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Assessment of Basalt Waste Isolation Project's Borehole Mud Pits Soils and Sediments for Chemical Constituents--Summary Report

Prepared for the U.S. Department of Energy
Assistant Secretary for Environment, Safety and Health

Westinghouse
Hanford Company Richland, Washington

Hanford Operations and Engineering Contractor for the
U.S. Department of Energy under Contract DE-AC06-87RL10930

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ABSTRACT

As part of an effort to characterize the geologic formations underlying the Hanford Site, 98 boreholes were drilled in support of the Basalt Waste Isolation Project. Review of drillings records indicated that certain drilling operations between 1973 and 1983 may have introduced hazardous substances into the environment. The suspected substances are constituents of drilling fluids that were channelled into mud pits adjacent to the drill sites.

This report details operations at the seven boreholes determined to have the greatest potential for contamination. It also describes the study conducted to determine if hazardous chemicals are present, and, if so identifies their concentrations and spatial distribution. The study was intended to provide input for decisions regarding remedial action. The data presorted herein were reviewed with respect to the regulations of the Resource Conservation and Recovery Act of 1976. The findings are as follows.

- *The mudpits are not considered dangerous according to the guidelines set by the Washington Department of Ecology.*

- *The pits do not require any action under the provisions of the Resource Conservation and Recovery Act of 1976.*

- *The original borehole reclamation project will proceed as planned.*

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ASSESSMENT OF THE BASALT WASTE ISOLATION PROJECT BOREHOLE MUD PITS SOILS AND SEDIMENTS FOR CHEMICAL CONSTITUENTS--SUMMARY REPORT

1.0 INTRODUCTION

As part of an effort to characterize the geologic formations underlying the Hanford Site for a nuclear waste repository, 98 boreholes were drilled to collect geologic, hydrologic, and geochemistry data in support of the Basalt Waste Isolation Project (BWIP). After an evaluation of the daily shift report of operations, mud engineers' reports, and other data from each of the 98 boreholes, it was determined that the mud pits at the borehole sites could contain regulated dangerous waste.

A program to evaluate the drilling fluids with respect to their regulated constituents was undertaken. Quantities of mud products were calculated according to their respective dry weights. Any dilution factor from water added to the solution was not considered. Therefore, a "worst case" (conservative) approach was applied.

In an April 4, 1988 meeting with the Washington Department of Ecology (Ecology), it was determined that the borehole mud pits with the greatest possibility for contamination would be sampled and chemical analyses performed to determine if any contained regulated wastes. Further evaluation of the daily shift report of operations, mud engineers' reports, and other data indicate that the sites most likely to contain regulated dangerous waste are DC-16A, DC-16B, and DC-20B.

The sampling program was conducted to form a preliminary assessment on whether or not the levels of the chemical constituents of the drilling fluids left in the mud pits warrant site characterization. In addition, all sampling data compiled would be presented to Ecology.

This report summarizes the methods, procedures, and results of the preliminary assessment of chemical constituents in the soils and sediments underlying the borehole mud pits. The sampling program included four primary objectives.

1. Determine if sediments and soils in and below pits contain specific hazardous chemicals.

2. Determine concentrations of hazardous chemicals (if present).

3. Determine spatial distribution of hazardous constituents if present within soil profile.

4. Provide data for input into decision-making process regarding potential remedial action.

All work was conducted in compliance with documents referenced within this text. A complete listing of the entire data package for hazardous waste analyses will be provided on request.

2.0 SITE DESCRIPTIONS

All of the mud pits of interest are located on the Hanford Site (Fig. 1). A brief description of each of the sites and the constituents of the drilling fluids is provided in the following sections.

2.1 BOREHOLE DB-2

Borehole DB-2 (Fig. 2) is located near the southeastern boundary of the Hanford Site, less than 0.5 mi west of the Columbia River. A pad was constructed to accommodate the drilling rig and equipment by leveling an area approximately 125 by 200 ft and adding a thin layer of gravel. The site contains a small, shallow-excavated mud pit approximately 55 ft long, 40 ft wide, and 2 ft deep. The pit is connected to the drill pad by a narrow trench 210 ft in length. Fluids used during the drilling operations were run along the trench and into the mud pit; both the pit and trench remain open. There is no visual indication of drilling mud in either the pit or trench.

The borehole was deepened by the BWIP by core drilling in a preexisting 6-in. access casing from 310 ft to a depth of 924 ft. This phase of drilling occurred between December 1973 and February 1974. In November 1980, DB-2 was deepened to 957 ft. A 3.875-in.-dia casing was then set from ground surface to total depth. In January 1981, a 3.032-in.-dia core bit was used to drill to a depth of 1,273 ft, using only fresh water as the drilling fluid. The depth to groundwater at this location is approximately 30 ft from the surface.

In the course of the drilling activities, 16 50-lb sacks of chrome lignosulfonate (RAYKROME*) were used as a portion of the drilling fluid. The primary constituent of concern in the RAYKROME compound is chromium III, which accounts for 3.4% of the total volume of RAYKROME by weight.

2.2 BOREHOLE DB-11

Borehole DB-11 (Fig. 3) is located on the west side of the Hanford Site, adjacent to the Yakima Barricade. A cable-tool drilling rig was used to drill a 6.625-in.-dia hole to a depth of 342 ft. The hole was cased with 4.5-in.-dia casing. The borehole was then core drilled to a depth of 1,046 ft and was reduced in diameter several times before final completion. A confined aquifer was encountered at 1,045 ft. This aquifer produced artesian flows at the surface. The well flowed at a rate of 200 gal/min and had a shut-in pressure of 60.5 lbf/in^2. Water produced by the well and mud used during the drilling operation were channeled away from the rigs along a narrow trench and allowed to run onto the surrounding terrain. An area approximately 70 to 80 ft in diameter has been identified as having received the majority of

*RAYKROME is a trade name of ITT Rayonier Inc.

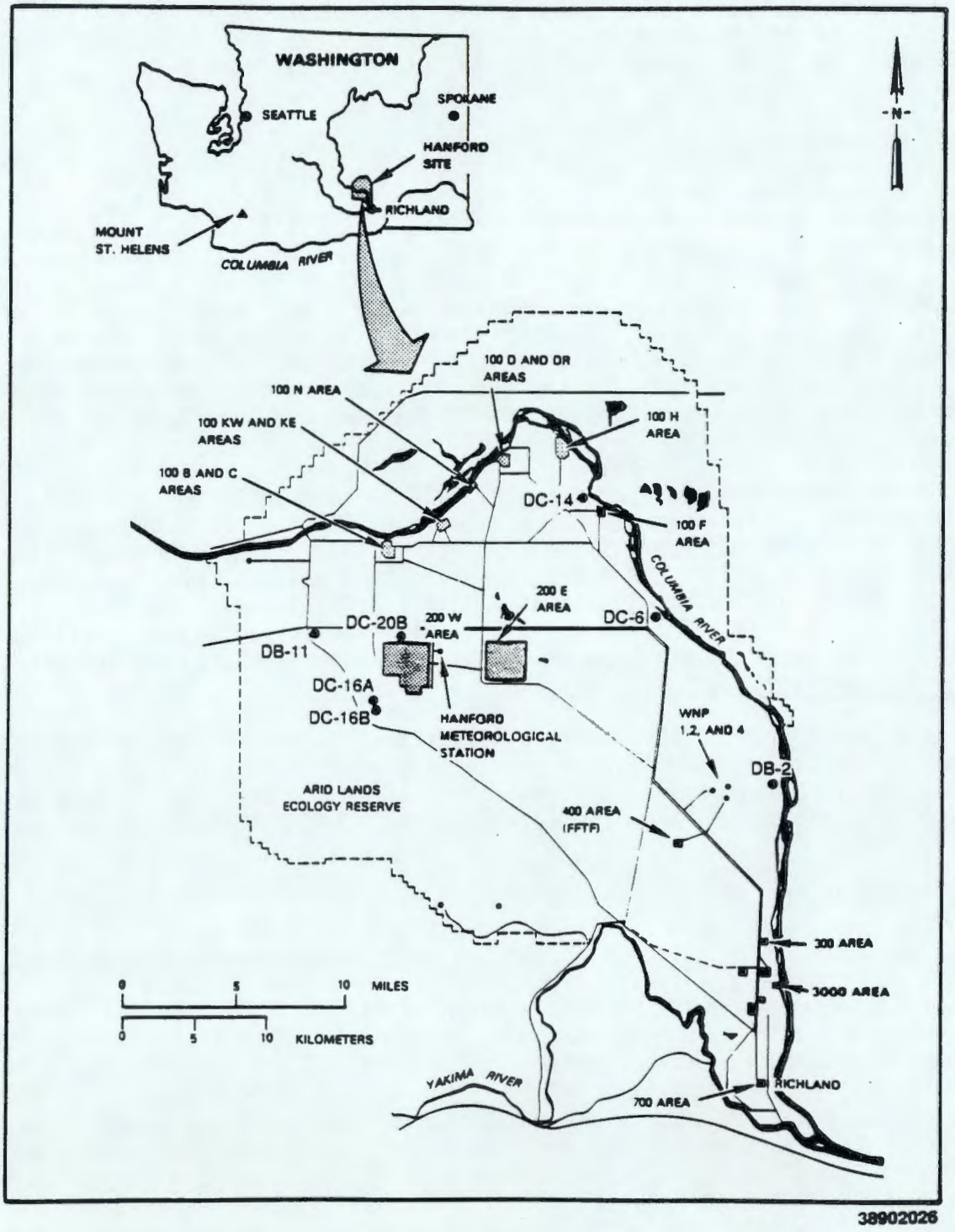

Figure 1. Hanford Site Map with Borehole Locations.

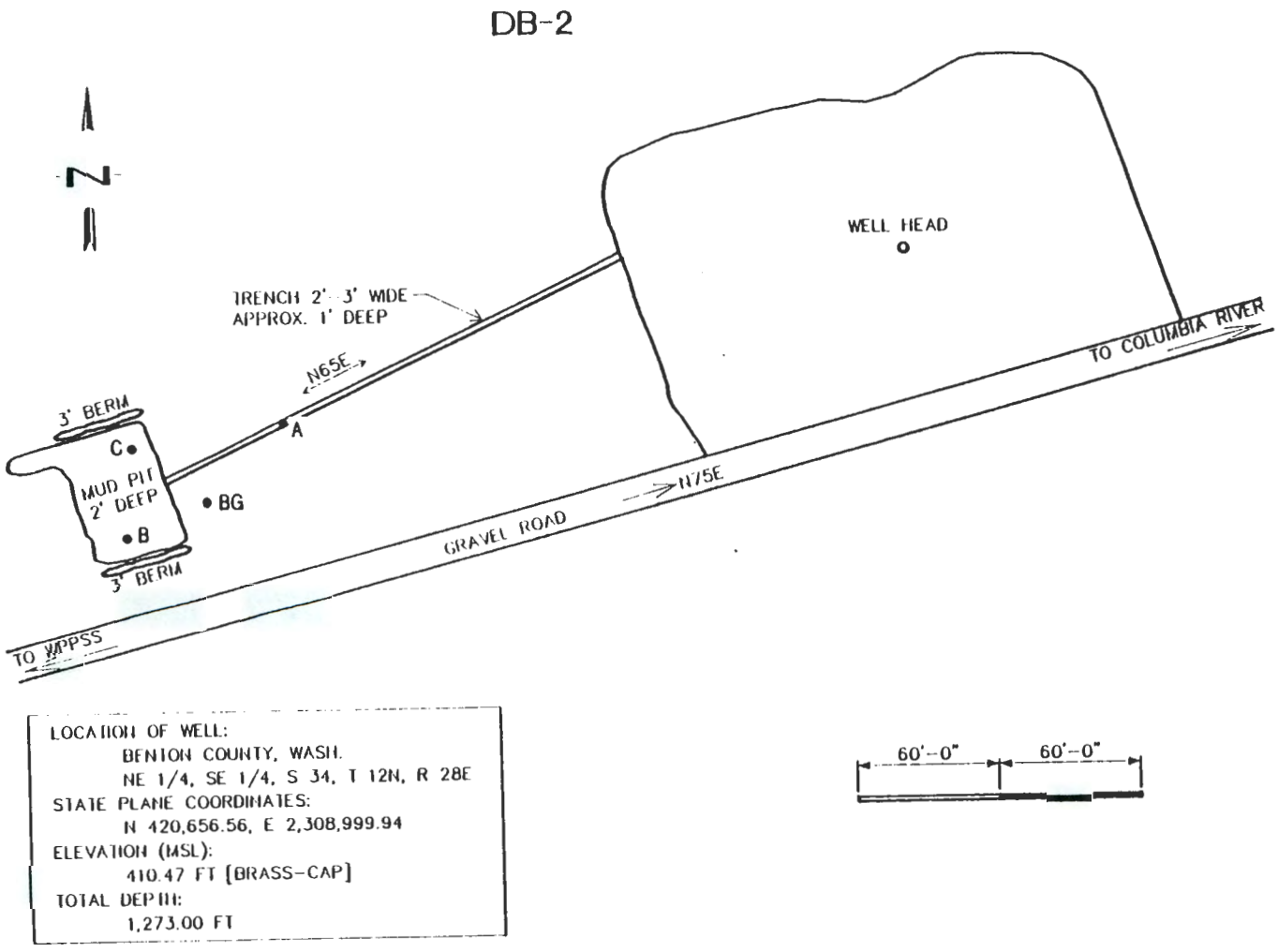

Figure 2. Borehole DB-2 and Mud Pit Sampling Locations (A, B, C, and Background).

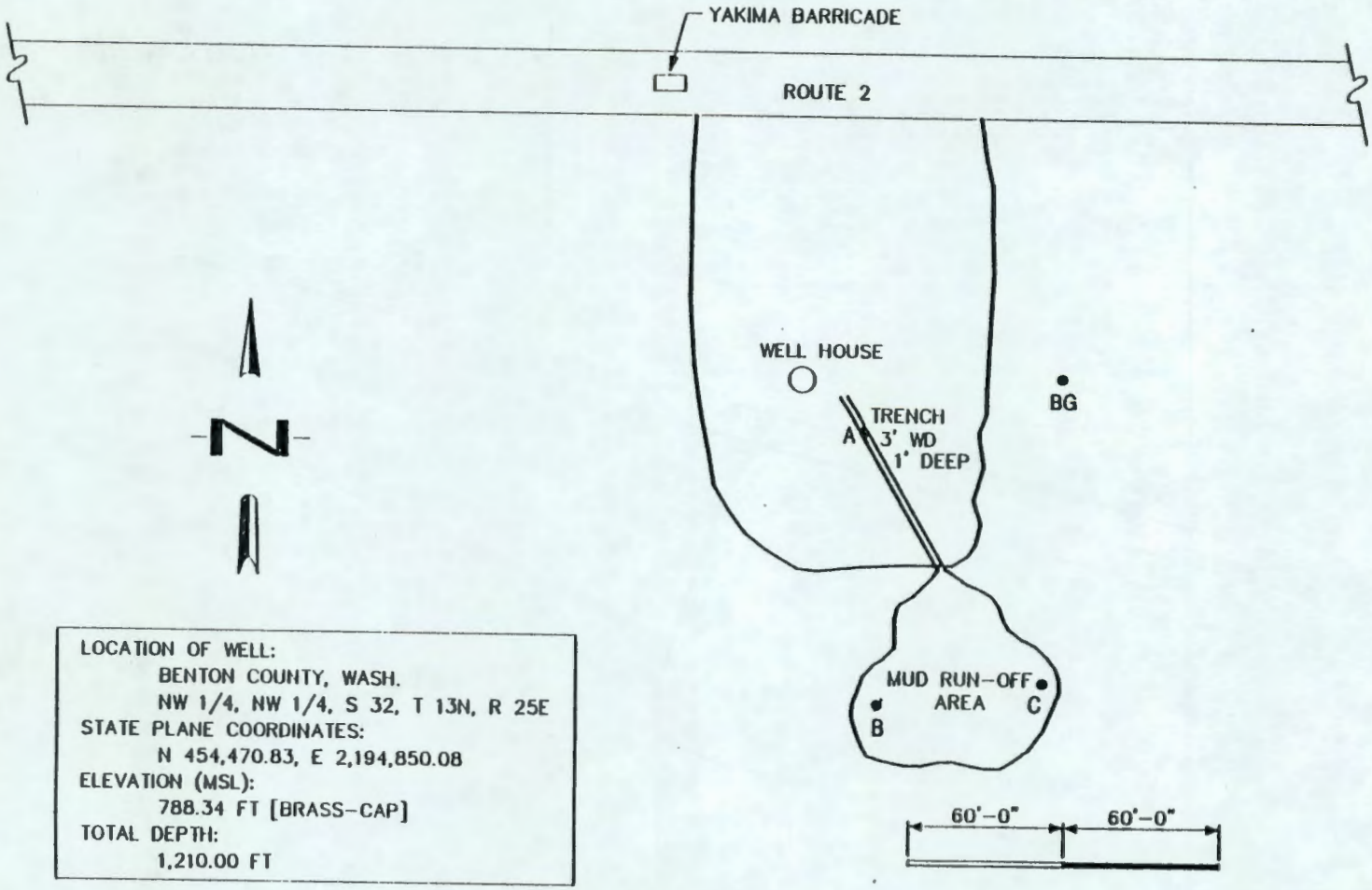

Figure 3. Borehole DB-11 and Mud Pit Sampling Locations (A, B, C, and Background).

the runoff. There is no visual indication of mud on the surface. The depth to groundwater at this location is approximately 325 ft from the surface. Drilling at DB-11 was conducted between August and October 1977.

