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Environmental
Resources
Management

2666 Riva Road, Suite 200
Annapolis, MD 21401
(410) 266-0006
(410) 266-8912 (fax)
http://www.erm.com

ERM

6 May 1999
Reference: 10556.65

DELIVERED VIA OVERNIGHT MAIL

Ms. Bonnie Guy Gross (3HW23)
Remedial Project Manager
U.S. Environmental Protection Agency
1650 Arch Street
Philadelphia, PA 19103

RE: Final Version of the Report titled *Engineering Evaluation/Cost Analysis for the Closure of the Sulfate Basins, WWTP Basins, and Fly Ash Basins and Stockpile* (EE/CA Report) at the Avtex Fibers Superfund Site, Front Royal, Virginia

Dear Bonnie:

On behalf of FMC Corporation (FMC), Environmental Resources Management (ERM) has enclosed five copies of the final EE/CA Report. The final report addresses EPA's and Virginia's comments to the previous draft versions of the EE/CA Report.

Call me if you need additional copies.

Sincerely,

Bob

Robert W. Keating
Project Manager

Enclosures (5)
cc: W. Cutler, FMC
J. Ely, VADEQ
B. Wright, VADEQ

REPORT

ENVIRONMENTAL RESOURCES MANAGEMENT

FMC Corporation

FINAL
Engineering Evaluation/Cost Analysis for the Closure of the Sulfate Basins, WWTP Basins, and Fly Ash Basins and Stockpile

Avtex Fibers Superfund Site
Front Royal, Virginia

5 May 1999

ERM.

AR106336

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Three management units at the Avtex Fibers Superfund Site (Site) in Front Royal, Virginia, namely the Sulfate Basins (SB), Fly Ash Basins (FABs) and Stockpile (FAS), and Wastewater Treatment (WWTP) Basins (WWBs), will be closed as a Non-Time-Critical Removal Action. Both the SBs 1-4E and WWTP Basins are located within the boundary of the 100-year floodplain of the South Fork of the Shenandoah River (River). In accordance with the National Contingency Plan (NCP), EPA designated this response action to be a Non-Time-Critical Removal Action because of concern that flooding of the River may cause the contaminants (primarily metals) in the SB and WWTP basin sludge to be released to the River. Two floods in January 1996 and September 1996 inundated the WWTP and SB 1, and entered a portion of SB 2, indicating that the threat of flooding is a real concern. Although the FABs and Stockpile are located outside the 100-year floodplain boundary, there is the potential for fly ash migration during times of high winds. The expedited closure of the SBs, WWBs, FABs and FAS will mitigate the potential threat of release of contaminants due to adverse weather conditions. The non-time-critical response action for the SBs, WWTP basins, FABs and stockpile is intended to be the final remedy.

As required by the NCP, an Engineering Evaluation/Cost Analysis (EE/CA) is necessary to support a Non-Time-Critical Removal Action if a planning period of at least six months exists before the on-site activities are initiated. This EE/CA Report presents the results of the engineering and cost analysis of response alternatives for the three management units. In accordance with the EPA guidance, the purpose of the EE/CA is to:

1. Provide detailed information pertaining to the potential threats posed by the units to public health, welfare and the environment;
2. Identify the objectives and proposed schedule for the response action;
3. Identify and analyze the alternatives that may be used to satisfy these objectives for cost, effectiveness, and implementability; and
4. Recommend the action for each unit that best satisfies the response action objective (s), and balances the evaluation criteria of cost, effectiveness, and implementability.

The previous data collected from each of the three management units during the Phase 1 remedial investigation conducted in 1993 and 1994 was evaluated to determine the nature and extent of the contamination in each management unit. For the most part, the contamination in these units was limited to the waste material itself and underlying soil, and does not extend into the underlying ground water.

The Phase 1 data were also used to conduct a risk assessment, which identifies the specific potential risks that the response action needs to mitigate, including the potential to impact ground water. The risk assessment showed that metals in the sulfate sludge in the SBs and WWBs, and fly ash can be toxic to ecological receptors. This finding indicates that the sulfate sludge and fly ash need to be covered to prevent direct contact exposure to ecological receptors. In addition, the sulfate sludge and fly ash need to be contained to the Site to prevent migration during weather events.

A quantitative risk assessment was performed to evaluate current and future potential risks to human health associated with exposure to uncovered sulfate sludge and fly ash by an adolescent trespasser. The human receptors most likely to be exposed to COPCs associated with the sulfate sludge and fly ash under current conditions are a potential adolescent trespasser (ages 8 to 17). The adolescent trespasser was assumed to enter the Site 35 days per year. Under future conditions, human receptors consist of recreational users, which would undergo similar exposure as an adolescent trespasser. The risk assessment indicates that there are no unacceptable risk to human health from exposure to the sulfate sludge and fly ash due to trespassing activities.

Based on the results of the risk assessment, a review of ARARs, and consideration of future site use, there are four response action objectives (RAOs) for the three units:

1. Mitigate future potential risk to ecological receptors from the migration of contaminants during flood and wind erosion events;
2. Mitigate current potential direct contact risk to ecological receptors associated with uncovered waste;
3. Meet federal and state ARARs; and
4. Ensure that future use considerations are addressed adequately.

Based on the four RAOs identified above, the overall scope of the response action for the three units consists of placement of cover materials and creation of positive drainage to promote runoff and limit infiltration. The primary objective of the cover is for material containment, direct contact protection, promotion or runoff and prevention of surface water ponding.

Treatment and stabilization technologies were considered for the sulfate sludge, and stabilization was considered for the fly ash. Treatability tests on the sulfate sludge indicated that treatment to recover zinc was difficult to implement and cost prohibitive. Although physical and chemical stabilization technologies for the sulfate sludge and fly ash were technically feasible, stabilization of such a large volume *was cost* prohibitive. Further, stabilization of the sulfate sludge and fly ash is unwarranted since investigation shows minimal impact to ground water. Therefore, treatment and stabilization are not considered to be qualified technologies to meet the RAOs.

The recommended alternative to meet the RAOs for the SBs is Alternative SB 2 - Eliminate SB 5 and Install Enhanced Soil Cover on SB 1-4E, with an estimated net present value cost of $11,822,000. The two containment remedies consisting of soil cover were evaluated for closure of the SBs. The primary difference between the two alternatives is that in Alternative SB 2, enhancements, such as fly ash fill and geotextile, are incorporated into the cover design to address constructability of the cover over the sludges. Alternative SB 1 consisted of placing a two-foot soil cover. Both alternatives include elimination of SB 5. Alternative SB 2 offers a more technically feasible approach to covering the basins, and utilizes on-site materials, especially fly ash, to a greater extent. Furthermore, it is uncertain whether the Alternative SB 1 approach of placement of the two-foot thick soil cover without engineering enhancements is technically feasible based on the results obtained from field test pads.

The recommended alternatives to meet the RAOs for the WWBs is Alternative WWB 3 - Eliminate WWTP Basins, with an estimated net present value cost of $760,000. Two other WWB alternatives consisted of in-place closure in all three WWBs or consolidation and in-place closure into one WWB. There are significant benefits to consolidating the sludge in the SBs, the most important of which is leaving the area of the current WWTP Basins available for unrestricted recreational use.

The recommended alternative to meet the RAOs for the FABs and FAS is Alternative FA 2 - Cover Fly Ash Basins and Stockpile with Soil, with an estimated net present value cost of $4,909,000. Alternative FAS 1 consists of only covering the FAS with a 24-inch soil cover. Covering the FAS eliminates an ecological risk and mitigates the release of fugitive emissions. Therefore, recommending one alternative over another is based on determining whether the FABs warrant a soil cover, as well. However, leaving the FABs uncovered does not comply with ARARs, specifically the requirements of Virginia's Solid Waste Management Regulations for closure of an industrial waste disposal unit. Further, the community and the state, as well as EPA, could raise concerns about not including any action for the FABs because contact with fly ash may create a nuisance. Covering the FABs is consistent with the proposed conceptual reuse plan of passive pedestrian recreation.

The proposed closure plan will provide unrestricted access to the River in the 30-acre area currently occupied by SB 5, and the WWTP and WWBs. Although the soil-covered basins could have some restrictions regarding the types of vehicles that can access the basins, the soil covers will support pedestrian recreational access. Therefore, the proposed conceptual closure plan is consistent with the proposed conceptual reuse plan adopted by the Town of Front Royal. The closure of the SBs, FABs and FAS is estimated to be completed by the end of 2000. The closure of the WWBs will be completed when the need to retain Site stormwater generated at the plant is eliminated.

1.0 *INTRODUCTION*

1.1 *PURPOSE*

Three types of management units at the Avtex Fibers Superfund Site (Site) in Front Royal, Virginia, namely the Sulfate Basins (SB), Fly Ash Basins (FAB) and Stockpile, and Wastewater Treatment (WWTP) Basins, will be closed as a Non-Time-Critical Removal Action. Figure 1 shows the locations of these three units at the Site. Both the SBs 1-4E and WWTP Basins are located within the boundary of the 100-year floodplain of the South Fork of the Shenandoah River (River) (floodplain boundary is shown on Figure 1).

In accordance with sections 40 CFR 300.415(b)(2)(iv) and (v) of the National Contingency Plan (NCP), EPA designated this response action to be a Non-Time-Critical Removal Action because of concern that flooding of the River may cause the contaminants (primarily metals) in the SB and WWTP basin sludge to be released to the River. Two floods in January 1996 and September 1996 inundated the WWTP and SB 1, and entered a portion of SB 2, indicating that the threat of flooding is a real concern. Furthermore, EPA's ecological risk assessment for the Site (Sprenger *et al*, 1999) demonstrated that the sulfate sludge and fly ash was toxic to benthic and aquatic receptors. The expedited closure of these basins will mitigate the potential threat of release during flooding. Although the FABs and Stockpile are located outside the 100-year floodplain boundary, there is the potential for fly ash migration during times of high winds or heavy rains. These units are therefore included in the Non-Time-Critical Removal Action and will undergo a similar response action as the SBs and WWTP Basins. The non-time-critical response action for the SBs, WWTP basins, FABs and stockpile is intended to be the final remedy.

EPA designated all the management units west of the railroad tracts as a single Area of Contamination (AOC). EPA justifies this designation due to the close proximity of all the various basins, stockpile and landfill (16 April 1999 letter from B. Gross, EPA to J. Ely, VADEQ). In the preamble to the 1990 NCP, EPA refers to an AOC as an area with continuous contamination of varying amounts and types. The preamble suggests that an AOC be defined as a "non-discrete land area on or in which there is generally dispersed contamination, as opposed to discrete, widely separated areas of contamination." Wastes can be consolidated within the AOC, including wastes that are diverse in composition, without being construed as disposal. The designation of the area west of the railroad tracks as an AOC allows for consolation of physically and chemically compatible waste to be considered as part of the closure of the EE/CA units.

As required by section 40 CFR 300.415(b)(4)(i) of the NCP, an Engineering Evaluation/Cost Analysis (EE/CA) is necessary to support a Non-Time-Critical Removal Action if a planning period of at least six months exists before the on-site activities can be initiated. The EE/CA is an analysis of the response alternatives for the three management units. In accordance with the EPA document titled *Guidance on Conducting Non-Time-Critical Removal Actions under CERCLA (EPA 540-R-93-057, August 1993)*, the purpose of the EE/CA is to:

1. Provide detailed information pertaining to the potential threats posed by the units to public health, welfare and the environment;
2. Identify the objectives and proposed schedule for the response action;
3. Identify and analyze the alternatives that may be used to satisfy these objectives for cost, effectiveness, and implementability; and
4. Recommend the action that best satisfies the response action objective, and balances the evaluation criteria of cost, effectiveness, and implementability.

This EE/CA Report presents the results of the engineering and cost assessment of alternatives. This document contains sufficient detail to allow EPA to select the appropriate response action for the units, but does not contain a detailed design. Comprehensive engineering design documents will be prepared after the response action has been formally selected by EPA.

The general response action consists of placement of cover materials over in-place waste and creation of positive drainage to promote runoff and limit infiltration. The primary objective of the cover is material containment, direct contact protection, and prevention of surface water ponding. The purpose of the EE/CA is to optimize the selection of an appropriate response action for each of the three units. As part of the optimization process, the EE/CA addressed three critical engineering issues.

1. The ability of the sulfate sludge to bear the loads that would be applied during construction of the soil covers was uncertain. Therefore, the EE/CA included a field pilot study to demonstrate the implementability of a soil cover over the sludge and develop preliminary design specifications for the actual full-scale placement of the proposed soil cover.

The potential for differential settlement is also a critical engineering issue. The potential for differential settlement is currently being evaluated through laboratory testing and will be further assessed during the final engineering design.

2. The potential for flooding to erode the soil cover placed on the SBs needed to be addressed. Therefore, the EE/CA included modeling of the River floodplain under proposed remediated conditions to ensure that the velocity of river water during a 100-year flood will not erode the vegetation and soil cover.
3. The sulfate basins are currently used to retain stormwater from the plant area prior to treatment and discharge to the River. Closure of the sulfate basins prior to completing the remediation of the plant area will require that stormwater be retained in another manner. Therefore, the EE/CA included an evaluation of options to manage Site stormwater after the sulfate basins are closed.

1.2 *REPORT ORGANIZATION*

The remainder of this EE/CA is organized as follows:

- *Section 2.0 – Site Characterization.* This section describes the nature and extent of the contamination in each management unit. The section also includes the risk assessment, which identifies the specific potential risks that the response actions need to mitigate, including the potential to impact ground water.
- *Section 3.0 - Identification of Response Action Objectives.* Applicable or relevant and appropriate requirements (ARARs) are identified, and the response action objectives are presented.
- *Section 4.0 – Identification and Analysis of Response Action Alternatives.* Alternatives are identified, described, and assessed against the criteria of cost, effectiveness, and implementability. Also, the response action alternatives for each unit are compared.
- *Section 5.0 – Recommendations.* The action that best satisfies the evaluation criteria for each management unit is identified. Also, the conceptual basin closure plan and a general schedule for the response activities, including both the start and completion date, are presented.

2.0 *SITE CHARACTERIZATION*

2.1 *SULFATE BASINS*

2.1.1 *Unit Description and Background*

The Sulfate Basin Management Unit consists of six basins, identified as SB 1, 2, 3, 4, 4E and 5, that are aligned in a predominantly north-south orientation bordering the River (Figure 1). The SBs occupy approximately 85 acres. The basins are unlined and were used for disposal of sludge formed in the primary clarifiers and polishing basins by the neutralization of spent viscose rayon spinning bath with lime in the WWTP. Activated sludge from secondary treatment was also transferred to the Sulfate Basins after undergoing stabilization in an aerobic digester. The basins are estimated to contain 936,000 cubic yards of sludge containing approximately 20 percent (dry weight) zinc in the form of zinc hydroxide, zinc sulfate, and zinc carbonate. The sludge also contains gypsum ($CaSO_4 \bullet 2H_2O$), cellulose, iron hydroxide and metal oxides. There are berms surrounding the basins that are believed to have been constructed by excavating soil from the basin and using the excavated soil to form the berms.

The composition of the sludge in SB-2, 3, 4, and 4E is mostly uniform. The sludge in SB-1 and SB-5 is somewhat different in makeup and thickness, respectively. The makeup of the sludge in SB-1 was changed when zinc was reclaimed from the sludge in the zinc recovery operation, and the sludge was deposited back in the basin. Approximately 65 percent of the zinc was recovered during the reclaiming process, with the remaining 35 percent disposed in the southeast corner of SB-1 as zinc acid cake. In addition, SB-1 contains River mud and silt deposited in the basin during floods. In SB-5, most of the sludge was removed in the 1980s, leaving approximately two feet in the basin. In the early 1980s, most of the sludge was also removed from former SB-6, and the basin, which is currently designated as fly ash basin FAB-6, was converted for fly ash disposal.

Since January 1990, as part of the emergency response action, EPA has directed storm water from the plant area into SB-1, where it is stored or pumped to basins SB-2 through SB-4E. Under current conditions, the Sulfate Basins generally contain variable amounts of water depending on the time of year and the status of WWTP operations. The stormwater is treated by FMC at the WWTP during the spring and summer months, and discharged to the River under an NPDES permit. During the fall and winter months, stormwater is retained in the SBs.

Data obtained from 21 borings drilled in the basins during the 1993 RI (see Figure 2 for boring locations) indicate the thickness of zinc sludge in the basins ranges from 1 to 25 feet. The estimated volume of zinc sludge and area for each of the Sulfate Basins is summarized below.

Sulfate Basin	Area (square feet)	Sludge Thickness (feet)	Soil Thickness Beneath Basin (feet)	Estimated Volume of Sludge (cubic yards)
1	1,370,000	5-25	2-16	429,000
2	260,000	6-11	8-10.5	56,000
3	354,000	13-20	4-5	153,000
4/4E	632,000	9.5-14/10-14	2-5/2-3	221,000
5	857,000	1-6	0-2	77,000
				Total 936,000

Based on the 21 borings completed in the Sulfate Basins, other materials, such as fly ash or viscose, were not encountered in the borings completed in the Sulfate Basins and surrounding berms. Each basin is underlain by natural sandy silts with trace clay with a thickness generally in the range of 2 to 10 feet overlying bedrock. Borings completed in the basin berms indicate the berms are constructed with native sandy silts with trace clay.

A number of sludge samples collected during the RI were analyzed for physical and geotechnical parameters to determine the characteristics of the material in the basins. These results are summarized in Table 1. The particle size of the sludge is classified as ranging from silty clay to silty sand based on laboratory sieve analysis using the Unified Soil Classification System. Laboratory testing indicates that the sludge has relatively low permeability in the range of 10^{-6} to 10^{-7} centimeters/second (cm/sec).

2.1.2 *Source, Nature and Extent of Contamination*

The investigation of the Sulfate Basins was conducted during the Phase 1 RI between July 1993 and April 1994. The objectives of the Sulfate Basin investigation were to:

- Determine the nature and extent of chemical constituents in the basins and underlying soils; and

- Determine the impacts, if any, on other media.

The remedial investigation of the Sulfate Basins consisted of: 1) collection and analysis of 77 samples from the sludge and soil beneath the sludge to determine physical and chemical characteristics; and 2) collection and analysis of ground water samples from eleven overburden and five shallow bedrock monitoring wells located hydraulically downgradient of the basins to determine potential ground water quality impacts. Off-site laboratory analytical data for the sludge and soil samples were generated to satisfy two analytical options. Seventy-seven samples were analyzed using SW-846 analytical methods to meet the Level III analytical option. The Level III samples were analyzed for 9 volatile and semi-volatile organic compounds, 4 PCB Aroclors, 6 metals, and cyanide. These 20 constituents were identified by EPA as key Site contaminants. 20 samples were analyzed using Contract Laboratory Program (CLP) methods to meet the Level IV analytical option, which included analysis for the Target Compound List (TCL) and Target Analyte List (TAL). The Level IV data, which were validated in accordance with EPA protocol, are presented in this EE/CA.

The source, nature and extent of Site contaminants in the Sulfate Basins were adequately characterized during RI activities. Analytical data for the Sulfate Basins were reported to EPA in 1993 (ERM, 1993). Key Level IV detections of organic and inorganic constituents in sludge samples are summarized in Table 2. The analytical results indicate the contaminants in the Sulfate Basins are metals associated with the zinc sludge. The constituents detected in the Sulfate Basins occur consistently and are evenly distributed throughout the zinc sludge in all six basins. Soil samples from the berms were uncontaminated, and the soils underlying the zinc sludge were generally uncontaminated, with detection of only a few organic compounds and slightly elevated zinc concentrations. Accordingly, the lateral and vertical extent of contamination in the six Sulfate Basins is contained within the zinc sludge, and the 1 to 2 feet of soil underlying the sludge and soil in the berms that is in contact with the sludge.

Table 2 indicates that the primary chemical constituents identified in sludge and soil samples from the basins are zinc (between 86 and 278,000 milligrams per kilogram (mg/kg)), chromium (12-338 mg/kg), copper (9.8-102 mg/kg), lead (5.6-2,240 mg/kg), and cadmium (0.86-87.8 mg/kg). In general, the zinc and lead concentrations decreased by one to two orders of magnitude in the soil zone within two to four feet beneath the basin sludge.

Table 2 indicates that organic compounds were detected in the Sulfate Basins infrequently, and included carbon disulfide, toluene, ethylbenzene and xylenes at 2-1,200 micrograms per kilogram (µg/kg)), phenol (74-570 µg/kg), polycyclic aromatic hydrocarbons (PAHs) (54-2,100 µg/kg), bis(2-

PYRENE IS A PAH

54-2100 ppb

ethylhexyl)phthalate (BEHP) (54-3,700 μg/kg), pesticides (0.11-27 μg/kg), and PCBs (140-200 μg/kg). The low concentrations, infrequent detection, and irregular spatial distribution for the detected organic constituents indicate the sludge does not contain substantive amounts of organic contamination.

Analytical results for waste characterization show that the zinc sludge in the sulfate basins is not a RCRA hazardous waste based on the Toxicity Characteristics. Nineteen samples of sulfate sludge were collected from the sludge and underlying soil in the SBs and WWBs during the Phase 1 RI in 1993, and analyzed for Toxicity Characteristic Leaching Procedure (TCLP) metals, cyanide and sulfide reactivity, ignitability and corrosivity testing. The metal results indicated barium was detected at concentrations ranging from 0.25 mg/l to 1.4 mg/l, which is well below the regulatory limit of 100 mg/l. There was also one trace detection of chromium and one detection of silver, both of which were well below their respective regulatory limits. All of the other characteristic results were well below regulatory limits. Additional waste characterization samples were also collected in 1997 as part of a pilot test for electrokinetic zinc recovery. These samples also indicated that the sulfate sludge is not a RCRA hazardous waste based on Toxicity Characteristics.

The sulfate sludge in the SB or WWTP basins is not a listed waste. There is no information to indicate that contaminants in the sulfate sludge were derived from a RCRA-regulated unit. Low concentrations of CS_2 in the sulfate sludge likely resulted from process wastewater discharged to the WWTP, rather than discharge of the moat water from the CS_2 storage units.

The principal potential route of migration for constituents in the zinc sludge is via flooding to the Shenandoah River. Another potential route of migration is dissolution and infiltration to the overburden water table, and subsequent migration through the overburden water table and discharge to the River. However, the ground water quality data from 16 overburden and shallow bedrock monitoring wells located hydraulically downgradient of the Sulfate Basins and the TCLP data show that metals are not readily leached from the sludge. Figure 3 presents a cross-section through a portion of SB-5 (see Figure 2 for location of cross section S-S'), which illustrates the attenuative capacity of the overburden soils. The cross-section shows the marked decrease in zinc concentrations for the zinc sludge in the Sulfate Basin (sample SB-BH-27-02 contained 23.7 percent zinc) and the underlying soil (sample SB-BH-27-06 contained 109 mg/kg or 0.0109 percent). The cross section also shows that low concentrations of zinc (0.157 to 0.191 mg/l) are present in the ground water in overburden soils (wells 010 and 011), and no zinc was detected in the shallow bedrock (wells 110 and 111) downgradient of the Sulfate Basins.

Ground water quality data collected from the overburden monitoring wells downgradient from the Sulfate Basins suggest that low levels of zinc have reached the water table in the overburden soils. Figures 4 and 5 show the direction of ground water flow in overburden and shallow bedrock, respectively, is from the Sulfate Basins toward the River. Maximum dissolved concentrations of zinc (62 to 941 micrograms per liter (µg/l)) and lead (below detection limits to 35 µg/l) in ground water samples collected from downgradient overburden wells in February and April 1994 (ERM, 1994d) appear to be slightly elevated relative to maximum concentrations of these metals (19 to 246 µg/l for zinc, and below detection limits to 0.7 µg/l for lead) in upgradient overburden wells (Table 3). Figures 6 and 7 illustrate the extent of dissolved zinc in the overburden and shallow bedrock wells. No other metals are elevated in ground water downgradient from the basins. Furthermore, ground water quality data from the shallow bedrock do not indicate impacts from the Sulfate Basins to the bedrock aquifer.

Three lines of evidence support the conclusion that the SBs are not releasing concentrations of trace metals to ground water at concentrations of concern.

1. The weight of the empirical ground water quality data from 12 overburden wells located no more than 100 feet downgradient from the edge of the SBs and WWBs indicates that the SBs are not a substantive source of metals to ground water (Figure 6).

2. The metals in the sulfate sludge are not readily leached because they are contained within the crystalline matrix of mineral species. Recent testing by Tallon Metals Technologies, Inc. (Tallon, 1998) indicates metals in the sludge are contained in zinc carbonate, zinc sulfate and sulfide, and to a lesser extent zinc hydroxide. Leaching with aggressive acids was unsuccessful in releasing substantive amounts of zinc from the mineral species because of the buffering capacity of the carbonate species. Consequently, moderately acidic rainwater (pH 5.0) will not be aggressive enough to release the metals from the mineral phase.

3. Zinc solubility (as well as other divalent metals such as lead, nickel and copper) in solution is very low in the presence of bicarbonate. Literature values for zinc solubility indicate that water that contains 610 mg/l bicarbonate will only contain less than 0.10 mg/l dissolved zinc at a pH greater than 8.0. (Hem, J.D., *Chemistry and Occurrence of*

Cadmium and Zinc in Surface and Groundwater, Water Resources Research, June 1972). Ground water samples collected in 1994 indicate that the average bicarbonate concentration in the 12 overburden wells downgradient of the WWBs and SBs was 1,000 mg/l, and the pH of the overburden ground water was 7.5 to 8.5. Consequently, the presence of the bicarbonate in ground water provides further explanation as to why the dissolved zinc concentrations in ground water are low.

The overall contribution of lead and zinc from the overburden water table to the River is minimal due to the limited thickness of the overburden water table and the corresponding low flux of the metals into the River. Two lines of evidence support the determination that there is a low flux of metals from overburden ground water into the River. First, lead and zinc were not detected in water samples collected from the River adjacent to the Sulfate Basins (Gannett Fleming, 1994). Second, the amount of ground water discharge from the overburden to the River is estimated to be 29,000 gallons per day (gpd), which is only 0.003 percent of the average daily flow of over one billion gpd (1,600 cubic feet per second) measured at a gauging station in the River located south of the Site. The discharge of ground water from the overburden to the River was estimated using Darcy's Law (Q=KiA) and the following assumptions:

- An average hydraulic conductivity (K) value of 3.14 feet/day based on slug tests conducted in the overburden monitoring wells installed along the riverbank;

- The steepest measured hydraulic gradient (i) of 0.05 in the overburden unit (Figure 4); and

- An area (A) of 25,000 square feet based on a length of 5,000 feet between SB-1 and SB-5, and the largest saturated thickness of 5 feet measured in the overburden wells located along the River.

The ground water flux from the overburden into the River indicates that a substantial amount of mixing of the ground water discharge occurs as a result of the River flow from upstream.

The overburden water table downgradient of the Sulfate Basins contains elevated concentrations of total dissolved solids (TDS) (1,420 to 5,680 mg/l) compared to upgradient overburden ground water quality (865 mg/l). The make-up of the TDS is primarily calcium and sulfate derived from the dissolution of gypsum, indicating the Sulfate Basins are a source for these constituents in shallow ground water. These findings indicate that ions not easily attenuated by soils beneath the basins migrate from the Sulfate Basins to shallow ground water. Closure of the basins, with the concomitant removal of the excessive water head and reduced infiltration rate, is expected to mitigate this water quality impact.

Potential migration of sludge via airborne particulates is not a viable migration pathway. Observations in the field indicate that when the basins are emptied of water and the sludge allowed to dry, the sludge remains cohesive due to the high residual moisture content.

2.1.3 *Risk Assessment*

The risk assessment was performed for the Sulfate Basins based on site-specific analytical data collected during the RI and knowledge of environmental conditions in the vicinity of the Site. The purpose of the risk assessment was to identify the current or future potential human health and ecological exposures that should be prevented by a response action. In accordance with EPA guidance (EPA, 1993), this risk evaluation:

- Describes the types of exposures to Contaminants of Potential Concern (COPCs) that may occur;
- Presents the COPCs identified for the Sulfate Basins as a result of a risk-based screening process;
- Provides an assessment of potential health effects (i.e., carcinogenic or non-carcinogenic) or ecological effects associated with these constituents; and
- Projects the potential risk to human health or ecological receptors that may occur if no response action is implemented at the Site.

Human Health Risks

Gradient Corporation (Gradient) performed a quantitative risk assessment to evaluate current and future potential risks to human health associated with exposure to uncovered sulfate sludge by an adolescent trespasser (Appendix E). The methods and results of the human health risk assessment are described in the Gradient report (Gradient, 1999). Samples collected from the sulfate and WWTP basins in 1993 as part of the Phase 1 remedial investigation were used for the risk assessment. Twenty samples were collected from within and below the SBs, and seven samples were collected from within and below the WWBs, and analyzed for the TCL and TAL using CLP methods to meet the Level IV analytical option. The data were validated in accordance with EPA protocol.

As the first step to selecting COPCs, samples that contained a mixture of soil and sulfate sludge were eliminated from the data set used to identify

COPCs for the risk assessment. These samples were excluded because there was no potential for direct contact with chemicals in soil located 15 feet below the sludge. As a result, the total of 27 Level IV samples for the SB and WWTP basins was reduced to 22 samples.

The second step included screening the constituents detected in the Level IV samples for the risk assessment (Table 4). COPCs for human health for the SBs an WWTP were selected by comparing maximum concentrations of detected constituents to current Region III Risk-Based Concentrations (RBCs) for an industrial soil exposure scenario for non-carcinogenic and carcinogenic health effects. Screening against industrial RBCs for an area that will never be developed for residential use is appropriate, and more conservative than the proposed recreational use. These COPCs were identified based on a Hazard Quotient of 0.1 for noncarcinogens (to account for possible systemic effects for non-carcinogens in accordance with EPA Region III guidance), and a risk level of 10^{-6} for carcinogens. The only constituents detected in sulfate sludge that exceeded the Region III RBCs for an industrial soil exposure were arsenic, lead and zinc.

The human receptors most likely to be exposed to COPCs associated with the soil and sludge in the Sulfate Basins under current conditions are a potential adolescent trespasser (ages 8 to 17). The adolescent trespasser was assumed to enter the Site 35 days per year. Under future conditions, human receptors consist of recreational users, which would undergo similar exposure as an adolescent trespasser. Gradient evaluated cancer risks and non-cancer hazards associated with potential exposure to arsenic and zinc via ingestion, dermal contact and inhalation. Risks from lead exposures were estimated using the adult lead model. The Gradient report describes the exposure parameters and toxicity factors used to calculate the cancer risks and non-cancer hazards.

Total cancer risk for the sulfate basins, across all pathways, was calculated to be 1×10^{-7}. This value is below EPA's target risk goal of 10^{-4} to 10^{-6}. The total non-cancer hazard index was 0.06, which is less than one and indicates non-cancer effects are not expected. Further, the Gradient report concludes that lead in the sulfate sludge does not pose an unacceptable risk for potentially exposed adolescents. The risk assessment indicates that there are no unacceptable risks to human health from exposure to the sulfate sludge due to trespassing activities.

Ecological Risks

COPCs for ecological receptors were selected based on comparison to EPA Region III benchmarks compiled by the Region III Biological Technical Assistance Group (BTAG) (Charters *et al*, 1996; Sprenger *et al*, 1999). The ecological COPCs identified by EPA were arsenic, cadmium, chromium, copper, lead, manganese, nickel, silver, zinc, and pyrene. Potential ecological receptors for the Sulfate Basins under current conditions consist of terrestrial and aquatic biota. Aquatic biota are limited to the fish that are present primarily in SB-5. Terrestrial biota include birds, mammals, reptiles, amphibians and invertebrate species, such as worms, that provide a food source for vertebrate species. Under future conditions, in the event that no response action is taken at the Site, the same terrestrial and aquatic receptors will exist. Also, the potential exists for the sludge to be released to the River during flooding, which would pose a risk to aquatic biota in the River.

The ecological COPCs identified by Charters *et al* (1996) for the Sulfate Basins have the potential to cause adverse health effects to both aquatic and terrestrial biota. The toxic effects to terrestrial and aquatic biota associated with the principal Sulfate Basin contaminants, lead and zinc, are varied depending on the species. The toxic effects of lead on aquatic and terrestrial organisms include reduced growth and reproductive output, blood chemistry alteration, and behavioral changes (Charters *et al*, 1996). The pancreas and bone appear to be primary targets of zinc toxicity in birds and mammals. In fish, zinc toxicity results in destruction of gill tissue. Other ecological COPCs, including cadmium, chromium, and copper, adversely affect both terrestrial and aquatic biota.

EPA prepared a Final Ecological Risk Assessment for the Site (Sprenger *et al*, 1999), which reported that sediment samples collected from SB-5 have some impact (either reduced survival or reduced growth) on sediment invertebrates. These effects where interpreted by EPA to be related to the direct toxicity of the metals concentrations. However, the investigators also determined that sediment samples from SB-1 did not have an effect on biota. Adverse effects to upper trophic levels were also identified for the sulfate basins, specifically piscivorous birds eating carp in SB-5 that contain copper and zinc (Sprenger *et al*, 1999).

The presence of ecological COPCs in the Sulfate Basins at levels exceeding risk-based concentrations, coupled with the results of the Final Ecological Assessment, indicate a potential risk to terrestrial and aquatic biota exists. The potential risk exists under current conditions, where terrestrial biota can contact the exposed sludge when the basins do not contain water. When water is present, the sulfate basins also provide habitat for migratory birds, which may pose a potential risk to these receptor populations.

Under future conditions, there is a potential risk to aquatic biota in the event that flooding releases sludge to the River. A response action is warranted to mitigate the exposure of ecological receptors to the exposed sludge in the basins, or to sludge released to the River during flooding.

Ground Water Pathway

Human and ecological receptors are not exposed to ground water in the overburden that has been affected by COPCs associated with the Sulfate Basins, therefore, the exposure pathway is incomplete. Ingestion of ground water from the overburden unit beneath the basins does not pose a risk to human health because this unit cannot be used as a source of potable water. The overburden unit is unsuitable for potable supply due to its limited thickness, lack of available drawdown, and low yield. Furthermore, ground water in the bedrock has not apparently been affected by COPCs derived from the SBs, indicating that communication between the overburden and bedrock beneath the SBs is limited. Ground water quality degradation in bedrock emanating from viscose basins 9-11 will be addressed as part of the RI/FS for that unit.

There is no unacceptable risk posed to ecological receptors by ground water discharge from the overburden unit to the River based on sampling conducted by EPA in 1994 as part of EPA's River investigation, and again in 1997 as part of the Final Ecological Risk Assessment (Sprenger *et al*, 1999). Furthermore, the pathway for potential exposure of ecological receptors in the River is incomplete because the flux of ground water discharge from the overburden unit to the River is negligible. This finding is supported by the fact that the overburden ground discharge quantity of approximately 29,000 gpd is 0.003 percent of the average daily flow in the River.

2.2 *WWTP BASINS*

2.2.1 *Unit Description and Background*

The WWTP Basins Management Unit consists of the emergency lagoon (EL) and two polishing basins (PB 1 and 2) (Figure 1). The EL covers an area of 70,600 ft^2 and the two polishing ponds cover an area of 98,200 ft^2. Current use of these units differs from historic use when the Avtex facility was still in operation. Previously, the emergency lagoon was used for emergency storage of the wastewater stream from the WWTP when the volume of the influent stream exceeded the WWTP capacity. The EL is currently used as an influent pumping basin for the active WWTP operation that treats stormwater stored in the Sulfate Basins. The EL contains water year round.

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The polishing basins have been inactive since the plant was shut down in 1989. When the Avtex facility was active, the polishing basins received the clarifier overflow and were used for the final step of zinc removal from the wastewater effluent stream. Currently, water enters the polishing basins from rainfall and flood events. The polishing basins are periodically emptied by pumping accumulated water to the Sulfate Basins.

Borings completed in the basin berms indicate the berms are constructed with native clayey silt soils. The berms for the emergency lagoon and polishing basins were probably built by excavating soil from the basin and using the excavated material to form the berms.

Data obtained from 3 borings drilled during the 1993 RI (see Figure 8 for boring locations) indicate the emergency lagoon contains an average of 5 to 10 feet of supernatant and a sludge thickness of 5 to 11 feet. Underlying the lagoon sludge is 5 to 10 feet of natural silty sand and silty clay above bedrock. The estimated total volume of sludge in the emergency lagoon is 12,000 cubic yards. Data obtained from 6 borings drilled in the two polishing basins indicate the average sludge thickness in the polishing basins ranges from two to five feet. The thickness of natural silty sand and silty clay beneath the polishing basins is 0 to 2 feet, and rests upon the shale bedrock. The estimated total volume of sludge in the polishing basins is approximately 16,500 cubic yards.

The chemical make-up of the sludge in both the emergency lagoon and polishing basins is identical to sludge contained in the Sulfate Basins. The sludge consists of zinc hydroxide, zinc sulfate, and zinc carbonate, gypsum, cellulose, iron hydroxide and metal oxides.

Six sludge samples collected during the RI were analyzed for physical and geotechnical parameters to determine the physical characteristics of the material in the basins. These results are summarized in Table 5. Particle size analysis indicates the sludge is predominantly silty sand or silty clay in the emergency lagoon, and silty sand in the polishing basins based on the Unified Soil Classification System. Laboratory testing of geotechnical samples indicates the permeability of the sludge in the emergency lagoon ranges from 10^{-7} to 10^{-9} cm/sec, while the polishing basins sludge has a permeability on the order of 10^{-8} cm/sec.

2.2.2 *Source, Nature and Extent of Contamination*

The investigation of the WWTP management unit was conducted during Phase I RI activities between August 1993 and April 1994. Sampling locations are shown in Figure 8. The objectives of the WWTP management unit investigation were to:

- Determine the nature and extent of chemical constituents in the basins and underlying soils; and

- Determine the impacts, if any, on other media.

The remedial investigation of the WWTP basins consisted of: 1) collection and analysis of 15 samples from the WWTP basins and the soil zone immediately beneath the basins to determine the physical and chemical characteristics; and 2) collection and analysis of ground water samples from two overburden and two shallow bedrock monitoring wells located hydraulically downgradient of the basins to determine ground water quality impacts. Fifteen samples collected from the WWTP sludge and underlying soil were analyzed by an off-site laboratory using SW-846 analytical methods to meet the Level III analytical option. Five samples were analyzed by an off-site laboratory using CLP methods to meet the Level IV analytical option. The Level IV data, which were validated in accordance with EPA protocol, are presented in this EE/CA.

The source, nature and extent of Site contaminants in the WWTP basins were adequately characterized during RI activities. Analytical data for this unit were submitted to EPA in 1994 (ERM, 1994a). Key Level IV detections of organic and inorganic constituents in sludge samples are summarized in Table 6. The analytical results are summarized below.

EL CS2 SVOC PEST PCBs arsenic, cadmium, chrom. lead & zinc

- *Emergency Lagoon.* Organic compounds detected in the emergency lagoon sludge and underlying soil include carbon disulfide (5-11,000 µg/kg), various semi-volatile organic compounds (SVOCs) (with constituent concentrations in the range of 200-9,800 µg/kg), pesticides (with constituent concentrations in the range of 1.6-280 µg/kg), and PCBs (470 to 890 µg/kg). Metals detected in the emergency lagoon samples include arsenic (2.7-4.8 mg/kg), cadmium (5.8-49.1 mg/kg), chromium (140-147 mg/kg), lead (298-1,090 mg/kg), and zinc (107,000-190,000 mg/kg).

P.B cad. chrom lead & zinc

- *Polishing Basins.* Organic compounds detected in the polishing basins sludge and underlying soil include low levels of volatile organic compounds (VOCs) (3-27 µg/kg), SVOCs (with constituent concentrations in the range of 69-2,900 µg/kg), and pesticides (with constituent concentrations in the range of 1.3-25 µg/kg). Numerous metals were detected in the polishing basins, including cadmium (1.5-35.9 mg/kg), chromium (83.1-188 mg/kg), lead (151-408 mg/kg), and zinc (116,000-260,000 mg/kg).

Analytical results for waste characterization show that the zinc sludge in the WWTP basins is not a RCRA hazardous waste based on the Toxicity Characteristics. Two samples were collected from the sludge and analyzed for the TCLP metals, cyanide and sulfide reactivity, ignitability and corrosivity testing. The metal results indicated barium was detected at concentrations ranging from 0.40 mg/l to 0.42 mg/l, which is well below the regulatory limit of 100 mg/l. None of the other seven RCRA metals were detected above the analytical detection limits. All of the other characteristic results were well below regulatory limits.

The sulfate sludge in the WWTP basins is not a listed waste. There is no information to indicate that contaminants in the sulfate sludge were derived from a RCRA-regulated unit. Low concentrations of CS_2 in the sulfate sludge likely resulted from process wastewater discharged to the WWTP, rather than discharge of the moat water from the CS_2 storage units.

The principal potential route of migration for constituents in the WWTP basins is by flooding to the Shenandoah River. Another potential route of migration is dissolution and infiltration to the overburden water table, and subsequent migration through the overburden and discharge to the River (Figures 4 and 5 show direction of ground water flow). However, ground water quality data for the two overburden and two shallow bedrock wells downgradient of the emergency lagoon and polishing basins show minimal impact to ground water quality. In the overburden water table, dissolved concentrations of chromium (3.2-4.4 µg/l in well 017 and 7.6 µg/l in well 004) are slightly elevated relative to background water quality (chromium was not detected in well 008). Zinc was present in overburden and shallow bedrock ground water at concentrations similar to the background concentration in well 008 (Figure 6). Carbon disulfide was detected in shallow bedrock wells PZ-1 and PZ-2 (2J-37J µg/l). All other organic chemical compounds and metals detected in the WWTP basin sludge were not detected in the downgradient wells. The ground water quality data for wells downgradient of the WWTP basins indicate that these basins are not a primary source of contaminants in ground water, and therefore a response action for ground water is not warranted.

As was the case for ground water quality beneath the Sulfate Basins, TDS levels downgradient of the WWTP basins are elevated relative to background water quality. The TDS may have been derived from dissolution of gypsum in the WWTP basins or the Sulfate Basins.

Potential migration of sludge in the WWTP basins via airborne particulates is not a viable migration pathway. Observations in the field indicate that when the basins are emptied of water and the sludge allowed to dry, the sludge remains cohesive due to the high moisture content.

2.2.3 Risk Assessment

Human Health Risks

The human health risks for the WWTP basins under current conditions are identical to those identified for the sulfate basins, as previously described in Section 2.1.3. Specifically, the COPCs are arsenic, lead and zinc. Each of these metals has potential non-carcinogenic health effects, and arsenic also has potential carcinogenic health effects. The Gradient risk assessment indicates that there are no unacceptable risks to human health from exposure to the sludge in the WWTP basins due to trespasser activities under current conditions.

Ecological Risks

The ecological COPCs for the Sulfate Basins (i.e., arsenic, cadmium, chromium, copper, lead, manganese, nickel, silver, zinc and pyrene) apply to the WWTP basins because these basins also contain zinc sludge. The receptor populations and exposure pathway for the WWTP under current conditions is identical to that described for the Sulfate Basins in Section 2.1.3. Additionally, the Final Ecological Risk Assessment for the Site (Sprenger *et al*, 1999) reported that sediment samples collected from the EL and PB-1 have some impact (either reduced survival or reduced growth) on sediment invertebrates, which EPA interpreted to be related to the direct toxicity of the metals. The presence of ecological COPCs in the WWTP basins at levels exceeding risk-based criteria, coupled with the results of the Final Ecological Assessment, indicate a potential risk to terrestrial and aquatic biota exists. The potential risk exists under current conditions, where terrestrial biota can contact the exposed sludge when the basins do not contain water. When water is present, the sulfate basins also provide habitat for migratory birds, which poses a potential risk to these receptor populations. Under future conditions, there is a potential risk to aquatic biota in the event that a flood releases sludge to the River. A response action is warranted to mitigate the exposure of ecological receptors to the exposed sludge in the WWTP basins, or to sludge released to the River during flooding.

Ground Water Pathway

As was the case for the Sulfate Basins, the ground water pathway for exposure of human and ecological receptors is incomplete. Human receptors cannot ingest overburden ground water because this unit is unsuitable for water supply due to limited thickness, lack of available drawdown, and low yield. Furthermore, ground water in the bedrock has not apparently been affected by COPCs derived from the WWTP basins, indicating that communication between the overburden and bedrock beneath the WWTP basins is limited.

The ground water pathway for potential exposure of ecological receptors in the River is incomplete because the flux of ground water discharge from the overburden water table to the River is negligible (previously described in Section 2.1.3). Consequently, impacts to ground water are not sufficient to warrant a response action to prevent migration of COPCs from sludge to ground water.

2.3 *FLY ASH BASINS AND STOCKPILE*

2.3.1 *Unit Description and Background*

The Fly Ash Basins and Stockpile Management Unit consists of four fly ash basins (FAB-1, FAB-2, FAB-3, and FAB-6) and the fly ash stockpile (Figure 1). The fly ash basins and stockpile were used for disposal of fly ash generated by the on-site coal-fired power plant. The fly ash basins are unlined. Fly ash was placed in FAB-1, FAB-2, FAB-3 and a former fly ash basin that was referred to as FAB-4, which was located beneath the north end of the existing fly ash stockpile. The fly ash in the stockpile was material removed from the fly ash basins. As previously stated, FAB-6 was originally a Sulfate Basin and converted to a fly ash basin in the early 1980s. Under current conditions, significant portions of the fly ash basins have re-vegetated naturally, and, depending on seasonal conditions, standing water accumulates in low areas within each basin. The berms surrounding the basins were probably built by excavating soil from the basin and using the excavated soil to form the berms.

Data obtained from 12 borings drilled during the 1993 RI (see Figure 9 for boring locations) indicate the thickness of fly ash in the basins ranges from 14 to 22 feet. Data obtained from 7 borings drilled in the fly ash stockpile indicate that the stockpile ranges in thickness from 28 to 68 feet. Material other than fly ash was not encountered in any of the borings completed in the fly ash basins and associated berms. Some zinc sludge was observed in samples collected near the bottom elevation of FAB-6, which supports anecdotal information that this basin was originally used to store zinc sludge. Drilling logs indicate the thickness of sludge is only 0.5 to 1.5 feet. The stockpile also contains multiple lenses of soil approximately six inches thick that were likely placed as cover material during historical placement of fly ash in the pile. No other material was found in the borings completed in the stockpile. The basins and stockpile are underlain by approximately 1 to 19 feet of native silty sand and silty clay.

The size and estimated volume of fly ash in each fly ash basin and the stockpile is summarized below. The estimated total volume of fly ash in the four basins and the stockpile is approximately 1,305,000 cubic yards.

Fly Ash Basin	Area (square feet)	Fly Ash Thickness (feet)	Soil Thickness Beneath Basin (feet)	Estimated Volume of Fly Ash (cubic yards)
1	143,000	14.5-17	2-7.5	94,000
2	132,000	15.5-22	2-5	87,000
3	89,000	15-16	1-5	50,000
6	635,000	16-21	3-4.5	431,000
Stockpile	641,000	28-68	9-19	643,000
				Total 1,305,000

A number of fly ash samples collected during the RI were analyzed for geotechnical parameters to determine the physical characteristics of the material in the basins. The results are summarized in Table 7. The particle size of the fly ash is predominantly silt based on laboratory sieve analysis using the Unified Soil Classification System, and is uniform throughout the basins and stockpile. Laboratory testing indicates that the fly ash has relatively low permeability in the range of 10^{-5} to 10^{-7} cm/sec.

2.3.2 *Source, Nature and Extent of Contamination*

The fly ash is a coal combustion by-product and the constituents of concern for the fly ash are metals contained in the residue that remains after the coal was combusted. Fly ash contains a potential source of metals that could be mobilized by leaching and subsequent migration to ground water.

The Phase 1 RI investigation of the fly ash basins and stockpile was conducted from October 1993 through April 1994. Sampling locations are shown in Figure 9. The objectives of the fly ash basins/stockpile investigation were to:

- Determine the nature and extent of chemical constituents in the basins and underlying soils; and
- Determine the impacts, if any, on other media.

The remedial investigation of the fly ash basins and stockpile consisted of: 1) collection and analysis of 90 samples from the fly ash and the soil immediately beneath the fly ash to determine the physical and chemical characteristics; and 2) collection and analysis of ground water samples from six overburden and six shallow bedrock monitoring wells located hydraulically downgradient of the basins and stockpile to determine ground water quality impacts. 90 samples collected from the fly ash and underlying soil were analyzed by an off-site laboratory using SW-846 analytical methods to meet the Level III analytical option. 30 samples were analyzed by an off-site laboratory using CLP methods to meet the Level IV analytical option. The Level IV data, which were validated in accordance with EPA protocol, are presented in this EE/CA.

The source, nature and extent of chemicals in the fly ash basins and stockpile were adequately characterized during RI activities. Analytical data for the fly ash unit were submitted to EPA in 1994 (ERM, 1994b). Key Level IV detections of organic and inorganic constituents are summarized in Table 8.

The analytical results indicate the key constituents in the fly ash basins and stockpile are metals typically found in coal combustion fly ash. Metals detected in fly ash samples include arsenic (2.1-193 mg/kg), barium (54.1-759 mg/kg), cadmium (0.49-9 mg/kg), chromium (9.1-56 mg/kg), lead (8.7-166 mg/kg), selenium (1.3-12.7 mg/kg), and zinc (12.1-132,000 mg/kg). Note that the maximum zinc concentrations reflect samples from a boring (FA-BH-15) located in FAB-6, which was historically used for storage of zinc sludge prior to being used for fly ash storage. The drilling log for this boring indicates that zinc sludge was identified in this boring during sampling.

Organic compounds were detected infrequently at low concentrations in the fly ash samples. The analytical results for organics are not indicative of a source area of organic compounds in the fly ash basins and stockpile.

Analytical results for waste characterization indicate that the fly ash is not a RCRA hazardous waste based on the Toxicity Characteristics. Four fly ash samples were analyzed for TCLP metals. The results indicate that although leachable concentrations of metals were detected (arsenic at non-detect (ND)-0.192 mg/l, barium at 0.758-2.3 mg/l, cadmium at ND-0.026 mg/l, chromium at ND-0.021 mg/l, lead at ND-0.14 mg/l, and selenium at 0.063-0.067 mg/l), the concentrations in leachate derived from the fly ash were below the respective regulatory limits.

The principal potential route of migration for constituents in the fly ash is by dissolution and infiltration to the overburden water table. However, ground water quality data from the twelve monitoring wells located hydraulically downgradient of the fly ash basins and stockpile, combined with the TCLP data, show that metals are not readily leached from the fly ash. This conclusion is illustrated by the cross section (F-F') through the fly ash stockpile and FAB 3 (Figure 10), which illustrates the morphology of the basins and stockpile and summarizes key analytical data. The chemical data presented on the cross section show the metal concentrations in the fly ash are not manifested in shallow bedrock well 114 downgradient of the fly ash basins and stockpile. The soil layer beneath the fly ash basins and stockpile apparently attenuates concentrations of any metals that may be leached from the fly ash. However, the capacity of the soil to continue attenuation in the future may be limited due to the limited thickness of soil beneath the fly ash basins.

Arsenic has been identified in the ground water plume emanating from areas beneath the viscose basins (VB) 9-11 management unit that is adjacent to the stockpile and FAB-3. However, empirical data indicate the fly ash basins and stockpile are not the source of arsenic detected in this localized ground water plume beneath the Site. Instead, arsenic appears to be mobilized from soils beneath VB 9-11 due to the high pH nature of the plume. Three reasons for this conclusion are provided below.

- Overburden well 014 is installed in FAB-3 and not in the overburden downgradient of the basins, and was used to evaluate the quality of pore water within the fly ash. Arsenic concentrations measured in well 014 were 0.948 mg/l and 0.932 mg/l, which are less than worst-case arsenic concentrations detected in ground water beneath viscose basins 9, 10 and 11.

- Arsenic is not present in overburden wells 012 and 013 and shallow bedrock wells 112, 113 and 114 located downgradient of the fly ash basins and stockpile.

- The pH of shallow ground water beneath the fly ash basins is not high enough to promote arsenic mobility.

Potential migration of fly ash via airborne particles is a viable migration pathway because portions of the basins and the stockpile are not entirely covered with vegetation. Observations during nine years of on-site activities indicate that fly ash is mobilized primarily during periods of high wind, when disturbed by driving a vehicle on areas of fly ash that are devoid of vegetation, or during excavation using construction equipment. Such disturbance, which occurs for short duration, may create visible clouds of dust, which generally disperses quickly over a relatively short distance.

2.3.3 *Risk Assessment*

Human Health Risks

Gradient performed a quantitative risk assessment to evaluate current and future potential risks to human health associated with exposure to uncovered fly ash by an adolescent trespasser using the same approach previously described for the sulfate basins in Section 2.1.3. The methods and results of the human health risk assessment are described in the Gradient report (Gradient, 1999; Appendix E). Samples collected from the fly ash basins and stockpile in 1993 as part of the Phase 1 remedial investigation were used for the risk assessment. Twenty-two samples were collected from within and below the FABs and FAS, and analyzed for the TCL and TAL using CLP methods to meet the Level IV analytical option. The data were validated in accordance with EPA protocol.

As the first step to selecting COPCs, samples that contained a mixture of soil and fly ash were eliminated from the data set used to identify COPCs for the risk assessment. These samples were excluded because there was no potential for direct contact with chemicals in soil located 15 feet below the fly ash. As a result, the total of 22 Level IV samples for the was reduced to 14 samples.

The second step included screening the constituents detected in the Level IV samples for the risk assessment (Table 9). COPCs for human health were selected by comparing maximum concentrations of detected constituents to current Region III Risk-Based Concentrations (RBCs) for an industrial soil exposure scenario for non-carcinogenic and carcinogenic health effects. Screening against industrial RBCs for an area that will never be developed for residential use is appropriate. These COPCs were identified based on a Hazard Quotient of 0.1 for noncarcinogens (to account for possible systemic effects for non-carcinogens in accordance with EPA Region III guidance), and a risk level of 10^{-6} for carcinogens. The only constituent detected in fly ash that exceeded the Region III RBCs for an industrial soil exposure was arsenic.

The human receptors most likely to be exposed to COPCs associated with the fly ash under current conditions are a potential adolescent trespasser (ages 8 to 17). The adolescent trespasser was assumed to enter the Site 35 days per year. Under future conditions, human receptors consist of recreational users, which would undergo similar exposure as an adolescent trespasser. Gradient evaluated cancer risks and non-cancer hazards associated with potential exposure to arsenic via ingestion, dermal contact and inhalation. The Gradient report describes the exposure parameters and toxicity factors used to calculate the cancer risks and non-cancer hazards.

Total cancer risk for exposure to fly ash, across all pathways, was calculated to be 2×10^{-6}. This value is within EPA's target risk goal of 10^{-4} to 10^{-6}. The total non-cancer hazard index was 0.04, which is less than one and indicates non-cancer effects are not expected. The risk assessment indicates that there are no unacceptable risk to human health from exposure to the fly ash associated with trespassing activities.

Ecological Risks

Potential ecological receptors for the fly ash basins and stockpile under current conditions are the same as for the Sulfate Basins, with the exception that the aquatic biota are limited to species that would be associated with ponds in low areas of the fly ash basins instead of the River. The COPCs for ecological receptors identified by EPA (Charters *et al*, 1996; Sprenger *et al*, 1999) that are applicable to the FABs and FAS are antimony, arsenic, cadmium, chromium, copper, lead, manganese, nickel and zinc. These COPCs have the potential to cause adverse health effects to both aquatic and terrestrial biota. The toxicity of lead and zinc to aquatic and terrestrial biota were identified previously. Studies have shown arsenic to be toxic to mammals and birds. Toxic effects to aquatic biota associated with arsenic are not available (Charters *at al*, 1996).

The Final Ecological Risk Assessment for the Site (Sprenger *et al*, 1999) reported that sediment samples collected from FAB-6 have some impact (either reduced survival or reduced growth) on sediment invertebrates. These effects where interpreted by Sprenger *et al* to be related to the direct toxicity of the metal concentrations.

The presence of ecological COPCs in the fly ash at levels that exceed risk-based concentrations, coupled with the results of the Final Ecological Assessment, indicate a potential risk to terrestrial and aquatic biota exists. The potential risk exists under current and future conditions, where terrestrial biota may have direct contact with fly ash. Indirect exposures to COPCs could also occur for some ecological receptors (e.g., birds eating worms from fly ash units, and the red fox ingesting small mammals affected by arsenic in fly ash). With respect to aquatic biota, the risk is associated with species that exist in or depend on the ponds of standing water that accumulate in portions of the fly ash basins. A response action would mitigate the exposure of ecological receptors to fly ash in the basins and stockpile.

Ground Water Pathway

Human and ecological receptors are not exposed to ground water in the overburden. The overburden water table cannot be used as a source of potable water because the water table unit is unsuitable for water supply due to limited thickness, lack of available drawdown, and low yield. Consequently, the ingestion pathway for ground water is incomplete with respect to human receptors. In addition, the available data indicate the fly ash basins and stockpile have not had any impact to bedrock ground water quality. Consequently, the ground water pathway for exposure to Site contaminants is incomplete, and no response action for ground water is warranted.

