (anisotropic) aquifer exists in the study area. One potential consequence of this heterogeneity is that groundwater flow direction may be highly variable over short distances.

(~100 meters) However on a larger scale (1 000 meters or more), the net flow direction will coincide with the inferred direction. These uncertainties have important implications for interpreting groundwater results from specific water well locations and for choosing locations for new well installations. Tracer experiments are planned to test the short-range variability (Johnson and Chou 1999b)

An indication of the predicted versus observed flow direction in the S-SX WMA can be obtained by overlaying a contaminant plume map on a water table map as shown in Figure 2-9. The contamination source is the 216-S-25 Crib which received tritiated wastewater from the 242-S Evaporator until 1995. This source was intermittent but extended over several years prior to 1995. The tritium plume contours shown in Figure 2-9 were drawn separately from the water table map and then added to the water table map. As evident from the combined plume and water table map the inferred flow direction (imaginary line perpendicular to the water table contours) is consistent with the tritium plume map.

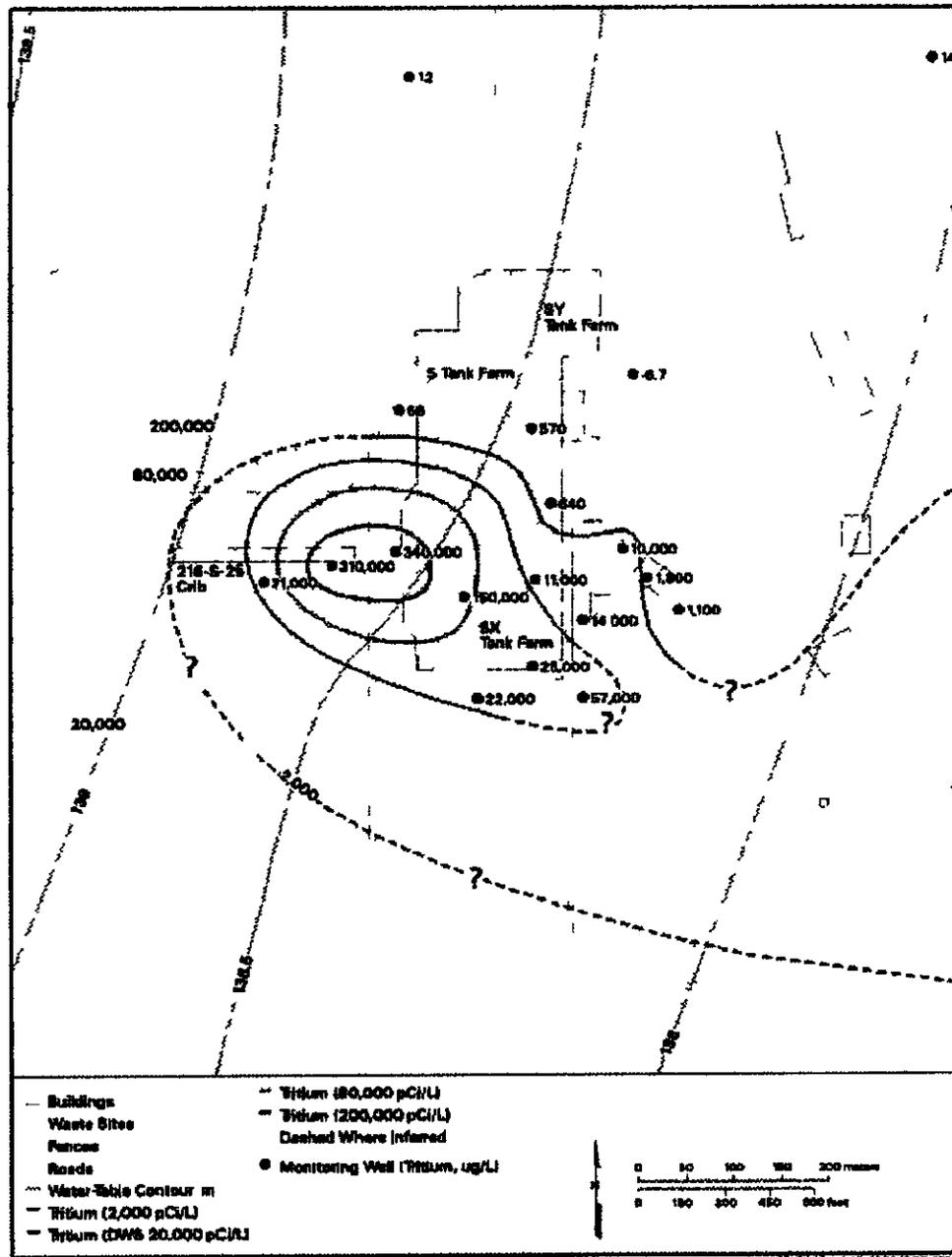
In addition to the flow direction, inferences about travel time can also be made from the tritium plume. For example based on the shape of time concentration plots the arrival time of tritium that originated at the 216-S-25 Crib (Well 299-W23-9) at downgradient wells (e.g. 299-W22-46) suggests an overall travel time of about 30 meters per year (Hartman and Dresel 1999, Section 5.9.3.2). The estimate is consistent with similar estimates using technetium-99 and other tritium arrival times and distances (e.g., 30–50 meters per year reported by Johnson and Chou 1999b).

2.5 Geochemistry

This section covers geochemical factors and material properties of vadose zone and unconfined aquifer soils underlying the S-SX WMA that control contaminant mobility in the soil column. Radionuclide and hazardous constituent mobility can be substantially different depending on the innate characteristics of the contaminant and the geochemistry of the soil/water system. In these soils, both factors are expected to be important. Different contaminants present in the soils are variably mobile and depending on interactions of tank fluids with the soil/water system a given contaminant's mobility can be considerably different at different locations within the vadose zone and unconfined aquifer.

The geochemical characteristics and contaminant mobility are described in terms of relatively undisturbed soils versus highly disturbed soils. Both types of soils are expected in the vadose zone underlying the S-SX WMA. For relatively undisturbed soils a substantial Hanford-specific but not S-SX WMA-specific database is available that quantifies geochemical characteristics and contaminant behavior particularly radionuclides (e.g. Ames and Rai, 1978; Serne and Wood 1990; Serne et al. 1993; Kaplan, Parker and Kutynakov

1998) Average soil properties are described in Section 2.2. Groundwater in the vadose zone and the unconfined aquifer have similar characteristics being



1998 Average Tritium Concentrations near WMA S-SX

Figure 2-9 Tritium Plume and Water Table Map for WMA S-SX and Vicinity

moderately alkaline (pH ~8) and containing moderate concentrations of cations and anions. Dominant cations are calcium (~50mg/L), magnesium (~14 mg/L), sodium (~30 mg/L) and potassium (~9 mg/L). Dominant anions are carbonate (~70 mg/L) and sulfate (75 mg/L).

Within the S-SX WMA, geochemical and related soil property data were collected for soils taken from Borehole 41-09-39 from depths of 130 to 200 feet (Myers et al 1998). Particle size, mineralogy, cation exchange capacity and water chemistry from leached soils were determined. The data indicate that interactions with tank fluids at these depths were not substantial. Mineralogy, moisture content, water chemistry are consistent with relatively undisturbed soils. The primary indicators of interaction with tank fluids is an increase in nitrate concentrations and the occurrence of small concentrations of cesium-137 and technetium-99 at the 130 foot depth.

Generally, contaminant mobility is quantified empirically through the collection of sorption coefficient data (K_ds). The K_d value (mL/g) quantifies the distribution of the radionuclide between solid and aqueous phases and generally is not associated with a particular sorption mechanism. Depending on the contaminant, the K_d value is variably sensitive to environmental conditions, particular water chemistry and types of mineral phases present. Contaminant mobility is roughly proportional to K_d value with a K_d value of 0 mL/g indicating a non-reactive contaminant. Generally speaking, for relatively undisturbed conditions, certain contaminants (technetium-99, chromium and nitrate) are non-reactive, forming anionic aqueous species and migrating with water moving through the soil column. The presence of these contaminants in the RCRA monitoring wells supports this expectation.

Given the available information on tank fluid chemistry, it is expected that more than one type of geochemical environment exists in the vadose zone underlying the S-SX WMA. The majority of the vadose zone volume and all of the unconfined aquifer soils are expected to be geochemically similar to undisturbed soil because migrating fluids are natural water or waste water not substantially different from natural waters. Consequently, soil parameters that tend to influence contaminant mobility (mineralogy, particle size distribution, and cation exchange capacity) are relatively unchanged from undisturbed conditions. Changes in water chemistry in relatively undisturbed parts of the vadose zone and unconfined aquifer tend to be limited to increased concentrations of mobile constituents (e.g., nitrate).

Highly disturbed geochemical environments are expected to exist locally in the vadose zone underlying the S-SX WMA. The zones exist because the chemistry of some leaked tank fluids is radically different from water and should change the soil water geochemical conditions as migration into the soil column occurs. The

spatial extent of such changes and longevity are not well known. The available database strongly indicates that the most severe changes have occurred in soils underlying and near Tanks 241-SX-107, -108, and -109. Within the high contamination zone, high pH conditions, high alkalinity and substantially altered mineralogy may occur. Sampling of soils in this region was taken but analyses of soil samples are not yet available.

Laboratory data were collected periodically to measure radionuclide Kds in soils controlled by tank fluid chemistry (primarily enhanced pH and ionic strength due to enhanced sodium concentrations). A recent summary of the data is reported in Jones et al., 1998. More recent experimental data was collected under these conditions and for cesium-137 (Serne et al., 1998) and iodine-129, technetium-99 and selenium-79 (Kaplan, Parker and Orr, 1998). Compared to undisturbed conditions, cesium-137 Kds were reduced in value (from > 100 to ~20 mL/g) and technetium-99 became somewhat reactive (Kd ~4 mL/g) at very high pH values (>10) and enhanced ionic strength (1M NaClO₄). Kd for iodine-129 and selenium-79 are nonzero and maximized (0.5 and 4 mL/g, respectively) only at moderate alkalinity (pH ~8) and high ionic strength (~1M sodium).

The only S-SX site-specific sorption information that has been collected is based on a series of sorption and desorption experiments for cesium-137 and strontium-99 on samples collected from Borehole 41-09-39 (Myers et al., 1998). Four soil samples were used in the sorption experiments: three from the Plio-Pleistocene and one from the Ringold. The soils were reacted with four solutions: a simulated Hanford groundwater (moderate pH ~8 and low sodium content), a 4 M sodium nitrate moderately alkaline (pH~8.6) solution and two simulated tank liquids. One tank liquid is a REDOX simulant that was characterized by high pH (~14), high sodium (~11 M) and high aluminum (~0.26 M). The second tank liquid was characterized by moderate alkalinity (pH~8), and high sodium (~14 M) content. Given this variety of conditions, the influence of pH, sodium content, aluminum content and soil type on cesium-137 and strontium-99 sorption could be studied.

Maximum strontium-99 sorption occurred in the presence of the high pH solution (~1000-2700 mL/g) and the Plio-Pleistocene soils. Precipitation reactions were occurring because of the high pH, thereby removing additional strontium-99 from solution. Sorption Kd values are much reduced (~1-40 mL/g) for all other cases where moderately alkaline pH conditions prevail. In this range, maximum Kds occur in the presence of Hanford groundwater and Plio-Pleistocene soil. The minimum Kds occur in the presence of high sodium solutions (> 4 M).

Maximum cesium-137 sorption Kds (>50,000 mL/g) occurred in the presence of Plio-Pleistocene sediments and Hanford groundwater. The presence of mica and mica-like clay minerals in these sediments are the primary reason for these very high Kds. A substantial reduction in Kds occurs with the other three solutions (5-2100 mL/g), each of which contain 4 M sodium or better. This

observation is consistent with the expectation that sodium at these concentrations competes successfully with cesium-137 for sorption sites. For conditions present in this lower K_d range, maximum values occur where Ringold and the 4 M sodium nitrate solution are present. This is difficult to explain because the reduced sorption sites provided by the Ringold compared to the Plio-Pleistocene and the high sodium content should present a poor environment for cesium-137 sorption. In the remainder of the data subset, larger sorption values occur with Plio-Pleistocene soils and the minimum sorption values occur in the presence of the second tank liquor which contains the very highest sodium content. Finally, desorption of cesium-137 from the Plio-Pleistocene soils was attempted with all solutions for up to 13 days. In all cases, cesium-137 was not detected in the leachate.

3 0 SUBSURFACE CONTAMINATION INFORMATION

This Section provides a summary of available information on the current state of contamination within the subsurface of the S-SX WMA. Section 3 1 provides an overview of gamma data collected in the vadose zone. The database containing the gamma data is discussed separately because it is the most pervasive information set on current contamination within the vadose zone and provides an overall perspective of contaminant characteristics for the total S-SX WMA. Sections 3 2 and 3 3 discuss specific contaminant information for the tank leaks and ancillary equipment respectively. Finally the characteristics of groundwater contamination are summarized in Section 3 4.

3 1 Gamma Ray Logging Information

Two types of gamma ray logging data were collected in the tank farms: gross gamma and spectral gamma logging. Gross gamma logging (Section 3 1 1) was first used then followed by spectral gamma logging (Section 3 1 2) which is ongoing. Together the databases provide an indication of gamma radionuclides (primarily cesium-137 in the S-SX WMA) emitting contaminant release into the vadose zone and subsequent migration. Currently the two types of analyses are synthesized to elicit additional information regarding the historic and ongoing movements of cesium-137 in the vadose zone (Section 1 1 3).

Gamma data are the most spatially and chronologically comprehensive type of data available on contaminant migration; therefore, quite valuable. By taking gamma measurements vertically in drywells arrayed around tanks and along laterals underneath tanks (where present), a crude three-dimensional picture of contamination in the vadose zone can be generated. However, some substantial limitations should be noted. Two are particularly important. First, gamma logging data do not provide direct information about the location or concentrations of non-gamma-emitting long-lived mobile radionuclides (technetium-99) or hazardous constituents (e.g., chromium and nitrate). Second, the gamma logging data are limited by the availability of boreholes and attenuation of gamma radiation. Gamma logging interrogates no more than a radius of 12 to 18 inches of soil around the borehole. Therefore, extrapolation of the gamma data between drywells is uncertain. Also, drywell distribution is not uniform and some areas in the S-SX WMA contain few or no drywells (e.g., between S-SX Tank Farm).

3 1 1 Gross Gamma Ray Logging Information

During the period 1960-1991, gross gamma logs were collected in the S-SX Tank Farm as part of the secondary leak-detection system (Isaacson and Gasper, 1981; Welty, 1988). Seven tanks in the SX Tank Farm also had laterals installed.

under the tanks for monitoring gamma activity. The gamma logs from the drywells and laterals were examined immediately after being taken to ascertain whether leak detection criteria were exceeded. If the logs did not exceed the established criteria, then the logs were archived and not reviewed further. If the logs exceeded the established criteria, other tank data were analyzed to determine if the tank was indeed leaking. Data derived from logging campaigns through the early 1970s were maintained as paper analog records, since 1974 logging data were stored digitally.

3.1.2 S-SX Tank Farm Spectral Gamma Logging Data

In 1995, a baseline spectral gamma logging program of all drywells in the SST farms was initiated by Mactec-ERS and its predecessor, Rust Geotech, through the U.S. Department of Energy Grand Junction Project Office (DOE-GJPO). Spectral gamma logging techniques provide information on quantities of specific gamma-emitting radionuclides. Baseline spectral gamma was reported in 1996 for the SX Tank Farm (DOE-GJPO, 1996) and in 1998 for the S Tank Farm (DOE-GJPO, 1998). Spectral gamma logging data are also available in separate reports for each Tank Farm.

This document focuses on identifying major areas of contamination (i.e., >10 pCi/g). Figures 3-1a, 3-1b, 3-2a, and 3-2b are plan views of the S Tank Farm providing locations of tanks and associated drywells. Drywells showing relatively high contamination are highlighted in several ways. Figures 3-1a and 3-1b show high gamma readings at locations above a depth of 35 feet. Figure 3-1a highlights gamma intensities between 10 and 100 pCi/g, and Figure 3-1b shows locations of gamma intensity ≥ 100 pCi/g. Figures 3-2a and 3-2b show the same split in gamma intensity for locations below 35 feet.

The data show limited contamination in the S Tank Farm, particularly below 35 feet. The locations are consistent with the historical record, which identifies a large surface leak from a junction box close to Tank 241-S-102 and a suspected leak from 241-S-104. Contamination in the SX Tank Farm is far more widespread, as shown in Figures 3-3a, 3-3b, 3-4a, and 3-4b. In general, the location and intensity of gamma readings in the northern part of the Tank Farm (Tanks 241-SX-101 through 241-SX-106) are above 35 feet and more often between 10 and 100 pCi/g. The characteristics are likely associated with surface leaks. Conversely, in the southern part of the Tank Farm, gamma readings are above 100 pCi/g and below 35 feet, characteristics that are consistent with tank leaks. Although not shown here, the highest levels of contamination are substantially greater than 100 pCi/g around Tanks 241-SX-108, -109, -111, and -112.

Location of Boreholes With Gamma Intensity Readings Above 10 pCi/g and Above 35' in S Tank Farm

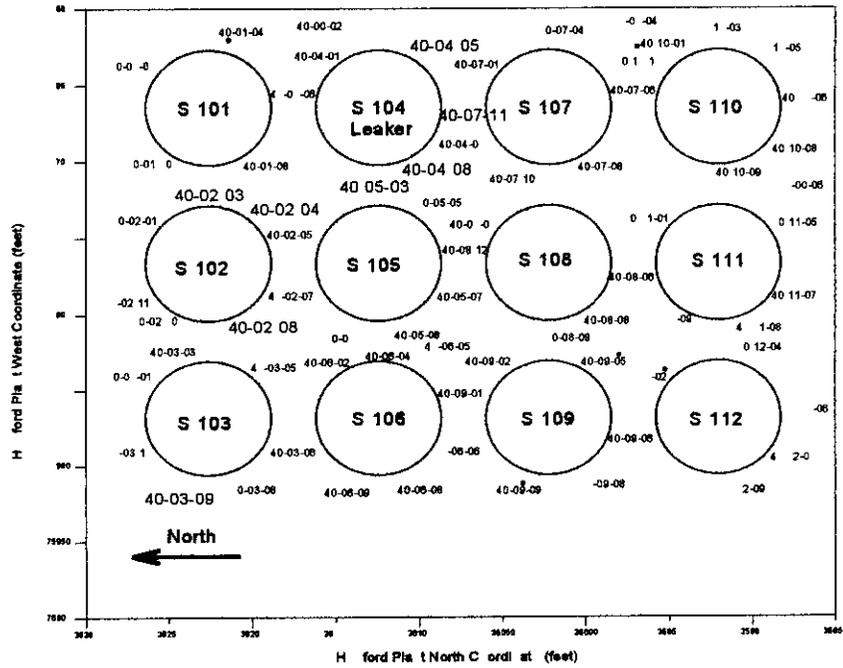


Figure 3 1a Gamma Contamination > 10 pCi/g and < 100 pCi/g between 0 and 35 ft

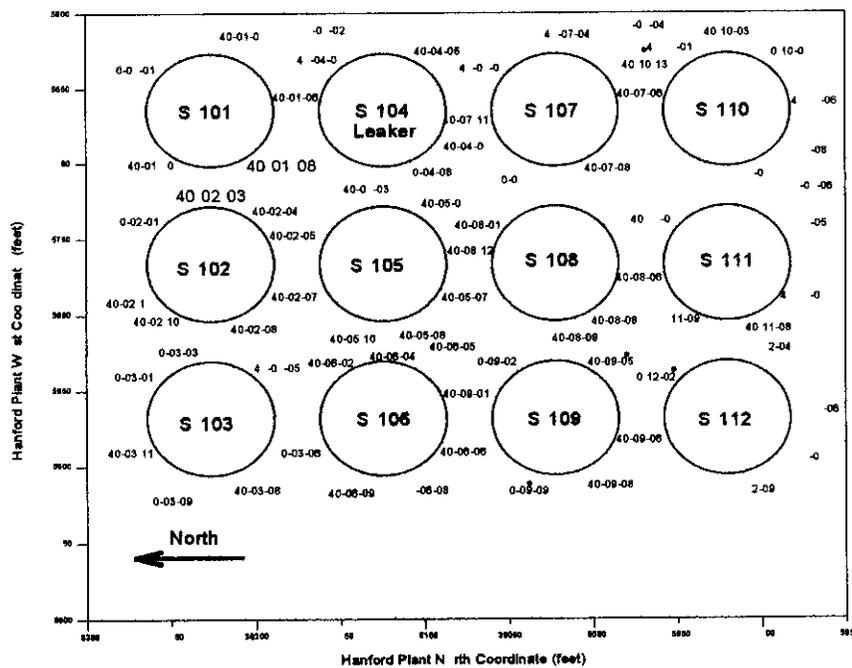


Figure 3-1b Gamma Contamination \geq 100 pCi/g between 0 and 35 ft

Location of Boreholes with Gamma Intensity Readings
Above 10 pCi/g and Below 35 in S Tank Farm

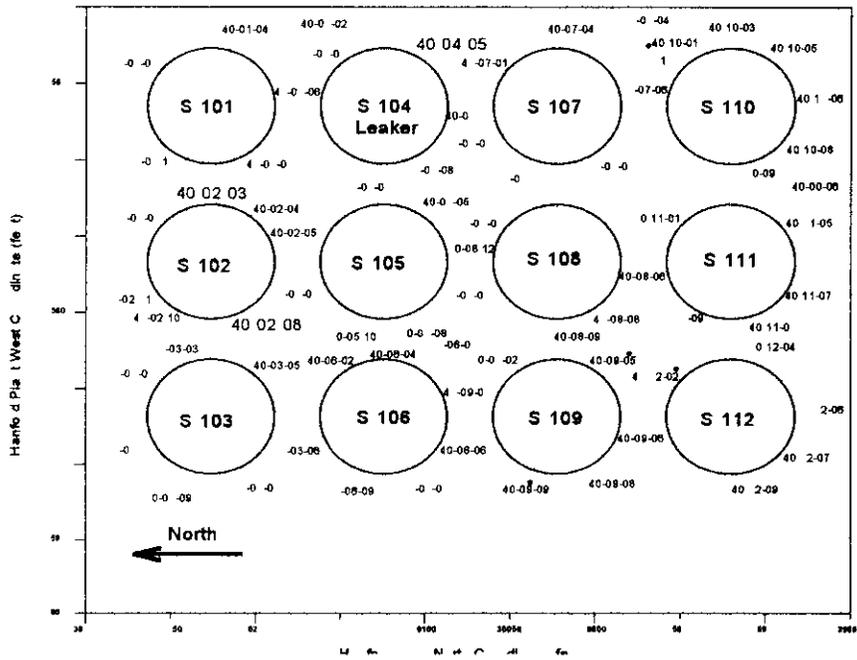


Figure 3 2a Gamma Contamination > 10 pCi/g and < 100 pCi/g below 35 ft

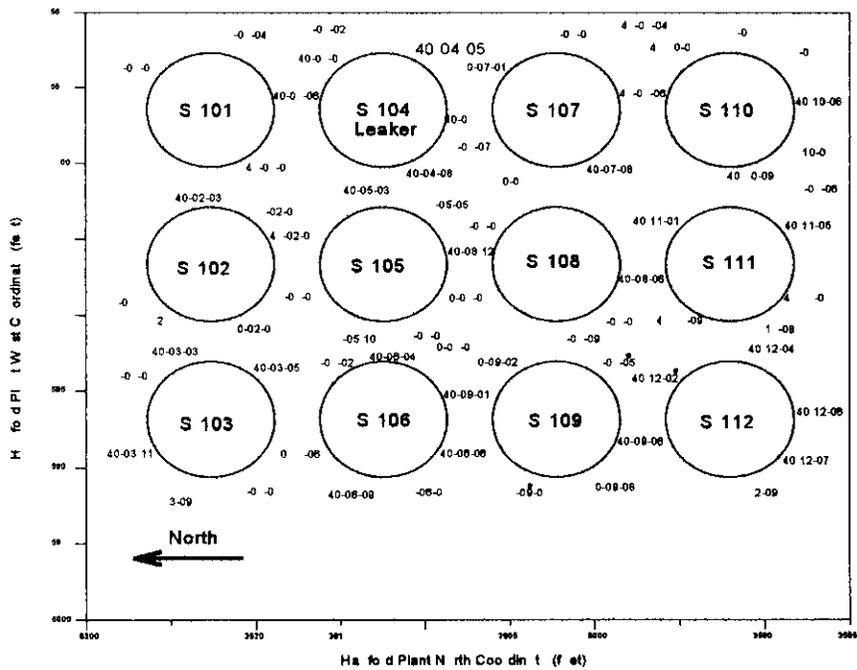


Figure 3 2b Gamma Contamination \geq 100 pCi/g below 35 ft

Location of Gamma Intensity Readings Above 10 pCi/g
and Above 35' in SX Tank Farm

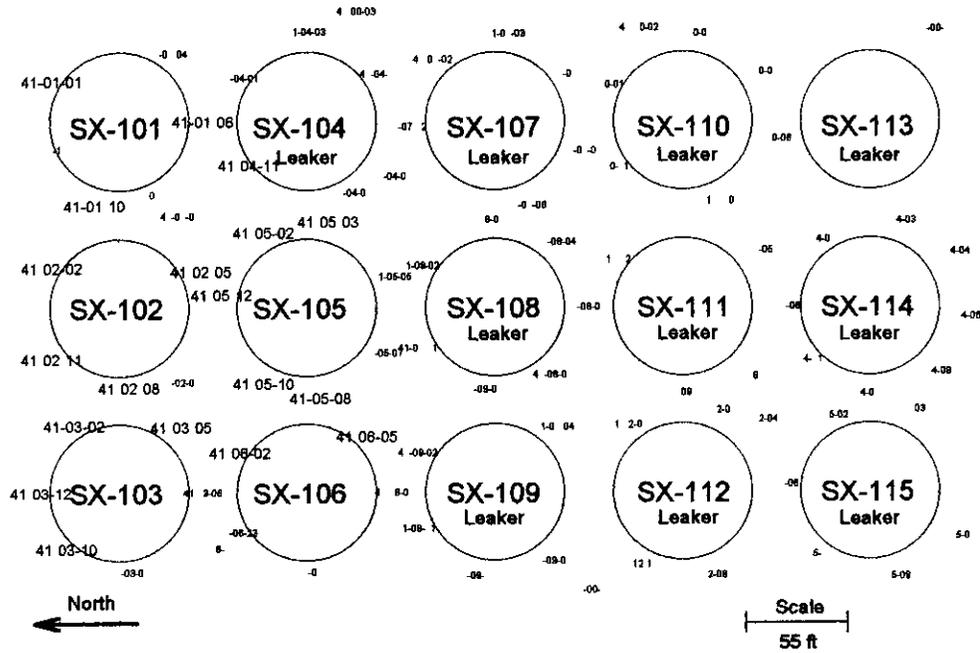


Figure 3 3a Gamma Contamination > 10 pCi/g and < 100 pCi/g between 0 and 35 ft

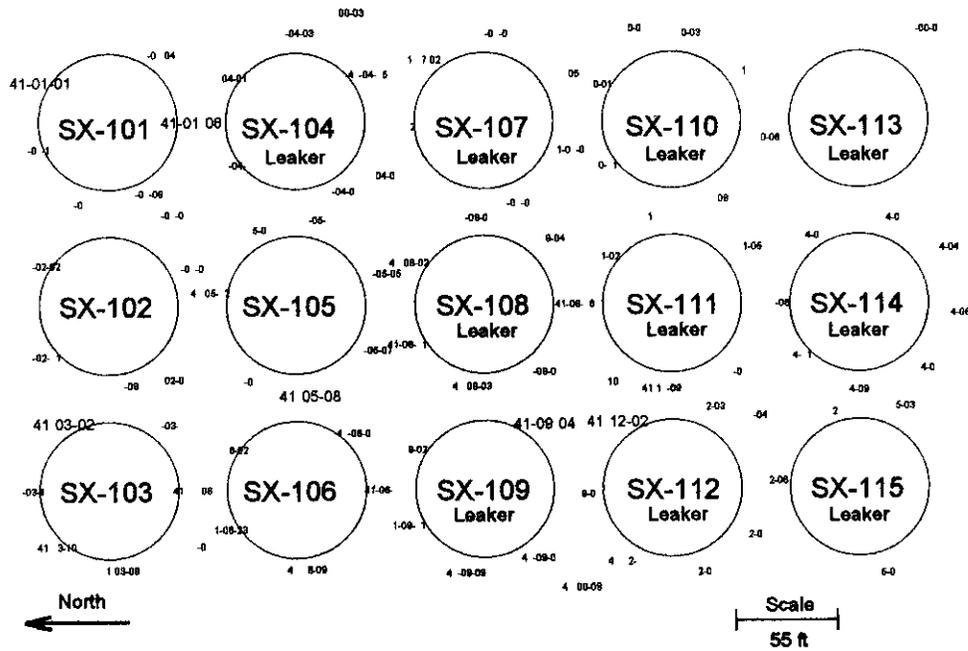


Figure 3-3b Gamma Contamination \geq 100 pCi/g between 0 and 35 ft

Location of Gamma Intensity Readings Above 10 pCi/g and Below 35' in SX Tank Farm