During the course of drilling at DB-11, 12 100-lb sacks of BAROID* were used in the drilling mud. The primary constituent of concern in the BAROID additive is barium (as $BaSO_4$). Trace amounts (on the order of 0.05 to 2.3 p/m) of arsenic, cadmium, chromium, cobalt, mercury, and nickel can also be found in this product. Additionally, 110 gal of diesel fuel were used as downhole lubricant and are considered part of this study.

2.3 BOREHOLE DC-6

Borehole DC-6 (Fig. 4) is located on the east-central portion of the Hanford Site near the old Hanford townsite. A cable-tool drilling rig was used to drill a starter hole to a depth of 354 ft. The starter hole was then lined with 6.625-in.-dia casing. The borehole was then core drilled to a depth of 3,981 ft with the borehole diameter being reduced in size several times before final completion. Borehole DC-6 is cased with 3.5-in.-dia casing through the Vantage Interbed to a depth of 2,260 ft. A confined aquifer was encountered at 2,438 ft. This aquifer produced artesian flows at the surface. The well flowed at a rate of approximately 8 gal/min with a shut-in pressure of 9.1 lbf/in^2. Water flowed from the borehole at completion at 14 to 18 gal/min. Drilling fluids and water were channeled through conduits (hoses and/or pipes) to an excavated pit approximately 150 ft long, 35 ft wide, and 10 ft deep. The pit currently remains open. There is little visual indication of mud present in the pit. The depth to groundwater at DC-6 is approximately 35 ft below the surface.

Core drilling at DC-6 was conducted between December 1977 and May 1978. During the course of core drilling, a polymer-bentonite-based mud was used to a depth of 1,100 ft. From 1,100 to 2,483 ft, where flowing water was encountered, a hydroxyethylcellulose-based drilling fluid was used. The primary constituents of concern are contained in a corrosion inhibitor that was used as a drilling fluid additive and includes cadmium (<0.5 p/m), phosphoric acid (<2%), and polychlorinated biphenyls (PCB) (<1.0 p/m). The total amount of corrosion inhibitor added to the system was 5 gal. Also under consideration in this investigation is the addition of 145 gal of organic mud lubricant and 220 gal of diesel fuel.

2.4 BOREHOLE DC-14

Borehole DC-14 (Fig. 5) is located on the east-central portion of the Hanford Site near the west shore of the Columbia River. An area approximately 250 ft long and 175 ft wide was leveled to accommodate the drilling equipment. The borehole was cable-tool drilled to a depth of 368 ft and lined with 8.625-in.-dia casing to 359 ft. A core rig was then used to drill to

*BAROID is a trade name for N. L. Baroid/N. L. Industries.

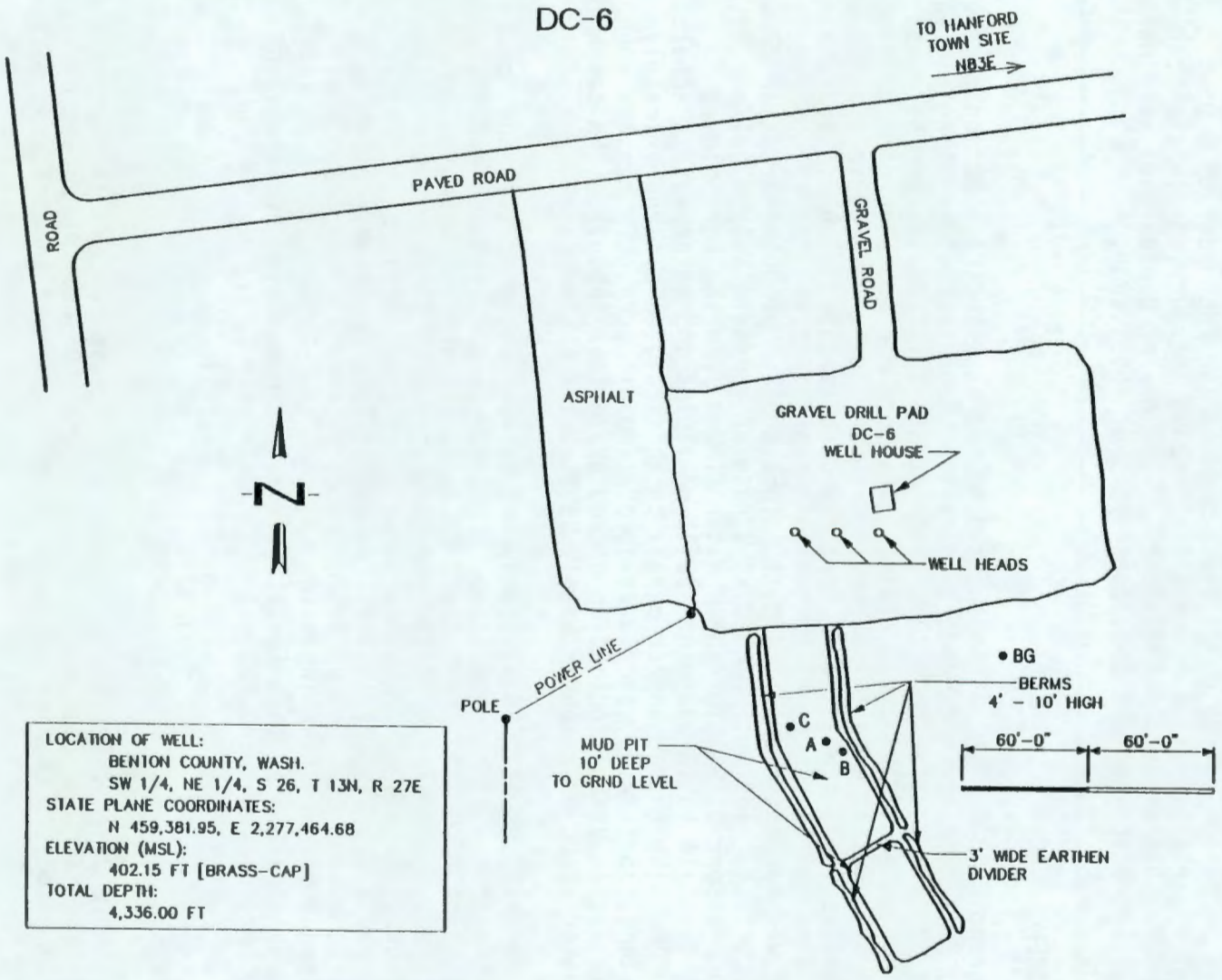

Figure 4. Borehole DC-6 and Mud Pit Sampling Locations (A, B, C, and Background).

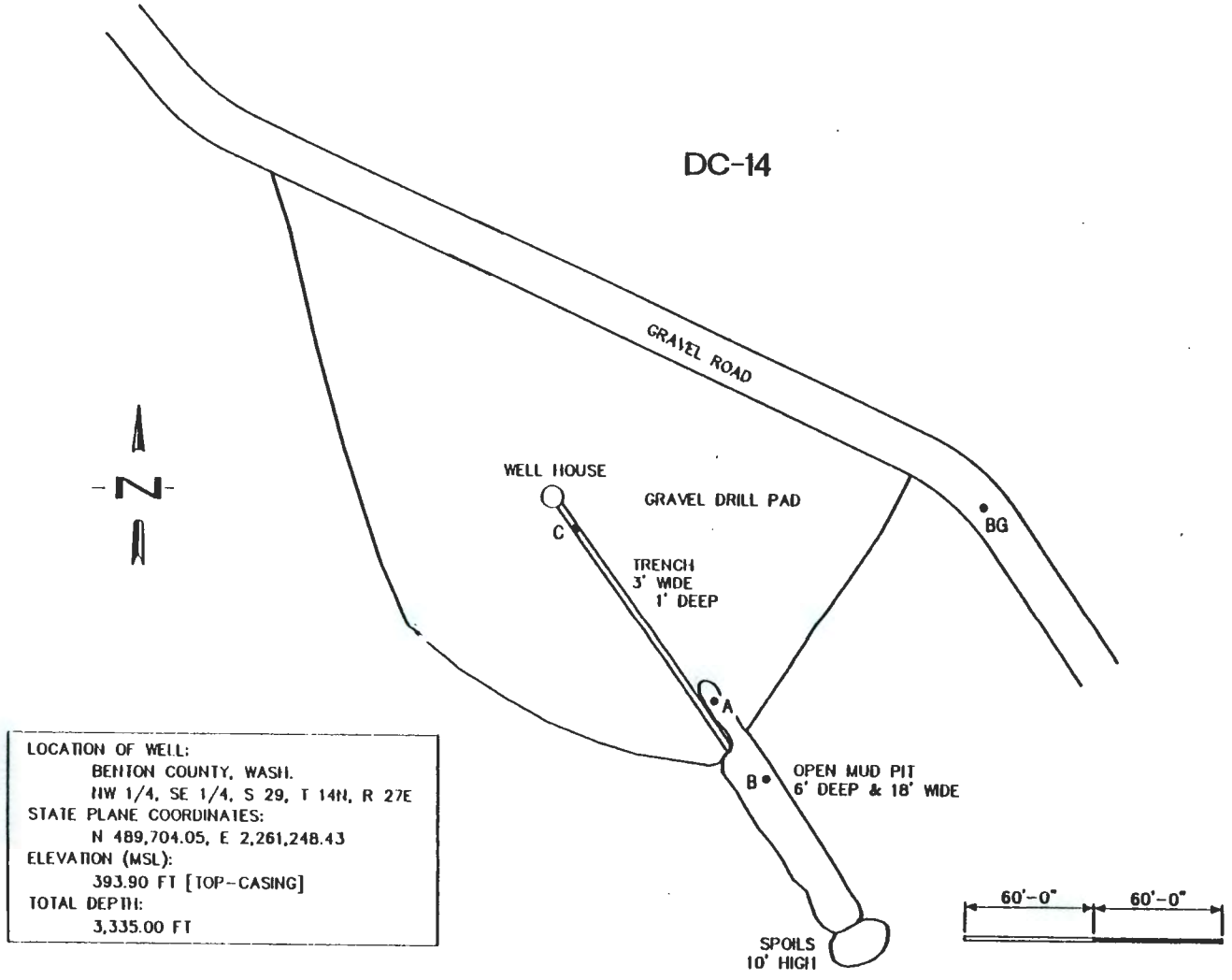

Figure 5. Borehole DC-14 and Mud Pit Sampling Locations (A, B, C, and Background).

3,336 ft. The diameter of the borehole was reduced in size several times before reaching total depth. The borehole produced artesian flow from the Grande Ronde Basalt Formation at a rate of approximately 10 gal/min. Drilling fluid used during the operation, as well as water produced by the borehole, was channeled along a narrow trench to an excavated mud pit approximately 130 ft long, 18 ft wide, and 6 ft deep. Both the trench and mud pit remain open and show little visual evidence of drilling mud. Coring activities were begun in January 1980 and completed in February 1981. The depth to groundwater at this location is approximately 25 ft below the surface.

Core drilling operations at DC-14 used a polymer-bentonite-based mud as the drilling fluid. During the course of drilling, 28 100-lb sacks of BAROID were used in the drilling mud (see Section 1.2). Eight 50-lb sacks of caustic soda were also used as part of this drilling fluid. This additive consists almost entirely of sodium hydroxide, which may have increased the pH of the soils beneath the mud pit.

2.5 BOREHOLE DC-16A

Borehole DC-16A (Fig. 6) is located on the west-central portion of the Hanford Site, approximately 1.5 mi southwest of the 200 West Area. Borehole DC-16A is situated on a large, graveled drill pad measuring approximately 445 by 310 ft. The borehole was cable-tool drilled to a depth of 615 ft and lined with 6.625-in.-dia casing to 602 ft. A core rig was then used to drill to 4,398 ft, and the diameter of the borehole was reduced in size several times before completion. Fluids from the drilling operations were run into an excavated mud pit on the north side of the borehole. The pit was subsequently backfilled and graveled; thus, the size and location of the pit can only be approximated. Coring activities were begun in August 1981 and completed in May 1983. The depth to groundwater at this location is approximately 180 ft below the surface.

In the course of the drilling activities, 181 50-lb sacks of RAYKROME were used as an additive to the drilling fluid. This product contained chromium III.

2.6 BOREHOLE DC-16B

Borehole DC-16B (Fig. 6) is located approximately 50 ft south of DC-16A. Borehole DC-16B was cable-tool drilled to a depth of 170 ft and a 20-in.-dia casing was set to 1,368 ft. Drilling fluids used during the operations were channeled into an excavated mud pit on the south side of the borehole. The pit was subsequently backfilled and partially graveled, thus, the exact size of the pit can only be approximated. Drilling operations at this site occurred during November and December 1982. The depth to groundwater at this location is approximately 180 ft below the surface.

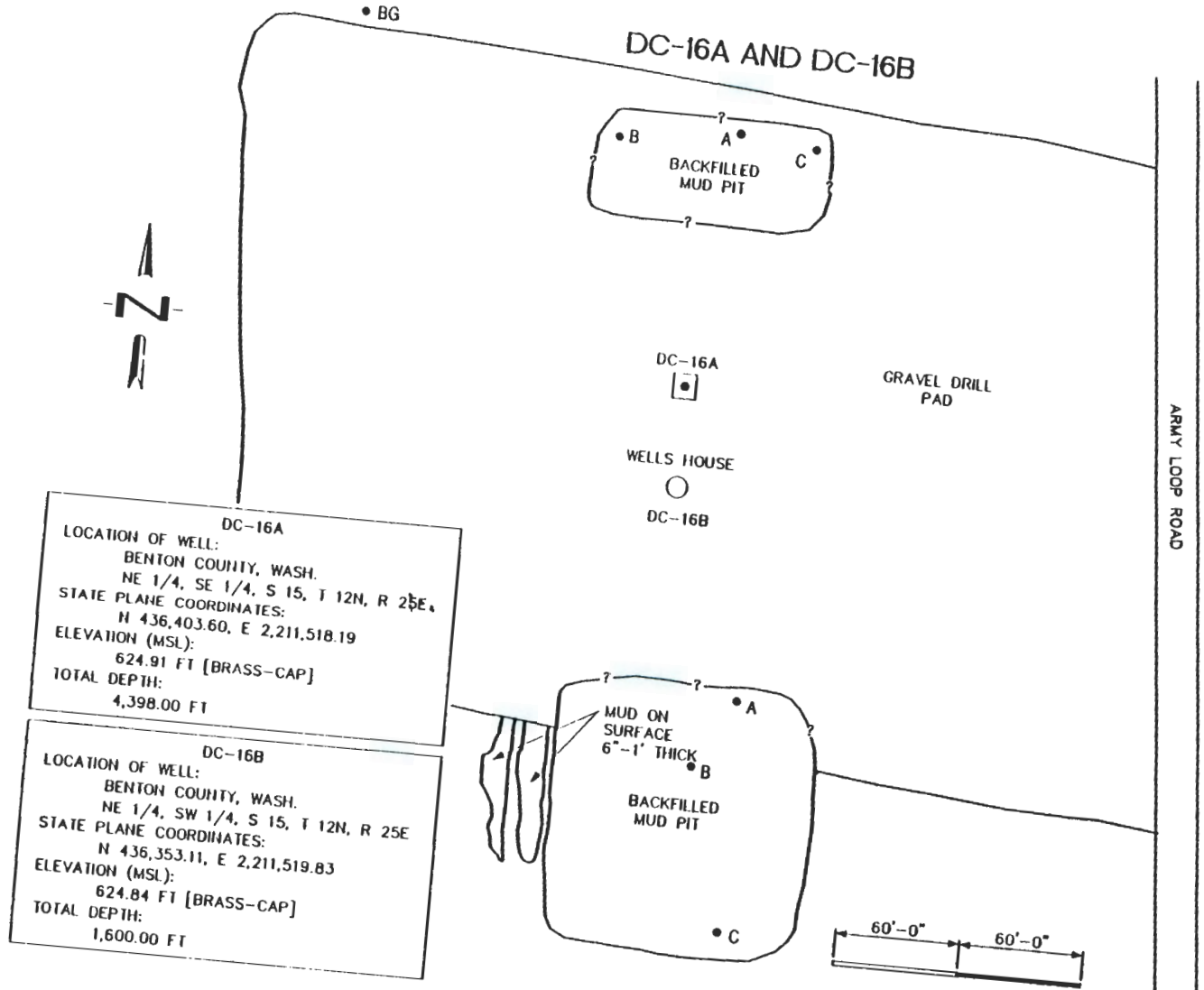

Figure 6. Boreholes DC-16A and 16B and Mud Pit Sampling Locations (A, B, C, and Background).

In the course of the drilling activities at DC-16B, 12 50-lb sacks of RAYKROME and 31 50-lb sacks of caustic soda were used as constituents of the drilling fluid. The chemicals being investigated in these compounds (chromium III and sodium hydroxide, respectively) have been discussed.

2.7 BOREHOLE DC-20B

Borehole DC-20B (Fig. 7) is located on the central portion of the Hanford Site just north of the 200 West Area perimeter fence. Borehole DC-20B is situated on a large, graveled drill pad measuring approximately 445 by 390 ft and has a relatively thick gravel cover. The borehole was drilled as one of a cluster of wells for hydrologic testing purposes. The DC-20B borehole was cable-tool drilled to a depth of 40 ft and a 20-in.-dia conductor casing was installed. A rotary rig then drilled to a depth of 1,560 ft and 13.375-in.-dia casing was set to total depth. Drilling fluids used during the operations were channeled into an excavated mud pit on the southwest side of the borehole. The mud pit has been partially backfilled to one side (Fig. 6); therefore, the exact size of the pit can only be approximated. The depth to groundwater at this location is approximately 245 ft below the surface.