3.0 IDENTIFICATION OF RESPONSE ACTION OBJECTIVES

3.1 ARAR IDENTIFICATION

Section 300.415(j) of the NCP requires certain types of removal actions to attain ARARs under Federal or State environmental laws and regulations to the extent practicable considering the urgency of the situation and the scope of the removal. While on-site CERCLA actions may not require a permit, substantive requirements of the ARARs may need to be met. In accordance with EPA guidance (EPA, 1991), the EPA will make the final determination of the actual ARARs and the extent to which they will be met.

Appendix A provides a list of the ARARs that apply potentially to the response action addressed in this EE/CA. This list is provided to EPA and Virginia for consideration in identifying the actual ARARs. This section highlights the location, chemical, and action- specific ARARs that have direct applicability to the closure of the Sulfate Basins, WWTP Basins, and Fly Ash Basins and Stockpile.

3.1.1 Chemical-Specific

Chemical-specific ARARs are risk-based numeric limitations or methodologies that establish acceptable quantities or concentrations of a contaminant on a site-specific basis. There are no chemical-specific ARARs identified to develop the response action objectives.

3.1.2 Location-Specific

Location-specific ARARs consist of restrictions placed on the conduct of activities because they occur in a specific location, such as wetlands or floodplains. One potential location-specific ARAR for the Sulfate and WWTP Basins is the location of SB 1-4E within the Federal Emergency Management Agency's boundary for the 100-year floodplain (Figure 1). Section 10 of the Rivers and Harbors Act of 1890 covers construction activities that could alter navigable water of the United States. Section 10 authority has been delegated to the Army Corps of Engineers (COE). Additionally, Section 404 of the Clean Water Act may apply to the placement of fill material on the floodplain. A permit may need to be obtained from the COE before construction activities are implemented.

Virginia also regulates activities that affect the floodplain through the Virginia Floodplain Management Program within the Department of Conservation and Recreation (Virginia Code Section 10.1-603). The State may require a permit application, and may need to involve the Virginia Marine Resources Commission to assess the potential impact to a floodplain. Joint federal and state permits can be filed to address Section 10 and 404 requirements.

3.1.3 *Action-Specific*

Action-specific ARARs are activity-based requirements on actions taken with respect to contaminants. These requirements define acceptable treatment, storage, and disposal procedures for hazardous substances. The action that is envisioned for the sulfate basins and fly ash is the placement of cover over in-place wastes and creation of positive drainage to promote runoff and limit infiltration. Three sections of Virginia regulations could provide potential action-specific Virginia ARARs that affect the scope of the action (26 February 1999 letter from J. Ely, VADEQ to B. Gross, EPA and W. Cutler, FMC):

- *Hazardous Waste Regulations*, 9 VAC 20-60-10 to 1480;
- *Solid Waste Management Regulations*, 9 VAC 20-80-10 to 790; and
- *Regulation Governing Management of Coal Combustion By-products*, 9 VAC 20-85-10 to 180.

Hazardous Waste Regulations

Sufficient information is available to indicate that the waste streams covered by this response action are not a listed or characteristic hazardous waste. As discussed in Section 2.0, the sulfate sludge and fly ash have been adequately characterized to demonstrate that the materials are not a RCRA hazardous waste based on Toxicity Characteristics. The sulfate sludge is not a listed waste. There is no information to indicate that contaminants in the sulfate sludge were derived from a RCRA-regulated unit. Low concentrations of CS_2 in the sulfate sludge likely resulted from process wastewater discharged to the WWTP, rather than discharge of the moat water from the CS_2 storage units. Recent EPA guidance (October 1998, *Management of Remediation Waste Under RCRA*) determined that in instances where the source of contamination is uncertain, a waste should not be considered to be a listed waste. Therefore, the Virginia *Hazardous Waste Regulations* are not applicable for this response action.

Solid Waste Management Regulations

Three sections of the Virginia *Solid Waste Management Regulations* (VSWMR) provide action-specific Virginia ARARs that affect the scope of the closure of the sulfate basin and fly ash units. First, the closures of both the sulfate basins and fly ash basins and stockpile must meet the requirements set out in 9 VAC-20-80-200D in order to close a solid waste management unit with waste left in place. These regulations require the demonstration that the facility will not pose a threat to human health or the environment when closed in-place. The demonstration needs to include the items listed below.

1. *Type of Waste.* A description of the amount, type, source and generating process of the waste, and a statement that there are no hazardous wastes must be provided.

2. *Siting.* A registered professional engineer must submit documentation that the in-place closure of waste will comply with the applicable siting restrictions under Part V of the VSWMR. These siting requirements include: airport safety; floodplains; unstable areas; wetlands; fault areas; seismic impact zones; setbacks from surface waters, sources of drinking water, and other important structures; and the ability to conduct ground water monitoring. The siting requirements that are relevant to the proposed response action described herein include floodplains and setback from a river.

3. *Certification.* A registered professional engineer or qualified ground water scientist must certify that in their professional judgement the facility can be closed with waste left in place without posing a threat to human health or the environment.

This EE/CA report provides adequate information to meet the 9 VAC 20-80-200D requirements stated above. Sections 2.1 and 2.3 of this EE/CA report describe the amount, type, source and generating process of the sulfate sludge and fly ash, and provide the data that indicate there are no hazardous wastes being closed in place. The siting requirements under Part V of the VSWMR indicate that waste can be closed in-place in the floodplain if it can be protected from washout and not restrict water flow when placed in areas subject to base floods. As discussed in Section 4.0 and Appendix B, modeling conducted to evaluate the flood condition under remediated conditions addresses this requirement. All of the setback requirements, including placement of waste any closer than 100 feet from a river, can be met. The required certification by a professional engineer in accordance with 9 VAC 20-80-200D3. is provided in Appendix F.

Second, placement of cover material on the sulfate basins and fly ash units requires adherence with the regulations for closure of a non-hazardous industrial waste disposal facility (9 VAC 20-80-270E). Pertinent requirements for closure under 9 VAC 20-80-270E include:

- A cover with a hydraulic conductivity less than or equal to the hydraulic conductivity of the natural subsurface soils, or no greater than $1x10^{-5}$ cm/sec, whichever is less;

- A cover that minimizes infiltration through the waste by using an infiltration layer that contains a minimum 18 inches of earthen materials;

- A cover that minimizes erosion of the final cover by using six inches of earthen materials capable of sustaining native plant growth;

- Finished side slopes that are stable and adequately control erosion and runoff; and

- Recording of a survey plat which delineates areas of waste disposal and states the future obligation to restrict disturbance of the Site.

The permeability requirement will be difficult to meet for the sulfate basin closure because the native soils have an estimated permeability of $1x10^{-7}$, and the results of the field pilot study (Appendix C) indicate the test pad had a placed permeability of $2.7x10^{-6}$ cm/sec. Repeated passes with equipment over the sludge to increase compaction and reduce permeability will cause deformation of the sludge and have a negative impact on the cover. However, the VSWMR (9 VAC 20-80-270E.1.c.(1)) allows for an alternative cover design that achieves equal performance relative to infiltration reduction. The specific language is

> c. "The director may approve an alternate final cover design that includes: (1) An infiltration layer that achieves an equivalent reduction in infiltration as the infiltration layer..."

Section 4.1.2 describes a conceptual remedy for the SB closure that includes the use of horizontally laid geotextile wicks draining to sumps. The purpose of this drainage layer was to provide for the removal of water leaking through the cover as well as water dispelled during consolidation. The strip drains can manage the difference in the amount of water that will infiltrate through a cover with a permeability of $2.7x10^{-6}$ and subsurface soils with a permeability of $1x10^{-7}$, and therefore be considered to achieve an equivalent reduction in infiltration. During the design phase, the use of the strip drains and other techniques, such as the use of water consumption plants, will be evaluated to ensure an equal level of performance is met. Consequently, the ARAR can be met.

In addition, Virginia's non-hazardous industrial waste regulations require that ground water monitoring and post-closure care of the cover be conducted. The response actions for both the SBs and fly ash units will include ground water monitoring and post-closure care.

Third, placement of cover material on the sulfate basins requires adherence with the regulations for closure of surface impoundments and lagoons (9 VAC 20-80-380). Pertinent requirements for closure include:

- Eliminate free liquids by removing liquid waste;
- Install a ground water monitoring system and initiate ground water monitoring;
- Stabilize the remaining waste residues to a bearing capacity sufficient to support the final cover;
- Place final cover in accordance with the requirements stated above for section 270.

These closure requirements are incorporated into the proposed remedies described in Section 4.0.

Proposed response actions discussed in Section 4.0 provide for the consolidation of sludges and contaminated soil from SB 5 into SB 1 through 4E, and the consolidation of sludges from the WWBs into SB 1 through 4E. In accordance with the VSWMR, consolidation of wastes from different waste disposal units ordinarily constitutes disposal, and would be subject to the provisions of the VSWMR relating to disposal of newly generated solid wastes. However, EPA has determined that consolidation of wastes within an AOC does not constitute disposal. As stated in Section 1.1, EPA designated all the management units west of the railroad tracts as a single AOC (16 April 1999 letter from B. Gross, EPA to J. Ely, VADEQ). Wastes can be consolidated within the AOC, including wastes that are diverse in composition, without being construed as disposal and without invoking the VSWMR.

Regulation Governing Management of Coal Combustion By-Products

The proposed action to close the sulfate basins includes fly ash placed within the cover for the SBs as an engineered fill to create positive grades. The fly ash is serving as a substitute for a natural resource (imported fill soil). The use of fly ash as engineered fill in this manner does not fall under an exemption or exclusion provided in the VSWMR (9 VAC 20-80-150 and 160). Therefore, Virginia's *Regulation Governing Management of Coal Combustion By-Products* is applicable to the use of fly ash in this manner. This regulation specifically prohibits the use of fly ash on sites of unpermitted lagoons (9 VAC 20-85-70.5.). However, EPA determined that the proposed use of fly ash as an engineered fill is consistent with operating under EPA's AOC policy (16 April 1999 letter from B. Gross, EPA to J. Ely, VADEQ). Therefore, the proposed use of fly ash on the cover for the sulfate basins does not invoke the requirements of Virginia's *Regulation Governing Management of Coal Combustion By-Products*.

Other Virginia Action-Specific ARARs

Additional potential Virginia action-specific ARARs identified by VADEQ include:

- Closure of the basins should be accomplished in compliance with the ambient air quality standards for particulate matter contained in 9 VAC 5-30 and the standards of performance for visible and fugitive dust emissions contained in 9 VAC 5-50;

- Stormwater management should be accomplished in compliance with the regulations contained in 4 VAC 3-20-10-251; and

- Soil and erosion control should be accomplished in compliance with the regulations contained in 4 VAC 50-30-10.

3.2 *RESPONSE ACTION OBJECTIVES*

The objectives of the response action for the Sulfate Basins, WWTP Basins, and Fly Ash Basins and Stockpile are four-fold:

- Mitigate future potential risk to ecological receptors from the migration of contaminants during flood and wind erosion events;

- Mitigate current potential direct contact risk to ecological receptors associated with uncovered waste;

- Meet federal and state ARARs; and

- Ensure that future use considerations are addressed adequately.

This response action is designated to be a Non-Time-Critical Removal Action because of the concern that: 1) flooding of the River can cause contaminants (primarily metals in sulfate and WWTP basin sludge) to be released to the River; and 2) fly ash can be mobilized by wind. The risk assessment showed that metals in the sulfate basin and WWTP basin sludge, in particular lead and zinc, can be toxic to aquatic biota. The risk assessment also showed that metals in the fly ash can be toxic to terrestrial biota. Therefore, the primary Response Action Objective (RAO) is to ensure that the sulfate and WWTP sludge and fly ash are contained at the Site and do not migrate during weather events.

The results of the risk assessment indicate that ecological COPCs in the sulfate sludge and fly ash are present at levels that exceed risk-based concentrations. This finding indicates a potential direct contact risk to ecological receptors may exist. In addition, site specific ecological risk assessment indicated that sediment samples collected from these units could have some impact (either reduced survival or reduced growth) on sediment invertebrates, even though these basins are not intended to provide habitat. Therefore, the second RAO is to eliminate direct contact of both human and ecological receptors to the uncovered sludge and fly ash.

A third RAO is to ensure that the basin closures comply with ARARs. Of particular importance is the Commonwealth of Virginia Solid Waste Management Regulations requiring that non-hazardous industrial waste, such as the sulfate sludge and fly ash, be covered with soil.

A fourth RAO is to ensure the basin closures are consistent with the proposed conceptual reuse plan for the basin area identified in the North American Realty Advisory Services (NARAS) Report (1998). This plan has been adopted by the Town of Front Royal to guide the redevelopment of the Site. The plan identifies the area west of the railroad tracks for use as a public recreation conservancy, providing for passive recreation uses, habitat preservation, and River access. The NARAS plan envisions that the area in and around the closed basins would contain trails and overlook spots. Therefore, the closure of the SBs, WWBs, FABs and FAS needs to be able to support pedestrian access. Further, the basins will need to be covered so that the fly ash and sulfate sludge will not present a nuisance to future site users.

Based on the four RAOs identified above, the overall scope of the response action for the Sulfate, WWTP, and Fly Ash Basins and Fly Ash Stockpile consists of placement of cover materials and creation of positive drainage to promote runoff and limit infiltration. The primary objective of the cover is for material containment, direct contact protection, promotion or runoff and prevention of surface water ponding. Consistent with the proposed conceptual reuse plan, the bearing capacity of the cover needs to be sufficient to handle pedestrians, but will not be designed to support vehicle traffic. Routine access to the covers will be limited to pedestrians. Vehicles for cover maintenance will need to be confined to well defined trails that will be constructed with adequate erosion control for these vehicles.

4.0 *IDENTIFICATION AND ANALYSIS OF RESPONSE ACTION ALTERNATIVES*

This section identifies a range of closure alternatives for the Sulfate Basins (SBs), WWTP Basins (WWBs) and Fly Ash Basins (FABs) and Stockpile (FAS), and provides analysis of those alternatives against the major criteria, namely effectiveness, implementability and cost, identified in the EPA *"Guidance on Conducting Non-time Critical Removal Actions Under CERCLA"* (EPA, August 1993 EE/CA Guidance). In accordance with the EE/CA Guidance (EPA, 1993), the following five criteria were also evaluated:

- Overall protection of human health and the environment;
- Compliance with ARARs;
- Long-term effectiveness and permanence;
- Reduction of toxicity, mobility or volumes through treatment; and
- Short-term effectiveness.

All of the proposed closure alternatives include installing a soil cover, except for Alternative 1 for the fly ash units, which includes no further action for the fly ash basins. Appendix A summarizes the Federal and Commonwealth of Virginia action-specific ARARs that potentially apply to the response activities necessary to close the SBs, FABs, FAS, and WWBs.

In all alternatives, free-standing supernatant water would be transferred via pumping to the on-site WWTP for treatment. Additional steps to promote drainage from sludges, such as creating sumps, installing collection standpipes or trenches, placement of hydrophilic wicks, or other measures to enhance removal of free water may be utilized.

All of the alternatives incorporate ground water monitoring, post-closure cover maintenance, and institutional controls as components for each alternative. Monitoring plans will be developed concurrent with preparation of operations and maintenance plans that will direct post-closure activities. Institutional controls, specifically a prohibition on disturbing the proposed soil covers, are necessary for each alternative to ensure that the integrity of the covers is maintained to eliminate direct contact risks and minimize infiltration of precipitation and runoff.

4.1 SULFATE BASINS (SB)

A broad range of in-situ and ex-situ technologies have been evaluated for the SBs. These include containment, treatment through zinc recovery, and stabilization of the SB sludge. Treatment via zinc recovery has been evaluated through bench-scale treatability studies and cost-benefit analysis by as many as five specialty vendors since 1994. The extensive evaluations that were completed reflect an extensive effort to address the CERCLA preference for treatment over containment remedies. However, despite the extensive evaluations, treatment technologies for 936,000 cubic yards of sulfate sludge were difficult to implement, cost prohibitive, or would require on-site treatment that is likely to be unacceptable to the community.

Two analyses of zinc recovery alternatives were completed in 1998 and provide an indication of the technical and cost issues associated with zinc recovery. The most intensive evaluation of a zinc recovery process involved a process to electrokinetically remove zinc from the sludge and electro-deposit the zinc at a specified purity on electrodes. This effort was conducted by Flour Daniel GTI (1998), who used Geo-Kinetics, Inc. to conduct the bench-scale studies and evaluations. The conceptual design included extracting the sludge from the basins, treatment in containers, and on-site placement of the post-treatment residues. Although initial bench-scale studies were promising, the results of the scale-up evaluation showed this technology to be difficult to implement because it needed large quantities of acid to overcome the buffering effect of the carbonates and hydroxides in the sludge and was highly energy intensive. Both of these factors make this technology cost prohibitive for application at the Site. The economics summary indicated that the project costs would be close to $50 Million with a projected zinc recovery revenue of $30 Million. Additionally, it was estimated that the project would take ten years to complete, which would make it potentially unacceptable to the community, and defer successful reuse of the Site.

Tallon (1998) evaluated the zinc sludges in the laboratory for several technologies to beneficiate (i.e., concentrate) the sludge on-site and recover the zinc through off-site smelting or refining (a process that involves an acid leach and metal recovery by electro-chemical plating). Tallon evaluated the following beneficiation techniques that are used to concentrate metals in metal sulfide ores:

- *Physical Separation.* A density separation using a heavy liquid indicated that the presence of aggregate particulate reduced the efficacy of the separation.

- *Froth Flotation*. This process involves the use of chemical reagents to target minerals amenable to physical separation with the injection of air. The results of trials were not promising as no tested reagents were able to create conditions permitting a clear separation of zinc.

- *Leaching*. Leaching with water and more aggressive acid and caustic leach solutions was determined to be unsuccessful. Acid leach solutions, although technically feasible, required extensive amounts of acid to overcome the pH buffering of the carbonate minerals in the sludge.

- *Roasting or Calcining*. This process consists of thermal treatment at 600°C to oxidize the metal sulfides and drive off CO_2 from the carbonates. Although the roasting process created a mineral array that was more amenable to leaching, the trials did not produce a zinc product deemed acceptable for processing at a zinc recovery facility.

The conclusion of this evaluation was that the roasted sludge would need to be shipped off-site for smelting or refining, and that the off-site processors would charge a substantial penalty for the inclusion of large quantities of non-value waste requiring disposal after the zinc is recovered. On-site roasting would also take many years to complete and would require construction and operation of a large on-site thermal unit, which would be inconsistent with timely reuse of the Site.

Physical/chemical stabilization was evaluated by ERM in 1993 as a standard technology for treatment of metal-bearing sludge. Physical and chemical stabilization technologies are available for ex-situ and in situ application. Initial bench-scale tests showed that it is technically feasible to stabilize the SB sludge. Typically, stabilization costs range between $25 and $50 per cubic yard. Even accounting for economics of scale for such a large volume, this technology is cost prohibitive (estimated to be an incremental $25 to $50 Million). Further, stabilization of the sludge to prevent leaching of contaminants and their migration to ground water is unwarranted since investigation shows minimal impact to ground water. Therefore, stabilization for purposes of preventing ground water contamination is not considered to be a qualified technology to meet the RAOs.

Based on the prior evaluations, containment of the sludge in SB 1-4E has proven to be the only qualified technology to address the RAOs for the SBs. Containment consists of placement of cover materials and creation of positive drainage to promote runoff and limit infiltration. The permeability of the cover material will not be critical because the primary objective of the cover is for material containment, direct contact protection, promotion of runoff, and prevention of surface water ponding.

Sulfate Basin 5 differs from SB 1-4E in that there is very little sludge in SB 5 and it has not been hydraulically connected to the other SBs during stormwater management activities which have been conducted in the SBs since 1989 when the plant closed. There is only 2.0 to 2.5 feet of sludge at the bottom of SB 5, and the supernatant water has been analyzed, determined to be clean, and discharged to the River without treatment at least three times in the past nine years. The management of SB-5 must reflect these differences. Initially, it was envisioned that SB-5 would remain in-place, as a water body, and the sludge would be dredged from the bottom and consolidated into SB-1-4E. However, after additional evaluation, it is now considered to be more appropriate and desirable to eliminate SB-5 by removing the supernatant and sludge, then removing the north, south and west berms to provide new access to the River. Under both of the alternatives analyzed below, SB 5 would be eliminated and the sludge would be consolidated from SB 5 into SB 2-4E.

The alternatives in this section describe conceptual alternatives. Additional field testing and design studies need to be performed, and design criteria will still need to be developed for the final response action (discussed further in Appendix C).

4.1.1 *Alternative SB 1: Eliminate SB 5 and Install Simple Soil Cover On SB 1-4E*

4.1.1.1 *Alternative Description*

This alternative consists of the following components:

- Removing supernatant water for treatment in the on-site treatment plant;
- Consolidating the sludge from SB 5 into SB 1-4E;
- Removing contaminated soil (1 foot) from beneath the SB 5 sludge to be managed with consolidated sludge;
- Placing a simple, nominal two-foot thick (minimum) soil cover over SB 1-4E to prevent direct contact and promote runoff;
- Removing the south and west SB 5 berms, regrading the north berm and the SB 5 area to establish minimum 2 percent grades, and installing a final 6 inch thick (minimum) vegetated soil cover;

- Post-closure cover maintenance and ground water monitoring; and
- Recording of a survey plat which delineates the areas of waste disposal and implementation of institutional controls to prevent disturbance of the soil cover.

After supernatant removal and prior to installing the cover on SB 1-4E, the berms around all of the basins would be cut down to follow the grade of the sludge in each basin, allowing for the final two-foot soil cover thickness. This is to facilitate surface drainage and avoid creating a "bathtub" within the SBs. In addition, some of the material in SB 1 would be regraded, probably together with the use of soil from the base of SB 5, berm soils, and imported soil, so that the final grade of SB 1 would gently slope (minimum 2 percent slope) from the eastern side of the basin down toward the River. This alternative does not account for use of fly ash for grading and filling soft areas, which may be necessary or appropriate in selected areas. The soil cover would consist of a total of two feet of imported soil capable of achieving at least a $1x10^{-5}$ cm/sec hydraulic conductivity, and preventing direct contact exposures, with the upper six inches capable of supporting the vegetative cover.

This proposed plan would eliminate the basins as water storage units, preclude ponding of stormwater and runoff, prevent direct contact with the sludge and provide adequate protection against sludge erosion during flood events.

Prior to installing the cover on SB 1-4E, the sludge contained in SB 5 would be dredged from the bottom (estimated volume is 77,000 cubic yards) and placed in SB 2-4E. In addition, it is assumed at this time that one foot of soil at the base of SB 5 would be excavated and placed in the other SBs prior to installing the cover. A performance measure will be identified in the design phase to indicate the allowable concentration of zinc in soil beneath SB 5.

The berm between SB 5 and FAB 6 may need to be strengthened once the lateral support provided by the current water elevation in SB 5 is removed. In addition, once the south and west berms of SB 5 are removed, the berm between SB 5 and FAB 6 could potentially be subjected to flood water. However, water surface profile modeling of the 100-year flood (see Appendix B) shows that the flood water depths and velocities would be low and non-erosive. Additional flood profile modeling may be performed as part of detailed design to identify any erosion or stability concerns that are not evident from the concept design analysis in Appendix B.

The northern, western and southern berms of SB 5 will be graded out, with the soil used to re-establish a gentle slope from the FAB 6 berm to the River to allow for post-remediation use. Any berm soils suspected or determined to be contaminated would be placed in SB 1-4E. Finally, a six-inch layer of cover capable of sustaining vegetation would be placed over the regraded SB 5 area and a vegetative cover will be established.

The ground water monitoring plan to be implemented during post-closure maintenance will be designed to determine whether ground water quality becomes further degraded from the sulfate sludge. If monitoring indicates that ground water quality becomes further degraded, risks to human health and the environment will be re-assessed, and the remedy modified to mitigate any unacceptable risk.

4.1.1.2 *Effectiveness*

Effectiveness addresses the ability of an alternative to meet the RAOs and to be protective of human health and the environment. Text in bold highlights the individual evaluation criteria identified in EPA's EE/CA guidance (EPA, 1993).

Alternative SB 1 would be **effective** in satisfying the RAOs of **protecting** against direct contact with the basin materials by ecological receptors, and **containing** these materials from release to the environment. As described in Appendix B, the results of the flood modeling indicate that it is not necessary to incorporate any special features into the cover design to protect the wastes from flood erosion. The modeling shows that flood flow velocities calculated for this area are sufficiently low (<3.5 fps) that the final vegetated cover would not be eroded by the flow and maintain integrity. Therefore, the soil cover primarily satisfies the need to provide a barrier to direct contact.

This alternative can achieve compliance with action-specific **ARARs**. This alternative would satisfy the action-specific ARARs of a minimum 18 inches of earthen material for an infiltration layer (which also provides protection from direct contact), 6 inches of soil that will sustain vegetation to minimize erosion, and finished side slopes that are stable and adequately control erosion and runoff. The VSWMR requirement that that the cover permeability be equal to or less than the underlying soils cannot be met because repeated passes with equipment over the sludge to increase compaction and reduce permeability will cause deformation of the sludge and have a negative impact on the cover. However, an alternative cover design will be developed to ensure that an equal level of performance is achieved, in accordance with the VSWMR.

This alternative may provide **long-term protection** against release to the environment and direct contact. Although the final grading and vegetative cover would be designed and constructed to promote drainage and protect the cover against erosion and deterioration and will comply with ARARs, this soil cover may be difficult to construct over soft areas of sludge. In addition, differential settlement could occur over time, requiring periodic filling of depressions and eroded areas and local re-vegetation.

This alternative does not provide **treatment** of the basin materials, however, based on the potential risk pathways, treatment of the nearly one million cubic yards of sludge is not warranted. The soil cover does provide **containment** of the sludge, preventing direct contact and release to the environment.

The major potential **short-term impact** may be the increased traffic through the town of Front Royal primarily due to soil delivery for the cover. Based on the quantity of imported fill and cover soil needed under this alternative, and assuming that soil from removed berms is utilized (but not including the use of soil from the base of SB 5), the community would see an increase in truck traffic of approximately 40 trucks per day for approximately 24 months (the maximum quantity of imported soil is estimated to be 376,900 cubic yards, without taking advantage of using on-site fly ash or soil from the base of SB 5). No unusual hazards would be posed to workers; the primary potential impacts to workers would be limited to common physical hazards associated with site work and materials handling.

4.1.1.3 *Implementability*

Implementability addresses the technical feasibility of constructing and maintaining an alternative and the availability of the resources required to implement the alternative. Text in bold highlights the individual evaluation criteria identified in EPA's EE/CA guidance (EPA, 1993).

The major issues with respect to the **technical feasibility** of installing a soil cover on the SBs are the ability of the sludge to support the soil cover and the practicability of installing the soil cover properly. Based on the result from the field test pads constructed in November 1998 on SB 1 and SB 3 and laboratory geotechnical evaluations (Appendix C), the sulfate sludge appears to provide adequate strength to support the load imposed by the soil cover. However, the point load imparted by soil delivery and placement equipment has resulted in shear failures in the sludge in SB 3. Thus, a simple soil cover alone may not be feasible over the SBs, and a combination of soil, fly ash and reinforcing geotextiles placed prior to cover installation may be necessary or appropriate in some or all SB areas.

Another issue related to technical feasibility is cover permeability. The field pilot study indicated that the test pad had a placed permeability of 2.7×10^{-6} cm/sec, which is greater than the permeability of the in-situ soils (1.0×10^{-7} cm/sec). This cover permeability, coupled with a 2 percent slope and vegetative cover, will be adequate to promote runoff and reduce infiltration. However, infiltration into the sludge cannot be greater than the "exfiltration" from the sludge. Therefore, an alternative cover design will likely be necessary, providing another indication that a simple soil cover may not be technically feasible.

As discussed further under Alternative SB 2, additional evaluation and studies will be performed to refine the cover design during the design phase. The more critical factor appears to be the loads imposed by soil delivery and the movement of equipment when making multiple passes over the same area. Special soil delivery/placement techniques such as conveyors or belt feeders and drag lines to avoid or reduce these loadings will be evaluated as part of the engineering design phase.

A limiting step in implementing this closure may be the **availability** of imported fill and the ability to deliver it to the site efficiently. Of the 490,900 cubic yards of fill and cover material needed for Alternative SB1, existing berm soil (from berms taken down) amounts to 114,000 cubic yards. That leaves 376,900 cubic yards of imported soil needed. At a soil delivery unit volume of fifteen cubic yards per truck, 25,127 truck loads will be required, which equates to 628 days (24 months with delivery six days a week) at a rate of 40 trucks per day. This would be the minimum traffic impact, assuming razed berm soils are used to the maximum extent. Use of the soil excavated from the base of SB 5 would reduce the above delivery timeframe by only two months (this would reduce the need for imported soil by 33,000 cubic yards). Although an additional portion of the total fill needs could be met with on-site fly ash, this is evaluated in Alternative SB 2.

State and community acceptance is primarily considered in selecting a recommended alternative. Further consideration of these concerns will be addressed in discussing the recommended alternatives.

4.1.1.4 *Cost*

Table 10 presents the estimated total present worth cost of $10,810,000 to implement Alternative SB 1. The estimated capital cost is $9,864,500 and the total present worth O&M cost is $945,400. The primary issue for

Alternative SB 1 is the uncertainty that remains regarding the technical feasibility and implementability of a simple soil cover. The costs include ground water monitoring for a period of five years, after which the monitoring would be included in the site-wide ground water monitoring program implemented as part of the final remedy for ground water.

4.1.2 *Alternative SB2: Eliminate SB 5 and Install Enhanced Soil Cover on SB 1-4E*

4.1.2.1 *Alternative Description*

This alternative consists of:

- Removing supernatant water for treatment;
- Consolidating the sludge from SB 5 into SB 1 - 4E;
- Removing contaminated soil (1 foot) from beneath the SB 5 sludge to be managed with consolidated sludge;
- Placing an enhanced soil cover, incorporating geotextile fabric and fly ash, over SB 1 – 4E to prevent direct contact, and promote runoff; and
- Removing the north, south and west SB 5 berms, regrading the SB 5 area to establish minimum 2% grades, and establishing a final vegetative cover over the SB 5 area;
- Post-closure cover maintenance and ground water monitoring; and
- Recording of a survey plat which delineates the areas of waste disposal and implementation of institutional controls to prevent disturbance of the soil cover.

After supernatant removal and prior to installing the cover on SB 1-4E, the western berm and portions of the north and south berms of all basins would be cut down to follow the grade of the sludge in each basin, allowing for the final cover thickness. This is to facilitate drainage and avoid creating a "bathtub" within the SBs. In addition, some of the material in SB 1 would be regraded, probably together with the use of on-site fly ash, imported fill soil and berm soils, so that the final grade of SB 1 would gently slope from the eastern side of the basin down to the River. Also prior to installing the cover on SB 1-4E, the sludge contained in SB 5 would be dredged from the bottom (estimated volume is 77,000 cubic yards) and placed in SB 2-4E. Figure 11 illustrates the concept design for the enhanced cover on the sulfate basins.

This alternative incorporates the use of the on-site fly ash as fill in SBs 2–4E to create the 2% slopes needed prior to installing the cover. The benefits of using fly ash include: 1) preventing risk to human health associated with truck traffic and air emissions associated with importing soil; 2) providing an equivalent, and potentially superior, standard of performance compared to the use of soil as structural fill; and 3) providing a cost savings. The sulfate sludge and fly ash are chemically compatible based on the similar pH (approximately 8) and their mineralogical nature. This alternative also would eliminate the basins as water storage units, preclude ponding of stormwater and runoff, prevent direct contact with the sludge, and provide adequate protection against sludge erosion during flood events.

Preliminary field studies using test pads were performed in November 1998 to confirm the ability of the sludge to support the soil cover and to assess the strength of the sludge and its response to the soil cover placement process (Appendix C). Based on these preliminary field tests and the evaluation of geotechnical data, the preliminary cover design consists of (from the sludge surface upward):

- A layer of reinforcing geotextile fabric (where necessary);
- Strip drains (horizontally placed wicks) distributed on the geotextile fabric;
- A layer, varying in depth, of soil and/or fly ash from the FAS to establish slopes for cover drainage (accounting for consolidation); and
- A minimum of eighteen inches of cover soil, with an additional overlying six inches of soil capable of supporting vegetation.

Figure 11 illustrates these layers comprising the cover.

The soil cover placement testing has shown that a reinforcing geotextile layer will be necessary to successfully place the desired soil cover on SB 3. It is expected that this will also be necessary on SB 2, SB 4/4E, and on a portion of SB 1. The geotextile would be sewn on seams and anchored at the edges of the basins. Strip drains, consisting of horizontally laid geotextile wicks, would be distributed on the geotextile reinforcing fabric surface, draining to strategically located sumps in the basin sludge surface. Liquids accumulating in the sumps as a result of dewatering will be collected and treated as necessary to meet discharge limits. Based on leach testing of the sludge, the dewatering liquids are not expected to be a characteristic hazardous waste. The fly ash and/or soil placed to regrade the basin surface for drainage would then be placed on the prepared geotextile surface to regrade the basin surface for drainage. The 24-inch soil layer would consist of 18-inches of imported general fill soil, overlain by 6 inches of soil capable of sustaining vegetative growth. This soil cover would be placed over the regraded SB area, and the area would be seeded to establish a final vegetative cover.

From the soil cover placement testing, there appear to be some differences in the surface strength of sulfate sludge in different SBs. For example, SB 1 has an accumulation of mud over much of the sludge surface due to deposition from previous flood events. SB 3 does not have this mud layer. These differences may effect the need for a geotextile fabric layer, or the type of geotextile fabric used over certain areas. The thickness of soil and/or fly ash layers will also be a function of sludge strength differences and anticipated consolidation. Therefore, there will be a range of cover designs within the soil cover concept and there may be different construction methods in different SB areas to achieve the final cover placement.

The potential variations of design and construction details will be further differentiated during the final engineering design. At this EE/CA stage, a number of aspects of the cover design remain uncertain. The major uncertainties are: 1) the materials and methods that will be needed to achieve adequate strength of the sludge in the northern end of SB 1; 2) the ability to regrade the SB 1 sludge; 3) the amount of additional fill that may be needed to account for settlement of the cover; 4) how much of the basin surface will require geotextile fabric as part of the cover design; 5) required measures for handling surface and subsurface water, and 6) the degree of long-term care and maintenance that will be required to repair areas of the cover that deteriorate. The range of quantities and level of effort for each of these items are outlined in the following matrix:

The ground water monitoring plan to be implemented during post-closure maintenance will be designed to determine whether ground water quality becomes further degraded from the sulfate sludge. If monitoring indicates that ground water quality becomes further degraded, risks to human health and the environment will be re-assessed, and the remedy modified to mitigate any unacceptable risk.

Lower Quantities/Level of Effort	Greater Quantities/Level of Effort
- Moderate modification of Northern SB 1 sludge; addition of gravel or dense soils may be sufficient to achieve sufficient strength.	- More difficult to achieve adequate strength of Northern SB 1 sludge; may require addition of material, such as Portland cement, to strengthen the area.
- Minor regrading of SB 1 sludge (average of 1-foot depth of sludge to be regraded).	- More extensive regrading of SB 1 sludge (average of 2-foot depth of sludge to be regraded).
- 20% of attic fill requirement needed for excess fill to account for settlement	- 40% of the attic fill requirement needed for excess fill to account for settlement

- Geotextile reinforcement needed everywhere, except on 1/3 of SB 1 area	- Geotextile reinforcement needed across entire area of SB 1 through SB 4E
- Moderate annual cap repairs to correct settlement/erosion	- More extensive cap repairs to correct settlement/erosion

Further studies during the design phase will assist in better determining the needs in each of the above areas. The engineering design will include geotechnical analysis and detailed design calculations addressing such concerns as in situ versus remolded strength, variable water content and consolidation characteristics.

The berm between SB 5 and FAB 6 may need to be strengthened once the lateral support provided by the current water elevation in SB 5 is removed. In addition, once the south and west berms of SB 5 are removed, the berm between SB 5 and FAB 6 could potentially be subjected to flood water. Water surface profile modeling of the 100-year flood (see Appendix B) shows that the flood water depths and velocities would be low and non-erosive. Final flood profile modeling will be performed as part of detailed design to determine the elevation and velocity of flood waters, and to identify any erosion or stability concerns that are not evident from the concept design analysis presented in Appendix B.

The northern, western and southern berms of SB 5 will be graded out, with the soil used to re-establish a gentle slope from the FAB 6 berm to the River to allow for post-remediation use. Any berm soils suspected or determined to be contaminated would be placed in SB 1-4E. Finally, a six-inch layer capable of sustaining vegetation would be placed over the regraded SB 5 area and a vegetative cover will be established.

4.1.2.2 *Effectiveness*

Alternative SB2 is effective in satisfying the RAOs of **protecting** against direct contact with the basin materials by ecological receptors, and **containing** these materials from release to the environment. As described in Appendix B, the results of the flood modeling indicate it is not necessary to incorporate any special features into the cover design to protect the wastes from flood erosion. The modeling shows that flood flow velocities calculated for this area are sufficiently low (<3.5 fps) that the final vegetated cover would not be eroded by the flow and maintain integrity. Therefore, the soil cover primarily satisfies the need to provide a barrier to direct contact.

This alternative can achieve compliance with action-specific **ARARs**. This alternative provides for a minimum 18 inches of earthen material for an infiltration layer (which also provides protection from direct contact), 6 inches of soil that will sustain vegetation to minimize erosion, and finished side slopes that are stable and adequately control erosion and runoff. Although the placement of fly ash in the sulfate basins is not allowed under the VSWMR, EPA views the use of fly ash as part of the engineered cover within a single AOC, which does not trigger disposal requirements under the VSWMR. The VSWMR requirement that that the cover permeability be equal to or less than the underlying soils cannot be met because repeated passes with equipment over the sludge to increase compaction and reduce permeability will cause deformation of the sludge and have a negative impact on the cover. However, an alternative cover design will be developed to ensure that an equal level of performance is achieved, in accordance with the VSWMR.

This alternative provides **long-term protection** against release to the environment and direct contact, as it will be designed and constructed to minimize erosion (runoff and flood) and will require minimal maintenance. The final grading and vegetative cover would promote drainage and protect the cover against erosion and deterioration. Differential settlement could occur overtime requiring periodic filling of depressions and eroded areas and local re-vegetation. However, post-closure care, including annual inspections and maintenance would facilitate maintenance of the integrity of the cover for an indefinite period.

This alternative does not provide **treatment** of the basin materials, however, based on the potential risk pathways, treatment of the nearly one million cubic yards of sludge is not warranted. The soil cover does provide containment of the sludge, preventing release to the environment.

The major potential **short-term impact** may be the increased traffic through the town of Front Royal primarily due to soil delivery for the cover. Based on the quantity of cover material needed, and assuming that fly ash and soil from removed berms are utilized to the maximum extent, the community would see an increase in truck traffic of approximately 30 trucks per day for approximately 13 months (the minimum quantity of imported soil (including the material needed to strengthened the sludge in northern SB 1) is estimated to be 130,000 cubic yards). No unusual hazards would be posed to workers; the primary potential impacts to workers would be limited to common physical hazards associated with site work and materials handling.

4.1.2.3 *Implementability*

The major issue with respect to the **technical feasibility** of installing a soil cover on the Sulfate Basins is designing a suitable cover that can be supported by the sludge, and defining the procedures and methods to install the cover properly. Based on the results from the field test pad on

SB 1 and SB 3 (Appendix C) and geotechnical evaluations, the sulfate sludge provides adequate strength to support the load imposed by the soil cover. A combination of soil, fly ash and reinforcing geotextiles placed prior to soil cover installation may be necessary or appropriate in some or all SB areas. Additional significant conclusions of the geotechnical evaluation are:

- Geotextiles are effective and can provide an important role in separating cover soils from the underlying sludges, distributing the load of construction materials and equipment over larger areas, and resisting cover or sludge failure;
- Water removal prior to and during soil cover placement is important for optimizing the sludge strength and conditions as necessary for cover placement;
- The design phase needs to address the conflict between increased compaction and the effect of repeated passes of equipment on sludge deformation;
- Sludge characteristics vary among the sulfate basins to some degree, and physical testing to characterize potential differences should be completed to support the design phase; and
- The design phase needs to consider in more detail issues such as sludge settlement and displacement, short-term equipment loadings, long-term strength, draining of dispelled water from the sludge, and similar issues.

The field pilot test also indicates that the loads imposed by soil delivery and the movement of equipment when making multiple passes over the same area is a critical engineering factor. Special soil delivery/placement techniques such as conveyors or belt feeders and drag lines to avoid or reduce these loadings will be evaluated as part of the engineering design phase. In addition, soil placement sequencing may be specified in the design to control sludge displacement/wave development, which will support the desired elevations of the final cover. For example, soil may be placed first in the areas that will be the lower elevations in the final grade plan. This will allow upward soil displacement to occur in areas where higher elevations are specified. This may reduce the volume of regrading (attic) fill required to achieve the final grading plan.

The field pilot study indicated that the test pad had a placed permeability of 2.7×10^{-6} cm/sec, which is greater than the permeability of the in-situ soils (1.0×10^{-7} cm/sec). This cover permeability, coupled with a 2 percent slope and vegetative cover, will be adequate to promote runoff and reduce infiltration. Infiltration through the cover could be captured in the strip drains placed on top of the sulfate sludge. The presence of the strip drains should prevent ponding of water within the sludge due to the low permeability soils beneath the SBs. In the design phase, an alternative cover design will be developed to ensure that infiltration into the sludge is not greater than the "exfiltration" from the sludge. Furthermore, placement techniques will be established during the design phase that provide the lowest permeability achievable. Appendix C identifies additional evaluation and studies that will be performed to refine the cover design during the design phase.

A limiting step in implementing this closure may be the **availability** of imported fill and the ability to deliver it to the site efficiently. Of the 598,550 cubic yards of fill and cover material needed for Alternative SB 2, fly ash could be utilized for 338,000 cubic yards and existing berm soil (from berms taken down) amounts to 130,550 cubic yards. That leaves 130,000 cubic yards of imported soil needed. At a soil delivery unit volume of fifteen cubic yards per truck, 8,667 truck loads will be required, which equates to 289 days (13 months with weekday deliveries) at a rate of 30 trucks per day. This would be the minimum traffic impact, assuming fly ash and razed berm soils are used to the maximum extent. Additional material demands of Alternative SB 2 could be reduced by utilizing the soil excavated from the base of SB 5. Although one foot was assumed to be excavated, the amount of soil that may actually have to be removed is uncertain. Thus, at this time, that soil from beneath SB 5 has not been factored into satisfying the fill needs.

State and community acceptance is primarily considered in selecting a recommended alternative. The final cover will have sufficient bearing capacity to support humans, but not vehicles. Therefore, vehicular access to the closed basins will need to be restricted.

4.1.2.4 *Cost*

As described above, uncertainties regarding the cover design and placement techniques remain. For the purpose of developing the estimated cost of Alternative SB 2, a mid-range of design complexity was used, with the exception of the geotextile coverage, which was assumed to be 100% coverage of SBs 1-4E. Engineering design and construction specifications, which will address the impacts of these potential variations, will be developed during the design phase.

Table 11 presents the estimated cost of $11,822,000, to implement this alternative. The estimated capital cost is $10,521,000 and the total present worth O&M cost is $1,301,000. The costs include ground water monitoring for a period of five years, after which the monitoring would be included in the site-wide ground water monitoring program implemented as part of the final remedy for ground water.

4.1.3 *Comparative Analysis of Alternatives*

The purpose of this section is to identify advantages and disadvantages of each alternative, as well as the tradeoffs associated with selecting one alternative over another.

The difference between these two alternatives is the incorporation of enhancements to the cover design in Alternative 2 to address constructability of the cover over the sludges in the SBs. In addition, although both alternatives satisfy the RAOs, namely providing similar levels of protection against direct contact by ecological receptors and against release of sludge by flood erosion, there are concerns over the feasibility of constructing the simple soil cover. Alternative SB 2 offers a more sound approach to covering the basins, is technically feasible, and utilizes on-site materials, especially fly ash, to a greater extent.

The costs of the two alternatives are similar, differing by approximately $1.0 Million. The estimated cost of implementing Alternative SB 2 is approximately 10 percent greater than the estimated cost of Alternative SB 1.

4.2 *WASTEWATER TREATMENT BASINS (WWB)*

4.2.1 *Alternative WWB 1: Cover with Soil In-place*

4.2.1.1 *Alternative Description*

After removing supernatant from the WWBs, the Polishing Basins and Emergency Lagoon would be graded toward SB-1 to avoid ponding, keeping the sludge in-place at these basins. Because the basins are not full, a significant amount of grading will need to be done in the areas surrounding these basins. Soil from the surrounding areas would be utilized to grade the areas to be covered. The final grading for the entire area would be integrated with the grading of SB-1. A two-foot soil cover, consisting of 18 inches of clean fill and six inches of earthen material capable of sustaining vegetation, would then be installed over each of the basins and a vegetative cover established. It is estimated that 23,300 cubic yards of imported soil will be required for the basin closure under this alternative.

Based on the results of the field tests on the sulfate basins, a geotextile-reinforced cover may be necessary. The necessity for geotextile will be evaluated during the engineering design phase.

This alternative will also include the following components:

- Post-closure cover maintenance and ground water monitoring; and
- Recording of a survey plat which delineates the areas of waste disposal and implementation of institutional controls to prevent disturbance of the soil cover.

4.2.1.2 *Effectiveness*

This alternative would satisfy the RAO by preventing direct contact by **ecological receptors** with the sludge, and would contain the sludge to preclude release to the River during a flood event. As shown by the flood modeling (Appendix B), the flood flow velocities calculated for this area are sufficiently low (<3.5 fps) that the final vegetated cover would not be eroded by the flow and maintain integrity.

The Alternative WWB 1 will attain **ARARs,** which are pertinent to the remedial objectives. The most important requirement is the cover design. The soil cover will require minimal long-term care, will be designed to control erosion and runoff, and will meet the cover thickness and permeability requirements. Side slopes will be much less than the 33 percent slope allowed by state regulations.

The soil cover will provide **long-term effectiveness.** Long-term reliability will be maintained through annual inspections and maintenance of the cover. Although no **treatment** is provided in this alternative, the mobility of contaminants will be reduced by the removal of the standing water head and by the presence of the cover and slopes to promote runoff.

There would be very little **short-term impacts** from implementing this alternative. Impacts to local traffic would be over two to three months. Again, workers would not be exposed to any unusual hazards, since the work is typical of any earth moving and materials handling project involving heavy equipment.

4.2.1.3 *Implementability*

This alternative is **technically and administratively feasible** to implement with no special conditions or considerations that would need to be addressed. The cover will be designed to promote runoff and limit infiltration. Compaction to meet the cover permeability requirements will not be as difficult to achieve compared to the sulfate basins because the small volume of sludge in the WWBs can be adequately compacted.

There would not be any significant concerns related to the **availability** of services and materials to implement this alternative. The actions are straightforward and require no unique equipment or supplies. Approximately 23,300 cubic yards of soil would need to be imported to install the cover, which would take a couple months to complete delivery.

There should not be any significant objections to this alternative by the **state or the community**. Based on the RAOs, the soil cover adequately protects against direct contact and release of contaminants during flooding.

4.2.1.4 *Cost*

Table 12 presents the estimated total present worth cost of $800,000 to implement Alternative 1. The estimated capital cost is $697,400 and the total present worth O&M cost is $99,600. The addition of a geotextile reinforced cover, including an addition 1-foot layer of soil/fly ash for support, will add approximately $150,000 to the capital cost. The cost for ground water monitoring is included under the sulfate basin response action because the ground water quality under the WWBs would be monitored as part of a larger unit.

4.2.2 *Alternative WWB 2: Consolidate Sludge into PB 1 and Cover with Soil*

4.2.2.1 *Alternative Description*

Under this alternative, all the sludge material in the three basins would be consolidated into PB 1, and would be closed by installing the same two-foot soil cover and final vegetative cover as in Alternative 1. As with Alternative 1, the necessity for a geotextile reinforced cover will be determined during the engineering design phase. Alternative 2 reduces the area under cover from approximately 4 acres to approximately 1.25 acres, and involves moving 20,000 cubic yards of sludge from PB 2 and the Emergency Lagoon. Alternative 2 also requires more grading than Alternative 1. PB 2 and the Emergency Lagoon would be graded and integrated with the SB 1 grading plan. An estimated 3,000 cubic yards of berm soils from around PB 2 and the Emergency Lagoon would be utilized as fill for the closure, and the reduced soil cover area reduces the need for imported soil to approximately 6,300 cubic yards.

This alternative will also include the following components:

- Post-closure cover maintenance and ground water monitoring; and

- Recording of a survey plat which delineates the areas of waste disposal and implementation of institutional controls to prevent disturbance of the soil cover.

4.2.2.2 *Effectiveness*

Alternative 2 also would satisfy the RAOs by preventing direct contact by **ecological receptors** with the sludge and containing the sludge to preclude release to the environment. As shown by the flood modeling performed by ERM (Appendix B), the flood flow velocities calculated for this area are sufficiently low (<3.5 fps) that the final vegetated cover will withstand the flow and maintain integrity. Because the sludge would be consolidated, the soil cover would be smaller and easier to maintain.

This alternative also will attain **ARARs**, which are pertinent to the remedial objectives. The most important requirement is the cover design. The soil cover will require minimal long-term care, will meet the hydraulic conductivity requirements, and cover thickness requirements. Side slopes will be much less than the 33% slope allowed by state regulations.

As with Alternative 1, the soil cover will provide **long-term effectiveness.** Long-term reliability will be maintained through annual inspections and maintenance of the cover, which is approximately one-third the size of the cover in Alternative 1. Although no **treatment** is provided in this alternative, the mobility of contaminants is greatly reduced by the presence of the cover, which promotes runoff and reduces infiltration.

There would be very little **short-term impacts** from implementing this alternative. Impacts to local traffic would be less than under Alternative 1. This alternative requires approximately one-quarter (6,300 cubic yards) of the amount of imported soil needed for Alternative 1. This volume of soil could be delivered within a month. Again, workers would not be exposed to any unusual hazards, since the work is typical of any earth moving and materials handling project involving heavy equipment.

4.2.2.3 *Implementability*

This alternative also would be **technically and administratively feasible** to implement. There may be special conditions or considerations regarding the ability to stabilize and compact the consolidated sludge. Furthermore, the consolidated sludge will need to be compacted to meet the cover permeability requirements. These potential issues will be resolved through geotechnical analysis as part of the engineering design.

There would not be any significant concerns related to the **availability** of services and materials to implement this alternative. The actions are straightforward and require no unique equipment or supplies. In fact, Alternative 2 only requires approximately 6,300 cubic yards of soil for the cover, which would take less than one month to deliver.

There should be no significant objections to this alternative by the **state or the community**. Based on the RAOs, the soil cover adequately protects against direct contact and release of contaminants during flooding.

4.2.2.4 *Cost*

Table 13 presents the estimated total present worth cost of approximately $800,000 to implement Alternative 2, which is the same total cost as Alternative 1. The estimated capital cost is $705,400 and the total present worth O&M cost is $99,600. The addition of a geotextile reinforced cover, including an additional 1-foot layer of soil/fly ash for support, will add approximately $70,000 to the capital cost. The cost for ground water monitoring is included under the sulfate basin response action because the ground water quality under the WWBs would be monitored as part of a larger unit.

4.2.3 *Alternative WWB 3: Eliminate WWTP Basins*

4.2.3.1 *Alternative Description*

Under this alternative, all the sludge material in the three basins would be consolidated into SB 1-4E prior to closing the Sulfate Basins, rather than closing the material in the originating basins or in PB 1. The area of the WWTP Basins would be graded to integrate with the final SB 1 grading plan, and vegetated. A performance measure will be identified in the design phase to indicate the allowable concentration of zinc in soil beneath the WWBs. Approximately 3,300 cubic yards of topsoil would be needed for establishing the final vegetative cover for this alternative.

For this alternative, ground water monitoring and institutional controls would not be required because the wastes will have been removed and relocated. The institutional controls and post-closure maintenance components of the selected alternative for SBs 1-4E would address the WWTP sludge.

4.2.3.2 *Effectiveness*

The RAO would be satisfied under Alternative 3 by eliminating the basins completely, and thus be **protective of human health and the environment.** The sludge would be covered in the Sulfate Basins by whichever alternative is selected. This would eliminate the WWTP Basins area as a separate closed unit, leaving the area to be utilized for other purposes, such as creating a stormwater equalization basin to handle runoff from the plant until the actions in the plant area are complete. Ultimately, when the treatment plant is demolished, approximately 10-acres of contiguous area would be left vacant, which could be used for relatively unrestricted recreational use.

This alternative will comply with **ARARs. Long-term effectiveness** of the Sulfate Basins closure was provided in Section 4.1. Long-term reliability or maintenance would no longer be a consideration if this alternative were selected. As with the other alternatives, no **treatment** is provided; however, the mobility of contaminants is greatly reduced by the having the sludge closed under the SB cover. This option would also reduce the number of units closed in-place requiring post-closure care.

There would be very little **short-term impacts** from implementing this alternative. There would be essentially no impact to local traffic because no additional fill would needed for this alternative, except for up to 3,300 cubic yards of soil potentially needed to promote sufficient vegetative growth. Again, workers would not be exposed to any unusual hazards, since the work is typical of any earth moving and materials handling project involving heavy equipment.

4.2.3.3 *Implementability*

This alternative also would be **technically and administratively feasible** to implement. There would not be any significant concerns related to the **availability** of services and materials to implement this alternative. The actions are straightforward and are not expected to require unique equipment or supplies. The impact of placing PB and EL sludge on top of SB sludge is expected to be inconsequential. However, this assumption will be confirmed in the engineering design phase if this alternative is selected.

As mentioned above, only 3,300 cubic yards of topsoil need to be delivered to the site, which could be accomplished in a couple of weeks. There should not be any significant objections to this alternative by the **state or the community.** Based on the RAOs, consolidating the sludge with the Sulfate Basins satisfactorily protects against direct contact and

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release of contaminants during flooding and leaves a significant area available for other uses.

4.2.3.4 *Cost*

Table 14 presents the estimated total present worth cost of approximately $760,000 to implement Alternative 3, which is slightly less than each of the first two alternatives,. All of this estimated cost is associated with capital construction; because the sludge would be consolidated in the Sulfate Basins, there would not be any long-term O&M for the WWTP Basins.

4.2.4 *Comparative Analysis of Alternatives*

Alternative 1 has the advantage of keeping the handling and movement of sludge to a minimum, but results in the cover extending over the 4-acre area of all three basins, which is a large area for the relatively small amount of sludge (29,000 cubic yards). Alternative 2 includes consolidating the sludge into one of the basins, so that a smaller unit can be closed. This opens up some of the area (where PB 2 and the emergency lagoon are now) for other, potentially unrestricted, uses. However, when the WWTP is demolished at some point in the future, PB 1 will be in the middle of an area that could be used by the community for recreational purposes.

Alternative 3, however, offers considerable advantages over the other two alternatives. Consolidating the WWTP basin sludge into the Sulfate Basins offers four advantages:

1. A large contiguous area (approximately 10 acres) is made available for unrestricted River access by the community; and

2. It results in elimination of one separate unit closure from long-term care and monitoring (there are no future O&M costs associated with this option);

3. The sludge could be placed in SB 1-4E, which would reduce the area of the flood plain that contains sludge regardless of which alternative is selected for the Sulfate Basins (although this is not a major concern based on the flood modeling);

4. It has the lowest cost of the three alternatives.

4.3 *FLY ASH BASINS (FAB) AND STOCKPILE (FAS)*

A containment remedy has been identified as the most qualified remedy for the FAS, and possibly as well as for the FAB. Containment is commensurate with the Virginia's regulations for the management of CCBs, including fly ash. Physical and chemical stabilization technologies are technically feasible for ex-situ and in situ application. Typically, stabilization costs range between $25 and $50 per cubic yard. Even accounting for economics of scale for such a large volume, this technology is cost prohibitive. Further, stabilization of the fly ash is unwarranted to resist chemical leaching because leaching of contaminants is not a driving force for remediation. Therefore, stabilization is not considered to be a qualified technology to meet the RAOs.

Containment consists of placement of cover materials and creation of positive drainage to promote runoff and limit infiltration. As previously discussed in Section 3, the permeability of the cover material will not be critical because the primary objective of the cover is for material containment, direct contact protection, promotion of runoff, and prevention of surface water ponding.

Fly ash from the FAS will first be utilized to the maximum extent possible as fill for the other unit closures. This will have the benefit of reducing the overall size of the FAS, as well as reduce costs to import soil to close the other units. Depending on the alternatives selected for the SBs, it is estimated that several hundred thousand cubic yards of fly ash could be utilized as fill in the SBs. As a result, final side slopes will be less than the maximum 33 percent side slope allowed by state regulations.

4.3.1 *Alternative FA 1: Cover Stockpile with Soil*

4.3.1.1 *Alternative Description*

The FAS would be regraded to reduce and stabilize the side slopes to meet the state requirement for a less than 33 percent slope for a final cover. This can be accomplished without taking any fly ash from the stockpile. The final height of the stockpile, prior to installing the cover would be approximately 40 feet, with side slopes expected to be no greater than 20 percent. The actual volume of fly as that will remain in the FAS at the time of closure is dependent on how much fly ash is used as part of the closure of SBs 1-4E.