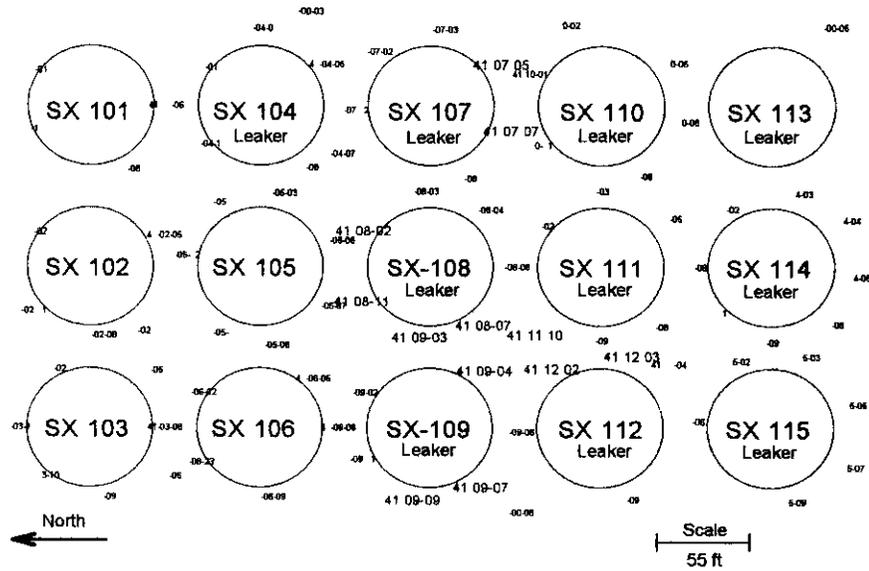


Figure 3-4a Gamma Contamination > 10 pCi/g and < 100 pCi/g below 35 ft

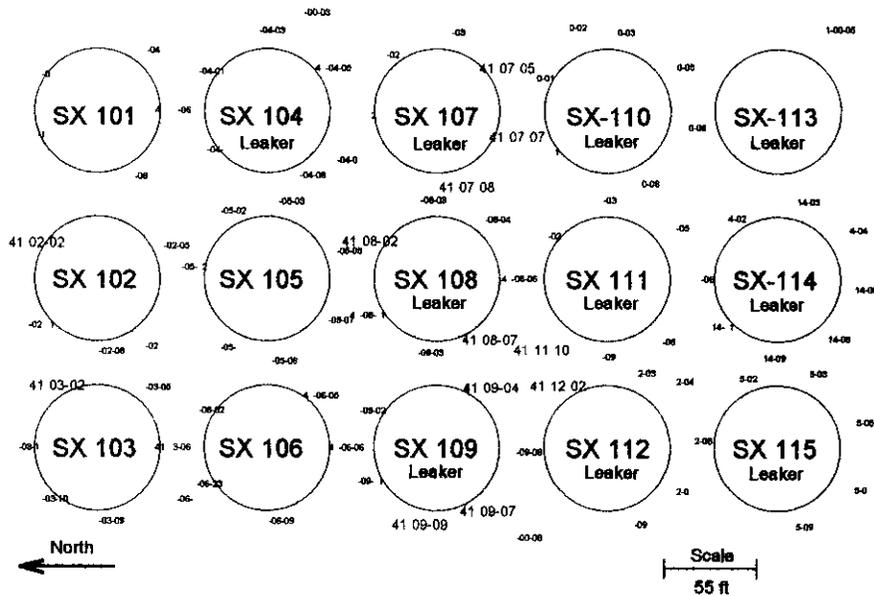


Figure 3 4b Gamma Contamination \geq 100 pCi/g below 35 ft

3 1 3 Synthesis of S-SX Tank Farm Historical and Spectral Gamma Logging Data

Because gross gamma logging was conducted over two decades an evaluation of the data provides information on the time-dependent behavior of the gamma-emitting radionuclides in the subsurface (Randall and Price, 1999) By using the recently collected spectral gamma data (concentrations of specific gamma emitting radionuclides) from the same drywells used to collect gross gamma data the concentrations of individual gamma emitting isotopes that contributed to the gross gamma curves over time can be estimated By factoring in decay the calculated curves can be propagated over time and compared with the gross gamma curve histories Using this process, changes in the curves due to decay or decay plus changes in gamma radionuclide concentrations at a given location over time can be distinguished

Results of the evaluations for drywells in SX Tank Farm are presented in Appendix C Table C-1 provides the location depth of measurement inferred changes in concentration at that location maximum intensity of gamma counts year of maximum intensity, and primary contributing radionuclide for each borehole Contamination is noted as stable if the activity levels decay at cesium-137 decay rate increasing if cesium-137 levels failed to decrease at the decay rate and "undetermined" if the data were insufficient to make a determination Evaluation of the SX Tank Farm reveals the occurrence of cesium-137 movement in the subsurface Movement tends to occur several years after the leak event and involves a small fraction of the activity located nearby In some cases lateral versus vertical movement can be determined

3 2 Tank Leak Contamination Characteristics

Section 3 2 1 provides a summary of estimated leak volumes and chemicals used in the REDOX facility In Section 3 2 2 known information about leaks from specific tanks (volume, timing and inventory) is summarized

3 2 1 Source Term for Waste Lost to Vadose Zone

Wastes may have entered the environment through numerous direct sources in the S-SX WMA such as tank leaks spills from diversion boxes and transfer lines and post-practice releases to cribs from activities Estimated releases or leaks from the tanks in WMA S-SX are presented in Table 3-1 The estimates were obtained from reports by Anderson (1990), Hanlon (1999), and Agnew and Corbin (1998) Note that a variety of values are provided for some tanks and some variability in the dates for estimated leaks were found in different sources

Table 3-1 Estimated Past Leak Losses from the S-SX SSTs from Various References

Tank Number	Estimated Leak Volume (gal)		
	Anderson (1990)	Hanlon (1999)	Agnew and Corbin (1998)
241-S-104	NA	24 000	NA
241-SX-104	NA	6 000	NA
241-SX-107	<500	<5 000	NA
241-SX-108	2 400	2 400 to 35 000	203 000
241-SX-109	<500	<10 000	111 000
241-SX-110	0	5 500	NA
241-SX-111	2 000	500 to 2 000	55 000
241 SX-112	30 000	30 000	44 000
241-SX 113	15 000	15 000	NA
241-SX-114	0	8 000	NA
214-SX-115	50 000	50 000	NA
Totals	100,400	156,400 to 190,500	413,000

Notes NA = not available

The S-SX Tank Farm received waste primarily from the 15 years of REDOX operations. Thus, the REDOX Plant essential material usage list developed from flowsheet information should provide a reasonable list of chemicals that could be expected to have entered the vadose zone from an S or SX tank leak (Kupfer et al 1998). The chemicals are listed in Table 3-2. The average usage of chemicals in terms of kg per metric ton of uranium (kg/MTU) processed in the REDOX plant are also listed. A total of approximately 19,500 metric tons of uranium were processed at the REDOX Plant. This total included approximately 245 MTU of zirconium-clad fuel. The remainder was aluminum-clad fuel. Both aluminum nitrate and ammonium fluoride were required in the zirconium de-cladding operations.

Table 3-2 REDOX Plant Essential Material Usage Predicted from Flowsheets
(from Kupfer et al 1998)

Solvent Extraction		Decladding		
Chemical	Amounts Used (kg/MTU)	Chemical	Amounts Used	
			No 9-Zr (kg/MTU)	Al Clad (kg/MTU)
Al(NO ₃) ₃ ·9H ₂ O	2 020	Al(NO ₃) ₃ ·9H ₂ O	700	---
Cr(NO ₃) ₃ ·9H ₂ O	---	Cr(NO ₃) ₃ ·9H ₂ O	---	0 43
Fe(NH ₂ SO ₃) ₂	17 8	Fe(NH ₂ SO ₃) ₂	---	3 8
H ₂ C ₂ O ₄	2 50	HNO ₃	694	937
HIO ₄	0 0202	KMnO ₄	---	1 16
HNO ₃	174	Na ₂ Cr ₂ O ₇	62	44 3
KMnO ₄	---	NaNO ₃	---	103
Na ₂ Cr ₂ O ₇	22 0	NaOH	296	96
NaBiO ₃	0 0260	NH ₂ SO ₃ H	---	---
NaNO ₃	17 8	NH ₄ F	244	---
NaOH	1 200	NH ₄ NO ₃	48	---
NH ₂ SO ₃ H	0 400			

The high-level waste streams coming from the REDOX Plant contained significant quantities of short-lived and long-lived radionuclides and the radionuclide composition changed as a function according to well understood decay processes (Kupfer et al , 1998) Current radionuclide inventories for all tanks are also available in Kupfer et al (1998) The radionuclide composition at the time of a tank leak event is of most interest for characterization of vadose zone soils contamination by the tank leaks The tank compositions at the time of leak events are currently being estimated using techniques similar to those used by Kupfer et al (1998)

3 2 2 Specific Tank Leaks in S-SX Waste Management Area

According to the *Waste Tank Summary Report for Month Ending February 28 1999* (Hanlon 1999) one tank in the S Tank Farm and 10 tanks in the SX Tank Farm are declared confirmed or assumed leakers This Section provides an overview of each of the questionable tanks within the S-SX WMA

Tank 241-S-104 Tank 241-S-104 was filled with REDOX waste during the first quarter of 1953 Waste was then cascaded from Tank 241-S-104 to Tank 241-S-105, the next tank in the three-tank cascade According to Agnew et al (1995) the waste volume in Tank 241-S-104 remained reasonably stable from 1958 through 1965 During the second quarter of 1965, Tank 241-S-104 received 96 kgal of supernatant to bring the total volume in the up to 807 kgal which was approximately 35 kgal above the cascade overflow level Over the next 5 years, waste volume decreased by ~24 kgal In 1968 the tank was declared a leaker In 1970, 474 kgal of supernatant was pumped out of the tank

leaving approximately 300 kgal of sludge and saltcake. An estimate of the composition of the supernatant that may have leaked is not available.

Based on recent spectral gamma logging, drywell 40-04-05, cesium-137 contaminated the surface (at ~100 pCi/g) down to about 60 feet (at 10 pCi/g) with very high contamination between 38 and 47 feet (>1 000 pCi/g). The high cesium-137 contamination at the tank bottom level suggests a tank leak. Another possibility is that waste levels above the cascade overflow outlet could have leaked from the spare inlet port located in the region of drywell 40-04-05.

Tank 241-SX-104 According to Hanlon (1999), Tank 241-SX-104 leaked 6 000 gallons in 1968. The estimate was based on decreases in interstitial liquid levels. Recent spectral gamma logging data of the drywells surrounding Tank 241-SX-104 do not support the statement that a major leak occurred (DOE-GJPO 1996). However, significant surface level contamination was reported. No estimate of the composition of the supernatant that may have leaked was made. Tank 241-SX-104 currently contains ~500 kgal saltcake and 140 kgal sludge.

Tank 241-SX-107 Tank 241-SX-107 was used to store REDOX high-level waste from 1956 through 1969. In 1964, the tank was suspected of leaking <5 000 gallons of waste (Hanlon 1999). Three drywells on the south and southwest sides of Tank 241-SX-107 (41-07-05, -07-07, and -07-08) show high levels of cesium-137 contamination in the 50 to 70 foot level (DOE-GJPO 1996). An estimate of the composition of the supernatant that may have leaked was not made. To date, an evaluation of the gamma contamination in the laterals under Tank 241-SX-107 is not available.

Tank 241-SX-108 The leak history for Tank 241-SX-108, which contains REDOX high-level waste, is well documented (WHC 1992a, Raymond and Shdo 1966). Estimated releases from Tank 241-SX-108 vary from 2 400 gallons to 35 000 gallons of supernatant between 1962 and 1964 based on WHC (1992a) to 203 000 gallons based on Agnew and Corbin (1998). Tank 241-SX-108 was suspected of leaking in December 1962; however, a determination was made that the leak self-sealed, therefore, the tank was kept in service. Tank 241-SX-108 was observed to have leaked again in August 1964. By late 1965, another determination was made that the leak self-sealed, but in March 1967, the tank was confirmed to be leaking and was taken out of service. Based on a leak volume ranging from 2 400 to 35,000 gallons, the 1965 supernate analysis, and decay calculations (January 1991), the radionuclides in contaminated sediment under Tank 241-SX-108 are estimated to be between 10 000 and 140 000 Ci of cesium-137 (WHC 1992a).

During development of the Historical Leak Model, Agnew and Corbin (1998) estimated tank compositions for the supernatants in four SX tanks including 241-SX-108. Agnew and Corbin assumed that the materials that leaked from these tanks are the same as the supernatant in that particular tank. Supernatant inventory estimates are shown in Table 3-3. As shown in Figure 3-4b a number of drywells around Tank 241-SX-108 are highly contaminated with cesium-137. The gamma contamination around Tanks 241-SX-108, -109, -111, and -112 is higher than any other Tank Farm contamination found to date.

Tank 241-SX-109 The leak history for Tank 241-SX-109 is well documented (WHC 1992b). Estimated releases from Tank 241-SX-109 vary from approximately 10,000 gallons of REDOX high-level liquid waste in January 1965 (based on WHC, 1992b) to 111,000 gallons beginning in 1960 (based on estimates by Agnew and Corbin 1998). In 1965, Tank 241-SX-109 was confirmed to be leaking and removed from service. Liquid was not immediately removed from the tank because a determination was made the leak self-sealed. During the third quarter of 1969 and the fourth quarter of 1971 some liquid was transferred out of the tank. In the fourth quarter of 1973 the tank was pumped down to minimum level. As of 1994 increases in radioactivity in the drywells and laterals were still being observed, which is presumed to be a result of movement of material that leaked earlier. Based on the assumption that the liquid that leaked from Tank 241-SX-109 was the same composition as the liquid leaking from Tank 241-SX-108, the radionuclides in the contaminated sediment under the tank are estimated at 40,000 cesium-137 (or less) as of January 1, 1992 (WHC, 1992b).

During development of the Historical Leak Model, Tank 241-SX-109 was one of the SX tanks. Agnew and Corbin (1998) estimated tank compositions for the supernatants. Materials that leaked from the tank is the same as the supernatant. The supernatant inventory estimates are shown in Table 3-5. As shown in Figure 3-4b a number of drywells around Tank 241-SX-109 are highly contaminated with cesium-137. The gamma contamination around Tanks 241-SX-108, -109, -111 and -112 is higher than any other Tank Farm contamination found to date. At this time an evaluation of the gamma contamination in the laterals is not available.

Tank 241-SX-110 In 1976 Tank 241-SX-110 was listed as 'questionable integrity' with a potential leak volume of 5,500 gallon. The composition of supernatant at the time of suspected leak was not determined. Initially Tank 241-SX-110 received REDOX boiling wastes, but later received a variety of other waste types, such as ion exchange waste from B-Plant, evaporator bottoms, and B-Plant low level wastes. Figure 3-4b shows that two drywells located between Tanks 241-SX-107 and 241-SX-110 are highly contaminated with cesium-137, presumably from a leak from Tank 241-SX-107. At this time, an evaluation of the gamma contamination in the laterals is not available.

Tank 241-SX-111 Hanlon (1999) lists a leak volume of 500 to 2 000 gallons for Tank 241-SX-111. During development of the Historical Leak Model, Tank 241-SX-111 was one of the SX tanks. Agnew and Corbin (1998) estimated tank compositions for the supernatants. Materials that leaked from Tank 241-SX-111 are the same as the supernatant. The supernatant inventory estimates are shown in Table 3-3. Figure 3-4b shows that a number of drywells around Tank 241-SX-111 are highly contaminated with cesium-137. The gamma contamination around Tanks 241-SX-108, -109, -111, and -112 is higher than any other Tank Farm contamination found to date. At this time, an evaluation of the gamma contamination in the laterals is not available.

Tank 241-SX-112 Hanlon (1999) lists a leak volume of 30,000 gallons for Tank 241-SX-112 and a leak date of 1969. However, Agnew et al. (1995) does not report volume discrepancies during the time period. One drywell around Tank 241-SX-112 (12-02) shows high level of cesium-137 contamination from 68 feet down to 125 feet. A second adjacent (12-03) shows cesium-137 contamination in the region of 60 to 70 feet with a maximum reading of 10,000 pCi/g.

During development of the Historical Leak Model, Tank 241-SX-112 was one of the SX tanks. Agnew and Corbin (1998) estimated tank compositions for the supernatants. Materials that leaked from Tank 241-SX-112 are the same as the supernatant. The supernatant inventory estimates are shown in Table 3-3. Figure 3-4b shows that a number of drywells around Tank 241-SX-112 are highly contaminated with cesium-137. The gamma contamination around Tanks 241-SX-108, -109, -111, and -112 is higher than any other Tank Farm contamination found to date. At this time, an evaluation of the gamma contamination in the laterals is not available.

Tank 241-SX-113 According to Hanlon (1999), Tank 241-SX-113 lost 15 000 gallons of waste in 1962. The leak history is reported in Hanson et al. (1962). In 1958, the tank bottom bulged shortly after receiving self-concentrating waste. Although the bulge receded several days later, the waste was pumped to another tank. While pumping the waste to the other tank, the tank bottom bulged a second time. A prototype leak detection system consisting of a caisson with five horizontal laterals that extend under Tank 241-SX-113 was installed in December 1958. During the period 1958 to 1962, gamma radiation was monitored and failed to detect leakage. However, approximately three weeks after conducting a leak test in late 1962, the tank began to leak at a rate of 1200 to 1400 gallons per day. The calculations show that ~8 000 Ci of cesium-137 was lost during the test. The tank was pumped to a minimum level in late 1962 and taken out of service.

Table 3 3 Chemical and Physical Characteristics of Historical Leak Model Leaks
(from Agnew and Corbin 1998)

Characteristics	SX 108	SX 109	SX-111	SX 112
Chemical Concentrations (mol/L)				
Na	7 55E+00	5 39E+00	3 41E+00	6 32E+00
Al(OH) ₄	1 51E+00	1 14E+00	3 77E 01	1 60E+00
F _e	4 30E 03	2 77E 03	4 15E 03	2 77E-03
Cr	2 58E 01	1 66E-01	8 96E 01	1 66E-01
Bi	1 29E 06	1 88E-06	9 00E 01	2 51E-06
La	5 01E 12	7 27E 12	1 69E 09	9 70E-12
Hg	2 03E 07	2 95E-07	9 82E-07	3 94E-07
Zr	6 28E-07	9 11E-07	5 18E-05	1 22E-06
Pb	3 22E-05	4 68E-05	1 32E-04	6 24E-05
Ni	3 87E-03	2 49E-03	1 42E-03	2 49E 03
Sr	1 67E-12	2 42E-12	5 64E-10	3 23E 12
Mn	9 42E-06	1 37E-05	2 85E-03	1 82E 05
Ca	1 93E-02	1 25E-02	7 11E-03	1 24E 02
K	3 07E-02	2 25E-02	1 69E-02	2 98E 02
Density (g/cc)	1 39	1 28	1 15	1 35
Wt % H ₂ O	59 4	68 9	78 8	66 7
TOC wt %C	1 22E 03	1 92E 03	3 17E 01	2 43E 03
Species Concentrations (mol/L)				
OH-	7 04E 02	4 62E 02	3 49E 01	3 78E-02
NO ₃ -	3 57E+00	2 41E+00	1 15E+00	2 20E+00
NO ₂ -	2 34E+00	1 73E+00	9 27E 01	2 34E+00
CO ₃	2 03E 02	1 38E-02	1 68E-01	1 43E-02
PO ₄ --	8 35E 05	1 21E-04	1 01E-02	1 62E 04
SO ₄ --	5 18E 02	3 78E-02	9 72E-02	4 75E 02
SiO ₃ -	4 51E 02	3 24E-02	2 68E-02	4 68E 03
F	7 40E 05	1 07E-04	4 55E-03	1 43E 04
Cl	1 41E-01	1 03E-01	6 02E-02	1 37E 01
C ₆ H ₅ O ₇ - -	6 90E-05	1 00E-04	2 08E-02	1 34E-04
EDTA -	2 69E-06	3 90E-06	3 72E-04	5 20E-06
HEDTA---	2 23E 06	3 24E-06	7 53E-04	4 32E 06
glycolate-	9 74E 05	1 41E-04	4 79E-03	1 89E 04
acetate	1 01E 05	1 47E-05	2 48E-06	1 96E 05
oxalate -	4 17E 12	6 06E-12	1 14E-09	8 09E 12
DBP	6 12E-05	8 88E-05	1 32E-02	1 18E-04
butanol	6 12E-05	8 88E-05	1 32E-02	1 18E 04
NH ₃	4 80E-02	3 65E-02	2 68E-02	5 92E 02
Radionuclide Concentrations (Ci/L unless otherwise noted) *				
Sr 90	7 31E 02	4 71E-02	5 28E-02	4 70E 02
Tc 99	1 07E 04	8 17E-05	1 47E-04	1 28E-04
I-129	2 00E-07	1 53E-07	2 79E-07	2 38E 07
Cs 137	3 49E 01	2 71E-01	4 54E-02	4 44E 01
U-232	2 35E-09	3 39E-09	6 24E-08	4 53E 09
U-233	8 76E-09	1 27E-08	2 38E 07	1 70E-08
U 234	5 15E-07	3 50E 07	2 63E 07	3 71E-07
U 235	2 13E 08	1 43E-08	1 09E-08	1 43E-08
U 236	1 56E-08	1 21E-08	6 96E-09	2 15E-08
U-238	4 76E-07	3 15E-07	2 55E-07	2 80E-07
U-Total (mol/L)	5 98E-03	3 95E-03	3 14E-03	3 50E-03

Table 3.3 Chemical and Physical Characteristics of Historical Leak Model Leaks
(from Agnew and Corbin 1998)

Characteristics	SX 108	SX 109	SX 111	SX 112
Np 237	5.89E 07	4.47E 07	9.08E 07	6.73E 07
Pu 238	4.40E 07	3.19E 07	4.95E 07	5.50E 07
Pu 239	1.90E 05	1.22E 05	2.13E-05	1.21E 05
Pu 240	2.79E 06	1.85E 06	3.49E-06	2.15E 06
Pu 241	2.28E 05	1.64E 05	3.43E 05	2.68E 05
Pu 242	1.16E 10	8.58E 11	1.42E 10	1.55E 10
Pu Total (g/L)	3.18E 04	2.05E 04	2.20E 04	2.05E 04
Am 241 (Ci/L)	3.69E 05	2.98E 05	6.21E 05	5.42E 05
Am 243	1.31E 09	1.15E 09	1.93E 09	2.47E 09
HDW Cs 137 MCi	2.68E 01	1.14E 01	1.06E 02	9.62E 02
HLM Cs 137 MCi	4.25E 01	3.21E 01	9.0E 03	2.5E 01
Soluble nuclide correction	1.6	2.8	0.93	2.6

*Decayed to 1/1/94

Figure 3-4b shows that drywells around Tank 241-SX-113 are not contaminated with gamma activity exceeding 10 pCi/g. Gamma contamination in the laterals under this tank was not evaluated. At this time, an evaluation of the gamma contamination in the laterals is not available.

Tank 241-SX-114 Hanlon (1999) lists a leak date of 1972 for Tank 241-SX-114 and does not include an estimated leak volume. Figures 3-3 and 3-4 show that drywells around Tank 241-SX-114 are not contaminated with gamma activity exceeding 10 pCi/g. Gamma contamination in the laterals under this tank was not evaluated. At this time, an evaluation of the gamma contamination in the laterals is not available.

Tank 241-SX-115 The leak history for Tank 241-SX-115 is well documented (WHC 1992c). Tank 241-SX-115 was built in 1954, put into service in 1958, and the waste inside the tank started boiling in 1959. In 1964, the aged waste was pumped out and condensate was added to dissolve sodium nitrate from the residual solids. In March 1965, a determination was made that Tank 241-SX-115 leaked about 50,000 gallons. In August 1965, 10 test wells were drilled around the tank (Raymond and Shdo, 1966). Data from the test wells, coupled with data from existing drywells and laterals, were used to define and characterize the contaminated area under the tank. Based on analysis of Tank 241-SX-115 supernate, approximately 40,000 Ci of cesium-137 was lost to the soil column during the leak. Upon examination, three separate areas of contamination were found. One was completely under the tank, the other two were closer to the edge of the tank with the contaminated zones primarily under the tank.

Recent spectral gamma logging found contamination of about ~10 pCi/g cesium-137 in only one drywell (15-07) around Tank 241-SX-115. Gamma contamination in the laterals under was not evaluated. At this time, an evaluation of the gamma contamination in the laterals is not available.

3.3 Crib and Ancillary Equipment Contaminant Information

Discharge of cooling waters and condensates to cribs, ponds and ditches was monitored routinely during the operations period. The monitoring activities were most recently summarized by Diedeker (1999). Diedeker reports that initial documentation of liquid volumes by facility and discharged inventory was provided in Anderson (1973). The Anderson report was followed by a subsequent publication (Anderson, 1976) and the establishment of a database, Crib Waste Management (CWM), in 1978 to track discharges. The CWM database was superseded in 1990 by the Environmental Release System (ERS) database.

Table 3-4 provides a summary of discharge information for cribs and trenches receiving S-SX tank wastes. The table also lists the source of waste for the cribs and the volume, time of operation, and partial inventory. Most cribs received steam and process condensate. However, Crib 216-S-8 received dissolved REDOX startup waste, and Crib 216-SA-9 received organic waste. An inventory is not available for Crib 216-S-4 because it received only cooling water, which was presumed to be uncontaminated. A clear explanation of measurement techniques used to quantify volume and inventory is not available. The reports indicate periodic measurements were taken for beta intensity and uranium and plutonium concentrations. Additional radionuclide inventory was derived from reactor production estimates. Table 3-6 shows that the technetium-99 inventory is based on this approach, not direct measurements. Consequently, it is difficult to evaluate the accuracy of these estimates.

Crib 216-S-25 is unique because it also received treated water from a pump and treat program completed in 1985. The goal of the pump and treat program was to remove uranium from the unconfined aquifer underlying Crib 216-U-16. The pump and treat results (Delegard, 1986) indicate that 94% of the uranium was removed from the pumped water. The remainder of the uranium was discharged into Crib 216-S-25. Technetium-99 was also present with uranium in the unconfined aquifer, but analyses were not conducted. Therefore, the amount of technetium-99 disposed in Crib 219-S-25 from this source is not known.