During drilling activities at DC-20B, 61 50-lb sacks of caustic soda (sodium hydroxide) were added to the drilling fluid, which may have increased the pH of the soils.

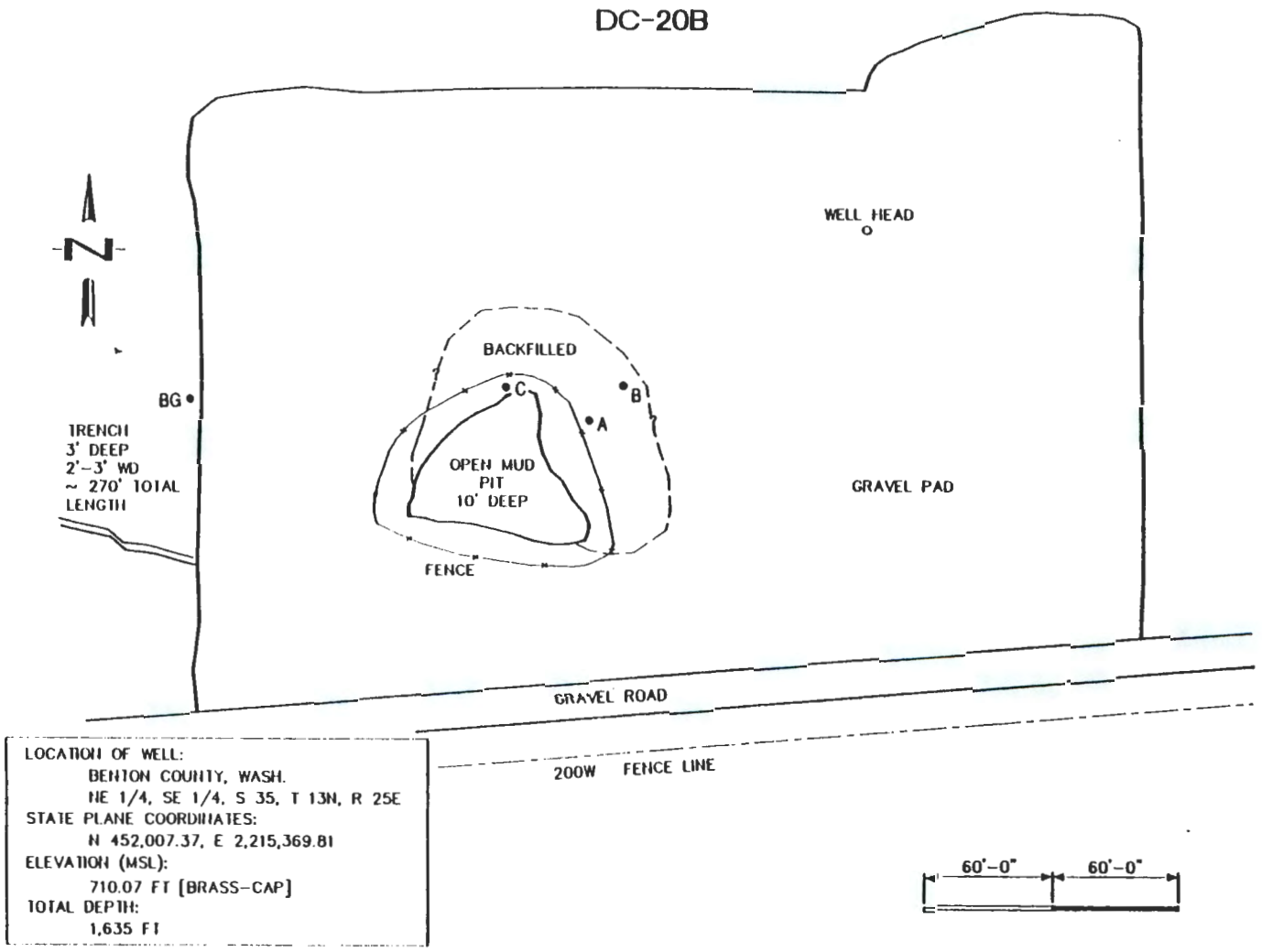

Figure 7. Borehole DC-20B and Mud Pit Sampling Locations (A, B, C, and Background).

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3.0 SAMPLING

All of the open mud pits show little visual evidence of the muds left behind by the drilling operations. The mud has either blown away or percolated into the soil column. Therefore, the soils and sediments underlying these pits were sampled. At the backfilled sites, the bottom of the pit was determined either by a noticeable change in lithology between the backfill and the natural soils (DC-16A, DC-16B, and DC-20B, sites B and C) or by the layer of drilling mud (DC-20B, site A).

3.1 SAMPLING STRATEGY

Four sampling strategies are typically applied to soil and sediment characterization efforts. The four methods include simple random, stratified random, systematic, and authoritative sampling. Where there is a lack of information about the precise spatial distribution of contaminants in the area of study, the simple random or systematic sampling designs are effective approaches to selecting sample locations (Mason 1983). Although the mud pits in this study represented relatively small areas and were likely to be nearly homogeneous with regard to the spatial distribution of chemical contaminants, a simple random sampling was initially employed in this evaluation.

Information about the specific chemicals in the mud pits is based on BWIP shift-report-of-operations records, which document the type and quantity of drilling fluid additives introduced at each of the subject sites. Table 1 categorizes the boreholes by the type and amount of potentially hazardous products that were added to the mud system, and lists the name and concentration of each hazardous constituent in the product (when known). Since the chemical constituents introduced in the mud pits are well documented, only hazardous constituents introduced by drilling activities were considered in this evaluation.

3.2 SAMPLING DESIGN

The design of sample collection was based on the assumption that all sites contained a localized area of contamination at or near the bottom of the mud pit. To comply with quality assurance/control requirements, split and background samples were collected. Split samples were used to measure the internal consistency of the sample. Background samples were collected to establish baseline values for concentrations of chemical constituents that may also occur naturally.

Table 1. Mud Products, Quantities, and Chemical Constituents Identified by Borehole.

Borehole designation	Mud additive (product name)	Quantity of additive	Chemical constituents of concern identified
DB-2	RAYKROME	800 lb	Chromium III
DB-11	BAROID	1,200 lb	Barium (as $BaSO_4$)
	Diesel fuel	110 gal	Various hydrocarbons
DC-6	Caustic soda	100 lb	Sodium hydroxide
	AZ-2 (organic mud lubricant)	145 gal	Unknown organics
	235-A (corrosion inhibitor)	5 gal	Cadmium, phosphoric acid, and PCBs
	Diesel fuel	200 gal	Various hydrocarbons
DC-14	BAROID	2,800 lb	Barium (as $BaSO_4$)
	Caustic soda	400 lb	Sodium hydroxide
DC-16A	RAYKROME	9,050 lb	Chromium III
DC-16B	RAYKROME	600 lb	Chromium III
	Caustic soda	1,550 lb	Sodium hydroxide
DC-20B	Caustic soda	3,050 lb	Sodium hydroxide

3.2.1 Sample Locations

Each study area was sectioned into one or more sample grids. Where a study area contained a mud pit and trench, these areas were treated separately. Multiple sample grids within a single study area were designated by a unique prefix (e.g., A, B, C, etc.). Each mud pit contained two individual sampling points and each trench contained one sampling point. Mud pits with no associated trench (DC-6, DC-16A & B, and DC-20B) were assigned a third, unique sample location within the pit.

Each mud pit was divided into 4-ft squares to establish a grid for sampling. Grid squares were numbered, and sample points selected at random from among the numbered squares. Given the narrow dimension of the trenches, a random sampling location was selected based only on the length of the trench (in feet). Each sample point was scaled off, located in the field, and marked so as to be easily identified. Documentation of the random selection process was entered into the field log book or the project file.

3.2.2 Sample Depth

All samples were collected at 2-ft intervals within 8 ft of the original pit or trench bottom. The first sample was collected as close to the original bottom of the pit or trench as possible (not more than 2 ft below the bottom). The second sample was collected from 2 to 4 ft below the first and so on for the remaining two samples. Therefore, each sample point was represented by four discreet samples. Each borehole location was thus characterized by a total of 14 samples (12 grab samples, 1 split sample, and 1 background sample). However, at borehole DC-16A, because of the difficulty in determining the bottom of the pit, extra samples were taken at sites A and B. At borehole DC-20B, site A, because of the inability of the auger rig to penetrate the rocky soils, only the first 4 ft below the mud pit were sampled. Table 2 shows the depth for each sample taken.

3.2.3 Background Sample

At least one background sample was taken near each borehole location. Each background sample was selected from comparable geologic strata at a similar horizon (0 to 8 ft below the original pit bottom) to those samples collected within the sample area. The background sample was tested for the same analytes as the other samples from the nearby site. Background samples consisted of an individual sample rather than a composite. All background samples were taken at location D (marked as BG on all figures) at 2 and 4 ft below the surface, except at site DC-16 where an additional sample was taken at 7 to 9 ft below the surface.

Physical setting (i.e., borehole location) was the criterion used to classify background values into groups. (See Section 1.1 for a detailed description of the borehole locations.) Background values at boreholes DB-11, DC-16A, DC-16B, and DC-20B were combined to calculate the background summary statistics for DB-11 and DC-20B. This was done because of the close proximity of the mud pits to each other. The second group consisted of combined background values from sites that were close to the Columbia River (DB-2, DC-6, and DC-14). Background values from DC-16A and DC-16B were combined due to their proximity to each other.

3.2.4 Sample Collection

Samples were collected with a power auger drill at sites DB-11, DC-14, DC-16A, and DC-16B. An attempt was made to collect the samples with the auger drill at sites DB-2, DC-6, and DC-20B; however, a backhoe had to be used at these sites because of the cobbly nature of the soils. The auger drill or backhoe was located as near as possible to the grid number generated by the random-number generator. Several of the mud pits were covered by overburden (DC-16A, DC-16B, and DC-20B). This overburden was drilled through or excavated until evidence of the bottom of the mud pit was noted; the four samples for that location were taken from that point. It should be noted

Table 2. Depth of Each Sample Below Ground Surface.

Sample number	Borehole (depth in ft)						
	DB-2[a]	DB-11[a]	DC-6[a]	DC-14[a]	DC-16A[b]	DC-16B[b]	DC-20[b]
A1	0 - 2	0 - 2	0 - 2	0 - 2	4 - 5	4 - 6	8 - 10
A2	2 - 4	2 - 4	2 - 4	2 - 4	5 - 6	6.67 - 8.67	10 - 12
A3	4 - 6	4 - 6	2 - 4	4 - 6	6 - 8	8.67 - 10.67	12 - 14
A4	6 - 8	6 - 8	4 - 6	6 - 8	8 - 10	10.67 - 12.67	14 - 16
A5			6 - 8		10 - 12		
B1	0 - 2	0 - 2	0 - 2	0 - 2	5 - 6	4 - 6	0 - 2[d]
B2	2 - 4	2 - 4[c]	2 - 4	2 - 4[c]	6 - 8	6 - 8[c]	2 - 4[c]
B3	4 - 6[c]	2 - 4	4 - 6	2 - 4[c]	8 - 10	6 - 8[c]	2 - 4[c]
B4	4 - 6[c]	4 - 6	6 - 8	4 - 6	10 - 12[c]	8 - 10	4 - 6[d]
B5	6 - 8	6 - 8		6 - 8	10 - 12[c]	10 - 12	6 - 8[d]
B6					12 - 14		
B7					14 - 15.25		
C1	0 - 2	0 - 2	0 - 2	0 - 2	6 - 8	4 - 6	0 - 2[d]
C2	2 - 4	2 - 4	2 - 4	2 - 4	8 - 10	6 - 8	2 - 4[d]
C3	4 - 6	4 - 6	4 - 6	4 - 6	12 - 14	8 - 10	4 - 6[d]
C4	6 - 8	6 - 8	6 - 8	6 - 8	10 - 12	10 - 12	6 - 8[d]
D1	2 - 4	2 - 4	2 - 4	2 - 4		2 - 4	2 - 4
D2						7 - 9	

[a]Open mud pit.

[b]Mud pit covered by overburden. (See description below for how bottom of mud pit was located.)

[c]Split sample.

[d]Depth from bottom of mud pit:

DC-16A - The bottom of the mud pit was indicated by a change in lithology. For Location A, this occurred between 4 to 6 ft below ground surface. For Location B, it occurred between 8 to 10 ft, and for Location C, it was between 6 to 8 ft.

DC-16B - For all locations, change in lithology between 4 to 6 ft indicated bottom of mud pit. Location A had a cobble between 6 to 6.67 ft.

DC-20B - Samples at Location A were taken through the overburden with power auger. The last 4 ft of sample could not be taken due to rocky soil. The upper two samples at this location are of the mud left in the pit. The bottom of the mud pit occurs 11 to 13 ft below overburden. For Locations B and C the overburden was removed to get a backhoe onto the locations and samples were taken from the sediments and soils underlying the mud pit.

that the bottom of the mud pit was difficult to determine for DC-16A and DC-20B. In the case of DC-16A, extra samples were taken at deeper depths at sample locations A and B. For site DC-20B, the depth of overburden was thick (>8 ft), and the first two samples at sample location A contained drilling mud, which indicated that the bottom of the pit had not been penetrated by the drill. These first two samples were also analyzed.

Samples collected by the auger drill were collected in a separate insert placed inside a 3-in.-dia split-tube barrel. The core barrel was then driven to the appropriate depth (2 ft) and then removed from the sample hole. The insert was then emptied into a bowl to thoroughly mix the sample before placing it into a sample bottle.

Due to the cobbly nature of the soils at sites DB-2, DC-6, and DC-20B, a backhoe was used to collect the samples. The backhoe dug to the appropriate depth, then scraped the sides of the wall to obtain the sample. The sample was taken from the center of the backhoe scoop, sieved through a mesh into a bowl, and mixed before being placed into a sample bottle.

Each sample was collected and handled using a different set of laboratory-cleaned stainless steel inserts. All sample bottles had been previously cleaned according to U.S. Environmental Protection Agency (EPA) specifications and quality control requirements. The sample bottles were then labeled, sealed with security tape, individually packaged, and immediately placed on ice (cooled to 4 °C). The appropriate chain of custody and analysis request forms were filled out and accompanied the shipment of samples to United States Testing Company, Inc. (U.S. Testing). All samples were transported to the laboratory on the day of collection.

The U.S. Testing Company serves as the Hanford Site contractor for analyses of all environmental samples collected onsite. All samples were shipped to the U.S. Testing facility in Richland, Washington, within 24 h of collection.

3.3 ANALYTES

The analytes for the soils and sediments underlying the mud pits at the above-mentioned sites were based on the information provided by the material safety data sheet for each of the drilling additives listed in Table 1. The analyses performed to identify each additive are listed in Table 3.

Table 3. Analyses to be Performed on Soil Samples, Specified by Borehole Location.

Borehole designation	Chemical constituents of concern identified	Analyses to be performed
DB-2	Chromium III	Metals,[a] pH
DB-11	Barium (as $BaSO_4$), various hydrocarbons	Metals, mercury, total organic carbon (TOC), extractable organic (EO), pH, anions[b]
DB-6	Sodium hydroxide, cadmium, phosphoric acid, polychlorinated biphenyls (PCB), unknown organics, various hydrocarbons	Metals, TOC, EO, pH, PCBs,[c] anions
DC-14	Barium (as $BaSO_4$), sodium hydroxide	Metals, mercury, pH, anions
DC-16A	Chromium III	Metals, pH
DC-16B	Chromium III, sodium hydroxide	Metals, pH, anions
DC-20B	Sodium hydroxide	Metals, pH, anions

[a]Metals analyses include aluminum, antimony, barium, beryllium, cadmium, calcium, chromium, copper, iron, manganese, magnesium, nickel, potassium, silver, sodium, strontium, vanadium, and zinc.

[b]Anion analyses include chloride, fluoride, nitrate, phosphate, and sulfate.

[c]Must specify PCB analysis by U.S. Testing method 739 (EPA 1986), which includes the following arochlors: 1016, 1221, 1232, 1242, 1248, 1254, and 1260.

4.0 RESULTS

Tables 4 through 10 show the results for all chemicals analyzed at each of the sites. Sample numbers indicate the site, location, and relative depth of the sample; i.e., DC-16A is the mud pit site. The location of borehole DC-16A is shown in Figure 1. The last part of the number (-A1, -B1, -A3, etc.) refers to the sample locations (A, B, C, and D), which are shown for each of the sites in Figures 2 through 7, while the number refers to the relative depth (with 1 indicating the shallowest sample taken at that location). All values are reported in micrograms per gram (micrograms/gram) except for pH. Values at or below detection were not included in these tables. Therefore, beryllium (0.5 micrograms/gram), cadmium (0.2 micrograms/gram), silver (1.0 micrograms/gram), and antimony (10.0 micrograms/gram) for all sites, and PCBs (1.0 micrograms/gram), and extracted organics (EO) variable, total organic carbon (TOC) (10.0 micrograms/gram), and phosphate (2.0 micrograms/gram) at selected sites were eliminated from further consideration as a result of being at or below detection limits and below regulatory concern.

Additionally, because basaltic soils naturally contain barium and chromium, an extraction process (EP) toxicity test (EPA 1980, 1988) was performed to determine if these constituents were in a leachable form. The samples analyzed with this test included a "worst case" sample and the background sample from each site. The worst case would be defined as the sample with the highest value for the chemical of concern (i.e., for DC-14, it would be barium; for DC-16A, it would be chromium). The results from this test are presented in Table 11. An ignitability test was also run at sites in which diesel fuel was used as an additive. A complete set of data packages for all analyses will be provided upon request.