A minimum 24-inch earthen cover will be installed, consisting of 18 inches of clean bedding soil and six inches of soil capable of sustaining vegetation, and a final vegetative cover will be established. Under this alternative, FAB 1-3 and FAB 6 will not be covered and will remain in their current vegetated condition. Some minor grading and berm rehabilitation areas these basins would be implemented. Soil import requirements for the cover under this alternative are estimated to be approximately 48,000 cubic yards.

Institutional controls, recording of a survey plat which indicates the areas of waste disposal, post-closure cover maintenance and ground water monitoring will be implemented as appropriate for the remedy.

4.3.1.2 *Effectiveness*

This alternative would satisfy the RAOs for the fly ash in the stockpile, which are to **protect ecological receptors** from direct contact exposure to the fly ash stockpile, and minimize fugitive emissions. However, the FABs may continue to present a potential direct contact risk to human or ecological receptors. Therefore, the RAO for preventing direct contact of fly ash by human and ecological receptors will not be met.

With appropriate dust, tracking and runoff controls in place, installing the soil cover on the FAS would attain compliance with **ARARs**. The cover satisfies the requirements for closure of a CCB site by providing the required 18-inch infiltration layer and a 6-inch layer of earthen material capable of sustaining vegetation. Future activities anticipated for the FAS would be restricted to pedestrian access in a recreational setting, so future use would be restricted so as not to disturb the cover. The only anticipated post-closure activities would be future inspection, monitoring and repair activities. However, leaving the FABs uncovered does not comply with ARARs, specifically the requirements of the VSWMR for closure of an industrial waste disposal unit.

Because future use would be restricted to pedestrian recreational use, the cover would provide **long-term effectiveness**. Potential **short-term impacts** while implementing this action would include potential dust and runoff concerns. However, construction plans would address these potential issues to satisfy the ARARs. The action would take 8 to 10 months to complete the work. Approximately 48,000 cubic yards of cover soil need to be imported to the Site. It could take five months to clear and grade the FAS, which could begin ahead of soil delivery. At 15 cy/truck, it would require 3,200 trucks, and at a delivery rate of 30 trucks/day, it would take five months to deliver soil. The soil cover could be placed as the soil is delivered, which will then take another six months approximately.

4.3.1.3 *Implementability*

This alternative, which consists of earth work and materials handling, is both **technically and administratively feasible**. Materials needed are readily **available**, although, as discussed above, it will take approximately four months for the cover soil to be delivered. This could have an impact on the local community for that time, particularly if other Site activities are ongoing with their own trucking requirements.

Both the **state and community** may not accept this remedy this remedy because not covering the FABs is not completely consistent with the conceptual reuse plan for passive recreational use at the Site. Specifically, the community and the state, as well as EPA, could raise concerns about not including any action for the FABs because contact with fly ash may create a nuisance. However, these units do not present a significant risk to human or ecological receptors.

4.3.1.4 *Cost*

Table 15 presents the total estimated present worth cost of $2,858,000 to implement this alternative. Of that total, $2,481,000 is for capital construction costs, and $377,000 is the present worth cost for annual O&M for 30 years. The costs include ground water monitoring for a period of five years, after which the monitoring would be included in the site-wide ground water monitoring program implemented as part of the final remedy for ground water.

4.3.2 *Alternative FA 2: Cover FA Basins and Stockpile with Soil*

4.3.2.1 *Alternative Description*

The FAS would be addressed as in the Alternative 1. However, under this alternative, the FABs would also be graded, have a 24-inch soil cover installed and receive a final vegetative cover. The basins would be first graded and filled with fly ash from the stockpile to prevent ponding and promote runoff once the final cover is installed. The estimated soil import requirements for the soil cover under this alternative is approximately 116,000 cubic yards.

Institutional controls, recording of a survey plat which indicates the areas of waste disposal, post-closure cover maintenance and ground water monitoring will be implemented as appropriate for the remedy.

4.3.2.2 *Effectiveness*

This alternative would satisfy the RAOs for the fly ash, which include the **protection of ecological receptors** from direct contact exposure to the fly ash stockpile.

With appropriate dust, tracking and runoff controls in place, installing the soil cover on both the FAS and FABs would attain compliance with **ARARs**. The cover satisfies the VSWMR closure requirements by providing the required 18-inch infiltration layer and a 6-inch layer of earthen material capable of sustaining vegetation. Future use activities anticipated for the fly ash units would be restricted to pedestrian travel in a recreational setting so as not to disturb the cover. The only anticipated post-closure activities would be future inspection, monitoring and repair activities.

Because future use is restricted to pedestrian recreational use, the cover would provide **long-term effectiveness**. Potential **short-term impacts** while implementing this action would include potential dust and runoff concerns. However, construction plans would address these potential issues to satisfy the ARARs. Implementation of this alternative will take at least twice as long as Alternative 1. For this alternative, approximately 116,000 cubic yards of cover need to be imported to the Site. Depending on the final sequence of work, the soil cover could be placed as the soil is delivered.

4.3.2.3 *Implementability*

As in Alternative 1, this alternative consists of earth work and materials handling and is both **technically and administratively feasible.** Materials needed are readily **available**, although, as discussed above, it may take over a year to complete this alternative. This could have an impact on the local community from increased truck traffic for that time, particularly if other site activities are ongoing with their own trucking requirements.

Both the **state and community** should readily accept this remedy. The soil cover is a beneficial component of the remedy to meet the community's desires for a relatively unrestricted pedestrian access to the area.

4.3.2.4 *Cost*

Table 16 presents the total estimated present worth cost of $4,909,000 to implement this alternative. Of that total, $4,532,000 is for capital construction costs, and $377,000, the same as in Alternative 1, is the present worth cost for annual O&M for 30 years. The cost for this

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alternative is more than twice the cost of Alternative 1. The costs include ground water monitoring for a period of five years, after which the monitoring would be included in the site-wide ground water monitoring program implemented as part of the final remedy for ground water.

4.3.3 *Comparative Analysis of Alternatives*

The two alternatives for closure of the FAB and FAS differ only in the scope of the actions. Both utilize the same soil cover, but Alternative 1 provides this cover on the FAS only and no action is taken for the FABs. Alternative 2 includes the soil cover on the basins as well as the fly ash stockpile. Consequently, Alternative 2 is almost twice the cost of Alternative 1, which addresses the stockpile as the portion of the unit that poses a potential risk to ecological receptors and is most susceptible to migration of fly ash via wind transport.

Covering the basins in the absence of significant risk potential needs to be weighed against an additional cost of $2.1 Million. However, leaving the FABs uncovered does not comply with ARARs, specifically the requirements of the VSWMR for closure of an industrial waste disposal unit. Further, the community and the state, as well as EPA, could raise concerns about not including any action for the FABs because contact with fly ash may create a nuisance. Covering the FABs is consistent with the proposed conceptual reuse plan of passive pedestrian recreation.

5.0 RECOMMENDED RESPONSE ACTION ALTERNATIVES

The recommended alternatives for each unit are:

- For the SBs, Alternative SB 2 – Eliminate SB 5 and Install Enhanced Soil Cover on SB 1-4E, with an estimated net present value cost of $11,822,000;
- For the WWBs, Alternative WWB 3 – Eliminate WWTP Basins, with an estimated net present value cost of $760,000; and
- For FABs and FAS, Alternative FA 2 – Cover Fly Ash Basins and Stockpile with Soil, with an estimated net present value cost of $4,909,000.

The total estimated net present value for the three EE/CA units is $17,491,000. The reasons for selecting each alternative are summarized below.

5.1 SULFATE BASINS

The two sulfate basin closure alternatives evaluated are containment remedies consisting of soil cover, and include elimination of SB 5. The primary difference between the two alternatives is that in Alternative SB 2, enhancements, such as fly ash fill and geotextile, are incorporated into the cover design to address constructability of the cover over the sludges. Alternative SB 2 offers a more technically feasible approach to covering the basins, and utilizes on-site materials, especially fly ash, to a greater extent. Furthermore, it is uncertain whether the Alternative SB 1 approach of placement of the two foot thick soil cover without engineering enhancements is technically feasible based on the results obtained from the field test pads.

Both alternatives satisfy the RAOs. Based on the results of the flood modeling that was performed, both alternatives would meet the RAO to ensure the sludge is not released to the River during flooding. The model results predicted flood over-bank velocities are sufficiently low (<3.5 fps) to allow a vegetative cover to be established without risking erosion of the cover by flood waters. Further, placement of a cover over the sludge protects against direct contact by ecological receptors. Both alternatives would also meet ARARs and would meet the RAO of ensuring that the closure is consistent with the proposed conceptual reuse plan of passive recreational use.

Alternative SB 2 is the recommended alternative for closing the SB 1-5 because it offers a more technically sound approach to covering the basins.

5.2 *WWTP BASINS*

The alternatives evaluated for the WWTP Basins included: regrading and installing a soil cover over the basins in their current configuration (Alternative WWB 1); consolidating the sludge into PB 1 and installing a soil cover (Alternative WWB 2); and consolidating the sludge into the SBs and eliminating the WWTP Basins (Alternative WWB 3).

The first two alternatives include installation of a cover, and leaving the sludge in-place in one or all three basins. Alternative WWB 3, however, includes moving the sludge to the SBs rather than closing the WWBs as a separate unit. In the SBs, the WWTP sludge would be covered utilizing essentially the same approach as described in Alternatives WWB 1 and WWB 2.

Alternative WWB 3 is the recommended alternative for closing the WWTP basins. There are significant benefits to consolidating the sludge in the SBs, the most important of which is leaving the area of the current WWTP Basins available for other short- and long-term unrestricted recreational use. Additional advantages of the WWB 3 alternative are:

- Relatively low volume of sludge consolidated with larger basin closure;
- Eliminates the WWTP Basins from separate closure of a relatively small isolated area (1.25 to 4 acres):
- Long-term care and maintenance of a small, isolated unit is eliminated; and
- The cover to be installed over the Sulfate Basins is equivalent to the soil cover that would otherwise be installed over the WWTP Basins.

5.3 *FLY ASH BASINS AND STOCKPILE*

The two alternatives evaluated both include covering the FAS with a 24-inch soil cover. Covering the FAS eliminates a direct contact risk and mitigates the release of fugitive emissions. Therefore, recommending one alternative over another is based on determining whether the FABs warrant a soil cover, as well. Based on risk evaluation, response actions are not warranted to mitigate either direct contact human health risk or ground water exposure risks, although a response action would mitigate potential risks to ecological receptors. Furthermore, covering the FABs is consistent with the proposed conceptual reuse plan of passive pedestrian recreation for the Site.

Alternative FA 2 is the recommended approach for closing the Fly Ash Units because of the potential risk to ecological receptors and community desire for relatively unrestricted pedestrian recreational access. Also, Alternative FA 2 provides adequate protection against direct contact and ecological receptors, complies with ARARs, and is more likely to gain community and state acceptance.

5.4 *CONCEPTUAL BASIN CLOSURE PLAN AND SCHEDULE*

Figure 12 shows that the proposed conceptual basin closure plan for the Site in the event that the three closure alternatives discussed are selected. The plan will provide unrestricted access to the River in the 30 acre area currently occupied by SB 5 and the WWTP and WWBs. Although the soil-covered basins will have some restrictions regarding vehicle access, the soil covers will support pedestrian recreational access. Therefore, the proposed conceptual closure plan is consistent with the proposed conceptual reuse plan adopted by the Town of Front Royal.

Closure of the SBs will require that Site stormwater that is currently captured in the SBs be managed in an alternative manner. The design phase for the EE/CA units will establish the detailed construction sequencing that is most appropriate for the project and accounts for future stormwater management once SB 1 is closed. A conceptual sequencing plan for the EE/CA units is as follows:

1. SB-5 would be drained, the sludge would be transferred to SB 2-4E, and the basin will be eliminated;

2. SB 2-4E would be closed, utilizing fly ash for filling and grading;

3. WWB sludge would be excavated and placed in SB 1;

4. The WWBs would be reconstructed to become a stormwater retention basins;

5. SB 1 would be closed; and

6. FAS and FAB would be covered.

A preliminary analysis of future stormwater management options presented in Appendix D indicates that the area currently occupied by the WWBs should provide adequate capacity for retention of a ten-year storm event. Prior to closure of the SBs and WWBs, FMC will perform a detailed evaluation of the stormwater runoff volume and WWTP capacity to develop appropriate stormwater control alternatives for stormwater management during implementation of the response action. This evaluation is expected to:

- Quantify the portions of the Site contributing runoff that will require retention and determine retention capacity alternatives;
- Assess potential runoff volumes during consecutive storms that can reasonably be anticipated;
- Assess the current WWTP capacity and identify repairs, modifications and/or upgrades necessary to increase the throughput of the WWTP;
- Identify treatment requirements to meet NPDES discharge limits; and
- Estimate of the near-term and long-term stormwater generation as well as the volume and rate of leachate likely to be generated by the closed SBs.

Once remediation of the areas of the Site requiring retention of stormwater runoff is completed and discharge limits are met, the WWTP would be demolished and the WWBs would be graded out of existence.

Figure 13 shows the anticipated schedule for the Non-Time-Critical Removal Action for the SAB, WWB, and FAB, and FAS. According to this schedule, specific start and completion milestones are:

- Submission of Final EE/CA to EPA by 5 May 1999;
- Release the EE/CA for public comment between 15 May and 14 June 1999;

- Prepare the Action Memorandum between 1 June and 30 June 1999, and issue the Action Memorandum on 1 July 1999;
- Obtain permits and approvals between 1 July and 31 December 1999;
- Complete the closure design between 1 July and 30 November 1999;
- Conduct regulatory review and approval of the design documents between 1 December 1999 and 29 February 2000; and
- Implement sulfate basin closures between 3 April and 29 December 2000.

Charters, D. W., Finley, N. J., and Huston, M., 1996. *Draft Report, Preliminary Ecological Risk Assessment, Avtex Fibers Site, Front Royal, Virginia*. Office of Emergency and Remedial Response, Environmental Response Team Center, November.

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Environmental Resources Management, 1994a. *Draft Analytical Quality Assurance Report, Wastewater Treatment Plant Management Unit, Avtex Fibers Site, Front Royal, Virginia*, 17 January.

Environmental Resources Management, 1994b. *Draft Analytical Quality Assurance Report, Fly Ash Basins/Landfill Area Management Unit, Avtex Fibers Site, Front Royal, Virginia*, 21 February.

Environmental Resources Management, 1994c. *Draft Analytical Quality Assurance Report, January 1994 Ground Water Sampling, Avtex Fibers Site, Front Royal, Virginia*, 16 May.

Environmental Resources Management, 1994d. *Draft Analytical Quality Assurance Report, April 1994 Ground Water Sampling, Avtex Fibers Site, Front Royal, Virginia*, 13 July.

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Gannett Fleming, Inc, 1994a. *Draft River Investigation Report, Avtex Fibers Site, Warren County, Virginia*, October.

Gannett Fleming, Inc., 1994b. *Draft Ecological Assessment, Avtex Fibers Site, Warren County, Virginia*, September.

Gradient, 1999. *Human Health Risk Assessment for the Sulfate Basins, Wastewater Treatment Plant Basins, and Fly Ash Basins and Stockpile*. 26 March.

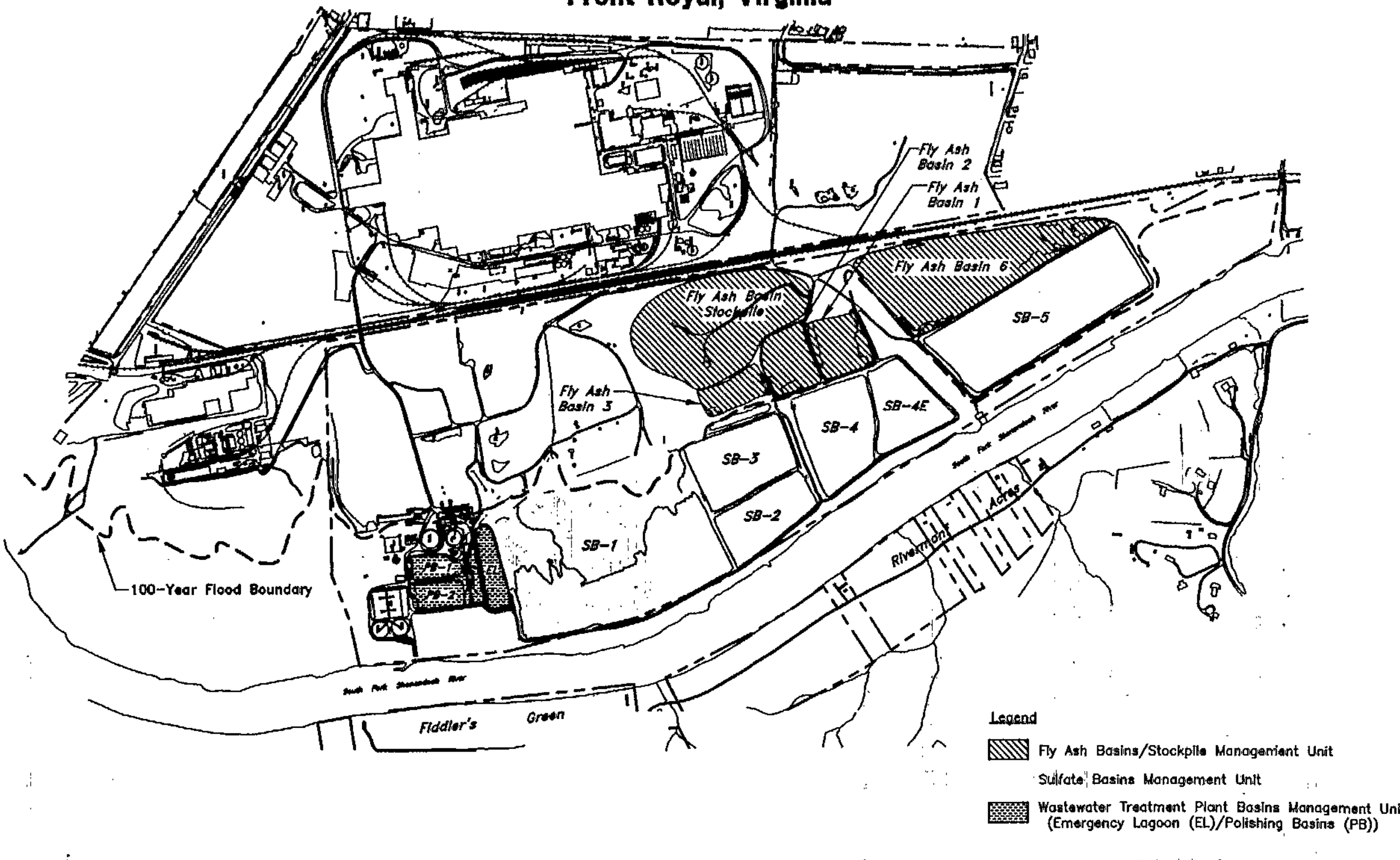
Menzie-Cura & Associates, Inc., 1997. *Risk-Based Screening of the Phase 1 Data*, 3 July. Presented as Revised Appendix A of the *Phase 2 Remedial Investigation Work Plan, Avtex Fibers Superfund Site, Front Royal, Virginia*, prepared by ERM, May 1995.

North American Realty Advisory Services (NARAS), 1998. Future Use and Implementation Strategy for the Former Avtex Fibers Site. Prepared by NARAS for FMC Corporation and the Town of Front Royal Economic Development Authority, May 1998.

Sprenger, M. D., Finley, N. J., and Huston, M., 1999. *Final Ecological Risk Assessment, Avtex Fibers Site, Front Royal, Warren County, Virginia.* Environmental Response Team Center, Office of Emergency and Remedial Response, February.

Tallon, 1998. *Preliminary Feasibility for the Beneficiation of Impounded Zinc-Containing Materials at the FMC-Avtex Fibers Site in Front Royal Virginia.* Final Report prepared by Tallon Metal Technologies, Inc for Flour Daniel GTI, Inc., October.

Figure 1
Locations of Sulfate Basins, WWTP Basins, and Fly Ash Basins/Stockpile Management Units
Avtex Fibers Superfund Site
Front Royal, Virginia



Note: Source of 100-year Flood Boundary - Federal Emergency Management Agency, 1988 Term Flood Insurance Rate Map - Town of Front Royal, Virginia, Warren County, Panel 2 of 5, Community Panel Number 5101670002 B Effective Date: July 15.

Figure 2
Sampling Locations for Sulfate Basin Management Unit
Avtex Fibers Superfund Site
Front Royal, Virginia

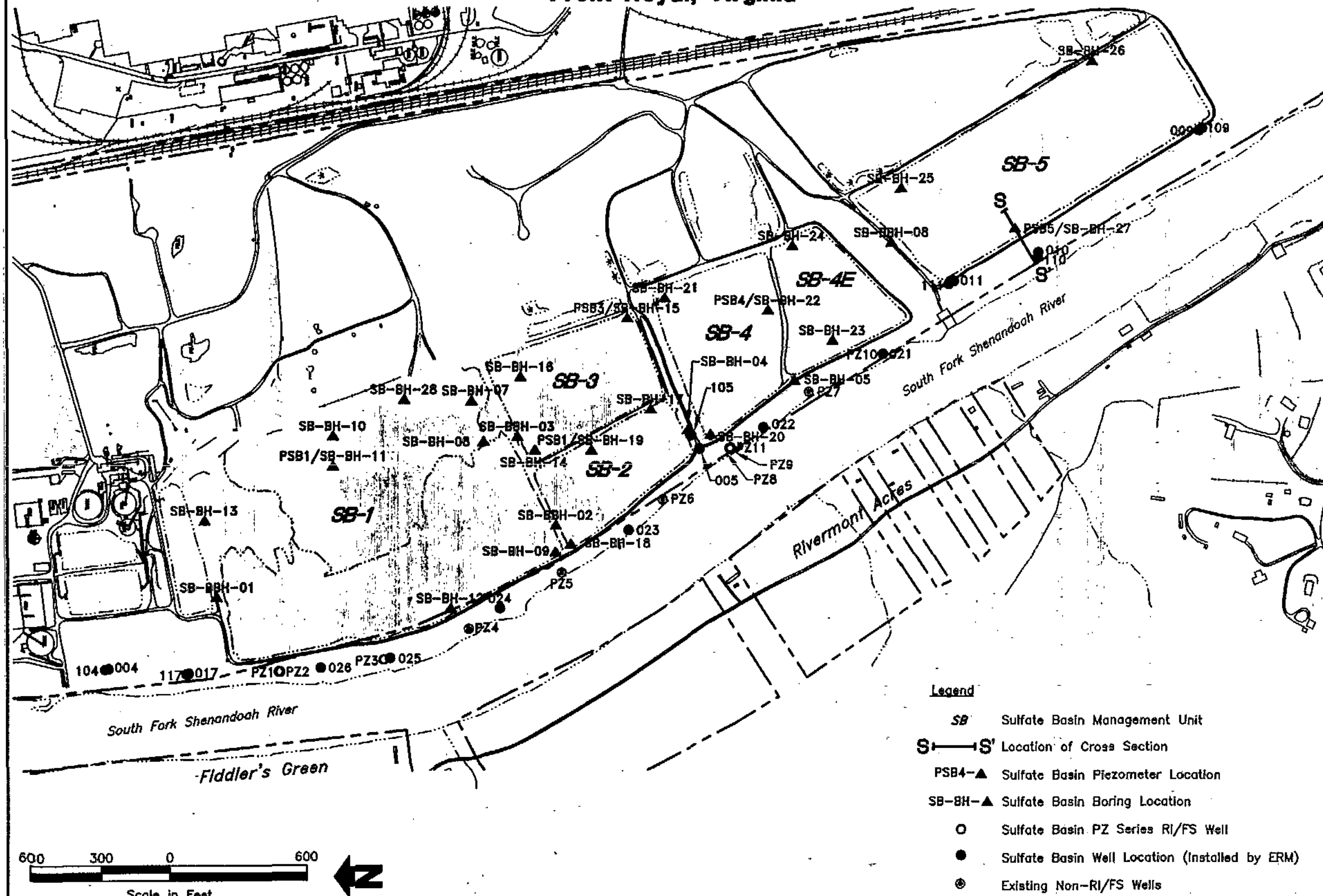
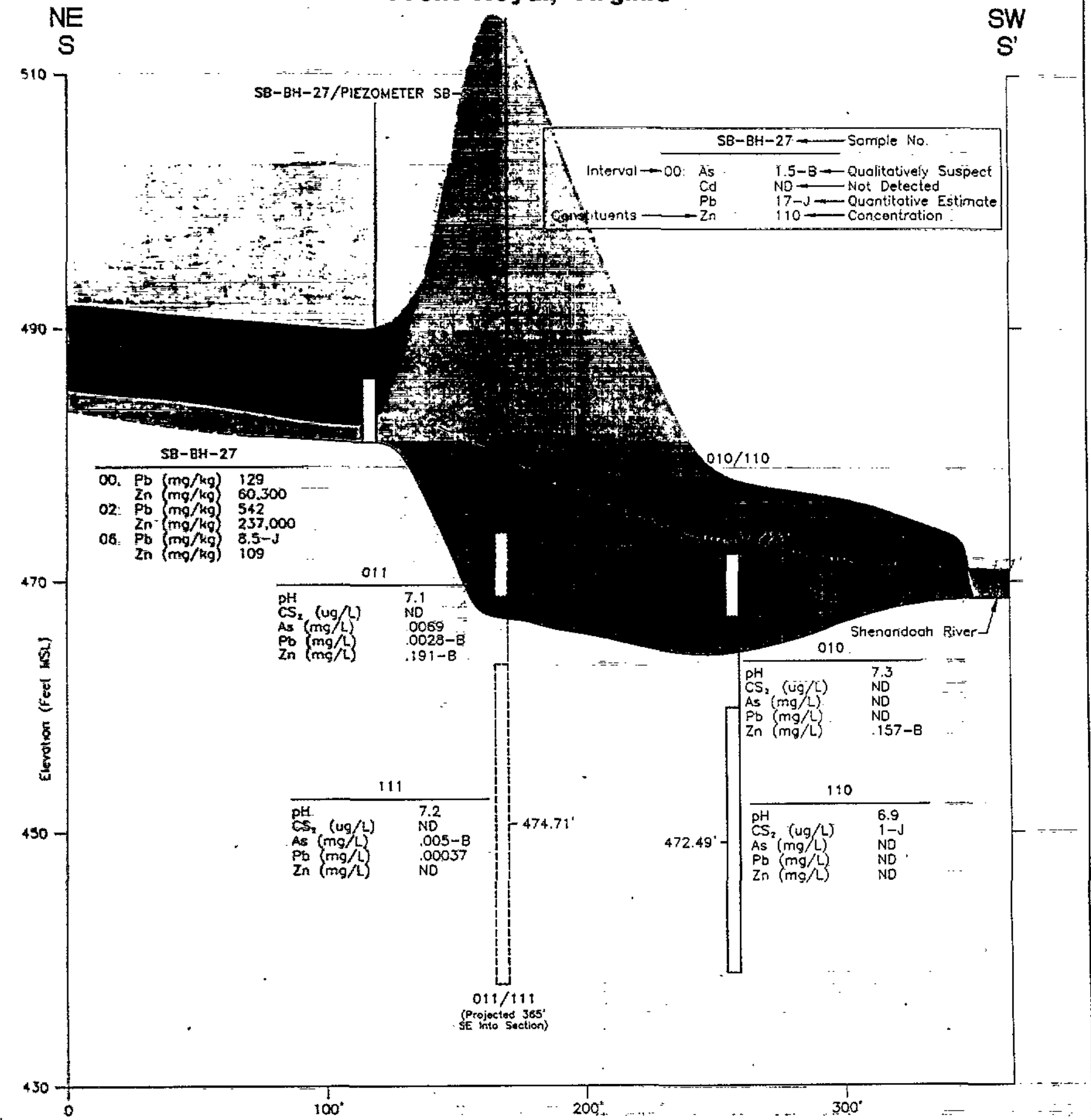


Figure 3
Illustrative Cross Section for Sulfate Basin Management Unit
Avtex Fibers Superfund Site
Front Royal, Virginia



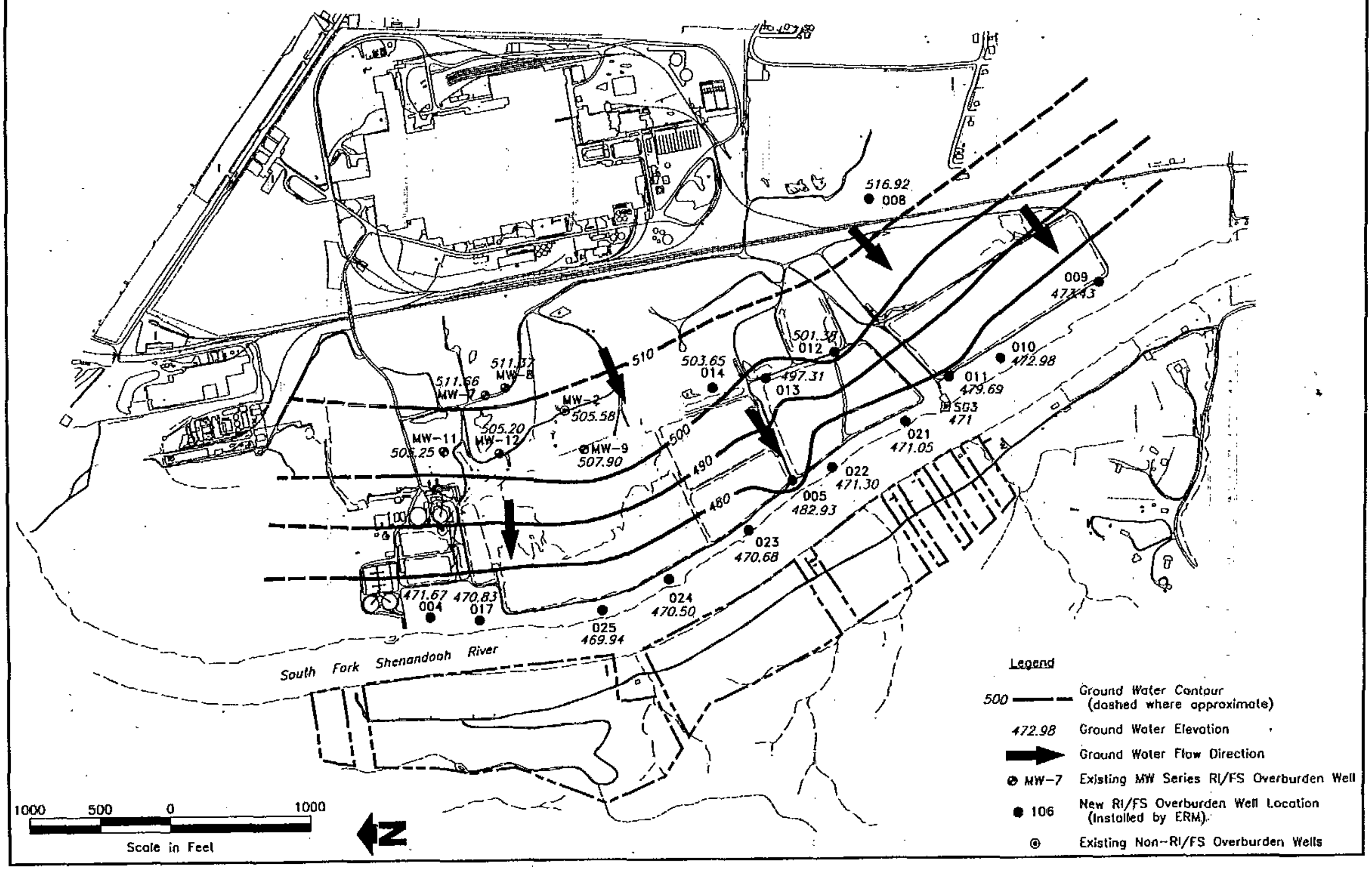
Notes:
1. Ground water chemical data obtained during January-February 1994 sampling event.
2. Sulfate basin chemical data obtained in August 1993.
3. Ground water level elevations were taken on 25 April 1994.
4. Soil analytical data are based on results for Level III and IV analysis. For samples having both Level III and Level IV data available, the Level IV data is presented.

60 30 0 60
Scale in Feet
Vertical Exaggeration = 5x

Legend

- Monitoring Well
- Open Borehole/Screened Interval
- Projected Monitoring Well
- Projected Open Borehole/ Screened Interval
- Top of Weathered Bedrock (Dashed Where Inferred)
- 473' Overburden Water Table Surface
- Light Gray to Gray ZINC SLUDGE
- Orange-Brown, Red-Brown, and Tan-Brown SANDY SILT and CLAYEY SILT
- Coarse SAND, GRAVEL and COBBLES, Poorly to Well Sorted
- Dark Gray to Black Calcareous SHALE with Fine-Grained Sandstone and Siltstone Interbeds

Figure 4
Ground Water Elevation Contours for the Overburden Monitoring Wells (4/25/94)
Avtex Fibers Superfund Site
Front Royal, Virginia



ERM

10556.65.01/11.11.98-MKB/05.19.99-CMP/A101-1F

Figure 5
Ground Water Elevation Contours for the Shallow Bedrock Monitoring Wells (4/25/94)
Avtex Fibers Superfund Site
Front Royal, Virginia

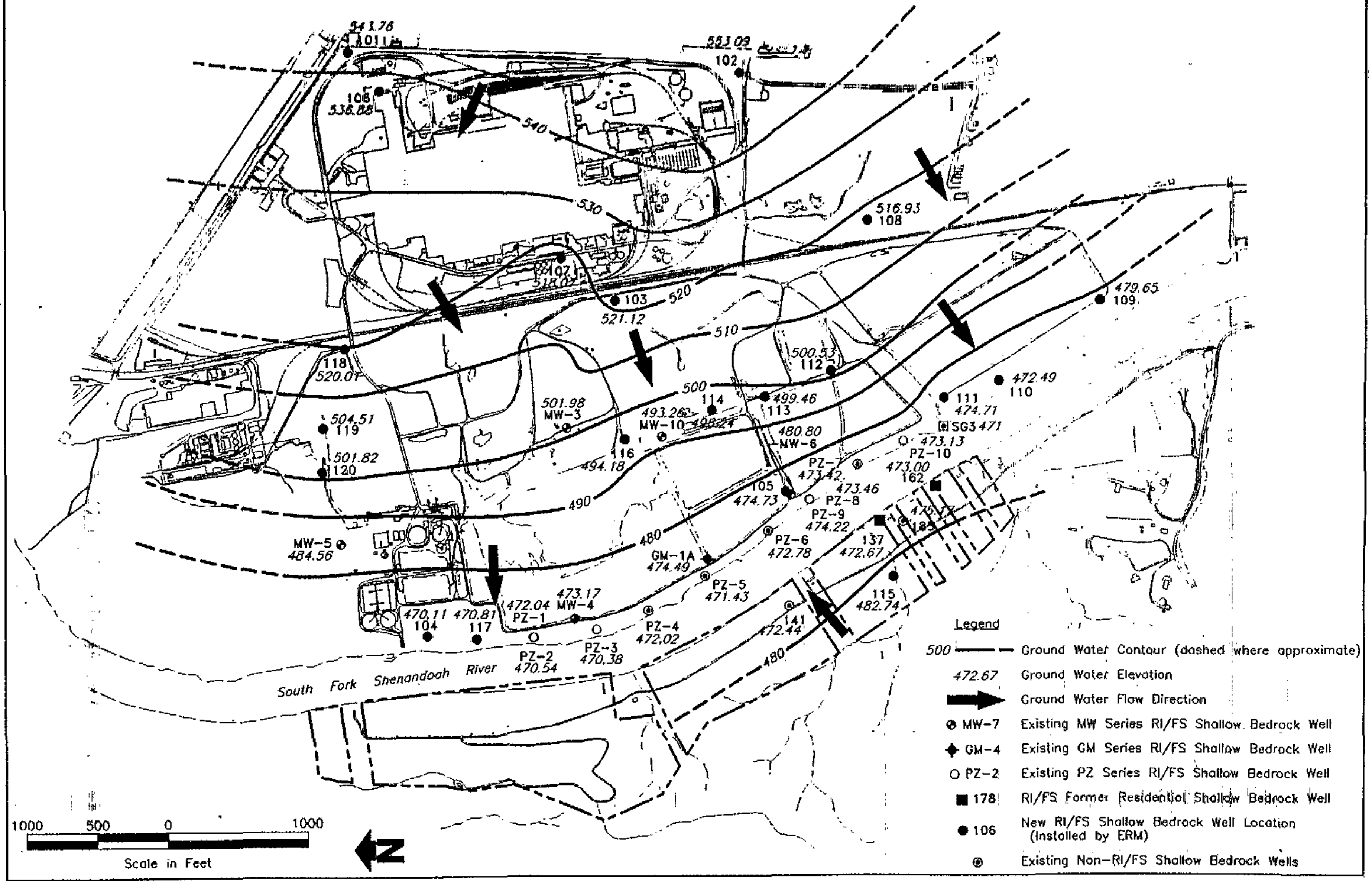


Figure 6
Distribution of Dissolved Zinc in Ground Water (Overburden)
Avtex Fibers Superfund Site
Front Royal, Virginia

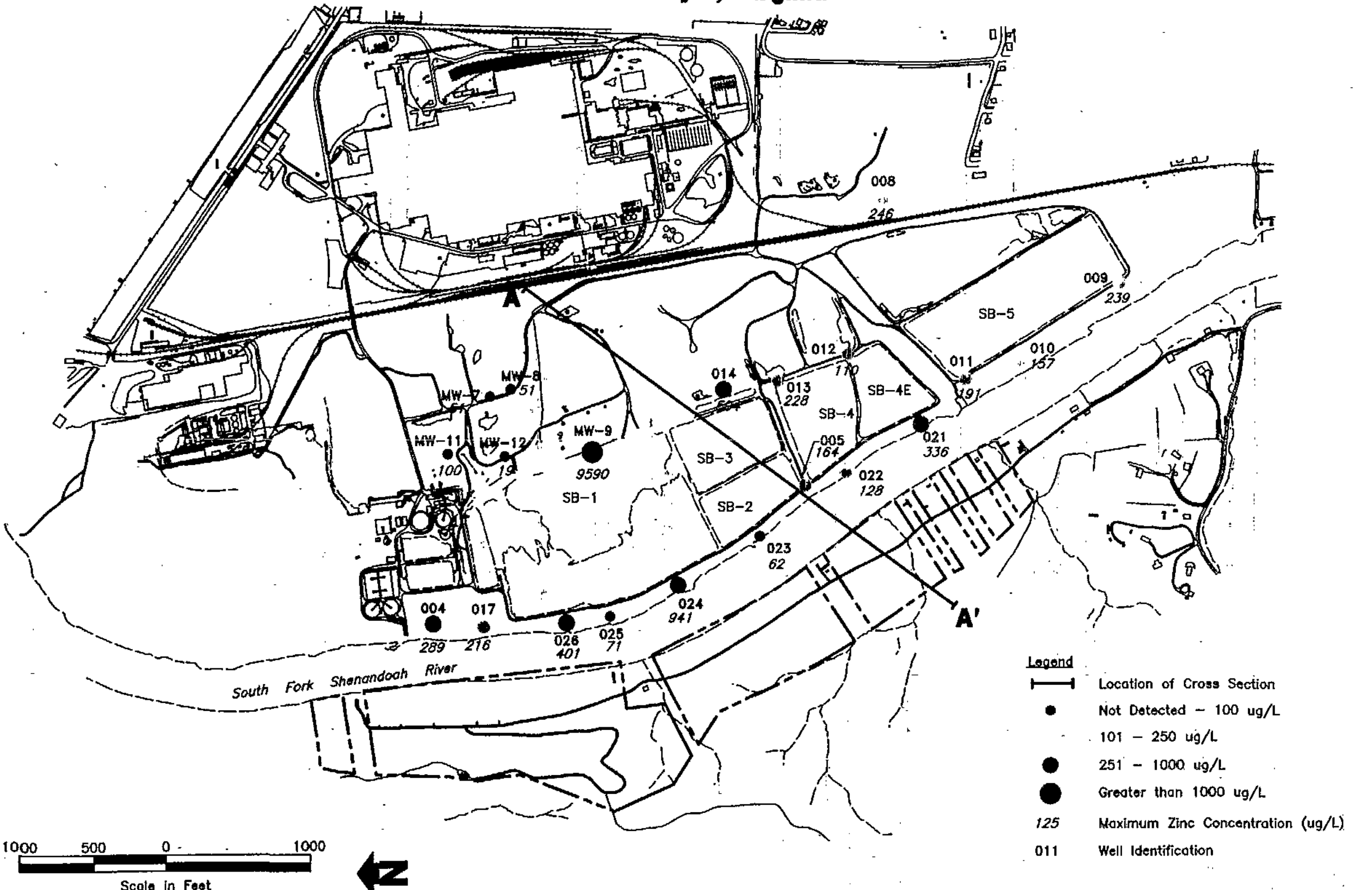


Figure 7
Distribution of Dissolved Zinc in Ground Water (Shallow Bedrock)
Avtex Fibers Superfund Site
Front Royal, Virginia

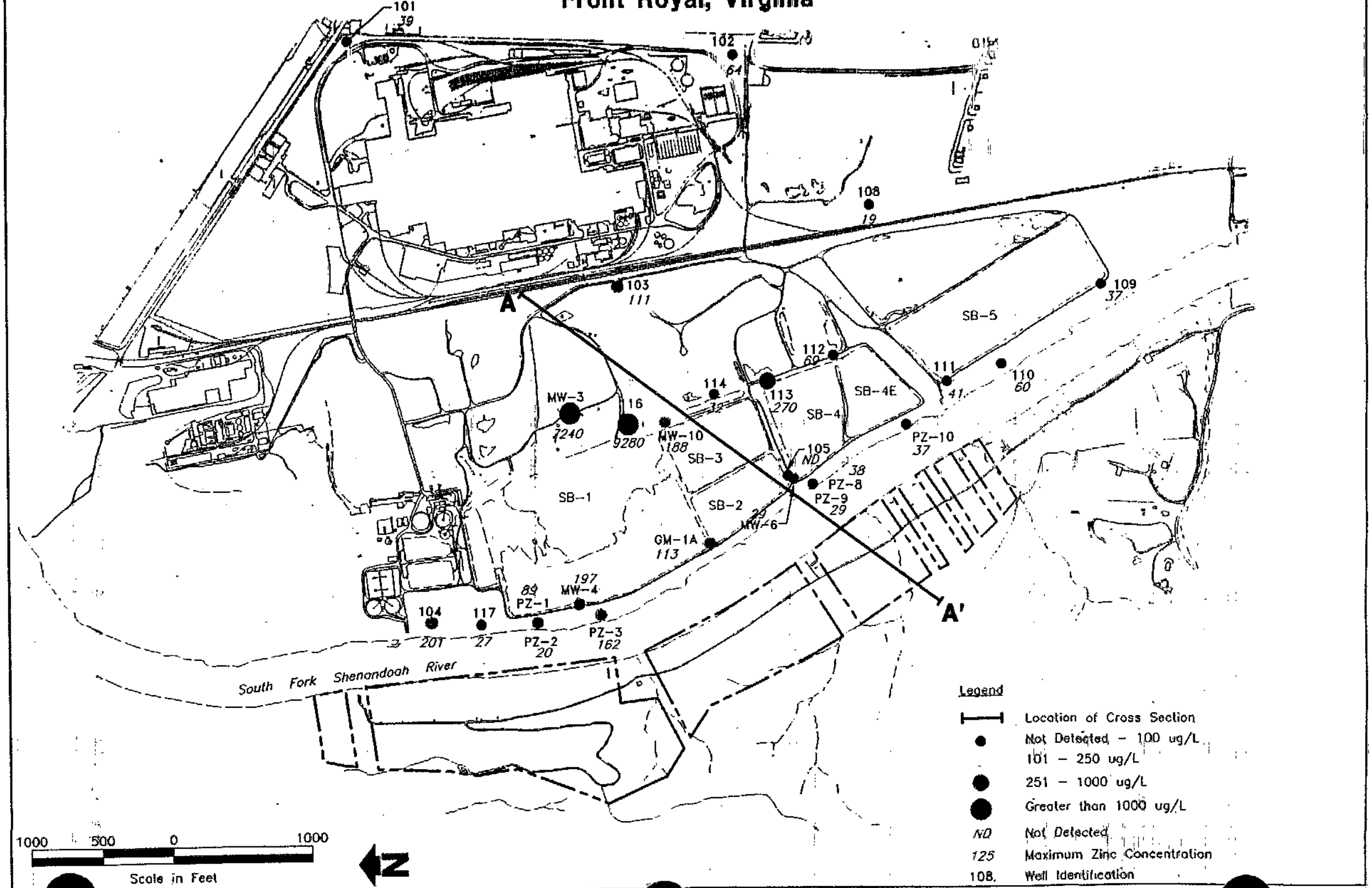


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Figure 8
Sampling Locations for Wastewater Treatment Plant Management Unit
Avtex Fibers Superfund Site
Front Royal, Virginia

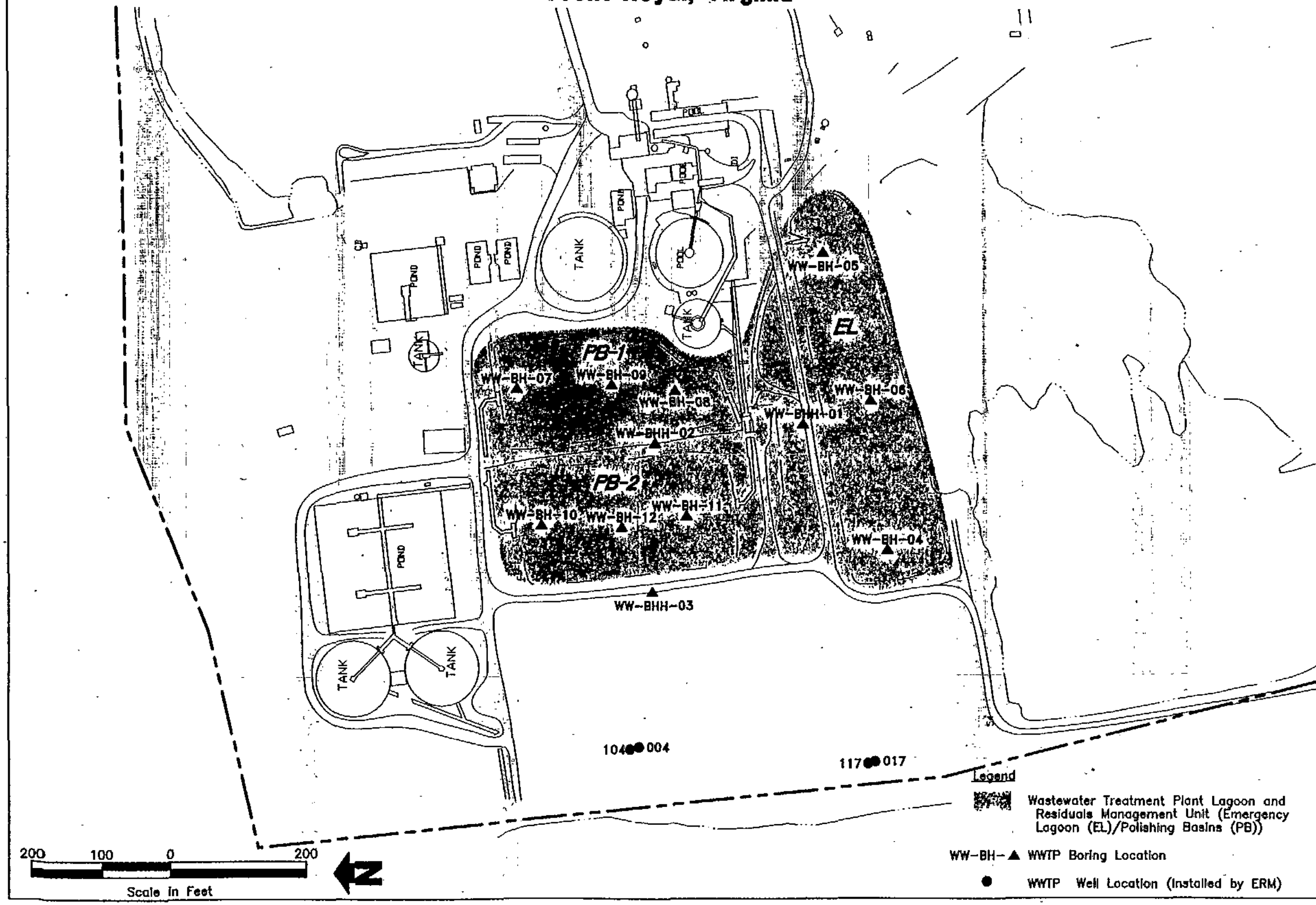


Figure 9
Sampling Locations for Fly Ash Basin/Stockpile Management Unit
Avtex Fibers Superfund Site
Front Royal, Virginia

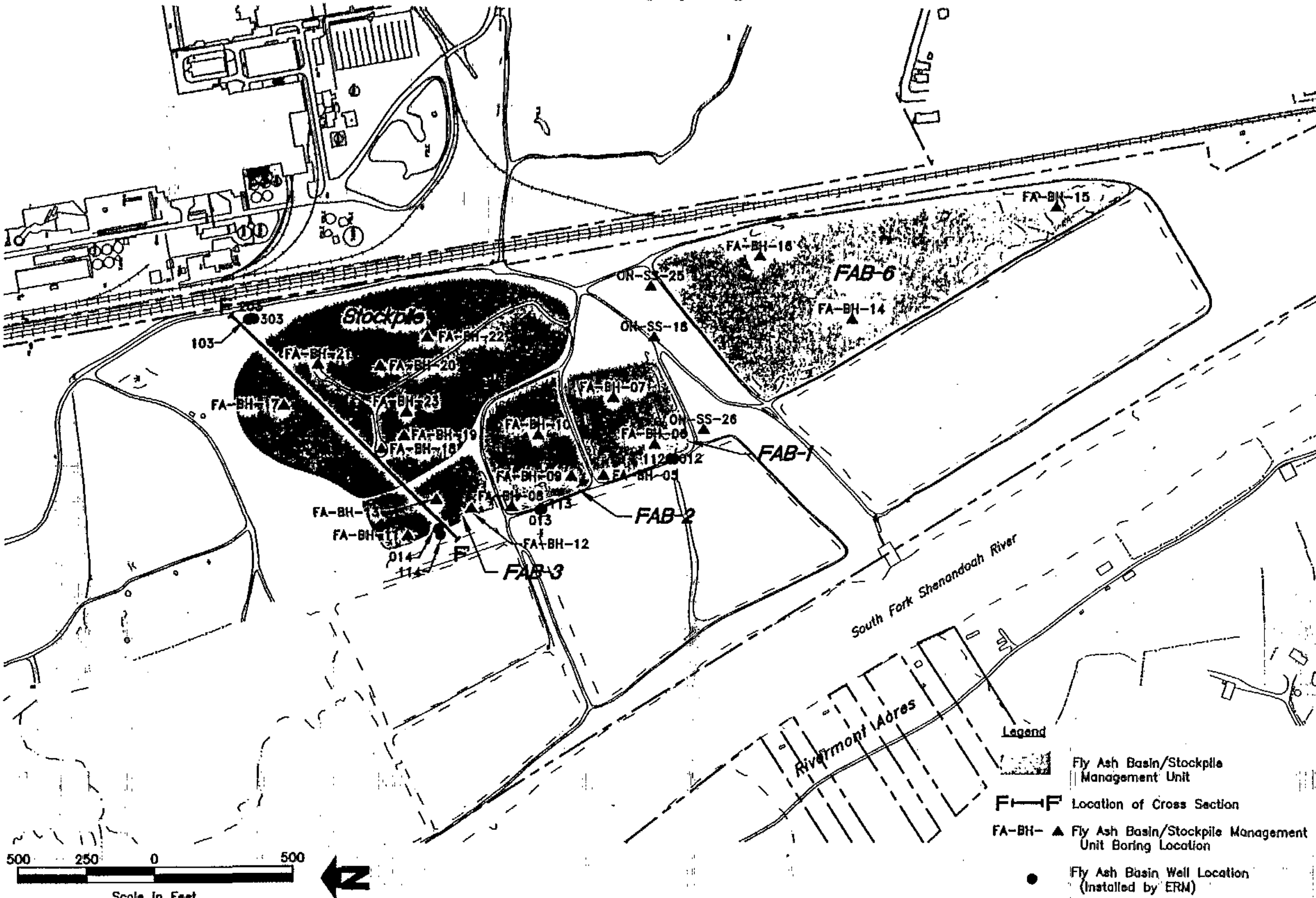
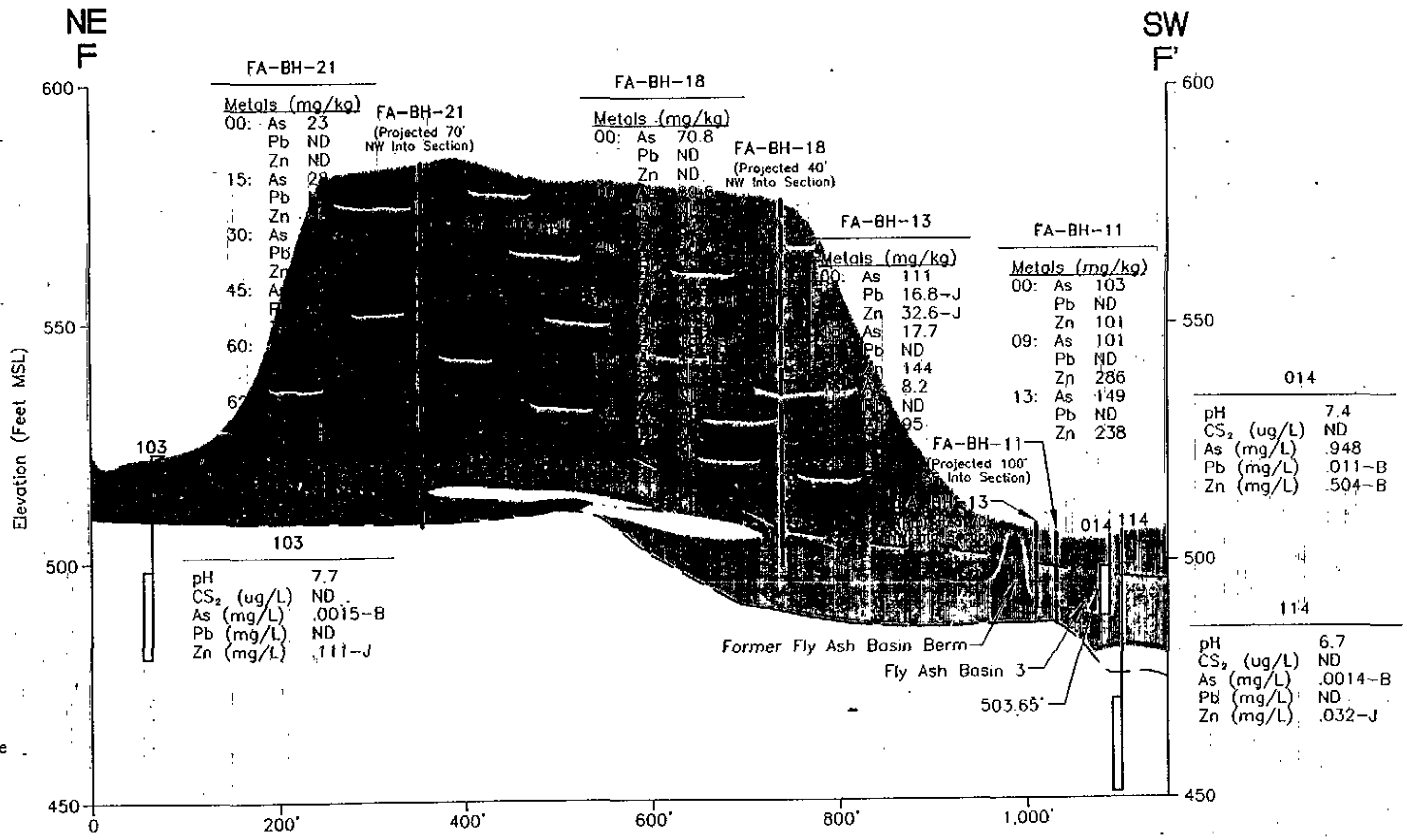


Figure 10
Illustrative Cross Section for Fly Ash Basin 3 and Stockpile
Fly Ash Basins/Stockpile Management Unit
Avtex Fibers Superfund Site
Front Royal, Virginia



Notes:
1. Ground water chemical data obtained during January–February 1994 sampling event.
2. Fly Ash basin chemical data obtained in September–October 1993.
3. Ground water level measurements were taken on 25 April 1994.
4. Soil analytical data are based on results for Level III and IV analysis. For samples having both Level III and IV data available, the Level IV data is presented.