Very little is known about the leak characteristics from ancillary equipment. Volume estimates for spill events are not available except as records of the areal extent of the leaks. Inventory estimates are also not available.

Table 3-4 Estimated Inventory Discharges from S-SX Tank Farm to Cribs and Trenches

Crib/ Trench	Waste Type	Volume L(gal)	Time of Operation	Activity (Ci)				Concentration (Ci/L)					Tc/Cs
				Sr 90	Cs 137	Total U	Tc 99	Sr 90	Cs 137	Total U	Tc 99		
216 S 1 and S 2	REDOX Process Condensate	1 6E+08 (4 2E+07)	1952 1956	1010	890	0 755	2 66	6 33E 08	1 51E 15	3 59E 23	8 55E 31	2 99E 03	
216 S 3	216 S 101 & 104 Condensate	4 2E+06 (1 1E+06)	1953 1956	0 335	17 8	0 000127	0 00025 8	2 35E 10	2 13E 16	1 94E 22	1 76E 28	1 45E 05	
216 S 5	REDOX Steam Condensate	4 1E+09 (1 1E+09)	1954 1957	43 7	21 4	0 0906	0 0019	1 73E 12	1 57E 21	1 43E 30	1 30E 39	8 88E 05	
216 S 6	REDOX Steam Condensate	4 5E+09 (1 2E+09)	1954 1972	165	93 4	0 0904	0 00642	5 35E 12	4 46E 21	3 72E 30	3 10E 39	6 87E 05	
216 S 7	REDOX Process Condensate	3 9E+08 (8 2E+07)	1956 1965	1120	570	0 86	0 978	1 19E 08	1 45E 16	1 77E 24	2 16E 32	1 72E 03	
216 S 8	REDOX Startup Waste	1 0E+07 (2 6E+06)	1951 1952	0 311	3 99	0 0649	0 005	1 92E 09	7 40E 16	2 84E 22	1 09E 28	1 25E 03	
216 S 9	REDOX Process Condensate	5 0E+07 (1 3E+07)	1965 1975	77 8	235	0 0113	1 74E 06	1 34E 13	1 03E 20	7 92E 28	6 09E 35	7 40E 09	
216 S 13	REDOX Organic Waste	5 0E+06 (1 3E+06)	1951 1956	0 0165	2 25	< 0 03	0 0015	1 15E 09	8 88E 16	6 83E 22	5 25E 28	6 67E 04	
216 S 21	SX Tank Farm Condensate	8 7E+07 (2 3E+07)	1954 1969	17 6	69 3	0 00139	0 00069	3 00E 11	1 30E 18	5 67E 26	2 47E 33	9 96E 06	
216 S 23	REDOX Process Condensate	3 41E+07 (9 0E+06)	1969 1972	0 919	2 82	0 00013	7 80E 05	8 67E 12	9 63E 19	1 07E 25	1 19E 32	2 77E 05	
216 S 25	242 Evaporator Condensate and U Crib Treated Groundwater	2 88E+08 (7 6E+07)	1973 1985	0 0338	0 054	0 054	1 60E 05	2 11E 13	2 77E 21	3 64E 29	4 80E 37	2 96E 04	

NOTES
Decayed to 12/31/98
Tc 99 inventory was not measured but estimated from either process knowledge or ORIGEN calculations
disagrees with Brevick et al

3 4 Groundwater Contaminant Information

This section provides the nature of groundwater contaminant occurrences in the S and SX Tank Farm vicinity. Constituent types, spatial and temporal characteristics, peak concentrations, and duration are discussed in relation to possible sources both within and upgradient of the S-SX WMA.

3 4 1 Background

Since the mid 1950 s, groundwater quality monitoring was conducted in the S-SX Tank Farm and around associated facilities. Prior to the original TPA (Ecology et al 1989 as amended) facility monitoring was conducted in accordance with Atomic Energy Act (AEA) of 1954. Under the TPA, SSTs were classified as hazardous waste management units and regulated under RCRA, the Washington State Hazardous Waste Management Act (HWMA, RCW 70 105) and Washington State Dangerous Waste Regulations (WAC 173-303). The S-SX Tank Farm, including ancillary equipment and waste systems, were grouped into one WMA for RCRA groundwater monitoring purposes (Jensen et al 1989, Caggiano and Goodwin 1991). In 1996, groundwater monitoring at WMA S-SX was elevated to assessment status (40 CFR 265 Subpart F) to determine the rate and extent of groundwater contamination in the S-SX WMA (Caggiano 1996, Johnson and Chou, 1998).

All recorded groundwater data, both historical (pre-TPA) monitoring data, as well as the more recent RCRA data, are stored in the Hanford Environmental Information System (HEIS). The database is electronically available to the public but requires specialized software for use of the data. The RCRA data were collected in accordance with SW-846 procedures (EPA 1986). The associated quality assurance and related quality control documentation are described in Hartman and Dresel (1999).

Groundwater monitoring well locations in relation to the Tank Farms, associated facilities, and major spill or leak sites are shown in Figure 3-5. Contaminant occurrences (based on the HEIS data base records) for the monitoring wells covering a time period of 1955 to the present, are summarized in the following Section.

3 4 2 Contaminants

The primary constituents of concern in tank waste (based on relative hazard ranking and toxicity) include cesium-137 strontium-90 technetium-99 nitrate hexavalent chromium, aluminum and other heavy metals (Caggiano 1996 Chou et al , 1997 Johnson and Chou 1999b) Known mobile constituents indicative of tank waste are technetium-99 (TcO_4) nitrate and hexavalent chromium (CrO_4) Selected samples were also analyzed for uranium and transuranics

Cesium-137 and Strontium-90 Cesium-137 and strontium-90 account for most of the remaining radioactivity in tank waste and are primary constituents of concern for the RCRA groundwater project Accordingly they are analyzed quarterly in the RCRA monitoring network wells

Cesium-137 and strontium-90 data exist for several older wells both prior to 1991, as well as more recently Except for one older well (299-W23-7), there is no confirmation of cesium-137 and strontium-90 presence in groundwater beneath or in the immediate vicinity of the S-SX Tank Farm However, listings in the HEIS database occasionally indicate concentrations above the 2-sigma counting uncertainty With the exception of well 299-W23-7 occurrences appear to randomly fluctuate around 0 (positive and negative values) and do not indicate a real detection A comparison of the mean for the field blanks (FTR) and corresponding well results for cesium-137 and strontium-90 respectively is shown in Figure 3-6 Results for the 299-W23-7 well were excluded since the occurrence of measurable cesium-137 and strontium-90 in the well is real

Figure 3-6 shows that there is no difference in the means between the field blanks and the S-SX wells because the two confidence intervals overlap However the comparison suggests that there may be a small blank or background concentration (for cesium-137) that occurs somewhere in the sampling and analytical process The small blank problem is not a significant impact for regulatory compliance monitoring purposes Both blank concentrations and detection limits are more than 10 times lower than the drinking water standards (e g , 200 pCi/L and 8 pCi/L for cesium-137 and strontium-90 respectively) However for other purposes, such as ultra low-level work to elucidate possible pathways (e g colloid transport studies) a lower detection limit would be needed to quantify any cesium-137 that might be present Also the use of low-level counting and contamination control procedures would be advisable

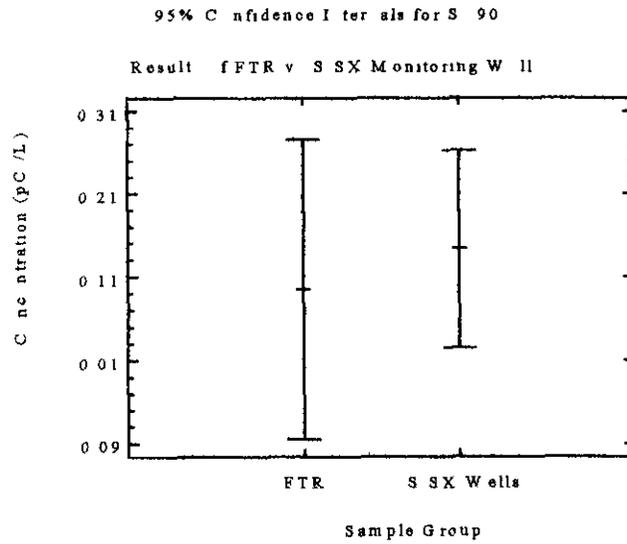
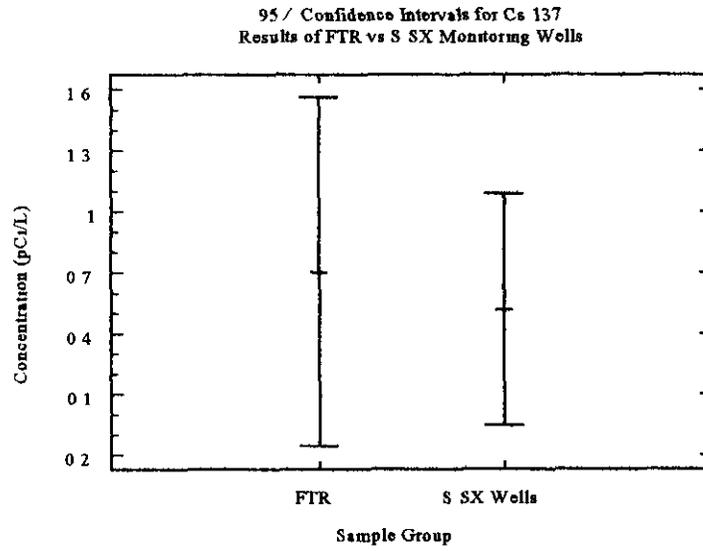


Figure 3-6 Comparison of Cesium-137 and Strontium-90 Groundwater Results with Blank Result

Anomalies in Well 299-W23-7 Occurrences of strontium-90 (up to 6.2 pCi/L) cesium-137 (up to 49 pCi/L) uranium (up to 90 µg/L), and traces of transuranics (< 0.1 pCi/L) were identified in well 299-W23-7. The radionuclides are primarily particulate in nature based on comparison of filtered and unfiltered samples (Johnson and Chou, 1998). Well 299-W23-7 typically produces water samples with very high turbidities and does not readily yield water when pumped. Currently, the well can not produce enough water to reach the surface by pumping; therefore, the results are questionable due to the physical condition of the well. Whether the activity is an artifact of the well (e.g., fugitive dust carrying tank waste contaminants) or representative of aquifer conditions is unclear. Follow-up testing was proposed (Johnson and Chou, 1998, 1999a, 1999b). Because it is unlikely that the well can be rehabilitated, a new well near this location would be needed to determine if the contaminant anomaly is representative of aquifer conditions or an artifact of the well.

Mobile constituents Figure 3-7 illustrates the occurrences of mobile tank waste indicators in RCRA monitoring wells. The correspondence of peaks in concentrations for technetium-99, chromium, and nitrate suggest a tank waste source since this pattern and combination (co-variance with elevated chromium) does not occur in upgradient monitoring wells.

High concentrations of tritium and traces of technetium-99 and nitrate occur in upgradient wells due to past discharges to cribs (e.g., to 216-S-25 Crib, 216-S-4) and to the 216-U-14 ditch/U Pond. Residual contaminants from past-practice upgradient sources are still present in groundwater due to the slow drainage from the soil column beneath the cribs and slow travel time (25–50 m/yr) through the area (Johnson and Chou, 1998, 1999a). Concentrations from the sources tend to extend over many years, as illustrated for tritium in wells at major upgradient sources (Figure 3-8). The persistence of high tritium concentrations at Crib 216-S-25 is due to discharges of process condensate from the 242-S Evaporator. Crib 216-S-25 also received treated effluent from a pump-and-treat campaign conducted over a 6-month period in 1985. The treated effluent contained uranium, nitrate, and an unknown amount of technetium-99. The latter source accounts for the presence of modest concentrations (10 – 100 pCi/L) of technetium-99 that occur in the upgradient RCRA monitoring well (299-W23-14) and were observed in groundwater from borehole 41-09-39 (Myers et al., 1998).

In contrast to the upgradient crib sources (Figure 3-8), contaminants attributed to tank waste and related sources tend to occur in groundwater as short-term or transient events (Johnson and Chou, 1998). The events occur as either short events of 1–2 months or longer events of 1–2 years, as indicated in Figures 3-9 and 3-7, respectively. The number, location, and duration of known events is summarized in Table 3-5.

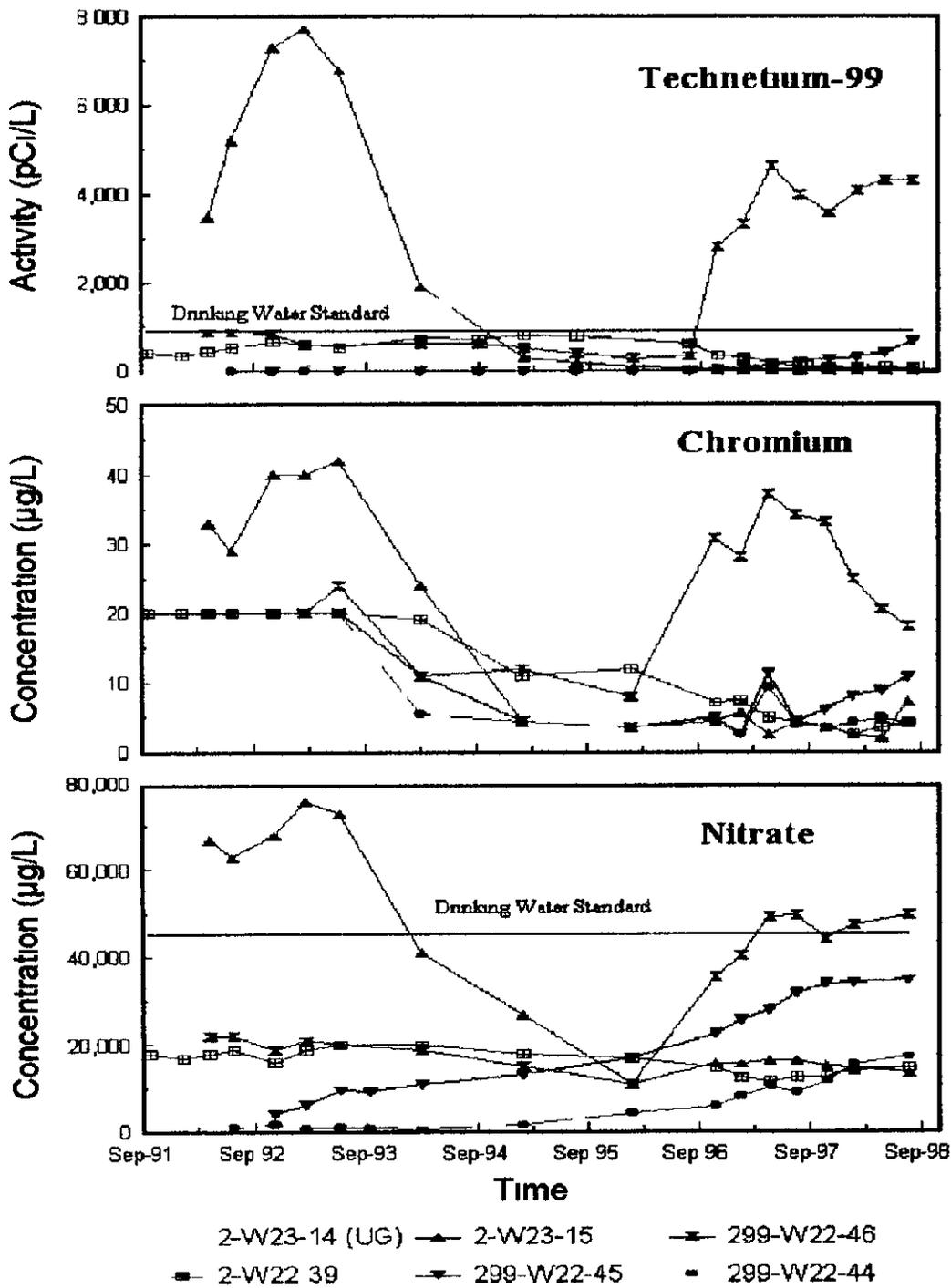


Figure 3-7 Time Series Plots of Technetium-99, Chromium, and Nitrate in Waste Management Area S-SX Monitoring Network

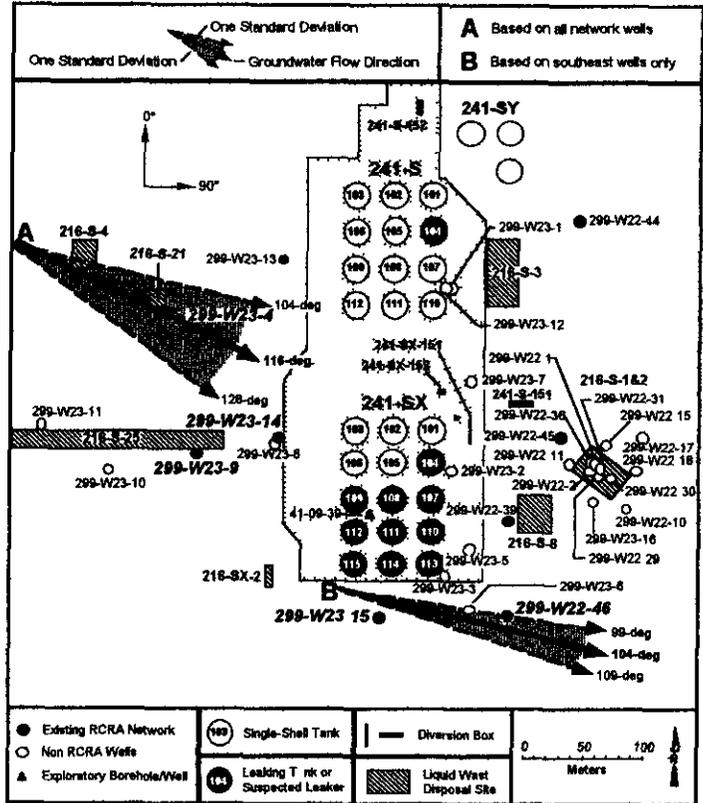
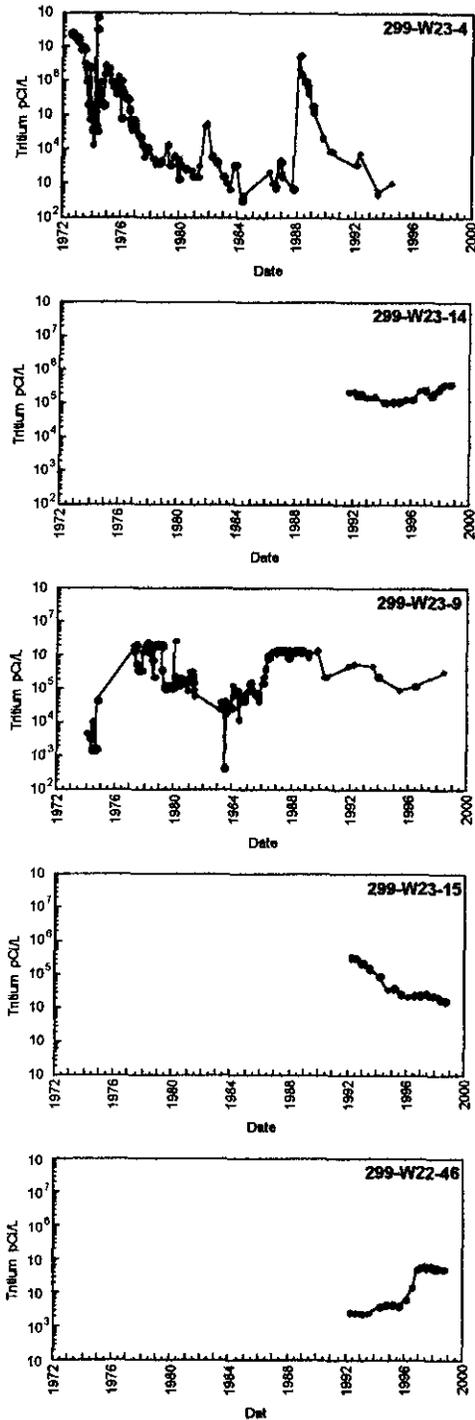


Figure 3-8 Tritium in Selected Upgradient and Downgradient Wells Near WMA S-SX

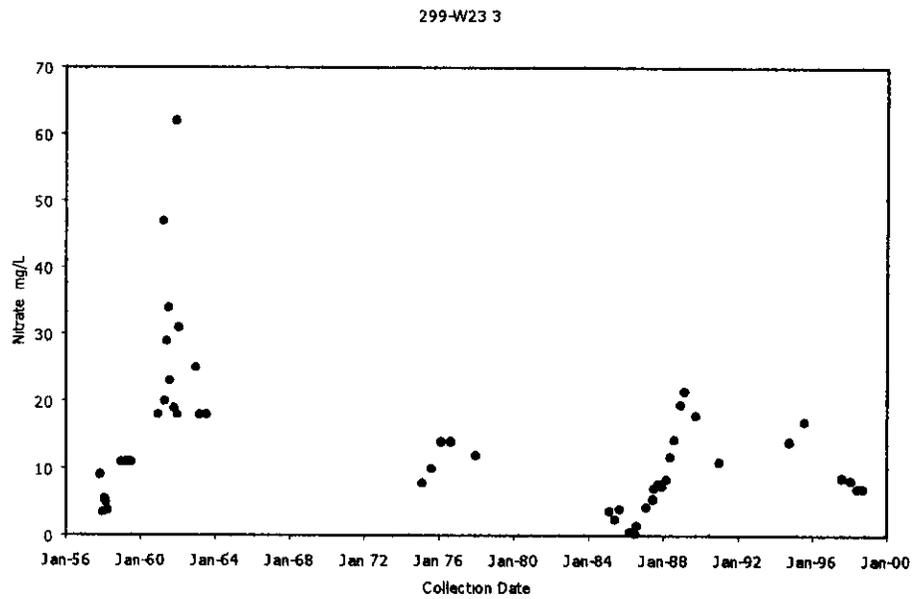
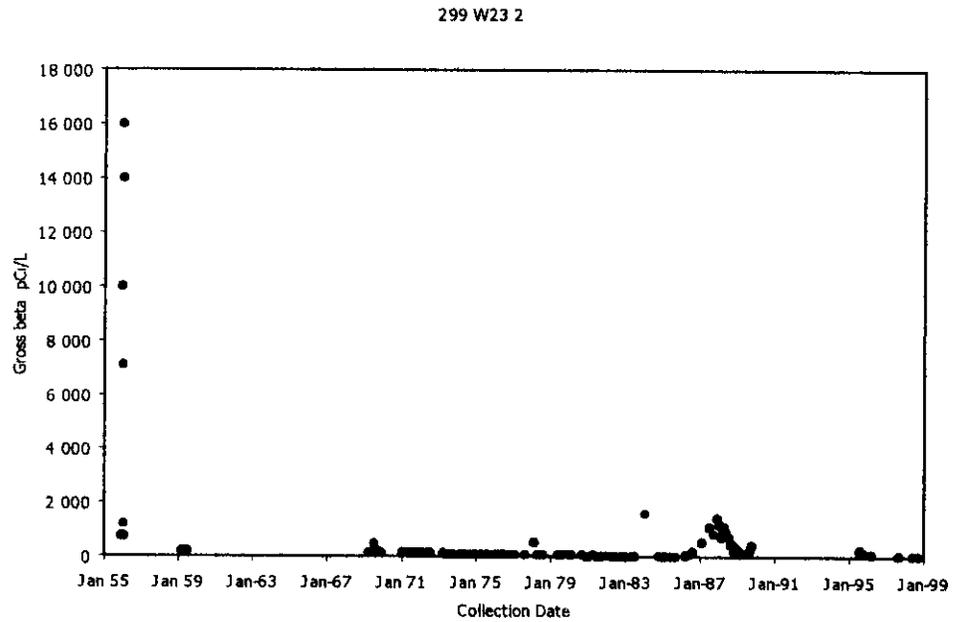


Figure 3-9 Transient Concentrations of Gross Beta and Nitrate in Wells 299-W23-2 and 299-W23-3

Table 3 5 Summary of Historical Contaminant Groundwater Occurrences in the Vicinity of WMA S SX

Well	Transient Occurrences			Information Source ^a	Comment ^b
	Peak		Duration		
	Time	Concentration			
299 W23 1					
Event #1					
NO ₃ (mg/L)	6/27/86	76	8/85 – 12/87	3	Monthly precipitation was 2 3 times higher than normal in 11/83 12/83 3/84 6/84 11/84 9/85 1/86 and 2/86 Rapid snowmelt was noted in 2/85
Beta (pCi/L)	6/27/86	3 470	8/85 – 12/87	1 2 3	
⁹⁹ Tc (pCi/L)	6/27/86	8 250	8/85 9/87	1 2 3	
Event #2					
NO ₃ (mg/L)	1/21/98	50	? 9/98	3	Monthly precipitation was 2 3 times higher than normal in 12/95 1/96 2/96 3/96 11/96 12/96 and 1/97 Rapid snowmelts were noted in 2/96 and 1/97
Beta (pCi/L)	1/21/98	1 090	4/97 9/98	3	
⁹⁹ Tc (pCi/L)	1/21/98	2 890	? 9/98	2 3	
299-W23 2					
Event #1					
Beta (pCi/L)	12/27/55	16 000	12/55 – 1/56	3	Monthly precipitation was ~2 times higher than normal in 11/55 12/55 and 1/56
Event #2					
NO ₃ (mg/L)	9/22/87	36 4	3/86 ?	3	Monthly precipitation was 2 3 times higher than normal in 6/84 11/84 9/85 1/86 2/86 9/86 and 3/87 Rapid snowmelt was noted in 2/85
Beta (pCi/L)	12/1/87	1 440	3/86 ?	1 2 3	
⁹⁹ Tc (pCi/L)	12/28/87	5 420	3/86 - ?	3	
Event #3					
NO ₃ (mg/L)	9/27/94*	56*	? - 8/97	3	Monthly precipitation was 2 3 times higher than normal in 6/91 4/92 6/92 1/93 2/93 and ~10 times in 7/93 Rapid snowmelts were noted in 1/93 and 3/93
⁹⁹ Tc (pCi/L)	9/27/94*	2 260*	? - 8/97	3	
Beta (pCi/L)	No Data	No Data	No Data		
299-W23 3					
Event #1					
NO ₃ (mg/L)	11/21/61	62	12/60 – 12/61	3	Monthly precipitation was 2 3 times higher than normal in 2/61 and 3/61
Event #2					
NO ₃ (mg/L)	12/19/88	21 5	6/86 ?	3	Monthly precipitation was 2 3 times higher than normal in 6/84 11/84 9/85 1/86 2/86 and 9/86 Rapid snowmelt was noted in 2/85
Beta (pCi/L)	5/19/88	129	6/86 ?	1 2 3	
⁹⁹ Tc (pCi/L)	No Data	No Data	No Data		

299 W23 7 Event #1 Beta (pCi/L) ⁹⁹ Tc (pCi/L) NO ₃ (mg/L) Event #2 NO ₃ (mg/L) Beta (pCi/L) ⁹⁹ Tc (pCi/L)	1/18/88 1/18/88 No Data Not observed 9/16/98 9/16/98	1 200 7 830 No Data Not observed 1 380 674	? 10/89 ? - 1/91 No Data 8/97 ? 8/97 - ?	1 2 3 1 2 3 2 3 3	Monthly precipitation was 2 3 times higher than normal in 1/86 2/86 9/86 3/87 and 7/87 Rapid snowmelt was noted in 2/85 Monthly precipitation was 2 3 times higher than normal in 12/95 1/96 2/96 3/96 11/96 12/96 and 1/97 Rapid snowmelts were noted in 2/96 and 1/97
299 W23 15 Event #1 NO ₃ (mg/L) Beta (pCi/L) ⁹⁹ Tc (pCi/L) Cr ^c (µg/L)	3/4/93 3/4/93 3/4/93 3/4/93	76 3 000 7 740 42	? - 11/96 ? - 11/96 ? - 11/96 ? - 11/96	1 2 3 4 1 2 3 1 2 3 4 1 2 3 4	Monthly precipitation was 2 3 times higher than normal in 6/91 4/92 6/92 1/93 and 2/93 Rapid snowmelt was noted in 1/93
299-W22-46 Event #1 NO ₃ (mg/L) Beta (pCi/L) ⁹⁹ Tc (pCi/L) Cr ^c (µg/L)	5/8/97 5/8/97 5/8/97 5/8/97	52 2 2 270 5 020 39 4	2/96 ? 2/96 ? 2/96 ? 2/96 ?	1 2 3 4 1 2 3 1 2 3 4 1 2 3 4	Monthly precipitation was 2 3 times higher than normal in 1/95 4/95 6/95 7/95 12/95 1/96 2/96 3/96 11/96 12/96 and 1/97 Rapid snowmelts were noted in 2/96 and 1/97
299 W22-45 Event #1 NO ₃ (mg/L) Beta (pCi/L) ⁹⁹ Tc (pCi/L) Cr ^c (µg/L)	12/15/98 12/15/98 12/15/98 12/15/98	38 4 38 3 1 160 16 1	4/93 - ? 2/96 - ? 8/96 ? 8/97 ?	3 4 3 3 4 3 4	Monthly precipitation was 2 3 times higher than normal in 1/95 4/95 6/95 7/95 12/95 1/96 2/96 3/96 11/96 12/96 and 1/97 Rapid snowmelts were noted in 2/96 and 1/97

^aInformation sources

- 1 = S SX Groundwater Assessment Report (Johnson and Chou 1998 PNNL 11810)
- 2 = Draft S SX RCRA Assessment Plan (Johnson and Chou 1999b PNNL 12114)
- 3 = HEIS and/or GeoDAT database
- 4 = FY 1998 Groundwater Annual Report (Hartman and Dresel 1999 PNNL 12086)

^bInformation sources Hanford Meteorological Station Monthly and Annual Precipitation and Johnson and Chou 1998 PNNL 1810

^cFiltred results

Assumed due to insufficient data

The transients in gross beta and nitrate in wells 299-W23-2 and 299-W23-3 (Figures 3-9) occurred very near the time Tank Farm operations first began. Well 299-W23-3 is located immediately adjacent to Tank 241-SX-113. While not located next to a tank, well 299-W23-2 is very near a tank waste spill that occurred in the 1950s. An evaluation was not made to determine whether the source was tank waste leaks that migrated rapidly through the vadose zone to groundwater or fluid migrating along the outside of the well casing. The latter is a likely explanation because the older wells were not sealed between the casing and the soil or formation until after 1975, when the wells were perforated and grouted.