4.1 DATA EVALUATION

The following approach was used to reduce the data.

1. Remove from consideration chemicals that are not of concern; i.e., fluoride, chloride, strontium, vanadium, etc., which were not identified in the shift report of operations as being introduced. The chemical constituents that are of concern for each mud pit are identified in Table 3.

2. Eliminate from further consideration hazardous constituents or specific analyses that are present at or below detection limits because, at the detection level, the constituents are below regulatory concern.

3. Prepare summary statistics for constituents.

Table 4. Summary Analyses for Soils Underlying the Mud Pit at Site DB-2.

Sample location and numbers	Analytes (µg/g except for pH)						
	pH	Strontium	Zinc	Calcium	Barium	Chromium	Sodium
DB-2-A1	8.6	19.6	37.2	3,190.0	66.9	9.8	161.0
DB-2-A2	8.8	18.1	38.1	5,340.0	64.2	2.9	209.0
DB-2-A3	8.6	18.0	36.1	4,190.0	67.8	6.4	166.0
DB-2-A4	8.9	15.4	27.7	4,420.0	42.1	2.3	157.0
DB-2-B1	9.1	20.3	41.7	3,490.0	80.2	11.5	317.0
DB-2-B2	9.0	14.6	28.0	4,450.0	46.5	1.7	168.0
DB-2-B3 split	9.0	17.7	30.9	5,760.0	63.4	2.6	194.0
DB-2-B4 split	8.9	16.3	32.9	5,570.0	51.9	2.4	200.0
DB-2-B5	8.5	17.2	31.9	5,070.0	51.7	2.8	176.0
DB-2-C1	9.1	25.5	45.1	8,210.0	88.1	11.2	240.0
DB-2-C2	8.9	15.6	30.2	4,600.0	48.5	2.6	166.0
DB-2-C3	8.8	16.7	31.2	4,820.0	51.9	3.3	175.0
DB-2-C4	8.9	19.4	30.4	5,420.0	52.7	2.5	202.0
DB-2-D1 background	8.9	21.0	50.0	4,980.0	66.6	5.8	213.0

BDL = Analysis is below detection limit. (Number enclosed by parentheses is the detection limit.)

Table 4. Summary Analyses for Soils Underlying the Mud Pit at Site DB-2. (cont.)

Sample location and numbers	Analytes (µg/g except for pH)							
	Nickel	Copper	Vanadium	Aluminum	Manganese	Potassium	Iron	Magnesium
DB-2-A1	8.2	(1.0)BDL	34.9	6,280.0	266.0	1,310.0	16,500.0	4,150.0
DB-2-A2	4.0	1.8	39.5	4,600.0	266.0	522.0	22,100.0	4,280.0
DB-2-A3	6.2	BDL	35.7	6,190.0	285.0	869.0	20,900.0	4,650.0
DB-2-A4	3.7	7.0	27.2	3,330.0	207.0	450.0	16,400.0	3,120.0
DB-2-B1	9.2	1.0	46.5	7,140.0	313.0	1,470.0	20,100.0	4,750.0
DB-2-B2	3.7	5.1	26.8	3,570.0	213.0	463.0	20,400.0	3,830.0
DB-2-B3 split	4.4	6.5	28.8	4,150.0	275.0	595.0	19,700.0	4,050.0
DB-2-B4 split	3.8	3.6	33.6	3,910.0	236.0	498.0	20,800.0	3,870.0
DB-2-B5	4.3	4.9	30.4	4,370.0	243.0	543.0	21,100.0	4,130.0
DB-2-C1	10.3	3.5	43.5	8,410.0	322.0	1,310.0	21,300.0	5,210.0
DB-2-C2	4.0	5.1	28.6	4,110.0	229.0	473.0	19,000.0	3,610.0
DB-2-C3	4.2	4.4	29.9	3,940.0	221.0	593.0	16,700.0	3,270.0
DB-2-C4	4.1	5.1	29.8	4,090.0	214.0	483.0	20,700.0	3,810.0
DB-2-D1 background	7.0	BDL	55.6	6,600.0	332.0	843.0	27,400.0	5,270.0

BDL = Analysis is below detection limit. (Number enclosed by parentheses is the detection limit.)

Table 5. Summary Analyses for Soils Underlying the Mud Pit at Site DB-11.

Sample location and numbers	Analytes (µg/g except for pH)									
	pH	Strontium	Zinc	Calcium	Barium	Chromium	Sodium	Nickel	Copper	Vanadium
DB-11-A1	8.5	54.8	49.6	15,700.0	206.0	12.5	363.0	10.0	1.8	58.9
DB-11-A2	8.4	56.1	45.5	15,400.0	128.0	13.7	389.0	12.6	3.7	54.3
DB-11-A3	8.3	44.1	51.5	14,400.0	123.0	13.5	264.0	11.4	7.7	31.6
DB-11-A4	8.4	40.6	48.5	18,400.0	102.0	14.0	271.0	12.4	11.8	30.4
DB-11-B1	8.3	30.9	44.1	11,400.0	117.0	11.4	183.0	10.3	4.5	47.0
DB-11-B2 split	8.4	55.5	43.0	15,400.0	120.0	11.7	415.0	11.4	2.5	49.3
DB-11-B3 split	8.3	55.7	42.2	15,600.0	117.0	11.1	396.0	10.9	3.1	46.1
DB-11-B4	8.2	56.7	51.9	19,000.0	128.0	14.4	485.0	11.9	5.8	46.0
DB-11-B5	8.5	43.9	51.7	15,100.0	104.0	15.0	348.0	13.5	9.4	35.6
DB-11-C1	8.5	37.2	42.8	17,700.0	125.0	11.5	160.0	10.1	3.2	47.9
DB-11-C2	9.0	50.0	39.6	18,200.0	103.0	12.0	324.0	11.5	4.5	41.6
DB-11-C3	9.3	39.6	45.3	15,400.0	105.0	13.9	447.0	11.5	6.9	37.4
DB-11-C4	9.4	37.8	49.5	17,000.0	103.0	14.8	403.0	12.0	8.5	32.2
DB-11-D1 background	8.3	71.9	47.8	19,600.0	139.0	14.2	882.0	12.2	4.0	59.1

BDL = Analysis is below detection limit. (Number enclosed by parentheses is the detection limit.)

Table 5. Summary Analyses for Soils Underlying the Mud Pit at Site DB-11. (cont.)

Sample location and numbers	Analytes (µg/g except for pH)									
	Aluminum	Manganese	Potassium	Iron	Magnesium	Nitrate	Sulfate	Fluoride	Chloride	TOC
DB-11-A1	12,500.0	403.0	1,490.0	26,000.0	6,790.0	12.7	3.8	1.0	2.0	67.1
DB-11-A2	12,700.0	415.0	1,770.0	24,700.0	6,860.0	17.1	410.0	2.9	(1.0) BDL	46.7
DB-11-A3	11,100.0	398.0	2,440.0	21,700.0	8,130.0	3.2	238.0	1.0	BDL	(10.0) BDL
DB-11-A4	10,500.0	390.0	2,222.0	20,700.0	8,200.0	1.1	270.0	(1.0) BDL	1.6	BDL
DB-11-B1	11,800.0	386.0	2,222.0	25,200.0	6,250.0	2.4	39.2	BDL	45.5	135.0
DB-11-B2 split	11,100.0	382.0	1,360.0	23,700.0	6,920.0	1.1	234.0	1.2	46.4	73.5
DB-11-B3 split	9,560.0	381.0	1,240.0	21,500.0	6,390.0	1.2	310.0	1.1	53.1	83.3
DB-11-B4	13,700.0	399.0	1,970.0	25,300.0	7,980.0	1.3	729.0	1.5	61.4	79.5
DB-11-B5	12,500.0	385.0	2,360.0	23,500.0	8,280.0	(1.0) BDL	441.0	2.8	5.5	13.5
DB-11-C1	11,200.0	376.0	1,860.0	23,500.0	5,880.0	2.2	2.7	1.0	BDL	131.0
DB-11-C2	10,300.0	340.0	1,460.0	19,300.0	6,300.0	BDL	15.3	4.4	2.6	45.4
DB-11-C3	12,800.0	394.0	2,290.0	22,900.0	7,480.0	BDL	23.4	4.1	BDL	16.0
DB-11-C4	11,700.0	378.0	2,240.0	20,500.0	7,720.0	BDL	12.7	2.7	BDL	11.5
DB-11-D1 background	12,600.0	405.0	1,490.0	24,600.0	7,490.0	2.7	911.0	3.5	1.9	74.0

BDL = Analysis is below detection limit. (Number enclosed by parentheses is the detection limit.)

Table 6. Summary Analyses for Soils Underlying the Mud Pit at Site DC-6.

Sample location and numbers	Analytes (µg/g except for pH)									
	pH	Strontium	Zinc	Calcium	Barium	Chromium	Sodium	Nickel	Copper	Vanadium
DC-6-A1	9.3	43.2	102.0	11,300.0	80.6	11.9	1,770.0	10.6	1.4	56.7
DC-6-A2 split	9.4	40.1	56.8	14,500.0	78.3	15.9	910.0	14.8	8.2	37.6
DC-6-A3 split	9.4	42.0	58.8	14,700.0	78.0	16.3	919.0	13.5	7.0	40.1
DC-6-A4	9.3	18.9	33.9	4,200.0	55.8	4.9	673.0	6.1	1.6	35.0
DC-6-A5	9.2	24.1	35.5	3,930.0	72.9	7.4	801.0	10.6	(1.0) BDL	43.0
DC-6-B1	9.6	28.7	44.1	7,450.0	56.6	10.8	797.0	12.0	2.2	41.6
DC-6-B2	9.6	19.4	31.7	3,210.0	66.7	7.8	683.0	12.4	BDL	33.9
DC-6-B3	9.6	30.5	34.5	3,510.0	76.6	7.4	650.0	9.7	BDL	42.2
DC-6-B4	9.6	26.3	36.4	3,760.0	66.5	7.5	785.0	9.3	BDL	41.7
DC-6-C1	9.6	31.3	32.1	5,350.0	56.7	9.5	495.0	8.5	4.4	26.0
DC-6-C2	9.4	40.4	52.6	10,600.0	82.6	18.0	961.0	16.4	8.4	43.6
DC-6-C3	9.5	24.3	37.0	4,870.0	56.9	8.2	590.0	9.5	BDL	42.2
DC-6-C4	9.6	25.6	39.5	5,070.0	59.7	8.8	677.0	10.4	BDL	44.9
DC-6-D1 background	7.0	23.5	47.5	4,180.0	103.0	10.2	207.0	9.3	BDL	57.6

BDL = Analysis is below detection limit. (Number enclosed by parentheses is the detection limit.)

Table 6. Summary Analyses for Soils Underlying the Mud Pit at Site DC-6. (cont.)

Sample location and numbers	Analytes (µg/g except for pH)										
	Aluminum	Manganese	Potassium	Iron	Magnesium	Nitrate	Sulfate	Fluoride	Chloride	EO	TOC
DC-6-A1	9,540.0	305.0	1,270.0	24,900.0	9,560.0	86.2	290.0	20.9	61.8	(VAR) BDL	102.0
DC-6-A2 split	9,720.0	376.0	1,600.0	23,600.0	7,310.0	2.1	44.7	7.2	25.7	BDL*	21.0
DC-6-A3 split	10,100.0	373.0	1,650.0	23,600.0	7,230.0	20.8	44.1	7.7	24.0	BDL*	28.0
DC-6-A4	5,350.0	236.0	589.0	18,500.0	4,070.0	(1.0) BDL	3.4	2.8	4.1	BDL*	(10.0) BDL
DC-6-A5	7,100.0	282.0	775.0	20,800.0	5,310.0	BDL	3.5	3.3	4.7	BDL*	BDL
DC-6-B1	6,800.0	285.0	978.0	19,400.0	5,150.0	12.1	11.7	5.8	8.3	BDL	18.1
DC-6-B2	5,800.0	259.0	628.0	17,400.0	4,820.0	1.5	2.9	2.8	4.2	BDL	BDL
DC-6-B3	5,920.0	281.0	649.0	18,100.0	4,350.0	1.5	6.0	2.5	5.1	BDL	BDL
DC-6-B4	6,460.0	245.0	731.0	19,000.0	4,730.0	BDL	3.5	2.7	5.1	BDL*	BDL
DC-6-C1	6,220.0	231.0	968.0	13,000.0	4,160.0	1.8	4.6	2.6	6.2	BDL*	17.0
DC-6-C2	11,500.0	376.0	2,020.0	26,200.0	7,870.0	3.2	15.0	6.1	15.6	BDL	19.0
DC-6-C3	6,190.0	290.0	783.0	20,000.0	4,940.0	BDL	4.8	3.5	4.8	BDL	BDL
DC-6-C4	6,140.0	295.0	796.0	21,400.0	5,350.0	BDL	7.3	3.6	5.7	BDL	BDL
DC-6-D1 background	10,800.0	419.0	1,890.0	28,700.0	6,070.0	6.1	9.5	BDL	6.0	BDL*	22.0

BDL = Analysis is below detection limit. (Number enclosed by parentheses is the detection limit.)

BDL* = Almost all Extractable Organics below detection limit, but there are some unknowns and several compounds that are greater than the detection limit (GDL), which are listed below:

GDL extracted organics for A2 aliphatic alcohol = 2.3 p/m	GDL extracted organics for A3 di-n-butyl phthalate = 2.2 p/m 3 unknowns #1 = 1.7, #2 = 5.8, #3 = 2.1 p/m unknown phthalate = 2.4 p/m mono(2-ethylhexyl) ester = 8.5 p/m	GDL extracted organics for A4 di-n-butyl phthalate = 1.5 p/m 2-ethyl, 1 hexanol = 1.9 p/m 2 unknowns #1 = 1.9, #2 = 2.5 p/m hexanedioic acid-dioctyl ester = 4.4 p/m	GDL extracted organics for A5 2-ethylhexyl phthalate = 1.5 p/m 2 unknowns #1 = 3.6, #2 = 1.3 p/m
GDL extracted organics for B4 di-n-butyl phthalate = 1.4 p/m 4 unknowns #1 = 1.9, #2 = 1.6, #3 = 5.0, #4 = 1.6 p/m mono(2ethylhexyl) ester = 6.0 p/m	GDL extracted organics for C1 di-n-butyl phthalate = 1.1 p/m 2 unknowns #1 = 0.9, #2 = 4.4 p/m	GDL extracted organics for D1 di-n-butyl phthalate = 1.6 p/m 5 unknowns #1 = 1.7, #2 = 1.2, #3 = 4.9, #4 = 6.8, #5 = 2.0 p/m unknown fatty acid = 8.5 p/m	

Table 7. Summary Analyses for Soils Underlying the Mud Pit at Site DC-14.

Sample location and numbers	Analytes (µg/g except for pH)									
	pH	Strontium	Zinc	Calcium	Barium	Chromium	Sodium	Nickel	Copper	Vanadium
DC-14 - A1	6.3	31.7	58.0	8,710.0	109.0	18.2	534.0	15.6	6.8	32.2
DC-14 - A2	6.5	31.5	55.0	5,090.0	118.0	21.5	451.0	16.5	6.5	39.2
DC-14 - A3	6.8	45.4	62.5	6,070.0	158.0	23.6	535.0	18.8	7.0	41.9
DC-14 - A4	6.7	48.4	64.9	11,530.0	105.0	22.6	619.0	17.0	9.4	40.9
DC-14 - B1	6.9	30.0	57.8	4,470.0	122.0	17.9	270.0	15.8	8.9	32.0
DC-14 - B2 split	6.8	32.2	50.9	4,510.0	89.9	21.5	372.0	17.6	8.3	37.5
DC-14 - B3 split	6.5	33.0	52.7	4,670.0	89.9	22.1	376.0	18.3	8.2	38.9
DC-14 - B4	6.4	31.3	50.3	3,760.0	79.8	19.5	316.0	17.9	8.1	36.2
DC-14 - B5	6.6	27.2	47.3	3,870.0	73.4	20.5	434.0	16.2	7.7	36.8
DC-14 - C1	6.3	39.8	75.0	10,800.0	116.0	18.7	503.0	14.8	8.4	36.3
DC-14 - C2	6.5	35.4	66.6	5,380.0	142.0	21.7	378.0	18.2	9.6	39.3
DC-14 - C3	6.6	25.2	46.1	2,910.0	71.4	19.2	249.0	16.5	7.2	31.6
DC-14 - C4	7.6	30.8	50.1	3,490.0	88.2	20.2	326.0	7.5	7.8	36.6
DC-14 - D1 background	6.5	39.3	55.1	8,310.0	111.0	21.3	511.0	14.8	6.8	40.1

BDL = Analysis is below detection limit. (Number enclosed by parentheses is the detection limit.)

Table 7. Summary Analyses for Soils Underlying the Mud Pit at Site DC-14. (cont.)