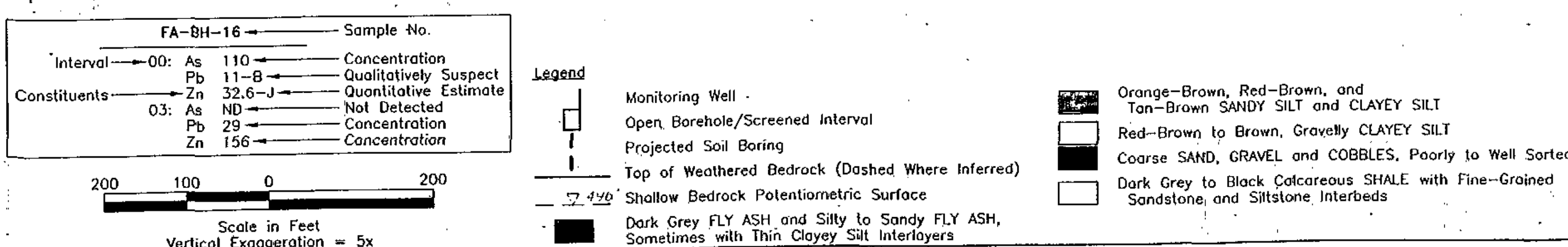
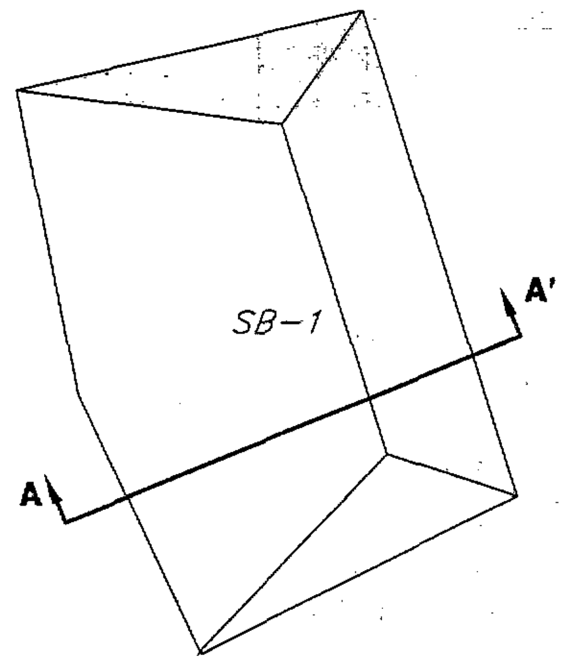
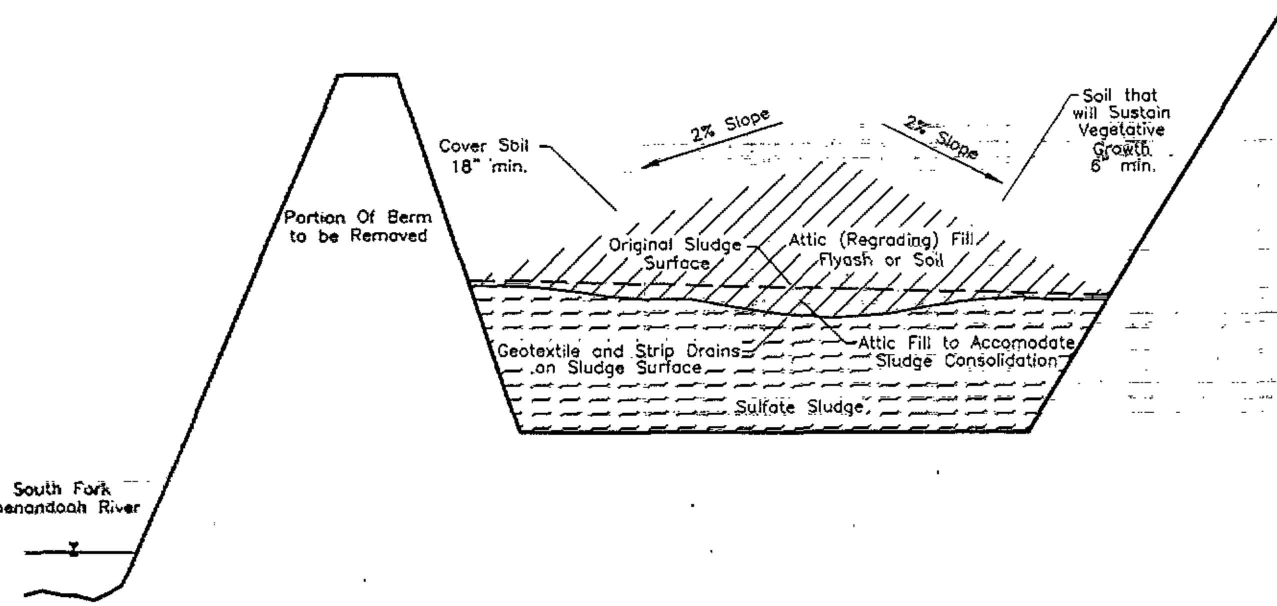


Figure 11
Sulfate Basin Closure with Enhanced Soil Cover
Avtex Fibers Superfund Site
Front Royal, Virginia



Plan View



Typical Section A-A'

Schematic: Not To Scale

Figure 12
Conceptual Closure Plan for Basins
Avtex Fibers Superfund Site
Front Royal, Virginia

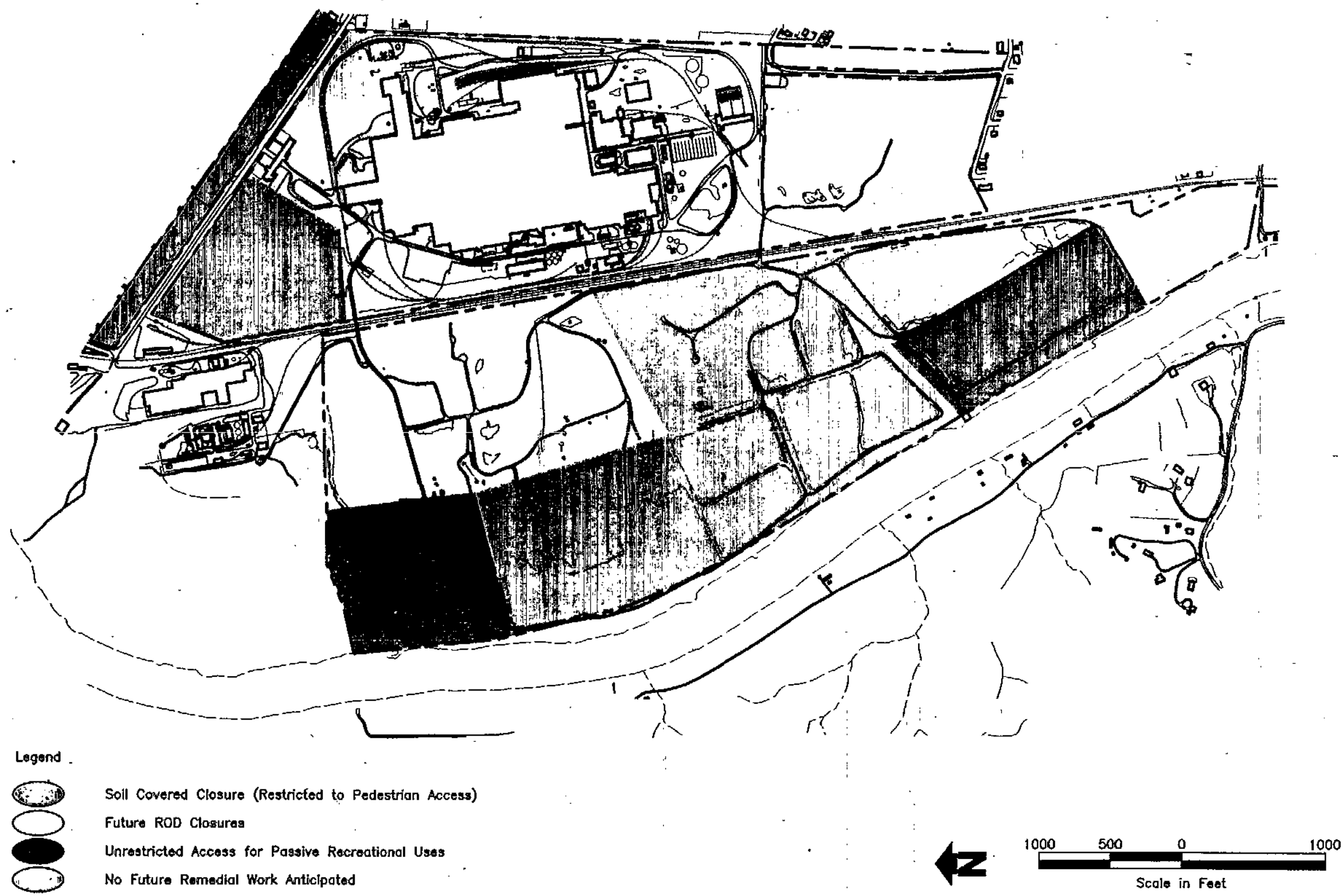
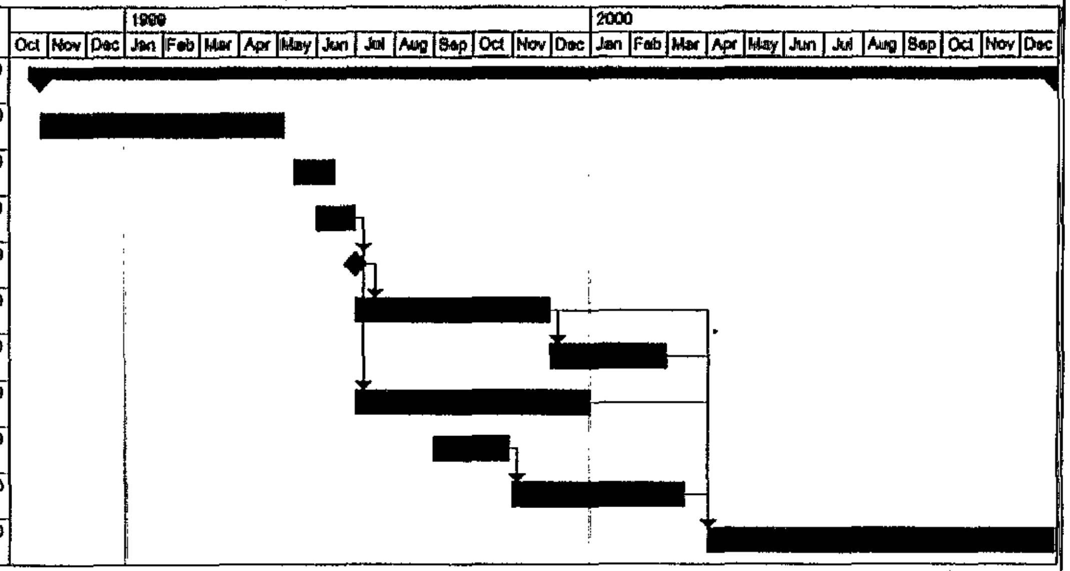


Figure 13
Non-Time-Critical Removal Schedule
Avtex Fibers Superfund Site, Front Royal, Virginia

Activity/Task	Duration	Start	Finish
Non-Time-Critical Removal Action for Basins	574 days	Mon 10/26/98	Fri 12/29/00
EE/CA Preparation	141 days	Mon 10/26/98	Wed 5/5/99
EE/CA Out for Public Comment	23 days	Fri 5/14/99	Mon 6/14/99
EPA Prepares Action Memorandum	22 days	Tue 6/1/99	Wed 6/30/99
EPA Issues Action Memorandum	0 days	Thu 7/1/99	Thu 7/1/99
Prepare Closure Design Documents	109 days	Thu 7/1/99	Tue 11/30/99
EPA/VA Review of Design Documents	65 days	Wed 12/1/99	Tue 2/29/00
Complete Permitting	132 days	Thu 7/1/99	Fri 12/31/99
Complete Contractor Procurement	43 days	Wed 9/1/99	Fri 10/29/99
Conduct Site Prep/Import Soil	97 days	Mon 11/1/99	Tue 3/14/00
Implement Basin Closures	195 days	Mon 4/3/00	Fri 12/29/00



Project: Avtex Project Schedule
Date: Wed 5/5/

Task | Milestone ◆ | Summary

AR106424

Table 1 Summary of Results for Geotechnical Analyses Obtained During the 1993 Phase 1 RI
Sulfate Basin Management Unit
Avtex Fibers Superfund Site, Front Royal, Virginia

Sulfate Basin No.	Sample*	Description	USCS Classification	Grain Size Distribution (Percent) Gravel	Sand	Silt	Clay	Moisture Content** (Percent)	Atterberg Limits LL	PL	PI	Specific Gravity	Permeability (cm/s)	Bulk Density (pcf) Wet	Dry	Cation Exchange Exchange Capacity (meq/100g)	Acidity/Alkalinity (mg/kg) To pH 4.5	To pH 8.3
1	AV-SB-BH-07-00	zinc sludge														66.5		
	AV-SB-BH-07-25	sandy clay/zinc sludge	CH[1]													31.1		
	AV-SB-BH-09-00	Shelby tube (zinc sludge)						433				2.81	2.7×10^{-6}					
	AV-SB-BH-09-02	zinc sludge	SM[2]	3.5	68.2	24	4.3	165	NP	NP	NP			84.4	15.8			
	AV-SB-BH-10-05	clay/zinc sludge	ML	0	13.7	77.7	7.5	87	NP	NP	NP	2.92						
	AV-SB-BH-12-00	zinc sludge	SM[2]	0	61.9	34	4.1	61	NP	NP	NP	2.78						
	AV-SB-BH-12-20	Shelby tube (soil)	CH[1]					25					1.1×10^{-6}	122	97.4			
	AV-SB-BH-13-00	zinc sludge															77,600	4,630
	AV-SB-BH-13-10	zinc sludge/soil															5,180	240
	AV-SB-BH-13-19	zinc sludge	ML*	21.9	23	40.3	14.8	19	44	38	6	2.86						
2	AV-SB-BH-17-05	zinc sludge	ML[2]	0	17.4	62.3	20.3	37	NP	NP	NP	2.9				41.9		
	AV-SB-BH-17-10	sandy clay	ML	0	28.7	57.8	13.5	27	37	32	5	2.86				41.1		
	AV-SB-BH-18-00	Shelby tube (zinc sludge)						252					3.5×10^{-6}	80.8	23			
	AV-SB-BH-18-02	zinc sludge	ML[2]	2.1	40.9	51	6	133	NP	NP	NP	2.92						
	AV-SB-BH-18-05	zinc sludge	SM[2]	0	52.3	37.7	10	304	NP	NP	NP	2.91						
	AV-SB-BH-18-10	zinc sludge/soil																
	AV-SB-BH-19-00	zinc sludge	SW to SM[2]	0	91.4	7.2	1.4	365	NP	NP	NP	2.76						
	AV-SB-BH-19-15	Shelby tube (soil)						31					8.64×10^{-5}		83.5		226,000	3,110
3	AV-SB-BH-14-00	zinc sludge						290					8.6×10^{-7}	68.1	17.5			
	AV-SB-BH-14-15	Shelby tube (soil)						24					3.2×10^{-7}	121.4	97.8			
	AV-SB-BH-15-05	zinc sludge														55.7		
	AV-SB-BH-15-10	zinc sludge	SP[2]	19.2	77.7	2.4	0.7	140	NP	NP	NP	2.84						
	AV-SB-BH-16-02	Shelby tube (zinc sludge)	SM[2]	0.3	85.6	11.9	2.2	362	39	28	11	2.9					365,000	3,160
	AV-SB-BH-16-12	zinc sludge	SM[2]	0	55.6	31.9	12.5	306	NP	NP	NP	2.94				31	368,000	400
	AV-SB-BH-16-20	silty clay	SW to SM	44	45.1	9	1.9	12	NP	NP	NP	2.78						
4	AV-SB-BH-20-00	zinc sludge	SM[2]	0	59.3	30.5	9.7	113	NP	NP	NP	2.92					136,000	867
	AV-SB-BH-21-00	Shelby tube (zinc sludge)																
	AV-SB-BH-21-02	zinc sludge	ML[2]	1	39.9	47.3	11.8	154	41	36	5	2.85				35.7		
	AV-SB-BH-21-06	zinc sludge	SM[2]	0	58.7	39.2	2.1	178	NP	NP	NP	2.98					317,000	10,400
	AV-SB-BH-22-12	zinc sludge														25.7		
	AV-SB-BH-22-14	Shelby tube (unknown)						187					9.9×10^{-6}	110.4	38.5			
4B	AV-SB-BH-23-00	zinc sludge	SM[2]	2.8	51.1	40.3	5.8	218	NP	NP	NP	2.92	2.4×10^{-6}	89.1	17.9	43.6		
	AV-SB-BH-23-09	zinc sludge	SP to SM[2]	0	89.7	9.4	0.9	191	NP	NP	NP	2.78						
	AV-SB-BH-24-05	zinc sludge	SM[2]	0	85	13.9	1.1	315	NP	NP	NP	2.78					201,000	Not detected
	AV-SB-BH-24-10	sandy clay/zinc sludge	CH[1]													40.2	68,200	Not detected
5	AV-SB-BH-25-05	sandy clay	SM	30	31.2	28.5	10.3	20	25	22	3	2.82					4,000	154
	AV-SB-BH-26-00	sludge	ML	0.7	41.3	44.3	13.7	34	NP	NP	NP	2.87			28.4			
	AV-SB-BH-27-00	zinc sludge															31,400	589
	AV-SB-BH-27-02	zinc sludge	SM[2]	1	78.1	17.5	3.4	251	NP	NP	NP	2.84						
	AV-SB-BH-27-06	zinc sludge	ML[2]	1.5	34.1	52.2	12.2	48	NP	NP	NP	2.91	1.5×10^{-6}	129.2	103	23.8		
	AV-SB-BH-27-09							15					1.3×10^{-6}	139.7	121.1			

[1] Field determination
[2] Laboratory determination based on grain size distribution
USCS - Unified Soil Classification System

LL - Liquid Limit
PL - Plastic Limit
PI - Plasticity Index
NP - Non plastic

meq/100g - milliequivilents per 100 grams
cm/s - centimeters per second
Blanks indicate no data obtained

* First pair of digits following letter designation identifies the boring location, second pair of digits indicates depth to top of sample interval.
** Moisture content - weight of water divided by weight of solids.

AR106425

Table 2 Summary of Constituents Detected in Sulfate Basin Sludge During the 1993 Phase 1 RI Avtex Fibers Superfund Site, Front Royal, Virginia

Analyte	Frequency of Detection	Range of Concentrations	Average Concentration*
Volatile Organics (µg/kg)			
2-butanone	9/20	2-74	28
2-hexanone	1/20	10	10
Acetone	20/20	4-260	88
Carbon disulfide	18/20	2-1,200	106
Chloroform	1/20	2	2
Ethylbenzene	3/20	4-7	5.5
Methylene chloride	9/20	1-16	6
Toluene	8/20	2-45	17
Xylenes (total)	3/20	3-25	12
Semi-volatile Organics (µg/kg)			
2-Methylnaphthalene	7/20	79-590	294
4-Methylphenol	1/20	210	210
Anthracene	2/20	130-160	145
Benzo(a)anthracene	7/20	69-860	347
Benzo(a)pyrene	1/20	640	640
Benzo(b)fluoranthene	5/20	54-1,300	413
Benzo(g,h,I)perylene	1/20	360	360
Bis(2-ethylhexyl)phthalate	18/20	54-3,700	1,276
Chrysene	12/20	130-1,800	643
Di-n-octylphthalate	5/20	42-880	279
Fluoranthene	3/20	92-1,000	441
Fluorene	5/20	120-220	174
N-nitrosodiphenylamine	2/20	750-1,100	925
Pentachlorophenol	2/20	200-1,300	750
Phenanthrene	15/20	54-1,900	1,090
Phenol	8/20	74-570	311
Pyrene	10/20	150-2,100	930
Pesticides/Polychlorinated Biphenyls (µg/kg)			
4,4'-DDE	6/20	0.52-7.6	3.5
4,4'-DDT	2/20	1.3-2.6	2.0
Aldrin	6/20	0.11-9.1	3.2
Alpha chlordane	6/20	0.81-2.8	1.6
Arochlor 1242	1/20	140	140
Arochlor 1254	1/20	200	200
Arochlor 1260	1/20	170	170
Beta-BHC	10/20	0.47-14	3.5
Delta-BHC	1/20	1.6	1.6
Dieldrin	3/20	0.97-24	9.2
Endosulfan I	10/20	0.16-20	4.7

Table 2 Summary of Constituents Detected in Sulfate Basin Sludge
During the 1993 Phase 1 RI
Avtex Fibers Superfund Site, Front Royal, Virginia

Analyte	Frequency of Detection	Range of Concentrations	Average Concentration*
Pesticides/Polychlorinated Biphenyls (µg/kg)			
Endosulfan II	1/20	2.2	2.2
Endosulfan Sulfate	1/20	10	10
Endrin	2/20	0.93-1.3	1.1
Endrin Aldehyde	1/20	0.75	0.75
Endrin ketone	5/20	2.6-5.9	3.8
Gamma Chlordane	2/20	0.32-0.47	0.40
Gamma-BHC (Lindane)	2/20	2.6-5.1	3.9
Heptachlor	1/20	0.19	0.19
Heptachlor expoxide	10/20	0.78-27	6.9
Methoxychlor	1/20	8.6	8.6
Metals (mg/kg)			
Aluminum	20/20	3,580-15,300	8,188
Antimony	3/20	2.7-20.9	11.1
Arsenic	20/20	0.61-11.8	5.1
Barium	20/20	34.4-280	103
Beryllium	12/20	0.33-1.1	0.81
Cadmium	17/20	0.86-87.8	21.3
Chromium	20/20	12-338	123
Cobalt	12/20	4.3-13	9
Copper	20/20	9.8-102	48
Iron	20/20	4,930-29,500	16,170
Lead	20/20	5.6-2,240	450
Manganese	20/20	24.3-744	317
Mercury	18/20	0.05-3	1
Nickel	20/20	6-129	46
Selenium	2/20	0.33-0.73	0.53
Silver	1/20	17	17
Vanadium	20/20	8.4-49.2	24.7
Zinc	20/20	86-278,000	103,333

- Table lists constituents detected in samples submitted for Level IV analysis.
- Analytical data presented in the Draft Analytical Quality Assurance Review Report for the Sulfate Basins Management Unit, 16 December 1993.
- Summary data obtained from Revised Appendix A (i.e., *Risk-Based Screening of the Phase I Data*, 3 July 1997) of *Phase 2 Remedial Investigation Work Plan*, May 1995.

µg/kg- micrograms per kilogram (reported on a dry weight basis)
mg/kg- milligrams per kilogram (reported on a dry weight basis)
* Arithmetic average, with a value of half the detection limit used for constituents that were not detected.

Table ɔ Ground Water Analytical Results for Selected Metals (Sulfate Basins)
Avtex Fibers Superfund Site, Front Royal, Virginia

WELL ID:	004				005				008				009			
LOCATION*:	Downgradient				Downgradient				Upgradient				Downgradient			
WELL TYPE:	Overburden				Overburden				Overburden				Overburden			
SAMPLING DATE:	2/7/90		4/3/90		2/7/90		4/3/90		2/8/90		4/6/90		2/6/90		4/4/90	
TAL Metals (µg/L)																
Arsenic (Dissolved)	1.5	UL	8.5	UL	4.2	K	1.7	L	1.5	U	1.7	U	3.6	L	8.5	UL
Arsenic (Total)	2.0	L	8.5	UL	12.4	L	33.5	L	6.2	L	1.7	U	14.9	L	9.0	L
Cadmium (Dissolved)	2.1	B	2.1	U	1.1	U	2.1	U	1.1	U	2.1	U	1.6	B	2.1	U
Cadmium (Total)	2.3	B	2.1	B	1.1	U	2.1	U	1.1	U	2.1	U	1.1	U	2.1	U
Chromium (Dissolved)	2.9	U	7.6		2.9	U	2.8	U	2.9	U	2.8	U	3.9	B	15.6	
Chromium (Total)	32.8		20.4		25.5		16.1		13.3		2.8	U	23.6		6.8	B
Lead (Dissolved)	1.7	UL	0.7	UL	2	B	0.7	U	4.7	B	0.70		4.9	B	0.7	UL
Lead (Total)	27.9		21.5	L	92.8		19.9	L	12.9		0.7	UL	22.5	J	5.7	L
Zinc (Dissolved)	289	B	130		117	B	164		246	B	60.1		239	B	111	
Zinc (Total)	503	J	861		158	B	83.3		211		39.5	B	66.3	B	16.4	B

WELL ID:	111				112				113				114			
LOCATION*:	Downgradient				Upgradient				Upgradient				Upgradient			
WELL TYPE	Shallow Bedrock				Shallow Bedrock				Shallow Bedrock				Shallow Bedrock			
SAMPLING DATE:	2/9/90		4/12/90		1/31/90		4/12/90		1/31/90		4/11/90		1/30/90		4/11/90	
TAL Metals (µg/L)																
Arsenic (Dissolved)	5.0	B	1.5	UL	1.1	U	1.5	U	1.1	U	2.5		1.4	B	1.5	UL
Arsenic (Total)	1.1	U	4.3	B	2.1	B	3.2		2.5	B	4.2	B	3.2	B	4.4	B
Cadmium (Dissolved)	1.2	U	1.7	U	1.8	U	1.7	U	1.8	U	3.0	U	1.8	U	1.7	U
Cadmium (Total)	1.2	U	3	U	1.2	UL	3	U	1.2	UL	3	U	4.9	L	3	U
Chromium (Dissolved)	2.8	U	5.1	U	2.8	U	5.1	U	5.7	B	8.3	B	2.8	U	5.1	U
Chromium (Total)	8.8		6.3		2.8	U	5.8	U	2.8	U	5.8	U	24.2		5.8	U
Lead (Dissolved)	0.37	L	0.29	UL	1.2	UL	0.29	UL	1.2	UL	0.29	UL	1.2	UL	0.3	UL
Lead (Total)	1.2	UL	0.29	UL	1.2	UL	0.29	UL	0.23	UL	0.29	UL	25	J	0.31	L
Zinc (Dissolved)	1.9	U	40.6	B	69.1	J	23.6	B	270	J	14.7	B	31.9	J	18.9	B
Zinc (Total)	1.9	U	7.3	B	22.4	B	14.2	B	6	B	10.1	B	1.9	U	65.8	B

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* - "Upgradient" or "Downgradient" refers [illegible]on of the well relative to the Sulfate Basins.

Table 3 Ground Water Analytical Results for Selected Metals (Sulfate Basins)
Avtex Fibers Superfund Site, Front Royal, Virginia

WELL ID:	010				011				012				013			
LOCATION*:	Downgradient				Downgradient				Upgradient				Upgradient			
WELL TYPE:	Overburden				Overburden				Overburden				Overburden			
SAMPLING DATE:	2/6/90		4/4/90		2/6/90		4/3/90		1/31/90		4/4/90		2/1/90		4/3/90	
TAL Metals (µg/L)																
Arsenic (Dissolved)	1.5	UL	1.7	U	6.9	K	8.5	UL	1.5	UL	3.4	L	1.5	U	1.7	U
Arsenic (Total)	7.1	L	3.1	L	55.8	L	8.5	UL	2.7	L	1.7	U	9.3	L	1.7	U
Cadmium (Dissolved)	1.1	U	2.1	U	2.9	B	2.1	U	1.1	U	2.1	U	1.1	U	2.1	U
Cadmium (Total)	1.1	U	2.1	U	1.1	U	2.1	U	1.1	U	2.1	U	1.8	B	2.1	U
Chromium (Dissolved)	2.9	U	2.8	U	4.3	B	2.8	U	2.9	U	5.1		5.4	B	2.8	U
Chromium (Total)	25.1		18.7		14.2		3.7		2.9	U	2.8	U	2.9	U	2.8	U
Lead (Dissolved)	1.7	UL	0.7	U	2.8	B	0.7	UL	1.7	U	0.7	U	2.1	B	0.70	
Lead (Total)	28.3		18.6	L	14.4	J	5.2	L	3.2		1.4	B	14.3		1.7	B
Zinc (Dissolved)	157	B	61.9		191	B	40.7		110	B	31.3		228	B	59.0	
Zinc (Total)	82.5	B	53.2	B	43.3	B	9.1	B	7	B	7.7	B	28	B	20.8	B

WELL ID:	116				116D		117				GM1A			
LOCATION*:	Upgradient						Downgradient				Downgradient			
WELL TYPE	Shallow Bedrock						Shallow Bedrock				Shallow Bedrock			
SAMPLING DATE:	2/9/90		4/12/90		4/12/90		2/1/90		4/10/90		2/2/90		4/13/90	
TAL Metals (µg/L)														
Arsenic (Dissolved)	1230		439	J	994	J	1.1	U	2.7		1.1	U	1.5	UL
Arsenic (Total)	1200		946		957		4.7	B	3.1	B	1.1	U	1.8	B
Cadmium (Dissolved)	1.2	U	1.7	U	1.7	U	9.2		3.0	U	1.8	U	1.7	UL
Cadmium (Total)	1.1	J	3	U	3	U	2.7	L	3	U	4.6	L	3	UL
Chromium (Dissolved)	340		337		323		2.8	U	6.7	B	2.8	U	5.1	UL
Chromium (Total)	333		318		318		2.8	U	10.0		2.8	U	5.8	UL
Lead (Dissolved)	1.4	L	2.9	UL	2.9	UL	1.2	UL	0.29	UL	0.93	B	1.3	B
Lead (Total)	2.3	UL	1.4	UL	1.4	UL	0.23	UL	0.78	B	2.3	UL	1.5	B
Zinc (Dissolved)	8880	J	9280	J	8870		11.9	J	26.8	B	113	B	16.7	B
Zinc (Total)	8890		9410		9360		1.9	U	7.7	B	70.5	J	31.3	B

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Table 3 Ground Water Analytical Results for Selected Metals (Sulfate Basins)
Avtex Fibers Superfund Site, Front Royal, Virginia

WELL ID:	014				017				017D				021			
LOCATION*:	Upgradient				Downgradient				Downgradient				Downgradient			
WELL TYPE:	Overburden				Overburden				Overburden				Overburden			
SAMPLING DATE:	2/1/90		4/3/90		2/2/90		4/3/90		2/2/90		4/3/90		2/3/90		4/5/90	
TAL Metals (µg/L)																
Arsenic (Dissolved)	948.0		932		1.5	U	1.7	UL	1.5	UL	1.7	UL	1.5	UL	1.7	UL
Arsenic (Total)	1900.0	L	7960	L	2.7	L	1.7	UL	1.5	UL	1.8	L	17.9	L	8.5	UL
Cadmium (Dissolved)	2.7	B	2.1	U	1.1	U	2.1	U	1.1	U	2.1	U	1.1	U	2.1	U
Cadmium (Total)	4	B	16.6		1.1	U	2.1	U	1.4	B	2.1	U	2.4	B	2.1	U
Chromium (Dissolved)	2.9	U	2.8	U	4.4	B	4.0		3.2	B	2.8	U	3.6	B	12.4	
Chromium (Total)	2.9	U	20.0		2.9	U	4		3.2		4.4		13.2		2.8	U
Lead (Dissolved)	11.3	B	0.7	U	29.5	B	0.7	UL	5.6	B	0.7	U	4.1	B	35.0	
Lead (Total)	3.3		21.7		4.4	L	3.9	B	2.6	L	3.1	B	70.7	J	0.80	B
Zinc (Dissolved)	504	B	33.1		216	B	49.1		140	B	70.4		145	B	336	
Zinc (Total)	5.4	U	143		47.3	B	42.3	B	36	B	37.9	B	951	J	57.4	

WELL ID:	MW3		MW3D				MW4				MW4D		MW6			
LOCATION*:	Upgradient						Downgradient						Downgradient			
WELL TYPE	Shallow Bedrock						Shallow Bedrock						Shallow Bedrock			
SAMPLING DATE:	2/6/90		4/13/90		4/13/90		2/3/90		4/12/90		2/3/90		2/8/90		4/12/90	
TAL Metals (µg/L)																
Arsenic (Dissolved)	358		485	L	477	L	1.7	B	1.5	U	1.6	B	6.4	B	7.4	B
Arsenic (Total)	340	L	423	J	658	J	1.1	U	1.5	U	1.1	U	4.2	B	7.2	B
Cadmium (Dissolved)	1.8	U	1.7	U	1.7	U	1.8	U	1.7	U	1.8	U	1.8	U	1.7	U
Cadmium (Total)	1.8		3	U	3	U	1.2	UL	3	U	6.5	L	1.2	U	3	U
Chromium (Dissolved)	88.5		129		122		9.5	B	5.1	U	5.7	B	6.1	U	5.1	U
Chromium (Total)	97.6		147		144		2.8	U	13.2		8.6		6.1	U	5.8	U
Lead (Dissolved)	2.8	UL	5.8	UL	5.8	UL	16.7	L	1.4	U	7.3	L	2.8	UL	1.4	UL
Lead (Total)	2.8	UL	2.9	UL	6.4	L	29	J	148	L	2.9	L	0.73	L	1.4	UL
Zinc (Dissolved)	54.2	B	7240		7170		87.6	J	32.4	B	197	J	2.4	U	36.7	B
Zinc (Total)	81	L	8040		7730		269		474		171	J	2.4	UL	17.6	B

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Table 3 Ground Water Analytical Results for Selected Metals (Sulfate Basins)
Avtex Fibers Superfund Site, Front Royal, Virginia

WELL ID:	022				023				024				025			
LOCATION*:	Downgradient				Downgradient				Downgradient				Downgradient			
WELL TYPE:	Overburden				Overburden				Overburden				Overburden			
SAMPLING DATE:	2/3/90		4/6/90		2/3/90		4/6/90		2/6/90		4/6/90		2/2/90		4/10/90	
TAL Metals (µg/L)																
Arsenic (Dissolved)	5.4	K	8.5	UL	4.9	K	2.6	L	6.3	K	2.6	L	1.5	UL	1.7	U
Arsenic (Total)	17.5	L	8.5	UL	11.3	L	2.9	L	9.6	L	2.9	L	2.6	L	1.8	L
Cadmium (Dissolved)	1.1	U	2.1	U	1.1	U	2.1	U	1.1	U	2.1	U	1.1	U	2.1	U
Cadmium (Total)	1.1	U	2.1	U	1.1	U	2.1	U	1.2	B	2.1	U	1.1	U	2.1	U
Chromium (Dissolved)	2.9	U	12.2		2.9	U	2.8	U	9.5	B	2.8	U	2.9	U	2.8	U
Chromium (Total)	8.1		4.8		6.4		9.9		6.7		12.6		7.8		11.7	
Lead (Dissolved)	5.9	B	0.7	UL	1.7	UL	0.7	U	26.1	B	0.7	U	1.7	U	0.7	U
Lead (Total)	27.9		18.7	L	29.6		25.0	L	30		10.6	L	6.4		5.9	L
Zinc (Dissolved)	128	B	22.9		62.2	B	24.3		941	L	17.2		70.8	B	21.2	
Zinc (Total)	36.2	B	27.0		413	J	229		44.2	B	55.0	B	27.2	B	53.5	B

WELL ID:	MW7				MW8				MW9				MW10			
LOCATION*:	Upgradient				Upgradient				Upgradient				Upgradient			
WELL TYPE	Overburden				Overburden				Overburden				Shallow Bedrock			
SAMPLING DATE:	2/3/90		4/10/90		2/3/90		4/7/90		2/8/90		4/13/90		2/7/90		4/11/90	
TAL Metals (µg/L)																
Arsenic (Dissolved),	1.1	UL	5.6	B	4.3	B	5.3	B	1480		1150	L	21.5		11.1	
Arsenic (Total)	3.9	L	3.3	B	1.1	B	1.9	B	1310		1420	J	22.5		9.8	J
Cadmium (Dissolved)	1.8	U	3.0	U	1.8	U	3.0	U	1.2	U	2.0	B	3.5	B	30.0	U
Cadmium (Total)	1.2	U	3	U	1.3		3	U	1.3	B	3.0	UL	21.7		3.8	
Chromium (Dissolved)	6.1	U	6.1	U	6.1	U	6		199		202		2.8	U	5.8	U
Chromium (Total)	6.1	U	5.8	U	6.1	U	6.1	U	233		245		70.9		59.6	
Lead (Dissolved)	0.57	U	0.29	UL	0.57	UL	0.29	UL	2.3	UL	2.9	UL	5.8		0.71	L
Lead (Total)	2.8	UL	0.72	L	6.8	L	0.29	UL	1.6	B	0.29	UL	194	L	109	
Zinc (Dissolved)	2.4	U	50.8	B	2.4	U	50.8	B	8430	J	9590		12.1	B	188	
Zinc (Total)	2.4	UL	4.1	U	2.4	UL	4.1	U	8590		11400		1.9	U	52.2	

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Table 3 Ground Water Analytical Results for Selected Metals (Sulfate Basins)
Avtex Fibers Superfund Site, Front Royal, Virginia

WELL ID:	026				103				104				105			
LOCATION*:	Downgradient				Upgradient				Downgradient				Downgradient			
WELL TYPE:	Overburden				Shallow Bedrock				Shallow Bedrock				Shallow Bedrock			
SAMPLING DATE:	2/2/90		4/10/90		1/30/90		4/7/90		2/1/90		4/12/90		2/8/90		4/5/90	
TAL Metals (µg/L)																
Arsenic (Dissolved)	2.7	K	3.1	B	1.5	B	10.9	B	1.1	U	1.5	U	1.6	B	10.9	B
Arsenic (Total)	1.5	UL	2.5	L	5.5	B	9.1	B	7.9	B	1.5	U	12.7	B	2.9	B
Cadmium (Dissolved)	1.1	UL	2.1	U	1.8	U	3.0	U	1.8	U	3.0	U	1.8	U	1.8	U
Cadmium (Total)	1.2	B	2.1	U	3.7	L	3	U	4.8	L	3	U	7.3		3	U
Chromium (Dissolved)	2.9	UL	2.8	U	2.8	U	6.1	U	2.8	U	5.8	U	6.1	U	22.5	B
Chromium (Total)	4		4.3		2.8	U	5.8	U	3.7		6.8		37.1		5.8	U
Lead (Dissolved)	1.7	U	0.7	U	1.2	UL	0.29	UL	4.9	L	0.29	UL	2.8	UL	4.3	L
Lead (Total)	21.5	J	5.5	L	1.2	UL	0.29	UL	2.9	L	1.3	B	8.8	L	2.9	UL
Zinc (Dissolved)	401	B	33.5		111	J	29.3	B	201	J	20.1	B	2.4	U	2.4	U
Zinc (Total)	2780	J	1890		52.5	J	4.1	U	430	J	155		2.4	UL	4	U

WELL ID:	MW11				MW12				MW12D		PZ1			
LOCATION*:	Upgradient				Upgradient						Downgradient			
WELL TYPE	Overburden				Overburden						Shallow Bedrock			
SAMPLING DATE:	2/2/90		4/10/90		2/3/90		4/11/90		4/11/90		1/16/90		4/7/90	
TAL Metals (µg/L)														
Arsenic (Dissolved)	1.3		4.0	L	104		111		95.8		1.9	B	2.4	L
Arsenic (Total)	3.3	L	1.5	U	86.3	L	161	J	117	J	5.5	U	7.5	UL
Cadmium (Dissolved)	1.8	U	3.0	U	1.8	U	3.0	U	3.0	U	1.8	U	3.0	UL
Cadmium (Total)	2		3	U	1.2	U	3	U	3	U	1.8	U	3	UL
Chromium (Dissolved)	6.1	U	5.8	U	6.1	U	5.8	U	5.8	U	6.1	U	5.8	UL
Chromium (Total)	59.5		47.6		6.6	B	9.0		8.2		6.1	U	9.4	
Lead (Dissolved)	10.6	B	0.29	UL	2.8	UL	0.29	UL	2.9	UL	0.84	L	0.3	UL
Lead (Total)	2.9	L	8.2		2.8	UL	1.4	UL	1.4	UL	0.83	L	0.91	B
Zinc (Dissolved)	93.1	B	99.9		19.1	B	16.2	B	19.2	B	88.8		36.4	B
Zinc (Total)	2.4	UL	74.1		2.4	UL	8.9	B	9.3	B	2.4	U	16.0	B

J - This result should be considered a quantitative estimate.
K - This result should be considered a biased high quantitative estimate.
L - This result Should be considered a biased low quantitative estimate.
B - This result is qualitatively invalid because the compound/analyte was also detected in a blank at a similar concentration.
U - This analyte was not detected. The numeric value represents the sample quantitation/detection limit for this analyte.
UL - This analyte was not detected. The numeric value that represents the actual sample quantitation/detection limit for this analyte is higher than presented.
* - "Upgradient" or "Downgradient" refers to locatio[illegible]e well relative to the Sulfate Basins.

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Table 3 Ground Water Analytical Results for Selected Metals (Sulfate Basins)
Avtex Fibers Superfund Site, Front Royal, Virginia

WELL ID:	108						109				110				110D	
LOCATION*:	Upgradient						Downgradient				Downgradient					
WELL TYPE:	Shallow Bedrock						Shallow Bedrock				Shallow Bedrock					
SAMPLING DATE:	1/27/90		4/10/90		1/27/90		2/9/90		4/11/90		2/8/90		4/10/90		4/10/90	
TAL Metals (µg/L)																
Arsenic (Dissolved)	1.6	B	1.5	U	1.1	U	4.8	B	1.5	UL	1.1	U	1.5	U	1.5	UL
Arsenic (Total)	7.8	B	2.2	B	6.6	B	9.8		5.4	B	1.6	B	3.2	L	3.0	L
Cadmium (Dissolved)	2.4	B	3.0	U	1.8	U	1.2	U	3.0	U	1.2	U	3.0	U	3.0	U
Cadmium (Total)	1.8	U	3	U	1.8	U	2.3		3	U	1.6	B	3	U	3	U
Chromium (Dissolved)	6.1	U	5.8	U	6.1	U	2.8	U	5.8	U	2.8	U	6.1	U	6.1	U
Chromium (Total)	8.2		5.8	U	7.7		7		6.7		3.3		5.8	U	5.8	U
Lead (Dissolved)	0.23	UL	0.29	UL	0.23	UL	0.23	L	0.29	UL	0.23	U	0.29	U	0.29	UL
Lead (Total)	1.9	L	0.29	U	1.3	L	1.2	UL	0.62	B	0.23	U	0.29	U	0.29	UL
Zinc (Dissolved)	2.4	U	19.4	B	2.4	U	37.3	B	8.7	B	1.9	U	22.6	B	60.4	B
Zinc (Total)	2.4	U	8.8	B	2.4	U	1.9	U	4.4	B	1.9	U	4.1	U	4.1	U

WELL ID:	PZ2				PZ3				PZ8				PZ9				PZ10			
LOCATION*:	Downgradient				Downgradient				Downgradient				Downgradient				Downgradient			
WELL TYPE	Shallow Bedrock				Shallow Bedrock				Shallow Bedrock				Shallow Bedrock				Shallow Bedrock			
SAMPLING DATE:	1/17/90		4/7/90		2/5/90		4/7/90		2/6/90		4/6/90		2/3/90		4/6/90		2/3/90		4/6/90	
TAL Metals (µg/L)																				
Arsenic (Dissolved)	7.3	B	6.8	L	1.5	B	1.5	UL	4.5	B	4.9	B	3.0	B	5.6	B	1.1	U	4.7	B
Arsenic (Total)	10.5	B	3.4	B	6.0	B	1.5	UL	3.7	L	6.9	B	3.8	L	3.9	B	7.1	L	1.6	B
Cadmium (Dissolved)	1.8	U	1.8	U	1.8	U	3.0	UL	1.8	U	3.0	U	1.8	U	3.0	U	1.8	U	3.0	U
Cadmium (Total)	1.8	U	3	U	8.6		3	UL	1.2	U	3	U	1.2	U	3	U	7.3		3	U
Chromium (Dissolved)	6.1	U	3	U	2.8	U	6.1	UL	6.1	U	6.1	U	6.1	U	6.1	U	6.1	U	9.9	B
Chromium (Total)	11.5		9.3		24.7		5.8	UL	6.1	U	5.8	U	7.9	B	7.2		8.9	B	5.8	U
Lead (Dissolved)	1.2	UL	0.29	UL	5.8	B	0.29	UL	2.8	UL	1.4	U	3	B	2.9	UL	0.57	U	0.29	UL
Lead (Total)	1.2	UL	1.6	B	9.5	J	0.29	UL	2.8	UL	0.82	B	2.8	U	6.6		2.8	U	3.9	B
Zinc (Dissolved)	19.6	B	16.7	B	162	B	46.1	B	14.2	B	38.3	B	24.6	B	29.4	B	37	B	33.6	B
Zinc (Total)	2.4	U	248		1.9	U	4.1	UL	2.4	UL	4.1	U	2.4	U	4.1	U	2.4	U	4.1	U

J - This result should be considered a quantitative estimate.
K - This result should be considered a biased high quantitative estimate.
L - This result Should be considered a biased low quantitative estimate.
B - This result is qualitatively invalid because the compound/analyte was also detected in a blank at a similar concentration.
U - This analyte was not detected. The numeric value represents the sample quantitation/detection limit for this analyte.
UL - This analyte was not detected. The numeric value that represents the actual sample quantitation/detection limit for this analyte is higher than presented.
* - "Upgradient" or "Downgradient" refers to location of the well relative to the Sulfate Basins.

Table 4 Human Health COPC Screening Results for Sulfate and WWTP Basins Sludge
Avtex Fibers Superfund Site, Front Royal, Virginia

Analytes	Frequency of Detection	No. of Samples	Maximum Concentration		Region III Industrial Soil RBC	Industrial Soil RBC Exceeded?
Volatiles						
1,2,4-Trichlorobenzene	1	20	2.5	J	2000	No
2-Butanone	6	20	1.1		120000	No
2-Hexanone (hexanone)	1	20	0.01	J	16000	No
4-Methyl-2-Pentanone	2	20	0.01	J	16000	No
Acetone	8	20	1.6		20000	No
Ethyl Benzene	6	20	0.009	J	20000	No
Methylene Chloride	1	20	0.005	J	760	No
Toluene	11	20	0.14	J	41000	No
Xylenes (Total)	8	20	0.04	J	410000	No
Semivolatiles						
2-Methylnaphthalene	11	20	3.1	J	4100	No
4-Methylphenol	1	20	0.21	J	1000	No
Acenaphthene	2	20	0.26	J	12000	No
Anthracene	1	20	0.16	J	61000	No
Benzo(a)anthracene	9	20	0.86	J	7.8	No
Benzo(a)pyrene	1	20	0.64	J	0.78	No
Benzo(b)fluoranthene	3	20	1.3	H	7.8	No
Benzo(g,h,i)perylene (pyrene)	1	20	0.36	J	6100	No
Bis(2-ethylhexyl)phthalate	19	20	4.6	J	410	No
Carbon disulfide	15	20	11		20000	No
Chrysene	15	20	6.7	J	780	No
Dibenzo(a,h)anthracene	1	20	0.16	J	0.78	No
Di-n-butylphthalate	2	20	1.2	J	20000	No
Di-n-octylphthalate	3	20	0.88	J	4100	No
Fluoranthene	4	20	1	J	8200	No
Fluorene	8	20	1.6	J	8200	No
Indeno(1,2,3-cd)pyrene	1	20	0.41	J	7.8	No
Naphthalene	2	20	9.8	J	4100	No
N-Nitrosodiphenylamine	1	20	0.75	J	1200	No
Pentachlorophenol	1	20	1.3	J	48	No
Phenanthrene (pyrene)	18	20	5.3	J	6100	No
Phenol	8	20	0.57	J	120000	No
Pyrene	14	20	4.1	J	6100	No
Pesticides/PCBs						
4,4'-DDD	2	22	0.0074	J	24	No
4,4'-DDE	4	22	0.0076	J	17	No
4,4'-DDT	1	22	0.0026	J	17	No
Aldrin	6	22	0.25	L	0.34	No
Alpha Chlordane (Chlordane)	6	22	0.0028	J	16	No
Aroclor 1242	3	24	0.65		2.9	No
Aroclor 1254	1	24	0.2	J	2.9	No
Aroclor 1260	3	24	0.89		2.9	No
Beta-BHC	4	22	0.014	J	3.2	No
Delta-BHC (beta)	2	22	0.0016	J	3.2	No
Dieldrin	4	22	0.024	J	0.36	No

Table 4 Human Health COPC Screening Results for Sulfate and WWTP Basins Sludge
Avtex Fibers Superfund Site, Front Royal, Virginia

Analytes	Frequency of Detection	No. of Samples	Maximum Concentration		Region III Industrial Soil RBC	Industrial Soil RBC Exceeded?
Endosulfan (I)	11	22	0.02	J	1200	No
Endosulfan (II)	1	22	0.0022	J	1200	No
Endosulfan Sulfate (Endosulfan)	1	22	0.01	J	1200	No
Endrin	2	22	0.0013	J	61	No
Endrin Aldehyde (endrin)	3	22	0.027	P	61	No
Endrin Ketone (endrin)	4	22	0.0059	J	61	No
Gamma Chlordane (chlordane)	6	22	0.074	L	16	No
Gamma-BHC (Lindane)	6	22	0.025	L	4.4	No
Heptachlor	3	22	0.28	L	1.3	No
Heptachlor Epoxide	8	22	0.027		0.63	No
Methoxychlor	1	22	0.0086	J	1000	No
Metals						
Aluminum	20	20	15300		200000	No
Antimony	2	20	20.9		82	No
Arsenic	19	20	11.8	L	3.8	Yes
Barium	20	20	280		14000	No
Beryllium	11	20	1.1		410	No
Cadmium	18	20	87.8		200	No
Calcium	20	20	177000		N/A *	No
Chromium (as Cr VI)	20	20	338	K	610	No
Cobalt	11	20	13		12000	No
Copper	20	20	179	J	8200	No
Cyanide, Total (as Free)	9	20	3.2		4100	No
Iron	20	20	29500	J	61000	No
Lead	20	20	2240		400^	Yes
Magnesium	20	20	30900		N/A *	No
Manganese	20	20	744		4100	No
Mercury (as Methyl)	18	20	9.8	L	20	No
Nickel	20	20	129		4100	No
Potassium	13	20	1340		N/A *	No
Selenium	3	20	2.3	L	1000	No
Silver	1	20	17		1000	No
Sodium	17	20	16600		N/A *	No
Vanadium	20	20	39.4		1400	No
Zinc	20	20	278000		61000	Yes

Notes:
All concentrations in mg/kg.
Only positively detected constituents listed above.
Data were screened according to USEPA Region III methodology (USEPA, 1993).
RBC - Risk-Based Concentration (USEPA Region III industrial soil; October, 1998). RBCs are based on a noncarcinogenic hazard index of 0.1 and a carcinogenic risk of 1×10^{-6}.
Where no RBC criteria are available, constituent shown in parenthases is used as a surrogate.
* - Essential nutrients (calcium, magnesium, potassium, and sodium) were not retained for further consideration in the risk assessment.
^ RBC for lead based on Revised Interim Soil Lead Guidance (USEPA, 1994).
14 out of 19 detections of arsenic exceed the Region III Industrial Soil RBC.
9 out of 20 detections of lead exceed the Region III Industrial Soil RBC.
14 out of 20 detections of zinc exceed the Region III Industrial Soil RBC.
N/A - Not applicable

Table 5 *Summary of Results for Geotechnical Analyses Obtained During the 1993 Phase 1 RI*
Wastewater Treatment Plant Management Unit
Avtex Fibers Superfund Site, Front Royal, Virginia

WWTP Basin No.	Sample*	Description	USCS Classification	% Passing No. 200 Sieve	Moisture Content** (Percent)	Atterberg Limits LL	PL	PI	Specific Gravity	Permeability (cm/s)	Cation Exchange Capacity (meq/100g)
Emergency	AV-WW-BH-04-00	Silty SAND (SM)	SM	41.9	68	45	34	11	2.73		
Lagoon	AV-WW-BH-04-15	Silty Clay								9.05×10^{-9}	
	AV-WW-BH-05-10	Poorly graded Sand with Gravel	SP	4.2	17	32	28	4	2.71		
	AV-WW-BH-06-00	Mixture of sludge and soil			87					1.5×10^{-7}	
	AV-WW-BH-06-05	SILT with Sand	ML	83	37	NP	NP	NP	2.68		
PB-1	AV-WW-BH-07-00	Silty SAND	SM	40.3	113	NP	NP	NP	2.75		37.5
	AV-WW-BH-08-03	Silty CLAY								8.29×10^{-8}	
PB-2	AV-WW-BH-11-00	Silty SAND	SM	46.6	60	NP	NP	NP	2.76		46.2
	AV-WW-BH-11-05	Silty CLAY								5.97×10^{-8}	
	AV-WW-BH-12-00	Silty SAND	SM	48.6	70	42	39	4	2.73	2.19×10^{-8}	39.8

USCS - Unified Soil Classification System
LL - Liquid Limit
PL - Plastic Limit
PI - Plasticity Index
NP - Non plastic
meq/100g - millequivalents per 100 grams
cm/s - centimeters per second
Blanks indicate no data obtained
* First pair of digits following letter designation identifies the boring location, second pair of digits indicates depth to top of sample interval.
** Moisture content - weight of water divided by weight of solids.

Table 6 Summary of Constituents Detected in Emergency Lagoon and Polishing Basins During the 1993 Phase 1 RI Avtex Fibers Superfund Site, Front Royal, Virginia

Analyte	Frequency of Detection	Range of Concentrations	Average Concentration*
Emergency Lagoon			
Volatile Organics (µg/kg)			
2-butanone	1/2	1,100	1,100
Acetone	2/2	23-1,600	812
Carbon disulfide	2/2	5-11,000	5,503
Ethylbenzene	1/2	7	7
Tolune	2/2	17-140	79
Xylenes (total)	2/2	6-40	23
Semi-volatile Organics (µg/kg)			
1,2,4-Trichlorobenzene	1/2	2,500	2,500
2-Methylnaphthalene	2/2	890-3,100	1,995
Benzo(a)anthracene	1/2	200	200
Bis(2-ethylhexyl)phthalate	2/2	2,300-4,600	3,450
Chrysene	2/2	500-6,700	3,600
Di-n-butylphthalate	1/2	1,200	1,200
Fluorene	2/2	260-1,600	930
Naphthalene	2/2	230-9,800	5,015
Phenanthrene	2/2	1,500-5,300	3,400
Pyrene	2/2	1,400-4,100	2,750
Pesticides/Polychlorinated Biphenyls (µg/kg)			
4,4'-DDE	2/4	3.4-7.4	5.4
Aldrin	2/4	1.6-250	126
Aroclor-1242	2/6	470-650	560
Aroclor-1260	2/6	830-890	860
Beta-BHC	1/4	7.3	7.3
Dieldrin	2/4	2.1-3	2.5
Endrin aldehyde	2/4	24-27	25.5
Gamma chlordane	4/4	8.7-74	27
Gamma-BHC (Lindane)	1/4	12	12
Heptachlor	1/4	280	280
Metals (mg/kg)			
Aluminum	2/2	3,380-3,550	3,465
Arsenic	2/2	2.7-4.8	3.8
Barium	2/2	61.8-73.6	67.7
Beryllium	1/2	0.23	0.23
Cadmium	2/2	5.8-49.1	27.5
Chromium	2/2	140-147	144
Cobalt	2/2	5.5-6.7	6.1
Copper	2/2	59.1-179	119
Iron	2/2	7,600-10,800	9,200
Lead	2/2	298-1,090	694
Manganese	2/2	236-321	279
Mercury	2/2	0.6-9.8	5.2
Nickel	2/2	47.3-58.3	52.8
Selenium	1/2	2.3	2.3
Vanadium	2/2	10.7-14.3	12.5
Zinc	2/2	107,000-190,000	148,500

Table 6 Summary of Constituents Detected in Emergency Lagoon and Polishing Basins During the 1993 Phase 1 RI Avtex Fibers Superfund Site, Front Royal, Virginia

Analyte	Frequency of Detection	Range of Concentrations	Average Concentration*
Polishing Basins			
Volatile Organics (µg/kg)			
Acetone	3/3	9-27	17
Carbon disulfide	2/3	3-5	4
Ethylbenzene	2/3	5-9	7
Tolune	2/3	14-21	18
Xylenes (total)	3/3	4-12	9
Semi-volatile Organics (µg/kg)			
2-Methylnaphthalene	3/3	78-930	383
Acenaphthene	2/3	69-260	165
Benzo(a)anthracene	3/3	140-500	287
Bis(2-ethylhexyl)phthalate	3/3	1,200-2,800	1,933
Chrysene	3/3	260-1,000	513
Di-n-butylphthalate	1/3	120	120
Fluoranthene	1/3	77	77
Fluorene	2/3	98-410	254
Phenanthrene	3/3	670-2,900	1,417
Pyrene	3/3	690-1,700	1,053
Pesticides/Polychlorinated Biphenyls (µg/kg)			
Delta-BHC	1/3	1.3	1.3
Endosulfan I	2/3	4-4.3	4
Gamma-BHC (Lindane)	3/3	2.6-25	10
Heptachlor	1/3	2.3	2.3
Metals (mg/kg)			
Aluminum	3/3	1,900-4,920	3,890
Arsenic	2/3	3.8-6.4	5.1
Barium	3/3	24.6-82.3	54.3
Beryllium	3/3	0.18-0.61	0.40
Cadmium	3/3	1.5-39.5	16.4
Chromium	3/3	83.1-188	138
Cobalt	3/3	1.8-5.4	4
Copper	3/3	30-77.7	59
Iron	3/3	4,740-12,500	9,480
Lead	3/3	151-408	275
Manganese	3/3	176-419	331
Mercury	3/3	0.6-2.3	1.2
Nickel	3/3	24.8-66.8	48.8
Selenium	1/3	1	1
Vanadium	3/3	7.3-18.3	13.1
Zinc	3/3	116,000-260,000	178,000

- Table lists constituents detected in samples submitted for Level IV analysis.
- Analytical data presented in the Draft Analytical Quality Assurance Review Report for the Wastewater Treatment Plant Management Unit, 17 January, 1994
- Summary data obtained from Revised Appendix A (i.e., *Risk-Based Screening of the Phase I Data*, 3 July 1997) of *Phase 2 Remedial Investigation Work Plan*, May 1995.