High precipitation and/or rapid melting of snow may have served as a driving force for some of the transient occurrences summarized in Table 3-5. For example, higher than normal precipitation and/or snowmelt events occurred 1-2 years prior to the two nitrate and technetium-99 transients that occurred in well 299-W23-1 respectively (June 1986 and January 1998). Likewise, the gross beta transient in well 299-W23-2 (December 1955) occurred 1-2 months after higher than normal precipitation. The same pattern appears to apply to the December 1987 transient event and well 299-W23-3 (Table 3-7). In fact, most of the transient contamination events listed in Table 3-5 were preceded by some type of abnormal precipitation.

Contaminant Ratios The concentration ratios of contaminants may be useful to evaluate spatial relationships between contaminant occurrences and distinguish upgradient sources from tank waste sources. For example, if contaminant occurrences in different wells have a similar ratio, a common source is implied. The ratio should remain constant even though concentrations may vary over a wide range. When the information is combined with flow direction and other factors, it may be possible to narrow down the approximate location of the vadose zone contaminant source based on the groundwater observations.

Figure 3-10 illustrates some spatial and temporal variation in the technetium-99/nitrate ratios for upgradient and downgradient wells at the SX Tank Farm. The error bars for the ratio data shown are the 2-sigma total error (counting error plus method error). Most of the uncertainty is due to the ion exchange column separation step. Although potential changes in technetium-99 oxidation state may alter the ratio from the theoretical ratio (e.g., Agnew 1997), the peak ratios are only about 2-fold lower than expected (based on estimated technetium and nitrate in Tanks 241-SX-108, -109 and -115) than if no chemical fractionation occurred. Even if technetium-99 were depleted relative to the nitrate inside the tanks and/or in the soil column, the ratio should be relatively stable once the constituents are in the groundwater and moving through the aquifer.

Ratio of Tc-99/Nitrate vs Time
241-SX Tank Farm

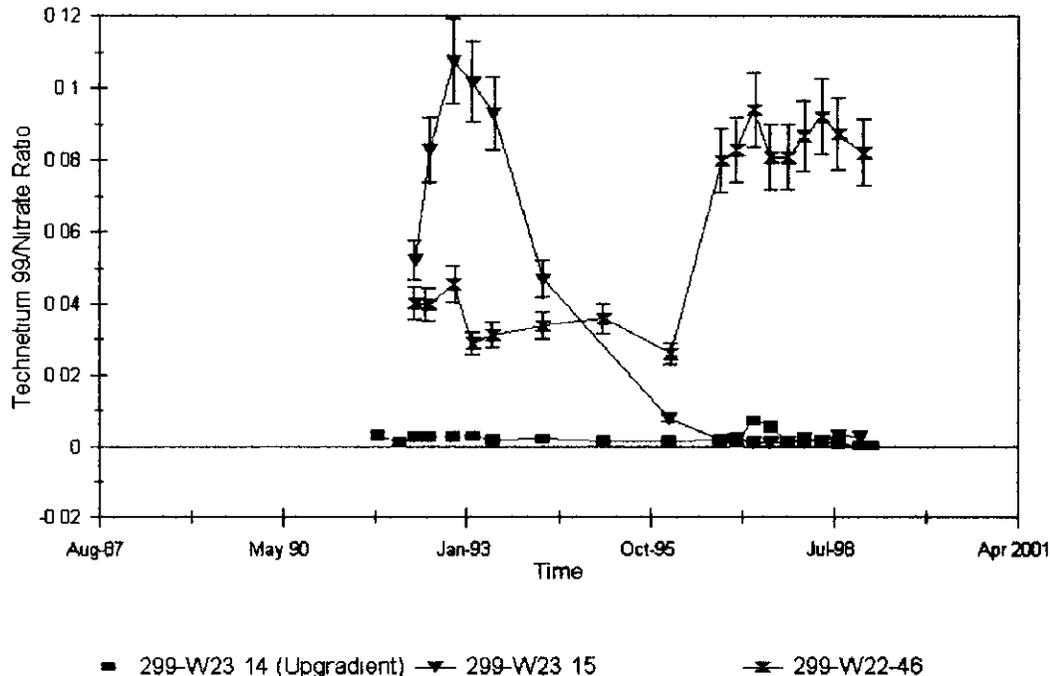


Figure 3-10 ⁹⁹Tc/Nitrate Ratios in Groundwater at SX Tank Farm

The technetium-99/nitrate ratio plots shown in Figure 3-10 demonstrate that the ratios for the upgradient well are dramatically different (lower, indicating a different source type) than those for the downgradient SX wells where high technetium-99 nitrate and chromium concentrations were observed (wells 299-W23-15 and 299-W22-46). Also, it was hypothesized (Johnson and Chou 1998) that the source that passed well 299-W23-15 accounted for the contaminant occurrences in downgradient well 299-W22-46 and that a single source near the southwest corner of the SX farm might account for the observed groundwater contamination in the two wells. However, the shape of the ratio plots for 299-W23-15 and 299-W22-46 suggest that the hypothesized source from the southwest corner of SX Tank Farm may mix with another source on the southeast side of SX Tank Farm. The shape of the chromium versus nitrate and technetium-99 plots (Figure 3-7) also suggests there are two different sources. For example, the chromium concentration declines more rapidly than the nitrate and technetium-99 in well 299-W22-46 as compared to well 299-W23-15 (i.e., a low chromium/high technetium-nitrate source appears to overlap with a high chromium-technetium-nitrate source).

3 4 3 Correlation with Possible Sources

Figure 3-11 summarizes tank leaks and spill events (sources) natural precipitation events (driving forces), groundwater contamination events (observations), and changes in groundwater flow direction over time. The precipitation events noted are above normal events retrieved from the Site meteorological records (summarized in Table 3-5). Total precipitation (rain and snow) is the primary information consistently available. The amount of rapidly melting snow (inches in 24 hours) is available from 1981. Tank leak history is from various sources as indicated in the footnotes.

As previously noted, the groundwater contaminant occurrences seem to be preceded by some type of natural precipitation event. In addition, there were very few abnormal (wet) years during the time period when most of the tank leaks and or spills apparently occurred. The long gap for groundwater data in the mid portion of the time line indicates where there are no historical data in the HEIS database.

The changes in groundwater flow direction indicated at the bottom of Figure 3-11 are a result of changes in wastewater discharge history in the 200 West area. During the early 1950s, the flow direction in the vicinity of S-SX Tank Farm was to the south due to the dominance of discharges to T Pond at the northwest corner of 200 West Area. When most of the wastewater was routed to U Pond in the mid-1950s, the groundwater flow direction was shifted to a more southeasterly direction beneath S-SX Tank Farm. The direction is now becoming more easterly as the water table continues to decline.

As illustrated in Figure 3-11, the earliest contamination events (wells 299-W23-2 and 299-W23-3) seem to occur over a very short interval and soon after or coincident with abnormally high precipitation. Both of these wells are located immediately adjacent to tank waste spills (UPR-200-W-51 and UPR-200-W-49 respectively) that existed prior to the groundwater contamination observed following the precipitation event. Since the well is very close to the spill source, groundwater flow direction is less of a consideration in making a connection between source and receptor in these two cases. Rapid movement of water down the outside of the unsealed casings of these wells would be consistent with the short-term transient observed. Contamination events also occurred recently (~1987 and ~1994) following above normal precipitation. However, in the latter cases, the transient is longer in duration than the 1955–1961 events. This may reflect the results of attempts to grout-seal the older wells inside the Tank Farms in the mid-1970s.

Between 1984-1985 and present (right hand side of Figure 3-11) contaminant occurrences appear to follow abnormal precipitation but extend over a longer time period. Flow directions are favorable for upgradient sources to pass more than one well. However, the technetium-99/nitrate ratios (Table 3-6) do not suggest a common source.

In addition to the abnormal precipitation events in 1996, a water line rupture occurred in September 1996 that released an estimated 500,000 gallons of raw water (Columbia River water) over a one-hour period. Water from this event flowed into the north end of the S Tank Farm and ran south along the fence line in a shallow depression. Most of the water infiltrated along the east side of the S Tank Farm. Although speculative, the infiltration event may explain the transient observed in well 299-W23-1 that peaked in early 1998. There is no obvious large source of contamination upgradient from this well. However, there is generally widespread surface contamination in the area (DOE 1998).

Table 3-6 Summary of Ratio of Technetium-99 to Nitrate for Wells
in the Vicinity of WMA S-SX

Well ^a	Position with Respect to Flow Direction	Observed Technetium-99 to Nitrate ^b Ratio		
		Peak (Time)	Minimum (Time)	Average ^c
S Tank Farm				
299-W23-13 ⁹⁰	Upgradient	0 0046 ± 0 0077 (2/5/98)	-0 00001 (11/23/92)	0 0007 ± 0 0011
299-W22-44 ⁹¹	Downgradient	0 0184 ± 0 0049 (9/9/92)	-0 0001 (8/7/97)	0 0025 ± 0 0043
299-W23-1 ⁵²	Downgradient	0 0646 ± 0 0076 (5/27/98)	0 0449 (9/16/98)	0 0467 ± 0 0099
299-W23-7 ⁶⁹	Downgradient	0 4519 ± 0 0505 ^d (3/11/96)	0 2285 ^d (6/19/96)	0 3402 ^d ± 0 1580
SX Tank Farm				
299-W23-14 ⁹¹	Upgradient	0 0073 ± 0 0009 (5/8/97)	0 0003 (12/9/98)	0 0023 ± 0 0017
299-W23-15 ⁹¹	Downgradient	0 1076 ± 0 0118 (11/23/92)	0 0012 (5/8/97)	0 0320 ± 0 0418
299-W22-46 ⁹¹	Downgradient	0 0941 ± 0 0104 (5/8/97)	0 0262 (2/8/96)	0 0617 ± 0 0263
299-W22-39 ⁹¹	Downgradient	0 0461 ± 0 0051 (2/14/95)	0 0043 (12/15/98)	0 0216 ± 0 0132
299-W22-45 ⁹²	Downgradient	0 0302 ± 0 0036 (12/15/98)	-0 0000 (4/5/93)	0 0064 ± 0 0083
299-W23-2 ⁵⁴	Downgradient	0 1617 ± 0 0185 (1/18/88)	0 0052 (9/16/98)	0 0706 ± 0 0635
299-W23-3 ⁵⁶	Downgradient	0 0374 ± 0 0042 (9/27/94)	0 0055 (5/28/98)	0 0143 ± 0 0124
299-W23-9 ⁷²	Upgradient	0 0013 ± 0 0002 (5/22/96)	0 0003 (8/12/97)	0 0010 ± 0 0005

Notes

^a Superscript following well number denotes the year of installation

^b As NO₃ (µg/L)

^c Average ratio ± one standard deviation the error shown for the maximum value is based on the 2 sigma counting/ total error for technetium 99

^d Outliers removed

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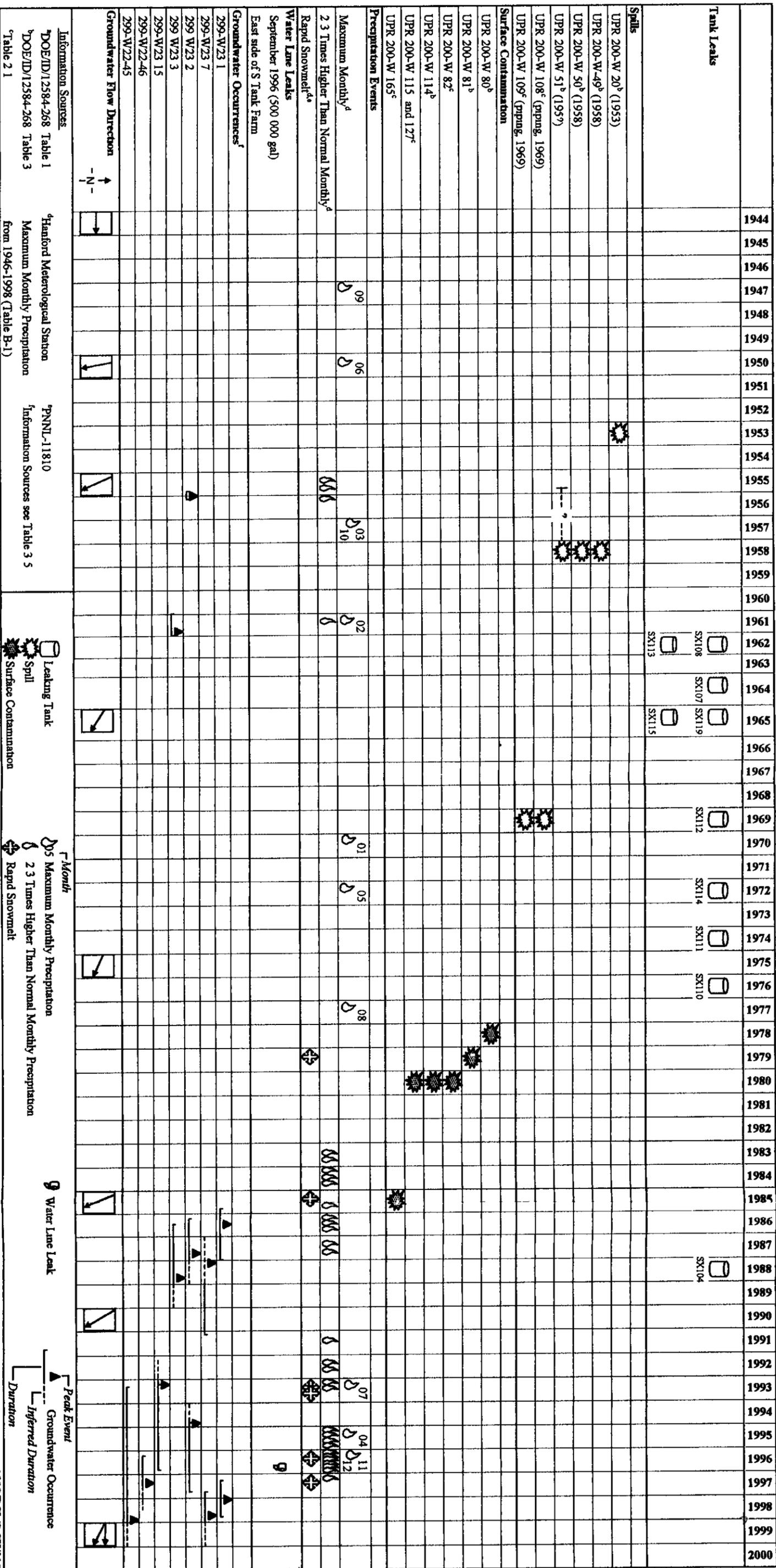


Figure 3-11 Time Line of Vadose Zone and Groundwater Infiltration and Contamination Events in the S-SX WMA and Vicinity

4 0 DATA INTEGRATION AND CONTAMINANT MIGRATION CONCEPTUALIZATION

A wide variety of data that are useful for identifying the sources and distributions of contaminants in the subsurface (both vadose zone and the unconfined aquifer) underlying the S-SX WMA and surrounding area were collected. This Section provides qualitative conclusions about the nature of the contaminating events by synthesizing the various kinds of data that were collected. Several of the conclusions are an iteration of work completed by Johnson and Chou (1998, 1999a, 1999b). Section 4.1 provides a general discussion of the current state of contamination and potential future migration within the S-SX WMA. Brief discussions of contamination within specific locations of interest are provided in Section 4.2.

4.1 S-SX WMA Observations

To evaluate the current state of contamination and to project future migration and additional contamination of the subsurface, a determination must be made of the source term and the driving forces causing migration of contaminants. The source term includes identification of specific contaminants, location, and distribution in the subsurface. The following data are most significant:

4.1.1 Cesium-137 Data

Of all the radionuclides, cesium-137 is measured most easily and most often. The following data are significant:

- Cesium-137 is readily dissolvable in tank fluids. It has routinely been measured in tank supernate. In the SX Tank Farm, Raymond and Shdo (1966) measured cesium-137 in supernate from Tanks 241-SX-108 and 241-SX-115.
- Cesium-137 is one of the few easily measurable radionuclides in the subsurface via gamma measurements and is the primary source of gamma radiation in S-SX Tank Farm.
- Comparison of historical and spectral gamma data (DOE-GJPO, 1996) with stratigraphic data (this document) indicate that the majority of cesium-137 activity appears to be distributed along the gravel-sand contacts around gravel unit A in the contaminated zone underlying Tank 241-SX-108 and to have migrated in the down-dip direction (southwest) from Tank 241-SX-108.

- Raymond and Shdo (1966) documented cesium-137 concentrations in tank supernate approximately 10 times higher in Tank 241-SX-108 than in the Tank 241-SX-115 supernate. Substantially higher concentrations of cesium-137 are also observed in the vadose zone underlying Tanks 241-SX-108 and 241-SX-109 versus Tank 241-SX-115. Gamma logging data (DOE-GJPA 1996) corroborate substantially larger cesium-137 concentrations under Tanks 241-SX-108 and 241-SX-109.
- Cesium-137 sorption and desorption K_d values measured in contaminated soils taken from Borehole 41-09-39 (Myers et al 1998) cover a large range (5 to 63,000 mL/g). The measurements were completed with different fluid compositions to represent potential variability in vadose zone water. Extremely high sorption values (>59,000 mL/g) were measured in the presence of Plio-Pleistocene soils and simulated Hanford groundwater.

The observations lead to several important concepts about the occurrence and nature of contamination in the S-SX WMA. First, within the tank farms where a comprehensive gamma logging database and some soil analyses are available, the historical records and data are well correlated. The combined information shows that the most contaminated area of vadose zone soils are under Tanks 241-SX-108 and 241-SX-109 and less contaminated, but potentially significant, contamination zones are under Tanks 241-SX-115 and 241-S-104. Conversely, given the ready solubility of cesium-137 in tank fluids, it is unlikely that unknown areas of discharge with comparable contamination levels exist within the tank farms. This explanation can not be assumed in the region between S and SX Tank Farm where gamma logging was not performed. In contaminated vadose zone soils, distribution of other contaminants of interest in the discharged fluids, particularly mobile constituents such as technetium-99, can not be inferred from the cesium-137 data except very generally.

Second, the cesium-137 distribution in the vadose zone and the sorption data suggest that introduction of tank supernate into the vadose zone created spatial and temporal variability in chemical and physical parameters affecting migration. In both Tank 241-SX-108 and 241-SX-115 leaks, the great majority of leaked cesium-137 is largely concentrated within small soil volumes. However, the extent and distribution of the volumes differ. High cesium-137 concentrations under Tank 241-SX-108 are extended over a larger area, meters to tens of meters away from the tank bottom. Tank 241-SX-115 cesium-137 concentrations are essentially adjacent to Tank 241-SX-115 and contaminate less soil volume. The sorption data in soils taken from Borehole 41-09-39 indicates that cesium-137 mobility could have been maximized in the leaked Tank 241-SX-108 fluid because of high sodium content in the leak fluid. In contrast, the Tank 241-SX-115 supernate sodium concentrations (~0.5 M from

measurements reported by Raymond and Shdo, 1966) were much lower. Other factors increasing cesium-137 mobility in the Tank 241-SX-108 supernate could have been differences in the physical properties of the fluid (mass, temperature, release rate). Given these indications of a historically dynamic environment affecting cesium-137 mobility, it is feasible that the mobility of other contaminants may have been or continue to be influenced by these conditions.

Third, the site specific sorption data support the conclusion that long term cesium-137 mobility is very low, particularly in the Plio-Pleistocene, which resides between the primary contamination and the unconfined aquifer. The indication of occasional cesium-137 movement in the vadose zone provided by the synthesis of the historical gross gamma and spectral gamma data should not be ignored and deserves further consideration. However, significant cesium-137 migration in the vadose zone and subsequent groundwater contamination by cesium-137 from the larger inventory sources near the surface is implausible unless significant and sustained changes in water chemistry occur in the presently contaminated vadose zone. The occurrence of cesium-137 in Well 299-W23-7 is not contradictory to this conclusion. The amounts of contamination in this well are very small and can be explained by the well itself acting as a manmade conduit for rapid transfer to the unconfined aquifer.

Fourth, the relative intensities of cesium-137 concentrations in supernates leaked from different tanks and associated contaminated vadose zone areas are likely to indicate relative intensities of other constituents of concern, particularly technetium-99. Estimates of supernate and total tank inventories suggest that the ratios of cesium-137 to technetium-99 are relatively constant in the various leaking fluids. If so, a qualitative ranking of technetium-99 inventory leaked into the various locations where gamma logging data are available can be made based on the intensity of cesium-137 concentrations. The largest technetium-99 inventory was discharged into the vadose zone underlying Tanks 241-SX-108 and 241-SX-109, followed by substantially smaller inventory discharges from Tanks 241-SX-115 and 241-S-104. Indications of subsequent distribution of technetium-99 in the vadose zone can not be determined from initial fluid ratios.

4.1.2 Transient Discharge Events and Groundwater Contamination Characteristics

Transient discharge events and groundwater contamination characteristics are considered together because both illustrate the nature of contaminant migration in the subsurface after initial release. The following observations are most significant:

- Numerous short-term (e.g., month duration or less) high volume discharges occurred in the S-SX WMA. Sources include leakage from tanks and ancillary equipment and natural precipitation in the form of heavy rain and snow melt. One known incident of leakage from a broken water main was recorded.
- Some long-term discharge events are also plausible. The cottonwood tree growth observed south of SX Tank Farm indicates consistent longer leakage.
- Outside the Tank Farm, much larger volumes of water were routinely discharged to cribs and trenches over longer time periods.
- General directions of groundwater flow in the S-SX WMA during Hanford operations are well known from water elevation readings and pond histories. General directions were in the range of north to south and west to east. Currently, the general direction is northwest to southwest in the northern part of the S-SX WMA and becomes more easterly just to the south.
- Two types of contaminant concentrations versus time trends were observed in groundwater monitoring wells around the S-SX WMA. One trend is a rapid rise in contaminant concentration at a well to a value that is then sustained for a long period of time. For example, tritium in Well 299-W23-9 existed at concentrations around 10^6 pCi/L for more than 20 years. The second trend is a short duration (2-5 years) but high intensity spike event, such as was found for the nitrate, chromium, and technetium occurrences in Well 299-W22-46.
- Spike contamination events occur with technetium-99, nitrate, and chromium in monitoring wells to the south and east of the S-SX WMA. In each of two southern wells, (299-W23-15 and 299-W22-46), technetium-99, nitrate, and chromium peak simultaneously, indicating at least one common tank source.
- Maximum technetium-99 peaks in groundwater occur in the wells south of SX Tank Farm.

By combining these observations with the cesium-137 data, some inferences can be drawn to link potential contaminant sources with observed groundwater contamination. Three sources or source areas of contamination that are causing current contamination events in the S-SX WMA monitoring wells were identified (Johnson and Chou, 1998, 1999a). Given the general direction of groundwater flow, all hypothesized sources are west to northwest of the well locations. The

sources include the 216-S-25 crib Tank 241-SX-115, and a less well defined source from within the S Tank Farm (e.g., leakage from Tank 241-S-104 or ancillary equipment spills). A brief discussion of each is provided below. The source area from Tanks 241-SX-108, -109, -111, and -112 is also discussed. The source area does not appear to be a current source of groundwater contamination, but the potential for contributing to future groundwater contamination is large.

4.2 Conceptualization of Specific Contaminating Sources

This Section provides a discussion of contaminant releases from the 216-S-25 crib S Tank Farm area sources. Tank 241-SX-115 and the Tank 241-SX-108 area are discussed. The critical data for each source location are defined and hypotheses are provided to explain the data.

4.2.1 Contaminant Releases from 216-S-25 Crib

Key information includes the following: 1) 216-S-25 is the most recently used crib to receive S-SX Tank Farm condensate via the 242-S Evaporator, 2) large volume discharges (3×10^8 L over the last 20 years) occurred, 3) treated waters from the unconfined aquifer underlying U cribs containing uranium and technetium-99 were also discharged into 216-S-25 in 1985, 3) tritium, uranium, and technetium-99 are found upgradient of the S-SX Tank Farm (west and south) and in samples from Well 41-09-39, 4) tritium was measured at a consistently high level from 1977 to 1980 and from 1986 to present, and 5) tritium is currently pervasive underneath the S-SX Tank Farm.

The collected data are consistent with typical crib discharges of contaminated fluids. Because the tritium data were collected extensively over time and space, the data are particularly illuminating. Large discharge rates over long periods of time through a crib increase moisture content in the underlying soil column, perhaps to saturation. The conditions, high discharge rates and soil moisture content create rapid travel times for water and mobile contaminants migrating through the vadose zone (probably on the order of months once saturation is achieved). If soluble contaminants in the discharging fluid are maintained at a fairly constant level, contaminant concentrations in downstream groundwater should build up rapidly to a peak level and remain at that level as long as the discharge rate continues. The tritium data from Well 299-W23-9 show this pattern. Because discharge to 216-S-25 ceased, the tritium levels immediately downstream should begin to drop off within a few years. The tritium contamination from this source is small as shown by the current concentrations (e.g., Well 41-09-39 shows concentrations of < 100 pCi/L). Therefore, 216-S-25 does not contain sufficient technetium-99 to contaminate groundwater levels above the Maximum Concentration Limit (MCL) of 900 pCi/L.