Sample location and numbers	Analytes (µg/g except for pH)									
	Aluminum	Manganese	Potassium	Iron	Magnesium	Nitrate	Sulfate	Fluoride	Chloride	TOC
DC-14 - A1	11,800.0	270.0	2,270.0	22,500.0	6,370.0	8.7	51.8	6.0	10.2	(2.0) BDL
DC-14 - A2	10,600.0	309.0	1,810.0	19,100.0	5,410.0	2.8	21.7	6.0	6.0	BDL
DC-14 - A3	12,600.0	366.0	2,150.0	22,100.0	6,390.0	(1.0) BDL	110.0	10.4	4.0	BDL
DC-14 - A4	11,700.0	359.0	1,680.0	19,800.0	5,620.0	1.3	29.1	32.2	2.5	3.6
DC-14 - B1	11,700.0	274.0	2,550.0	22,000.0	6,610.0	34.7	12.0	11.8	1.4	BDL
DC-14 - B2 split	9,990.0	300.0	1,730.0	18,200.0	5,680.0	8.3	7.3	18.7	2.8	BDL
DC-14-B3 split	10,500.0	305.0	1,810.0	19,000.0	5,930.0	7.7	7.0	19.3	3.3	BDL
DC-14 - B4	9,470.0	298.0	1,430.0	17,800.0	5,530.0	5.5	3.4	19.4	2.5	BDL
DC-14 - B5	9,810.0	274.0	1,320.0	17,800.0	5,590.0	1.9	8.4	22.1	3.3	BDL
DC-14 - C1	11,400.0	312.0	2,490.0	21,100.0	5,720.0	47.2	160.0	12.2	22.1	BDL
DC-14 - C2	11,000.0	350.0	2,430.0	19,400.0	5,580.0	11.4	279.0	18.0	21.8	BDL
DC-14 - C3	8,070.0	246.0	1,200.0	15,300.0	4,250.0	1.2	11.1	24.1	28.1	3.9
DC-14 - C4	10,600.0	331.0	1,570.0	19,200.0	5,430.0	1.9	9.6	31.9	9.9	4.7
DC-14 - D1 background	14,000.0	298.0	2,004.0	23,100.0	6,780.0	BDL	536.0	2.4	55.2	BDL

BDL = Analysis is below detection limit. (Number enclosed by parentheses is the detection limit.)

Table 8. Summary Analyses for Soils Underlying the Mud Pit at Site DC-16A.

Sample location and numbers	Analytes (µg/g except for pH)						
	pH	Strontium	Zinc	Calcium	Barium	Chromium	Sodium
DC-16A-A1	9.0	39.0	32.5	11,200.0	95.5	8.6	179.0
DC-16A-A2	9.1	30.5	32.8	8,670.0	56.1	10.9	164.0
DC-16A-A3	9.4	21.5	29.0	4,710.0	48.8	8.1	177.0
DC-16A-A4	9.4	19.9	31.8	5,770.0	53.1	9.8	192.0
DC-16A-A5	9.5	25.5	33.8	6,830.0	49.2	10.2	167.0
DC-16A-B1	8.4	37.6	35.4	14,300.0	80.0	9.5	159.0
DC-16A-B2	8.4	51.0	48.1	20,100.0	115.0	14.4	261.0
DC-16A-B3	8.5	47.9	51.6	10,200.0	116.0	12.5	231.0
DC-16A-B4 split	8.6	49.6	54.5	11,000.0	129.0	13.7	302.0
DC-16A-B5 split	8.6	48.0	51.2	11,200.0	115.0	12.9	234.0
DC-16A-B6	8.6	37.0	44.8	13,100.0	94.3	10.4	155.0
DC-16A-B7	8.9	32.7	46.6	9,560.0	96.0	16.6	141.0
DC-16A-C1	9.2	62.5	33.1	15,400.0	64.3	12.0	327.0
DC-16A-C2	8.9	20.7	22.4	6,570.0	63.9	7.3	140.0
DC-16A-C3	9.0	21.7	32.1	7,600.0	51.2	9.7	116.0
DC-16A-C4	9.3	23.3	28.5	8,850.0	50.7	8.9	121.0
DC-16A-D1 background	8.9	36.6	42.7	19,000.0	102.0	12.7	145.0
DC-16A-D2 background	9.3	27.1	29.4	10,200.0	51.8	8.8	158.0

BDL = Analysis is below detection limit. (Number enclosed by parentheses is the detection limit.)

Table 8. Summary Analyses for Soils Underlying the Mud Pit at Site DC-16A. (cont.)

Sample location and numbers	Analytes (µg/g except for pH)							
	Nickel	Copper	Vanadium	Aluminum	Manganese	Potassium	Iron	Magnesium
DC-16A-A1	6.6	(1.0)BDL	34.5	7,410.0	358.0	954.0	18,200.0	5,250.0
DC-16A-A2	6.7	BDL	34.3	6,630.0	247.0	908.0	17,100.0	4,820.0
DC-16A-A3	9.5	BDL	23.4	4,520.0	191.0	675.0	12,200.0	3,280.0
DC-16A-A4	9.0	3.0	32.0	5,240.0	319.0	682.0	14,200.0	3,920.0
DC-16A-A5	8.6	1.8	32.1	5,740.0	229.0	885.0	14,700.0	4,080.0
DC-16A-B1	8.6	1.5	38.9	9,030.0	293.0	1,440.0	21,100.0	5,570.0
DC-16A-B2	11.2	6.5	52.7	12,200.0	361.0	1,970.0	26,800.0	7,460.0
DC-16A-B3	11.1	3.2	62.7	9,920.0	460.0	1,420.0	26,200.0	6,230.0
DC-16A-B4 split	11.7	4.4	62.9	12,400.0	447.0	1,650.0	29,700.0	7,180.0
DC-16A-B5 split	11.9	3.8	62.2	11,100.0	434.0	1,550.0	29,800.0	7,240.0
DC-16A-B6	9.7	1.1	42.6	8,480.0	375.0	1,240.0	20,900.0	5,880.0
DC-16A-B7	9.4	6.1	33.0	9,630.0	320.0	2,030.0	17,900.0	5,980.0
DC-16A-C1	9.5	2.5	37.8	7,600.0	239.0	1,000.0	17,100.0	4,920.0
DC-16A-C2	4.8	2.0	24.6	4,820.0	169.0	689.0	12,300.0	3,520.0
DC-16A-C3	9.1	1.5	22.7	5,860.0	206.0	979.0	12,700.0	4,510.0
DC-16A-C4	9.0	2.7	20.0	5,750.0	212.0	956.0	11,800.0	4,480.0
DC-16A-D1 background	10.2	1.9	38.9	11,800.0	349.0	2,310.0	24,300.0	7,080.0
DC-16A-D2 background	9.3	1.6	32.8	6,490.0	212.0	1,010.0	17,100.0	4,890.0

BDL = Analysis is below detection limit. (Number enclosed by parentheses is the detection limit.)

Table 9. Summary Analyses for Soils Underlying the Mud Pit at Site DC-16B.

Sample location and numbers	Analytes (µg/g except for pH)				
	pH	Strontium	Zinc	Calcium	Barium
DC-16B-A1	8.7	15.3	28.6	2,410.0	52.0
DC-16B-A2	8.8	36.0	34.4	14,200.0	79.7
DC-16B-A3	8.9	22.9	31.2	2,580.0	70.7
DC-16B-A4	9.1	21.5	27.7	4,760.0	52.8
DC-16B-B1	8.9	32.2	34.7	9,030.0	73.2
DC-16B-B2 split	9.1	18.3	24.6	3,110.0	76.9
DC-16B-B3 split	9.1	17.7	23.3	2,770.0	52.0
DC-16B-B4	9.1	20.9	25.3	5,150.0	48.2
DC-16B-B5	9.1	18.0	26.3	5,210.0	53.7
DC-16B-C1	8.9	52.5	40.7	17,700.0	85.6
DC-16B-C2	9.1	18.7	24.4	7,620.0	39.0
DC-16B-C3	9.2	24.0	26.8	7,300.0	43.6
DC-16B-C4	9.2	18.1	23.6	4,820.0	37.7
DC-16B-D1 background	8.9	36.6	42.7	19,000.0	102.0
DC-16B-D2 background	9.3	27.1	29.4	10,200.0	51.8

BDL = Analysis is below detection limit. (Number enclosed by parentheses is the detection limit.)

Table 9. Summary Analyses for Soils Underlying the Mud Pit at Site DC-16B. (cont.)

Sample location and numbers	Analytes (µg/g except for pH)				
	Chromium	Sodium	Nickel	Copper	Vanadium
DC-16B-A1	9.0	128.0	7.3	1.4	29.5
DC-16B-A2	9.0	144.0	8.4	(1.0) BDL	30.8
DC-16B-A3	8.5	105.0	9.4	2.7	23.8
DC-16B-A4	8.5	115.0	6.4	1.7	23.0
DC-16B-B1	8.4	129.0	7.4	BDL	36.6
DC-16B-B2 split	8.0	165.0	9.8	1.9	27.3
DC-16B-B3 split	7.7	155.0	6.0	2.2	26.8
DC-16B-B4	7.9	132.0	6.5	2.3	25.5
DC-16B-B5	8.2	136.0	9.6	1.4	23.0
DC-16B-C1	12.5	175.0	9.8	3.0	39.5
DC-16B-C2	5.2	168.0	4.4	1.5	29.7
DC-16B-C3	9.5	165.0	7.7	2.7	27.7
DC-16B-C4	5.0	162.0	4.2	1.4	28.6
DC-16B-D1 background	12.7	145.0	10.2	1.9	38.9
DC-16B-D2 background	8.8	158.0	9.3	1.6	32.8

BDL = Analysis is below detection limit. (Number enclosed by parentheses is the detection limit.)

Table 9. Summary Analyses for Soils Underlying the Mud Pit at Site DC-16B. (cont.)

Sample location and numbers	Analytes (µg/g except for pH)			
	Aluminum	Manganese	Potassium	Iron
DC-16B-A1	5,830.0	230.0	923.0	14,900.0
DC-16B-A2	7,470.0	290.0	1,290.0	16,900.0
DC-16B-A3	6,300.0	240.0	1,140.0	13,300.0
DC-16B-A4	5,390.0	223.0	1,060.0	11,500.0
DC-16B-B1	6,460.0	278.0	1,140.0	16,500.0
DC-16B-B2 split	5,110.0	175.0	702.0	13,600.0
DC-16B-B3 split	5,130.0	238.0	680.0	12,900.0
DC-16B-B4	5,520.0	194.0	807.0	12,400.0
DC-16B-B5	5,730.0	209.0	956.0	12,700.0
DC-16B-C1	9,710.0	315.0	1,620.0	20,700.0
DC-16B-C2	5,010.0	167.0	565.0	11,800.0
DC-16B-C3	5,570.0	205.0	777.0	13,400.0
DC-16B-C4	4,500.0	161.0	545.0	13,500.0
DC-16B-D1 background	11,800.0	349.0	2,310.0	24,300.0
DC-16B-D2 Background	6,490.0	212.0	1,010.0	17,100.0

BDL = Analysis is below detection limit. (Number enclosed by parentheses is the detection limit.)

Table 9. Summary Analyses for Soils Underlying the Mud Pit at Site DC-16B. (cont.)

Sample location and numbers	Analytes (µg/g except for pH)				
	Magnesium	Nitrate	Sulfate	Fluoride	Chloride
DC-16B-A1	4,040.0	3.1	3.0	(1.0) BDL	(1.0) BDL
DC-16B-A2	4,990.0	9.9	36.0	BDL	8.1
DC-16B-A3	4,190.0	2.1	5.7	BDL	BDL
DC-16B-A4	3,940.0	1.3	2.0	BDL	BDL
DC-16B-B1	4,080.0	7.9	5.4	1.2	BDL
DC-16B-B2 split	3,880.0	2.5	2.9	BDL	BDL
DC-16B-B3 split	3,440.0	2.3	2.8	BDL	BDL
DC-16B-B4	3,970.0	(1.0) BDL	3.3	BDL	BDL
DC-16B-B5	4,220.0	BDL	3.3	BDL	BDL
DC-16B-C1	6,400.0	BDL	18.9	1.3	4.7
DC-16B-C2	4,080.0	1.2	1.2	BDL	BDL
DC-16B-C3	4,360.0	BDL	1.2	BDL	BDL
DC-16B-C4	3,190.0	BDL	BDL	BDL	BDL
DC-16B-D1 background	7,080.0	2.8	5.0	1.2	1.7
DC-16B-D2 Background	4,890.0	BDL	3.0	BDL	BDL

BDL = Analysis is below detection limit. (Number enclosed by parentheses is the detection limit.)

Table 10. Summary Analyses for Soils Underlying the Mud Pit at Site DC-20B.

Sample location and numbers	Analytes (µg/g except for pH)									
	pH	Strontium	Zinc	Calcium	Barium	Chromium	Sodium	Nickel	Copper	Vanadium
DC-20-A1	8.2	30.4	64.0	8,510.0	258.0	10.0	1,020.0	7.7	(1.0) BDL	61.2
DC-20-A2	12.1	53.1	56.9	34,300.0	274.0	12.3	1,230.0	8.0	4.0	54.2
DC-20-A3	10.0	25.7	27.9	9,950.0	78.4	3.8	1,470.0	2.7	4.8	26.1
DC-20-A4	9.5	26.1	34.9	9,650.0	97.3	7.0	404.0	5.4	1.3	45.7
DC-20-B1	9.4	20.3	44.0	6,520.0	50.5	8.6	590.0	6.4	BDL	45.1
DC-20-B2 split	9.1	30.7	52.8	7,570.0	108.0	7.3	462.0	7.2	BDL	64.8
DC-20-B3 split	9.1	26.9	49.7	8,600.0	93.3	6.7	436.0	6.7	BDL	60.4
DC-20-B4	9.3	15.8	24.9	4,070.0	37.6	4.2	172.0	3.4	BDL	26.8
DC-20-B5	9.3	23.3	22.7	5,330.0	51.1	5.5	281.0	5.9	8.1	23.0
DC-20-C1	8.7	33.7	33.4	9,310.0	68.3	7.9	369.0	9.6	2.5	38.9
DC-20-C2	9.8	37.5	40.7	8,870.0	101.0	9.7	773.0	9.5	3.3	34.0
DC-20-C3	9.5	17.9	27.8	4,700.0	44.9	5.9	354.0	8.4	3.8	26.5
DC-20-C4	9.6	19.1	31.9	5,770.0	44.9	5.3	369.0	5.7	2.1	34.9
DC-20-D1 background	8.6	31.1	43.7	19,600.0	89.3	6.8	142.0	6.8	BDL	46.9

BDL = Analysis is below detection limit. (Number enclosed by parentheses is the detection limit.)

Table 10. Summary Analyses for Soils Underlying the Mud Pit at Site DC-20B. (cont.)

Sample location and numbers	Analytes (µg/g except for pH)								
	Aluminum	Manganese	Potassium	Iron	Magnesium	Nitrate	Sulfate	Fluoride	Chloride
DC-20-A1	8,270.0	332.0	1,860.0	25,600.0	4,870.0	(1.0) BDL	8.5	8.5	19.6
DC-20-A2	9,580.0	305.0	2,230.0	27,000.0	5,350.0	BDL	106.0	62.6	21.9
DC-20-A3	5,670.0	229.0	1,360.0	20,700.0	4,310.0	BDL	72.1	1.2	8.3
DC-20-A4	6,980.0	293.0	783.0	24,700.0	5,280.0	BDL	16.5	(1.0) BDL	1.8
DC-20-B1	6,900.0	225.0	1,180.0	21,600.0	4,430.0	12.7	28.8	1.3	12.7
DC-20-B2 split	7,070.0	464.0	1,200.0	29,600.0	5,670.0	35.7	25.4	2.4	9.8
DC-20-B3 split	7,130.0	426.0	1,250.0	31,100.0	5,960.0	37.3	25.0	2.3	10.5
DC-20-B4	3,720.0	163.0	459.0	12,800.0	2,730.0	3.4	5.1	BDL	2.3
DC-20-B5	4,050.0	170.0	518.0	13,200.0	3,160.0	1.9	4.2	BDL	1.8
DC-20-C1	7,550.0	259.0	1,360.0	18,600.0	4,880.0	1.0	49.3	1.7	8.9
DC-20-C2	9,210.0	372.0	1,670.0	21,900.0	6,880.0	4.4	12.1	BDL	7.4
DC-20-C3	4,880.0	194.0	711.0	16,400.0	4,080.0	1.2	4.2	BDL	2.0
DC-20-C4	4,180.0	199.0	631.0	16,800.0	3,310.0	1.4	5.2	BDL	2.0
DC-20-D1 background	6,740.0	374.0	1,260.0	23,400.0	5,560.0	3.9	1.4	BDL	(1.0) BDL

BDL = Analysis is below detection limit. (Number enclosed by parentheses is the detection limit.)

Table 11. Results from the EP Toxicity and Ignitability Tests.