µg/kg- micrograms per kilogram (reported on a dry weight basis)
mg/kg- milligrams per kilogram (reported on a dry weight basis)
* Arithmetic average, with a value of half the detection limit used for constituents that were not detected.

Table 7 Summary of Results for Geotechnical Analyses Obtained During the 1993 Phase 1 RI
Fly Ash Basins/Stockpile Management Unit
Avtex Fibers Superfund Site, Front Royal, Virginia

Location	Sample*	USCS Classification	Grain Size Distribution (Percent) Gravel	Sand	Silt	Clay	Moisture Content** (Percent)	Atterberg Limits LL	PL	PI	Specific Gravity	Permeability (cm/s)	Unit Dry Weight (pcf)
Fly Ash Basin 2	AV-FA-BH-09-02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.25×10^{-5}	54.5
Fly Ash Basin 2	AV-FA-BH-09-20	ML	0.8	16.5	63.8	18.9	26	36	26	10	2.67	NA	NA
Stockpile	AV-FA-BH-20-12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.45×10^{-7}	101.6
Stockpile	AV-FA-BH-21-40	ML	2.3	28.9	60.8	8.0	32	NP	NP	NP	2.69	NA	NA
Stockpile	AV-FA-BH-21-40D	ML	4.5	28.2	64.0	3.3	33	NP	NP	NP	2.69	NA	NA

USCS - Unified Soil Classification System
LL - Liquid Limit
PL - Plastic Limit
PI - Plasticity Index
NP - Non plastic
NA - Not analyzed
pcf - pounds per cubic foot
cm/s - centimeters per second
* First pair of digits following letter designation identifies the boring location, second pair of digits indicates depth to top of sample interval.
** Moisture content - weight of water divided by weight of solids.

Table 8 Summary of Constituents Detected in Fly Ash Basins/Stockpile During the 1993 Phase 1 RI Avtex Fibers Superfund Site, Front Royal, Virginia

Analyte	Frequency of Detection	Range of Concentrations	Average Concentration*
Fly Ash Stockpile			
Volatile Organics (µg/kg)			
Acetone	1/10	59	59
Benzene	2/10	9-11	10
Bromodichloromethane	1/10	140	140
Carbon disulfide	1/10	34	34
Chloroform	5/10	11-110	63
Methylene Chloride	1/10	48	48
Toluene	2/10	11-17	14
Trichloroethene	2/10	13-14	13.5
Semi-volatile Organics (µg/kg)			
Bis(2-ethylhexyl)phthalate	1/5	46	46
Pesticides/Polychlorinated Biphenyls (µg/kg)			
None detected	—	—	—
Metals (mg/kg)			
Aluminum	7/7	7,290-16,900	12,791
Arsenic	7/7	85.7-193	116
Barium	7/7	215-759	611
Beryllium	7/7	2.6-5	4
Cadmium	4/7	0.86-1.5	1
Chromium	7/7	13.6-25.2	20
Cobalt	7/7	8.5-18.2	14.1
Copper	6/7	26.4-52.7	40.1
Iron	7/7	8,440-23,400	16,563
Lead	7/7	16.8-22.9	20
Manganese	7/7	31.7-79.7	64
Mercury	7/7	0.21-1	0.46
Nickel	7/7	14.6-28.8	22.1
Selenium	7/7	3.2-12.7	7.8
Thallium	7/7	1.9-2.8	2.4
Vanadium	7/7	54.2-81.7	66.6
Zinc	7/7	32.6-222	67
Fly Ash Basins			
Volatile Organics (µg/kg)			
Acetone	6/39	11-59	34
Benzene	2/39	9-11	10
Bromodichloromethane	1/39	140	140
Carbon disulfide	7/39	2-120	43
Chloroform	15/39	4-110	36
Methylene Chloride	4/39	3/48	30

Table 8 Summary of Constituents Detected in Fly Ash Basins/Stockpile During the 1993 Phase 1 RI Avtex Fibers Superfund Site, Front Royal, Virginia

Analyte	Frequency of Detection	Range of Concentrations	Average Concentration*
***Fly Ash Basins** (continued)*			
Volatile Organics (µg/kg) (continued)			
Toluene	3/39	2-17	10
Trichloroethene	3/39	4-14	10
Semi-volatile Organics (µg/kg)			
2-Methylnaphthalene	1/19	62	62
Bis(2-ethylhexyl)phthalate	5/19	45-210	85
Di-n-butylphthalate	1/19	80	80
Di-n-octylphthalate	2/19	65-130	98
Diethyelphthalate	1/19	110	110
Phenanthrene	1/19	53	53
Pesticides/Polychlorinated Biphenyls (µg/kg)			
4,4'-DDD	1/7	1.2	1.2
Methoxychlor	1/7	17	17
Metals (mg/kg)			
Aluminum	23/23	5,790-16,900	9,980
Arsenic	23/23	2.1-193	54
Barium	23/23	54.1-759	400
Beryllium	23/23	0.52-5	3
Cadmium	16/23	0.49-9	2
Chromium	23/23	9.1-56	19
Cobalt	23/23	3.6-18.2	10.5
Copper	23/23	4.5-54.4	31.2
Iron	23/23	5,700-33,600	16,207
Lead	23/23	8.7-166	26
Manganese	23/23	14.6-306	100
Mercury	23/23	0.035-1.1	0.44
Nickel	23/23	2.8-29.8	16.4
Selenium	16/23	1.3-12.7	5.8
Silver	3/23	1.1-1.2	1.1
Thallium	16/23	0.43-2.8	1.6
Vanadium	23/23	24.5-81.7	49.7
Zinc	23/23	12.1-132,000	7,201

- Table lists constituents detected in samples submitted for Level IV analysis.
- Analytical data presented in the Draft Analytical Quality Assurance Review Report for the Fly Ash Basin/Landfill Area Management Unit, 21 February 1994.
- Summary data obtained from Revised Appendix A (i.e., *Risk-Based Screening of the Phase I Data*, 3 July 1997) of *Phase 2 Remedial Investigation Work Plan* May 1995.

µg/kg- micrograms per kilogram (reported on a dry weight basis)
mg/kg- milligrams per kilogram (reported on a dry weight basis)
* Arithmetic average, with a value of half the detection limit used for constituents that were not detected.

Table 9 Human Health COPC Screening Results for Fly Ash Basins and Stockpile Avtex Fibers Superfund Site, Front Royal, Virginia

	Frequency of Detection	No. of Samples	Maximum Concentration		Region III Industrial Soil RBC	Industrial Soil Exceeded?
Volatiles						
Acetone	1	14	0.011	J	20000	No
Bromodichloromethane	1	14	0.14	J	92	No
Chloroform	10	14	0.11	J	940	No
Methylene Chloride	2	14	0.048	J	760	No
Toluene	1	14	0.002	J	41000	No
Trichloroethene	1	14	0.004	J	520	No
Semivolatiles						
Carbon Disulfide	2	14	0.055	J	20000	No
Di-n-butylphthalate	1	12	0.08	J	20000	No
Di-n-octylphthalate	1	12	0.13	J	4100	No
Pesticides						
Methoxychlor	1	6	0.017	J	1000	No
Metals						
Aluminum	14	14	16900		200000	No
Arsenic	14	14	193	J	3.8	Yes
Barium	14	14	759	J	14000	No
Beryllium	14	14	5		410	No
Cadmium	9	14	1.5		200	No
Calcium	14	14	21200	J	N/A *	N/A
Chromium (as Cr VI)	14	14	25.2		610	No
Cobalt	14	14	18.2		12000	No
Copper	14	14	54.4		8200	No
Cyanide, Total (as Free)	13	13	3.3		4100	No
Iron	14	14	23400		61000	No
Lead	14	14	22.9	J	400^	No
Magnesium	14	14	2660		N/A *	N/A
Manganese	14	14	152	K	4100	No
Mercury (as Methyl)	14	14	1		20	No
Nickel	14	14	28.8	L	4100	No
Potassium	12	14	3590		N/A *	N/A
Selenium	14	14	12.7		1000	No
Sodium	14	14	777		N/A *	N/A
Thallium	13	14	2.8		14	No
Vanadium	14	14	81.7		1400	No
Zinc	14	14	2870	L	61000	No

Notes:

All concentrations in mg/kg.

Only positively detected constituents listed above.

Data were screened according to USEPA Region III methodology (USEPA, 1993).

RBC - Risk-Based Concentration (USEPA Region III industrial soil; October, 1998). RBCs are based on a noncarcinogenic hazard index of 0.1 and a carcinogenic risk of 1×10^{-6}.

Where no RBC criteria are available, constituent shown in parenthases is used as a surrogate.

* - Essential nutrients (calcium, magnesium, potassium, and sodium) were not retained for further consideration in the risk assessment.

^ RBC for lead based on Revised Interim Soil Lead Guidance (USEPA, 1994).

All 14 detections of arsenic exceed the Region III Industrial Soil RBC.

N/A - Not applicable

Table 10

Sulfate Basins Response Action Alternative No. 1

Cost Estimate for Sulfate Basins Alternative SB 1 - Simple Soil Cover on SB 1-4E/Eliminate SB-5

Avtex Fibers Superfund Site, Front Royal, Virginia

Item Description	Quantity	Unit	Unit Cost	Item Cost
I. *Site Preparation*				
Mobilization/Set-Up	1	Lot	$55,000	$55,000
Dust Controls	1	Lot	$25,000	$25,000
Erosion and Sedimentation Controls	1	Lot	$40,000	$40,000
Surface Water Controls	1	Lot	$60,000	$60,000
Access Roads	1	Lot	$35,000	$35,000
II. *Install Soil Cover on SB 1-4E*				
Lower Berms Along West Side of SB 1 to Design Elevation	60,000	CY	$3	$180,000
Water Removal/Draining	1	Lot	$50,000	$50,000
Reuse Berm Material for General Fill	60,000	CY	$4	$240,000
Imported general Fill/Grading	85,000	CY	$8	$680,000
Additional Soil for Soft Areas/Settlement (1)	80,900	CY	$8	$647,200
Place Geotextile Reinforcing (2)	430,000	SF	$0.50	$215,000
18-inch Cover Soil, imported (SB-1-4E)	145,000	CY	$12	$1,740,000
6-inch Top Soil (SB-1-4E)	50,000	CY	$18	$900,000
Seeding/Mulching (SB-1-4E)	290,000	SY	$0.40	$116,000
II. *Eliminate SB 5*				
Dewatering of SB-5 (to WWTP)	1	Lot	$150,000	$150,000
Aggregate Filter Bedding Placement (30' upslopex1,900 lf.x1' d)	2,100	CY	$12	$25,200
Rip-Rap Placement (30' upslope x 1,900 lf. x 3' depth)	6,300	CY	$15	$94,500
Remove Outer Berms (stockpile for cover soil)	54,000	CY	$3	$162,000
Sludge Movement to SB2-4E	77,000	CY	$4	$308,000
Excavate and Move 1 foot of Soil at Base of SB 5 to SB 1- 4E (3)	33,000	CY	$5	$165,000
General Fill/Grading (berm soil provides 20 inches of cover)	54,000	CY	$4	$216,000
6-inch Top Soil	16,000	CY	$18	$288,000
Seeding/Mulching	95,000	SY	$0.40	$38,000
Direct Construction Total (DCT)				$6,429,900
Indirect Construction (15% of DCT)				$964,500
Construction Total				$7,394,400
Permitting/Legal ($40,000 + 5 x ($CT^{0.6}$))				$106,000
Design and Resident Engineering ($30,000 + ($CT^{0.85}$))				$720,000
Sub-Total Capital Closure Costs				$8,220,400
Total Capital Closure Costs with 20% Contingency				$9,864,500
Sub-Total Projected O&M and Ground Water Monitoring Costs (from below)				$787,800
Projected O&M and Ground Water Monitoring Costs with Contingency (20%)				$945,400
Estimated Cost (NPV)				$10,810,000

(1) Additional 1 foot of Soil over entire surface area of SB1-4E, except along rive where geotextile is added)

(2) Place geotextile along river side of SB 1-4E and along north perimeter of SB-1 back 100 feet

(3) Assumes excavation of 1 ft. of soil at base of SB 5 to remove impacted soils.

Annual O&M Costs

Operation and Maintenance Costs	Quantity	Unit	Unit Cost	Item Cost
Site Inspections	40	Hour	$70	$2,800
Cover, Road, Berm Repair/Maintenance	1	Lot	$40,000	$40,000
Total Annual O&M Cost				$42,800
30 Year Present Worth O&M Cost (interest rate = 5%)				$657,900
Ground Water Monitoring Cost				
Ground Water Monitoring	1	Lot	$ 30,000	$ 30,000
Total Annual Ground Water Monitoring Cost				$ 30,000
5 Year Present Worth Ground Water Monitoring Cost (interest rate = 5%)				$129,900
Estimated Cost (NPV) for O&M and Ground Water Monitoring				$787,800

Table 11
Cost Estimate for Sulfate Basins Alternative SB 2 -
Enhanced Soil Cover on SB 1-4E/Eliminate SB-5
Avtex Fibers Superfund Site, Front Royal, Virginia

Item Description	Quantity	Unit	Unit Cost	Item Cost
I. *Site Preparation*				
Mobilization/Set-Up	1	Lot	$50,000	$50,000
Dust Controls	1	Lot	$25,000	$25,000
Erosion and Sedimentation Controls	1	Lot	$40,000	$40,000
Surface Water Controls	1	Lot	$60,000	$60,000
Access Roads	1	Lot	$40,000	$40,000
II. *Sulfate Basins 1-4E*				
Water Removal to WWTP	1	Lot	$100,000	$100,000
Remove Berms to Final Design Elevation (1)	47,300	CY	$3	$141,900
Special Handling of Northern SB 1 Sludge (2)	50,750	CY	$6	$304,500
Regrading of SB 1 Sludge (2 feet on average)	76,200	CY	$3	$228,600
Additional Fly Ash for Soft Areas/Settlement (3)	78,000	CY	$5	$390,000
Place Geotextile Reinforcing (4)	2,615,000	SF	$0.40	$1,046,000
Install Strip Drains and Sumps to Collect Additional Water	1	Lot	$150,000	$150,000
Soil Cover				
Place Fly Ash as "Attic" Fill on each basin to establish 2% slopes (5)	260,000	CY	$5	$1,300,000
Portion of 1-foot Soil Cover from SB 1-4E Berms	47,300	CY	$5	$236,500
Portion of 1-foot Soil Cover from SB 5 Berms	36,450	CY	$5	$182,300
Portion of 1-foot Soil Cover, imported (SB-1-4E)	13,250	CY	$12	$159,000
6-inch Top Soil (SB-1-4E)	50,000	CY	$18	$900,000
Seeding/Mulching (SB-1-4E)	290,000	SY	$0.40	$116,000
III *Sulfate Basin No. 5*				
Dewatering of SB-5 (to WWTP)	1	Lot	$150,000	$150,000
Reuse Berm Soil To Install Toe Berm Along Outer side of FAB 6/SB 5 Berm (6)	13,300	CY	$5	$66,500
Remove Outer (No., West & So.) Berms (Use for toe berm, attic fill & SB 1-4E cover)	83,250	CY	$3	$249,750
Regrading and Sludge Movement				
Sludge Movement to SB2-4E	77,000	CY	$4	$308,000
Excavate and Move 1 foot of Soil at Base of SB 5 to SB 1- 4E	33,000	CY	$5	$165,000
Reuse Portion of Berm Soil for "Attic Fill"	33,500	CY	$4	$134,000
6-inch Top Soil	16,000	CY	$18	$288,000
Seeding/Mulching	95,000	SY	$0.40	$38,000
Direct Construction Total (DCT)				$6,869,050
Indirect Construction (15% of DCT)				$1,030,400
Construction Total				$7,899,450
Permitting/Legal ($40,000 + 5 x ($CT^{0.6}$))				$109,000
Design and Resident Engineering ($30,000 + ($CT^{0.85}$))				$759,000
Sub-Total Capital Closure Costs				$8,767,450
Total Capital Closure Costs with 20% Contingency				$10,520,900
Sub-Total Projected O&M and Ground Water Monitoring Costs (from below)				$1,084,500
Projected O&M and Ground Water Monitoring Costs with Contingency (20%)				$1,301,400
Estimated Cost (NPV)				$11,822,000

NOTES:

(1) SB 1-4E berms lowered to elevation of the top of soil cover; Volumes (cy) removed: SB 1: 13,000 SB 2: 9,300 SB 3: 7,000 SB 4/4E: 18,000

(2) Assumes gravel or Portland cement will be added to the upper 5 feet of sludge in the north end of SB 1 to provide support for soil cover.

(3) Assumes 30% of the Attic fill volume will be required to account for settlement of SB1-4E.

(4) Geotextile to be placed over entire area of SB 1-4E.

(5) Fill required to achieve 2% slopes prior to installing soil cover. Fly ash will be utilized for this purpose.

(6) The toe berm along FAB 6 would be 1,500 lf (length) x 30 ft (height) x 8 ft (thickness).

Annual O&M Costs

Operation and Maintenance Costs	Quantity	Unit	Unit Cost	Item Cost
Site Inspections	30	Hour	$70	$2,100
Cover, Road, Berm Repair/Maintenance	2	Lot	$30,000	$60,000
Total Annual O&M Cost				$62,100
30 Year Present Worth O&M Cost (interest rate = 5%)				$954,600
Ground Water Monitoring Cost				
Ground Water Monitoring	1	Lot	$ 30,000	$ 30,000
Total Annual Ground Water Monitoring Cost				$ 30,000
5 Year Present Worth Ground Water Monitoring Cost (interest rate = 5%)				$129,900
Estimated Cost (NPV) for O&M and Ground Water Monitoring				$1,084,500

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Table 12
Cost Estimate for WWTP Basins Alternative WWB1 - Cover with Soil In-Place
Avtex Fibers Superfund Site, Front Royal, Virginia

Item Description	Quantity	Unit	Unit Cost	Item Cost
I. *Site Preparation*				
Mobilization/Set-Up	1	Lot	$10,000	$10,000
Erosion and Sedimentation Controls	1	Lot	$10,000	$10,000
Dust Controls	1	Lot	$10,000	$10,000
Surface Water Controls	1	Lot	$15,000	$15,000
Access Roads	1	Lot	$10,000	$10,000
II. *Soil Cover*				
Site Preparation, Clearing	4.00	Acre	$2,000	$8,000
Transfer Supernatant from Basins to WWTP	1.00	Lot	$50,000	$50,000
Surface Grading/Fill	10,000	CY	$8	$80,000
18-inch Cover Soil, imported	10,000	CY	$12	$120,000
6-inch Top Soil	3,300	CY	$18	$59,400
Seeding/Mulching	19,400	SY	$0.40	$7,800
Direct Construction Total (DCT)				$380,200
Indirect Construction (15% of DCT)				$57,000
Construction Total				$437,200
Permitting/Legal ($40,000 + 5 x ($CT^{0.6}$))				$52,000
Design and Resident Engineering ($30,000 + ($CT^{0.85}$))				$92,000
Sub-Total Capital Closure Costs				$581,200
Total Capital Closure Costs with 20% Contingency				**$697,400**
Sub-Total Projected O&M Cost (from below)				$83,000
Projected O&M Cost with Contingency (20%)				**$99,600**
Estimated Cost (NPV)				**$797,000**

Annual O&M Costs

Operation and Maintenance Costs	Quantity	Unit	Unit Cost	Item Cost
Site Inspections	20	Hour	$70	$1,400
Cover, Road Repair/Maintenance	1	Lot	$4,000	$4,000
Total Annual O&M Cost				**$5,400**
30 Year Present Worth Cost				$83,000
Estimated Cost (NPV)				**$83,000**

Table 13
Cost Estimate for WWTP Basins Alternative WWB 2 - Consolidate Sludge into PB 1 and Cover with Soil
Avtex Fibers Superfund Site, Front Royal, Virginia

Item Description	Quantity	Unit	Unit Cost	Item Cost
Site Preparation				
Mobilization/Set-Up	1	Lot	$10,000	$10,000
Erosion and Sedimentation Controls	1	Lot	$10,000	$10,000
Dust Controls	1	Lot	$10,000	$10,000
Surface Water Controls	1	Lot	$15,000	$15,000
Access Roads	1	Lot	$10,000	$10,000
Consolidation & Engineered Cap (PB 1)				
Site Preparation, Clearing	4.00	Acre	$2,000	$8,000
Remove supernatant & treat in on-site treatment plant	1	Lot	$50,000	$50,000
Consolidate sludge to PB 1 (1)	20,000	CY	$5	$100,000
Remove Berms/Grade out PB2 & EL (2)	10,700	CY	$5	$53,500
Utilize Soil From Grading PB 2 & EL to Grade/Fill PB 1 Prior to Cover	3,000	CY	$5	$15,000
18-inch Cover Soil, imported	3,000	CY	$12	$36,000
6-inch Top Soil	1,000	CY	$18	$18,000
Seeding/Mulching	6,000	SY	$0.40	$2,400
Soil Cap over PB 2 & Emerg. Basin				
6-inch Top Soil	2,300	CY	$18	$41,400
Seeding/Mulching	13,700	SY	$0.40	$5,500
Direct Construction Total (DCT)				$384,800
Indirect Construction (15% of DCT)				$57,700
Construction Total				$442,500
Permitting/Legal ($40,000 + 5 x ($CT^{0.6}$))				$52,000
Design and Resident Engineering ($30,000 + ($CT^{0.85}$))				$93,000
Sub-Total Capital Closure Costs				$587,500
Total Capital Closure Costs with 20% Contingency				$705,000
Sub-Total Projected O&M Cost (from below)				$83,000
Projected O&M Cost with Contingency (20%)				$99,600
Estimated Cost (NPV)				$805,000

Notes:
(1) Estimated sludge volume in PB 2 is 8,000 cy and in Emergency Lagoon is 12,000 cy.
(2) An average of 3 ft. is assumed for grading out PB 2/EL area; 3,000 of 13,700 cy utilized for attic fill in PB 1.

Annual O&M Costs

Operation and Maintenance Costs	Quantity	Unit	Unit Cost	Item Cost
Site Inspections	20	Hour	$70	$1,400
Cover, Road Repair/Maintenance	1	Lot	$4,000	$4,000
Total Annual O&M Cost				$5,400
30 Year Present Worth Cost				$83,000
Estimated Cost (NPV)				$83,000

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Table 14
Cost Estimate for WWTP Basins Alternative WWB 3 - Eliminate WWTP Basins
Avtex Fibers Superfund Site, Front Royal, Virginia

Item Description	Quantity	Unit	Unit Cost	Item Cost
I. *Site Preparation*				
Mobilization/Set-Up	1	Lot	$10,000	$10,000
Erosion and Sedimentation Controls	1	Lot	$10,000	$10,000
Dust Controls	1	Lot	$10,000	$10,000
Surface Water Controls	1	Lot	$15,000	$15,000
Access Roads	1	Lot	$10,000	$10,000
II. *Soil Cover*				
Site Preparation, Clearing	4.0	Acre	$2,000	$8,000
Remove Supernatant to WWTP	1.0	Lot	$50,000	$50,000
Consolidate sludge to SB 1-4E	29,000	CY	$5	$145,000
Surface Grading with existing basin soils (1)	19,360	CY	$5	$96,800
6-inch Top Soil	3,300	CY	$18	$59,400
Seeding/Mulching	19,400	SY	$0.40	$7,800
Direct Construction Total (DCT)				$422,000
Indirect Construction (15% of DCT)				$63,300
Construction Total				$485,300
Permitting/Legal ($40,000 + 5 x ($CT^{0.6}$))				$53,000
Design and Resident Engineering ($30,000 + ($CT^{0.85}$))				$98,000
Sub-Total Capital Closure Costs				$636,300
Total Capital Closure Costs with 20% Contingency				$764,000
Sub-Total Projected O&M Cost (from next page)				$0
Projected O&M Cost with Contingency (20%)				$0
Estimated Cost (NPV)				**$764,000**

Notes:
(1) An average of 3 ft. is assumed for grading out entire WWTP basins area.

Annual O&M Costs

Operation and Maintenance Costs	Quantity	Unit	Unit Cost	Item Cost
Site Inspections		Hour	$70	$0
Cover, Road Repair/Maintenance		Lot	$4,000	$0
Total Annual O&M Cost				$0
30 Year Present Worth Cost				$0
Estimated Cost (NPV)				**$0**

Table 15
Cost Estimate for Fly Ash Basins and Stockpile Alternative FA 1 - No Action on FA Basins/Cover Stockpile with Soil
Avtex Fibers Superfund Site
Front Royal, Virginia

Item Description	Quantity	Unit	Unit Cost	Item Cost
I. *Site Preparation*				
Mobilization/Set-Up	1	Lot	$15,000	$15,000
Dust Controls	1	Lot	$100,000	$100,000
Erosion and Sedimentation Controls	1	Lot	$15,000	$15,000
Surface Water Controls	1	Lot	$50,000	$50,000
Access Roads	1	Lot	$10,000	$10,000
I. *Fly Ash Mountain*				
Soil Cover				
Site Preparation, Clearing (1)	15.0	Acre	$2,000	$30,000
Ash Movement/Grading (2)	121,000	CY	$5	$605,000
18-inch Cover Soil, imported	36,300	CY	$12	$435,600
6-inch Soil to Support Vegetation	12,100	CY	$18	$217,800
Seeding/Mulching	72,600	SY	$0.40	$29,000
II. *Fly Ash Basins*				
Site Improvements, Rehabilitation	22	Acre	$2,000.00	$28,000
Direct Construction Total (DCT)				$1,535,400
Indirect Construction (15% of DCT)				$230,300
Construction Total				$1,765,700
Permitting/Legal ($40,000 + 5 x ($CT^{0.6}$))				$68,000
Design and Resident Engineering ($30,000 + ($CT^{0.85}$))				$234,000
Sub-Total Capital Closure Costs				$2,067,700
Total Capital Closure Costs with 20% Contingency				$2,481,200
Sub-Total Projected O&M and Monitoring Costs (from below)				$314,100
Projected O&M and Monitoring Costs with Contingency (20%)				$376,900
Estimated Cost (NPV)				$2,858,000

Notes:

(1) **Assumes that minimal amount of fly ash used in other basins, so closure area is larger than current stockpile footprint so that maximum side slope limits (33%) is not exceeded.**

(2) **Assumes that the upper 5 ft. of fly ash will need to be disturbed to regrade the stockpile.**

Annual Costs

Operation and Maintenance Costs	Quantity	Unit	Unit Cost	Item Cost
Site Inspections	40	Hour	$70	$2,800
Cover, Road Repair/Maintenance	1	Lot	$12,000	$12,000
Total Annual O&M Cost				$14,800
30 Year Present Worth O&M Cost (interest rate = 5%)				$227,500
Ground Water Monitoring Costs				
Ground Water Monitoring	1	Lot	$20,000	$20,000
Total Annual Ground Water Monitoring Cost				$20,000
5 Year Present Worth Ground Water Monitoring Cost (interest rate = 5%)				$86,600
Estimated Cost (NPV) for O&M and Ground Water Monitoring				$314,100

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Table 16

Cost Estimate for Fly Ash Basins and Stockpile Alternative FA 2 - Cover FA Basins and Stockpile with Soil

Avtex Fibers Superfund Site

Front Royal, Virginia

Item Description	Quantity	Unit	Unit Cost	Item Cost
I. *Site Preparation*				
Mobilization/Set-Up	1	Lot	$30,000	$30,000
Dust Controls	1	Lot	$125,000	$125,000
Erosion and Sedimentation Controls	1	Lot	$30,000	$30,000
Surface Water Controls	1	Lot	$100,000	$100,000
Access Roads	1	Lot	$20,000	$20,000
II. *Fly Ash Mountain*				
Soil Cover				
Site Preparation, Clearing	13.3	Acre	$2,000	$26,600
Ash Movement/Grading (1)	107,000	CY	$5	$535,000
18-inch Cover Soil, imported	33,000	CY	$12	$396,000
6-inch Soil to Support Vegetation	11,000	CY	$18	$198,000
Seeding/Mulching	65,000	SY	$0.40	$26,000
II. *Fly Ash Basins*				
Dewater via pits (sumps) to WWTP	1	Lot	$50,000	$50,000
Soil Cover				
Site Preparation, Clearing	22.3	Acre	$2,000	$44,600
Ash Movement & Grading from FA Mtn (2)	72,000	CY	$4	$288,000
18-inch Cover Soil, imported	54,000	CY	$12	$648,000
6-inch Soil to Support Vegetation	18,000	CY	$18	$324,000
Seeding/Mulching	108,000	SY	$0.40	$43,200
Direct Construction Total (DCT)				$2,884,400
Indirect Construction (15% of DCT)				$432,700
Construction Total				$3,317,100
Permitting/Legal ($40,000 + 5 x ($CT^{0.6}$))				$81,000
Design and Resident Engineering ($30,000 + ($CT^{0.85}$))				$379,000
Sub-Total Capital Closure Costs				$3,777,100
Total Capital Closure Costs with 20% Contingency				$4,532,500
Sub-Total Projected O&M and Monitoring Costs (from below)				$314,100
Projected O&M and Monitoring Costs with Contingency (20%)				$376,900
Estimated Cost (NPV)				**$4,909,000**

Notes:

(1) Assumes that the upper 5 ft. of fly ash will be removed to regrade the stockpile; this fly ash will be used in basins.

(2) Additional fly ash from stockpile needed for attic fill over basins to achieve 2 % slopes.

Annual Costs

Operation and Maintenance Costs	Quantity	Unit	Unit Cost	Item Cost
Site Inspections	40	Hour	$70	$2,800
Cover, Road Repair/Maintenance	1	Lot	$12,000	$12,000
Total Annual O&M Cost				$14,800
30 Year Present Worth O&M Cost (interest rate = 5%)				$227,500
Ground Water Monitoring Costs				
Ground Water Monitoring	1	Lot	$20,000	$20,000
Total Annual Ground Water Monitoring Cost				$20,000
5 Year Present Worth Ground Water Monitoring Cost (interest rate = 5%)				$86,600
Estimated Cost (NPV) for O&M and Ground Water Monitoring				$314,100

Appendix A
ARARs

1.0 *INTRODUCTION*

Section 300.415(j) of the NCP requires certain types of removal actions to attain applicable or relevant and appropriate requirements (ARARs) under Federal or State environmental laws and regulations to the extent practicable considering the urgency of the situation and the scope of the removal. While CERCLA actions may not require a permit, substantive requirements of the ARAR may need to be met.

In accordance with EPA guidance (EPA, 1991), a potentially responsible party (PRP) is responsible for requesting potential Federal and State ARARs from EPA and Virginia, respectively. Virginia provided a list of state ARARs for the closure of the EE/CA units in a 26 February 1999 letter from Mr. John Ely of the Virginia Department of Environmental Quality to Mr. William Cutler of FMC and Ms. Bonnie Gross of the U.S. EPA. The purpose of Appendix A is to provide a list of Federal and State ARARs that apply potentially to the response actions addressed in the EE/CA for the closure of the sulfate basins, WWTP basins, and fly ash basins and stockpile. This list will be used to guide the design phase activities for the closure of the EE/CA units.

A requirement under other environmental laws may be either "applicable" or "relevant and appropriate" to a response action, but not both. Applicable and relevant and appropriate, as defined by EPA (1991), are as follows:

- **Applicable requirements** are clean-up standards, standards of control and other substantive requirements, criteria or limitations promulgated under federal environmental or state environmental or facility siting laws that specifically address a hazardous substance, pollutant, contaminant, remedial action, location or other circumstance at a CERCLA site.
- **Relevant and appropriate** are clean-up standards, standards of control and other substantive requirements, criteria or limitations promulgated under federal environmental or state environmental or facility siting laws that, while not "applicable" to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstances at a CERCLA site, address problems or situations

sufficiently similar to those encountered at the CERCLA site and are well suited to the particular site.

2.0 *ARAR IDENTIFICATION*

Tables A-1 and A-2 list the federal and state ARARs identified for response actions at the Avtex Fibers Superfund Site. Table A-2 includes the ARARs identified by Virginia in their 26 February 1999 letter. In accordance with the NCP, the ARARs fall into three categories:

- **Chemical-Specific**. These ARARs are health or risk-based numeric values or methodologies that establish the acceptable amount or concentration of a chemical that may be found or discharges to the ambient environment. Examples of contaminant-specific ARARs are MCLs or National Ambient Air Quality Standards (NAAQS).
- **Location-Specific**. These ARARs are restrictions placed on the concentration of hazardous substances or the conduct of activities because they occur in special natural or man-made designated site features. Examples of natural site features include wetlands, scenic rivers, and floodplains.
- **Action-Specific**. These ARARs are activity- or technology-based requirements that pertain to the implementation of a given remedy. Examples of action-specific ARARs include monitoring requirements, effluent discharge limitation, hazardous waste manifesting requirements, and occupational health and safety requirements.

Other Federal and State advisories, criteria, or guidance may, as appropriate, be considered in the formulation of the removal action. Other information To Be Considered (TBC) are now promulgated advisories or guidelines issued by federal or state governments that are not legally binding and do not have Stature of ARARs. Examples of TBC are health effects information, and guidance on how to conduct response actions.

3.0 *WAIVER OF ARARs*

In certain cases, a preferred remedy may substantially control the site risk to acceptable levels but can not meet one or more of the ARARs. CERCLA §121(d)(4) provides that under certain circumstances, ARARs may be waived during on-site CERCLA remedial actions. NCP section 300.415(j) extends the waivers to removal actions. The six criteria for an ARAR waiver are described in CERCLA §121(d)(4). Based on the ARARs identified by Virginia in their 26 February 1999 letter, and EPA's 16 April 1999 response to Virginia's letter, a waiver of ARARs will not be necessary to complete the closure of the EE/CA units.

REFERENCES

EPA, 1988. CERCLA Compliance with other Laws Manual. Office of Emergency and Remedial Response. Publication EPA/540/G-89/006. August.

EPA, 1989. CERCLA Compliance with other Laws Manual: Part II. Clean Air Act and Other Environmental Statues and State Requirements. Office of Emergency and Remedial Response. Publication EPA/540/G-89/009. August.

EPA, 1991. Superfund Removal procedures, Guidance on the Consideration of ARARs during Removal Actions. Office of Emergency and Remedial Response. Publication 9360.3.02.

Table A-1 Potential Federal Applicable or Relevant and Appropriate Requirements Avtex Fibers Superfund Site

ARARs/TBC	Description
Chemical-Specific	
Safe Drinking Water Act - Maximum Contaminant Levels (MCLs) - Maximum Contaminant Level Goals (MCLGs)	May apply to ground water remediation
Clean Water Act (PL92-5090) - Federal Ambient Water Quality Criteria	TBC for remedial actions resulting in treated water and surface water discharges
Clean Air Act (42 USC 7401) - National Ambient Air Quality Standards (NAAQS) (40 CFR Part 5)	Applicable for remedial alternatives which may result in the release of contaminants to the air (e.g., air stripping, excavation, groundwater treatment)
Reference Doses (RfDs), EPA Office of Research and Development	TBC in risk assessment
Carcinogenic Slope Factors, EPA Environmental Criteria and Assessment Office; EPA Carcinogen Assessment Group	TBC in risk assessment
Toxic Substances Control Act (15 U.S.C. 2601) TSCA health data, chemical advisories, and compliance program policy	Applicable for site which may require remediation of PCB containing materials TBC in risk assessment
Guidance on Remedial Action for Superfund sites with PCB contamination. OSWER 9335.4-07	TBC for site where remediation of PCB-impacted areas may be required
Health Advisories, EPA Office of Drinking Water	TBC in risk assessment
Asbestos NESHAPs (40 CFR Part 61).	Relevant and appropriate for asbestos containing material which may require management
Location-Specific	
Within 100-year floodplain (Executive Order 11988) Section 10 of the Rivers and Harbors Act Section 404 of the Clean Water Act	Effects of response actions on the navigable water of the U.S. may need to be addressed.
Wetland Management (Executive Order 11990). Section 404 of the Clean Water Act	Appropriate requirement for remedial action affecting wetland resources. 404 permits not required but COE should be consulted.
Fish and Wildlife Conservation Act of 1980 (16 USC 2901) Fish and Wildlife Coordination Act (16 USC 661). Fish and Wildlife Improvement Act (16 USC 742a) Fish and Wildlife Migratory Bird Treaty Act (16 USC 701)	Appropriate for remedial alternatives affecting fish and wildlife habitat Provides protection for migratory birds

Table A-1 Potential Federal Applicable or Relevant and Appropriate Requirements Avtex Fibers Superfund Site

ARARs/TBC	Description
Endangered Species Act of 1978 (16 USC 1531)	Fish and Wildlife Service and Virginia determined that no federally listed endangered or threatened plant, animal or insect species have been documented at the site.
Fish and Wildlife Improvement Act of 1978 (16 USC 742a).	Appropriate for remedial alternatives affecting fish and wildlife habitat
Flood Disaster Protection Act of 1973 and National Flood Insurance Act of 1968	Appropriate as the site is partially within the floodplain and floodplain resources may be affected by remedial action.
Wild and Scenic Rivers Act (36 CFR 297.4)	Site is adjacent to the South Fork of the Shenandoah River.

Action-Specific

Hazardous Waste Requirements (RCRA Subtitle C, 40 CFR, Part 261-264)	Applicable; standards applicable to identifying, treating, storing, and disposing hazardous wastes.
RCRA Land Ban Requirements (40 CFR, PART 268)	Applicable; remediation may require off-site disposal of contaminated material.
OSHA Requirements (29 CFR, Parts 1910, 1926, and 1904)	Applicable; required for workers engaged in on-site remedial activities.
Threshold Limit Values, American Conference of Governmental Industrial Hygienists	TBCs; may be applicable to air concentrations during remedial activities.
DOT rules for Hazardous Materials Transport (49 CFR, Parts 107, 171.1-500)	Appropriate; remedial alternatives may include off-site treatment and disposal.
Clean Water Act (PL92-500) a. NPDES permits	Standards applicable to surface water discharges.
EPA PCB Spill Policy (40 CFR, Part 761)	Applicable; PCB remediation requirements.
Guidance on Remedial Action for Superfund sites with PCB contamination OSWER Directive 9355.4-01	TBC for PCB remediation guidelines.
RCRA Organic Air Emissions Standards for Process Vents (40 CFR 264 Subpart AA)	Applicable remedial actions may involve the release of contaminants to the air (e.g., air stripping, soil vapor extraction).
Air Stripper Control Guidance (OSWER Directive 9355.0-28)	TBC; remedial actions may result in the release of contaminants to the air.

Table A-2 Potential Commonwealth of Virginia Applicable or Relevant and Appropriate Requirements Avtex Fibers Superfund Site

ARAR/TBC	Description
Contaminant-Specific	
Virginia State Water Control Law, Va. Code Ann. Sections 62.1-44.2 to 44.34:28 (1998)	
Virginia Water Quality Standards (9 VAC 25-260-5 to 550)	Remedial actions may involve discharge to surface waters.
Virginia Pollutant Discharge Elimination System Permit Regulation (9 VAC 25-31-10 to 940)	VPDES Permits required for surface water discharges.
Virginia Water Protection Permit Regulations (9 VAC 25-210-10 to 260)	Remedial actions may involve dredging or filling adjacent to surface waters
Virginia Air Pollution Control Law, Va. Code Ann. Sections 10.1-1300 to 1326 (1998)	Applicable; air emission standards must be met for release of volatile compounds from treatment facilities. Particulate emission standards must also be met for the disturbance of soil.
Virginia Regulations for the Control and Abatement of Air Pollution (9 VAC 5)	
Virginia Ambient Air Quality Standards (9 VAC 5-30-10 to 80)	
Virginia Standards of Performance for Visible Emissions and Fugitive Dust/Emissions [Rule 5-1] (9 VAC 5-50-60 to 120)	
Virginia Standards of Performance for Toxic Pollutants [Rule 5-3] (9 VAC 5-50-160 to 230)	
Location-Specific	
Virginia Department of Game and Inland Fisheries, Va. Code Ann. Sections 29.1-100 et seq.:	
Virginia Wetlands Regulations	May apply to wetlands identified on site for the protection of general ecological concerns.
Virginia Floodplain Management Program	Related to construction activities on the floodplain.
Virginia General Provisions Relating to Marine Resources Commission (Va. Code Ann. Sections 28.2-1300 to 1320)	
Virginia Wetlands Mitigation Compensation Policy (4 VAC 20-390-10 to 50)	
Virginia Chesapeake Bay Preservation Act Sections 10.1-2100 to 2116	
Virginia Chesapeake Bay Preservation Area Designation and Management Regulations (9 VAC 10-20-10 to 280)	

Table A-2 Potential Commonwealth of Virginia Applicable or Relevant and Appropriate Requirements Avtex Fibers Superfund Site

ARAR/TBC	Description
Location-Specific (continued)	
Virginia Endangered Species Act, Va. Code Ann. Sections 29.1-563 to 570 (1998) Virginia Definitions and Miscellaneous in General (4 VAC 15-20-130 to 140) Virginia Endangered Plant and Insect Species Act, Va. Code Ann. Sections 3.1-1020 to 1030 Virginia Rules and Regulations for the Enforcement of the Endangered Plant and Insect Species Act (4 VAC 5-320-10)	Remedial actions may impact endangered species.
Virginia Natural Area Preserves Act, Va. Code Ann. Sections 10.1-209 to 217 (1998)	May apply if anticipated activities threaten natural heritage resources
Action-Specific	
Virginia Waste Management Act, Va. Code Ann. Sections 10.1-1400 to 1457 (1998):	
Virginia Hazardous Waste Regulations (VHWR) (9 VAC 20-60-10 to 1480)	Applicable; any activity with RCRA-type hazardous wastes must comply.
Virginia Solid Waste Management Regulations (VSWMR) (9 VAC 20-80-10 to 790)	May apply to solid waste or sludge.
Virginia Regulations Governing Management of Coal Combustion By-Products (9 VAC 20-85-10 to 180)	May apply to solid waste or sludge.
Virginia Regulations for the Transportation of Hazardous Materials (9 VAC 20-110-10 to 130)	May apply to solid waste or sludge.
Virginia Erosion and Sediment Control Law, Va. Code Ann. Sections 10.1-560 to 571; and the Virginia Erosion Control Handbook Virginia Stormwater Management Act, Va. Code Ann. Sections 10.1-603.1 to 603.15 (1998) Virginia Stormwater Management Regulations (4 VAC 3-20-10 to 251) Virginia Erosion and Sediment Control Law, Va. Code Ann. Sections 10.1-560 to 571 (1998) Virginia Erosion and Sediment Control Regulations (4 VAC 50-30-10 to 110	Soil disturbances may require compliance with erosion and sedimentation control statutes.

Table A-2 Potential Commonwealth of Virginia Applicable or Relevant and Appropriate Requirements Avtex Fibers Superfund Site

ARAR/TBC	Description
Action-Specific (continued)	
Virginia Air Pollution Control Law, Va. Code Ann. Sections 10.1-1300 to 1326 (1998) Virginia Regulations for the Control and Abatement of Air Pollution (9 VAC 5)	Air emission standards may need to be met for treatability studies and remedial action.
Virginia Stormwater Management Act, Va. Code Ann. Sections 10.1-603.1 to 603.15 (1998) Virginia Stormwater Management Regulations (4 VAC 3-20-10 to 251)	Stormwater may need to be managed for all land-disturbing activities that disturb more than one acre of land.

Appendix B
HEC-RAS Floodplain Analysis for the Closure of Sulfate Basins 1-5

APPENDIX B - HEC-RAS FLOODPLAIN ANALYSIS FOR THE CLOSURE OF SULFATE BASINS 1-5 AT THE AVTEX FIBERS SUPERFUND SITE, FRONT ROYAL, VIRGINIA

1.0 INTRODUCTION

The proposed remedy for the Sulfate Basins (SB) at the Avtex Fibers Superfund Site (Site) includes a soil cover over the existing sludge surfaces and lowering of the impoundment dikes (berms) to match the proposed grades. Since these basins lie within the floodplain of the South Fork of the Shenandoah River (River) or may be subject to inundation after the berms are lowered, flood impacts, especially potentially erosive flood velocities are of potential concern. A water surface profile analysis of the River at Front Royal, Virginia was conducted to evaluate the water surface elevations and overbank velocities on the Site for the 100-year flood event. The Hydrologic Engineering Center River Analysis System (HEC-RAS) software was used to perform steady flow calculations using data provided by the Federal Emergency Management Agency (FEMA) and modified to reflect anticipated post-remediation contours.

2.0 AVAILABLE FLOODPLAIN MODELING

A model of the River reach was provided to ERM in electronic format by Gannett Fleming, Inc., (GF). GF generated HEC-RAS input files including cross section data for a previous evaluation at the Avtex Fibers Site. GF utilized river floodplain cross section data used by the U.S. Geological Survey in the preparation of the FEMA Warren County Flood Insurance Study using the U.S. Geological Survey Model for Water Surface Profile Computations (WSPRO) and calibrated the HEC-RAS modeling to obtain close agreement with the results of the WSPRO modeling.

The HEC-RAS input data provided was reviewed by ERM to develop an understanding of the cross sections modeled in the area of concern; the SB's had new cross sections surveyed to the North and South of SB 4 and 4E and substituted the new sections for two of the USGS/FEMA model cross sections for evaluation of a proposed on-site landfill location. ERM did not use these new sections, because these sections went through the valleys between the basin, and therefore were not indicative of flood conditions at the basin elevations. Instead, we used USGS/FEMA cross sections located through the basins. Three USGS/FEMA cross sections, L, M, and N, were identified as crossing the SB portion of the Site. The locations of these cross sections are shown on Figure B-1.

The USGS/FEMA model input data indicates that the existing cross sections modeled the SB as though they were full to the top of berm elevations, providing no conveyance in the basins. The USGS/FEMA modeling results indicate that SB 1 and 2 would be inundated by 100-year flood waters as they are currently configured, but SB 3, 4, and 5 would not be inundated. Historically, the berm of SB 1 was observed to be over-topped on at least one occasion.

3.0 *MODEL DEVELOPMENT*

ERM conducted a surveying evaluation to identify the sludge surface elevation relative to the existing berm crest elevation. The water surface in SB 4, 4e, and 5 precluded a definitive identification of the sludge surface in those basins. Sounding was done to identify the approximate top of sludge elevation in SB 5.

ERM used the surveyed data to modify the USGS/FEMA geometric data to develop an input file for proposed future conditions. The proposed geometric data assumes that there will be a nominal two-foot thick soil cover placed on top of the sludge in SB 1, 2, 3, 4, and 4E, and that the cover will slope at a minimum of two percent. This assumption, along with the data collected in the field regarding the sludge elevation in those basins, enabled ERM to construct proposed cross sections. SB 5 was assumed to be emptied of sludge and the bottom graded using a minimum of six inches of topsoil.

Cross Section N is the most upstream section that ERM modified. This cross section cuts through SB 5. Field measurements indicate that the sludge surface is approximately 13.7 feet below the embankment crest elevation. The proposed remedy for SB 5 is to empty the basin of sludge and regrade the area by adding a minimum of 0.5 feet of topsoil. Using the available data and proposed remedy, ERM produced new overbank contours across the basin representing its proposed condition with all sludge removed. It was assumed that the regraded bottom will have a minimum slope of two percent. To minimize "attic" fill required to achieve this slope in the bottom, a peak was assumed to be formed in the center of the basin directing runoff to all sides. A visual interpretation of the existing and proposed Cross Section N is presented as Figure B-2.

Cross Section M is directly downstream of N, approximately 1,400 feet, cutting through SB 2 and 3. Field measurements indicate that the sludge surface is approximately 9 feet below the embankment crest for Basin 2 and 12.2 feet below the embankment crest for SB 3. The proposed cross section eliminates the embankment between basins 2 and 3 while again utilizing an approach that will limit the use of excess cover soil to a minimum. A visual interpretation of the existing and proposed Cross Section M is presented as Figure B-3.

Cross Section L is directly downstream of M, approximately 1,400 feet, cutting through SB 1. Field measurements indicate that the sludge surface is approximately 7.9 feet below the embankment crest on the west (river) side of the basin. The proposed cross section is based on cutting the west embankment down to an elevation 2 feet above the measured sludge elevation. The sludge in SB 1 slopes upward from west to east at between 0.75% and 1.2% from the west embankment, as a result of past deposition practices. The soil cover was assumed to be placed upon this slope where it exceeds 2% and end at the basin's east boundary. Areas with less than 2% slope (e.g., the north end) would receive attic fill to create that minimum slope. A visual interpretation of the existing and proposed Cross Section L is presented as Figure B-4.

In addition to the originally modeled cross sections L, M, and N, ERM evaluated an interpolated cross section cut through SB 4/4E. This section was stationed approximately midway between Sections M and N cutting through SB 4/4E. The channel and left overbank points were interpolated using data in for Sections M and N. Right over bank data was constructed using existing topographic information and data obtained during field evaluation of the depth to sludge below the existing berms. Although this section was not modeled in the HEC-RAS software, ERM interpolated the projected 100-year flood elevation based on results for Sections N and M. A visual interpretation of this estimated data for this cross section through SB 4/4E is presented as Figure B-5.

4.0 MODELING RESULTS

Utilizing the proposed cross sections developed by ERM for L, M, and N the HEC-RAS model was run to evaluate the impacts of the overbank modifications for the 100-year flood event. Figures B2, B3, and B4 present the computed water surface elevations for post-modification channel cross-sections. The 100-year flood event predicts flow in the right overbank for Cross Sections N, M, L, and at SB 4. The average predicted velocity in the right overbank for Cross Sections N, M, and L are 2.89 feet per second (fps), 1.78 fps, and 1.54 fps respectively with velocity through SB 4 predicted to be in the same range, based on the section geometry and conditions, and similar depth of flow.

The maximum velocity computed by dividing the overbank areas into segments for computation purposes is approximately 3.5 fps in Cross Section N. The maximum allowable velocity with a vegetative (grass) cover identified in the Virginia Soil Erosion and Sediment Control Handbook is 5 fps. Therefore, the model results indicate that the maximum velocity of 3.5 fps is non-erosional.

The result according to Cross Section N provides a minimum factor of safety of 1.4 relative to the maximum computed velocity of 3.5 fps. The calculated safety factor for Cross Section N is considered adequate since this cross section cuts through SB 5 for which the proposed remedy is to excavate sludge and regrade with topsoil. Therefore, there is no concern associated with scour in SB 5 since the proposed remedy includes excavation of the sludge. The next highest predicted maximum velocity is estimated at 2.5 fps at Cross Section M which traverses SB 2 and 3. The result according to Cross Section M equates to a safety factor of 2.0 relative to the maximum computed velocity of 2.5.

The modeling conclusion indicates that no adverse impacts (increase) in flood elevations would be realized anywhere along the SBs as a result of the proposed closure related modifications to the cross sections that traverse the SBs. Table B-1 compares the computed water surface elevations at Cross Sections L, M, and N through the SB, as well as at upstream and downstream cross sections (O and K) for existing and proposed conditions. Over-bank velocities are sufficiently low so as to allow establishment and maintenance of a vegetated cover on the basins without long term risk of erosion by River flood waters. A copy of the HEC-RAS results are included as Attachment A.