4 2 2 Contaminant Releases from S Tank Farm Area Sources

Key information includes the following 1) contaminants were leaked from Tank 241-S-104 and ancillary equipment, particularly a feed tank between Tanks 241-S-107 and 241-S-102 and various diversion boxes or valve pits, 2) numerous high rainfall events and one large snow melt event occurred during the early to mid 1980's 3) unplanned release occurred in the SY Tank Farm and extended to the 216-S-23 trench in 1985 4) topographic depression exists along the east side of the S-SX Tank Farm that is conducive to the collection of precipitation runoff and snowmelt, 5) technetium-99 peaks were observed in three groundwater monitoring wells (299-W23-1 -W23-7, and -W23-2) and possibly 299-W22-39 and 299-W22-46, trending from north to south occurring in 1986 1988 and 1989 (Johnson and Chou, 1998), 6) about 500,000 gallons of water was discharged east of the 242-S Evaporator and 7) second transient technetium-99 peak occurred in 299-W23-1 in 1998

The collected data suggest that vadose zone soils initially contaminated by a variety of leaks in the S Tank Farm area were subsequently subjected to a transient, but relatively high volume discharges of water from natural and artificial sources The precipitation versus technetium-99 peak occurrences at the well closest to the source (299-W23-1) suggest about a 1 to 4 year process for contamination to be mobilized in the vadose zone and reach a peak in a nearby monitoring well The period of the peaks (2 to 4 years) indicates the relatively short duration of fluid discharge event that created the groundwater contamination The occurrence of the water main leak in 1996 and the second transient technetium-99 peak in 299-W23-1 occurring in 1998 could be related This suggests that spiking events are repeatable if rapid fluid discharges reoccur and sufficient contamination is present in the vadose zone to be remobilized

4 2 3 Contaminant Releases from Tank 241-SX-115

Key information includes the following 1) three localized zones of high gamma activity were determined near the tank from soil measurements and laterals gamma data 2) relatively dilute fluids (compared to Tank 241-SX-108 supernate) were present in the tank at the time of the leak, 3) size of the leak was one of the largest from the tanks (~50,000 gallons), 4) technetium, nitrate, and chromium groundwater contamination occurred downstream of the Tank 241-SX-115 location in W-23-15 and W-22-46 about 20 years after the leak, and 5) circumstantial evidence provided by the growth of a cottonwood tree just south of SX Tank Farm and the presence of a water line in the area suggest leaking from the water line in the early 1990's sufficient to permit germination and sustain growth in that area

As with the north S Tank Farm area, collected data suggest that vadose zone soils initially contaminated by leaks from Tank 241-SX-115 were subsequently subjected to transient, but relatively high, volume discharges of water from natural sources. Also, the presence of the cottonwood tree indicates a recent underground water source in the area that could act as the driving force to remobilize leaked constituents from Tank 241-SX-115 that are still present in the vadose zone. The rather dilute tank leachate would not be expected to substantially alter the soil chemistry or the change the mobility of the contaminants. The observation of small zones of cesium-137 contamination in soil near the tank bottom suggests that cesium-137 sorption behavior was relatively normal, therefore, strongly reactive with soils leading to rapid sorption ($K_d > 100 \text{ mL/g}$) following discharge into the soil column.

Mobile constituents (technetium, chromium, and nitrate) are likely to behave normally and not be retarded by chemical and physical processes. The concurrent appearance in downstream wells is consistent with this hypothesis. The high technetium-99 peak observed in 299-W23-15 and the small period of the pulse is consistent with a nearby source that contains a large technetium-99 inventory (i.e. Tank 241-SX-115 leak). The technetium-99 concentrations at 299-W22-46 are more complex. Because of the well location, contaminants from both the Tank 241-SX-115 and S Tank Farm sources are likely (see discussion in Section 3.5.2). The technetium-99 and nitrate peaks in 299-W22-46 were longer lasting than the 299-W23-15 peaks, suggesting overlapping pulses. Regardless of the complexity, the timing of the peak occurrence in 299-W-22-46 relative to that in 299-W23-15, and the known direction and rate of groundwater flow are consistent with the technetium-99 concentration pulse occurring in both wells sequentially. Almost 30% decrease in peak technetium-99 concentration occurs within 100 meters travel distance in the unconfined aquifer.

4.2.4 Contaminant Releases from Tank 241-SX-108

Key information includes the following: 1) highly localized zone of very high gross and spectral gamma readings occur in the vadose zone underlying Tank 241-SX-108; 2) compared to Hanford groundwater, large amounts of silicon and aluminum were present in the discharged Tank 241-SX-108 liquid; 3) very low cesium and technetium concentrations were measured around 130 feet and small amounts of technetium-99 and tritium were measured in groundwater directly below this area in Borehole 41-09-39, and 4) only small changes in gamma distribution over time were observed in the contaminated vadose zone.

Leaks from Tanks 241-SX-108, -109, -111, and -112 formed a contamination zone with the greatest concentration of gamma constituents (primarily cesium-137) in the depth range of 60 to 90 feet. The high silicon and aluminum content in leaks from Tanks 241-SX-108 and 241-SX-109 are unique among leaks identified in the S-SX WMA. The constituents are potentially conducive to

substantial chemical reaction with the soils underlying the tanks and could have caused formation of large amounts of amorphous materials, thereby, plugging pores, impeding spreading of the tank fluids, and allowing entrapment of the majority of contaminant mass within the main body of the leaked fluid

The high initial sodium content in the tank supernate solution and gamma indicators of widespread cesium distribution underlying Tanks 241-SX-108 and 241-SX-109 suggest that cesium was fairly mobile within the tank fluid when it was first released into the vadose zone. However, as the tank fluid reacted with soil and water, cesium-137 mobility decreased substantially and perhaps rapidly. If so, the rapid drop-off of cesium concentrations provided by the gamma logging data suggest that cesium is a fairly good indicator of the initial tank fluid distribution and supports the idea that the tank fluids were largely contained within a specific soil volume. The potential for dissolution/precipitation and the minimal technetium concentrations at 130 feet in Borehole 41-09-39 may indicate that technetium-99 is still strongly associated with cesium-137 in this leak. If so, technetium-99 contamination in the groundwater would not result from these sources. However, due to the apparent large source of contamination in this area, future contamination of groundwater in larger concentrations than presently observed is plausible, particularly if a transient fluid discharge (e.g., water line break) migrates through the contamination zone.

5 0 FUTURE GROUNDWATER CONTAMINATION POTENTIAL AND DATA GAPS

In the previous chapters information pertinent to the occurrence of contaminants in RCRA groundwater monitoring wells surrounding the S-SX WMA attributed to tank waste sources was provided. Qualitative hypotheses of events leading to the observed groundwater contamination were derived from the information (Chapter 4) some of which originated in previous documentation (e.g., Johnson and Chou 1998). The primary observations include

- Numerous sources of contamination are present in the S-SX WMA and surrounding region
- Apparent contamination levels are quite varied, with contaminants underlying Tanks 241-SX-108, -109, -111, and -112 being the most concentrated (gamma concentrations are orders of magnitude higher)
- Large short-term discharges of water into the vadose zone occurred previously and could occur again, given current environmental conditions (e.g., permeable tank farm cover, ponding areas, operating water lines) and proposed remediation actions (e.g., retrieval)
- Recent groundwater contamination attributed to tank waste sources occurred after brief travel time (~20 years or less) through the vadose zone and are short-term (~2 to 4 years)
- Some perhaps large fraction of contaminants released from the tank farm infrastructure remains in the vadose zone

To make remediation decisions in the future (e.g., corrective action, retrieval and closure decisions), a more quantitative evaluation of the contaminating events in the past and are ongoing, is required. Estimates of the potential for future contamination are also required. To complete the evaluations, additional site-specific data must be gathered and modeling analyses must be completed that estimate contaminant migration through the vadose zone underlying the S-SX WMA and into the unconfined aquifer. Some of the primary uncertainties are

- Quantity, distribution and mobility of contaminants remaining in the vadose zone that were observed in the groundwater (technetium-99, nitrate, chromium)

- Identification, concentration and distribution of additional contaminants that are present in sufficient quantity in the vadose zone and sufficiently mobile to contaminate groundwater at concentration levels of concern
- Quantification of recharge events that account for the observed transient (2 to 4 years) pulses of contaminant concentration in RCRA monitoring wells
- Site-specific hydrologic properties of the vadose zone soils and the influence of geologic heterogeneities (e.g., clastic dikes) on contaminant migration

The remainder of Chapter 5.0 provides additional options for vadose zone characterization (data collection) and modeling needs and approaches including some that are in progress. Options listed are partly based on recommendations from the Expert Panel and Steering Committee associated with the initial DQO meetings for decommissioning Borehole 41-09-39 and drilling the borehole near Tank 241-SX-115.

5.1 Vadose Zone Characterization Needs and Approaches

Contaminant migration characteristics can be categorized in various ways. A convenient method for evaluating characterization options is to separate characterization needs among three broad topics: 1) source term, 2) hydraulic driving forces, and 3) physical setting. In this Section, the discussion of characterization approaches considered during the DQO process for the S-SX WMA are grouped according to the three broad topics. The source term includes the nature and extent of contamination existing in the vadose zone and mobility of contaminants when exposed to hydraulic driving forces. The driving forces are processes or events that push contaminants through the vadose zone and into the unconfined aquifer. The physical setting includes geologic, hydrologic, and geochemical properties of the vadose zone that affect contaminant migration.

5.1.1 Source Term

The previous discussion in this document established that contamination in the vadose zone underlying the S-SX WMA is unevenly distributed and occurs at varying degrees of concentration. On a relative scale, gamma data indicates the greatest concentration of contaminants is found in a soil volume 70 to 80 feet beneath Tanks 241-SX-108 and 241-SX-109, and the next highest areas of contamination are in the vicinity of Tanks 241-SX-115 and 241-S-104. In addition, the distribution of specific contaminants is not uniform or consistent. Given the multiple areas of contamination, likely variability of contaminant distribution within each broad soil volume and limitations on resources, some

amount of data extrapolation is unavoidable when using the source region as input to a fate and transport model. Consequently, a rationale that identifies the amount of characterization must be developed and decisions related to specific locations for characterization and types of characterization is needed. Several approaches to source characterization that were used or proposed are briefly discussed below.

Soil Sampling and Analysis Collection and analysis of soil samples from contaminated zones are the most direct means of quantifying the type and level of contamination present in the vadose zone at a specific location. Previously completed soil sampling within the S-SX WMA was summarized in preceding chapters. Currently, soil samples are being collected from Borehole 41-09-39 as it is being decommissioned. Borehole 41-09-39 intersects the contamination zone adjacent to Tanks 241-SX-108 and 241-SX-109. A second vertical borehole is being completed near and southwest of Tank 241-SX-115 that will extend to the unconfined aquifer. Sampling over much of the borehole length is planned. A suite of analyses is planned for each of the boreholes. These include analysis for radionuclides and chemicals known to be present or may be present. Other chemicals that are indicative of soil contact with the tank fluids and may influence contaminant mobility will be analyzed. Leaching tests will be run on the soil samples to evaluate water chemistry and mobility of contaminants related to ongoing recharge within the vadose zone. The moisture content will be measured. If the samples are sufficiently large and intact, matric potential, moisture retention, and hydraulic conductivity will also be measured.

Collection of samples from other locations within the S-SX WMA should be considered during the DQO process because some of the information collected from soil sample collection and analysis can not be derived by other methods (e.g., in-situ technetium-99 concentration and mobility). Characterization data that can be derived by soil sample collection and analysis include

Tanks 241-SX-108 and 241-SX-109 Vadose Zone Region

- Technetium-99, nitrate, and chromium vertical distribution and concentrations, particularly in the most concentrated gamma zone
- Contaminants and concentration distributions and identifications
- Cesium-137 distribution versus other contaminants
- In-situ moisture content and hydrologic properties
- Contaminant leachability in the highest concentrated gamma zone

- Mineralogical, chemical reactivity, density and porosity changes in soil from interactions with tank fluid in the highest gamma concentration zone
- Chemistry of extracted pore water (pH inorganic and organic concentrations)
- Cation exchange capacity of soils

Tanks 241-SX-115 and 241-S-104 Vadose Zone Region

- Technetium-99, nitrate and chromium vertical distribution and concentrations
- Additional contaminant and concentration identification and distribution
- Cesium-137 distribution versus other contaminants comparison
- In-situ moisture content and hydrologic properties
- Contaminant leachability in the soil column (indicator of contaminant mobility)
- Chemistry of extracted pore water (pH inorganic and organic concentrations)
- Cation exchange capacity of soils

Soil samples can be collected using a borehole drilling rig or a cone penetrometer. The methods have advantages and disadvantages that must be considered carefully when making decisions to collect additional characterization data. Borehole drilling provides the opportunity to collect relatively large soil samples in a continuous and discrete fashion with depth. Samples can be collected throughout the vadose zone and in the unconfined aquifer, if desired. Borehole drilling was utilized many times, although some desirable techniques designed to minimize drag down are less routine.

There are disadvantages to borehole drilling approach. Borehole drilling, soil sampling and analysis are the costliest characterization methods available to the point that a substantial portion of an annual characterization budget can be consumed by one borehole. Within the Tank Farms, underground infrastructure and tanks limit the locations available to drill a borehole. Sampling techniques are less favorable for collecting large samples when sampling in highly radioactive zones is required. Currently, a sidewall sampling technique is being implemented as part of the Borehole 41-09-39 decommissioning effort. With the

sidewall sampling technique, the borehole casing is first placed in the borehole and gamma readings are measured as a function of depth to determine the zones of highest contamination. Soil samples are taken from the sidewalls using a flexible boring tube as the casing is raised. This technique is safer for the worker because it predetermines the most radioactive samples and limits the size of the sample.

The potential advantage of the cone penetrometer approach is that the cost of sample collection may be lower than borehole drilling, and that soil samples can be collected in several locations from one setup. The disadvantage of the cone penetrometer method is that it was not used in a production mode in the tank farms; therefore, real costs and success rate are not well known. Also, the sample size that can be collected is smaller than the borehole sample and the feasible depth of penetration may be limited to soils with large cobbles.

The cone penetrometer may be more effectively utilized for investigating shallow contamination sites (e.g., between S-SX Tank Farm), borehole drilling for investigating deeper contamination sites (Tanks 241-SX-108 and 241-SX-109) and interrogating the deep vadose zone for evidence of contaminant pathways between tank waste sources and contaminated groundwater. Another option to consider is extending existing drywells deeper into the vadose zone to identify deep vadose zone contamination.

Gamma Logging An extensive amount of gamma logging was completed within the S-SX WMA. Gross gamma logging ceased in 1994 and spectral gamma logging, which began in the early 1990s, is ongoing. From the data, locations and relative intensities of gamma contaminants, primarily cesium-137, were identified. Also, because gamma measurements were frequently taken over time in the same locations, cesium-137 movement in the soil column was detected. Reinstatement of gross gamma logging extends the currently available database, thereby enabling the evaluation of gamma movement over a greater period of time. Similarly, limited continuation of spectral gamma logging within the S-SX WMA extends the spectral gamma database developed over the last 5 years.

The advantages of gamma logging include techniques that provide the most extensive interrogation of the contaminated soil volume in the vadose zone, best historical record of contaminating events, and are easy to deploy once boreholes (vertical and laterals) are in place. The disadvantages include inaccessibility of contamination zones (e.g., zones directly under numerous tanks) and measurements largely confined to a small area around a borehole (typically a few inches) that make extrapolation between data points uncertain. Also, the distribution of non-gamma emitting radionuclides and chemical contaminants are not measurable and additional information (e.g., soil sampling in the contamination zone) is needed to determine if some correlation between gamma distribution and other contaminants is feasible.

Opportunities for additional gamma data collection include any new boreholes or cone penetrometer holes, existing dry wells and laterals. Gamma logging was utilized during the decommissioning of Borehole 41-09-39 and is being used during the drilling of the borehole near Tank 241-SX-115. For cone penetrometer holes, gamma logging may be useful as a screening tool to locate contaminated zones for future sampling during placement of the hole. Long-term use of the hole would be required to permit collection of high quality gamma data, which requires accurate control over the movement of the gamma probe as a function of depth. The laterals underneath SX tanks are currently inaccessible and require an evaluation of necessary actions to reopen them.

Neutron Logging, Neutron Activation, Electrical Resistance Tomography (ERT) and Thermal Measurements Neutron logging provides an indication of relative moisture content in soil and was used with spectral gamma logging. The data are qualitative and provide an indication of zones that retained greater amounts of liquid than surrounding soils. The information combined with gamma data may improve the understanding of contaminant plume extent. The advantage of neutron logging is that measurements can be taken simultaneously with gamma measurements and are inexpensive to obtain. The disadvantages of neutron logging are 1) measurements are relative and can only be made quantitative with accompanying soil measurements, and 2) increased moisture content may not indicate interaction with tank fluid (i.e., natural variations in particle size distribution impose variations in moisture content, lenses with a high fine particle size fraction tend to retain moisture in the pore structure).

Neutron activation and ERT are two techniques that have the capacity for detecting the occurrence of tank fluid constituents in the vadose zone. Neutron activation logs could detect anomalous concentrations of salts, calcium, and aluminum in soils. ERT could detect anomalous salt concentrations. The information combined with gamma data could provide further definition of contaminant plume distribution in the vadose zone. Neutron activation equipment can be deployed in the same fashion as gamma and neutron moisture probes and have the same advantages and disadvantages of location availability. However, an important disadvantage is the lack of use in the tank farms or on-site in a production mode. ERT is more difficult to deploy because equipment must be placed in the vadose zone using some type of hole emplacement method that allows direct contact with surrounding soil, therefore, currently available drywells and boreholes or drilling new holes must be adapted.

Temperature readings can be taken in any borehole and may provide additional information regarding gamma and tank fluid distribution within the vadose zone when coupled with computational analyses designed to estimate temperature distribution as a function of contaminant distribution (primarily cesium-137). Ideally, temperature readings would be taken with instrumentation directly in contact with vadose zone soil rather than in cased boreholes or in contact with

casing This approach would be dependent on removing the casing during the borehole decommissioning effort. At present, the majority of boreholes are drywells used for gamma probes. A large number of the holes are unlikely to be decommissioned. Measurements on the casing surface are difficult to extrapolate to soil temperatures but are cheap to measure and provide a qualitative indication of the extent of contamination.

5.2 Contaminant Driving Forces

The primary driving forces that move contaminants through the vadose zone are hydraulic. As described previously, the sources of fluids discharged into and the resulting recharge through the vadose zone are varied. Quantitative site-specific data to measure fluxes or recharge are limited to the measuring the matric potential values on soil samples taken from Borehole 41-09-39 (Myers et al 1998). Consequently, estimates of effective recharge through the vadose zone are qualitative and the ability to quantitatively model contaminant releases that occurred is hindered. Three standard measurement techniques are feasible: 1) matric potential, 2) moisture retention curves and hydraulic conductivity measurements on retrieved soil samples and 3) emplacement of tensiometers in the soil column, and lysimeters in the soil column.

Measured matric potential in combination with moisture retention data and unsaturated hydraulic conductivity can be used to quantify recharge estimates in a soil column. When matric potential is measured in soil samples at different depths, a matric potential gradient can be defined that indicates the direction of water movement. The advective flow rate can then be estimated if the unsaturated hydraulic conductivity is known. Measurement of the properties is inexpensive and rapidly performed if soil samples are available and sufficiently undisturbed during extraction from the soil column. Confidence in estimates of recharge rates using this approach is enhanced as greater numbers of samples are analyzed in a greater number of locations. Samples in undisturbed sediments below the tank bottoms are more indicative of actual recharge. One disadvantage of measuring matric potential is the high cost of collecting deeper representative samples. Another disadvantage is that matric potential measurements reflect recharge conditions at the time of sampling. Given the *variety of transient fluid discharges into the soil column, recharge rates can change over time, which adds uncertainty to recharge estimates.*

Another option for measuring matric potential is to install tensiometers in-situ at depth. Using data from tensiometers avoids the issue of whether the relevant properties of sampled soils were altered during retrieval. Tensiometer data can be taken over time, allowing an evaluation of the degree of variation that may occur due to seasonal infiltration and leaks from the tank infrastructure. Development of a tensiometer-derived database is limited to the number of devices that can be installed. Installation is dependent on borehole drilling to reach the deeper locations. The benefit derived from a more representative data

base must be balanced against the additional cost of installation. The database is enhanced by increasing the time period over which measurements are taken.

Lysimeters were used extensively on the Hanford Site to measure recharge rates through a variety of soils and engineered barriers from natural and enhanced precipitation infiltration sources (Gee et al. 1992). Typically, the rate of recharge is measured by periodically collecting the water that passes through the media of interest. Some of the data were collected for media similar to current tank farm covers and used to estimate average recharge. However, site-specific data were not collected. Lysimeters are a simple and standard data collection technique that could be placed near the tank farm boundary in tank farm cover materials. Once recharge rate data is collected, site-specific seasonal and average recharge rates from precipitation would be quantified.

5.3 Physical Setting

Characterization of the physical setting consists of data collection to define geologic, hydrologic, and geochemical properties of the vadose zone that influence contaminant migration. The geologic database is the most complete because of the numerous well log descriptions that were developed over time, not only in and around the S-SX WMA, but also across the 200 West area. Most recently, split spoon samples from Borehole 41-09-39 below 130 feet were characterized for stratigraphic correlation and particle size distribution. The existence of geologic heterogeneities such as, clastic dikes are known to occur within the vadose zone, although precise locations are unknown. Features, such as, cross bedding were noted in well logs. Similar characterization was completed for additional boreholes during fiscal year 1999 (e.g., new borehole near Tank 241-SX-115 and three RCRA boreholes east of the SX Tank Farm) and planned for future boreholes.

Hydrologic data includes moisture content, matric potential and unsaturated hydraulic conductivities. Site-specific data are unavailable except for moisture content in RCRA monitoring wells and matric potential data for the split spoon samples taken from Borehole 41-09-39. Compared to contaminated soil samples retrieved from boreholes inside the tank farm, soil samples collected from RCRA monitoring wells will provide the best opportunity for collecting high quality hydrologic property data. The RCRA samples will be larger and less disturbed. The quality of the data are always limited because only a few small samples relative to the total soil volume of interest can be collected. Some disturbance of the materials is unavoidable during retrieval, leading to uncertainty in the accuracy of the measurements. Additionally, the data must be used to represent larger soil volumes in modeling analyses. Despite the drawbacks, no other practical means of quantifying vadose zone hydrologic properties is available.

Geochemical properties affecting contaminant mobility includes pore water chemistry mineralogy and cation exchange capacity. Standard tests are routinely used to measure the properties. With hydrologic property measurements, the quality of measurement is largely dependent on the integrity of the soil sample. A comparison of the properties in contaminated zones (e.g., Tanks 241-SX-108 and 241-SX-109 contamination zone) near the source of contaminant release with soils having minimal interaction with tank fluids is of interest due to differences in contaminant mobility because of tank fluid-soil interactions.

5.4 Modeling Approaches

A modeling approach and computer code or codes is needed to simulate past, current, and potential groundwater contamination events due to migration of contaminants from the S-SX WMA sources. A numerical simulation of past contamination events is useful in the event that similar processes leading to the observed contamination recur. If the processes can be quantified, the adequacy of remediation actions to prevent or mitigate the processes can be more effectively evaluated.

To date, site-specific modeling of contaminant transport through the vadose zone underlying the S-SX WMA is not available. Vadose zone modeling was conducted only for the AX Tank Farm (DOE-RL, 1998). The model should simulate critical environmental properties and processes hypothesized to influence contaminant migration. These include:

- Short term (years or less) transient recharge
- Partially saturated flow in the vadose zone coupled to saturated flow in the adjacent unconfined aquifer out to a monitoring well
- Variable chemical reactivity of contaminants
- Geohydrologic heterogeneities in the soil column (e.g., clastic dikes)
- Contaminant concentration histories at various potential compliance boundaries (e.g., WMA boundary, 200 Area boundary, and future Site Used Working Group Exclusion and Buffer Zone boundaries)

A numerical modeling approach is needed that can represent release through the vadose zone into the unconfined aquifer. Numerical computer codes are available that were previously used by Hanford projects to the modeling. These include VAM3D-CG for solid low-level waste burial grounds (Wood, et al., 1995, 1996), PORFLOW for an immobilized low-level tank waste disposal facility (Mann

et al , 1998), and STOMP for the composite analysis (Kincaid, et al 1998) Far field modeling in the unconfined aquifer can be addressed by the site wide groundwater model (CFEST)

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APPENDIX A

SUPPORTING STRATIGRAPHIC INFORMATION

Appendix A provides the detailed stratigraphic cross sections (Section A 1) and an evaluation of the uncertainty (Section A 2) in stratigraphic unit/depth assignments used to construct the revised subsurface physical model of S-SX Waste Management Area (WMA)

A 1 Stratigraphic Cross Sections

Section A 1 contains five geologic cross sections through or in the vicinity of the S-SX Tank Farm area. Figure A1-1 shows the locations of the cross sections present in Figures A1-2 to A1-6. Two cross sections are west to east (A-A and B-B) and three are north to south (C-C', D-D', and E-E')

Drilling logs, archived samples, and geophysical logs are the principal data sets used to construct the cross sections. In addition, numerous reports describing the geology of the S-SX Tank Farm area and vicinity are available and were used in the present effort (Price and Fecht, 1976a, 1976b, 1976c, Tallman et al., 1979 DOE, 1988, Lindsey, 1991-1995, see main text reference section). Archived natural gamma geophysical logs from boreholes in the S-SX Tank Farms and surrounding area were located and the logs incorporated into the interpretations. The previously unused geophysical logs included were from surrounding waste disposal sites obtained prior to discharge of effluent and provide an invaluable source of information for stratigraphic correlation.

Initially, well-site geology logs or drilling logs were examined and compared to geophysical logs from the boreholes. The quality of drilling logs varies because many wells and boreholes were drilled without a geologist present at the site. In addition, well logs are constrained by the drilling method and by sample recovery. Sample retrieval in the vadose zone is difficult and typically does not allow the exact depth of samples and contacts to be determined. Samples are archived in 5-foot intervals, thus, can introduce as much as a 5-foot uncertainty in lithology in either direction. Changes in drilling-blow counts provide additional information on depth of lithology changes because of differing sediment resistance to drilling.

Geophysical logs (e.g., gross gamma ray) provide a continuous record of the borehole and, in most cases, allow more precise placement of geologic contacts. Geophysical logs can show subtle lithology differences because of differing amounts of natural gamma-ray emitters (most commonly potassium-40). Gamma-ray logs are proportional to clay and silt abundance and record changes in grain size. When geophysical logs are compared to the well-site geology logs and archived samples, the uncertainty in the depth of lithologic changes is greatly reduced. The newly located natural gamma-ray logs allowed older wells for which

only drilling logs were previously available to be reinterpreted and correlated with newer wells. This greatly increased the confidence in locating stratigraphic contacts, especially the Plio-Pleistocene-Hanford contact. In addition, the signature of the geophysical response from the borehole can provide an additional tool for correlating stratigraphy between boreholes. Although the geophysical logs were important tools for developing the stratigraphy and correlations, for presentation purposes only the unit contacts determined from the drilling logs and geophysical logs are shown on these cross sections.