Sample number	Ignitability (flash point)	Analyses (p/m)							
		Arsenic	Barium	Cadmium	Chrome	Lead	Selenium	Silver	Mercury
DB - 2 - B1		(0.05) BDL	0.14	(0.01) BDL	(0.05) BDL	(0.05) BDL	(0.05) BDL	(0.05) BDL	(0.02) BDL
DB - 2 - D1		BDL	0.16	BDL	BDL	BDL	BDL	BDL	BDL
DB - 11 - A1		BDL	0.73	BDL	BDL	BDL	0.05	BDL	BDL
DB - 11 - B1	>210°F	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
DB - 11 - C1	>210°F	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
DB - 11 - D1		0.06	0.42	BDL	BDL	BDL	0.05	BDL	BDL
DC - 6 - A1	>210°F	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
DB -6-A4	>210°F	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
DC - 6 - C1		BDL	0.21	BDL	BDL	BDL	BDL	BDL	BDL
DC - 6 - D1		BDL	0.14	BDL	BDL	BDL	BDL	BDL	BDL
DC - 14 - C2		BDL	0.30	BDL	BDL	BDL	BDL	BDL	BDL
DC - 14 - D1		BDL	0.27	BDL	BDL	BDL	BDL	BDL	BDL
DC - 16A - B2		BDL	0.67	BDL	BDL	BDL	BDL	BDL	BDL
DC - 16A - B7		BDL	0.43	BDL	BDL	BDL	BDL	BDL	BDL
DC - 16B - C1		BDL	0.59	BDL	BDL	BDL	0.06	BDL	BDL
DC - 16 - D1		BDL	0.70	BDL	BDL	BDL	BDL	BDL	BDL
DC - 20B - A2		BDL	2.53	BDL	BDL	0.19	BDL	BDL	BDL
DC - 20B - A3		BDL	0.53	BDL	BDL	BDL	BDL	BDL	BDL
DC - 20B - D1		BDL	0.53	BDL	BDL	BDL	BDL	BDL	BDL

NOTE: Classified as a dangerous waste at these levels according to WAC 173-3030-90:

Arsenic	5.0 - 5,000 p/m
Barium	100 - 10,000 p/m
Cadmium	1.0 - 100 p/m
Chrome	5.0 - 500 p/m
Lead	5.0 - 500 p/m
Selenium	1.0 - 100 p/m
Silver	5.0 - 500 p/m
Mercury	0.2 - 20 p/m

BDL = Analysis is below detection limit (Number enclosed by parentheses is the detection limit.)

4. Compare the mud pit sample results to the background sample results, with reference to RCRA Groundwater Monitoring Technical Enforcement Guidance Document, Chapter 5 (EPA 1986). [This manual was used only for comparison and does not imply that Resource Conservation Recovery Act of 1976 (RCRA) waste is present at the site.] Comparison was made in the following steps:

   - Test homogeneity of variability between mud pit sample data and the background sample data (at the 5% level of significance) to determine the appropriate statistical test for comparison of mean concentrations.

   - Apply appropriate statistical test for comparison of mean concentrations.

5. Compare the results from a EP toxicity test on the worst case (i.e., high chromium or barium value) sample from each pit to that of the background.

6. If a significant difference in mean concentrations existed between mud pit and the combined background samples, or if insufficient data were available for a statistical comparison of the mud pit and background sample results for a constituent, specific sample profiles were examined and contaminant levels were compared with acceptable regulatory standards on a constituent-by-constituent basis. An assessment was made as to whether the levels of the constituent in the mud pit are of regulatory, health, or environmental concern.

4.2 STATISTICAL METHOD

In applying the statistics to the results from the sampling, the following method was used:

1. Average the data for the constituent of concern from each sample location within the mud pit

2. Determine if there is a location effect within the mud pit (see Appendix A). If there is a location effect, use the location with the highest average value (represents worst case scenario; therefore, it is a conservative approach) to compare to background values. If location effect is not present, use the average of all mud pit samples to compare to background values

3. Apply the F-test at the 5% level of significance to determine if there is a significant difference in variability between mud pit samples and background samples

4. If there is no significant difference in variability, use the Student's t-test to examine the hypothesis of equality of mean concentration. Appendix A provides a detailed description of the statistical methods and the results; only a summary of those results is presented here.

4.3 SITE RESULTS

4.3.1 Borehole DB-2

The total dry weight of the products used to drill borehole DB-2 was 7,065 lb, of which 800 lb (11.32%) were RAYKROME. The material safety data sheet for RAYKROME indicates that it contains 3.4% chromium III and that a 1 percent solution of this product has a pH of 2.8. Summary statistics were compiled for chromium and pH only (identified in Table 3 as constituents of concern). The summary statistics reveal no significant difference in the mean concentrations between mud pit samples and background values for these constituents.

Since chromium III was known to have been introduced as an additive, it is necessary to verify that the chromium was not further oxidized to hexavalent chromium. An EP toxicity test was performed to verify that the mud pits did not contain dangerous waste as defined in Washington Administrative Code (WAC) 173-303, Dangerous Waste Regulations (Ecology 1987). The test was run on the sample that had the highest chromium value (worst case) as well as on the background sample from this site. The chromium values for both the background and the mud pit sample were below the detection limit (0.050 micrograms/gram) for the EP toxicity test (Table 11).

4.3.2 Borehole DB-11

At the DB-11 site, 1,200 lb (18.13 wt% of total drilling products used) of BAROID (barite) and 110 gal (11.30 wt% of total drilling products used) of diesel fuel were used as additives in the drilling fluid. Summary statistics were compiled for the chemical constituents identified in Table 3 (barium, pH, sulfate, TOC, and EO). The statistics reveal no significant difference in mean concentrations between mud pit samples and background samples for these constituents.

A comparison between background and mud pit samples for EO and TOC could not be made due to insufficient data. All EO samples were below the detection limits and consequently are not of concern. The TOC is not regulated; however, it was used to decide which sample would be tested for ignitability because of the diesel fuel used in drilling fluids. The results from the ignitability test indicated a flash point above 210 °F for both the mud pit sample and the background sample.

Since barium sulfate was known to have been introduced as an additive to the drilling fluid, it was necessary to verify that the barium was not EP toxic. An EP toxicity test was performed to verify that the mud pits did not contain dangerous waste as defined in WAC 173-303 (Ecology 1987). The results from this test for barium value are 0.42 and 0.73 micrograms/gram, respectively (Table 11). Barium is considered to be a dangerous waste if the results from the EP toxicity test indicate a concentration above 100 micrograms/gram.

Although this site does not require remediation under RCRA, the elevated sulfate values could become a potential concern. Therefore, only for comparison purposes to determine the relative levels of contamination, the Final Cleanup Policy (Ecology 1984) was applied. For the mud pit, sulfate has a maximum value of 729 micrograms/gram. The National Secondary Drinking Water Regulations (EPA 1987) secondary maximum contaminant level (SMCL) for sulfate is 250 micrograms/gram. Applying the Final Cleanup Policy (Ecology 1984), the value for soil becomes 2,500 micrograms/gram. Sulfate occurs in these samples at levels below regulatory concern. The background sample also exhibits a high sulfate value (all micrograms/gram). The background sample taken was not close to the mud runoff area, and at sufficient distance as to be unaffected by the drilling activities. Most likely, this high sulfate value is a result of naturally occurring gypsum in the sample. It should be noted that even though this value is high, it is still below the Final Cleanup Policy (Ecology 1984) standard.

4.3.3 Borehole DC-6

At the DC-6 site, the following products were used: sodium hydroxide (100 lb), corrosion inhibitor (5 gal), organic mud lubricant (145 gal), and diesel oil. (It was only possible to obtain material data safety sheets for the sodium hydroxide and diesel oil because the manufacturers of the mud lubricant and the corrosion inhibitor have gone out of the business.) The corrosion inhibitor was sent out for chemical analysis. There was not enough organic mud lubricant on the site to allow chemical analysis; thus, the chemical makeup is unknown. However, it is believed that this product is very similar to Torque Trim II* in which the main ingredient identified is isopropyl alcohol.

The analyses for PCBs revealed that all samples were below the detection limit (1.0 p/m) for soils. The chemical analysis of the corrosion inhibitor, 235-A, indicates that PCBs may occur in this product at concentration levels less than or equal to 1 p/m. However, at this site, only 43 lb of this product were used. This represents only 0.12 wt% of the total weight of the mud products used at this site. Therefore, the concentration levels of the PCBs in the drilling mud would be much less than 1 p/m. Further, the concentration is estimated to be approximately 1.2 p/b. Since concentrations of PCBs below 1 p/m are excluded under WAC 173-303-071(3)(k)(ii) (Ecology 1987), this level is not of regulatory concern.

The EO analyses indicate that there are several organic compounds present above detection limits. These are unknown aliphatic alcohol, di-n-butyl phthalate, unknown phthalate, 2-ethyl 1-hexanol, mono(2-ethylhexyl)ester, bis(2-ethylhexyl)phthalate, unknown fatty acid, and several other unknowns. Of the known compounds, only bis(2-ethylhexyl)ester and di-n-butyl phthalate appear in Appendix IX of 40 CFR 261 (EPA 1980).

The EP toxicity test confirmed that the mud pit did not contain chemical constituents designated as dangerous waste for EP toxicity as defined in WAC 173-303 (Ecology 1987). All concentrations for the analyses except for barium were below the detection limit (Table 11). Additionally, an ignitability test was conducted on the background and the sample with the highest TOC because diesel oil was used during drilling. The results from the ignitable test indicate flash point above 210 °F for both the background and mud pit sample.

Although this site does not require remediation under RCRA, it does, however, contain constituents that appear on Appendix IX (EPA 1980). For comparison purposes, Final Cleanup Policy (Ecology 1984) was applied. These constituents are found in the Handbook of Toxic and Hazardous Chemicals (Sittig 1985); the ambient water criterion is 15 mg/L for bis(2-ethylhexyl)ester and 34 mg/L for di-n-butyl phthalate to protect human health. Applying the Final Cleanup Policy (Ecology 1984), these values become 150 and 340 mg/L for soil, respectively. The value for this bis(2-ethylhexyl)ester in sample A5 is 1.5 micrograms/gram and the highest value for di-n-butyl phthalate in sample A3 is 3.3 micrograms/gram. These values are below regulatory concern. Unknown compounds appear in both background and mud pit samples; they occur, with the exception of sample C1, in the deeper samples rather than the surface samples (where it is expected that the highest concentration of contaminants from the drilling products would occur). It is believed that these compounds were introduced as spills before the DOE gained institutional control of the old Hanford townsite.

4.3.4 Borehole DC-14

At the DC-14 site, 1,800 lb (4.69 wt% of total drilling products used) of barite and 800 lb (1.34 wt% of total drilling products used) of sodium hydroxide were used in the drilling fluids. The chemical constituents of concern, identified in Table 3, are barium, sulfate, sodium, and pH. Summary statistics were prepared for those constituents. There were insufficient data to make a comparison for sulfate; however, the statistics for the other constituents reveal no significant difference in mean concentrations between mud pit samples and background samples for those constituents.

Since barium sulfate was known to have been introduced as an additive to the drilling fluid, it was necessary to verify that the barium was not EP toxic. An EP toxicity test was performed to verify that the mud pits did not contain dangerous waste as defined in WAC 173-303 (Ecology 1987). The results from this test for barium in the background sample and high barium

in the mud pit sample are 0.26 and 0.3 micrograms/gram, respectively (Table 3). Barium is considered a dangerous waste if the results from the EP toxicity test indicate a concentration above 100 micrograms/gram.

Although this site does not require remediation under RCRA, the elevated sulfate values could become a potential concern. Therefore, for comparison, the Final Cleanup Policy (Ecology 1984) was applied. For the mud pit, sulfate has a maximum value of 279 micrograms/gram. The 40 CFR 143 (EPA 1987) SMCL for sulfate is 250 micrograms/gram. Applying the Final Cleanup Policy (Ecology 1984), the value for soil becomes 2,500 micrograms/gram. Sulfate occurs in these samples at levels far below regulatory concern. The background sample also exhibits a high sulfate value (536 micrograms/gram). The background sample taken was not close to the mud pit area, and was at sufficient distance so as to be unaffected by the drilling activities. Most likely, this high sulfate value is a result of naturally occurring gypsum in the sample. It should be noted that even though this value is high, it is still below the regulatory limit.

4.3.5 Borehole DC-16A

At the DC-16A site, 9,050 lb (4.72 wt% of total drilling products used) of RAYKROME were used in the drilling mud. Summary statistics were compiled for chromium and pH, the hazardous constituents identified in Table 3. The summary statistics do not reveal a difference in mean concentrations between mud pit samples and background samples.

Since chromium III was known to have been introduced as an additive, it is necessary to verify that the chromium was not oxidized to hexavalent chromium. An EP toxicity test was performed to verify that the mud pit did not contain dangerous waste as defined in WAC 173-303 (Ecology 1987). The test was run on the sample that had the highest chromium value (worst case) as well as the background from this site. The chromium value for both the background and the mud pit sample were below the detection limit (<0.050 micrograms/gram) for the EP toxicity test (Table 11).

4.3.6 Borehole DC-16B

At the DC-16B site, 600 lb (0.83 wt% of total drilling products used) of RAYKROME and 1,550 lb (2.15 wt% of total drilling products used) of sodium hydroxide were used in the drilling fluids. The chemical constituents of concern are chromium, sodium, and pH. Summary statistics were prepared for those constituents. The summary statistics do not reveal a difference in mean concentrations between mud pit samples and background samples.

Since chromium III was known to have been introduced as an additive, it is necessary to verify that the chromium was not oxidized to hexavalent chromium. An EP toxicity test was performed to verify that the mud pit did not contain dangerous waste as defined in WAC 173-303 (Ecology 1987). The test was run on the sample that had the highest chromium value (worst case)

as well as the background from this site. The chromium value for both the background and the mud pit sample were below the detection limit (<0.050 micrograms/gram) for the EP toxicity test (Table 11).

4.3.7 Borehole DC-20B

At the DC-20B site, 3,050 lb (2.20 wt% of total drilling products used) of sodium hydroxide were used in the drilling fluids. The chemical constituents of concern, identified in Table 3, are sodium and pH. Summary statistics were prepared for those constituents. The statistics reveal a difference in mean concentrations between mud pit samples and background samples for sodium, but not for pH. However, at the present time, sodium is not regulated.

Two samples (A1 and A2) from DC-20B has significantly higher barium values. These samples came from the mud left in the pit, rather than the sediments underlying the mud pit. However, in the course of drilling this borehole, an approximately 200-ft section of the Umatilla Member Basalt was encountered that contained 3,000 to 3,500 micrograms/gram of barium, five to six times as much barium as the other flows (Ames 1980). It is believed that the high barium in these samples is a result of drilling through this flow. It can also be shown that the barium is not leaching from the mud pit because the underlying samples do not show elevated barium values.

Although barium was not introduced as an additive to the drilling fluid, an EP toxicity test was performed to verify that the mud pit does not contain dangerous waste and to demonstrate that unusually high concentrations of barium occur naturally in the soil. The EP toxicity test results for barium in the background sample, worst case (i.e., highest barium) sample, and the sample underlying the worst case sample are 0.53, 2.53, and 0.53 micrograms/gramm respectively (Table 7). Barium is considered to be a dangerous waste if the results from the EP toxicity test indicate a concentration above 100 micrograms/gram.

5.0 SUMMARY AND CONCLUSIONS

These data were interpreted primarily with respect to issues covered in RCRA. All data collected from these boreholes should be entered into a waste information data system data base for future reference.

- The waste data presented indicate that the mud pits are not designated as dangerous waste, as defined in WAC 173-303 (Ecology 1987) and, therefore, are not regulated under RCRA. This precludes site characterization.

- Unusually high concentrations of chromium, barium, and nickel, which are observed at all borehole locations, occur naturally at these levels (i.e., background samples) in the Hanford Site soils.

- All BWIP borehole locations scheduled for reclamation can be reclaimed.

- Low concentrations of soil contamination were observed at one borehole site that are not attributable to drilling operations. This contamination was likely caused by spills before DOE gained institutional control over the old Hanford townsite. The pre-BWIP impacted sites will be included in the Waste Information Data System (WIDS) as it is a priori that these sites be considered in cleanup activities.

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APPENDIX A

STATISTICAL METHODS AND RESULTS

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APPENDIX A

1.0 STATISTICAL METHODS AND RESULTS

The sampling results from the borehole mud pits (DB-2, DB-11, DC-6, DC-14, DC-16A, DC-16B, and DC-20B) and the background are presented in Table A-1. The background samples were grouped together according to the physical setting of the borehole locations. That is, background values from boreholes DC-16A and DC-16B were used to calculate the background mean and variance for comparisons with the mud pit samples from boreholes DB-2, DC-6, and DC-14 were combined. Similarly, background values from DB-11, DC-20B, DC-16A, and DC-16B were used for comparisons with boreholes DB-11 and DC-20B, respectively.