Table B-1. Comparison of 100-Year Flood Elevation HEC-RAS Model Results

Section	Gannett Fleming, Inc. Existing Conditions (ft)	Proposed Sulfate Basin Remedy Conditions (ft)	100-Year Flood Elevation Difference (ft)
O	501.91	501.22	-0.69
N	500.53	500.54	0.01
M	499.22	499.21	-0.01
L	497.95	497.77	-0.18
K	497.26	497.24	-0.02

Figure B-1
Location of HEC-RAS Cross Sections Through Sulfate Basins
Avtex Fibers Superfund Site
Front Royal, Virginia

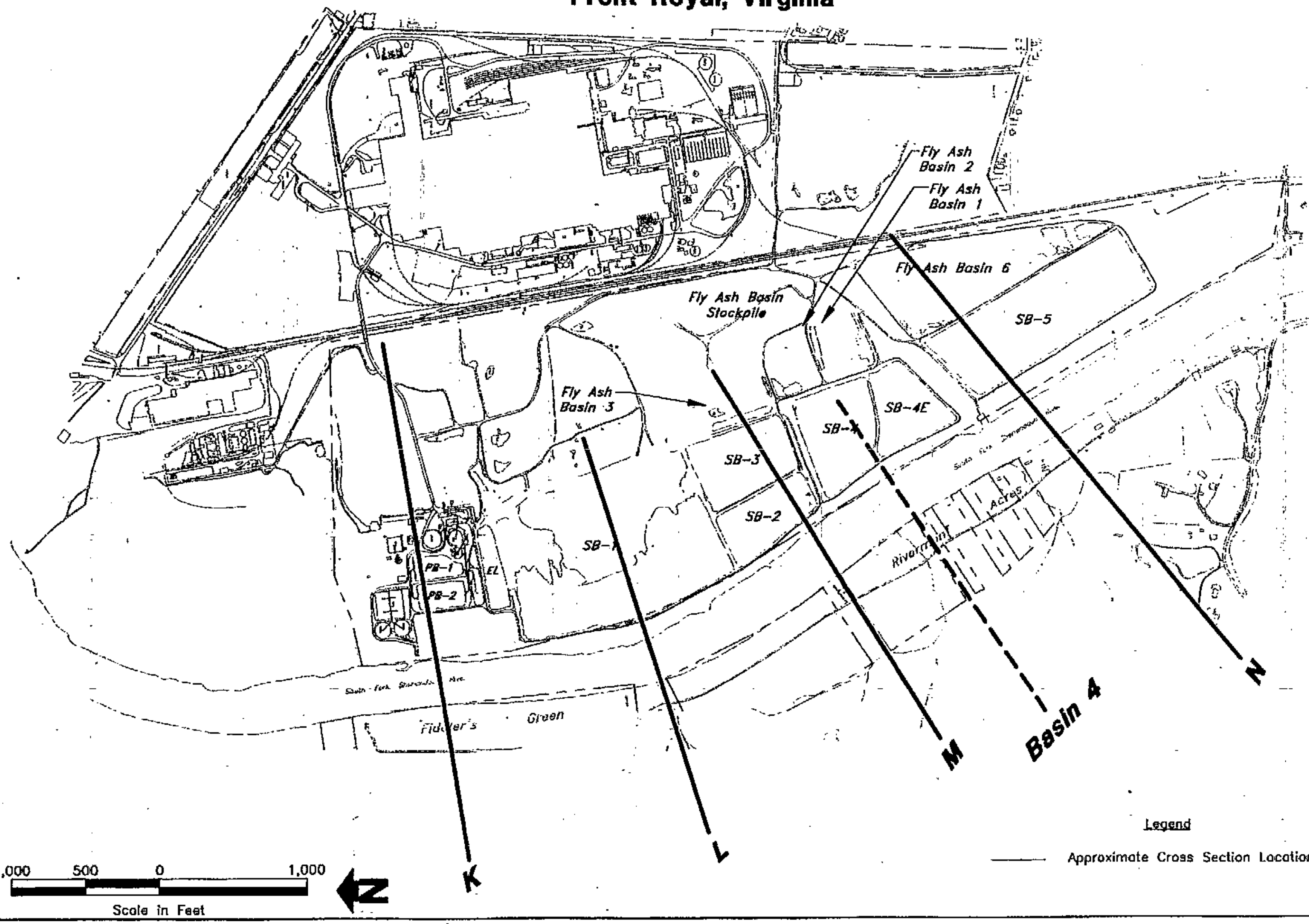


Figure B-2. Section N

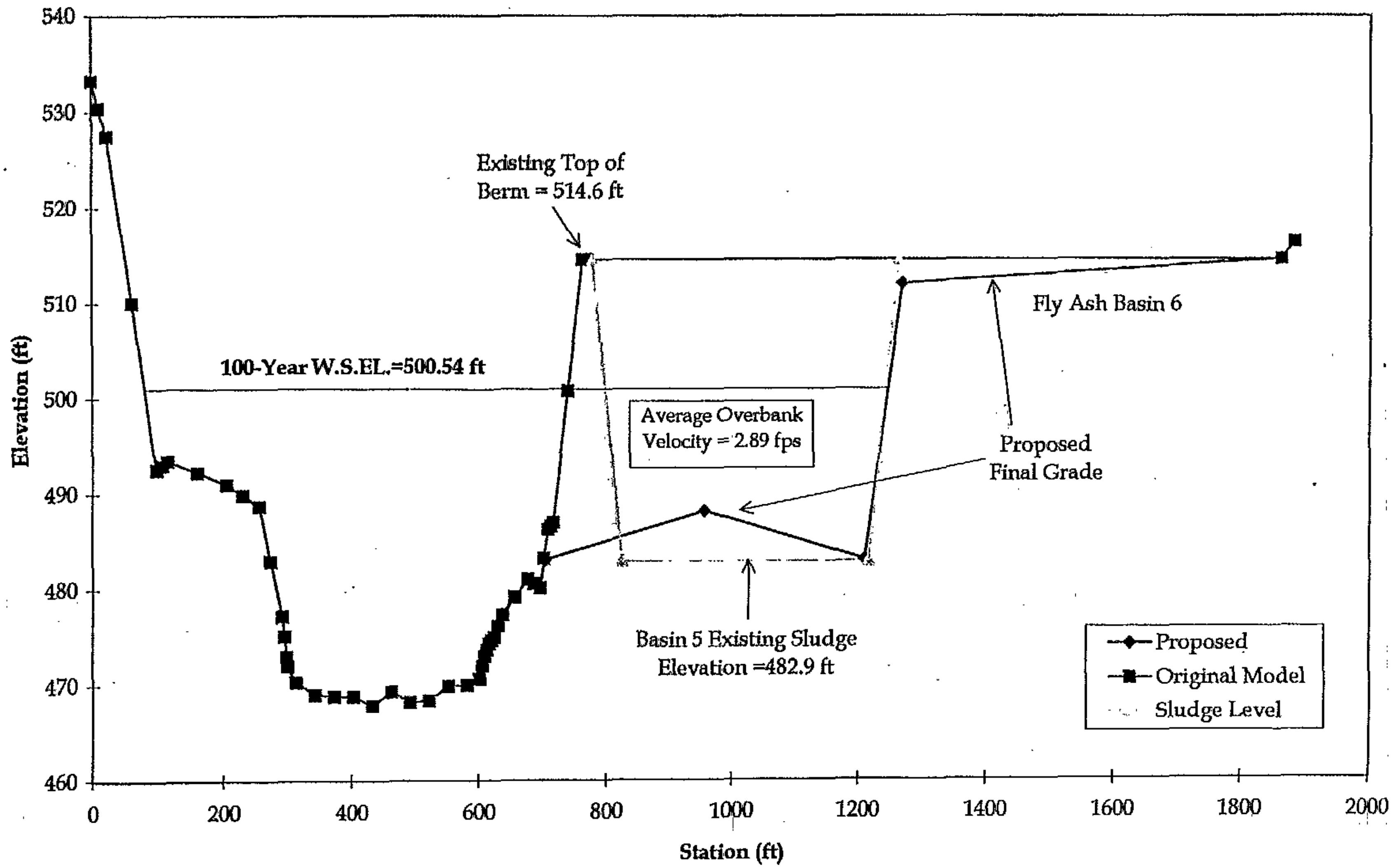
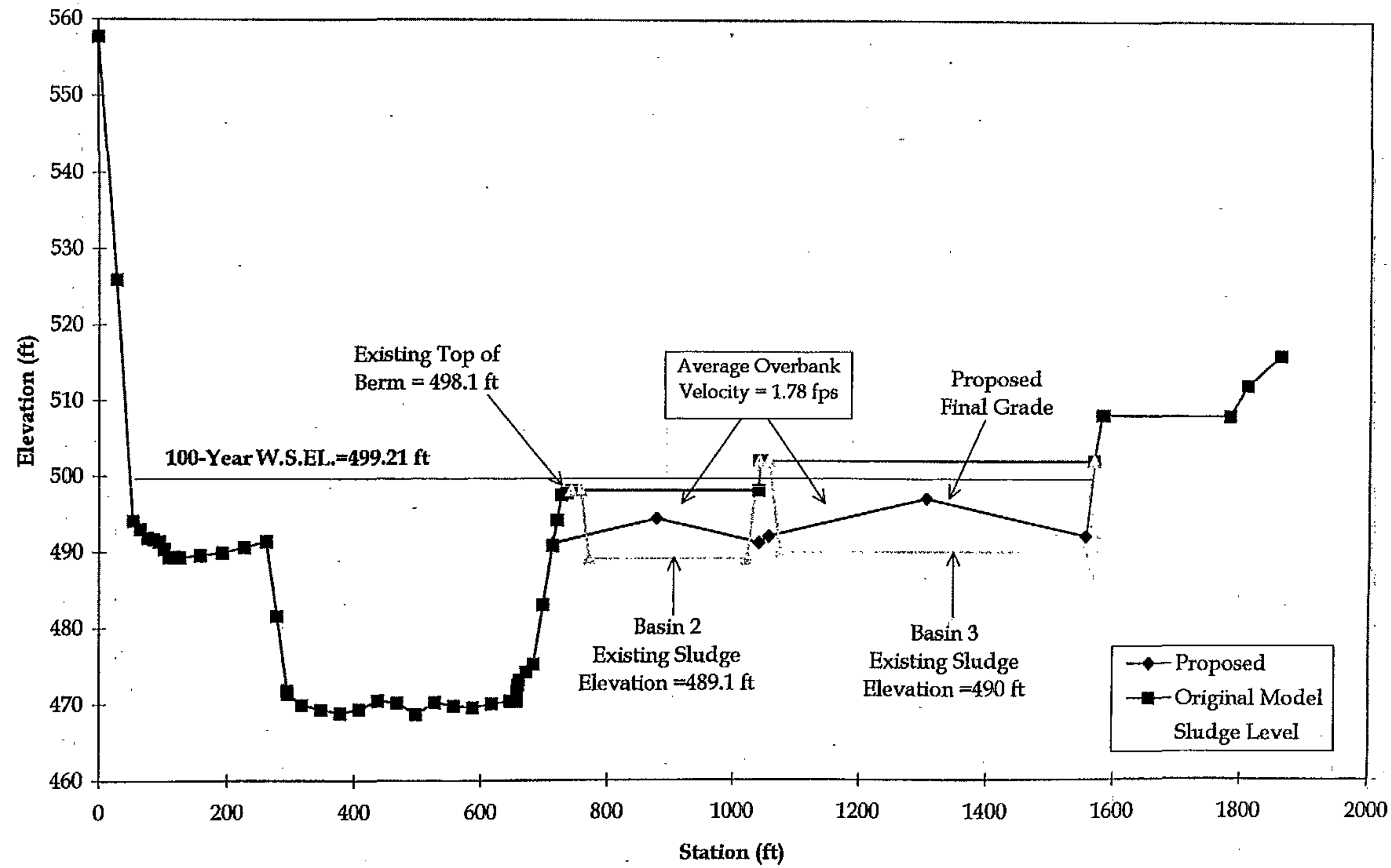
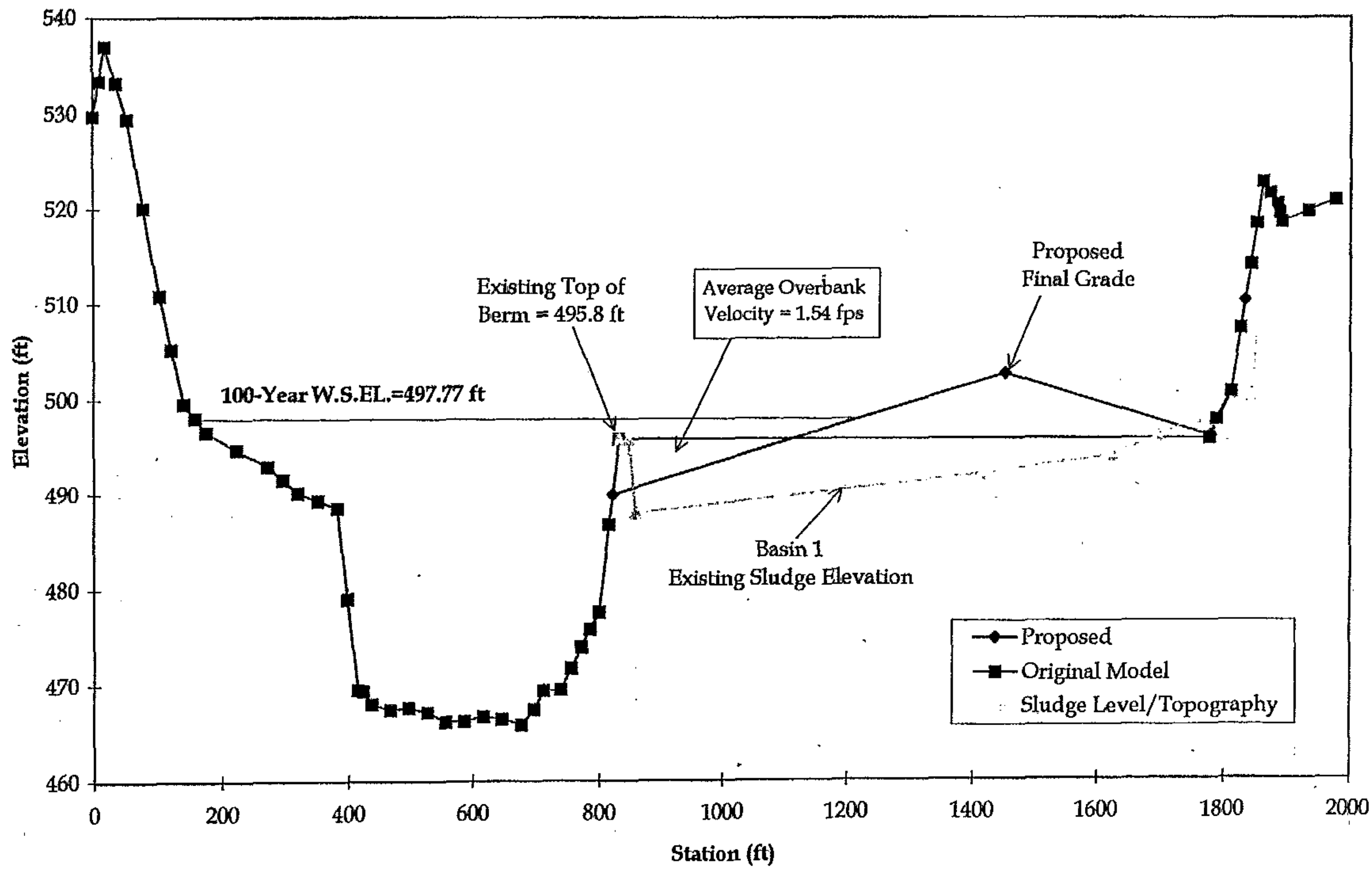


Figure B-3. Section M



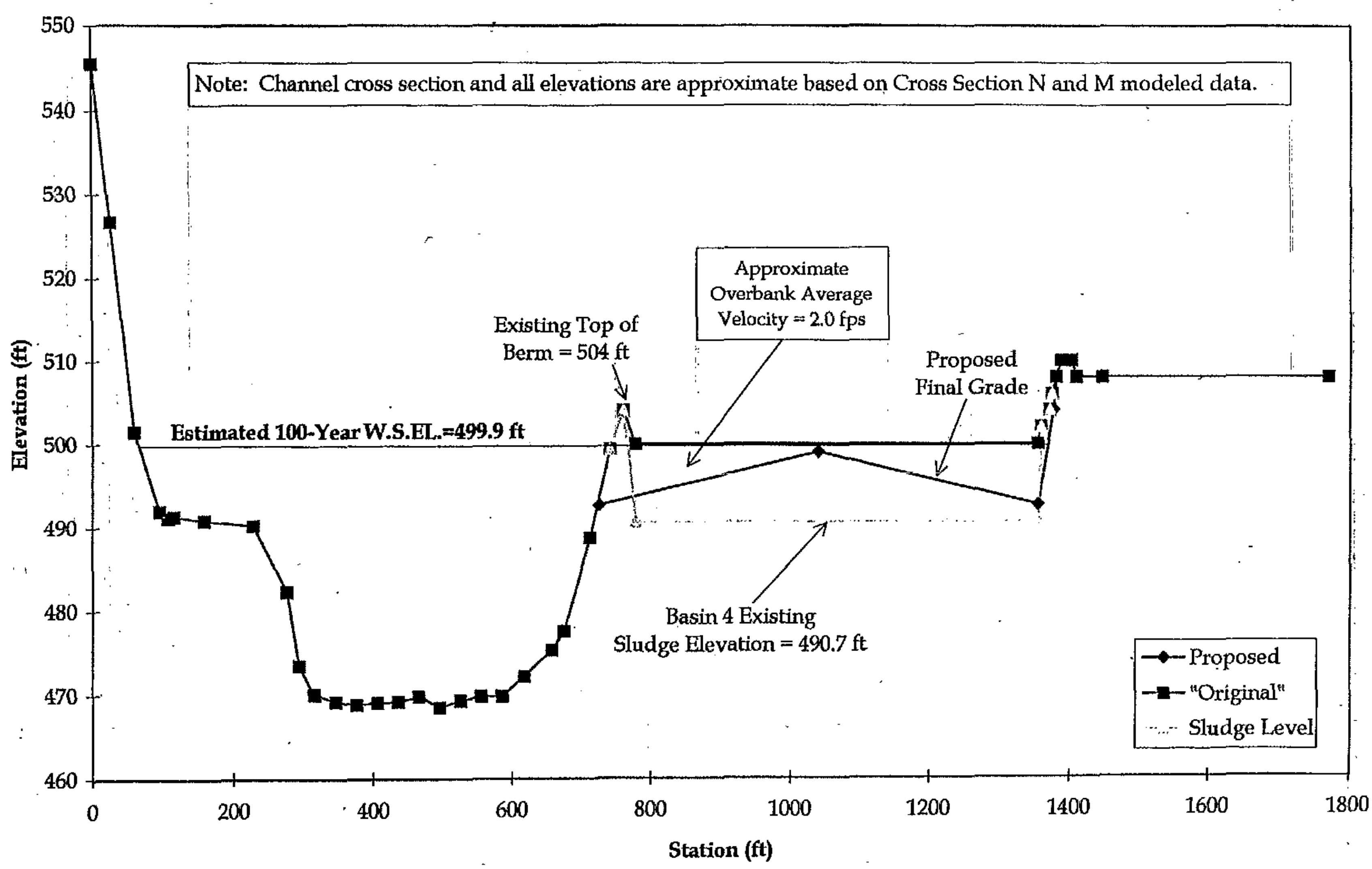
AR106467

Figure B-4. Section L



AR106468

Figure B-5. Estimated Basin 4 Section



Attachment A
HEC-RAS Model Output

HEC-RAS Version 2.0 April 1997
U.S. Army Corp of Engineers
Hydrologic Engineering Center
609 Second Street, Suite D
Davis, California 95616-4687
(916) 756-1104

```
X     X  XXXXXX   XXXX        XXXX      XX       XXXX
X     X  X       X    X       X   X    X  X     X
X     X  X       X            X   X   X    X    X
XXXXXXX  XXXX    X      XXX   XXXX    XXXXXX     XXXX
X     X  X       X            X X     X    X         X
X     X  X       X    X       X  X    X    X         X
X     X  XXXXXX   XXXX        X   X   X    X    XXXXX
```

PROJECT DATA
Project Title: Front Royal, Virginia - South Fork Shen.
Project File : fmc.prj
Run Date and Time: 12/4/98 10:39:24 AM

Project in English units

PLAN DATA

Plan Title: LMN-2% Cover Slopes
Plan File : c:\work\fmc-hec\fmc.p07

Geometry Title: New L, M, N Stations-2%
Geometry File : c:\work\fmc-hec\fmc.g05

Flow Title : Fema Flow Data
Flow File : c:\work\fmc-hec\fmc.f01

Plan Summary Information:

Number of:					
Cross Sections	=	23	Mulitple Openings	=	0
Culverts	=	0	Inline Weirs	=	0
Bridges	=	1			

Computational Information
Water surface calculation tolerance = 0.01
Critical depth calculaton tolerance = 0.01
Maximum number of interations = 20
Maximum difference tolerance = 0.3
Flow tolerance factor = 0.001

Computational Flow Regime: Subcritical Flow

FLOW DATA

Flow Title: Fema Flow Data
Flow File : c:\work\fmc-hec\fmc.f01

Flow Data (cfs)

River	Reach	RS	PF#1	100 year	200 year	500 year
Fork Shenando	Front Royal	23	60110	125140	164860	0

AR106471

S. Fork ShenandoFront Royal 00	1	75000	139000	174000

Boundary Conditions

River	Reach	Profile	Upstream	Downstream
S. Fork Shenando	Front Royal	PF#1		Known WS = 482.47
S. Fork Shenando	Front Royal	100 year		Known WS = 492.63
S. Fork Shenando	Front Royal	200 year		Known WS = 496.67
S. Fork Shenando	Front Royal	500 year		Known WS = 507.16

GEOMETRY DATA

Geometry Title: New L, M, N Stations-2%
Geometry File : c:\work\fmc-hec\fmc.g05

CROSS SECTION RIVER: S. Fork Shenando
REACH: Front Royal RS: 23

INPUT
Description: Q
Station Elevation Data num= 68

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
0	538.5	67.3	523.3	134.6	508.1	139.7	504.65	144.8	501.2
158.2	501.2	171.6	501.2	178.9	497.55	186.3	493.9	235.9	488.7
285.6	483.5	359.4	480.9	433.8	478.3	437.5	476.6	440	475
443	473.2	453	470.4	463	469.5	473	469.6	483	469.6
493	469.4	503	470	513	469.6	523	469.1	533	470.7
543	469.8	553	470.6	563	471.1	573	471.3	583	471.3
593	471.2	603	471.5	613	471.6	623	471.8	633	471.3
643	471.8	653	471.1	663	470.6	673	471.4	683	471.6
693	472.2	703	471.9	713	472.4	723	472.4	733	472.5
740	475	746.1	477.05	753.9	479.2	802.7	484.5	851.6	489.8
898.1	488.6	944.6	487.4	970.9	488.75	997.3	490.1	1010.3	490.55
1023.3	491	1027.7	490.5	1032.2	490	1046.1	491.05	1060	492.1
1063.9	493.1	1067.9	494.1	1071.6	494.1	1075.3	494.1	1079.7	492.9
1084.1	491.7	1134	500	1184	520				

Manning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
0	.065	433.8	.04	753.9	.065

Bank Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
433.8	753.9	1004	1004	1004	.1	.3

CROSS SECTION OUTPUT Profile #100 year

		Element	Left OB	Channel	Right OB
W.S. Elev (ft)	501.97	Wt. n-Val.	0.065	0.040	0.065
Vel Head (ft)	1.08	Reach Len. (ft)	1004.00	1004.00	1004.00
E.G. Elev (ft)	503.05	Flow Area (sq ft)	4528.25	9777.12	4868.43
Crit W.S. (ft)		Area (sq ft)	4528.25	9777.12	4868.43
E.G. Slope (ft/ft)	0.000688	Flow (cfs)	16862.23	92496.37	15781.40
Q Total (cfs)	125140.00	Top Width (ft)	290.14	320.10	385.03
Top Width (ft)	995.27	Avg. Vel. (ft/s)	3.72	9.46	3.24
Vel Total (ft/s)	6.53	Hydr. Depth (ft)	15.61	30.54	12.64
Max Chl Dpth (ft)	32.87	Conv. (cfs)	642675.0	3525340.0	601480.8
Conv. Total (cfs)	4769496.0	Wetted Per. (ft)	292.73	323.32	387.49
Length Wtd. (ft)	1004.00	Shear (lb/sq ft)	0.66	1.30	0.54
Min Ch El (ft)	469.10	Stream Power (lb/ft s)	2.48	12.30	1.75
Alpha	1.63	Cum Volume (acre-ft)	3642.49	5673.30	2307.81
Frctn Loss (ft)	0.56	Cum SA (acres)	252.29	181.46	200.11
C & E Loss (ft)	0.09				

AR106472

S SECTION RIVER: S. Fork Shenando
: Front Royal RS: 22

INPUT
Description: P
Station Elevation Data num= 91

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
0	561.5	24.6	552.85	49.3	544.2	78.9	520.35	108.5	496.5
110.5	497.55	112.5	498.6	123.8	498.6	135.1	498.6	147	491.55
159	484.5	197.2	481.3	235.4	478.1	272.5	478.7	309.6	479.3
320.4	479.2	331.3	479.1	335.7	476.75	340.1	474.4	347	471
357	468	367	467.8	377	468	387	468.1	397	468
407	467.1	417	467.8	427	467.8	437	467.9	447	467.7
457	467.7	467	467.8	477	467.7	487	467.4	497	467.6
507	467.5	517	467.4	527	467.1	537	467.4	547	467.7
557	467.8	567	468.2	577	468.5	587	468.7	597	469
607	470.4	617	470.3	627	470.4	637	470.7	647	471
672.5	474.4	673.6	474.95	674.7	475.5	686	476.1	697.3	476.7
719.7	481.45	742.1	486.2	755.4	486.2	768.8	486.2	805.8	487.95
842.9	489.7	871.3	487.7	899.7	485.7	914.8	483.5	929.9	481.3
955.1	485.7	980.3	490.1	1018.6	490.95	1057	491.8	1061.1	491.2
1065.3	490.6	1070.4	490.6	1075.5	490.6	1087.9	492.9	1100.3	495.2
1108.2	498.35	1116.2	501.5	1120.3	501.5	1124.5	501.5	1127.2	502.65
1129.9	503.8	1133.5	503.8	1137.2	503.8	1144.9	501.95	1152.7	500.1
1162.1	501.6	1171.6	503.1	1188.8	504.55	1206	506	1252.1	512.65
1298.3	519.3								

Manning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
0	.065	331.3	.04	742.1	.065

Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
331.3	742.1	732	732	732	.1	.3

CROSS SECTION OUTPUT Profile #100 year

		Element	Left OB	Channel	Right OB
W.S. Elev (ft)	501.63	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.77	Wt. n-Val.	0.065	0.040	0.065
E.G. Elev (ft)	502.40	Reach Len. (ft)	732.00	732.00	732.00
Crit W.S. (ft)		Flow Area (sq ft)	4082.87	12698.45	4865.77
E.G. Slope (ft/ft)	0.000459	Area (sq ft)	4082.87	12698.45	4865.77
Q Total (cfs)	125140.00	Flow (cfs)	13391.26	98883.89	12864.85
Top Width (ft)	1038.66	Top Width (ft)	229.16	410.80	398.70
Vel Total (ft/s)	5.78	Avg. Vel. (ft/s)	3.28	7.79	2.64
Max Chl Dpth (ft)	34.53	Hydr. Depth (ft)	17.82	30.91	12.20
Conv. Total (cfs)	5840687.0	Conv. (cfs)	625013.2	4615230.0	600444.0
Length Wtd. (ft)	732.00	Wetted Per. (ft)	235.62	414.94	402.06
Min Ch El (ft)	467.10	Shear (lb/sq ft)	0.50	0.88	0.35
Alpha	1.49	Stream Power (lb/ft s)	1.63	6.83	0.92
Frctn Loss (ft)	0.34	Cum Volume (acre-ft)	3543.25	5414.29	2195.63
C & E Loss (ft)	0.01	Cum SA (acres)	246.31	173.04	191.07

Warning - Divided flow computed for this cross-section.

CROSS SECTION RIVER: S. Fork Shenando
REACH: Front Royal RS: 21

INPUT
Description: O
Station Elevation Data num= 58

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
0	573.9	25.2	537.65	50.4	537.4	64.6	535.1	78.8	532.8
.2	521.75	123.7	510.7	131.2	505.6	138.7	500.5	154.7	500.4
.8	500.3	179.2	496.25	187.7	492.2	225.2	485.75	262.8	479.3

293.2	477.7	323.6	476.1	326.6	474.9	329.7	473.7	342	468.2
352	466.3	372	465.7	392	465.3	412	465.2	432	465.4
452	465.3	472	465.3	492	465.6	512	465.6	532	465.5
552	466.3	572	466.3	592	466.8	601	468.2	623.9	473.7
626.5	474.25	629.2	474.8	658.4	475.6	687.7	476.4	711.4	477.5
735.2	478.6	767.6	481	800	483.4	862.2	484.75	924.4	486.1
1024.5	487.25	1124.6	488.4	1169.1	491	1213.7	493.6	1276	498.75
1338.4	503.9	1352.5	504.4	1366.7	504.9	1380.2	507.8	1393.8	510.7
1454	512	1570	516	1634	520				

Manning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
0	.065	326.6	.04	629.2	.07

Bank Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
326.6	629.2	1440	1440	1440	.1	.3

CROSS SECTION OUTPUT Profile #100 year

W.S. Elev (ft)	501.22	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.84	Wt. n-Val.	0.065	0.040	0.070
E.G. Elev (ft)	502.05	Reach Len. (ft)	1440.00	1440.00	1440.00
Crit W.S. (ft)		Flow Area (sq ft)	2779.60	10465.89	10040.88
E.G. Slope (ft/ft)	0.000471	Area (sq ft)	2779.60	10465.89	10040.88
Q Total (cfs)	125140.00	Flow (cfs)	8177.13	89058.95	27903.93
Top Width (ft)	1168.24	Top Width (ft)	188.95	302.60	676.69
Vel Total (ft/s)	5.37	Avg. Vel. (ft/s)	2.94	8.51	2.78
Max Chl Dpth (ft)	36.02	Hydr. Depth (ft)	14.71	34.59	14.84
Conv. Total (cfs)	5767624.0	Conv. (cfs)	376878.7	4104671.0	1286075.0
Length Wtd. (ft)	1440.00	Wetted Per. (ft)	192.43	305.09	677.45
Min Ch El (ft)	465.20	Shear (lb/sq ft)	0.42	1.01	0.44
Alpha	1.86	Stream Power (lb/ft s)	1.25	8.58	1.21
"rctn Loss (ft)	0.72	Cum Volume (acre-ft)	3485.59	5219.65	2070.38
& E Loss (ft)	0.02	Cum SA (acres)	242.79	167.05	182.04

CROSS SECTION RIVER: S. Fork Shenando
REACH: Front Royal RS: 20

INPUT
Description: N
Station Elevation Data num= 46

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
0	533.3	11.5	530.4	23.1	527.5	60.8	510.05	98.5	492.6
106.6	493.05	114.8	493.5	159.6	492.25	204.5	491	230.2	489.85
255.9	488.7	273.2	482.95	290.5	477.2	294.5	475.1	298.5	473
300	472	312	470.3	342	469	372	468.8	402	468.8
432	467.9	462	469.3	492	468.2	522	468.4	552	469.9
582	470	602	470.6	607	472	610.1	473	613.4	473.65
616.7	474.3	620.7	474.65	624.8	475	630.6	476.15	636.5	477.3
656.4	479.15	676.3	481	686.2	480.55	696.1	480.1	702.7	483.15
704	483	957	488.1	1210	483	1270	512	1863	514.6
1883	516.4								

Manning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
0	.065	255.9	.04	704	.07

Bank Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
255.9	704	1492	1492	1492	.1	.3

CROSS SECTION OUTPUT Profile #100 year

W.S. Elev (ft)	500.54	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.78	Wt. n-Val.	0.065	0.040	0.070
. Elev (ft)	501.32	Reach Len. (ft)	1492.00	1492.00	1492.00
.t W.S. (ft)		Flow Area (sq ft)	1483.21	12643.98	7902.89

E.G. Slope (ft/ft)	0.000526	Area (sq ft)	1483.21	12643.98	7902.89
Total (cfs)	125140.00	Flow (cfs)	3215.00	99087.73	22837.27
p Width (ft)	1164.94	Top Width (ft)	174.55	448.10	542.29
l Total (ft/s)	5.68	Avg. Vel. (ft/s)	2.17	7.84	2.89
ax Chl Dpth (ft)	32.64	Hydr. Depth (ft)	8.50	28.22	14.57
Conv. Total (cfs)	5456922.0	Conv. (cfs)	140195.0	4320873.0	995854.1
Length Wtd. (ft)	1492.00	Wetted Per. (ft)	176.41	453.16	546.41
Min Ch El (ft)	467.90	Shear (lb/sq ft)	0.28	0.92	0.47
Alpha	1.56	Stream Power (lb/ft s)	0.60	7.18	1.37
Frctn Loss (ft)	0.92	Cum Volume (acre-ft)	3415.14	4837.67	1773.79
C & E Loss (ft)	0.04	Cum SA (acres)	236.79	154.64	161.89

CROSS SECTION RIVER: S. Fork Shenando
REACH: Front Royal RS: 19

INPUT
Description: M
Station Elevation Data num= 52

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
0	557.7	26.6	525.9	53.2	494.1	64.3	493	75.5	491.9
84.4	491.65	93.3	491.4	100.6	490.4	108	489.4	116.3	489.35
124.7	489.3	158	489.6	191.4	489.9	225.7	490.65	260.1	491.4
276.7	481.6	293.3	471.8	294	471.4	317	469.9	347	469.3
377	468.8	407	469.36	437	470.5	467	470.2	497	468.7
527	470.3	557	469.8	587	469.6	617	470.1	647	470.4
657	470.4	657	471.4	657.4	471.8	658.9	472.5	660.4	473.2
671.8	474.25	683.3	475.3	697.8	483.05	712.3	490.8	713	491.1
878	494.4	1040	491.2	1055	492	1305	497	1555	492
1568	502	1580	508.1	1581.5	508.1	1583	508.1	1782	508
1810	512	1862	516						

M--ning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
0	.065	260.1	.04	713	.07

Bank Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
260.1	713	1412	1412	1412	.1	.3

CROSS SECTION OUTPUT Profile #100 year

		Element	Left OB	Channel	Right OB
W.S. Elev (ft)	499.21	Wt. n-Val.	0.065	0.040	0.070
Vel Head (ft)	1.15	Reach Len. (ft)	1412.00	1412.00	1412.00
E.G. Elev (ft)	500.36	Flow Area (sq ft)	1808.25	12423.23	4611.28
Crit W.S. (ft)		Area (sq ft)	1808.25	12423.23	4611.28
E.G. Slope (ft/ft)	0.000739	Flow (cfs)	4664.77	112284.40	8190.82
Q Total (cfs)	125140.00	Top Width (ft)	211.18	452.90	851.38
Top Width (ft)	1515.46	Avg. Vel. (ft/s)	2.58	9.04	1.78
Vel Total (ft/s)	6.64	Hydr. Depth (ft)	8.56	27.43	5.42
Max Chl Dpth (ft)	30.51	Conv. (cfs)	171576.1	4129966.0	301269.0
Conv. Total (cfs)	4602812.0	Wetted Per. (ft)	213.84	464.05	854.02
Length Wtd. (ft)	1412.00	Shear (lb/sq ft)	0.39	1.24	0.25
Min Ch El (ft)	468.70	Stream Power (lb/ft s)	1.01	11.17	0.44
Alpha	1.67	Cum Volume (acre-ft)	3358.77	4408.38	1559.48
Frctn Loss (ft)	1.11	Cum SA (acres)	230.18	139.21	138.02
C & E Loss (ft)	0.03				

Warning - The energy loss was greater than 1.0 ft (0.3 m). between the current and previous cross section. This may indicate the need for additional cross sections.

CROSS SECTION RIVER: S. Fork Shenando
REACH: Front Royal RS: 18

INPUT
iption: L
on Elevation Data num= 51

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Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
0	529.7	9.7	533.35	19.5	537	36.7	533.2	53.9	529.4
78.4	520.15	103	510.9	121.6	505.2	140.2	499.5	158.1	498
176	496.5	223.9	494.7	271.8	492.9	295.7	491.5	319.7	490.1
351.1	489.3	382.6	488.5	398.9	479	415.3	469.5	423	469.4
437	468	467	467.4	497	467.6	527	467.1	557	466.1
587	466.2	617	466.7	647	466.4	677	465.8	697	467.4
712	469.4	739.6	469.5	755.9	471.75	772.2	474	786.1	475.8
800.1	477.6	816.1	486.7	821.8	489.9	1585	505.3	1811.7	500.7
1827.4	507.4	1834.2	510.3	1843.2	514.1	1852.9	518.45	1862.6	522.8
1873.9	521.65	1885.2	520.5	1889	519.55	1892.9	518.6	1934.7	519.75
1976.6	520.9								

Manning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
0	.065	382.6	.04	821.8	.07

Bank Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
382.6	821.8	1608	1608	1608	.1	.3

CROSS SECTION OUTPUT Profile #100 year

		Element	Left OB	Channel	Right OB
W.S. Elev (ft)	497.77	Element	Left OB	Channel	Right OB
Vel Head (ft)	1.44	Wt. n-Val.	0.065	0.040	0.070
E.G. Elev (ft)	499.22	Reach Len. (ft)	1608.00	1608.00	1608.00
Crit W.S. (ft)		Flow Area (sq ft)	1137.77	12284.36	1536.22
E.G. Slope (ft/ft)	0.000845	Area (sq ft)	1137.77	12284.36	1536.22
Q Total (cfs)	125140.00	Flow (cfs)	2246.98	120530.30	2362.75
Top Width (ft)	1051.21	Top Width (ft)	221.80	439.20	390.21
Vel Total (ft/s)	8.37	Avg. Vel. (ft/s)	1.97	9.81	1.54
Max Chl Dpth (ft)	31.97	Hydr. Depth (ft)	5.13	27.97	3.94
Conv. Total (cfs)	4305656.0	Conv. (cfs)	77311.1	4147050.0	81294.5
Length Wtd. (ft)	1608.00	Wetted Per. (ft)	222.02	448.41	390.29
Min Ch El (ft)	465.80	Shear (lb/sq ft)	0.27	1.44	0.21
Alpha	1.33	Stream Power (lb/ft s)	0.53	14.18	0.32
Frctn Loss (ft)	1.04	Cum Volume (acre-ft)	3311.02	4007.93	1459.84
C & E Loss (ft)	0.21	Cum SA (acres)	223.16	124.75	117.90

Warning - The velocity head has changed by more than 0.5 ft (0.15 m). This may indicate the need for additional cross sections.

Warning - The energy loss was greater than 1.0 ft (0.3 m). between the current and previous cross section. This may indicate the need for additional cross sections.

CROSS SECTION RIVER: S. Fork Shenando
REACH: Front Royal RS: 17

INPUT
Description: K
Station Elevation Data num= 55

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
0	606.1	22.4	598.2	44.9	590.3	69.3	572.25	93.8	554.2
112.7	531.9	131.6	509.6	153.5	497.65	175.5	485.7	197.5	485.05
219.6	484.4	247.8	484.15	276	483.9	305.2	485.4	334.4	486.9
374.5	487.75	414.7	488.6	436.5	489.25	458.4	489.9	483.6	479.3
508	468.8	532	466.5	562	465.3	592	465.6	622	465.4
652	465.7	682	466.4	712	466.2	742	465.8	772	466.3
802	466	822	466.5	834	468.8	854.8	474.45	877.8	480.2
1001.9	481.1	1126.1	482	1182.2	482.25	1238.4	482.5	1274.8	484.2
1311.2	485.9	1372.1	485.45	1433	485	1470.4	487.85	1507.9	490.7
1566.4	491.65	1624.9	492.6	1657.9	494.85	1690.9	497.1	1728.8	500
1766.7	502.89	1796.7	506.2	1826.8	509.5	1843.4	512.1	1860	514.7

Manning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
0	.065	458.4	.04	877.8	.07

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B- k Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
458.4	877.8	1556	1556	1556	.1	.3

S SECTION OUTPUT Profile #100 year

W.S. Elev (ft)	497.24	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.73	Wt. n-Val.	0.065	0.040	0.070
E.G. Elev (ft)	497.96	Reach Len. (ft)	1556.00	1556.00	1556.00
Crit W.S. (ft)		Flow Area (sq ft)	3200.17	12025.31	9588.88
E.G. Slope (ft/ft)	0.000509	Area (sq ft)	3200.17	12025.31	9588.88
Q Total (cfs)	125140.00	Flow (cfs)	7873.45	93515.16	23751.38
Top Width (ft)	1538.43	Top Width (ft)	304.14	419.40	814.89
Vel Total (ft/s)	5.04	Avg. Vel. (ft/s)	2.46	7.78	2.48
Max Chl Dpth (ft)	31.94	Hydr. Depth (ft)	10.52	28.67	11.77
Conv. Total (cfs)	5546012.0	Conv. (cfs)	348939.3	4144448.0	1052624.0
Length Wtd. (ft)	1556.00	Wetted Per. (ft)	307.21	425.54	815.37
Min Ch El (ft)	465.30	Shear (lb/sq ft)	0.33	0.90	0.37
Alpha	1.84	Stream Power (lb/ft s)	0.81	6.98	0.93
Frctn Loss (ft)	0.78	Cum Volume (acre-ft)	3230.95	3559.24	1254.50
C & E Loss (ft)	0.01	Cum SA (acres)	213.45	108.90	95.66

CROSS SECTION RIVER: S. Fork Shenando
REACH: Front Royal RS: 16

INPUT
Description: J
Station Elevation Data num= 62

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
0	579.2	44.1	565.25	88.2	551.3	103.7	540.35	119.2	529.4
129.9	516.65	140.6	503.9	154.4	495.35	168.3	486.8	185	485.5
201.7	484.2	220.8	485.6	239.9	487	268.4	486.95	297	486.9
314.8	487.7	332.6	488.5	355	486.6	377.5	484.7	387.2	483.55
397	482.4	407.7	474.85	418.4	467.3	420	467.9	445	464.6
475	463.5	505	464.4	535	464.3	565	464.8	595	465.3
625	463.7	655	463.8	685	463.7	715	465.2	723	467.9
725.4	467.3	737.3	470.05	749.2	472.8	773.6	478.85	798.1	484.9
822.8	485.4	847.5	485.9	902.4	484.5	957.3	483.1	1017.1	481.7
1076.9	480.3	1146.8	478.4	1216.7	476.5	1276.4	476.45	1336.1	476.4
1369.1	480.45	1402.1	484.5	1439.5	489.5	1477	494.5	1501.9	500.9
1526.9	507.3	1593.2	507.25	1659.6	507.2	1692.8	508.65	1726.1	510.1
1874	512	1934	516						

Manning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
0	.065	397	.04	798.1	.07

Bank Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
397	798.1	792	792	792	.1	.3

CROSS SECTION OUTPUT Profile #100 year

W.S. Elev (ft)	496.47	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.71	Wt. n-Val.	0.065	0.040	0.070
E.G. Elev (ft)	497.18	Reach Len. (ft)	792.00	792.00	792.00
Crit W.S. (ft)		Flow Area (sq ft)	2409.17	11758.79	10132.22
E.G. Slope (ft/ft)	0.000492	Area (sq ft)	2409.17	11758.79	10132.22
Q Total (cfs)	125140.00	Flow (cfs)	5565.41	90919.45	28655.13
Top Width (ft)	1332.08	Top Width (ft)	244.41	401.10	686.57
Vel Total (ft/s)	5.15	Avg. Vel. (ft/s)	2.31	7.73	2.83
Max Chl Dpth (ft)	32.97	Hydr. Depth (ft)	9.86	29.32	14.76
Conv. Total (cfs)	5642777.0	Conv. (cfs)	250953.8	4099714.0	1292109.0
Length Wtd. (ft)	792.00	Wetted Per. (ft)	247.68	408.96	688.11
Min Ch El (ft)	463.50	Shear (lb/sq ft)	0.30	0.88	0.45
lpha	1.72	Stream Power (lb/ft s)	0.69	6.83	1.28
tn Loss (ft)	0.38	Cum Volume (acre-ft)	3130.77	3134.44	902.27
E Loss (ft)	0.03	Cum SA (acres)	203.66	94.25	68.84

C. SS SECTION RIVER: S. Fork Shenando
REACH: Front Royal RS: 15

INPUT
Description: I
Station Elevation Data num= 64

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
0	557.9	42	553.12	84.1	548.4	103.1	541	122.1	533.6
140.3	524.85	158.6	516.1	181.8	506.2	205.1	496.3	227.1	490.9
249.2	485.5	274.9	484.45	300.7	483.4	320	484.25	339.3	485.1
368.9	486.3	398.6	487.5	442	487.8	485.4	488.1	511.9	487.4
538.5	486.7	555.2	484.85	571.9	483	580.4	474.85	587	467.6
607	464.5	637	464.3	667	463.6	697	464.3	727	464.6
757	464.7	787	465.5	817	464.3	847	464.7	877	464.2
897	465.1	911	467.6	919.5	472.3	941.6	477.9	962.5	481.5
983.5	485.1	1029.7	483.6	1075.9	482.1	1114.9	480.6	1154	479.1
1211.5	478.45	1269	477.8	1295.3	476.4	1321.7	475	1370.1	476
1418.5	477	1462.9	477	1507.3	477	1540.3	479.8	1573.3	482.6
1609.4	486.25	1645.6	489.9	1688.5	493.7	1731.4	497.5	1798	501.65
1864.7	505.3	1937	508	1973	512	1993	516		

Manning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
0	.065	571.9	.04	983.5	.07

Bank Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
571.9	983.5	508	508	508	.1	.3

CROSS SECTION OUTPUT Profile #100 year

		Element	Left OB	Channel	Right OB
W.S. Elev (ft)	496.16	Element	Left OB	Channel	Right OB
1 Head (ft)	0.61	Wt. n-Val.	0.065	0.040	0.070
.G. Elev (ft)	496.77	Reach Len. (ft)	508.00	508.00	508.00
Crit W.S. (ft)		Flow Area (sq ft)	3448.98	11816.50	11125.35
E.G. Slope (ft/ft)	0.000458	Area (sq ft)	3448.98	11816.50	11125.35
Q Total (cfs)	125140.00	Flow (cfs)	7498.65	86698.88	30942.47
Top Width (ft)	1510.63	Top Width (ft)	366.24	411.60	732.79
Vel Total (ft/s)	4.74	Avg. Vel. (ft/s)	2.17	7.34	2.78
Max Chl Dpth (ft)	32.56	Hydr. Depth (ft)	9.42	28.71	15.18
Conv. Total (cfs)	5850287.0	Conv. (cfs)	350561.6	4053167.0	1446558.0
Length Wtd. (ft)	508.00	Wetted Per. (ft)	367.88	421.15	733.88
Min Ch El (ft)	463.60	Shear (lb/sq ft)	0.27	0.80	0.43
Alpha	1.76	Stream Power (lb/ft s)	0.58	5.88	1.20
Frctn Loss (ft)	0.18	Cum Volume (acre-ft)	3077.51	2920.12	709.02
C & E Loss (ft)	0.06	Cum SA (acres)	198.11	86.86	55.94

CROSS SECTION RIVER: S. Fork Shenando
REACH: Front Royal RS: 14

INPUT
Description: H
Station Elevation Data num= 66

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
0	564	16.2	555.05	32.5	546.1	51.7	530.45	70.9	514.8
92.7	503.45	114.5	492.1	125	490.8	135.5	489.5	150.8	486.3
166.2	483.1	193.9	482.15	221.7	481.2	241.1	481.15	260.6	481.1
285.8	482.7	311.1	484.3	349.3	484.3	387.6	484.3	438.2	484.5
488.9	484.7	554.2	483.3	619.6	481.9	643.8	480.85	668	479.8
694.6	473	721.2	466.2	731	464.2	749	463.3	779	463.3
809	462.5	839	462.2	869	462.5	899	462	929	462.4
959	462.2	989	462	1019	461.7	1049	462.3	1057	464.2
062.4	466.2	1071.7	470.5	1081.1	474.8	1115.9	476.8	1150.7	478.8
10.3	477.95	1269.9	477.1	1308.2	475.3	1346.6	473.5	1374	474.55
01.5	475.6	1471.9	475.8	1542.4	476	1593.4	476.9	1644.4	477.8

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1672.7	482.3	1701.1	486.8	1732.7	490.3	1764.3	493.8	1801.5	498.15
1838.8	502.5	1887.9	504	1937	505.5	2053	508	2093	512
2113	516								

Manning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
0	.065	668	.04	1081.1	.07

Bank Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
668	1081.1	672	672	672	.1	.3

CROSS SECTION OUTPUT Profile #100 year

		Element	Left OB	Channel	Right OB
W.S. Elev (ft)	496.12	Wt. n-Val.	0.065	0.040	0.070
Vel Head (ft)	0.42	Reach Len. (ft)	672.00	672.00	672.00
E.G. Elev (ft)	496.54	Flow Area (sq ft)	6960.09	13152.34	12289.17
Crit W.S. (ft)		Area (sq ft)	6960.09	13152.34	12289.17
E.G. Slope (ft/ft)	0.000280	Flow (cfs)	14231.31	81548.17	29360.52
Q Total (cfs)	125140.00	Top Width (ft)	561.22	413.10	703.04
Top Width (ft)	1677.36	Avg. Vel. (ft/s)	2.04	6.20	2.39
Vel Total (ft/s)	3.86	Hydr. Depth (ft)	12.40	31.84	17.48
Max Chl Dpth (ft)	34.42	Conv. (cfs)	850445.7	4873221.0	1754549.0
Conv. Total (cfs)	7478216.0	Wetted Per. (ft)	563.23	417.53	704.54
Length Wtd. (ft)	672.00	Shear (lb/sq ft)	0.22	0.55	0.30
Min Ch El (ft)	461.70	Stream Power (lb/ft s)	0.44	3.41	0.73
Alpha	1.80	Cum Volume (acre-ft)	3016.82	2774.53	572.49
Frctn Loss (ft)	0.19	Cum SA (acres)	192.70	82.05	47.56
C & E Loss (ft)	0.05				

CROSS SECTION RIVER: S. Fork Shenando
REACH: Front Royal RS: 13

r
Description: G
Station Elevation Data num= 67

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
-214	516	-168	512	-122	508	-76	504	-20	500
0	494.9	50.5	491.4	101	487.9	141.2	485.2	181.4	482.5
242.2	482.8	303.1	483.1	385.7	482.4	468.4	481.7	526.5	480.45
584.6	479.2	613	478.05	641.4	476.9	690.4	476.25	739.5	475.6
789.8	476.65	840.2	477.7	896.3	476.2	952.4	474.7	979.9	473.95
1007.4	473.2	1020.4	469.45	1033.5	465.7	1052	463.8	1062	462.9
1092	461.3	1122	461.1	1152	461	1182	461	1212	460.8
1232	460.6	1262	461.6	1292	460.4	1322	463	1332	463.8
1343.8	465.7	1351.8	468.95	1359.8	472.2	1450	471.09	1540.3	471.6
1589.1	473.9	1638	476.2	1685.9	478.95	1733.8	481.7	1766.1	486.05
1798.4	490.4	1824.2	498.85	1850.1	507.3	1923.4	509.5	1996.8	511.7
2025.1	509.65	2053.5	507.6	2086.3	504.9	2119.1	502.2	2135.5	501.3
2152	500.4	2175.6	503.45	2199.2	506.5	2211.3	508	2223.4	509.5
2259	512	2371	516						

Manning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
-214	.06	1007.4	.05	1359.8	.06

Bank Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
1007.4	1359.8	1300	1300	1300	.1	.3

CROSS SECTION OUTPUT Profile #100 year

		Element	Left OB	Channel	Right OB
W.S. Elev (ft)	496.05	Wt. n-Val.	0.060	0.050	0.060
Vel Head (ft)	0.25	Reach Len. (ft)	1300.00	1300.00	1300.00
E.G. Elev (ft)	496.30	Flow Area (sq ft)	15386.73	11787.27	8928.83
Crit W.S. (ft)		Area (sq ft)	15386.73	11787.27	8928.83
E.G. Slope (ft/ft)	0.000274	Flow (cfs)	38708.35	59894.06	26537.59
Q Total (cfs)	125140.00				

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Top Width (ft)	1820.16	Top Width (ft)	1011.91	352.40	455.85
Vel Total (ft/s)	3.47	Avg. Vel. (ft/s)	2.52	5.08	2.97
Max Chl Dpth (ft)	35.65	Hydr. Depth (ft)	15.21	33.45	19.59
Conv. Total (cfs)	7557420.0	Conv. (cfs)	2337664.0	3617106.0	1602651.0
Length Wtd. (ft)	1300.00	Wetted Per. (ft)	1012.65	355.25	457.61
Min Ch El (ft)	460.40	Shear (lb/sq ft)	0.26	0.57	0.33
Alpha	1.35	Stream Power (lb/ft s)	0.65	2.89	0.99
Frctn Loss (ft)	0.41	Cum Volume (acre-ft)	2844.44	2582.16	408.83
C & E Loss (ft)	0.01	Cum SA (acres)	180.56	76.14	38.62

CROSS SECTION RIVER: S. Fork Shenando
REACH: Front Royal RS: 12

INPUT
Description: F
Station Elevation Data num= 54

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
-69.1	516	-29.1	512	50.9	508	134.9	504	246.9	500
274.9	496	294.9	492	374.9	486.3	455.5	485.2	536.2	484.1
618.7	482.85	701.3	481.6	758	479.6	814.8	477.6	875.9	476.85
937	476.1	981.1	476.45	1025.2	476.8	1117.5	478.3	1209.9	479.8
1254.9	479	1299.9	478.2	1363.4	475.7	1427	473.2	1458.6	471.3
1490.2	469.4	1523	469.25	1555.9	469.1	1571.7	467.1	1587.5	465.1
1599	464.4	1619	462.1	1649	461.2	1679	460.6	1709	460.7
1739	460.9	1769	461.2	1799	461.1	1829	461.9	1839	462.6
1851	464.4	1862.2	465.1	1870.4	472	1878.6	478.9	1885.6	491.65
1892.7	504.4	1906.9	510.6	1921.2	516.8	1945.8	525.55	1970.4	534.3
1991.9	534.75	2013.4	535.2	2043	537.35	2072.6	539.5		

Manning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
-69.1	.06	1490.2	.05	1870.4	.06

Bank Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
1490.2	1870.4	1728	1728	1728	.1	.3

CROSS SECTION OUTPUT Profile #100 year

		Element	Left OB	Channel	Right OB
W.S. Elev (ft)	495.54	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.34	Wt. n-Val.	0.060	0.050	0.060
E.G. Elev (ft)	495.88	Reach Len. (ft)	1728.00	1728.00	1728.00
Crit W.S. (ft)		Flow Area (sq ft)	18812.70	12142.94	240.86
E.G. Slope (ft/ft)	0.000367	Area (sq ft)	18812.70	12142.94	240.86
Q Total (cfs)	125140.00	Flow (cfs)	55474.10	69204.87	461.02
Top Width (ft)	1610.58	Top Width (ft)	1213.01	380.20	17.37
Vel Total (ft/s)	4.01	Avg. Vel. (ft/s)	2.95	5.70	1.91
Max Chl Dpth (ft)	34.94	Hydr. Depth (ft)	15.51	31.94	13.87
Conv. Total (cfs)	6532876.0	Conv. (cfs)	2896000.0	3612808.0	24067.6
Length Wtd. (ft)	1728.00	Wetted Per. (ft)	1213.94	383.34	29.72
Min Ch El (ft)	460.60	Shear (lb/sq ft)	0.36	0.73	0.19
Alpha	1.36	Stream Power (lb/ft s)	1.05	4.14	0.36
Frctn Loss (ft)	0.55	Cum Volume (acre-ft)	2334.12	2225.07	272.00
C & E Loss (ft)	0.00	Cum SA (acres)	147.36	65.21	31.56

CROSS SECTION RIVER: S. Fork Shenando
REACH: Front Royal RS: 11

INPUT
Description: E
Station Elevation Data num= 66

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
-136	516	-104	512	0	508.5	80.6	504.7	161.2	500.9
69.2	495.55	377.2	490.2	439.5	486.55	501.8	482.9	549.4	481.05
7.1	479.2	652.4	478.25	707.8	477.3	789.4	476.35	871	475.4
99.7	474.45	928.5	473.5	956.1	474.6	983.8	475.7	1044.3	476.8

1104.9	477.9	1173.8	478.1	1242.7	478.3	1285.9	479.55	1329.1	480.8
87.2	480.95	1445.3	481.1	1482.4	478.75	1519.5	476.4	1567.1	473.9
14.8	471.4	1628.8	467.55	1643	461.2	1650	459.6	1657	459.45
1665	460	1673	461.3	1688	463.9	1708	465.8	1725	464
1735	461.6	1753	459	1783	458.6	1813	458.6	1843	459.2
1873	458.9	1903	459	1933	459.2	1963	459.5	1977	461.4
1993.8	481.3	2012.1	498.9	2025.2	508.95	2038.3	519	2051.2	523.75
2064.2	528.5	2075.8	527	2087.4	525.5	2099.4	531.55	2111.5	537.6
2137.2	543.5	2162.9	549.4	2192.3	559.3	2221.8	569.2	2248.3	573.7
2274.8	578.2								

Manning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
-136	.06	1614.8	.045	1993.8	.06

Bank Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
1614.8	1993.8	924	924	924	.1	.3

CROSS SECTION OUTPUT Profile #100 year

		Element	Left OB	Channel	Right OB
W.S. Elev (ft)	495.00	Wt. n-Val.	0.060	0.045	0.060
Vel Head (ft)	0.33	Reach Len. (ft)	924.00	924.00	924.00
E.G. Elev (ft)	495.33	Flow Area (sq ft)	20538.89	12835.36	97.57
Crit W.S. (ft)		Area (sq ft)	20538.89	12835.36	97.57
E.G. Slope (ft/ft)	0.000279	Flow (cfs)	52526.67	72496.36	116.98
Q Total (cfs)	125140.00	Top Width (ft)	1334.49	379.00	14.24
Top Width (ft)	1727.73	Avg. Vel. (ft/s)	2.56	5.65	1.20
Vel Total (ft/s)	3.74	Hydr. Depth (ft)	15.39	33.87	6.85
Max Chl Dpth (ft)	36.40	Conv. (cfs)	3145911.0	4341930.0	7005.9
Conv. Total (cfs)	7494847.0	Wetted Per. (ft)	1335.33	391.44	19.76
Length Wtd. (ft)	924.00	Shear (lb/sq ft)	0.27	0.57	0.09
Min Ch El (ft)	458.60	Stream Power (lb/ft s)	0.68	3.22	0.10
lpha	1.52	Cum Volume (acre-ft)	1553.59	1729.63	265.28
ctn Loss (ft)	0.22	Cum SA (acres)	96.83	50.15	30.94
E Loss (ft)	0.01				

CROSS SECTION RIVER: S. Fork Shenando
REACH: Front Royal RS: 10

INPUT
Description: D
Station Elevation Data num= 90

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
0	527.7	46.6	522.6	93.3	517.5	158.7	512.25	224.2	507
274.1	503.75	324	500.5	370.1	497.75	416.3	495	417.4	494.7
418.5	494.4	421.7	494.85	425	495.3	441.9	494.9	458.9	494.5
490.8	493.1	522.8	491.7	560.2	490.5	597.7	489.3	625	488.85
652.3	488.4	665.5	488.85	678.7	489.3	690.1	488.75	701.6	488.2
730.7	485.25	759.8	482.3	783.2	480.35	806.6	478.4	854.2	477.85
901.8	477.3	985.7	477.3	1069.7	477.3	1157.2	476.25	1244.8	475.2
1287.8	474.9	1330.9	474.6	1380.7	475.55	1430.5	476.5	1520.3	478.2
1610.1	479.9	1676.6	479.05	1743.1	478.2	1763.3	477.25	1783.6	476.3
1816.5	476.15	1849.5	476	1867.8	469.55	1886.1	463.1	1896	460.4
1905	458.1	1935	458.1	1965	457.4	1995	457.1	2025	456.44
2055	456.1	2085	457.2	2115	457.4	2145	458	2165	458
2175	460.4	2183.7	463.1	2194.9	469.55	2206.1	476	2220.4	483.95
2234.7	491.9	2252.2	491.35	2269.8	490.8	2362.7	491.85	2455.7	492.9
2474.4	496.35	2493.1	499.8	2510.6	510.25	2528.2	520.7	2535.3	521.95
2542.4	523.2	2556.6	522.4	2570.8	521.6	2577.3	524.25	2583.8	526.9
2596.2	536.3	2608.7	545.7	2639.2	549	2669.8	552.3	2705.6	552.95
2741.4	553.6	2764.2	551.4	2787.1	549.2	2823.8	548.7	2860.6	548.2

Manning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
0	.055	1849.5	.035	2234.7	.06

Ba-k Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
1849.5	2234.7	1188	1188	1188	.1	.3

CROSS SECTION OUTPUT   Profile #100 year

			Left OB	Channel	Right OB
W.S. Elev (ft)	494.72	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.38	Wt. n-Val.	0.055	0.035	0.060
E.G. Elev (ft)	495.11	Reach Len. (ft)	1188.00	1188.00	1188.00
Crit W.S. (ft)		Flow Area (sq ft)	20626.96	12816.00	661.84
E.G. Slope (ft/ft)	0.000198	Area (sq ft)	20626.96	12816.00	661.84
Q Total (cfs)	125140.00	Flow (cfs)	47054.41	77620.96	464.63
Top Width (ft)	2019.73	Top Width.(ft)	1403.64	385.20	230.89
Vel Total (ft/s)	3.67	Avg. Vel. (ft/s)	2.28	6.06	0.70
Max Chl Dpth (ft)	38.62	Hydr. Depth (ft)	14.70	33.27	2.87
Conv. Total (cfs)	8902918.0	Conv. (cfs)	3347623.0	5522240.0	33055.7
Length Wtd. (ft)	1188.00	Wetted Per. (ft)	1404.45	396.37	231.09
Min Ch El (ft)	456.10	Shear (lb/sq ft)	0.18	0.40	0.04
Alpha	1.84	Stream Power (lb/ft s)	0.41	2.42	0.02
Frctn Loss (ft)	0.27	Cum Volume (acre-ft)	1116.99	1457.57	257.23
C & E Loss (ft)	0.02	Cum SA (acres)	67.79	42.05	28.34

Warning - Divided flow computed for this cross-section.