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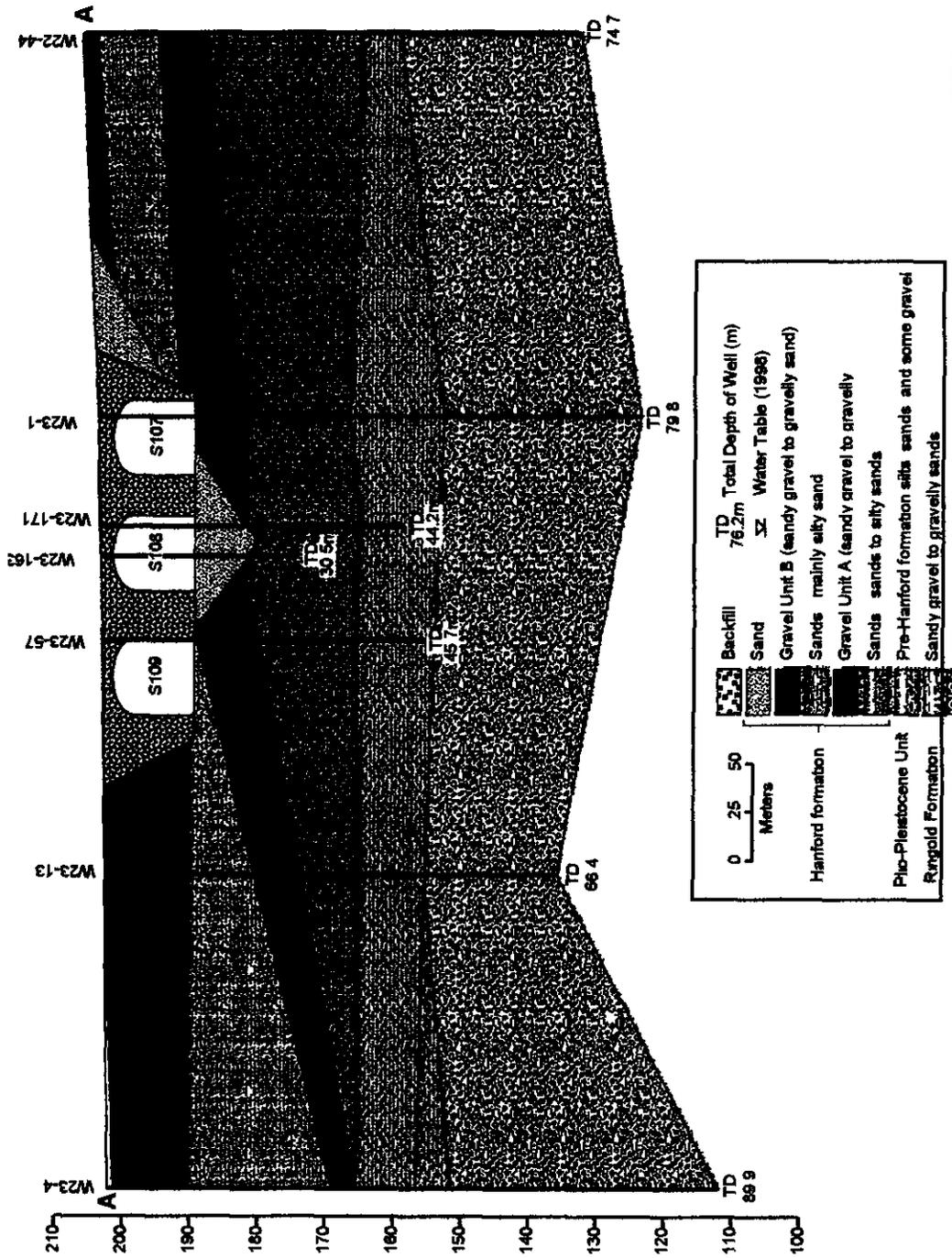


Figure A1-2 Geologic Cross Section A-A'

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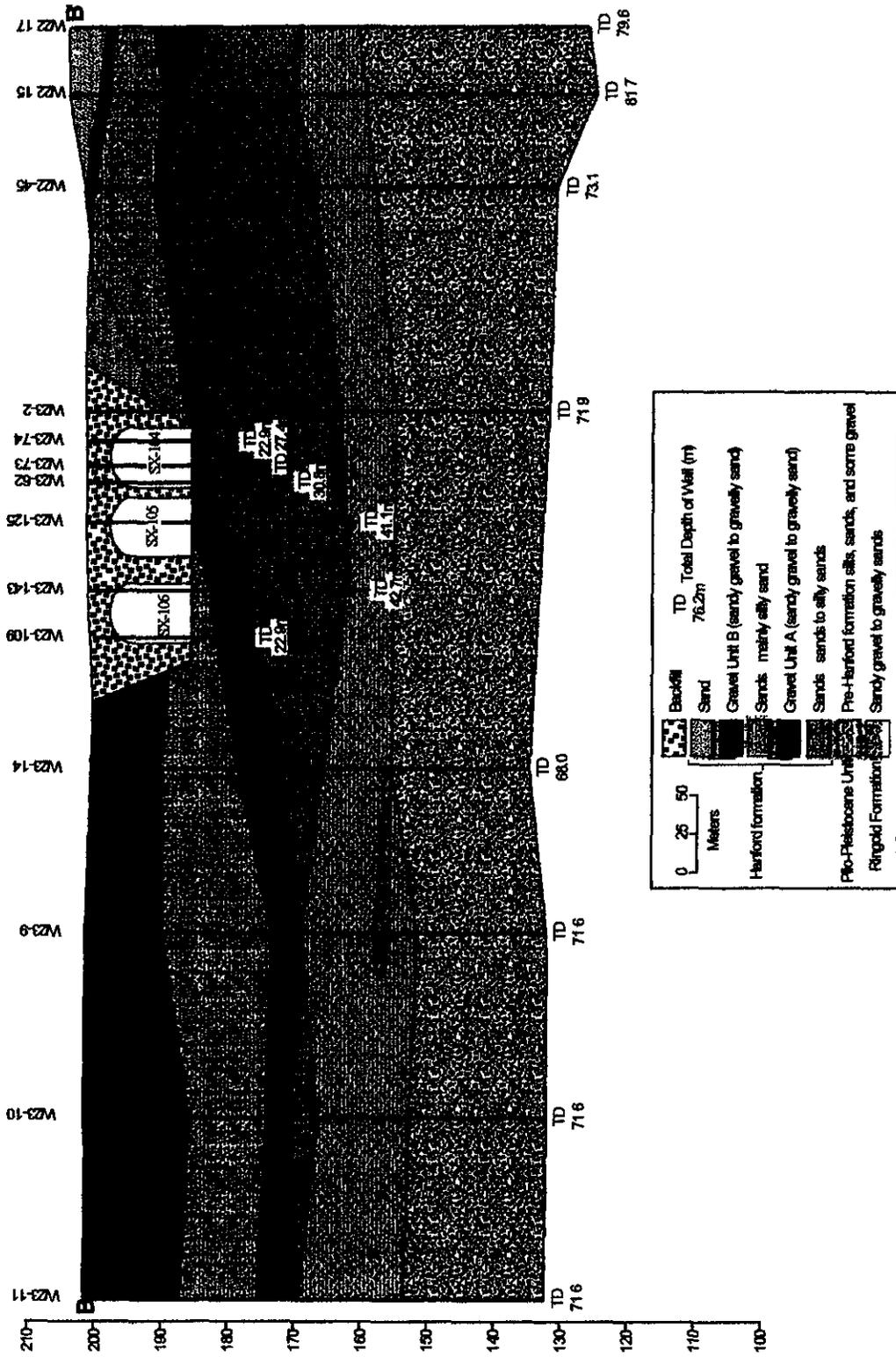


Figure A1-3 Geologic Cross Section B-B'

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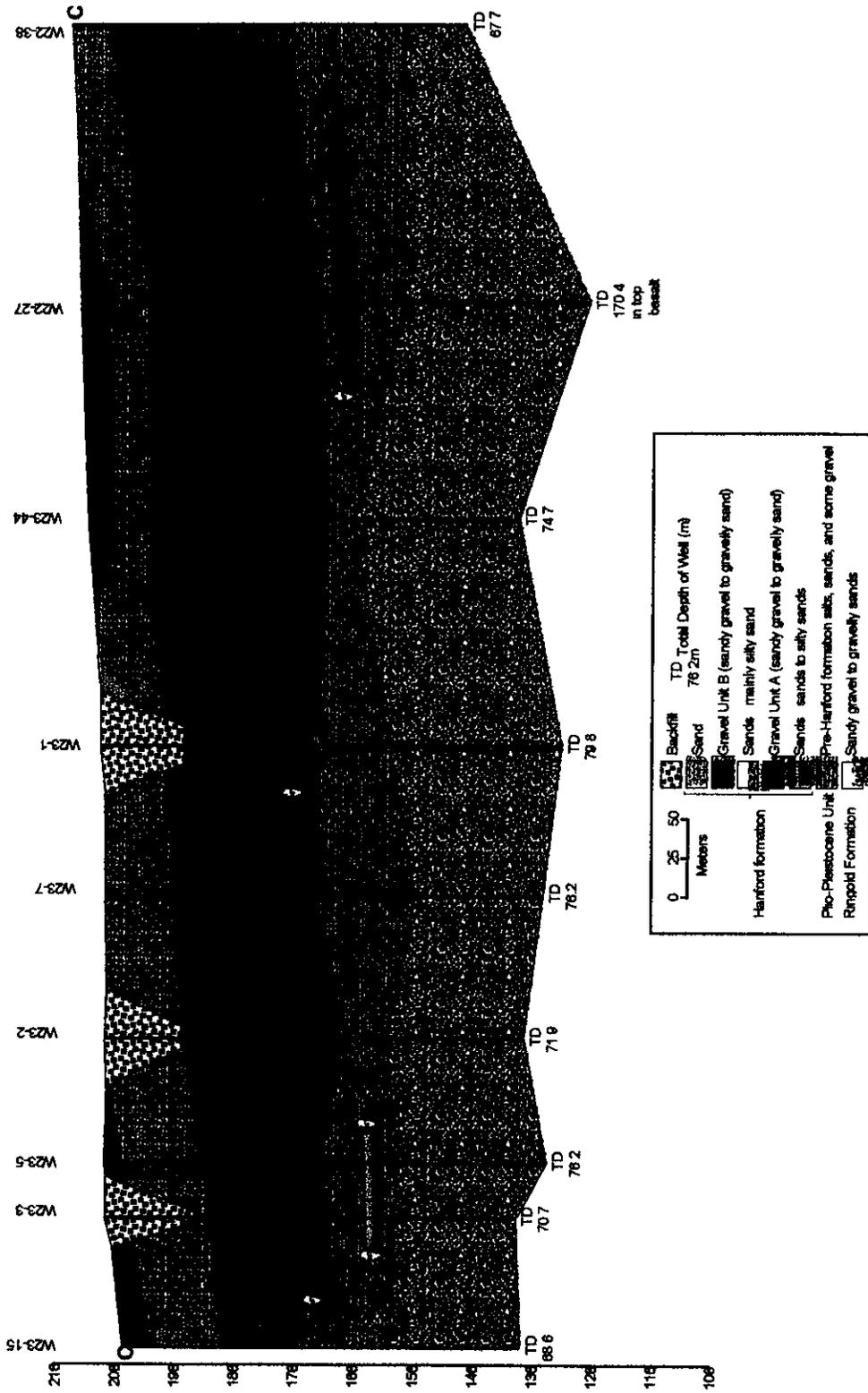


Figure A1-4 Geologic Cross Section C-C'

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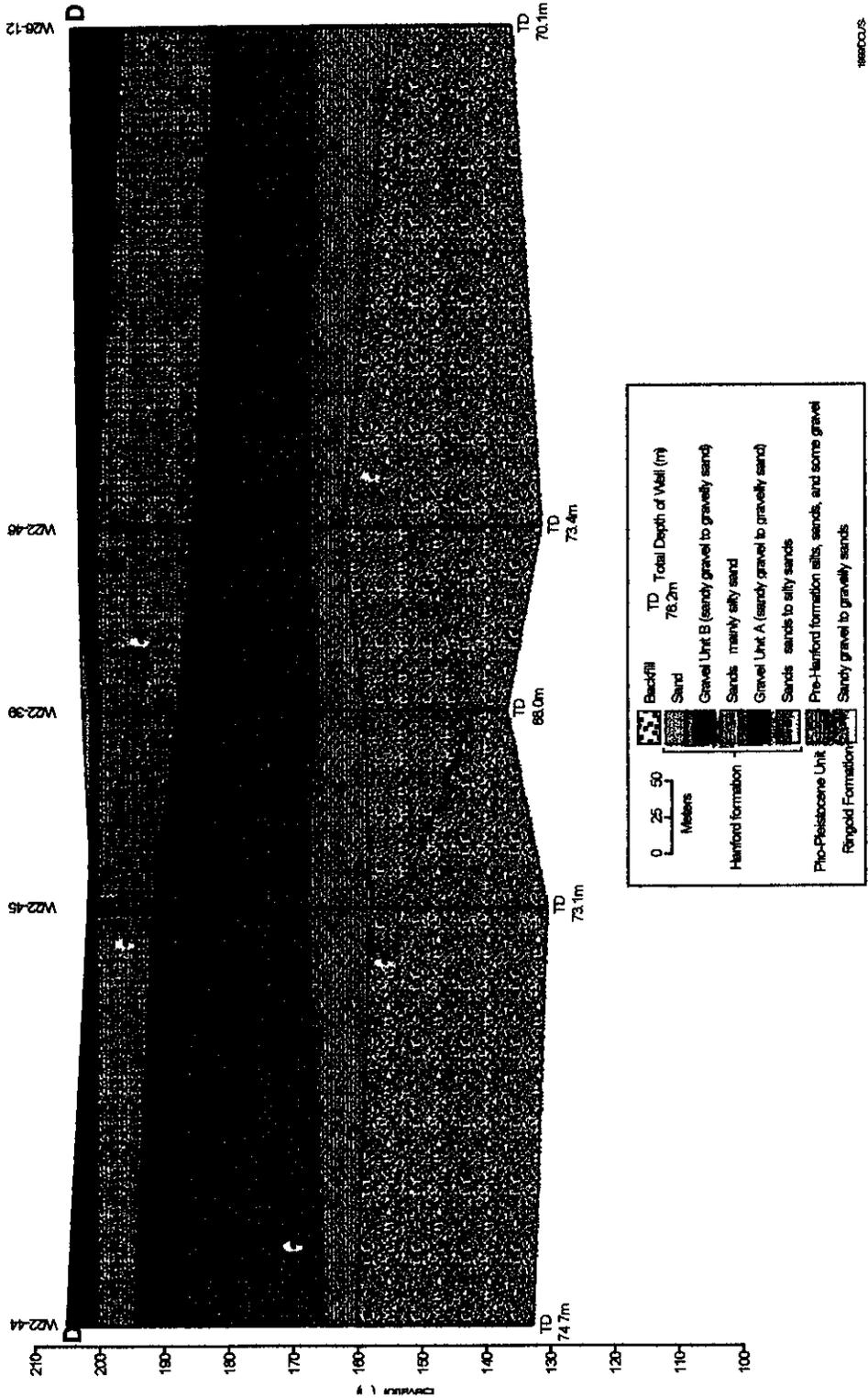


Figure A1-5 Geologic Cross Section D-D'

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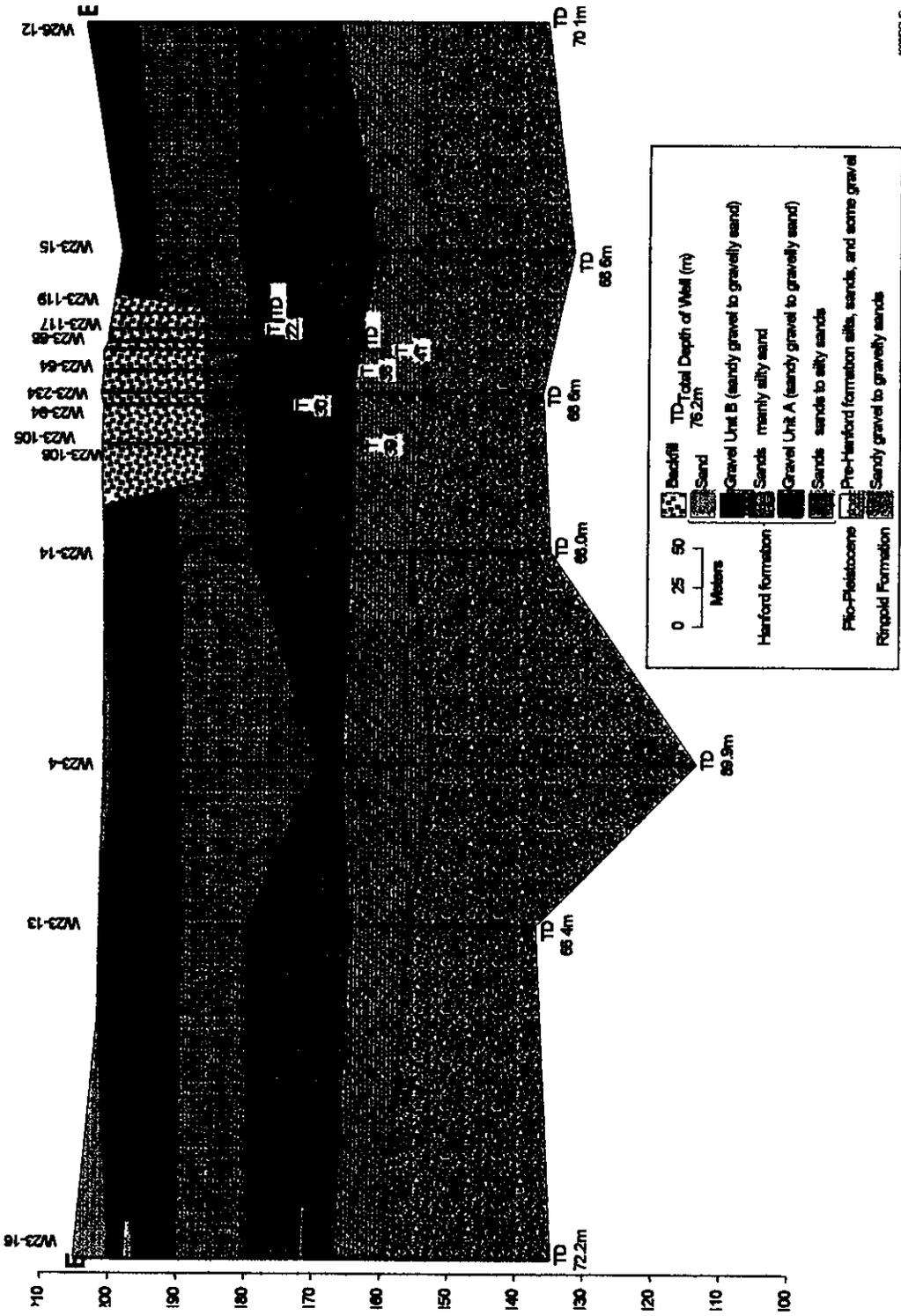


Figure A1-6 Geologic Cross Section E-E'

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A 2 Uncertainty Evaluation

The principal sources of uncertainty in borehole data are related to the drilling technique logging of the borehole and sample collection. Subtle differences between stratigraphic units, such as, silty sandy layers of the Hanford formation and the underlying Plio-Pleistocene unit make identification of the contact difficult. The quality of the drilling/geology logs, archived samples and use of geophysical logs become crucial to reducing this type of uncertainty.

In addition to the uncertainty in borehole data, uncertainty exists in the geometric shape of the sediment body. Because of the nature of the cataclysmic flooding that produced the Hanford formation, very few analogs are available to compare the geologic model at the S-SX Tank Farm to a field locality. Borrow pits in the Pasco Basin may provide a glimpse into the geometric shape of a sediment body, but often the nature of the sediment body must be interpreted from boreholes.

A 2.1 Drilling Techniques

Most boreholes at and near the S-SX Tank Farms were drilled using cable tool techniques or air rotary techniques. Cable tool drilling was the standard technique from earliest drilling at Hanford because drilling can be performed without adding water. The drill tool advances by use of drive barrel or hard tool and driven temporary casing. The technique generally provides good sample control and is successful. More recently, in uncontaminated areas air rotary was the preferred technique. There are several disadvantages to the cable tool drilling.

- Sample size is limited
- Samples can be difficult to retain in the drive barrel, especially samples from very dry zones
- Gravels are not easily retrieved because they are not easily retained in the drive barrel
- The depth of the sample is difficult to control
- Cemented units or large gravels must be drilled with a "hard tool" which breaks up to sample and alters the grain size distribution of samples

Prior to the 1980s most boreholes were drilled without a well-site geologist to log the samples. Thus, the only records of early drilling are drilling logs that vary in the quality of the sample description. The quality of the geology logs may also vary from borehole to borehole. For example, a geologist new to the site will recognize the major sediment changes in drill cuttings, but may not recognize the subtler changes that also represent changes in stratigraphy.

Many boreholes were completed without the benefit of being geophysically logged. Geophysical logging is an important tool for determining the depth of lithologic changes. Geophysical logs show subtle lithology differences stemming from differing amounts of natural gamma-ray emitters (most commonly potassium-40). Gamma-ray logs typically are proportional to clay and silt abundance and record changes in grain size. When geophysical logs are used along with the well-site geology logs and archived samples, the uncertainty in the depth of lithologic changes is greatly reduced.

A 2 2 Borehole Location and Coverage

Borehole coverage is usually dictated by factors other than addressing a geologic problem (e.g., installation of groundwater monitoring wells and vadose zone investigations of tank leaks). Therefore, the spatial coverage of boreholes is generally inadequate to address geologic descriptions on an appropriate scale.

A 2 3 Sampling

Sample retrieval is often difficult and sample quantities are limited. Sample recovery from vadose zone boreholes is often difficult because the samples are typically dry and are not easily retained in the drive barrel. Thus, the incomplete lithologic record adds to uncertainty in visual stratigraphic description. As indicated above, the grain size of the sample can also be affected by the drilling technique. Such as, "hard tool" drilling or sonic drilling increase the fine-grained portion of the sediment samples.

In order to perform certain tests, samples from several depths must be composited. Also, certain tests performed on samples may also destroy the integrity of the sample. For example, in the past, particle-size testing resulted in loss of fines when the samples were returned to the Hanford Geotechnical Sample Library.

A 2 4 Discussion on Quality of the Data

For the reasons considered above, the quality of the borehole data available for the Hanford Site is variable. This Section discusses how the uncertainty of the data was factored into the geologic model.

Drilling All except seven boreholes were drilled using the cable tool method. The seven exceptions were drilled using air rotary techniques. Both techniques provide cuttings that can be logged. Both methods provide samples and, if the drilling technique is recorded, sample quality can be easily factored in to the geologic interpretations (e.g., the cable tool method uses a hard tool that breaks up gravel, thus particle size distributions in gravels are in error and not usable for S-SX Tank Farm geologic interpretations).

Geology and Drilling Logs The main factor affecting data quality is the drilling log. Prior to the late 1970s, the geologist did not sit the well during drilling, thus, logs are poor to fair. Some drillers were very good at describing the sediments drilled, but even then only the major stratigraphic changes or properties are recorded. The best quality well logs are those written by experienced geologists. The seven Resource Conservation and Recovery Act (RCRA) wells (299-W22-39, 299-W22-44, 299-W22-45, 299-W22-46, 299-W23-13, 299-W23-14 and 299-W23-15) have the highest quality geologist logs for the S-SX Tank Farms.

Geophysical Logs Geophysical logging techniques improved over the years, but even an older gross gamma-ray log from a borehole is an invaluable piece of information. Probably the poorest quality interpretation is from a borehole with only a drilling log. The borehole logged by a geologist provides a higher quality interpretation and a borehole with a geology log and a gross gamma-ray log offer the highest quality information for interpretation.

The newly located natural gamma-ray logs, for which only drilling logs were previously available, allowed the older wells to be reinterpreted and correlated with newer wells. This greatly enhanced the confidence in locating stratigraphic contacts, especially the Plio-Pleistocene-Hanford contact. In addition, the signature of the geophysical response from the formations provided an additional tool for correlating stratigraphy among boreholes.

Geologic Model Uncertainty in the geologic model is the sum of all the uncertainties. In order to reduce the uncertainty in the geologic model, data sets are prioritized (weighted) to ensure that the main features of the model are based on the highest quality data. Lower quality data can be used but given less weight.

The first priority data used for this model were for the seven RCRA wells with higher quality geology logs, good samples, and geophysical logs. The location of the wells provided reasonable spatial coverage of the S-SX Tank Farms. Next data for boreholes and wells with gross gamma-ray logs and drilling logs were used. The newly located natural gamma-ray logs served as a valuable aid in interpreting drilling logs. The wells were close enough to the RCRA wells that a direct comparison of the geophysical logs could be made. It was the newly located gross gamma-ray logs that allowed confirmation of the initial interpretation from the seven RCRA wells. The lowest quality data sets were for boreholes and wells with only drilling logs. These were used to help control contacts and/or for confirmation.

Building of the model followed a series of steps that were designed to ensure the data were used properly. First, the main stratigraphic units and contacts were located in the RCRA boreholes. This was done by comparing the geology log with the gross gamma-ray log and picking the contact. In the case of the RCRA

boreholes chip samples were examined to confirm stratigraphic units and lateral changes in the percentage of silt sand and gravel. Next, boreholes with drilling logs and gross gamma-ray logs that lie between the RCRA wells were examined. The selection of contacts in these wells was based more on the gross gamma-ray signatures and less on the drilling descriptions. The gross gamma-ray logs for the wells were compared to the gross gamma-ray logs from the RCRA boreholes. This was particularly important for selecting the contact between the Hanford silty sands and the Plio-Pleistocene unit.

In this way, the model was built around the highest quality control points in incremental steps. At each step the contacts and the nature of the sediments comprising a layer were determined and compared to adjoining wells for changes in percentages of silt, sand, and gravel. Once the model was assembled, a geologist familiar with the Hanford stratigraphy and the geophysical logs checked the stratigraphic interpretations and contacts. The results of this process were presented in a series of cross sections in Section A 1.

A 2.5 Geostatistical Approach to Quantify Uncertainty in Borehole Stratigraphy

Section A 2.5 describes two approaches used to quantify the uncertainty in S-SX Tank Farm stratigraphic correlations. Both approaches used a statistical analysis of the geophysical logs from boreholes 299-W22-39, 299-W22-44, 299-W22-45, 299-W22-46, 299-W23-13, 299-W23-14, and 299-W23-15 to correlate stratigraphic units between boreholes. In one approach, the geology contacts were included and tested. In the second, no prior correlation was made and the analysis was allowed to choose the best statistical correlation. The first approach found good levels of correlations between wells using the geology contacts. Correlations among stratigraphic units for adjacent boreholes derived using the second approach were found to be relatively consistent with the results obtained using the geology contacts. Both approaches indicated that the stratigraphy in the S-SX Tank Farms is relatively consistent. However, the greater the distance between two boreholes, the lower the correlation coefficients became. The principal factor that caused lower correlations between boreholes was changing amounts of silt, sand, and gravel in the sedimentary units.

Geophysical Log Correlation The correlation between boreholes was quantified by calculating the cross-correlation of the existing geophysical well log data. Seven RCRA well logs surrounding the Tank Farm were selected (Table A2-1). The wells have high quality geology logs and geophysical logs, and provide good coverage of the tank farms.

The values of the geophysical well logs were digitized at the interval of 1 foot, generally beginning from 2 feet to 240 feet below ground surface. The effects of casing overlaps were removed to ensure that only geologic factors were influencing the geophysical logs, thus the correlation coefficients.

The correlation coefficients between pairs of wells using the entire digitized geophysical log for each well are listed in Table A2-1. There is a good linear correlation between most pairs of well logs (at an $\alpha = 0.01$ significance level, Hogg and Tanis, 1993), except, when a well is paired with well 299-W22-44. The lower correlations seen in wells paired with borehole 299-W22-44 are expected because this borehole is located in the northeast part of the tank farms where the Hanford sandy gravels are becoming less gravelly and more sandy. The change in texture is reflected in changes in the geophysical log in response to a more sandy-like unit compared to the intercalated sands and gravels elsewhere at the S-SX Tank Farms. This change is most evident (low correlation) between well 299-W22-44 and 299-W22-14 as indicated in Table A2-1 (e.g. correlation coefficient of 0.514). The two wells are located the maximum distance apart in the S-SX Tank Farm area and reflect slightly different depositional environments.