Table A-1. Input Data for Borehole Mud Pits. (sheet 1 of 2)

Borehole DC-16, Mud Pits A and B						
DC-16A			DC-16B			
Site and sample location	pH	Chromium (p/m)[a]	Site and sample location	pH	Chromium (p/m)[a]	Sodium (p/m)[a]
DC-16A-A1	9.0	8.6	DC-16B-A1	8.7	9.0	128.0
DC-16A-A2	9.1	10.9	DC-16B-A2	8.8	9.0	144.0
DC-16A-A3	9.4	8.1	DC-16B-A3	8.9	8.5	105.0
DC-16A-A4	9.4	9.8	DC-16B-A4	9.1	8.5	115.0
DC-16A-A5	9.5	10.2				
DC-16A-B1	8.4	9.5	DC-16B-B1	8.9	8.4	129.0
DC-16A-B2	8.4	14.4	DC-16B-B2[b]	9.1	8.0	165.0
DC-16A-B3	8.5	12.5	DC-16B-B3[b]	9.1	7.7	155.0
DC-16A-B4[b]	8.6	13.7	DC-16B-B4	9.1	7.9	132.0
DC-16A-B5[b]	8.6	12.9	DC-16B-B5	9.1	8.2	136.0
DC-16A-B6	8.6	10.4				
DC-16A-B7	8.9	16.6				
DC-16A-C1	9.2	12.0	DC-16B-C1	8.9	12.5	175.0
DC-16A-C2	8.9	7.3	DC-16B-C2	9.1	5.2	168.0
DC-16A-C3	9.0	9.7	DC-16B-C3	9.2	9.4	165.0
DC-16A-C4	9.3	8.9	DC-16B-C4	9.2	5.0	162.0
DC-16-D1 BG[c]	8.9	12.7	DC-16-D1 BG[a]	8.9	12.7	145.0
DC-16-D2 BG[c]	9.3	8.8	DC-16-D2 BG[c]	9.3	8.8	158.0

Borehole DC-20B, Mud Pit DB-2					
DC-20B			DB-2		
Site and sample location	pH	Sodium (p/m)[a]	Site and sample location	pH	Chromium (p/m)[a]
DC-20B-A1	8.2	1,020.0	DB-2-A1	8.6	9.8
DC-20B-A2	12.1	1,230.0	DB-2-A2	8.8	2.9
DC-20B-A3	10.0	1,470.0	DB-2-A3	8.6	6.4
DC-20B-A4	9.5	404.0	DB-2-A4	8.9	2.3
DC-20B-B1	9.4	590.0	DB-2-B1	9.1	11.5
DC-20B-B2[b]	9.1	462.0	DB-2-B2[b]	9.0	1.7
DC-20B-B3[b]	9.1	436.0	DB-2-B3[b]	9.0	2.6
DC-20B-B4	9.3	172.0	DB-2-B4	8.9	2.4
DC-20B-B5	9.3	281.0	DB-2-B5	8.5	2.8
DC-20B-C1	8.7	369.0	DB-2-C1	9.1	11.2
DC-20B-C2	9 8	773.0	DB-2-C2	8.9	2.6
DC-20B-C3	9.5	354.0	DB-2-C3	8.8	3.3
DC-20B-C4	9.6	369.0	DB-2-C4	8.9	2.5
DC-20B-D1 BG[c]	8.6	142.0	DB-2-D1 BG[c]	8.9	5.8
DB-11-D1 BG[c]	8.3	882.0	DC-6-D1 BG[c]	7.0	10.2
DC-16-D1 BG[c]	8.9	145.0	DC-14-D1 BG[c]	6.5	21.3
DC-16-D2 BG[c]	9.3	158.0			

Table A-1. Input Data for Borehole Mud Pits. (sheet 2 of 2)

Boreholes DC-6 and DC-14, Mud Pits							
DC-6			DC-14				
Site and sample location	pH	Sodium (p/m)[a]	Site and sample location	pH	Barium (p/m)[a]	Sodium (p/m)[a]	Sulfate (p/m)a
DC-6-A1	9.3	1,770.0	DC-14-A1	6.3	109.0	534.0	51.8
DC-6-A2[b]	9.4	910.0	DC-14-A2	6.5	118.0	451.0	21.7
DC-6-A3[b]	9.4	919.0	DC-14-A3	6.8	158.0	535.0	110.0
DC-6-A4	9.3	673.0	DC-14-A4	6.7	105.0	619.0	29.1
DC-6-A5	9.2	801.0	DC-14-B1	6.9	122.0	270.0	12.0
DC-6-B1	9.6	797.0	DC-14-B2[b]	6.8	89.9	372.0	7.3
DC-6-B2	9.6	683.0	DC-14-B3[b]	6.5	89.9	376.0	7.0
DC-6-B3	9.6	650.0	DC-14-B4	6.4	79.8	316.0	3.4
DC-6-B4	9.6	785.0	DC-14-B5	6.6	73.4	434.0	8.4
DC-6-C1	9.6	495.0	DC-14-C1	6.3	116.0	503.0	160.0
DC-6-C2	9.4	961.0	DC-14-C2	6.5	142.0	378.0	279.0
DC-6-C3	9.5	590.0	DC-14-C3	6.6	71.4	249.0	11.1
DC-6-C4	9.6	677 0	DC-14-C4	7.6	88.2	326.0	9.6
DC-6-D1 BG[c]	7.0	207.0	DC-14-D1 BG[c]	6.5	111.0	511.0	536.0
DB-2-DI BG[c]	8.9	213.0	DB-2-D1 BG[c]	8.9	66.6	213.0	[d]
DC-14-D1 BG[c]	6.5	511.0	DC-6-D1 BG[c]	7.0	103.0	207.0	9.5

Borehole DB-11, Mud Pit					
DB-11					
Site and sample location	pH	Barium (p/m)[a]	Sulfate (p/m)[a]	Extractable organics (p/m)[a]	Total organic carbon (p/m)[a]
DB-11-A1	8.5	206.0	3 8	BDL[e]	67.1
DB-11-A2	8.4	128.0	410.0	BDL[e]	46.7
DB-11-A3	8.3	123.0	238.0	BDL[e]	BDL[e]
DB-11-A4	8.4	102.0	270.0	BDL[e]	BDL[e]
DB-11-B1	8.3	117.0	39.2	BDL[e]	135.0
DB-11-B2[b]	8.4	120.0	234.0	BDL[e]	73.5
DB-11-B3[b]	8.3	117.0	310.0	BDL[e]	83.3
DB-11-B4	8.2	128.0	729.0	BDL[e]	79.5
DB-11-B5	8.5	104.0	441.0	BDL[e]	13.5

Borehole DB-11, Mud Pit					
DB-11					
Site and sample location	pH	Barium (p/m)[a]	Sulfate (p/m)[a]	Extractable organics (p/m)[a]	Total organic carbon (p/m)[a]
DB-11-C1	8.5	125.0	2.7	BDL[e]	131 0
DB-11-C2	9.0	103.0	15.3	BDL[e]	45 4
DB-11-C3	9.3	105.0	23.4	BDL[e]	16.0
DB-11-C4	9.4	103.0	12.7	BDL[e]	11.5
DB-11-D1 BG[c]	8.3	139.0	911.0	BDL[e]	74.0
DC-16-D1 BG[c]	8.9	102.0	5.0	[d]	[d]
DC-16-D2 BG[c]	9.3	51.8	3.0	[d]	[d]
DC-20B-D1 BG[c]	8.6	89.3	1.4	[d]	[d]

[a]p/m = Parts per million.
[b]Split samples.
[c]BG = Background samples.
[d]Sample was not requested for chemical analyses.
[e]BDL = Below detection limits.

2.0 CALCULATIONS

2.1 ASSUMPTIONS

The following assumptions were used in the statistical analyses in accordance with the EPA Region 10 policy statement.

- Metals are assumed to be log normally (natural logarithm) distributed, since they are naturally occurring in the soil.
- Other chemical constituents in the soil are assumed to be normallydistributed.

A goodness-of-fit test to examine the distributional shapes was not performed due to insufficient data.

2.2 CALCULATION OF SUMMARY STATISTICS

The three locations at each borehole site were selected at random. At each location, several mud pit samples were taken 0 to 2 ft, 2 to 4 ft, 4 to 6 ft, and 6 to 8 ft below the bottom of the pit, except at C-16A where additional samples were taken because of overburden. In addition, one sample from each site was randomly chosen and split in the field for duplicate analysis. The split samples were treated as if they were independent replicates in the statistical analyses (i.e., calculations of summary statistics, variance of component estimates, etc.) since only one split sample was obtained per site.

The calculated summary statistics for the mud pit samples (for each location/site and the site as an entity) and background samples are presented in Tables A-2 and A-3, respectively. Cohen's method for the calculation of maximum likelihood estimates of mean and standard deviation was used when there were less-than-detection-limit values.

The use of physical setting (i.e., borehole location) was adopted as a criterion to classify background values into groups (see Section 1.1 for a detailed description of the borehole locations). Background samples at boreholes DB-11, DC-16A, DC-16B, and DC-20B were combined to calculate the background summary statistics for DB-11 and DC-20B. This was done because of the close proximity of the mud pits to each other. The second group consisted of combined background values from sites that were close to the Columbia River (DB-2, DC-6, and DC-14). Background values from DC-16A and DC-16B were combined due to their proximity to each other.

Table A-2. Summary Statistics for Borehole Mud Pits. (sheet 1 of 6)

Description	No. of LTDL values[a]	No. of GTDL values[b]	Mean	Median	Std dev	Coefficient of variation (%)	Minimum	Maximum
DC-16A pH								
Location A_1	0	5	9.28	9.40	0.2168	2.34	9.00	9.50
Location B1	0	7	8.57	8.60	0.1704	1.99	8.40	8.90
Location C_1	0	4	9.10	9.10	0.1826	2.01	8.90	9.30
Total	0	16	8.93	8.95	0.3733	4.18	8.40	9.50
Chromium[c]								
Location A_1	0	5	9.53	9.46	1.1738	12.32	8.10	10.90
Location B_1	0	7	12.89	12.66	2.4795	19.24	9.50	16.60
Location C_1	0	4	9.53	9.33	1.9830	20.81	7.30	12.00
Total	0	16	10.98	10.71	2.4948	22.72	7.30	16.60
DC-16B pH								
Location A_2	0	4	8.88	8.85	0.1708	1.92	8.70	9.10
Location B_2	0	5	9.06	9.10	0.0894	0.99	8.90	9.10
Location C_2	0	4	9.10	9.15	0.1414	1.55	8.90	9.20
Total	0	13	9.02	9.10	0.1573	1.74	8.70	9.20

Table A-2. Summary Statistics for Borehole Mud Pits. (sheet 2 of 6)

Description	No. of LTDL values[a]	No. of GTDL values[b]	Mean	Median	Std dev	Coefficient of variation (%)	Minimum	Maximum
DC-16B								
Chromium[c]								
Location A_2	0	4	8.75	8.75	0.2889	3.30	8.50	9.00
Location B_2	0	5	8.04	8.04	0.2700	3.36	7.70	8.40
Location C_2	0	4	8.23	7.43	3.9087	47.49	5.00	12.50
Total	0	13	8.28	8.05	1.9857	23.98	5.00	12.50
Sodium[c]								
Location A_2	0	4	123.28	122.14	16.8915	13.70	105.00	144.00
Location B_2	0	5	143.56	142.73	15.5224	10.81	129.00	165.00
Location C_2	0	4	167.52	167.43	5.5304	3.30	162.00	175.00
Total	0	13	144.72	142.90	142.90	23.2010	105.00	175.00
DC-6								
pH								
Location A_3	0	5	9.32	9.30	0.0837	0.90	9.20	9.40
Location B_3	0	4	9.60	9.60	0.0000	0.00	9.60	9.60
Location C_3	0	4	9.53	9.55	0.0957	1.00	9.40	9.60
Total	0	13	9.47	9.50	0.1437	1.52	9.20	9.60
Sodium[c]								
Location A_3	0	5	1022.35	955.86	387.8741	37.94	673.00	1770.00
Location B_3	0	4	729.70	725.96	74.0849	10.15	650.00	797.00
Location C_3	0	4	686.84	660.23	196.9936	28.68	495.00	961.00
Total	0	13	822.03	783.76	259.9842	31.63	495.00	1770.00

Table A-2. Summary Statistics for Borehole Mud Pits. (sheet 3 of 6)

Description	No. of LTDL values[a]	No. of GTDL values[b]	Mean	Median	Std dev	Coefficient of variation (%)	Minimum	Maximum
DC-14 pH								
Location A_4	0	4	6.58	6.60	0.2217	3.37	6.30	6.80
Location B_4	0	5	6.64	6.60	0.2074	3.12	6.40	6.90
Location C_4	0	4	6.75	6.55	0.5802	8.60	6.30	7.60
Total	0	13	6.65	6.60	0.3406	5.12	6.30	7.60
Bariumc								
Location A_4	0	4	122.95	120.86	22.9600	18.67	105.00	158.00
Location B_4	0	5	91.28	89.60	17.7514	19.45	73.40	122.00
Location C_4	0	4	105.63	100.92	32.6610	30.92	71.40	142.00
Total	0	13	105.03	101.91	26.2078	24.95	71.40	158.00
Sodium[c]								
Location A_4	0	4	535.89	531.42	69.6581	13.00	451.00	619.00
Location B_4	0	5	354.87	349.02	65.2190	18.38	270.00	434.00
Location C_4	0	4	367.97	352.47	110.3202	29.98	249.00	503.00
Total	0	13	414.01	398.43	116.9282	28.24	249.00	619.00
Sulfate								
Location A_4	0	4	53.15	40.45	40.0052	75.27	21.70	110.00
Location B_4	0	5	7.62	7.30	3.0858	40.50	3.40	12.00
Location C_4	0	4	114.93	85.55	130.1606	113.25	9.60	279.00
Total	0	13	54.65	12.00	82.2927	150.58	3.40	279.00

Table A-2. Summary Statistics for Borehole Mud Pits. (sheet 4 of 6)

Description	No. of LTDL values[a]	No. of GTDL values[b]	Mean	Median	Std dev	Coefficient of variation (%)	Minimum	Maximum
DC-20B pH	0							
Location A_5	0	4	9.95	9.75	1.6217	16.30	8.20	12.10
Location B_5	0	5	9.24	9.30	0.1342	1.45	9.10	9.40
Location C_5	0	4	9.40	9.55	0.4830	5.14	8.70	9.80
Total	0	13	9.51	9.40	0.9060	9.53	8.20	12.10
Sodium[c]								
Location A_5	0	4	1096.02	929.08	685.9116	62.58	404.00	1470.00
Location B_5	0	5	401.22	356.32	207.6573	51.76	172.00	590.00
Location C_5	0	4	471.74	439.35	184.4417	39.10	354.00	773.00
Total	0	13	616.62	510.38	418.0566	67.80	172.00	1470.00
DB-2 pH								
Location A_6	0	4	8.73	8.70	0.1500	1.72	8.60	8.90
Location B_6	0	5	8.90	9.00	0.2345	2.63	8.50	9.10
Location C_6	0	4	8.93	8.90	0.1258	1.41	8.80	9.10
Total	0	13	8.85	8.90	0.1898	2.14	8.50	9.10
Chromium[c]								
Location A_6	0	4	5.69	4.52	4.3319	76.13	2.30	9.80
Location B_6	0	5	4.22	3.21	3.5901	85.07	1.70	11.50
Location C_6	0	4	5.06	3.94	4.0778	80.59	2.50	11.20
Total	0	13	4.74	3.80	3.5438	74.76	1.70	11.50

Table A-2. Summary Statistics for Borehole Mud Pits. (sheet 5 of 6)

Description	No. of LTDL values[a]	No. of GTDL values[b]	Mean	Median	Std dev	Coefficient of variation (%)	Minimum	Maximum
DB-11 pH								
Location A_7	0	4	8.40	8.40	0.0816	0.97	8.30	8.50
Location B_7	0	5	8.34	8.30	0.1140	1.37	8.20	8.50
Location C_7	0	4	9.05	9.15	0.4041	4.47	8.50	9.40
Total	0	13	8.58	8.40	0.3940	4.59	8.20	9.40
Barium[c]								
Location A_7	0	4	141.04	134.86	43.1694	30.61	102.00	206.00
Location B_7	0	5	117.27	116.94	8.8246	7.53	104.00	128.00
Location C_7	0	4	109.11	108.63	10.2818	9.42	103.00	125.00
Total	0	13	121.53	119.44	22.7973	18.76	102.00	206.00
Sulfate								
Location A_7	0	4	230.45	254.00	168.5523	73.14	3.80	410.00
Location B_7	0	5	350.64	310.00	256.6966	73.21	39.20	729.00
Location C_7	0	4	13.53	14.00	8.5348	63.08	2.70	23.40
Total	0	13	209.93	234.00	224.3511	106.87	2.70	729.00

Table A-2. Summary Statistics for Borehole Mud Pits. (sheet 6 of 6)

Description	No. of LTDL values[a]	No. of GTDL values[b]	Mean	Median	Std dev	Coefficient of variation (%)	Minimum	Maximum
Extractable organics								
Location A_7	4	0	BDL[d]	BDL	N/S[e]	N/S	BDL	BDL
Location B_7	5	0	BDL	BDL	N/S	N/S	BDL	BDL
Location C_7	4	0	BDL	BDL	N/S	N/S	BDL	BDL
Total	13	0	BDL	BDL	N/S	N/S	BDL	BDL
Total organic carbon[f]								
Location A_7	2	2	16.97	N/S	48.1125	283.52	BDL	67.10
Location B_7	0	5	76.96	79.50	43.1695	56.09	13.50	135.00
Location C_7	0	4	50.98	30.70	55.4275	108.72	11.50	131.00
Total	2	11	51.36	46.70	50.1077	97.56	BDL	135.00

[a]LTDL = Less than detection limit.

[b]GTDL = Greater than detection limit.

[c]Metals are assumed to be log-normally distributed. The summary statistics are calculated based on log-normal distribution and are transformed to parts per million (p/m). Note that all values are expressed in p/m except pH.

[d]BDL = Below detection limit.

[e]N/S = Not sufficient data.

[f]Cohen's method was used to calculate the summary statistics due to LTDL values.