CROSS SECTION   RIVER: S. Fork Shenando
REACH: Front Royal   RS: 9

INPUT
Description: RT340
Station Elevation Data   num=   85

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
0	532.1	0	526.1	20	525	50	507	58	506.9
58	520	62	520	62	507.1	90	503.4	140	498.9
174	494.5	174	520	180	520	180	493.9	250	484.2
320	475.6	368	474.4	368	520	374	520	374	475.9
450	474.8	530	476.2	561	475.8	561	520	566	520
566	476	650	475.2	720	474.4	753	474.7	753	520
757	520	757	475.6	840	475.7	920	474.8	948	475.3
948	520	953	520	953	475.3	1020	473.3	1057	470.6
1067	459.1	1090	457.5	1110	457.3	1130	456.6	1144	456.4
1144	520	1148	520	1148	456.2	1170	456.4	1200	455.6
1230	455.5	1260	457.4	1290	456.5	1320	457	1341	456.5
1341	520	1346	520	1346	458.3	1360	459	1390	471.1
1430	488.9	1480	487.4	1520	487	1536	486.9	1536	520
1540	520	1540	486.3	1620	485	1700	488.5	1731	491.5
1731	520	1736	520	1736	491.9	1750	495.1	1757	502.5
1790	512.9	1830	516.6	1850	517.9	1850	520	1854	520
1854	517.8	1870	523	1900	537	1914	541	1914	547.6

Manning's n Values   num=   3

Sta	n Val	Sta	n Val	Sta	n Val
0	.04	1057	.04	1390	.04

Bank Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
1057	1390	252	252	252	.1	.3

CROSS SECTION OUTPUT   Profile #100 year

			Left OB	Channel	Right OB
W.S. Elev (ft)	494.51	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.30	Wt. n-Val.	0.040	0.040	0.040
E.G. Elev (ft)	494.81	Reach Len. (ft)	252.00	252.00	252.00
Crit W.S. (ft)		Flow Area (sq ft)	15359.14	11900.01	2796.20
E.G. Slope (ft/ft)	0.000265	Area (sq ft)	15359.14	11900.01	2796.20
Q Total (cfs)	125140.00	Flow (cfs)	57566.48	60973.05	6600.47
~~p Width (ft)	1529.50	Top Width (ft)	857.08	324.00	348.42
. Total (ft/s)	4.16	Avg. Vel. (ft/s)	3.75	5.12	2.36
..x Chl Dpth (ft)	39.01	Hydr. Depth (ft)	17.92	36.73	8.03

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Conv. Total (cfs)	7688234.0	Conv. (cfs)	3536715.0	3746005.0	405513.6
gth Wtd. (ft)	252.00	Wetted Per. (ft)	1012.17	482.41	374.19
Ch El (ft)	455.50	Shear (lb/sq ft)	0.25	0.41	0.12
ha	1.13	Stream Power (lb/ft s)	0.94	2.09	0.29
ctn Loss (ft)	0.06	Cum Volume (acre-ft)	626.27	1120.54	210.07
C & E Loss (ft)	0.02	Cum SA (acres)	36.97	32.38	20.44

Warning - Divided flow computed for this cross-section.

CROSS SECTION RIVER: S. Fork Shenando
REACH: Front Royal RS: 8

INPUT
Description: C
Station Elevation Data num= 71

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
-416	512	-320	508	-220	504	-152	504	0	505.3
30.6	503.55	61.2	501.8	89.1	498.2	117.1	494.6	143.2	491.9
169.3	489.2	191	486.85	212.7	484.5	244.5	480.35	276.3	476.2
298.7	475.45	321.2	474.7	357.4	474.05	393.7	473.4	441.5	474.1
489.3	474.8	645.8	475.7	820.4	476.6	871.4	475.15	922.5	473.7
940	467.9	957.6	462.1	965	460	974	458.5	1004	457.6
1034	456.6	1064	456.4	1094	455.8	1124	455.4	1154	455
1184	455.3	1214	455.7	1244	456.8	1254	457.2	1264	460
1270.3	462.1	1287.5	469.8	1304.8	477.5	1320.1	481.5	1335.5	485.5
1361.2	484	1386.9	482.45	1435.3	482.85	1483.7	483.2	1534.6	484.5
1585.5	485.8	1607.6	487.25	1629.8	488.7	1650.9	489.4	1672	490.1
1695	494.25	1718	498.4	1728.9	502.2	1739.9	506	1749.2	510.05
1758.6	514.1	1765.3	515.1	1772.1	516.1	1783.4	515.2	1794.7	514.3
1815.6	526.8	1836.5	539.3	1858.5	544.35	1880.6	549.4	1925.4	549.5
1970.2	549.6								

M ng's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
416	.06	922.5	.035	1335.5	.065

Bank Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
922.5	1335.5	1851	1851	1851	.1	.3

CROSS SECTION OUTPUT Profile #100 year

		Element	Left OB	Channel	Right OB
W.S. Elev (ft)	494.28	Wt. n-Val.	0.060	0.035	0.065
Vel Head (ft)	0.46	Reach Len. (ft)	1851.00	1851.00	1851.00
E.G. Elev (ft)	494.74	Flow Area (sq ft)	13668.85	13953.41	3196.80
Crit W.S. (ft)		Area (sq ft)	13668.85	13953.41	3196.80
E.G. Slope (ft/ft)	0.000208	Flow (cfs)	32317.89	88301.47	4520.63
Q Total (cfs)	125140.00	Top Width (ft)	802.27	413.00	359.65
Top Width (ft)	1574.92	Avg. Vel. (ft/s)	2.36	6.33	1.41
Vel Total (ft/s)	4.06	Hydr. Depth (ft)	17.04	33.79	8.89
Max Chl Dpth (ft)	39.28	Conv. (cfs)	2239243.0	6118235.0	313225.8
Conv. Total (cfs)	8670704.0	Wetted Per. (ft)	803.42	420.39	360.27
Length Wtd. (ft)	1851.00	Shear (lb/sq ft)	0.22	0.43	0.12
Min Ch El (ft)	455.00	Stream Power (lb/ft s)	0.52	2.73	0.16
Alpha	1.81	Cum Volume (acre-ft)	542.30	1045.76	192.74
Frctn Loss (ft)	0.47	Cum SA (acres)	32.17	30.25	18.39
C & E Loss (ft)	0.00				

CROSS SECTION RIVER: S. Fork Shenando
REACH: Front Royal RS: 7

INPUT
Description: A.2
Station Elevation Data num= 70

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
40	530.02	-40	498.82	0	498.42	4.5	497.52	9	496.62

24.9	491.02	40.8	485.52	88.1	485.07	135.4	484.62	187.7	479.07
240	473.52	266.6	472.02	293.2	470.52	316.2	471.42	339.2	472.32
[illegible]7.85	473.22	436.5	474.12	478.1	472.82	519.7	471.52	531.5	467.97
543.4	464.42	545.95	463.02	548.5	461.62	550	459.62	561	454.82
591	454.82	621	455.12	651	455.12	681	454.92	698	454.32
728	454.72	758	454.72	788	454.52	818	454.12	838	454.52
848	456.92	855	459.62	857.7	461.62	865.25	462.52	872.8	463.42
893.65	463.62	914.5	463.82	936.5	472.42	958.5	481.02	1056.75	480.82
1155	480.62	1172.45	483.42	1189.9	486.22	1204.95	489.12	1220	492.02
1232	496.82	1244	501.62	1249.35	502.02	1254.7	502.42	1257.95	503.02
1261.2	503.62	1270.25	503.22	1279.33	502.82	1281.8	502.17	1284.3	501.52
1292.95	508.02	1301.6	514.52	1312.75	514.52	1323.9	514.52	1332.5	518.12
1341.1	521.72	1370.45	526.47	1399.8	531.22	1416.25	529.12	1432.7	527.02

Manning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
-40	.065	519.7	.045	936.5	.065

Bank Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
519.7	936.5	113	113	113	.1	.3

CROSS SECTION OUTPUT Profile #100 year

		Element	Left OB	Channel	Right OB
W.S. Elev (ft)	493.76	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.50	Wt. n-Val.	0.065	0.045	0.065
E.G. Elev (ft)	494.26	Reach Len. (ft)	113.00	113.00	113.00
Crit W.S. (ft)		Flow Area (sq ft)	8381.61	15044.09	3421.93
E.G. Slope (ft/ft)	0.000318	Area (sq ft)	8381.61	15044.09	3421.93
Q Total (cfs)	125140.00	Flow (cfs)	22238.78	95684.70	7216.51
Top Width (ft)	1207.23	Top Width (ft)	502.58	416.80	287.85
Vel Total (ft/s)	4.66	Avg. Vel. (ft/s)	2.65	6.36	2.11
Max Chl Dpth (ft)	39.64	Hydr. Depth (ft)	16.68	36.09	11.89
[illegible]nv. Total (cfs)	7017782.0	Conv. (cfs)	1247139.0	5365945.0	404698.1
[illegible]gth Wtd. (ft)	113.00	Wetted Per. (ft)	504.74	423.76	290.81
[illegible]n Ch El (ft)	454.12	Shear (lb/sq ft)	0.33	0.70	0.23
Alpha	1.49	Stream Power (lb/ft s)	0.87	4.48	0.49
Frctn Loss (ft)	0.03	Cum Volume (acre-ft)	73.81	429.66	52.11
C & E Loss (ft)	0.01	Cum SA (acres)	4.44	12.62	4.63

CROSS SECTION RIVER: S. Fork Shenando
REACH: Front Royal RS: 6

INPUT
Description:
Station Elevation Data num= 70

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
-40	530	-40	498.8	0	498.4	4.5	497.5	9	496.6
24.9	491	40.8	485.5	88.1	485.05	135.4	484.6	187.7	479.05
240	473.5	266.6	472	293.2	470.5	316.2	471.4	339.2	472.3
387.85	473.2	436.5	474.1	478.1	472.8	519.7	471.5	531.5	467.95
543.4	464.4	545.95	463	548.5	461.6	550	459.6	561	454.8
591	454.8	621	455.1	651	455.1	681	454.9	698	454.3
728	454.7	758	454.7	788	454.5	818	454.1	838	454.5
848	456.9	855	459.6	857.7	461.6	865.25	462.5	872.8	463.4
893.65	463.6	914.5	463.8	936.5	472.4	958.5	481	1056.75	480.8
1155	480.6	1172.45	483.4	1189.9	486.12	1204.95	489.1	1220	492
1232	496.8	1244	501.6	1249.35	502	1254.7	502.4	1257.95	503
1261.2	503.6	1270.25	503.2	1279.33	502.8	1281.8	502.15	1284.3	501.5
1292.95	508	1301.6	514.5	1312.75	514.5	1323.9	514.5	1332.5	518.1
1341.1	521.7	1370.45	526.45	1399.8	531.2	1416.25	529.1	1432.7	527

Manning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
-40	.065	519.7	.035	936.5	.065

B[illegible] Sta: Left Right Lengths: Left Channel Right Coeff Contr. Expan.

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519.7	936.5	429	429	429	.1	.3

S SECTION OUTPUT Profile #100 year

.S. Elev (ft)	493.64	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.58	Wt. n-Val.	0.065	0.035	0.065
E.G. Elev (ft)	494.23	Reach Len. (ft)	429.00	429.00	429.00
Crit W.S. (ft)		Flow Area (sq ft)	8333.60	15004.28	3395.75
E.G. Slope (ft/ft)	0.000217	Area (sq ft)	8333.60	15004.28	3395.75
Q Total (cfs)	125140.00	Flow (cfs)	18183.88	101073.30	5882.85
Top Width (ft)	1206.72	Top Width (ft)	502.31	416.80	287.61
Vel Total (ft/s)	4.68	Avg. Vel. (ft/s)	2.18	6.74	1.73
Max Chl Dpth (ft)	39.54	Hydr. Depth (ft)	16.59	36.00	11.81
Conv. Total (cfs)	8504174.0	Conv. (cfs)	1235727.0	6868665.0	399782.4
Length Wtd. (ft)	429.00	Wetted Per. (ft)	504.45	423.76	290.55
Min Ch El (ft)	454.10	Shear (lb/sq ft)	0.22	0.48	0.16
Alpha	1.71	Stream Power (lb/ft s)	0.49	3.22	0.27
Frctn Loss (ft)	0.11	Cum Volume (acre-ft)	52.12	390.68	43.27
C & E Loss (ft)	0.04	Cum SA (acres)	3.14	11.53	3.88

CROSS SECTION RIVER: S. Fork Shenando
REACH: Front Royal RS: 5

INPUT
Description: SRRR
Station Elevation Data num= 41

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
0	497.9	0	497.2	15	496.3	38	484.46	45	474.6
68	472.4	92	466	100	460.4	112	456.2	132	454.1
152	454.7	172	454.9	182	456.5	192	459.4	205	459.4
212	456.2	232	453.8	252	453.8	272	453.6	292	453.9
312	453.8	332	454.3	342	457	352	459.4	364	459.4
372	453.8	392	453.7	412	453.8	432	454.6	442	456.9
453	460.4	476	467.9	487	472.6	502	475.2	509	490.4
514	491.6	524	494.8	529	495.7	534	496.6	535.5	496.8
535.5	497.9								

Manning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
0	.065	68	.035	487	.065

Bank Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
68	487	14	14	14	.3	.5

CROSS SECTION OUTPUT Profile #100 year

W.S. Elev (ft)	493.04	Element	Left OB	Channel	Right OB
Vel Head (ft)	1.03	Wt. n-Val.	0.065	0.035	0.065
E.G. Elev (ft)	494.07	Reach Len. (ft)	1.00	1.00	1.00
Crit W.S. (ft)	471.06	Flow Area (sq ft)	615.68	15047.22	372.35
E.G. Slope (ft/ft)	0.000324	Area (sq ft)	615.68	15047.22	372.35
Q Total (cfs)	125140.00	Flow (cfs)	1284.39	123197.50	658.13
Top Width (ft)	497.19	Top Width (ft)	46.68	419.00	31.51
Vel Total (ft/s)	7.80	Avg. Vel. (ft/s)	2.09	8.19	1.77
Max Chl Dpth (ft)	39.44	Hydr. Depth (ft)	13.19	35.91	11.82
Conv. Total (cfs)	6950816.0	Conv. (cfs)	71340.8	6842920.0	36555.1
Length Wtd. (ft)	1.00	Wetted Per. (ft)	53.95	429.21	41.84
Min Ch El (ft)	453.60	Shear (lb/sq ft)	0.23	0.71	0.18
Alpha	1.08	Stream Power (lb/ft s)	0.48	5.81	0.32
Frctn Loss (ft)	0.00	Cum Volume (acre-ft)	8.06	242.70	24.72
C & E Loss (ft)	0.11	Cum SA (acres)	0.44	7.42	2.31

W ning - The conveyance ratio (upstream conveyance divided by downstream conveyance) is less than 0.7 or greater than 1.4. This may indicate the need for additional cross ons.

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I 3E RIVER: S. Fork Shenando
R. .H: Front Royal RS: 4.5

INPUT
Description:
Distance from Upstream XS = 1
Deck/Roadway Width = 13
Weir Coefficient = 2.6
Bridge Deck/Roadway Skew =
Upstream Deck/Roadway Coordinates
num= 2

Sta	Hi Cord	Lo Cord	Sta	Hi Cord	Lo Cord
0	501	496	535.5	501	496

Upstream Bridge Cross Section Data
Station Elevation Data num= 41

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
0	497.9	0	497.2	15	496.3	38	484.46	45	474.6
68	472.4	92	466	100	460.4	112	456.2	132	454.1
152	454.7	172	454.9	182	456.5	192	459.4	205	459.4
212	456.2	232	453.8	252	453.8	272	453.6	292	453.9
312	453.8	332	454.3	342	457	352	459.4	364	459.4
372	453.8	392	453.7	412	453.8	432	454.6	442	456.9
453	460.4	476	467.9	487	472.6	502	475.2	509	490.4
514	491.6	524	494.8	529	495.7	534	496.6	535.5	496.8
535.5	497.9								

Manning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
0	.065	68	.035	487	.065

B--k Sta: Left	Right	Coeff Contr.	Expan.
68	487	.3	.5

Downstream Deck/Roadway Coordinates
num= 2

Sta	Hi Cord	Lo Cord	Sta	Hi Cord	Lo Cord
0	501	496	535.5	501	496

Downstream Bridge Cross Section Data
Station Elevation Data num= 41

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
0	497	0	496.3	15	495.4	38	483.56	45	473.7
68	471.5	92	465.1	100	459.5	112	455.3	132	453.2
152	453.8	172	454	182	455.6	192	458.5	205	458.5
212	455.3	232	452.9	252	452.9	272	452.7	292	453
312	452.9	332	453.4	342	456.1	352	458.5	364	458.5
372	452.9	392	452.8	412	452.9	432	453.7	442	456
453	459.5	476	467	487	471.7	502	474.3	509	489.5
514	490.7	524	493.9	529	494.8	534	495.7	535.5	495.9
535.5	497								

Manning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
0	.065	68	.035	487	.065

Bank Sta: Left	Right	Coeff Contr.	Expan.
68	487	.3	.5

Upstream Embankment side slope = 1.33 horiz. to 1.0 vertical
Downstream Embankment side slope = 1.33 horiz. to 1.0 vertical
Maximum allowable submergence for weir flow = .95
Elevation at which weir flow begins =
En--gy head used in spillway design =
S way height used in design =
W. crest shape = Broad Crested

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[illegible]er of Piers = 2

[illegible] Data
[illegible]r Station Upstream= 199 Downstream= 199
Upstream num= 6

Width	Elev	Width	Elev	Width	Elev	Width	Elev	Width	Elev
25	458.5	25	478	32	478	32	482	39	482
39	496								

Downstream num= 6

Width	Elev	Width	Elev	Width	Elev	Width	Elev	Width	Elev
25	458.5	25	478	32	478	32	482	39	482
39	496								

Pier Data
Pier Station Upstream= 358 Downstream= 358
Upstream num= 6

Width	Elev	Width	Elev	Width	Elev	Width	Elev	Width	Elev
25	458.5	25	478	32	478	32	482	39	482
39	496								

Downstream num= 6

Width	Elev	Width	Elev	Width	Elev	Width	Elev	Width	Elev
25	458.5	25	478	32	478	32	482	39	482
39	496								

Number of Bridge Coefficient Sets = 1

Low Flow Methods and Data
Energy
Selected Low Flow Methods = Highest Energy Answer

High Flow Method
Pressure and Weir flow
Submerged Inlet Cd =
Submerged Inlet + Outlet Cd = .8
Max Low Cord =

Additional Bridge Parameters
Add Friction component to Momentum
Do not add Weight component to Momentum
Class B flow critical depth computations use critical depth
inside the bridge at the downstream end
Criteria to check for pressure flow = Upstream water surface

CROSS SECTION RIVER: S. Fork Shenando
REACH: Front Royal RS: 4

INPUT
Description: SRRR
Station Elevation Data num= 41

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
0	497	0	496.3	15	495.4	38	483.56	45	473.7
68	471.5	92	465.1	100	459.5	112	455.3	132	453.2
152	453.8	172	454	182	455.6	192	458.5	205	458.5
212	455.3	232	452.9	252	452.9	272	452.7	292	453
312	452.9	332	453.4	342	456.1	352	458.5	364	458.5
372	452.9	392	452.8	412	452.9	432	453.7	442	456
453	459.5	476	467	487	471.7	502	474.3	509	489.5
514	490.7	524	493.9	529	494.8	534	495.7	535.5	495.9
535.5	497								

Manning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
0	.065	68	.035	487	.065

[illegible] Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
68	487	7	7	7	.3	.5

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S SECTION OUTPUT   Profile #100 year

		Element	Left OB	Channel	Right OB
W.S. Elev (ft)	492.76	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.99	Wt. n-Val.	0.065	0.035	0.065
E.G. Elev (ft)	493.75	Reach Len. (ft)	7.00	7.00	7.00
Crit W.S. (ft)		Flow Area (sq ft)	644.92	15306.38	392.44
E.G. Slope (ft/ft)	0.000306	Area (sq ft)	644.92	15306.38	392.44
Q Total (cfs)	125140.00	Flow (cfs)	1326.02	123137.80	676.18
Top Width (ft)	500.32	Top Width (ft)	47.88	419.00	33.45
Vel Total (ft/s)	7.66	Avg. Vel. (ft/s)	2.06	8.04	1.72
Max Chl Dpth (ft)	40.06	Hydr. Depth (ft)	13.47	36.53	11.73
Conv. Total (cfs)	7154953.0	Conv. (cfs)	75816.1	7040476.0	38660.7
Length Wtd. (ft)	7.00	Wetted Per. (ft)	55.30	429.21	43.87
Min Ch El (ft)	452.70	Shear (lb/sq ft)	0.22	0.68	0.17
Alpha	1.09	Stream Power (lb/ft s)	0.46	5.48	0.29
Frctn Loss (ft)	0.00	Cum Volume (acre-ft)	7.86	238.51	24.60
C & E Loss (ft)	0.06	Cum SA (acres)	0.42	7.31	2.30

CROSS SECTION   RIVER: S. Fork Shenando
REACH: Front Royal   RS: 3

INPUT
Description: A.1
Station Elevation Data   num=   52

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
-40	520.04	-40	473.44	0	473.94	8.1	471.14	16.3	468.34
20.1	467.74	24	467.14	28	464.34	32	459.64	43	457.24
73	453.44	103	452.54	133	451.64	163	451.64	193	452.24
223	451.84	253	452.34	283	452.34	303	453.54	313	459.64
318.3	462.04	323.5	462.54	330.9	463.74	338.3	464.94	356.7	472.59
375.1	480.24	420.4	480.79	465.8	481.34	497.2	481.94	528.6	482.54
45.3	483.74	562	484.94	576	491.64	590	498.34	595	499.44
600	500.54	605	500.54	610	500.54	614.3	500.09	618.7	499.64
636.2	498.39	653.8	497.14	680.7	497.09	707.7	497.04	722.6	497.99
737.6	498.94	746.4	498.94	755.2	498.94	764.2	502.69	773.2	506.44
795.3	507.84	817.4	509.24						

Manning's n Values   num=   3

Sta	n Val	Sta	n Val	Sta	n Val
-40	.065	0	.035	356.7	.065

Bank Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
0	356.7	244	244	244	.1	.3

CROSS SECTION OUTPUT   Profile #100 year

		Element	Left OB	Channel	Right OB
W.S. Elev (ft)	492.48	Element	Left OB	Channel	Right OB
Vel Head (ft)	1.21	Wt. n-Val.	0.065	0.035	0.065
E.G. Elev (ft)	493.69	Reach Len. (ft)	244.00	244.00	244.00
Crit W.S. (ft)		Flow Area (sq ft)	751.60	13059.08	2369.09
E.G. Slope (ft/ft)	0.000386	Area (sq ft)	751.60	13059.08	2369.09
Q Total (cfs)	125140.00	Flow (cfs)	1840.08	118180.00	5119.89
Top Width (ft)	617.76	Top Width (ft)	40.00	356.70	221.06
Vel Total (ft/s)	7.73	Avg. Vel. (ft/s)	2.45	9.05	2.16
Max Chl Dpth (ft)	40.84	Hydr. Depth (ft)	18.79	36.61	10.72
Conv. Total (cfs)	6370516.0	Conv. (cfs)	93673.3	6016204.0	260639.0
Length Wtd. (ft)	244.00	Wetted Per. (ft)	59.04	365.33	224.40
Min Ch El (ft)	451.64	Shear (lb/sq ft)	0.31	0.86	0.25
Alpha	1.30	Stream Power (lb/ft s)	0.75	7.79	0.55
Frctn Loss (ft)	0.09	Cum Volume (acre-ft)	7.75	236.23	24.37
C & E Loss (ft)	0.00	Cum SA (acres)	0.41	7.25	2.28

S SECTION   RIVER: S. Fork Shenando
R. .CH: Front Royal   RS: 2

AR106488

ription: A
ion Elevation Data num= 52

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
-40	520	-40	473.4	0	473.9	8.1	471.1	16.3	468.3
20.1	467.7	24	467.1	28	464.3	32	459.6	43	457.2
73	453.4	103	452.5	133	451.6	163	451.6	193	452.2
223	451.8	253	452.3	283	452.3	303	453.5	313	459.6
318.3	462	323.5	462.5	330.9	463.7	338.3	464.9	356.7	472.55
375.1	480.2	420.4	480.75	465.8	481.3	497.2	481.9	528.6	482.5
545.3	483.7	562	484.9	576	491.6	590	498.3	595	499.4
600	500.5	605	500.5	610	500.5	614.3	500.05	618.7	499.6
636.2	498.35	653.8	497.1	680.7	497.05	707.7	497	722.6	497.95
737.6	498.89	746.4	498.9	755.2	498.9	764.2	502.65	773.2	506.4
795.3	507.8	817.4	509.2						

Manning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
-40	.065	0	.035	356.7	.065

Bank Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
0	356.7	412	412	412	.1	.3

CROSS SECTION OUTPUT Profile #100 year

		Element	Left OB	Channel	Right OB
W.S. Elev (ft)	492.38	Element	Left OB	Channel	Right OB
Vel Head (ft)	1.21	Wt. n-Val.	0.065	0.035	0.065
E.G. Elev (ft)	493.59	Reach Len. (ft)	412.00	412.00	412.00
Crit W.S. (ft)		Flow Area (sq ft)	749.21	13037.72	2355.86
E.G. Slope (ft/ft)	0.000388	Area (sq ft)	749.21	13037.72	2355.86
Q Total (cfs)	125140.00	Flow (cfs)	1837.08	118213.20	5089.70
Top Width (ft)	617.63	Top Width (ft)	40.00	356.70	220.93
Total (ft/s)	7.75	Avg. Vel. (ft/s)	2.45	9.07	2.16
Chl Dpth (ft)	40.78	Hydr. Depth (ft)	18.73	36.55	10.66
nv. Total (cfs)	6351376.0	Conv. (cfs)	93239.4	5999813.0	258323.4
Length Wtd. (ft)	412.00	Wetted Per. (ft)	58.98	365.33	224.26
Min Ch El (ft)	451.60	Shear (lb/sq ft)	0.31	0.86	0.25
Alpha	1.30	Stream Power (lb/ft s)	0.75	7.84	0.55
Frctn Loss (ft)	0.14	Cum Volume (acre-ft)	3.54	163.14	11.14
C & E Loss (ft)	0.17	Cum SA (acres)	0.19	5.25	1.04

Warning - The velocity head has changed by more than 0.5 ft (0.15 m). This may indicate the need for additional cross sections.

CROSS SECTION RIVER: S. Fork Shenando
REACH: Front Royal RS: 1

INPUT
Description: NWRR - Downstream Limit of the Study Reach - At Junction of South Fork and North Fork of the Shenandoah River
Station Elevation Data num= 59

Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev	Sta	Elev
-190	520	-190	503	-90	502.8	-90	491.8	-65	487.7
-50	480.3	-25	479.4	-20	479.4	-20	503	-10	503
-10	479.3	0	481.1	7	481.6	17	477.7	51	477.2
96	475.3	131	462.4	148	460.5	148	503	161	503
161	461.2	175	462.4	182	459.2	196	457.5	226	457
256	455.5	276	452.9	286	451.2	306	455.3	306	503
318	503	318	454.5	326	452.8	356	450.6	386	453.1
416	451.4	446	450.2	465	455.4	465	503	476	503
476	456.1	486	455.1	516	452	546	451.5	576	454.7
584	459.2	609	465.8	631	468.6	631	503	642	503
642	472.7	657	474.6	669	475.7	682	476	697	480.6
720	486.6	720	501.1	820	500.6	820	520		

M--ning's n Values num= 3

Sta	n Val	Sta	n Val	Sta	n Val
-190	.04	-90	.03	720	.04

Bank Sta: Left	Right	Lengths: Left	Channel	Right	Coeff Contr.	Expan.
-90	720	0	0	0	.1	.3

CROSS SECTION OUTPUT Profile #100 year

		Element	Left OB	Channel	Right OB
W.S. Elev (ft)	492.63	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.65	Wt. n-Val.		0.030	
E.G. Elev (ft)	493.28	Reach Len. (ft)			
Crit W.S. (ft)	469.43	Flow Area (sq ft)		21459.49	
E.G. Slope (ft/ft)	0.000308	Area (sq ft)		21459.49	
Q Total (cfs)	139000.00	Flow (cfs)		139000.00	
Top Width (ft)	753.00	Top Width (ft)		753.00	
Vel Total (ft/s)	6.48	Avg. Vel. (ft/s)		6.48	
Max Chl Dpth (ft)	42.43	Hydr. Depth (ft)		28.50	
Conv. Total (cfs)	7917315.0	Conv. (cfs)		7917315.0	
Length Wtd. (ft)		Wetted Per. (ft)		1055.58	
Min Ch El (ft)	450.20	Shear (lb/sq ft)		0.39	
Alpha	1.00	Stream Power (lb/ft s)		2.53	
Frctn Loss (ft)		Cum Volume (acre-ft)			
C & E Loss (ft)		Cum SA (acres)			

Warning - Divided flow computed for this cross-section.
Warning - The parabolic search method failed to converge on critical depth. The program will try the cross section slice/secant method to find critical depth.

S--MARY OF MANNING'S N VALUES

R. er:S. Fork Shenando

Reach	River Sta.	n1	n2	n3
Front Royal	23	.065	.04	.065
Front Royal	22	.065	.04	.065
Front Royal	21	.065	.04	.07
Front Royal	20	.065	.04	.07
Front Royal	19	.065	.04	.07
Front Royal	18	.065	.04	.07
Front Royal	17	.065	.04	.07
Front Royal	16	.065	.04	.07
Front Royal	15	.065	.04	.07
Front Royal	14	.065	.04	.07
Front Royal	13	.06	.05	.06
Front Royal	12	.06	.05	.06
Front Royal	11	.06	.045	.06
Front Royal	10	.055	.035	.06
Front Royal	9	.04	.04	.04
Front Royal	8	.06	.035	.065
Front Royal	7	.065	.045	.065
Front Royal	6	.065	.035	.065
Front Royal	5	.065	.035	.065
Front Royal	4.5	Bridge		
Front Royal	4	.065	.035	.065
Front Royal	3	.065	.035	.065
Front Royal	2	.065	.035	.065
Front Royal	1	.04	.03	.04

S. .ARY OF REACH LENGTHS

: S. Fork Shenando

Reach	River Sta.	Left	Channel	Right
Front Royal	23	1004	1004	1004
Front Royal	22	732	732	732
Front Royal	21	1440	1440	1440
Front Royal	20	1492	1492	1492
Front Royal	19	1412	1412	1412
Front Royal	18	1608	1608	1608
Front Royal	17	1556	1556	1556
Front Royal	16	792	792	792
Front Royal	15	508	508	508
Front Royal	14	672	672	672
Front Royal	13	1300	1300	1300
Front Royal	12	1728	1728	1728
Front Royal	11	924	924	924
Front Royal	10	1188	1188	1188
Front Royal	9	252	252	252
Front Royal	8	1851	1851	1851
Front Royal	7	113	113	113
Front Royal	6	429	429	429
Front Royal	5	14	14	14
Front Royal	4.5	Bridge		
Front Royal	4	7	7	7
Front Royal	3	244	244	244
Front Royal	2	412	412	412
Front Royal	1	0	0	0

ARY OF CONTRACTION AND EXPANSION COEFFICIENTS
: S. Fork Shenando

Reach	River Sta.	Contr.	Expan.
Front Royal	23	.1	.3
Front Royal	22	.1	.3
Front Royal	21	.1	.3
Front Royal	20	.1	.3
Front Royal	19	.1	.3
Front Royal	18	.1	.3
Front Royal	17	.1	.3
Front Royal	16	.1	.3
Front Royal	15	.1	.3
Front Royal	14	.1	.3
Front Royal	13	.1	.3
Front Royal	12	.1	.3
Front Royal	11	.1	.3
Front Royal	10	.1	.3
Front Royal	9	.1	.3
Front Royal	8	.1	.3
Front Royal	7	.1	.3
Front Royal	6	.1	.3
Front Royal	5	.3	.5
Front Royal	4.5	Bridge	
Front Royal	4	.3	.5
Front Royal	3	.1	.3
Front Royal	2	.1	.3
Front Royal	1	.1	.3

Appendix C
Geotechnical Evaluation of the Sulfate Basin Closure

APPENDIX C – GEOTECHNICAL EVALUATION OF THE SULFATE BASIN CLOSURE

1.0 *INTRODUCTION*

This report presents the results of the initial geotechnical evaluation for the installation of a soil cover on Sulfate Basins (SB) 1 through 4E at the Avtex Fibers Site (Site) in Front Royal, Virginia. Anticipated closure of the basins involves the construction of an 24-inch (minimum) soil cover over the sludge in the 60 acres (approximate) of aggregate basin area. SBs 1 though 4E would be closed with the sulfate sludge left in place. The soil cover would be a nominal 24 inches thick, but would also include additional underlying fill materials where necessary to create slopes (2% minimum) that will promote positive surface drainage. The objective of the soil cover would be to contain the basin material and eliminate the direct contact pathways for human and animal exposure.

Placing an 24-inch thick soil cover over the entire surface of the sludge in SB 1 through 4E cannot be done in a totally conventional manner given the soft and variable nature of the sludge. The creation of drainage on the surface of the closed sludge basins will additionally require varying the soil thickness placed upon the generally flat sludge surface in each basin. In order that the desired two-percent minimum slopes exist following sludge consolidation and cover settlement, the thickness of soil cover materials placed will need to vary further to account for anticipated settlement under the imposed cover loadings.

The soft nature of the sludge in SBs combined with the depth of sludge in each SB necessitate investigation of how cover materials can be distributed across the sludge surface in each SB, especially to determine if the distribution can be accomplished without treatment or stabilization of the sludge. The need to place a varying thickness of cover material necessitates an understanding of the strength of the sludge and its response to loadings imposed during and after cover placement. For the purposes of the Engineering Evaluation/Cost Analysis (EE/CA), it was determined to be appropriate to perform certain field and laboratory investigations to: 1) demonstrate that a soil cover can be placed on the untreated (non-stabilized) sludge surface; 2) identify minimum requirements for accomplishing cover soil placement; and 3) ensure that SB soil cover cost projections adequately reflect the amount of materials and level of effort that could be realized in actual cover installation.

This geotechnical evaluation has developed in a three-step process, the first step including data generated from preliminary laboratory results on sludge collected from the basins, and is described in Section 1.1 below. The second step consisted of a field pilot study, which investigated potential soil cover placement scenarios by constructing test pads on Basins 1 and 3, the results of which are described in Section 2. The third step consisted of additional field and laboratory measurements collected to support the soil cover design. These results are presented in Section 3. The geotechnical evaluation was performed with the knowledge of the EPA. Further, EPA input was solicited, received and addressed, and EPA observed some of the field activities. Additional testing may be conducted as necessary during the engineering design phase.

1.1 *INITIAL FIELD OBSERVATIONS OF SULFATE SLUDGE BASINS*

The conditions of the SB sludges were observed by ERM engineers and construction experts during a site visit on 28 September 1998. The seasonally low water level in the basins allowed for close inspection of the accumulated sludge, especially in SB 1 and 3.

At the time of site inspection, nearly three-quarters of the sludge surface in SB 1 was exposed. The sludge in SB 1 has a sloping surface, sloping downward to the west from the plant side toward the South Fork of the Shenandoah River (River). A crust exists on the top of the sludge, which helped allow engineers to walk out onto it. The surface was riddled with desiccation cracks forming a "scaled" appearance. The crust was somewhat soft, but relatively dry for as much as six inches in depth. This crust appears to have formed in a period of 2-3 months in which the SB 1 water level was sufficiently low to expose the sludge surface. The cracking and dry appearance gradually transitioned into a smooth moist sludge surface near the water's edge. These observations are qualitative and the understanding of the drying process may need to be supported by empirical data collected during the design stage.

SB 3 was dry across the majority of the surface. The sludge surface was cracked like that of SB 1, but the surface of the sludge in SB 3 is relatively flat.

The opinion obtained from the field observations was that distributed loads could be supported by the sulfate sludge without chemical or physical stabilization of the sludge if the standing water (i.e., supernatent) was removed and the sludge was caused or allowed to drain. With a program of drainage and supernatent removal, a thick, firm crust is expected to form as it has in areas on the east side of SB 1 where standing water has been permitted to drain. This expectation for the development of a firm surface crust is also supported by observations of SB 3, where a surface crust developed in a relatively short period of time following the removal of several feet of free-standing water in Spring 1998. It was evident, however, from the movement of sludge beneath the crust underfoot that standard construction equipment would likely not be able to be operated directly on the sludge surface for regrading or soil cover placement.

1.2 PRELIMINARY GEOTECHNICAL EVALUATION

Samples of the sulfate sludge were collected during the 28 September 1998 site visit for preliminary testing. The samples collected represented the soft sludge from the center of SB 1 below the upper crust layer. Consolidated Undrained (CU) and Unconsolidated Undrained (UU) triaxial shear strength tests were performed on remolded sludge samples in accordance with ASTM D-4767 and ASTM D-2850, respectively, to estimate strength parameters of the sludge. This preliminary evaluation was conducted to provide some initial insight into the potential for a bearing capacity failure in the sludge during potentially worst-case loading conditions associated with soil cover placement.

In the evaluation of the preliminary data, a short-term (total stress) analysis was utilized to reflect the worst-case, undrained strength parameters that would be representative of short-term loadings from construction equipment and soil cover placement. The results of the bearing capacity analysis indicated a relatively low but potentially acceptable factor of safety against failure (i.e., greater than 1.5), but a deep-seated circular failure surface was estimated to have a potentially unacceptable factor of safety against failure. The results of this preliminary evaluation will be supplemented and/or superceded by the subsequent and more detailed engineering design testing and analysis activities that are planned in 1999 (see Section 4.2).

1.3 PLANS FOR ADDITIONAL TESTING

Based on the results of the preliminary evaluation, it was determined that the collection of additional geotechnical and constructability data through the implementation of a field pilot study and pre-design testing program would be the most appropriate course of action, and would provide the most relevant results. The results from the initial stages of this testing program are discussed in the next section. The results of subsequent tests and evaluations will be incorporated in the engineering design. The following table summarizes the field and laboratory testing performed in support of the EE/CA.

Testing	Data Use
Present Testing – Laboratory	
Triaxial Strength UU (unconsolidated undrained)	Provides indication of expected material strength parameters for construction loading/sludge relocation.
Triaxial Strength CU (consolidated undrained with pore pressures)	Provides indication of expected material strength parameters for long-term strength stability predictions
Classification Testing (sieve, hydrometer, moisture content, Atterberg limits) [ASTM procedures]	Provides basic physical property comparisons between sludge samples (limited applicability of this testing due to change in material properties caused by material prep).
Classification Testing [wet prepared]	Provides basic physical property comparisons between sludge samples (initial samples analyzed provide a more realistic picture of sludge grain size distribution).
Consolidation Testing	Provides indication of the expected settlement of the sludge caused by the cover system load application (from test results time rate calculations, time rate settlement values, and time rate consolidate liquid expulsion can be calculated).
Present Testing – Field	
Test Pad construction (observational summary of construction performance)	Provides a field scale demonstration for the potential of cover placement on the sulfate basins utilizing typical construction equipment and materials.
Test Pad documentation (physical property analysis of test pad construction)	Provides initial feedback on compaction, placement, permeability, and settlement.
In-situ sludge strength testing (vane shear)	Provides some initial information on in-situ strength of the sludges with depth.

1.0 GEOTECHNICAL FIELD STUDY

2.1 OBJECTIVES

The primary objectives of the field study were to evaluate and demonstrate the feasibility of certain soil cover placement methods, and to support the development of guidance, requirements, and specifications for the actual full-scale implementation of the proposed soil cover.

Specific objectives of the field pilot study were to evaluate the following:

1. The ability of differing soil bridging layer thicknesses of one to three feet to support construction equipment and soil cover materials above the sludge;
2. The minimum width of the equipment and soil material access paths;
3. The ability to utilize normal ground pressure construction equipment in comparison to low ground pressure (wide track) equipment;
4. The required degree of dewatering or surface drying required to facilitate soil placement and equipment access (as measured by surface "crust" thickness, moisture content and strength);
5. The effectiveness of non-woven and woven geotextiles for separation and reinforcement between the soil access roads and the sludge;
6. The feasibility and effectiveness of sludge draining/dewatering during the cover soil placement activities (i.e., does the sludge give up pumpable amounts of water to a localized sump?);
7. The amount of settlement occurring during, and as the result of, cover soil placement, together with any corresponding swelling or "wave" build up in the uncovered sludge; and
8. The ability to use fly ash as an element of the cover.

Modifications to the study procedures and objectives were made during the course of the study in response to the observations made in the field and discussions with EPA.

2.2 PROCESS SUMMARY

The field pilot study began on 9 November 1998, with the primary focus on the evaluation of constructability issues for placing a soil cover on the

SBs. To do this, test pads were constructed in portions of SB 1 and SB 3 with equipment, materials, and procedures intended to conservatively represent potential full-scale operations. Test pad locations were selected based on accessibility and condition of the sludge surface. SB 3 and the eastern side of SB 1 were relatively dry and are expected to be representative of the starting conditions for the full-scale basin closure work.

The following procedures were generally performed during construction of the test areas:

1. Preparing test areas by stockpiling materials adjacent to test areas;
2. Using geotextile-reinforced access paths to get equipment and cover materials out across sludge and in soft areas as needed; and
3. Pushing soil ahead of equipment, and keeping equipment on top of soil. Using low ground pressure (wide-track) equipment (3 to 4 psi) as necessary.

In addition to the test pad construction, trenches were excavated in the sludge and a sump was installed utilizing a perforated 55-gallon steel drum to observe the accumulation of water draining from the trench sides. The sludge excavated from the trenches was placed on a plastic-lined portion of the berm, constructed to allow collection of any water which freely drained from the sludge.

Soil for the field test was obtained from a local borrow source. While not selected as having met any particular specification, the soil was evaluated visually to be a material that could likely meet the objectives for cover soils on the sludge basins. These soils were stockpiled near the selected test areas as well as delivered continuously through portions of the test. The material was a silt with sand, and it arrived in a condition suitable for use and was placed without moisture adjustment.

2.3 *FIELD PILOT TESTING PROCEDURES AND RESULTS*

2.3.1 *Test Pad 1 Construction (SB 3)*

The first pilot testing took place in the southeast corner of SB 3 (see Figures C-5 and C-6). Woven geotextile fabric was laid in a path over the existing sludge surface in a northwesterly direction from the southeast corner of the basin. The geotextile was overlapped by approximately 3 feet along the seam down the axis of the path. A low-ground-pressure D-6 bulldozer was used to push soil out over the geotextile to a depth ranging from one foot to four feet, and averaging approximately two feet. The sludge surface surrounding the soil being placed was monitored with elevation surveying, photographs and video recording.

After advancing the soil access path approximately 105 feet from the toe of the berm at a width of approximately 20 feet, soil was pushed in a fan-shaped pattern over the sludge surface. On the area to the west of the access path, soil was placed directly on sludge without first laying out geotextile to assess behavior with a soil-only cover. This filling covered a radius of approximately 75 feet in an arc of approximately 70 degrees.

2.3.2 *Observations and Conclusions from Test Pad 1*

The following observations were made during the test:

1. Repeated passes (approximately as many as 200-300) over the same path with the D-6 resulted in the soil cover eventually sinking into the sludge. The geotextile, however, supported the soil on top of the sludge. The sinking represented an upward displacement of the sludge on both sides of the access path, along with some downward movement directly under the path.
2. The repeated passes and spreading of soil over the same location resulted in building of a thick (four or more feet) layer of soil along the access path. The weight of this layer, together with the weight of the bulldozer and impact loading at the toe of the berm, exacerbated the displacement of sludge. At at least one point, a shear failure of the soil layer occurred due to the apparent displacement of sludge at depth. The dried, upper crust of the sludge was observed to crack open and fracture during displacement of the deeper sludge.
3. In spite of the sinking of soil and the displacement of sludge, a layer of soil was placed over a significant area of the sludge surface utilizing a relatively heavy piece of equipment and minimal geotextile reinforcement.

The following lessons were learned that are important considerations for the engineering design of the sulfate basin covers:

1. Repeated trips over the same location should be minimized to avoid repeated loading, build up of the soil layer thickness and weight, and disturbance of the sludge, and time should be allowed between passes to allow built up pore-water pressures to dissipate.
2. Geotextile and/or soil or fly ash cover beyond the immediate equipment operation area is needed to help confine sludge displacement.

3. Every effort should be made to keep the sludge surface drained and dry and, to the extent practical, to drain the sludge below the surface, prior to initiating soil cover placement Although it appears that the sludge surface will dry to a limited extent after standing water is removed from the basins, field dewatering tests indicate that significant quantities of water cannot be drained rapidly from below the sludge surface with simple gravity drainage. As a result, initiating drainage well in advance of soil cover construction will be critical if this type of dewatering is employed. Other means of dewatering (e.g., surcharge loading with wick drain, alternate sump construction methods, etc.) may be considered pending the results of further geotechnical testing.

4. Means of delivering soil onto the sludge surface other than by bulldozer or trucks (such as belt feeders, conveyors, or drag lines) may be appropriate for minimizing the amount of cover materials needed, increasing the potential rate of material delivery and distribution, and minimizing potential failure of the sludge or soils from larger construction equipment.

2.3.3 *Test Pad 2 Construction (SB 1)*

A second test was performed, this time in SB 1, following the Test Pad 1 work in SB 3. A test location was chosen near the middle of the basin to best represent typical sludge conditions (see Figure C-1). The goal was to advance the test from the firmer surface provided by the zinc recovery sludge in the eastern side of the basin, toward the observably softer sludge and the existing pool of water on the western side of SB 1. Access was gained to the middle of SB 1 by advancing a single lane roadway of mixed soil and fly ash on top of a single layer of geotextile. This roadway successfully supported the loads due to deliveries of test soils and fly ash delivered via dump truck to the test site.

Based on experience gained from Test Pad 1, the test performed in SB 1 was modified. A larger area (approximately 60 feet by 60 feet) of geotextile was laid down with large overlaps (3 to 4 foot) to better simulate conditions of continuously sewn geotextile. Unlike what was done at Test Pad 1, the geotextile was laid out with the length perpendicular to the direction of soil advancement. Along two opposite edges, nonwoven geotextile was placed perpendicular to the woven geotextile, and soil was advanced in narrow (bulldozer wide) lanes to provide anchoring of the woven geotextile across the middle of the pad. A smaller, D-4 bulldozer was used in this test in lieu of the larger D-6 machine used during the initial test at SB 3. Both machines have a similar ground contact pressure, although the total weight of the D-4 is less than that of the D-6.

With the geotextile stretched taut by the anchoring along each edge, the middle area of the test pad was next covered with approximately two feet of fly ash worked forward from side to side to minimize immediately-repeated passes over the same area. The potential displacement of sludge was again monitored with surveying, photographs and video camera. The focus of the displacement monitoring was the geotextile-covered middle of the test pad.

Soil and fly ash was advanced first on the edges, to anchor the geotextile, and subsequently in the middle of the pad to within approximately 25 feet of the pooled water surface in SB 1. The result was a broad area of soil and fly ash coverage with minimal observed sludge displacement.

2.3.4 *Observations and Conclusions from Test Pad 2*

The following Test Pad 2 observations were made during the test:

1. Fly ash excavated from the base of the side slope of the fly ash mountain at its in-situ moisture content proved to be suitable for placement and use in the cover.
2. The sludge in SB was firmer than the sludge in SB 3. This is believed to be mostly due to the soil/mud that has historically accumulated on top of the sludge surface of SB 1 from river flooding of the basin. In addition, the SB 1 sludge may be firmer due to its higher elevation along the eastern side of SB 1, and enhanced ability to drain.
3. Sludge in the extreme north end of SB 1 is affected by site discharges (i.e., this area has functioned as a settling area for the site surface water runoff for the past ten years) and, based on visual observations, may require measures in addition to dewatering to reach a strength suitable to support cover placement activities. The strength of this sludge as compared to other sludges will be further evaluated through the use of vane shear testing to be performed during the engineering design phase.
4. Geotextile fabric performs a valuable role in separating the sludge from soils or fly ash placed above, and spreading and supporting the cover and equipment load.
5. Cover materials can be delivered by truck to large portions of the SB 1 sludge surface.

The location and extent of the SB 1 test pad is shown on Figure C-1, and photographs of the work are presented in Attachment 1 to this Appendix. Figure C-1A shows the soil thickness of the test pad at selected locations across the pad. Surveying measurements collected over time during the test are depicted on Figures C-2 through C-4. Figures C-2 and C-3 depict the deformation of the specified stations over time. These figures also indicate there was an increase in elevation at nearly all points, and at many points the increase in elevation is more than at the edges after fill placement, as a result of sludge displacement caused by the soil load at the center of the pad. Figure C-4 presents the changes in elevation of the settlement plates, which were placed directly above the geotextile.

It should be noted that, based on the data collected, the relative contribution of individual factors such as settlement, consolidation and displacement to the observed overall sludge movement is difficult to quantify. The initial movements are most likely the result of sludge displacement. The anchored geotextile appeared to help with management of sludge displacement in the middle of the pad as was desired. The collected field data will subsequently be evaluated in conjunction with the additional settlement, consolidation and shear strength data so that factors such as settlement, consolidation and displacement will be addressed appropriately in the design. The results of consolidation testing, discussed in Section 3.2.2, indicate that consolidation from pore water dissipation will take weeks to months to occur given the low permeability of the sludge. At least a portion of the further settlement observed one month and three months following test pad completion may therefore be attributable to pore water dissipation. The balance of the additional settlement is likely related to sludge displacement.

2.3.5 *Test Pad 3 Construction (SB 3)*

A third soil cover placement test was performed to determine whether the modified construction procedures, which proved successful at SB 1, could be repeated at SB 3. For Test Pad 3, a broad path of access was prepared along the edge of SB 3 and a large geotextile pad (50 feet by 100 feet) was placed similar to that in SB 1 (see location on Figure C-5). Placement of the first 10 to 15 feet out from the basin edge was accomplished via the reach of an excavator bucket. The excavator was used in order to reduce the number of dozer passes across the basin slope/sludge contact, an area in which Test Pad 1 soil became very deep as sludge was displaced. SB 3 berm soil and borrow soils were used instead of fly ash for this test to minimize fugitive dust during construction. Fly ash can be used successfully in the full-scale cover installation by employing appropriate dust suppression techniques.

Test Pad 3 was advanced onto the sludge surface of SB 3 in a manner similar to that employed in Test Pad 2. Woven geotextile was first spread in approximately 60 feet long strips parallel to the basins edge and perpendicular to the direction in which the pad soils were advanced (outward toward the center of the sludge basin). The geotextile was overlapped to help simulate sewn seams. Narrow soil anchor pathways were then advanced away from the basin edge at each edge of the geotextile pad to stretch and secure the geotextile strips across the center of the test pad area. The soil cover was then advanced from side to side across the middle area of the test pad, completing the pad for a distance of approximately 100 feet out onto the SB 3 sludge surface. The potential displacement of sludge in the process was again monitored with surveying, photographs and video camera, focusing on the geotextile-covered middle of the test pad.

The test pad construction in this area was successful (i.e., no unacceptable sludge displacement or cover soil failure occurred under the load of the cover soil and equipment). Some upward sludge displacement initially occurred in areas with no soil cover as a result of cover soil placement in adjacent areas, but this displacement was generally offset once soil was placed over those areas. The effectiveness of the geotextile was evidenced by the observed ability to operate the equipment directly above the geotextile, with no cover soil to help distribute the loads. This practice will not be recommended for the actual cover installation because of the risk for damage of the geotextile layer. Although some of the lap seams in the geotextile opened up during the test, no sludge failures (i.e., cracking or other evidence of excessive displacement) occurred, and this condition could be corrected in the full-scale construction if necessary through the use of sewn geotextile seams.

Neglecting some minor edge effects (i.e., displacement that occurred in the sludge at the edges and the thickness of the soil layer required to anchor the geotextile), the thickness of the test pad was able to be controlled. Measurements of the soil cover thickness in Test Pad 3 are shown on Figure C-6A. Access to SB 3 for Test Pad 1 was obtained by building a ramp down the inner slope at the southeast corner of the basin. All of the soil for the cover test was deposited at the beginning of this ramp and pushed down the ramp and out onto the sludge surface. As noted in Section 2.3.2, the repeated passes down the slope, pushing soil ahead of the dozer, caused the soil layer to thicken substantially at the basin's edge, although the majority of this thickening was intentional to provide for access ramp construction. This edge effect did not reoccur in Test Pad 2 as the result of the sludge strength in the eastern portion of SB-1, and because of the easier access to the test pad location.

After observing the edge effects in Test Pad 1, access to SB 3 for Test Pad 3 was obtained by removing a portion of the dike to shorten the path to the sludge surface. This approach allowed soil to be deposited along a length of the edge to reduce the number of repeat passes required over the same path. This approach also minimized the need for construction of a thick soil ramp above the sludge to allow access from the berm to the sludge surface. While some thickening of the soil layer occurred at the basin's edge as shown in Figure C-6A, it was not as substantial as in Test Pad 1. Minimizing the frequency and number of trips made across the same path to distribute cover soils will likely be a requirement in the final design specifications. Once the soil is distributed across a basin's sludge surface, repeated passes for compaction will not result in soil layer thickening (i.e., because no additional soil will be placed).

Test Pad 3 confirmed that the construction methods successfully employed at SB 1 are also applicable for SB 3 out on the basin surface where the geotextile was stretched and anchored. The thickness of the test pad was also able to be controlled in this test as shown on Figure C-6A.

The locations of the survey monitoring cross sections are presented on Figure C-6, and photographs of the work are presented in Attachment 1 to this Appendix. Surveying measurements collected over time during the test are depicted on Figures C-7 through C-9-. Figures C-7 and C-8 depict the deformation of the specified stations over time. Figure C-9 presents the changes in elevation of the settlement plates, which were placed directly above the geotextile.

2.3.6 *Dewatering Test*

In conjunction with the second SB 3 cover placement test, a trench was excavated in the SB 3 sludge (see location on Figure C-6) and a perforated gravel-packed sump (constructed from a 55-gallon drum) was installed to observe what, if any, dewatering would occur from the sludge over time. The sump was dry when initially installed. Water accumulation rates into this sump were relatively slow, approximately 40 gallons per day. If significant sludge dewatering is determined to be necessary or appropriate during the design, it will need to be initiated significantly in advance of cover installation, and/or measures such as surcharge loading and wick drains or vacuum-enhanced dewatering will be considered.

3.0 SUPPLEMENTAL TESTING

Follow-up investigation to the test pad construction began on 30 November 1998, and continued over the next few months. These activities have been developed in coordination with the EPA and their technical contractor (Gannett Flemming Engineers and Planners), to provide a portion of the data that will be required to support the soil cover design. The following follow-up data collection and geotechnical evaluation activities have been performed to supplement the information gathered from the field pilot test:

1. Continued settlement monitoring of the installed test pads.

   – This settlement monitoring has included repeated monitoring of the remaining settlement plates on the test pads. This information is be available to help identify long-term movements, which could be attributed to consolidation, creep or sludge displacement.

2. Base-line physical property identification of the soils used for the construction of the test pad.

   This includes the following field and laboratory testing:

   – Monitoring of the test pads for in-situ density, using a nuclear density gauge, with samples from the area of the density test collected for moisture determination in the lab to allow correlation with the nuclear gauge.

   – Depth measurement within the test pad areas to determine actual soil placement thickness from the field pilot test.

   – Laboratory testing of soil index properties including, grain size, Atterberg limits, moisture content and proctor density.

   – Permeability testing of the soil cover material remolded to the approximate moisture content and density as the test pad soils.

3. Sulfate sludge baseline physical property testing in the field and laboratory to further supplement existing data.

This testing includes:

   – Performance of in situ vane shear tests at a number of locations within and around the test pads. The vane shear work was repeated after three months to identify potential changes to the sludge strength characteristics as a result of disturbance from test pad construction.

- Field density and moisture content testing of in-situ sludge at locations in SB 1 and SB 3 using a nuclear density gage.
- Confirmation of sludge depth at various points around the basins.
- Laboratory testing to include the characterization of comparative indicator properties, and some detailed testing of consolidation. Sludge samples from SB 1 and SB 3 have been tested for general indicator properties that include moisture content, unit weight, grain size, and Atterberg limits.
- Evaluation of consolidation properties of the sludges in the overburden load range, and potential strain values, which will be seen in the field as part of the final remedy.

Data sheets containing the results of laboratory geotechnical tests are presented in Attachment 2 to this Appendix.

3.1 *FOLLOW-UP FIELD TESTING*

3.1.1 *Settlement Monitoring*

Settlement plates located on Test Pad 2 in SB 1 and Test Pad 3 in SB 3 were surveyed on 30 November 1988 and 15 February 1999 in continuation of the monitoring of the test pad settlement. The data gathered has been added to Figures C-4, C-8, and C-9. Based on typical performance of a consolidating soil, the settlement strain should, after some time passes, occur nearly linear on a log rate basis. As time passes, the expected settlement should decrease per unit time. Because the test pads are resting upon the sludge without the benefit of a geotextile and/or soil cover to contain sludge displacement in the area beyond the test pad, it is impossible to determine whether the movements observed are attributable to consolidation settlement, additional displacement or both.

3.1.2 *Test Pad Soils Testing*

3.1.2.1 *Soil Classification*

Laboratory tests were performed on samples of the soil used in the construction of the test pads. According to ASTM D-2487, the soil samples collected from Test Pad 3 of SB 3 were classified as silt with sand (ML).