Table A2-1 Correlation Coefficients Between Pairs of Geophysical Well Logs

	W23-13	W23-14	W23-15	W22-39	W22-44	W22-45
W23-14	0.789					
W23-15	0.672	0.656				
W22-39	0.644	0.634	0.713			
W22-44	0.668	0.514	0.655	0.672		
W22-45	0.622	0.596	0.742	0.762	0.677	
W22-46	0.736	0.671	0.712	0.750	0.646	0.700

Stratigraphic Correlation Two approaches were used to examine how well the geophysical logs could be used to correlate stratigraphy between the wells. In the first approach, the main correlation points in the geophysical well logs were based on the geological interpretation of the borehole stratigraphy. The four layers described in Section 1 were used as primary correlation points. The layers are: 1) top of the Ringold gravels, 2) top of the Plio-Pleistocene unit, 3) top of gravelly unit B, and 4) bottom of gravelly unit A.

Starting with the geologist's correlation points in the wells, a search radius of 15 vertical feet and a window of 21 vertical feet centered at the correlation points were used to compare the two wells' geophysical logs. The search radius and window values ensured that random noise in the geophysical logs would not influence the correlations. The correlation coefficients were then calculated for the values within the window and the search radius. By comparing the correlation coefficients in one well with the neighboring locations in each of the other wells located within the search radius, the best-correlated locations were determined and listed along with the original correlation points (Table A2-2).

Table A2-2 Correlation Coefficients of Well Logs with Original and Local Optimal Correlation Points

Well-1 Well-2	Unit	Well-1	Well 2		Correlation Coefficient	
		Depth ft	Depth ft	Opt Depth	Original depth	Optimal Depth
W23-13	B	39 6	34 3	31	0 722	0 762
W23 14	A	72 4	77 0	84	-0 414	0 544
	PPU	124 9	122 9	122	0 463	0 602
	RG	154 445	152 445	157	0 032	0 727
W23-14	B	34 329	25	20	0 603	0 825
W23 15	A	76 982	71 263	60	0 115	0 386
	PPU	122 916	123 759	119	0 138	0 578
	RG	152 445	150 007	150	0 81	0 81
W23-15	B	20	20	20	0 756	0 756
W22-46	A	71 263	61 015	64	0 718	0 847
	PPU	123 759	120 073	126	0 43	0 466
	RG	150 007	136 5	140	0 519	0 566
W22-46	B	20	20	21	0 521	0 523
W22 39	A	61 015	44 891	53	-0 516	0 756
	PPU	120 073	120 354	123	0 47	0 699
	RG	136 5	149 883	148	0 363	0 592
W22-39	B	20	20	25	0 429	0 574
W22-45	A	44 891	33 048	43	0 115	0 256
	PPU	120 354	118 354	120	0 557	0 736
	RG	149 883	147 883	135	0 478	0 58
W22-45	B	20	20	20	0 729	0 729
W22-44	A	33 048	35 205	26	-0 304	0 362
	PPU	118 354	133 635	129	0 484	0 572
	RG	147 883	189 412	185	0 393	0 564
W22-44	B	20	39 61	46	0 369	0 702
W23 13	A	35 205	72 42	84	0 345	0 583
	PPU	133 635	124 916	110	0 478	0 584
	RG	189 412	154 445	170	0 221	0 587
W23-14	B	34 329	20	19	0 604	0 756
W22-45	A	76 982	33 048	39	-0 137	0 325
	PPU	122 916	118 354	120	0 547	0 689
	RG	152 445	147 883	157	0 355	0 541

Note The number of values within a moving window centered at the listed locations along the well logs is 21 Therefore the lowest value for Gravelly unit B will be 20
Unit Designations are B = Bottom of Gravelly unit B A = Top of Gravelly unit A PPU = Top of Plio-Pleistocene unit RG = Top of Ringold Gravels

The second approach was to use all depths in one geophysical well log as potential correlation points rather than using a limited search radius and window. Then, as described in the first approach, the correlation coefficients in one well compared with potential correlation points in the other well were calculated. The only difference is that no prior correlation points (the geology contacts) were assigned, and the detailed cross-correlation between all locations in two well logs were obtained. This approach resulted in a list of correlation coefficients.

However, when using the second approach, the list of correlations should be carefully checked against the geologic units. A threshold value can be used as a cutoff to screen the low correlation coefficients. A continuous high correlation is preferred in screening, indicating vertical continuity with a geologic unit between the two well logs.

A 2 6 Results

The two approaches described above were applied to the geophysical well log data from the seven RCRA wells. Table A 2-2 lists the correlation coefficients between the geology correlation points and locally optimal correlated point within the search radius of 15 vertical feet. As might be expected in sediments that have lateral changes in silt, sand, and gravel contents, the prior correlation points were not necessarily the best points in terms of correlation coefficients. Borehole 299-W22-44 is a good example. The Hanford gravelly units become increasingly more sandy in the area penetrated by borehole 299-W22-44. The results might better define the extent of the dominant lithologies or percent silt, sand, and gravel in a geological unit.

In the second approach, the correlation coefficients for all points in one entire well against a second well were calculated for the seven well logs. Analysis results indicate that sequential depths with high correlation coefficients in one major stratigraphic unit in one well are correlated to sequential depths with high correlations of the same major stratigraphic unit in the paired well. As with well 299-W22-44 in the first approach, the correlations are not as high because of changes in the percentage of silt, sand, and gravel across the S-SX Tank Farm area.

A 2 7 Conclusions

Both approaches used to evaluate stratigraphic/depth uncertainty indicate that the stratigraphy in the S-SX Tank Farms is relatively consistent across the area. The geophysical logs have similar shapes, which indicates a coherent and predictable stratigraphy at the tank farms. Geology correlations based on a combination of geology logs and geophysical logs typically include good correlation coefficients when analyzed using the geophysical logs alone. Using 21 samples for calculating the correlation coefficients, the test of correlation

indicated that the correlation coefficients higher than 0.369 and 0.503, for original depth and optional depth were accepted at an $\alpha = 0.05$ and 0.01 significance level, respectively (Hogg and Tanis, 1993). The uncertainty usually resided in measurement deviations made during the digitizing of the well logs and the random noise of the well log signals. The uncertainty factors reduced and screened the underlying correlation behavior between geophysical logs. By correcting the signals based on knowledge of casings or water table, the correlations can be improved.

The optimal depths for stratigraphic correlation based on geophysical logs were typically within a few feet to ten feet of the original geologist's selection. This is an indication that the geologist's criteria for selecting a contact were valid. When prior contacts were omitted and the selection was based on geophysical logs alone, the major contacts picked by the geologist were reasonably close. This also indicates valid criteria were used for selecting horizons that correlate.

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APPENDIX B

SUPPORTING HYDROLOGIC AND CONTAINMENT INFORMATION

B 1 Introduction

Appendix A provides additional hydrologic information summarizing the historical information known about hydrologic conditions at the Hanford Site and the S-SX Waste Management Area (WMA) (Figures B-1 and B-2, Table B-1), the available hydrologic property data considered applicable to the S-SX WMA (Table B-2) and current contamination in the unconfined aquifer underlying the 200 West

Figure B-1 provides the chronological sequence of water table levels under the Hanford Site from 1944 to 1998. Figure B-2 provides the discharge history for cribs and trenches involved in S-SX Tank Farm operations. Table B-1 provides monthly and annual precipitation at the Hanford Site from 1946 to 1998. Table B-2 summarizes physical and hydrologic soil property data collected from soil samples in the 200 West area.

Figures B-3 and B-4 provide measured contaminant concentrations (radionuclides and chemical, respectively) and extrapolated plumes in the unconfined aquifer underlying the 200 West area. Contaminants currently underlying the S-SX WMA that originated from sources other than the S-SX Tanks include uranium and tritium (originating in the S-25 crib) and carbon tetrachloride (originating from the Plutonium Finishing Plant (PFP) liquid waste disposal sites). The large nitrate, uranium and technetium-99 plumes to the east of the S-SX Tank Farm area are due to past discharges to the 216-U-1/2 cribs from U Plant operations.

B 2 References

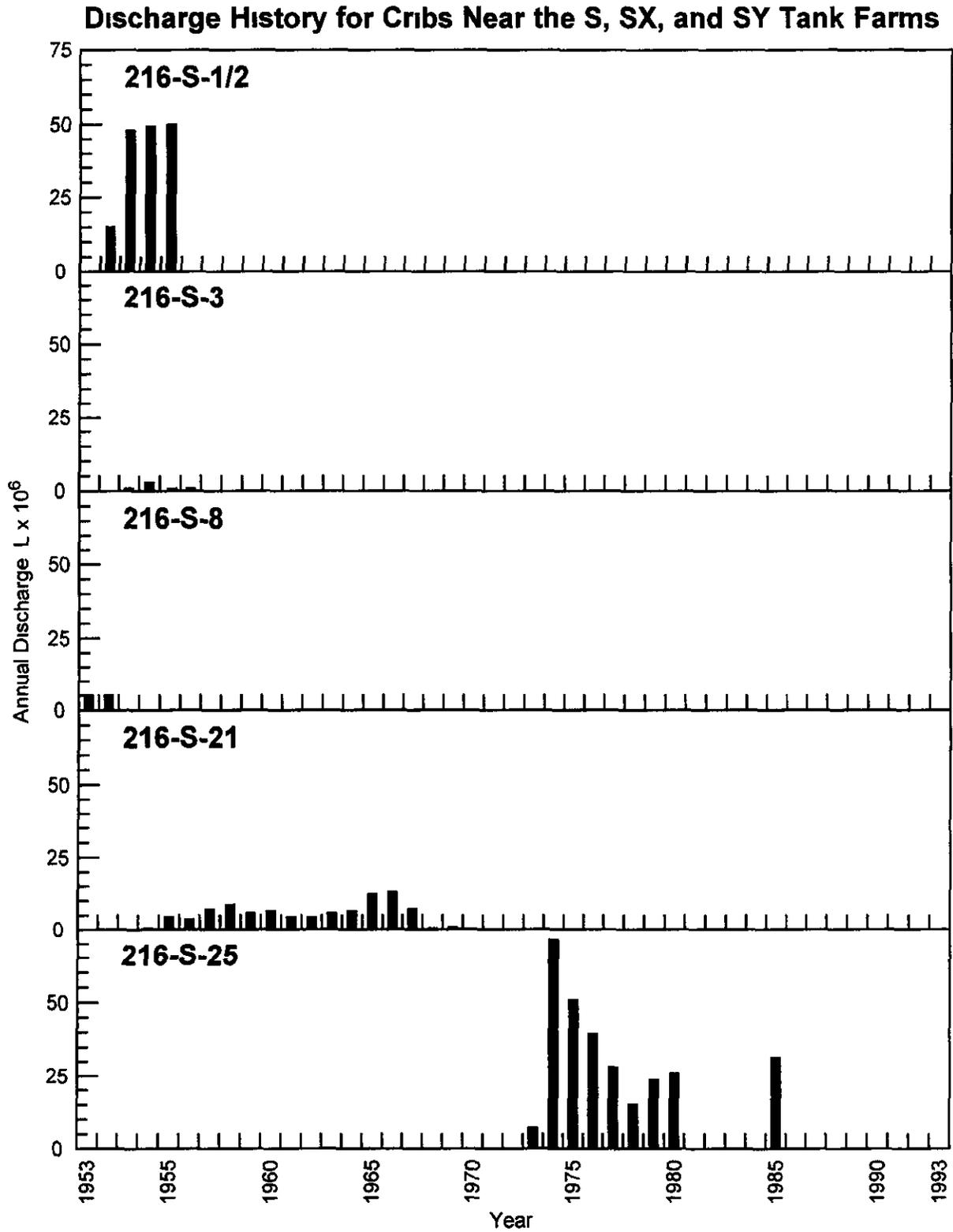
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1999/DCL/S-SX/014

Figure B-2 Discharge History for Wastewater Disposal Sites Adjacent to WMA S-SX

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Table B-1 Monthly and Annual Precipitation at the Hanford Site, 1946 to 1998

Monthly and Annual Precipitation (inches)
Amounts in RED are Maximums BLUE are Minimums

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1946	--	--	--	--	--	--	0 15	0 35	0 52	0 65	0 66	0 11	-
1947	0 32	0 27	0 42	0 70	0 02	1 07	0 71	0 68	1 34	2 20	0 81	0 75	9 29
1948	1 36	0 69	0 07	0 95	1 71	1 47	0 40	0 39	0 16	0 45	0 95	1 11	9 71
1949	0 13	0 68	1 12	0 02	0 16	0 01	0 01	0 03	0 23	0 10	1 47	0 16	4 12
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1950	1 80	1 06	0 87	0 47	0 27	2 92	0 07	T	0 01	2 46	0 55	0 97	11 45
1951	0 84	0 51	0 46	0 53	0 43	1 38	0 37	0 15	0 10	0 71	0 82	0 70	7 00
1952	0 65	0 50	0 06	0 13	0 58	1 07	T	0 08	0 08	0 04	0 20	0 77	4 16
1953	2 16	0 25	0 17	0 77	0 28	0 55	T	0 96	0 13	0 20	0 96	0 49	6 92
1954	1 48	0 28	0 59	0 07	0 41	0 10	0 22	0 42	0 51	0 42	0 86	0 35	5 71
1955	0 56	0 22	0 17	0 40	0 59	0 28	0 57	0	0 77	0 40	1 54	2 03	7 53
1956	1 71	0 56	0 10	T	0 22	0 86	T	0 38	0 01	1 03	0 15	0 58	5 60
1957	0 48	0 23	1 86	0 38	0 82	0 47	0 05	0 02	0 34	2 72	0 39	0 53	8 29
1958	1 74	1 48	0 46	0 64	0 74	0 81	0 02	T	0 05	0 19	0 77	1 84	8 74
1959	2 05	1 17	0 40	0 20	0 50	0 23	T	0 03	1 26	0 56	0 41	0 26	7 07
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1960	0 51	0 58	0 67	0 53	0 71	0 14	T	0 26	0 23	0 23	0 92	0 64	5 42
1961	0 33	2 10	1 02	0 48	0 80	0 42	0 15	0 09	T	0 07	0 49	0 89	6 84
1962	0 13	0 90	0 14	0 34	1 35	0 12	T	0 50	0 38	0 95	0 65	0 60	6 06
1963	0 95	0 69	0 53	1 17	0 43	0 28	0 31	0 01	0 02	0 04	0 74	1 14	6 31
1964	0 37	0 01	0 03	0 11	0 04	0 90	0 04	0 24	0 09	0 28	0 94	2 34	5 39
1965	0 93	0 14	0 03	0 09	0 15	0 49	0 11	0 03	0 11	0 01	1 17	0 39	3 65
1966	0 68	0 03	0 39	0 03	0 05	0 43	0 81	T	0 27	0 39	2 25	0 60	5 93
1967	0 32	T	0 14	0 90	0 56	0 57	T	T	0 05	0 13	0 16	0 43	3 26
1968	0 88	0 58	0 02	0 01	0 06	0 19	0 04	0 51	0 25	0 93	1 23	1 25	5 95
1969	1 24	0 54	0 10	1 22	0 51	0 75	T	T	0 48	0 10	0 13	1 29	6 36
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1970	2 47	0 75	0 27	0 45	0 54	0 25	0 01	T	0 03	0 24	0 71	0 61	6 33
1971	0 78	0 10	1 02	0 07	0 56	0 71	0 13	0 09	1 13	0 18	0 46	1 07	6 30
1972	0 19	0 27	0 58	0 10	2 03	0 66	0 16	0 56	0 02	T	0 55	1 27	6 39
1973	0 90	0 21	0 08	T	0 24	0 01	T	0 02	0 43	1 72	2 64	2 02	8 27
1974	0 90	0 41	0 52	0 46	0 28	0 12	0 71	T	0 01	0 21	0 71	0 97	5 30
1975	1 43	0 98	0 33	0 42	0 38	0 24	0 32	1 16	0 03	0 87	0 60	0 70	7 46
1976	0 56	0 36	0 23	0 41	0 08	0 11	0 13	0 96	T	0 04	T	0 11	2 99
1977	0 08	0 57	0 41	T	0 65	0 37	0 06	1 36	0 66	0 15	0 63	1 47	6 41
1978	1 72	0 92	0 30	0 46	0 41	0 09	0 52	0 57	0 11	T	1 21	0 26	6 57
1979	0 54	0 17	0 54	0 52	0 10	T	0 09	0 38	0 20	0 67	1 36	0 99	5 56
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1980	1 32	1 30	0 30	0 86	1 41	0 96	T	0 02	0 85	0 33	0 44	1 89	9 68
1981	0 56	0 60	0 70	0 02	0 99	0 43	0 19	0 03	0 60	0 39	1 08	1 45	7 04
1982	0 33	0 57	0 30	0 75	0 28	0 75	0 22	0 20	0 55	1 33	0 91	1 79	7 98

1983	1 44	1 36	1 00	0 42	0 52	0 68	0 31	0 12	0 46	0 52	2 12	2 12	11 07
1984	0 23	0 94	1 01	0 60	0 55	0 99	0 06	T	0 42	0 07	1 83	0 57	7 27
1985	0 34	0 82	0 36	0 01	0 12	0 15	0 12	0 01	0 63	0 46	1 24	0 84	5 10
1986	1 76	1 37	0 76	T	0 30	T	0 21	0 02	0 96	0 29	0 65	0 77	7 09
1987	0 80	0 19	1 05	0 14	0 17	0 11	0 50	0 07	0 01	T	0 40	1 63	5 07
1988	0 48	T	0 39	1 12	0 33	0 11	0 13	0	0 39	0 01	0 82	0 40	4 18
1989	0 21	1 67	1 56	0 84	0 59	0 01	0 01	0 26	0 02	0 42	1 04	0 29	6 92
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL
1990	0 77	0 09	0 10	0 40	0 86	0 36	0 14	0 83	T	0 78	0 02	0 72	5 07
1991	0 33	0 19	1 12	0 45	0 49	1 44	0 29	0 07	0	0 53	1 44	0 40	6 75
1992	0 44	0 94	0 09	0 94	T	1 14	0 38	0 20	0 27	0 61	1 07	1 82	7 90
1993	1 30	1 17	0 67	0 71	0 60	0 12	1 76	0 24	0 04	0 09	0 19	0 94	7 83
1994	0 44	0 11	0 03	0 61	1 27	0 38	0 15	0 08	0 08	0 93	0 68	1 36	6 12
1995	2 14	0 69	0 95	1 54	0 79	0 77	0 34	0 07	0 79	0 87	1 04	2 32	12 31
1996	1 42	1 22	0 83	0 43	0 62	0 05	0 14	0 02	0 22	0 88	2 67	3 69	12 19
1997	1 51	0 25	0 70	0 33	0 33	0 46	0 19	0 06	0 32	0 92	1 01	0 31	6 39
1998	1 24	1 15	0 50	0 07	0 52	0 48	0 34	0 04	0 10	0 28	1 29	0 44	6 45
AVERAGE	0 93	0 63	0 51	0 45	0 53	0 53	0 22	0 24	0 32	0 55	0 91	1 01	6 82
NORMAL	0 79	0 62	0 47	0 41	0 51	0 38	0 18	0 27	0 31	0 39	0 91	1 03	6 26

Table B-2 Physical and Hydraulic Properties of Soil in the 200 West Area

Formation	Site	sample no	borehole	depth (m)	Sieve Analysis					soil type	van Genuchten Parameters					Sampling technique	Source
					gr	cs	fs	silt	clay		alpha (1/cm)	n	theta _r	theta _s	Ks (cm/s)		
Hanford sand	218-W-5	0-073	298-W7 8	20.3	0	27	54	10	9	loamy sand (1)	0.0008	1.9785	0.0600	0.4134	N/A	spiltspoon	
Plio-Pleistocene		0-082	298-W7 9	24.5	2	38	47	8	5	sand (2)	0.0064	1.7084	0.1483	0.3336	6.30E-04	spiltspoon	
Plio-Pleistocene		0-085	298-W7 9	26.9	0	50	37	5	8	sand (2)	0.0049	2.1261	0.0578	0.2105	1.30E-04	spiltspoon	
Upper Ringold		0-101	298-W7 9	31.8	0	65	8	2	5	sand (2)	0.0695	1.4447	0.0228	0.2082	2.10E-04	spiltspoon	
Upper Ringold		0.104	298-W7 9	34.2	0	72	24	3	1	sand (2)	0.0849	1.3106	0.0000	0.2082	1.10E-03	spiltspoon	
Palouse paleosol		5-0001	298-W7 9	21.6	4	4	79	8	5	sand (2)	0.0057	2.8152	0.0200	0.3727	1.40E-04	spiltspoon	Relyea 1995
Plio-Pleistocene		5-0002	298-W7 9	24.9	2	38	47	8	5	sand (2)	0.0039	1.9321	0.0678	0.3454	1.32E-04	spiltspoon	
Upper Ringold		5-0003	298-W7 9	43.2	0	74	22	1	3	sand (2)	0.0414	1.9382	0.0211	0.3004	1.80E-04	spiltspoon	
Upper Ringold		5-0004	298-W7 9	30.3	0	58	30	7	5	sand (2)	0.0102	1.5737	0.0267	0.3256	1.65E-04	spiltspoon	
Palouse paleosol		5-0005	298-W7 9	21.1	0	0	73	22	5	sandy loam (1)	0.0069	2.2430	0.0400	0.3851	6.70E-05	spiltspoon	
Hanford sand		5-0006	298-W7 9	19.9	0	27	54	10	9	loamy sand (1)	0.0064	2.2593	0.0584	0.3274	N/A	spiltspoon	
Upper Ringold		5-0007	298-W7 9	40.3	0	80	13	5	2	sand (2)	0.1308	1.7017	0.0231	0.3502	3.00E-03	spiltspoon	
Plio-Pleistocene	218-W 5	W7 2-65	298-W07-02	19.8	35	38	11	16	0	silty sandy gravel (3)	0.02102	1.4563	0.064	0.3752	6.80E-02	spiltspoon	Bjornstad 1990
Upper Ringold		W7 2.94	298-W07-02	28.6	48	39	7	6	0	sandy gravel (5)	0.0557	1.9689	0.0223	0.2168	3.70E-02	spiltspoon	
Middle Ringold		W7 2.154	298-W07-02	46.9	32	36	15	17	0	silty sandy gravel (3)	0.1027	1.3782	0.0150	0.3071	2.10E-02	spiltspoon	
Middle Ringold		W7 2.219	298-W07-02	66.8	39	35	18	8	0	sandy gravel (5)	0.068	1.7788	0.0517	0.1594	2.70E-03	spiltspoon	
Hanford Sand		W10 13-45	298-W10-13	13.7	0	62	33	5	0	sand (2)	0.0408	2.0672	0.0396	0.3915	5.80E-02	spiltspoon	
Hanford Gravel		W10-13-80	298-W10 13	24.4	64	25	6	5	0	sandy gravel (5)	0.2758	1.3718	0.0367	0.1781	2.70E-02	spiltspoon	
Hanford gravel	241 T 106	3-0210	298-W10-196	3.1	48	30	22	0	0	sandy gravel (5)	0.0115	2.2692	0.0450	0.1854	1.00E-03	spiltspoon	Relyea 1995
Hanford gravel		3-0213	298-W10-196	5.6	31	33	36	0	0	gravelly sand (4)	0.0040	2.4233	0.0494	0.2083	1.02E-03	spiltspoon	
Hanford gravel		3-0279	298-W10 196	1.8	46	32	20	2	0	sandy gravel (5)	0.0061	2.1046	0.0337	0.1492	N/A	spiltspoon	
Hanford sand		3-0589	298-W10 196	25.5	2	56	42	0	0	sand (2)	0.0040	2.0685	0.0575	0.3443	1.38E-05	spiltspoon	
Middle Ringold		3-0667	298-W10 196	42.2	80	13	7	0	0	sandy gravel (6)	0.0115	1.3466	0.0000	0.0718	2.83E-05	spiltspoon	
Middle Ringold		3-0668	298-W10-196	38.9	63	15	12	10	0	sandy gravel (5)	0.0023	1.5765	0.0100	0.1470	1.60E-03	spiltspoon	
Middle Ringold		3-0682	298 W10 196	46.1	0	54	35	10	1	sand (1)	0.0128	2.0864	0.0519	0.4334	4.57E-05	spiltspoon	
Middle Ringold		3-0688	298-W10 196	48.5	0	38	28	28	6	sandy loam (1)	0.0036	1.6568	0.0302	0.3230	N/A	spiltspoon	
Middle Ringold		3-0689	298-W10-196	52.2	0	36	30	25	9	sandy loam (1)	0.0022	1.6651	0.0300	0.3208	N/A	spiltspoon	
Middle Ringold		3-0690	298-W10 196	53.7	0	39	31	23	7	sandy loam (1)	0.0042	1.6376	0.0564	0.3683	6.55E-06	spiltspoon	
Plio-Pleistocene	C-018-H	2 1169	689-48-77	8.1	14	40	44	2	0	gravelly sand (4)	0.0076	2.5367	0.0569	0.3069	5.30E-03	spiltspoon	Relyea 1995
Plio-Pleistocene		2 1170	689-48-77	8.9	22	42	33	3	0	gravelly sand (4)	0.0048	1.9770	0.0635	0.3011	1.30E-04	spiltspoon	
Plio-Pleistocene		2 1176	689-48-77	13.0	1	79	20	0	0	sand (2)	0.0223	1.7587	0.0262	0.2230	2.00E-02	spiltspoon	
Plio-Pleistocene		2 1181	689-48-77	14.1	8	82	10	0	0	sand (2)	0.0728	1.3096	0.0230	0.2147	8.20E-03	spiltspoon	