Table A-3. Summary Statistics for Background Samples. (sheet 1 of 2)

Description	No. of LTDL values[a]	No. of GTDL values[b]	Mean	Median	Std dev	Coefficient of variation (%)	Minimum	Maximum
Background for Boreholes DC-16 Mud Pits A and B								
pH	0	2	9.10	9.10	0.2828	3.11	8.90	9.30
Chromium[c]	0	2	10.93	10.57	2.8845	26.39	8.80	12.70
Sodium[c]	0	2	151.64	151.36	9.2149	6.08	145.00	158.00
Boreholes DB-2, DC-6, and DC-14								
pH	0	3	7.47	7.00	1.2662	16.95	6.50	8.90
Barium[c]	0	3	94.86	91.32	26.6751	28.12	66.60	111.00
Chromium[c]	0	3	13.36	10.80	9.7310	72.84	5.80	21.30
Sodium[c]	0	3	322.27	282.44	177.0863	54.95	207.00	511.00
Sulfate	0	2	N/S	N/S	N/S	N/S	N/S	N/S

Table A-3. Summary Statistics for Background Samples. (sheet 2 of 2)

Description	No. of LTDL values[a]	No. of GTDL values[b]	Mean	Median	Std dev	Coefficient of variation (%)	Minimum	Maximum
Boreholes DB-11 and DC-20B								
pH	0	4	8.78	8.75	0.4272	4.87	8.30	9.30
Barium[c]	0	4	87.97	89.99	42.1662	43.04	51.80	139.00
Sodium[c]	0	4	344.86	231.44	380.9558	110.47	142.00	882.00
Sulfate	0	4	230.10	4.00	453.9357	197.28	1.40	911.00
Extractable organics	1	0	N/S	N/S	N/S	N/S	N/S	N/S
Total organic carbon	0	1	N/S	N/S	N/S	N/S	N/S	N/S

[a]LTDL = Less than detection limit.

[b]GTDL = Greater than detection limit.

[c]Metals are assumed to be log-normally distributed. The summary statistics are calculated based on log-normal distribution and are transformed to parts per million (p/m). Note that all values are expressed in p/m except pH.

[d]N/S = Not sufficient data.

Note that the three locations A, B, and C were selected randomly from each site (borehole). The subscripts 1, 2, ..., 7 (associated with these letters were used to denote the seven subject sites. For example, A_1, B_1, and C_1 represent three random locations (location A, B, and C) of site 1 (DC-16A).

2.3 ESTIMATES OF VARIANCE COMPONENTS

As described earlier, the locations were selected randomly from each site. The statistical model used to characterize the data is an analysis-of-variance procedure for a one-way random-effects model. The model, for each constituent at each site, can be written as

Concentration = Overall mean concentration + Location effect + Error,

In mathematical terms, for each hazardous constituent at a specific site the model is

$$y_{ij} = \mu + L_i + \epsilon ij, \qquad i = 1, 2, \ldots, a,$$
$$j = 1, 2, \ldots, n_i,$$

where:

a = number of locations per site

n_i = the number of samples per location

y_{ij} = the measured concentration for the j^{th} sampled unit in the i^{th} location

μ = the unknown overall population mean

L_i = the effect of the i^{th} location

ϵij = a random error associated with the j^{th} sample unit in the i^{th} location. This contains both the depth effect and analytical measurement error.

Additionally, it is assumed that L_i's are a random sample from a normal population with a mean of zero and a variance of σ_L^2, and ϵ_{ij}'s are normally and independently distributed with a mean of zero and a variance of σ_e^2. It is also assumed that the random factors are all distributed independently of each other. Thus, each observation (for each hazardous constituent from each site) is assumed to be from a normal population with a mean of μ and a variance of

$$Var(y_{ij}) = \sigma_L^2 + \sigma_e^2.$$

The objectives of the experiment and subsequent data analysis are to estimate μ, σ_L^2 and σ_e^2 and to test the hypothesis that there is no location effect (i.e., $\sigma_L^2 = 0$). Statistical inferences from the random effect analysis are applicable to the entire site (borehole), not just the three locations present in the experiment.

The analysis-of-variance table (Table A-4) was constructed for testing the hypothesis that there is no location effect. Note that the quantity n_o (expected mean squares) is given by

$$n_o = (N^2 - \Sigma n_i^2)/[N\ (a-1)]$$

where:

$N = \Sigma n_i$ (total samples per site).

Table A-4. One-Way Random Effects Analysis of Variance Table (location effect is random).

Source of variation	Degrees of freedom (df)	Sums of squares (SS)	Mean squares (MS)	Expected mean squares E(MS)	Calculated F-statistic
Between locations	a-1	SS_B	MS_B	$\sigma_e^2 + n_o\ \sigma_L^2$	MS_B/MS_W
Within locations	N-a	SS_W	MS_W	σ_e^2	
Total	N-1	SS_T			

Estimates of the variance components are obtained by equating the MS_B and MSW with the corresponding E(MS) expressions and then solving for σ_e^2 and σ_L^2. When there is a location effect, it is of interest to estimate σ_L^2 and σ_e^2. The estimators (a ^ over a symbol is used to denote an estimate) of σ_e^2 and σ_L^2 are given by

$$\hat{\sigma}_e^2 = MS_W$$

and

$$\sigma_L^2 = (MS_B - MS_W)/n_o.$$

2.4 ESTIMATION OF THE OVERALL MEAN

An important objective of the one-way random-effects analysis of the variance is often to estimate the overall mean μ. When the n_i's are equal (equal observations per location), the minimum variance unbiased estimator of μ is given by

$$\bar{y}_{..} = \Sigma y_{ij}/N.$$

However, when the n_i's are unequal, the above equation assigns more weight to locations with larger n_i values and less weight to locations with smaller n_i values. It can be shown that when $\sigma_L^2 \geq \sigma_e^2$, the unweighted average of the location sample means, $\bar{y}_u$ ($\bar{y}_u = \Sigma \bar{y}_{i.}/a$) has a smaller variance than $\bar{y}_{..}$ for any set of unequal n_i. Thus, $\bar{y}_u$ is used whenever there is a significant location effect. If the location effect is not significant (at the 5% level) then $\bar{y}_{..}$ is used.

A 95% confidence interval (CI) for μ is

$$\bar{y}_{..} \pm \sqrt{\hat{Var}(\bar{y}_{..})}\ t_{0.975\ (N-1)}$$

or an approximate 95% CI for μ is

$$\bar{y}_u \pm \sqrt{\hat{Var}(\bar{y}_u)}\ t_{0.975\ (\hat{df}_u)}$$

depending on whether $\bar{y}_{..}$ or $\bar{y}_u$ is chosen to estimate μ. The estimates of variance of $\bar{y}_{..}$, $\hat{Var}(\bar{y}_{..})$ and the variance of $\bar{y}_u$, $\hat{Var}(\bar{y}_u)$, are given by the following formulas:

$$\hat{Var}(\bar{y}_{..}) = s^2/N$$

$$\hat{Var}(\bar{y}_u) = m_1\ MS_B + m_2\ MS_W$$

where:

$$m_1 = 1/an_0$$

$$m_2 = (r_1/a - m_1)$$

$$r_1 = (1/a)\ \Sigma(1/n_i).$$

The approximate degrees of freedom of $\hat{Var}(\bar{y}_u)$, $\hat{df}_u$, are obtained by applying Satterthwaite's formula for linear combinations of independent mean squares. That is,

$$\hat{df}_u = (m_1\ MS_B + m_2\ MS_W)^2/[(m_1\ MS_B)^2/(a - 1) + (m_2\ MS_W)^2/(N - a)],$$

and $\hat{df}_u$ is rounded down to the nearest integer, for conservativeness.

The above described procedures were used to compute the estimate of the variance components, the estimate of overall mean, and the 95% CI for each hazardous constituent at each site. The results are presented in Table A-5.

Table A-5. Estimates of Variance Components and 95% Confidence Intervals for Mean Concentrations. (sheet 1 of 2)

Description	Location[b]	Estimate of variance components[a]			Sample mean[a,d]	95% confidence interval of mean[a]	
		Location[c]	Experimental error	Total			
DC-16A							
pH	s	0.15003	0.03556	0.18559	8.98	[8.00	9.96]
	location A_1	(80.84%)	(19.16%)	(100%)			
Chromium	s	0.02767	0.03118	0.05885	10.38	[6.57	16.39]
	location B_1	(47.02%)	(52.98%)	(100%)			
DC-16B							
pH	ns	N/A	0.02474 (100%)	0.02474 (100%)	9.02	[8.92	9.11]
Chromium	ns	N/A	0.05590 (100%)	0.05590 (100%)	8.05	[6.98	9.29]
Sodium	s	0.02064	0.01056	0.03120	142.90	[97.96	208.48]
	location C_2	(66.15%)	(33.85%)	(100%)			
DC-6							
pH	s	0.02102	0.00555	0.02657	9.48	[9.11	9.85]
	location B_3	(79.11%)	(20.89%)	(100%)			
Sodium	ns	N/A	0.09534 (100%)	0.09534 (100%)	783.76	[650.35	944.55]
DC-14							
pH	ns	N/A	0.11603 (100%)	0.11603 (100%)	6.65	[6.45	6.86]
Barium	ns	N/A	0.06040 (100%)	0.06040 (100%)	101.91	[87.84	118.22]
Sodium	s	0.04542	0.04413	0.08955	402.86	[224.12	724.16]
	location A_4	(50.72%)	(49.28%)	(100%)			
Sulfate	ns	N/A	6772.09 (100%)	6772.09 (100%	54.65	[4.91	104.38]
DC-20B							
pH	ns	N/A	0.82077 (100%)	0.82077 (100%)	9.51	[8.96	10.06]
Sodium	s	0 19700	0.23676	0.43376	525.89	[151.0	1831.4]
	location A_5	(45.42%)	(54.58%)	(100%)			
DB-2							
pH	ns	N/A	0.03603 (100%)	0.3603 (100%)	8.85	[8.74	8.97]
Chromium	ns	N/A	0.44364 (100%)	0.44364 (100%)	3 80	[2.54	5.68]

Table A-5. Estimates of Variance Components and 95% Confidence Intervals for Mean Concentrations. (sheet 2 of 2)

Description	Location[b]	Est. of variance components[a]			Sample mean[a,d]	95% confidence interval of mean[a]	
		Location[c]	Experimental error	Total			
DB-11							
pH	s	0.13797	0.05620	0.19417	8.60	[7.63	9.56]
	location C_7	(71.06%)	(28.94%)	(100%)			
Barium	ns	N/A	0.03458 (100%)	0.03458 (100%)	119.44	[106.75	133.66]
Sulfate	ns	N/A	50333.4 (100%)	50333.4 (100%)	209.93	[74.34	345.52]
Total organic carbon	N/S	N/S	N/S	N/S	N/S	N/S	
Extractable organics	ns	N/A	N/A	N/A	N/A	N/A	

[a]Units are in (p/m) for variance component estimates of metals. The sample means and 95% confidence intervals are expressed in p/m except pH.

[b]s = Significant at 5% level of significance.

ns = Not significant at 5% level of significance.

N/S = Not sufficient data.

[c]N/A = Not applicable.

[d]The calculated sample mean is the weighted sample mean ($y_{..}$) if there is no location effect; it is the unweighted sample mean (y_u) if there is a significant location effect.

The one-way analysis of variance for random-effects model indicated that the location effects were significant at the 5% level for the following hazardous constituents.

Borehole	Constituent
DC-16A	pH and chromium
DC-16B	sodium
DC-6	pH
DC-14	sodium
DC-14	sodium
DC-20B	sodium
DB-11	pH

For these constituents the unweighted sample mean ($\bar{y}_u$) and the location (for each hazardous constituent at each site) that had the highest mean concentration are shown in Table A-5. For the other constituents the weighted sample means ($\bar{y}_{..}$) were computed (see Table A-5).

2.5 COMPARISONS OF BOREHOLE MUD PIT SAMPLES WITH BACKGROUND SAMPLES USING AVERAGE MEAN CONCENTRATIONS FROM MUD PIT SAMPLES

The next step was to compare, for each site, the mud pit sample results with the background sample results. This was done in the following manner:

- Test of homogeneity of variability between the mud pit samples and the background samples (at the 5% level of significance) using F-test (Snedecor and Cochran 1980). This check is necessary to select the appropriate version of the t-test for comparison of mean concentration.

- Apply appropriate statistical test (i.e., t-test) for comparison of mean concentration (Ostle and Malone 1988; Snedecor and Cochran 1980). Note that for pH the null hypothesis (H_0) is that the mean concentration for the borehole mud pit is equal to the respective background mean; the alternative hypothesis (H_a) is that the mud pit value is not equal to the background value (this is a "two-sided" test). For other hazardous constituents, the H_0 is that the mud pit value is equal to the background value, and the H_a is that the mud pit value is larger than the background value (this is a "one-sided" test).

The F-test statistic, for testing homogeneity of variances, was calculated by

$$F = \max (s_b^2, s_i^2) / \min (s_b^2, s_i^2).$$

That is, divide the larger of the two sample variances by the smaller of the two, where s_b^2 = the background sample variance; and s_i^2 = the sample variance for the ith site (i = 1, 2, ..., 7). Note that the s_i^2 and its respective degrees of freedom depended on whether the presence of any location effect. When there was no location effect, $\sigma_L^2 = 0$, s_i^2 was calculated by pooling all the observations in the ith site. When there was location effect, $\sigma_L^2 > 0$, s_i^2 was the sum of $\hat{\sigma}_e^2$ and $\hat{\sigma}_L^2$, and its degrees of freedom was approximated by the Satterthwaite's formula for linear combinations of independent mean squares.

If $s_b^2 > s_i^2$, let $k_1 = n_b - 1$, and k_2 = the degrees of freedom associated with s_i^2; and if $s_b^2 < s_i^2$, let k_1 = the degrees of freedom associated with s_i^2, and $k_2 = n_b - 1$, where n_b = number of respective background samples. The hypothesis of equality of variance is rejected if F is larger than the tabulated value of F (from Snedecor and Cochran, 1980, F distribution, upper 2.5% points) with k_1 and k_2 degrees of freedom.

The results of the F-test were presented in Table A-6. The F-test indicated significant difference in variability between the borehole mud pit samples and the background samples at the 5% level of significance for the following.

Borehole	Constituent
DC-6	pH
DC-14	pH
DB-2	pH
DB-11	Barium

The Cochran's Approximation of Behrens-Fisher's t-test (CABF t-test) was used to examine the hypothesis of equality of mean concentration between the borehole mud pit and background samples. The formulas are listed in Ostle and Malone (1988).

The F-test indicated no significant difference in variability between the borehole mud pit samples and background samples at the 5% level of significance for the following.

Borehole	Constituent
DC-16A	pH and chromium
DC-16B	pH, chromium, and sodium
DC-6	sodium
DC-14	barium and sodium
DC-20B	pH and sodium
DB-2	chromium
DB-11	pH and sulfate

Table A-6. Comparison of Mud Pit Samples with Background Samples Using Largest Mean Concentrations from Mud Pits.

Test of homogeneity of variance			Test of equality of mean concentrations			
Description	Calculated F-value	Result	CABF t-value	Result	Student's t-value	Result
DC-16A						
pH	2.32	ns			0.38	ns
Chromium	1.14	ns			-0.10	ns
DC-16B						
pH	3.23	ns			0.62	ns
Chromium	1.20	ns			-1.50	ns
Sodium	8.46	ns			-0.44	ns
Dc-6						
pH	60.34	s	2.75	ns		
Sodium	2.77	ns			4.61	s
DC-14						
pH	13.82	s	1.10	ns		
Barium	1.26	ns			0.68	ns
Sodium	2.95	ns			1.64	ns
Sulfate	N/S	N/S	N/S	N/S	N/S	N/S
DC-20B						
pH	4.50	ns			1.53	ns
Sodium	1.84	ns			2.02	s
DB-2						
pH	44.50	s	1.88	ns		
Chromium	1.04	ns			-2.46	ns
DB-11						
pH	1.06	ns			0.71	ns
Barium	4.91	s	1.33	ns		
Sulfate	4.09	ns			-0.12	ns
TOC	N/S	N/S	N/S	N/S	N/S	N/S
EO	N/S	N/S	N/S	N/S	N/S	N/S

ns = Not signficant at 5% level of significance.

s = Significant at 5% level of significance.

N/S = Not sufficient data to compare variability or difference in mean concentration statistically.

TOC = Total organic carbon.

EO = Extractable organics.

The Student's t-test was applied in these cases. The formulas are listed in Snedecor and Cochran (1980).

The results of the CABF t-test or the Student's t-test indicated no significant difference in mean concentrations between the borehole mud pit samples and the background samples except for the following.

Borehole	Constituent
DC-6	sodium
DC-20B	sodium

2.6 COMPARISONS OF BOREHOLE MUD PIT SAMPLES WITH BACKGROUND SAMPLES USING LARGEST MEAN CONCENTRATIONS FROM MUD PIT SAMPLES

The F-test (homogeneity of variance) and t-test (equality of means) procedures were also applied to the cases where the location effect was significant. The largest mean concentration (from the three locations of each borehole) was compared with the background mean. The results were presented in Table A-7.

Table A-7. Comparison of Mud Pit Samples with Background Samples Using Average Mean Concentrations from Locations.

Test of homogeneity of variance			Test of equality of mean concentrations			
Description	Calculated F-value	Result	CABF t-value	Result	Student's t-value	Result
DC016A						
pH (location A_1)	2.25	ns			1.06	ns
Chromium (location B_1)	2.16	ns			1.19	ns
DC-16B						
Sodium (location C_2)	2.86	ns			1.17	ns
DC-6						
pH (location B_3)	288.89	s	2.91	ns		
DC-14						
Sodium (location A_4)	5.98	s	2.01	ns		
DC-20						
Sodium (location A_5)	3.37	ns			3.25	s
DB-11						
pH (location C_7)	1.12	ns			0.94	ns

ns = Not signficant at 5% level of signficance.
s = Significant at 5% level of significance.

3.0 REFERENCES

Ostle, B. and L. C. Malone, 1988, Statistics in Research: Basic Concepts and Techniques for Research Workers, 4th ed., The Iowa State University Press, Ames, Iowa, pp. 154.

Snedecor, G. W. and W. G. Cochran, 1980, Statistical Methods, 7th ed., The Iowa State University Press, Ames, Iowa, pp. 89-99, 469, 480-488.

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