Table B-2 Physical and Hydraulic Properties of Soil in the 200 West Area

Formation	Site	sample no	borehole	depth (m)	Sieve Analysis						soil type #	van Genuchten Parameters						Sampling technique	Source
					gr	cs	fs	silt	clay	alpha (1/cm)		n	theta _r	theta _s	Ks (cm/s)				
Plio Pleistocene		2 1431	699-48-77A	20.6	--	N/A	--	--	--	sand (2)	0.0227	1.6859	0.0432	0.2346	1.80E-02	spillspoon	Weekes and Borgheese, 1994		
Middle Ringold		2 1432	699-48-77A	27.6	51	30	15	4	0	sandy gravel (5)	0.0083	1.5938	0.0191	0.1128	1.40E-02	spillspoon	Relvas, 1995		
Hanford sand	ERDF 2B	4 0837	699-35-63A	74.9	--	--	N/A	--	--	sand (2)	0.0261	3.2937	0.0278	0.3743	N/A	spillspoon	Relvas, 1995		
Hanford sand		4 0642	699-35-69A	25.7	0	60	30	10	0	sand (2)	0.0119	1.6727	0.0566	0.3513	N/A	spillspoon	Weekes and Borgheese, 1994		
Hanford sand		4 0644	699-35-69A	49.8	0	27	56	12	5	loamy sand (1)	0.0069	2.2673	0.0828	0.3922	N/A	spillspoon			
Hanford sand		4 0791	699-35-65A	63.2	0	50	50	0	0	sand (2)	0.0217	2.4513	0.0303	0.3371	N/A	spillspoon			
Middle Ringold		4 0792	699-35-65A	75.4	70	21	8	1	0	sandy gravel (6)	0.0276	1.6636	0.0091	0.0825	N/A	spillspoon			
Hanford sand		4 0855	699-35-66B	12.2	0	7	83	5	5	sand (2)	0.0088	3.2652	0.0689	0.3836	N/A	spillspoon			
Hanford sand		4 0873	699-35-68A	37.0	0	21	64	12	3	loamy sand (1)	0.0169	2.0085	0.0190	0.3525	1.27E-04	spillspoon			
Upper Ringold		4 0983	699-35-68A	82.9	17	35	42	4	2	gravelly sand (4)	0.0156	2.0226	0.0100	0.3373	5.43E-05	spillspoon			
Plio-Pleistocene		4 1011	699-35-69A	73.0	0	4	60	28	8	loamy sand (1)	0.0042	1.5218	0.0450	0.4913	1.00E-05	spillspoon			
Middle Ringold		4 1012	699-35-69A	73.9	50	20	20	7	3	sandy gravel (5)	0.0062	1.6452	0.0100	0.1643	5.10E-05	spillspoon			
Middle Ringold		4 1013	699-35-69A	77.9	77	6	12	3	2	sandy gravel (5)	0.0064	1.6574	0.0214	0.1397	1.90E-07	spillspoon			
Hanford sand		4 1056	699-32-72B	61.7	0	6	88	4	2	sand (2)	0.0071	2.7253	0.0350	0.4288	N/A	spillspoon			
Hanford sand		4 1057	699-32-72B	49.5	0	2	68	24	6	loamy sand (1)	0.0046	2.2861	0.0890	0.4877	N/A	spillspoon			
Hanford sand		4 1058	699-32-72B	64.7	0	1	41	43	15	loam (1)	0.0029	1.5267	0.1023	0.5661	N/A	spillspoon			
Hanford sand		4 1076	699-35-61A	76.4	0	75	25	0	0	sand (2)	0.0235	2.0956	0.0265	0.3433	N/A	spillspoon			
Middle Ringold		4 1079	699-35-61A	90.9	85	24	11	0	0	sandy gravel (5)	0.0073	1.6688	0.0295	0.1236	1.30E-03	spillspoon			
Middle Ringold		4 1080	699-35-61A	93.5	63	24	10	3	0	sandy gravel (5)	0.0062	1.6601	0.0302	0.1316	3.30E-06	spillspoon			
Warden silt loam	FLTF 15	D02 10	N/A	<6.1	0	2	54	34	10	sandy loam (1)	0.0049	1.9773	0.0778	0.4531	1.20E-04	excavation	Gene et al, 1989		
Warden silt loam		D02 16	N/A	6.1	0	2	63	25	10	sandy loam (1)	0.0035	2.4632	0.0820	0.4630	1.20E-04	excavation	Volk, 1993		
Warden silt loam		D04-04	N/A	<6.1	0	4	58	28	10	sandy loam (1)	0.0072	1.6501	0.0700	0.4508	1.20E-04	excavation			
Warden silt loam		D04 10	N/A	<6.1	0	3	58	30	9	sandy loam (1)	0.0056	1.7574	0.0800	0.4428	2.90E-04	excavation			
Warden silt loam		D05-03	N/A	6.1	0	4	63	23	10	sandy loam (1)	0.0055	1.6647	0.0860	0.4332	2.90E-04	excavation			
Warden silt loam		D07-04	N/A	6.1	0	3	58	30	9	sandy loam (1)	0.0051	1.9424	0.0820	0.4435	1.20E-04	excavation			
Warden silt loam		D08 15	N/A	<6.1	0	2	57	31	10	sandy loam (1)	0.0059	1.8533	0.0850	0.4543	1.20E-04	excavation			
Warden silt loam		D09-01	N/A	<6.1	0	3	51	37	9	sandy loam (1)	0.0066	1.7677	0.0800	0.4544	1.20E-04	excavation			
Warden silt loam		D09-02	N/A	<6.1	0	2	57	31	10	sandy loam (1)	0.0069	1.8488	0.0825	0.4559	1.20E-04	excavation			
Warden silt loam		D09 05	N/A	<6.1	0	7	60	29	4	sandy loam (1)	0.0088	1.6183	0.0681	0.4461	2.90E-04	excavation			
Warden silt loam		D10-04	N/A	6.1	0	6	59	30	5	sandy loam (1)	0.0064	1.7899	0.0850	0.4481	1.20E-04	excavation			
Warden silt loam		D11-06	N/A	6.1	0	4	57	33	6	sandy loam (1)	0.0061	1.8575	0.0850	0.4308	1.20E-04	excavation			
Warden silt loam		D11-08	N/A	6.1	0	5	58	32	5	sandy loam (1)	0.0061	1.7567	0.0850	0.4312	1.20E-04	excavation			

Table B-2 Physical and Hydraulic Properties of Soil in the 200 West Area

Formation	Site	sample no	borehole	depth (m)	Sieve Analysis							soil type	van Genuchten Parameters					Sampling technique	Source
					gr	cs	fs	silt	clay	alpha (1/cm)	n		theta _r	theta _s	K _s (cm/s)				
Warden silt loam		D12 14	N/A	<6.1	0	3	52	34	11	0.0063	1.7576	0.0980	0.4686	1.20E-04	excavation				
Warden silt loam		D13-08	N/A	6.1	0	4	52	35	9	0.0070	1.7877	0.0820	0.4513	1.20E-04	excavation				
Warden silt loam		D14-04	N/A	6.1	0	3	56	36	5	0.0065	1.8553	0.0837	0.4586	1.20E-04	excavation				
Plio-Pleistocene	VOC	3-0647	299-W18-246	42.9	0	2	76	14	6	0.0051	2.0531	0.0400	0.4895	2.00E-04	spit spoon	Rehyes 1995			
Middle Ringold		3-0648	299-W18 246	59.6	62	16	20	0	0	0.0124	1.6450	0.0000	0.1462	8.70E-03	spit spoon				
Plio-Pleistocene		3-0649	299-W18-247	41.1	0	10	38	40	12	0.0010	1.7024	0.0600	0.5331	N/A	spit spoon				
Plio-Pleistocene		3-0650	299-W18 247	45.1	0	46	28	15	11	0.0120	1.5539	0.2412	0.6306	2.60E-07	spit spoon				
Plio-Pleistocene		3-0651	299-W18 247	46.9	0	58	24	9	9	0.0286	1.9721	0.1006	0.3728	9.40E-03	spit spoon				
Hanford Sand		3-0652	299-W18-248	38.4	0	40	52	4	4	0.0092	1.8848	0.0300	0.3586	3.70E-04	spit spoon				
Plio-Pleistocene		3-0653	299-W18-248	42.5	0	24	54	14	8	0.0067	1.8378	0.1096	0.4223	5.80E-06	spit spoon				
Plio-Pleistocene		3-0654	299-W15-216	35.6	59	30	3	4	4	0.0119	1.2618	0.0166	0.1833	2.70E-04	spit spoon				
Upper Ringold		3-0655	299-W15 216	36.9	34	28	8	24	6	0.0029	1.6285	0.0559	0.2625	1.58E-04	spit spoon				
Middle Ringold		3-0656	299-W15-216	39.0	42	40	18	0	0	0.0166	1.3941	0.0090	0.1814	1.36E-02	spit spoon				
Hanford Sand		3-0657	299-W15-217	37.4	34	38	10	10	8	0.0145	1.3692	0.0469	0.2505	2.67E-04	spit spoon				
swelling clay not included in variability and scaling analyses																			
* signifies that the residual moisture content has been fixed to improve the curve fit through the measured data																			
* van Genuchten parameters are defined in van Genuchten (1980)																			
# soil category																			
(1) SS sand mixed with finer fraction																			
(2) S sand																			
(3) SSG sand and gravel mixed with finer fraction																			
(4) GS gravelly sand																			
(5) SG1 sandy gravel with gravel content approximately <60%																			
(6) SG2 sandy gravel with gravel content approximately >60%																			
1 K _s hydraulic conductivity measured by falling head permeameter																			
2 K _s hydraulic conductivity measured by constant head permeameter																			
Moisture Retention Data Measurements																			
3 0 to 60 cm hanging water column 100 to 15300 cm pressure plate extraction (Klute 1986)																			
4 0 to 1000 cm Tempe cell 500 to 15300 cm pressure plate extraction																			
5 0 to 150 cm hanging water column 310 to 15300 cm pressure plate extraction < 15300 cm thermocouple psychrometer (Rawlins and Campbell 1986)																			
6 0 to 1000 cm Tempe cell 500 to 10000 cm pressure plate extraction < 10000 cm thermocouple psychrometer																			

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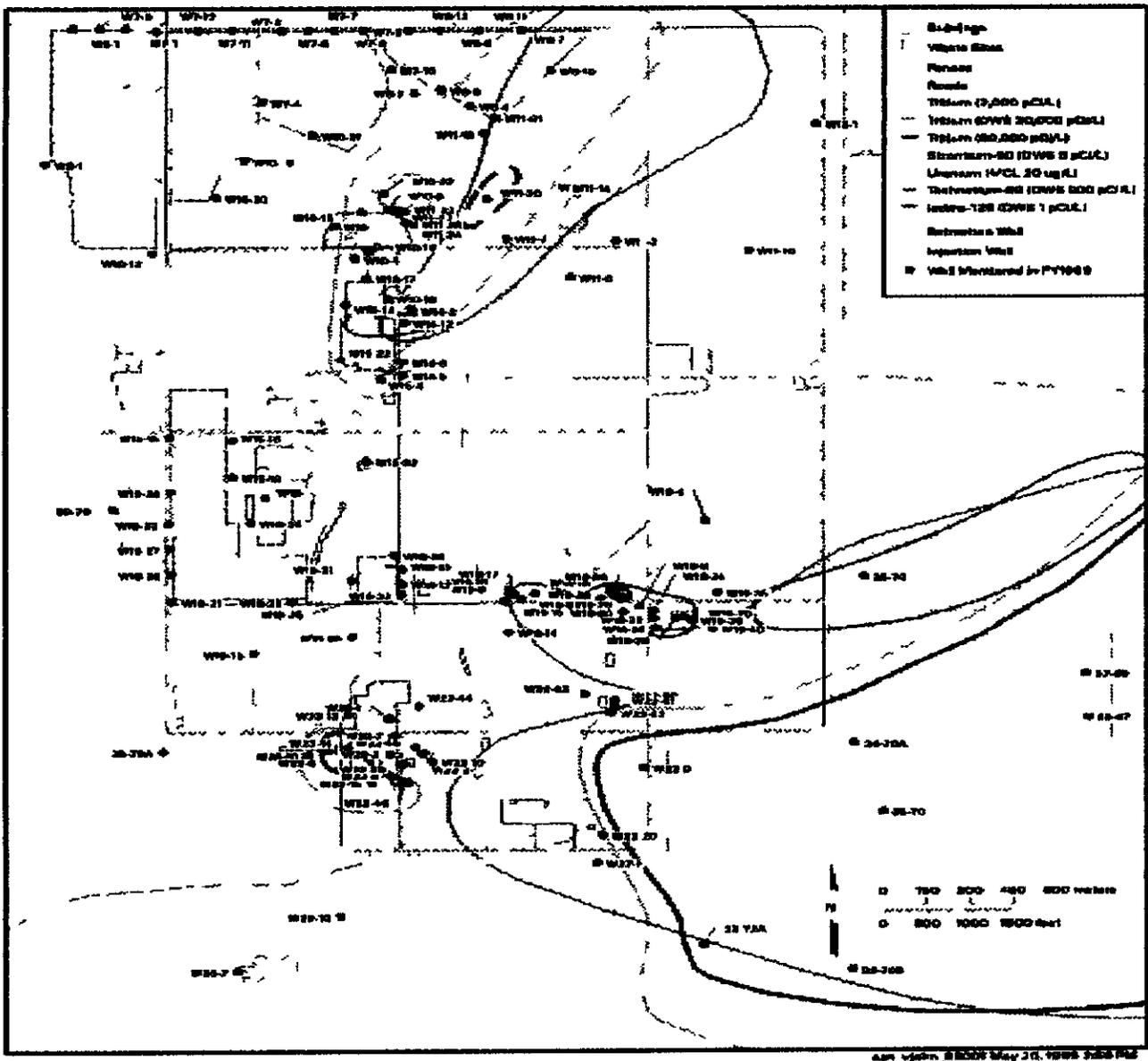


Figure B-3 Major Radionuclide Plumes in the 200 West Area

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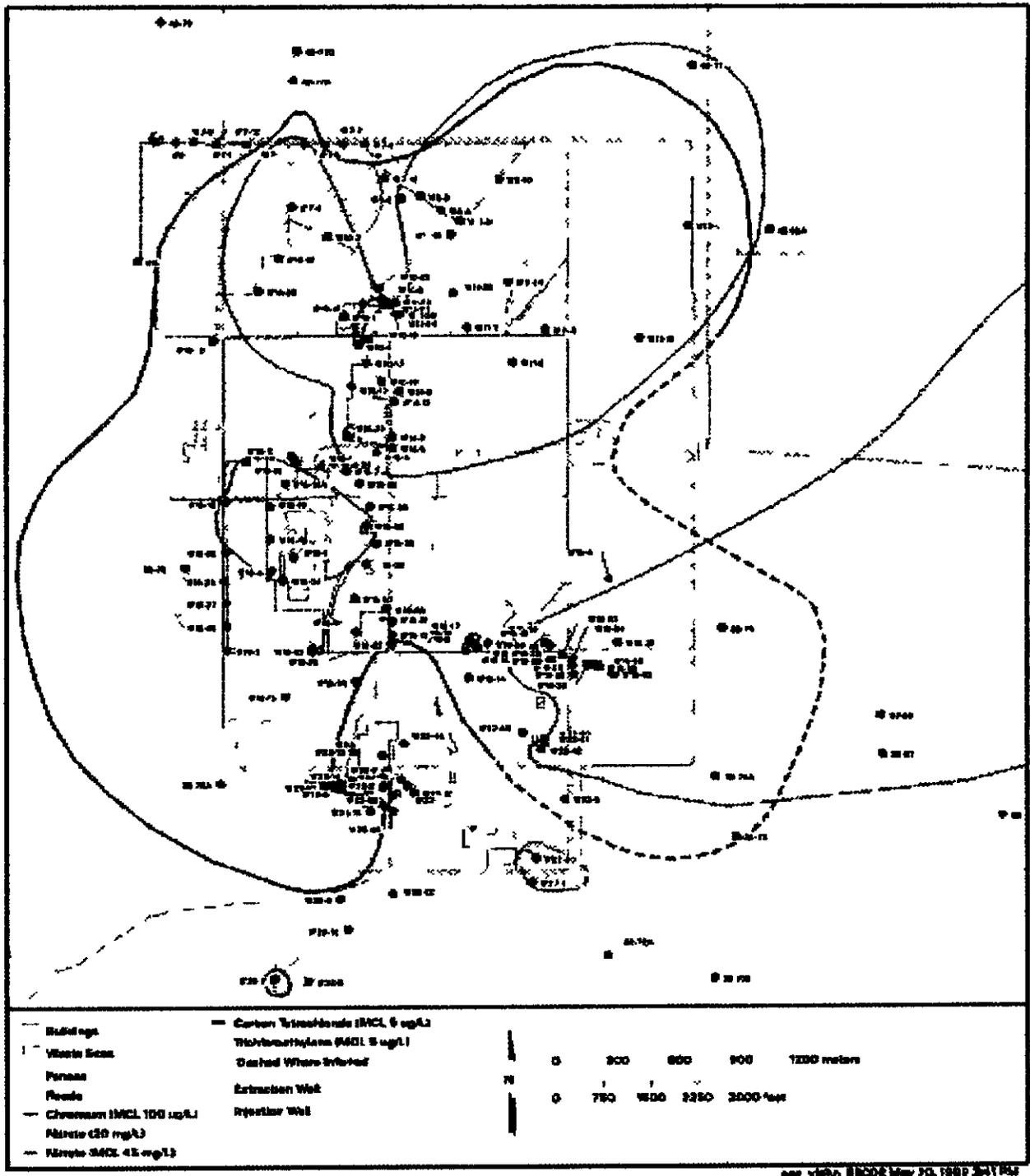


Figure B-4 Major Hazardous Chemical Plumes in the 200 West Area

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APPENDIX C

SUPPORTING GAMMA LOGGING INFORMATION

Appendix C (Table C-1) provides a summary of analyses of gamma logging data that uses historical gross gamma logs and recently acquired spectral gamma logs taken from drywells in the SX Tank Farm. The summary provides the data to deduce migration of gamma emitting radionuclides (primarily cesium-137) in the vadose zone as a function of drywell location and time.

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Table C-1 SX Tank Farm Radiation Zones

Borehole	Total Depth (ft)	Survey #	Survey Reject #	Probe Type	Category	Zone Depth (ft)	Max GTP (ft*c/s)	Year max GTP	Isotope	Comments
41 00-02	99	215	2	4	Undetermined	99	200	1975		
41-00-03	150	313	1	4	Clean					1976 Step Ave Bkg
41-00-04	150	122	1	4	Clean					1976 Step Ave Bkg
41-00-05	155	126	2	4	Clean					1976 Step Ave Bkg
41 00-08	125	213	4	4	CHANGED	68	300	1994	Cs137	Zone Start Incr 1983
41-00-08	125	213	4	4	Stable	78	800	1975	Cs137	
41-01-01	142	871	0	4	Stable	8	260	1975	Cs137	
41 01-01	142	871	0	4	Stable	15	180	1975	Cs137	
41 01-01	142	871	0	4	Undetermined	142	300	1975		
41-01-04	100	524	6	4	Stable	10	80	1975	Cs137	
41-01-04	100	524	6	4	Undetermined	100	80	1975		
41 01-06	100	536	10	4	Stable	8	38000	1975	Cs137	
41 01-06					Stable	16	-1	1975	Cs137	
41-01-06					Stable	22-28	100	1975	Cs137	
41-01-06					Stable	30-38	120	1975	Cs137	
41 01-06					Undetermined	95-98	100	1975		
41 01-07	100	487	1	4	Stable	2-12	900	1984	Cs137	
41-01-07					Undetermined	100	200	1975		
41-01-08	100	544	0	4	Stable	2-10	200	1984	Cs137	
41 01-08					Undetermined	92-102	300	1975		
41 01-10	103	584	0	4	Undetermined	0-7	100	1975		
41-01-10					Undetermined	92-105	200	1976		
41-01-11	99	865	0	4	Undetermined	2-8	25	1975		
41 01-11	99	865	0	4	Undetermined	92-105	100	1976		
41-02-02	140	900	0	4	CHANGED	45-55	620	1993	Cs137	
41-02-02					Stable	30-40	80	1975	Cs137	
41 02-02					Stable	2-10	1200	1975	Cs137	
41 02-02					Undetermined	136-145	200	1975		
41 02-05	120	405	0	4	Stable	2-9	700	1985	Cs137	
41-02-05					Stable	9-14	100	1985	Cs137	

Table C-1 SX Tank Farm Radiation Zones

Borehole	Total Depth (ft)	Survey #	Survey Reject #	Probe Type	Category	Zone Depth (ft)	Max GTP (ft*c/s)	Year max GTP	Isotope	Comments
41-02-07	100	588	0	4	Undetermined	95-105	200	1975		
41-02-08	100	899	0	4	Stable	10-20	300	1975	Cs137	
41-02-08					Stable	42-55	180	1975	Cs137	
41-02-08					Undetermined	100	300	1975		
41-02-11	100	598	0	4	Stable	11	450	1975	Cs137	
41-02-11					Stable	17-32	200	1975	Cs137	
41-02-11					Undetermined	100	50	1975		
41-03-02	100	602	0	4	Stable	2-9	13000	1984	Cs137	
41-03-02					Stable	10-20	450	1975	Cs137	
41-03-02					Stable	32-65	250	1975	Cs137	
41-03-02					Undetermined	100	100	1975		
41-03-05	100	590	0	4	Stable	5-25	400	1975	Cs137	
41-03-05					Undetermined	100	200	1975		
41-03-06	100	868	0	4	Undetermined	100	200	1975		
41-03-09	100	874	0	4	Undetermined	100	200	1975		
41-03-10	100	861	0	4	Stable	0-4	200	1986	Cs137	
41-03-10					Stable	4-15	450	1975	Cs137	
41-03-12	140	896	0	4	Stable	0-4	300	1986	Cs137	
41-03-12					Stable	4-10	250	1975	Cs137	
41-03-12					Stable	132-145	70	1983	Cs137	
41-04-01	100	900	0	4	Clean					
41-04-03	100	608	0	4	CHANGED	14-30	3500	1975	Mult	Please Examine
41-04-05	100	845	0	4	Clean					
41-04-07	100	557	0	4	Clean					
41-04-08	123	742	0	4	Clean					
41-04-11	100	825	0	4	Stable	2-10	1300	1985	Mult	Eu ¹⁵⁴ /Cs ¹³⁷ = 64 @1995
41-05-02	125	591	0	4	Stable	2-20	250	1984	Cs137	
41-05-02					Undetermined	125	100	1979		
41-05-03	122	596	0	4	Stable	2-30	700	1978	Cs137	Deepened 1978
41-05-05	133	622	0	4	Undetermined	115-133	250	1975		Stack on to 130

Table C-1 SX Tank Farm Radiation Zones

Borehole	Total Depth (ft)	Survey #	Survey Reject #	Probe Type	Category	Zone Depth (ft)	Max GTP (ft*c/s)	Year max GTP	Isotope	Comments
41-05-07	125	600	0	4	Clean					1978 step Avg Bkg
41 05 08	125	602	0	4	Undetermined	2-12	250000	1975	Cs137	Exceeded c/s Limits
41-05 10	125	610	0	4	Stable	2 20	150	1984	Cs137	Deepened 1978
41-05-12	125	617	0	4	Stable	2 10	270	1984	Cs137	Deepened 1978
41-06-02	100	881	0	4	Stable	5-14	1500	1975	Cs137	Stable since 1986
41 06 02					TF Work	3		1984		Possible TF Activity
41-06-05	140	902	0	4	TF Work	0-10	200	1984		Possible TF Activity
41 06-06	122	731	0	4	Stable	3-12	200	1978	Cs137	
41 06-09	98	888	0	4	Stable	20-50	600	1975	Ru106	Ru106 Assumed
41-06-11	96	446	0	4	Clean					
41-06 23	125	719	0	4	Clean					
41-07-02	76	146	0	4	Undetermined	76	150	1976		
41-07-03	75	142	0	4	Stable	3-15	200	1976	Cs137	
41-07 05	75	162	0	2	Stable	56	10000	1978	Cs137	
41-07 07	75	192	0	2	CHANGED	50-75	60000	1989	Cs137	
41-07-08	77	286	0	4	CHANGED	50 65	65000	1989	Cs137	
41-07 08					Undetermined	68-80	100	1975		
41-07 10	73	141	0	4	Clean					
41-07-12	77	544	0	4	Clean					1978 Step Avg Bkg
41-08-02	75	132	0	14	Stable	55	40000	1976	Cs137	
41 08 03	75	150	0	4	Clean					
41-08 04	75	142	6	4	Stable	10 55	30000	1976	Cs137	Abrupt change 1981
41-08-06	135	140	2	4	Clean					
41-08 07	75	163	5	2	Stable	60 75	60000	1978	Cs137	Probably Stable See
41 08 11	75	199	7	2	Stable	45-65	30000	1979	Cs137	
41-09-02	75	356	6	4	Stable	6	900	1975	Cs137	Undetermined Early
41-09-03	75	251	7	2	Stable	65	25000	1979	Cs137	
41 09 04	104	154	3	2	CHANGED	82 87	4000	1980	Cs137	Stop Log 1983
41-09-04					Stable	74 82	17000	1979	Cs137	
41-09-04					Stable	65	300	1979	Cs137	

Table C-1 SX Tank Farm Radiation Zones

Borehole	Total Depth (ft)	Survey #	Survey Reject #	Probe Type	Category	Zone Depth (ft)	Max GTP (ft*c/s)	Year max GTP	Isotope	Comments
41-09-04					Stable	57	100	1979	Cs137	
41-09-06	75	222	0	4	Stable	6	450	1975	Cs137	
41-09-07	75	132	0	1	CHANGED	60 75	120000	1989	Cs137	Green & Red GM
41-09-09	135	319	0	4	CHANGED	74	200000	1994	Cs137	Zone start mcr 1984
41-09-09					Stable	64	450	1975	Cs137	
41-09-11	75	362	0	4	Clean					
41-10-01	135	254	0	4	Undetermined	66	120	1976	Cs137	
41-10-02	125	227	0	4	Clean					
41-10-03	75	223	0	4	Undetermined	8	150	1975	Cs137	
41-10-03					Undetermined	63 80	200	1975		
41-10-05	75	221	0	4	Clean					
41-10-06	75	223	0	4	Undetermined	3	150	1975		
41-10-06					Undetermined	75	200	1975		
41-10-08	75	217	0	4	Stable	54	600	1975	Ru106	Ru106 Assumed
41-10-10	125	222	0	4	Undetermined	125	200	1975		
41-10-11	75	223	0	4	Undetermined	75	150	1975		
41-11-02	75	131	0	4	Clean					
41-11-03	75	219	1	4	Stable	56	100	1975	Ru106	Ru106 Assumed
41-11-05	135	134	0	4	Clean					
41-11-06	75	179	0	4	Undetermined	75	100	1975		
41-11-08	135	127	0	4	Clean					
41-11-09	75	124	0	4	Clean					
41-11-10	125	131	2	1	CHANGED	83	400	1994	Cs137	Green GM
41-11-10					Undetermined	60-74	50000	1988	Cs137	Green & Red GM
41-11-10					Stable	76-80	180	1980	Cs137	Green GM
41-12-02	125	146	3	2	Stable	65 94	8000	1978	Cs137	
41-12-02					Stable	98 108	200	1978	Cs137	
41-12-02					Stable	118 125	200	1978	Cs137	
41-12-03	75	77	2	14	CHANGED	58 72	60000	1978	Cs137	
41-12-04	125	127	0	4	Clean					

Table C-1 SX Tank Farm Radiation Zones

Borehole	Total Depth (ft)	Survey #	Survey Reject #	Probe Type	Category	Zone Depth (ft)	Max GTP (ft*c/s)	Year max GTP	Isotope	Comments
41-12-06	75	129	0	4	Clean					
41-12-07	75	131	0	4	Clean					
41-12-09	75	126	0	4	Undetermined	2	150	1975		
41-12-10	75	131	0	4	Clean					
41-13-10	100	108	1	4	Clean					
41-14-02	75	175	2	4	Clean					
41-14-03	75	177	0	4	Clean					
41-14-04	125	177	0	4	Stable	59	250	1975	Ru106	Ru106 Assumed
41-14-06	75	188	7	4	Stable	29-42	8000	1975	Ru106	Ru106 Assumed
41-14-06					CHANGED	46-73	3000	1975	Ru106	1981-1988 Moved Down
41-14-08	75	175	3	4	Clean					
41-14-09	75	184	5	4	Stable	63	180	1975	Cs137	
41-14-11	75	177	0	4	Clean					
41-15-02	75	83	0	4	Clean					
41-15-03	75	84	1	4	Clean					
41-15-05	75	82	0	4	Clean					
41-15-07	125	84	1	4	Stable	58	950	1975	Cs137	
41-15-09	75	82	0	4	Clean					
41-15-10	125	88	1	4	Clean					

Table 3 2 is a summary of the radiation zones for all boreholes in the SX Tank Farm The table contains the following information

- Total borehole depth
- Number of gamma ray surveys in the library
- Number of rejected from the analysis
- Main probe used for surveying the borehole
- Classification Category for the borehole (if CLEAN) for each radiation zone encountered
- Maximum Grade Thickness Product (average) for the radiation zone with
- Year the maximum Grade Thickness Product was observed
- Radio isotope identified from the SGLS surveys Ru 106 is assumed but has been a common isotope in the vadose zone (yet not identified since 1990) which has likely decayed to non detectable levels because of its short half life (1 02 years)
- Comment is a brief state of unusual conditions

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