3.1.2.2 *Proctor Compaction Testing*

A Standard Proctor compaction (ASTM D-698) test was conducted on one bulk sample collected from Test Pad 3 of SB 3. From the analysis of this test, the maximum density was found to be 108.7 lbs/ft^3, with an optimal moisture content of 18.0% according to ASTM D-698. Comparing the maximum density values to the recorded field densities, measured with the nuclear density gauge (see Section 3.1.5), the average density was found to be approximately 100.3 lbs/ft^3 at 12.2% moisture, for a compaction of 92.3% of Standard Proctor density.

3.1.2.3 *Permeability Testing*

The bulk sample collected from Test Pad 3 was re-compacted to a similar dry density to that achieved in the field (100.3 lbs/ft^3)in the test pad and as measured with the nuclear density gauge. A permeability test was then conducted on the remolded soil sample, and was determined to be 2.7x10^{-6} cm/sec according to ASTM D-5084.

Reduced laboratory data for all soils testing performed is included in Attachment 2 to this Appendix.

3.1.2.4 *Test Pad Data Summary*

The information gained in the field and laboratory regarding the test pad soil placement provided the following indications. The local soil could be excavated, transported, placed, and lightly compacted to reach a typical landscaping earthwork placement criteria (typically 90 to 92% of Standard Proctor density). Under a full scale operation it would be expected that a more consistent compaction effort can be applied on the soil layer. However, it will be important to select soils with which the desired compaction and permeability can be achieved with a minimal compactive effort. Of particular concern would be minimizing the number of equipment passes since the sludge surface may soften or deform with repeated passes. The conflict between increased compaction and the effect of repeated passes on sludge deformation will be addressed in the development of specifications for the cover construction. Soils to be used as a soil cover should classify as a clay or silt with sand or better according to ASTM D-2487. The "or better" requirement would imply a larger coarse fragment (i.e., sand fraction). As the material moves to the larger coarse fraction materials placement and compaction would become easier, but permeability of the placed soils should also increase.

The soil used for the test pad construction would be acceptable by the criteria defined above, but an increased coarse fragment (i.e., sand fraction) would be desirable to improve handling, placement and compaction. These characteristics would be balanced with a potentially increased permeability that such material may have to ensure that excessive permeability is not obtained.

3.1.3 *Sludge Vane Shear Tests*

In-situ vane shear tests were performed in SB 1 and SB 3 at various locations, as presented on Figures C-10 and C-11. These tests were conducted in accordance with ASTM D-2573. The tests were performed on top of a plywood platform working surface, constructed with a 4-inch diameter hole through the center, with an attached steel flange and 4-inch diameter steel riser pipe. The steel pipe supported the vane shear apparatus. The following is a brief description of the procedure followed for each test.

Setup:

1. The working platform was placed over each selected test location.

Shaft Friction Reading:

2. A section of drill rod (vane shaft) was lowered through the supporting riser pipe to a depth equal to that of the test interval (less the vane height), with a bearing guide secured to the rod.

3. The rod was then pushed down into the sludge until the bearing guide collar came to rest on top of the thrust bearing. The thrust bearing supported the weight of the rod and allowed the rod to rotate freely in the sludge while maintaining the appropriate depth.

4. Once in place, a torque wrench was attached to the end of the rod, and the angle of the torque wrench handle was noted.

5. The torque wrench was rotated clockwise, as slowly and as steadily as possible.

6. The maximum torque reading was recorded, along with the corresponding angle of rotation.

Remolded Shaft Friction Reading:

7. The rod was rapidly rotated clockwise and then let to rest for a 1-minute period. The test was then repeated to obtain the remolded torque shaft friction reading.

8. The rod was then removed by lifting the rod out of the sludge, with pipe wrenches, and wiped off to remove sludge which had adhered to the rod.

Vane Shear Test:

9. The largest vane size (3.625-inch diameter) was selected due to the expected sludge properties, and was attached to the end of the rod.

10. The vane and rod were lowered down into the pipe casing, the collar was slipped over the rod, and the bearing guide secured to the rod. The vane and rod were pushed down into the sludge until the bearing guide came to rest on top of the thrust bearing.

11. Once in place, the torque wrench was attached to the end on the rod, and the initial angle of the torque wrench handle was noted.

12. The torque wrench was rotated clockwise, as slowly and as steadily as possible, until the maximum torque was reached.

13. The maximum torque reading for the depth interval was recorded, along with the corresponding angle of rotation.

Remolded Vane Shear Test:

14. The rod was rapidly rotated and left to rest for a 1-minute period, after which the test was repeated, to obtain the remolded vane torque reading.

15. The vane and rod were then removed using pipe wrenches, and cleaned off.

Vane shear testing was performed at the 3 to 5 and 8 to 10 foot depth intervals. The average shaft friction values are summarized in Table 1.

Table 1 Average Shaft Friction Values

Test Type and Depth	Mean Friction Value on Vane Shaft (lbs-in)
3-5 ft (Undisturbed)	31.25
3-5 ft (Remolded)	20
8-10 ft (Undisturbed)	45.5
8-10 ft (Remolded)	30

Using the mean friction values, the torque readings, and the vane constant, the corresponding shear strengths were calculated using the ASTM D-2573 procedure and are presented in Table 2.

Table 2 Vane Shear Test Results

Sample Location	Computed Shear Strength (psf)			
	3-5 ft (U)	3-5 ft (R)	8-10 ft (U)	8-10 ft (R)
Basin 1:				
T-2	175.34	40.73	162.45	[1]
T-3	[2]	[2]	[2]	[2]
T-4	71.27	13.58	207.70	40.73
Basin 3:				
T-1	62.22	4.53	162.45	18.10
T-6	39.59	9.05	49.32	4.53
T-8	93.89	40.73	103.62	36.20
Average Sensitivity	6.00		6.96	

Notes:

[1] Invalid measurement because the vane reading was smaller than the shaft friction reading, and therefore no shear strength could be calculated.

[2] The sludge at this location was too hard to push through, and therefore no measurements were taken.

U = undisturbed; R = remolded.

Shear strength values calculated using the ASTM D-2573 procedure.

Figures C-12, C-13, and C-14 present the shear strength results graphically.

On 15 February 1999, additional vane shear tests were performed at SB 3 in the vicinity of Test Pad 3 to estimate potential strengths longer after completion of the test pad. These test locations are shown on Figure C-11, and the reduced results are summarized on Table 3.*Table 3*

Supplemental Vane Shear Test Results

Sample Location	Computed Shear Strength (psf)			
	3-5 ft (U)	3-5 ft (R)	8-10 ft (U)	8-10 ft (R)
Basin 3:				
T-10	45.25	*[1]*	90.50	*[1]*
T-11	45.25	*[1]*	45.25	*[1]*

Notes:

[1] Invalid measurement because the vane reading was equal to or smaller than the shaft friction reading, and therefore no shear strength could be calculated.

U = undisturbed; R = remolded.

Shear strength values calculated using the ASTM D-2573 procedure.

Consistent with the initial results, shear strengths were generally greater at the deeper depth interval, and remolded (disturbed) strengths were significantly lower than undisturbed strengths (in this case, virtually no shear strength was observed in the disturbed sludge. It is suspected that overall shear strength from these tests were generally lower than previous results because the tests were conducted in areas likely disturbed during the test pad construction. The undisturbed results are considered to partially reflect some strength gain achieved in disturbed sludges since the test pad activities were completed.

3.1.3.1 *Vane Shear Testing Summary*

The vane shear testing for SB 1 and SB 3 showed similar trends. The trend for the material indicated the material is stronger with depth, and remolded strength is significantly lower than undisturbed strength. Both of these results were expected based on typical soil and sludge behaviors. The reduced remolded data demonstrated strengths in the field which were similar to those observed in the triaxial UU testing performed earlier on a remolded sample of the sulfate sludge (see Attachment 2 for UU test results).

A more extensive profiling of in-situ strengths with the vane shear apparatus is recommended as a measure of sludge variability.

3.1.4 *Thickness of Sludge Measurements*

The thickness of the sludge in SB 1 and SB 3 were determined concurrently with the vane tests. Once a given vane test was completed, the bearing guide at the top of the vane rod was removed and additional sections of drill rod were attached and pushed into the sludge until the layer of resistance, or bottom of the sludge, was attained. The length of rod remaining above the sludge surface was recorded and subtracted from the total rod length to determine the thickness of the sludge at each test location. Table 4 below shows the results of these measurements.

Table 4 Sludge Basin Depths

Location	Total Length of Rod (ft)	Length of Rod Above Sludge Surface (ft)	Thickness of Sludge (ft)
Basin 1:			
T2	17	5.67	11.33
T3	7	4.25	2.75*
T4	12	3.67	8.33
Basin 3:			
T1	17	4.60	12.40
T6	17	6.75	10.25
T8	17	5.17	11.83

Note: * Resistance was encountered almost immediately at this location, possibly due to some localized heterogeneity or obstruction, and therefore, this value may not be representative of the actual sludge thickness.

3.1.5 *Density Measurements*

Density readings were taken at several locations in SB 1 and SB 3. A Troxler Model 3430 nuclear densometer was used to measure the field densities and moisture contents, according to ASTM D-2922 and ASTM D-3017, respectively. The results of testing performed on sludge are shown on Table 5. The results of testing performed on Test Pad 3 soils are shown on Table 6.

Table 5 Field Density Test Results - Sludges

Sample Location	Wet Density (lb/cf)	Dry Density (lb/cf)	Moisture Content (%) ASTM D-3017	Oven Dried MC (%) ASTM D-2216
Basin 1 Sludge:*				
T-1	84.0	40.3	66.2	108.3
T-2	85.2	41.0	75.1	107.6
T-3	92.7	45.8	63.7	102.2
T-4	83.3	42.0	65.0	98.5
Basin 3 Sludge:				
T-3	91.9	27.6	63.2	232.8
T-4	86.8	53.8**	61.3	
T-5	87.8	55.2**	59.1	
T-6	86.5	26.3	76.4	229.2
T-7	86.1	57.9**	48.9	
T-8	88.6	40.2	42.0	120.2
T-9	84.4	50.5**	67.3	

* Tests were performed on 12/1/98. All other tests were performed on 11/30/98.

** Dry density computed based on nuclear gage moisture content. All others based on oven dried moisture contents.

Table 6 Field Density Test Results - Soil

Sample Location	Wet Density (lb/cf)	Dry Density (lb/cf)	Moisture Content (%) ASTM D-3017	Oven Dried MC (ASTM D-2216
Basin 3 Test Pad #3 Soil:				
		Nuclear/Oven		
T-1	112.9	100.9/99.3	12.0	13.7
T-2	112.0	99.6/100.6	12.4	11.3

As a check for interferences possibly caused by the soil or sludge properties, oven-dried moisture content tests were performed in accordance with ASTM D-2216 for several different samples of sludge and soil collected. As can be seen in Table 5, the results indicate a significant variance in moisture contents for the sulfate sludge material. Based on the testing/analysis method of ASTM D-3017, a significant variance was expected.

3.2 FOLLOW-UP LABORATORY TESTING

3.2.1 Sludge Physical Property Index Testing

As a part of the laboratory testing of the sulfate sludge, described in the 25 November 1998 memo to M. Byle of Gannett Flemming, ERM has identified a non-typical response to the physical property index testing planned. ERM initially proposed the use of typical soil index properties to identify variability in sulfate sludges encountered in the SBs. This method was proposed in order to increase the confidence in key performance properties to be used for the development of the design.

The indicator properties initially planned for comparative analysis were moisture content, sieve, hydrometer, and Atterberg limit analysis. In the performance of these tests ERM has identified some non-typical performance of the materials.

ERM has identified that the sulfate sludge from all SBs, in its existing condition, would visually classify as an elastic silt (MH) with at most a trace (0 to 5%) of sand. The classification of the material utilizing the ASTM D-2487 method yields a low-elasticity silt with sand (ML) to a silty sand (SM), which contains in the range of 19 to +50% sand.

Based on experience with this and other sulfate sludges, a common property change has been identified that is created through the sample preparation/drying process. An apparent change in the material during drying is causing "interparticulate bonding" creating larger aggregate particles. Presently, the actual mechanics of this change with this specific sludge are not known, but it is believed to be due to the change in water of hydration in the sulfate due to drying. This problem is alleviated with sulfate sludge generated from flue gas desulfurization systems by drying the material at a lower temperature, approximately 70° C. This is approximately 34° less than the ASTM standard for moisture content determination, which is performed at 104° C. ERM dried the sludge at both 70° C and at ambient temperature 18-22° C and found the same aggregating response of the sludge.

The following analysis has been completed in accordance with ASTM procedures for 5 samples of sludge collected from SBs 1, 2 and 3:

- Moisture content;
- Sieve analysis; and
- Hydrometer analysis.

The reduced laboratory data figures, which show the "sandy" material on the grain size plots, are included as Attachment 2 to this Appendix.

ERM performed a select set of additional duplicate analysis on two sludge samples through a modified wet preparation procedure to try assess the impacts of the preparation process. This data is also included in Attachment 2.

The wet prepared materials tested classified to be a silt (ML) with at most a trace >5% sand. The samples duplicated in this modified testing are from SB 3 and are noted in the reduced laboratory data as BASIN-3 1.1 and BASIN-3 2.1 and co plotted with the dry preparation samples noted as BASIN-3 1.0 and BASIN-3 2.0. The wet preparation of the samples adds significant error in the testing procedures but provided a more realistic sample gradation.

Based on the data available, the use of physical indicator properties (classification) to determine potential variations or similarities of the sulfate sludge does not appear to be applicable. In lieu of classification testing, in situ shear testing and laboratory consolidation testing are recommended for determining the variability of sludge characteristics as it relates to the cover design. A field testing program is described in Section 4.2.1.

3.2.2 *Sludge Consolidation Testing*

ERM performed a large-diameter consolidation test on one sludge sample. It was initially planned to perform tests on a number of samples, which varied from basin to basin and over the range of water contents found. However, only one test was completed because of the length of the test (1 week per load cycle, 8 to 10 weeks for the entire test). This test was performed to generate an order of magnitude estimate of the expected consolidation due to the application of the cover system and attic fill loads.

The consolidation test performed is a modification of the typical one-dimensional fixed ring consolidation test. The fixed ring test utilizes a 2 to 3 inch diameter sample approximately 1 inch thick over a load range of 500 pounds per square foot to 32,000 pounds per square foot (0.25 to 16 tons per square foot). ERM developed this modification of the test for the following reasons:

- The use of a large diameter sample allows controlled application of loads throughout the anticipated load range The load range used was 177 to 2,023 pounds per square foot (0.09 to 1.01 ton per square foot). This equates to loads of approximately 1 - 2 to 15 – 20 feet of material depending on material density. This covers the range of loads anticipated for the cap system on the sludge basins.
- The larger thickness sample allows expected consolidations of greater than 25% to be monitored effectively. The use of a very thin sample with this much movement has demonstrated problems with the limits of the laboratory equipment.
- The volume of pore water generated is significantly larger with a big sample as compared to the standard sample. With this type of analysis the pore water generated can be visually inspected for issues that may potentially clog or damage a drainage system.

The initial sample selected for analysis was sludge bulk sample Basin 3, 1.0. The laboratory analysis of this sample is included in Attachment 2 to this document. This sample was selected based on moisture content and general consistency. This sample had a moderate consistency and demonstrated a median moisture content for the samples recovered. The bulk samples from SB-1, 2, and 3 covered a moisture content range of 111% to 209%. The Basin 3, 1.0 sample had a moisture content of 144%.

The sample was placed in the consolidometer utilizing a procedure similar to that used to develop wet density of semi-solid samples (e.g., wet concrete density). The material was placed in three lifts and rodded 25 times per lift to minimize trapped air voids. Initial measurements to determine density, height, etc. were collected and an initial seating load was applied to the sample. The seating load was monitored for deflection and was allowed to continue until the deflection has tailed. At this point additional loads were added on an approximate doubling rate typical to consolidation tests. For each load, deflection was monitored on a log time basis for the initial 24-hour period and then regularly until the consolidation appeared to have tailed. This took approximately 1 week per load cycle.

The initial and final properties of the sample are detailed in the following tables.

Table 7 Consolidation Test Physical Parameters

	Initial Sample	Final Sample
Wet Density (#/ft³)	85.6	95.4
Dry Density (#/ft³)	35.1	51.5
Moisture Content	144.0%	85.1%
Sample Height (in)	5.128	3.554
Sample Diameter (in)	6.024	6.024

Table 8 Consolidation Test Summary of Load vs. Consolidation

Load (tsf)	Load (psf)	Percent Consolidation
0.0886	177	10.6%
0.1574	315	13.8%
0.2135	427	15.1%
0.3257	651	18.6%
0.5501	1,100	23.9%
1.0115	2,023	30.7%

The plotted consolidation curve is included with the reduced laboratory data in Attachment 2. The pore water generated from the consolidation of the sample did not appear to demonstrate conditions that may clog a drainage system (i.e., transport of fines, expulsion of gelatinous material, expulsion of oils or higher viscosity fluids).

The use of the consolidation curve to predict potential settlements due to applied load is only a relative tool. The placement of the material in the consolidation cell is done to simulate the material in the near surface condition as closely as possible (i.e., without air voids). As loads are applied, this material will consolidate along the virgin consolidation curve.

Since the materials were hydraulically placed in the basin and there have been no significant loads applied to the material (i.e., glaciers, building foundations, significant fills) the material should be in a normally consolidated condition. Therefore with the imposition of additional loads due to the cover system application, the material should undergo consolidation on the virgin consolidation curve. With this understanding, an estimate can be made of initial load due to overlying material at one half of the sludge layer depth and a comparison made to the design load condition at the same depth. At each load the corresponding percent strain can be predicted from the consolidation curve, and a total consolidation can be estimated based on a change in percent strain from the existing to design loads.

Consolidation assessments typically include the evaluation of secondary compression (also referred to as creep). However, the data from the consolidation test indicated that secondary compression would need to be measured over a period of several weeks to a month, which would have prevented the progression of the test to the next load cycle. Each consolidation load took one week to complete and six tests were completed. Therefore, measurement of secondary compression was not feasible within the time allotted for the consolidation test.

Critical factors in the prediction of time rate settlements due to consolidation are permeability and the length of the drainage path. The sludge has demonstrated a permeability on the order of 1×10^{-7}. The time lengths of consolidation on each load cycle confirmed the low permeability. The drainage path length can be controlled through physical means to speed consolidation by the addition of vertical drains or other drainage methods. The permeability and drainage path length only impact the speed at which settlement occurs not the total settlement.

The initial consolidation test results provide a general indication of potential consolidation settlements to be expected in the field. Additional consolidation testing should be completed during the design phase once potential variations in the sludge are identified by the recommended field vane shear testing, and once more representative test conditions can be defined through subsequent phases of the engineering design. Additional consolidation testing should also include an evaluation of secondary compression.

4.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

4.1 SUMMARY AND CONCLUSIONS

The results of the field and laboratory tests completed to date support the conclusion that the placement of a soil cover on the Sulfate Basins is technically feasible. These results further support the assumptions made in developing estimated cost ranges for the sludge basins soil covers presented in the EE/CA. Subsequent engineering design testing and evaluations will support the selection of the appropriate construction methods and materials to ensure that the soil cover meets the applicable performance requirements (e.g., thickness, stability, etc.).

Substantive results and conclusions from the field and laboratory tests conducted to date, relative to the design and construction of a soil cover over the Sulfate Basins, include the following:

- As demonstrated during the field test, and as shown on the project photographs (Attachment 1 to this Appendix), a soil cover, ranging in thickness from 1 to 4 feet ,can be placed on top of some of the existing sulfate sludge surfaces utilizing readily available construction methods and materials. Engineering design evaluations will address the placement of greater depths of attic fill that may be needed to account for consolidation settlement when achieving desired final slopes on the basin covers. The potential interaction between cover thickness and the compactive effort to achieve a required cover permeability will also need to be further evaluated during the engineering design phase.

- Compaction of cover soils above the sludge surface is feasible. Field test results indicate that the cover soils utilized were compacted to at least 90% of the standard proctor maximum dry density via moderate tracking with a relatively small, low-ground-pressure dozer. While no effort was made to achieve a particular degree of compaction in the field test, the level of compaction achieved is typically acceptable for landscaping and similar non-load bearing applications (such as soils caps with shallow slopes). The engineering design will further consider permeability goals in relation to compactive effort.

- Geotextiles can be effective for distributing loads, separating soil and sludge, and increasing the stability of the cover system (soils and geotextile) and construction equipment above the sludge surface. Where geotextiles were adequately anchored, construction equipment was able to operate directly on top of the geotexile placed on the sludge surface.

- The large quantities of fly ash available at the site can be effectively utilized as attic fill in the construction of the SB soil covers.

- Surface draining and solar evaporation can improve the conditions of the sludge surface with regards to cover soil placement. Based on the high moisture content of the sulfate sludge, additional draining and/or dewatering to depths below the surface could be appropriate for improving sludge characteristics for soil cover placement. However, a significant period of time may be likely to realize any improvements in sludge dewatering. Another potential approach would be to promote desiccation and thereby develop a crust on the surface of the sludge that would buffer the underlying weak sludge from construction-induced stresses. The potential means and benefits of sludge dewatering, as well as other approaches to stabilize the sludge surface, will be evaluated further in the engineering design phase.

- In-situ strength test results indicate that undisturbed sludge strengths are greater than the strengths of disturbed sludge. The engineering design will consider this characteristic for situations that require significant sludge movement or disturbance, and whether all sludge subject to loading, vibration, etc., of soil cover placement should be considered to be disturbed. Subsequent tests will investigate potential strength gain over time for disturbed sludges.

- Sludge displacement and consolidation settlement will be considered in the soil cover design. Field test results indicate upward sludge displacements of less than one foot in response to soil cover placement in adjacent areas, and total displacements (as compared to the original sludge surface) of approximately one foot in soil cover areas. These displacements are likely greater than would be expected in the full scale construction because of boundary conditions present for the field test that can be avoided for the full scale construction. However, unfavorable boundary conditions cannot be avoided all together in placing the cover soils. SB will be drained to the extent practicable through the summer of 1999, and periodic visual assessments of the conditions of the soil cover will be made.

The density, thickness, and slope of cover materials can be varied in the soil cover design as necessary to accommodate the expected differential and total settlements. Consolidation test results can also be used to predict the volume of water to be managed during consolidation settlement of the sludge.

Sludge characteristics may vary from basin to basin and geographically within each basin. Differences in sludge character between the test pad locations in SB 1 and SB 3 were described earlier. Further identification of sludge variability and the need to account for those differences will be addressed in engineering design phase.

4.2 *RECOMENDATIONS FOR FURTHER GEOTECHNICAL EVALUATIONS*

A preliminary plan for further design testing and geotechnical evaluation has been developed based on the ongoing testing of the sulfate sludge in the laboratory and field, and the results of the field study performed to investigate the feasibility of a soil cover placement. Listed below is a summary of the present data gaps may be further addressed as part of the engineering design:

- In-situ sulfate sludge strength;
- Actual sludge thicknesses/volumes/areas;
- Potential settlement of the sludge due to cover and equipment loads; and
- Potential water generation volumes and rates due to applied cover and equipment loads and sludge consolidation.

A recommended laboratory and field testing program to address the above data needs is presented in the following subsections.

4.2.1 *Field Testing Program*

The field testing program will be directed to address the first two items presented as data needs. The field program will include the following items:

1. In-situ strength survey of the SB materials.

   A survey should be performed of in-situ strength over the SB area. This would include the performance of additional vane shear testing on a grid/regular pattern over the basin area to develop an aerial strength pattern over the basin area. At each sampling node, the vane shear testing should be performed at selected depths to assess strength variation with depth.

The anticipated end product of the data collection would be a three dimensional strength map of the sludge contained within each basin. This strength map could then be used to assist in identifying variations in sludge properties, and allowing the necessary design provisions to be developed prior to construction.

The strength profiling will also allow the refinement of laboratory samples collected for critical design physical property analysis. As a part of the testing, samples for moisture content will be collected to potentially define a strength/moisture relationship

2. Sludge Thickness Surveying

   Concurrent with the in-situ strength testing, a survey of each strength test location should be performed. This surveying would document the location and top of the sludge and the bottom of the sludge material based on the ability to push the drilling rods into the sludge.

   This data would be utilized to supplement site topographic data to develop sludge isopach thickness maps. These isopach maps would be used to develop actual volumes of sludge and allow prediction of the final cover profile in combination with laboratory data.

4.2.2 *Laboratory Testing Program*

The laboratory testing program will be an extension of the present program. As a result of the in-situ strength testing, additional locations for the collection of samples will be developed. The additional samples will be collected based on strength data and correlated with moisture content to potentially develop a relationship between moisture content and strength.

Testing to be performed will include primarily the following tests:

1. Large diameter consolidation testing.

   Additional samples should be selected for consolidation testing based on the vane shear determination. The consolidation testing should include evaluation of secondary compression. The samples should be selected to represent the potential range of consolidation curves for each basin.

   The development of this data would allow the prediction of settlement due to the application of the cover system. Additionally, the consolidation test data would be used in conjunction with other data to generate a prediction of water volume generating as a function of time due to the consolidating sludges so that this water can be managed appropriately.

2. Undisturbed/remolded triaxial strength testing (UU and CU w/pore pressures).

   Triaxial strength testing should be performed on selected samples both as undisturbed (thin walled/Shelby tube) samples if possible and remolded samples. Analysis would be performed to support the field vane shear testing results. This would be a limited program since limited benefit is expected to be gained from the laboratory determination of strength of collected sludge samples. At a minimum, an attempt would be made to correlate this data with the in-situ strength testing results.

Table 9 summarizes the geotechnical field and laboratory testing listed above in context of its use in engineering design and as it relates to the geotechnical evaluations reported upon in this Appendix.

This is an initial recommendation for the scope of the engineering design data requirements and the required testing to meet the requirements.

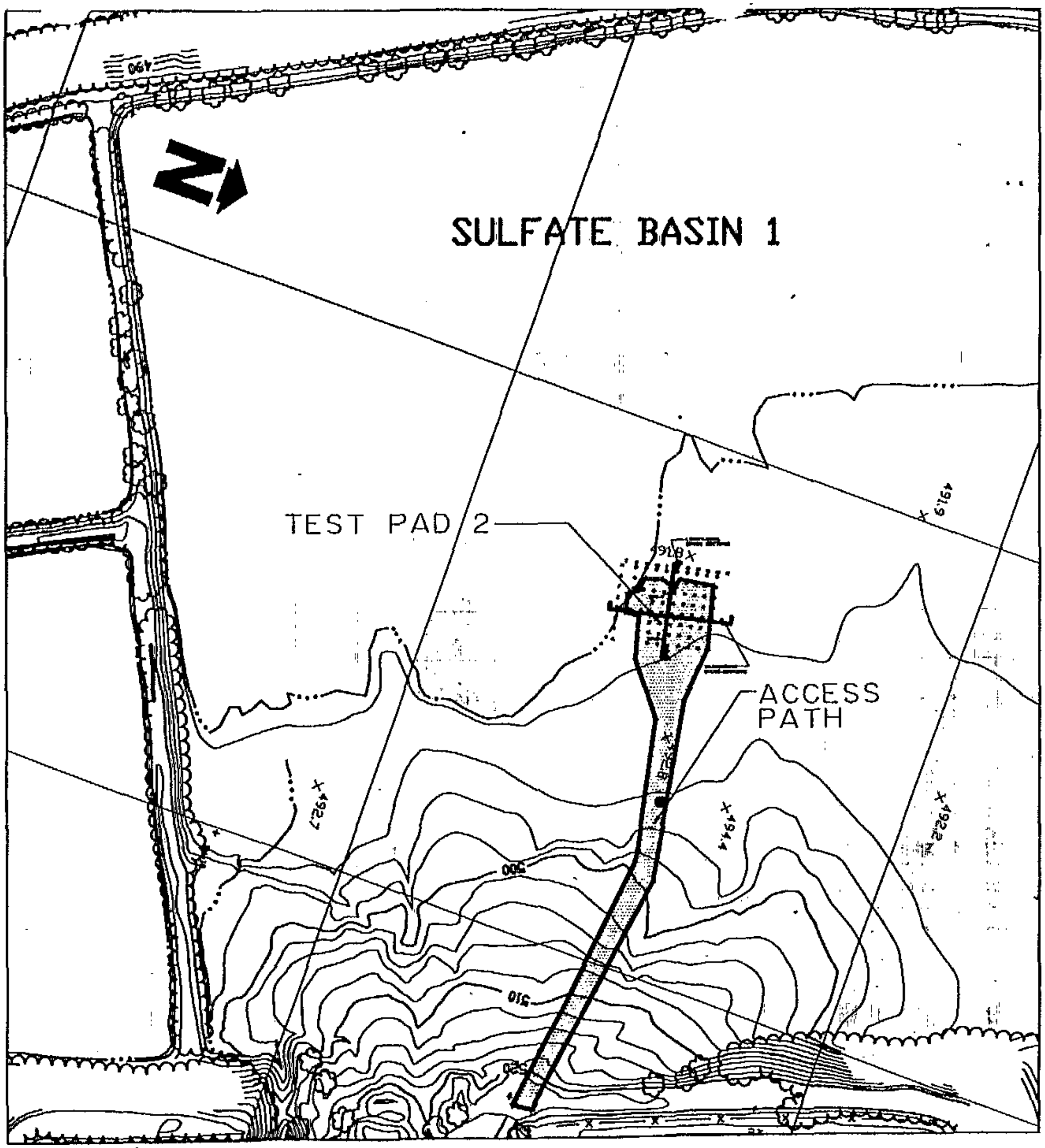
Table 9 Geotechnical Testing Summary

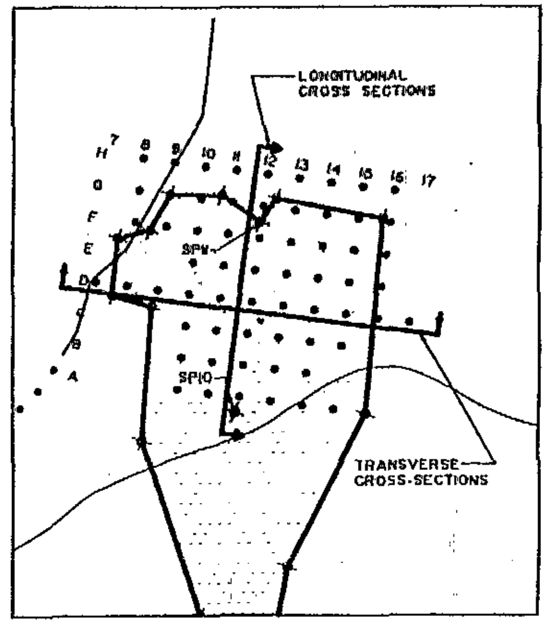
Testing	Data Use
Present Testing – Laboratory	
Triaxial Strength UU (unconsolidated undrained)	Provides indication of expected material strength parameters for construction loading/sludge relocation.
Triaxial Strength CU (consolidated undrained with pore pressures)	Provides indication of expected material strength parameters for long-term strength stability predictions
Classification Testing (sieve, hydrometer, moisture content, Atterberg limits) [ASTM procedures]	Provides basic physical property comparisons between sludge samples (limited applicability of this testing due to change in material properties caused by material prep).
Classification Testing [wet prepared]	Provides basic physical property comparisons between sludge samples (initial samples analyzed provide a more realistic picture of sludge grain size distribution).
Consolidation Testing	Provides indication of the expected settlement of the sludge caused by the cover system load application (from test results time rate calculations, time rate settlement values, and time rate consolidate liquid expulsion can be calculated).
Present Testing – Field	
Test Pad construction (observational summary of construction performance)	Provides a field scale demonstration for the potential of cover placement on the sulfate basins utilizing typical construction equipment and materials.
Test Pad documentation (physical property analysis of test pad construction)	Provides initial feedback on compaction, placement, permeability, and settlement.
In-situ sludge strength testing (vane shear)	Provides some initial information on in-situ strength of the sludges with depth.

Table 9 Geotechnical Testing Summary (Continued)

Testing	Data Use
Future Testing – Laboratory	
Triaxial Strength/Direct Shear UU (unconsolidated undrained)	Provides indication of expected material strength parameters for construction loading/sludge relocation and interface friction for construction of cover system layers.
Triaxial Strength/Direct Shear CU (consolidated undrained with pore pressures)	Provides indication of expected material strength parameters for long term strength stability predictions and interface friction for long term stability of cover system layers.
Consolidation Testing (including an evaluation of secondary compression)	Provides indication of the expected settlement of the sludge caused by the cover system load application (from test results time rate calculations, time rate settlement values, and time rate consolidate liquid expulsion can be calculated).
Future Testing – Field	
In-situ sludge strength testing (vane shear)	Provides patterned logging of in-situ strength over the basin area. Used primarily to identify inconsistencies with the sludge within each basin. Areas which have been identified as potential variances in basin use/depositional environments should be investigated with a tighter test spacing.

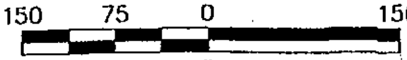
Figure C-1
Test Pad 2 (SB1)
Avtex Fibers Superfund Site
Front Royal, Virginia





TEST PAD 2 DETAIL
SCALE: 1" = 60'

SP = Settlement Plate



SCALE: 1" = 150'

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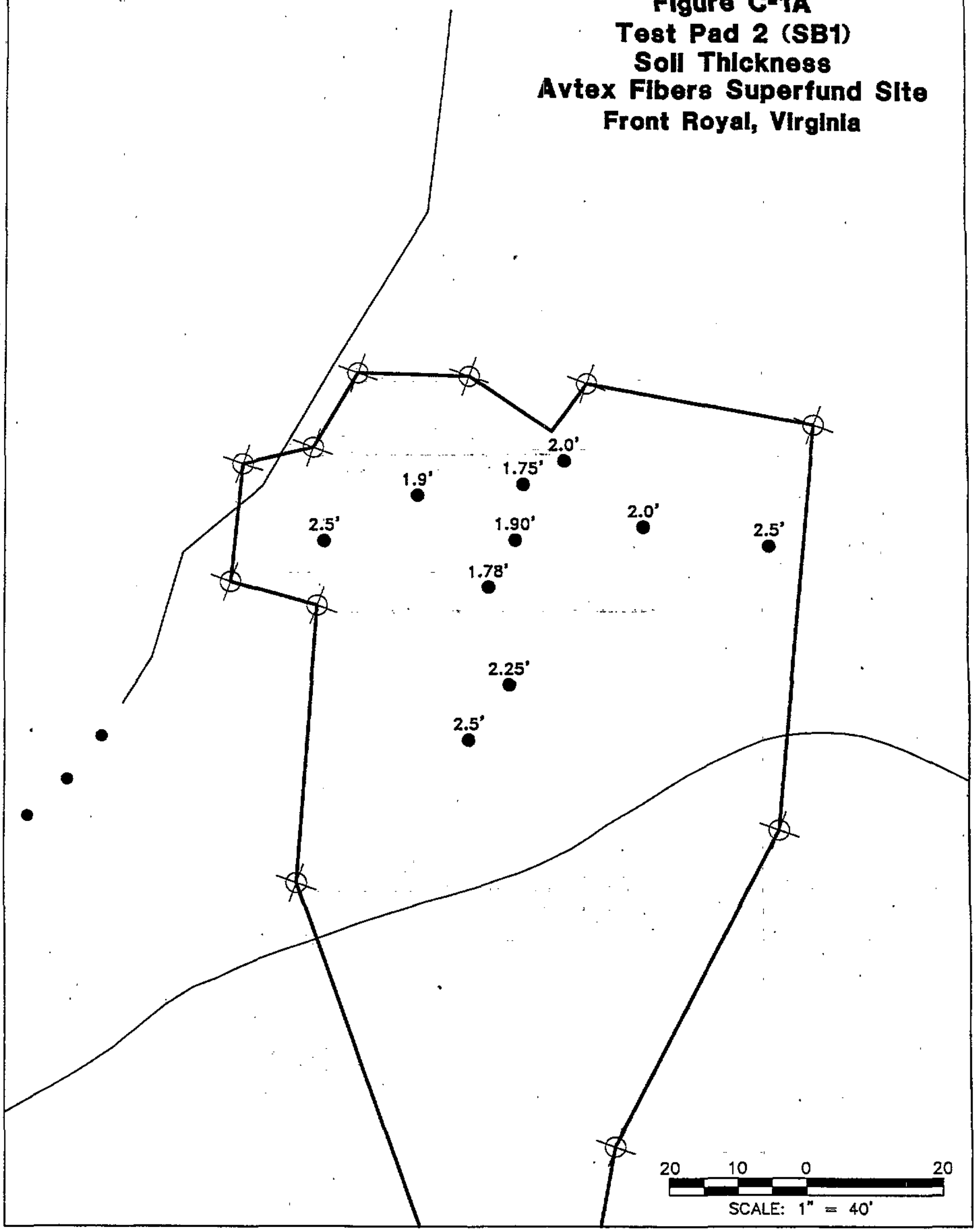
Figure C-1A
Test Pad 2 (SB1)
Soil Thickness
Avtex Fibers Superfund Site
Front Royal, Virginia



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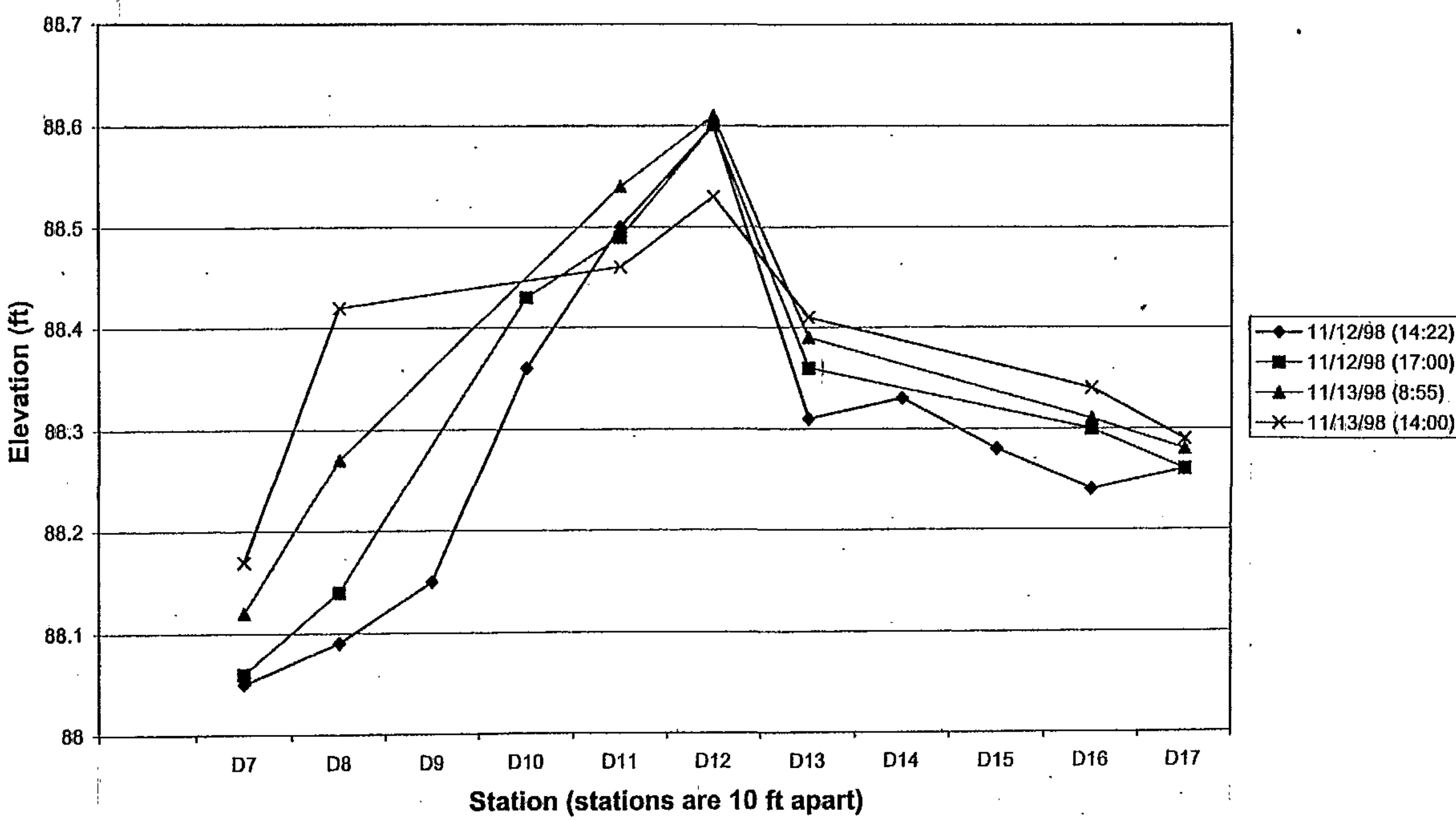
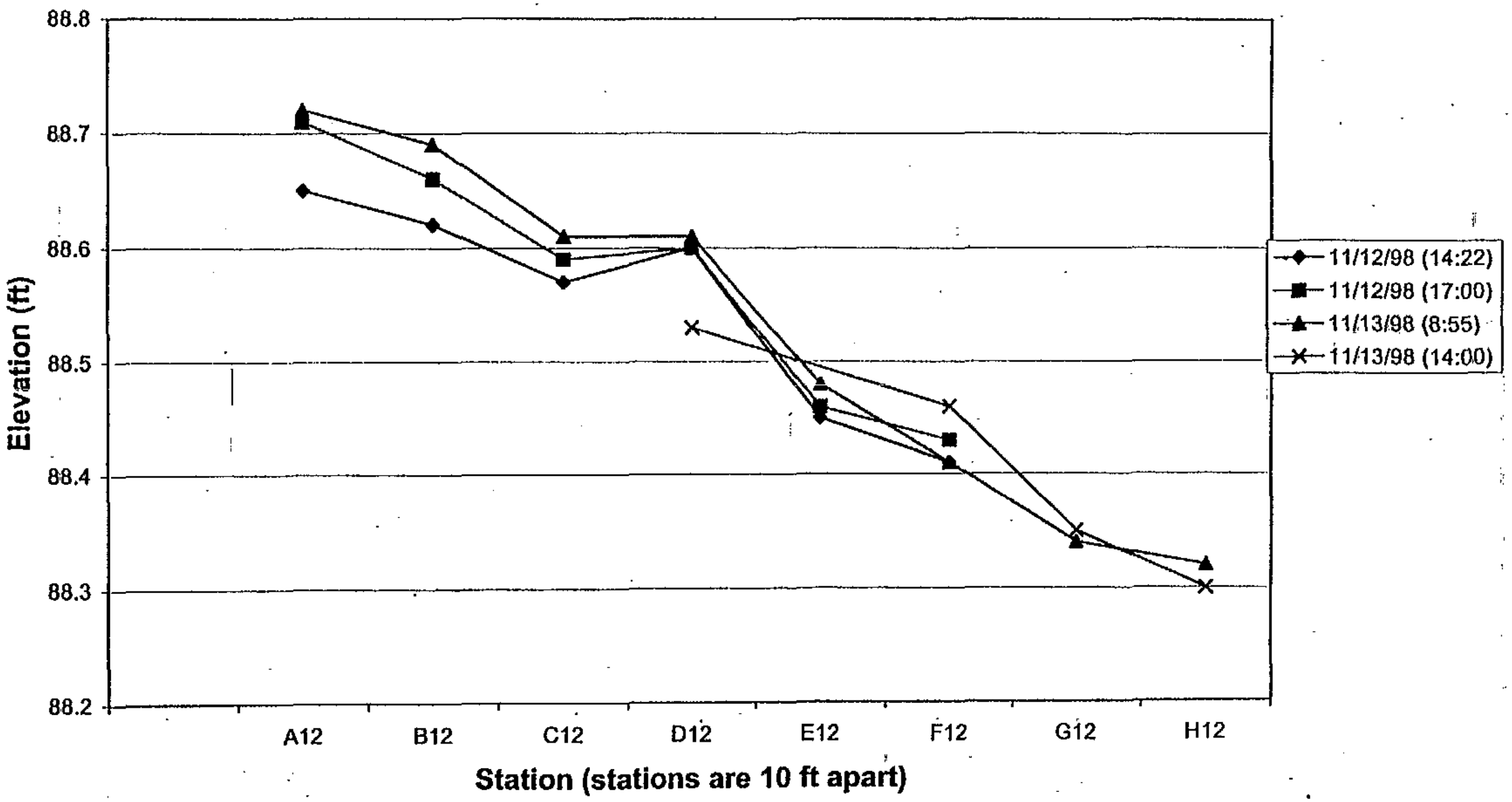
Fi e C-2
Test Pad 2 (Sulfate Basin 1)
Transverse Cross-Section Over Time
Avtex Fibers Superfund Site
Front Royal, Virginia



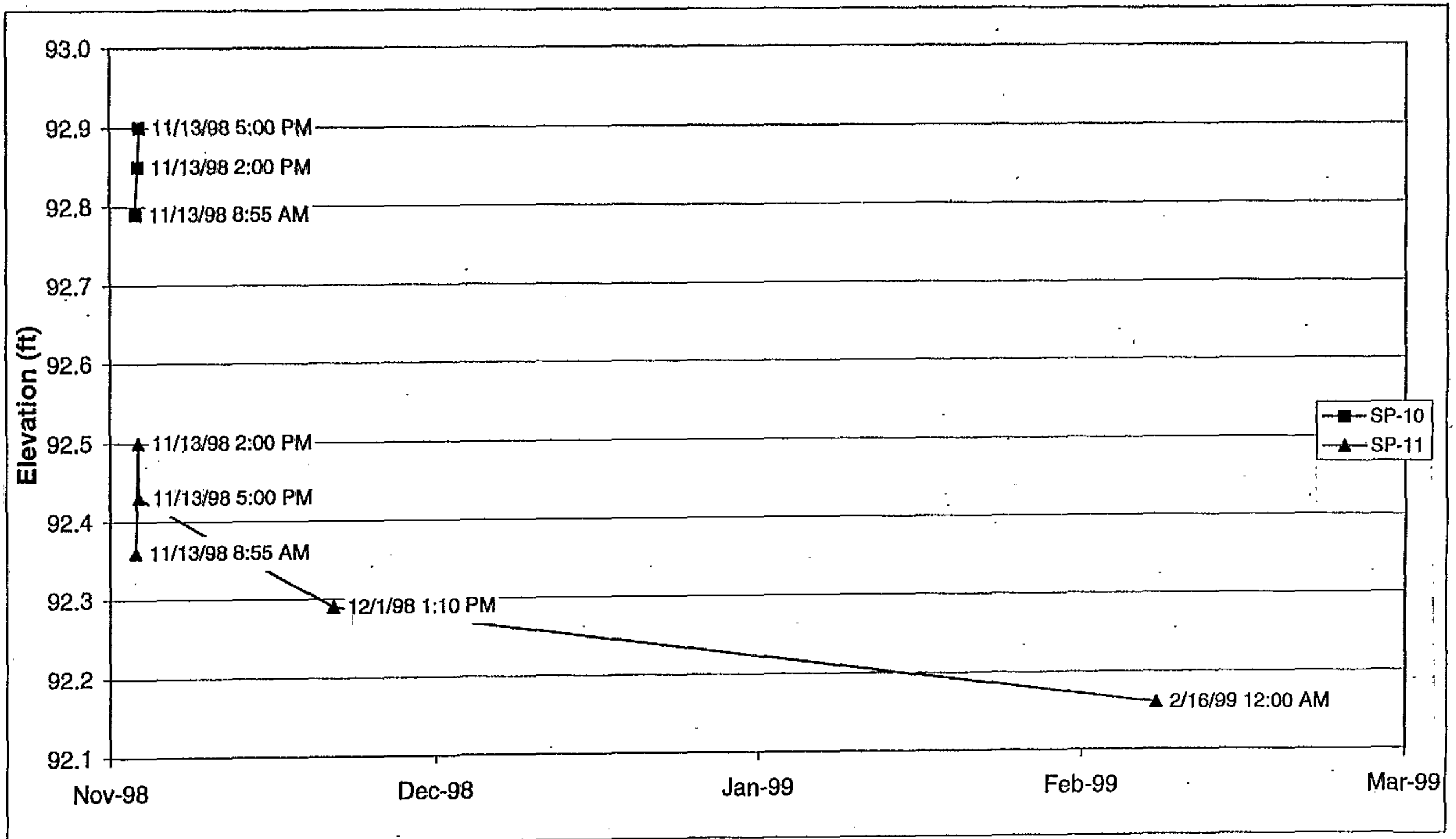
The 11/12/98 (14:22) elevations presented are approximately the original sludge surface elevations.
The 11/13/98 (14:00) elevations represent the sludge surface immediately after completion of the pad.

Figure C-3
Test Pad 2 (Sulfate Basin 1)
Longitudinal Cross-Section Over Time
Avtex Fibers Superfund Site
Front Royal, Virginia



The 11/12/98 (14:22) elevations presented are approximately the original sludge surface elevations.
The 11/13/98 (14:00) elevations represent the sludge surface immediately after completion of the pad.

Fi C-4
Test Pad 2 (Sulfate Basin 1)
Settlement Plate Elevations vs. Time
Avtex Fibers Superfund Site
Front Royal, Virginia



The test pad was constructed on 11/12/98 and 11/13/98.
The 11/13/98 (8:55) elevations presented are approximately the original SP-10 and SP-11 elevations, and the SP-11 elevation was estimated from the G-12 elvation.

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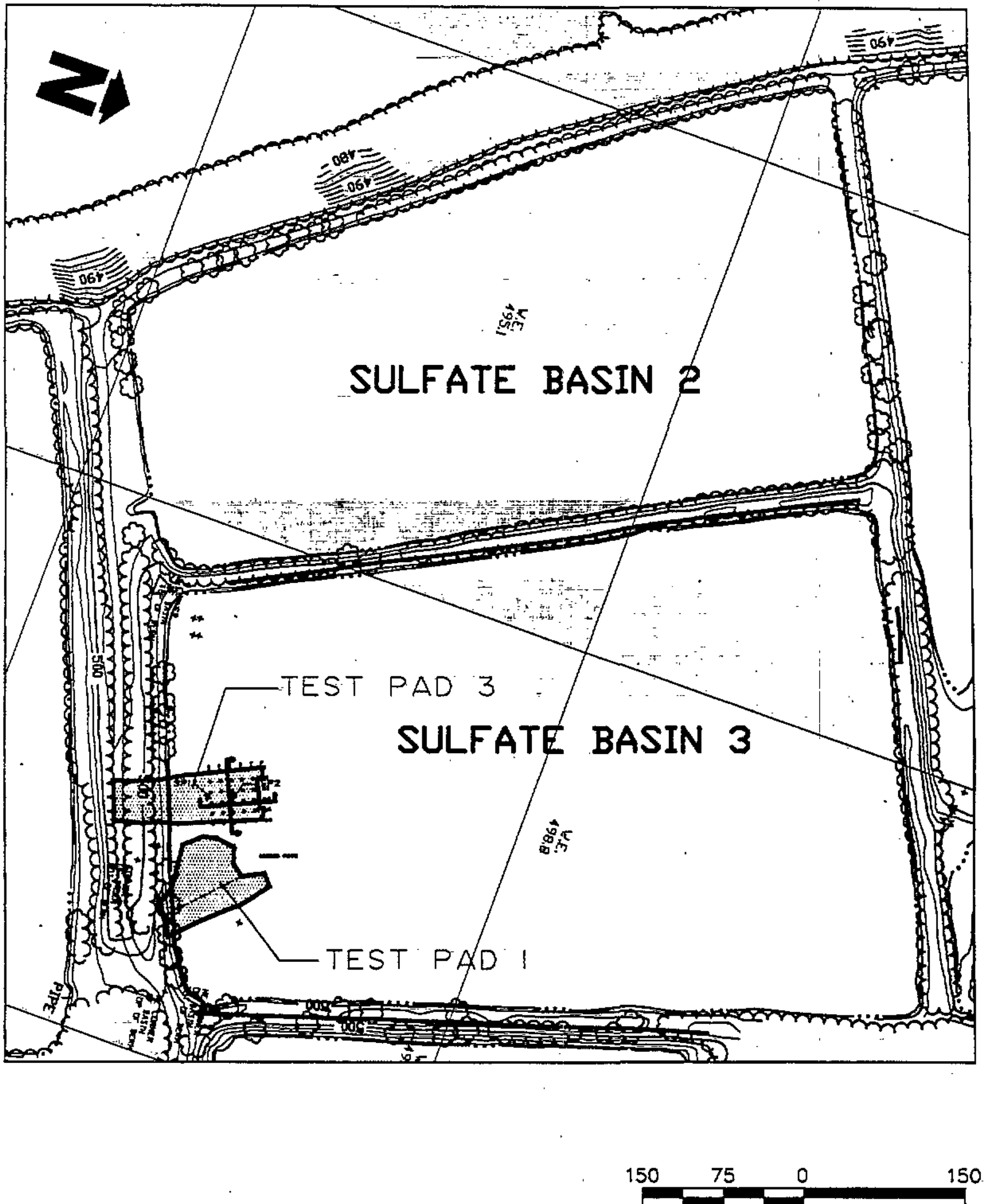
Figure C-5
Test Pads 1 & 3 (SB3)
Avtex Fibers Superfund Site
Front Royal, Virginia



SP = Settlement Plate

Figure C-6
Detail of Test Pads 1 & 3 (SB3)
Avtex Fibers Superfund Site
Front Royal, Virginia

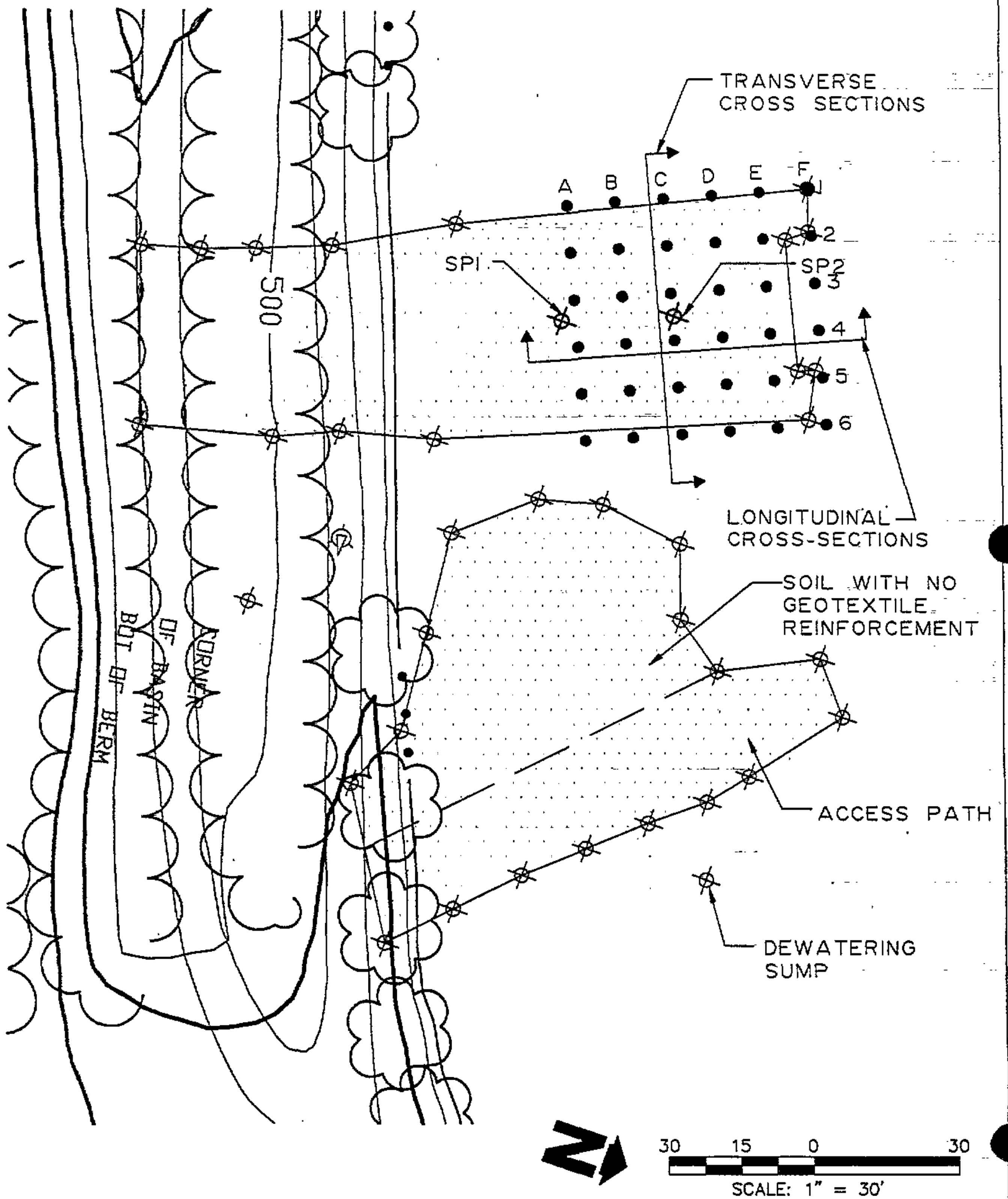


Figure C-6A
Test Pad 3
Soil Thickness
Avtex Fibers Superfund Site
Front Royal, Virginia

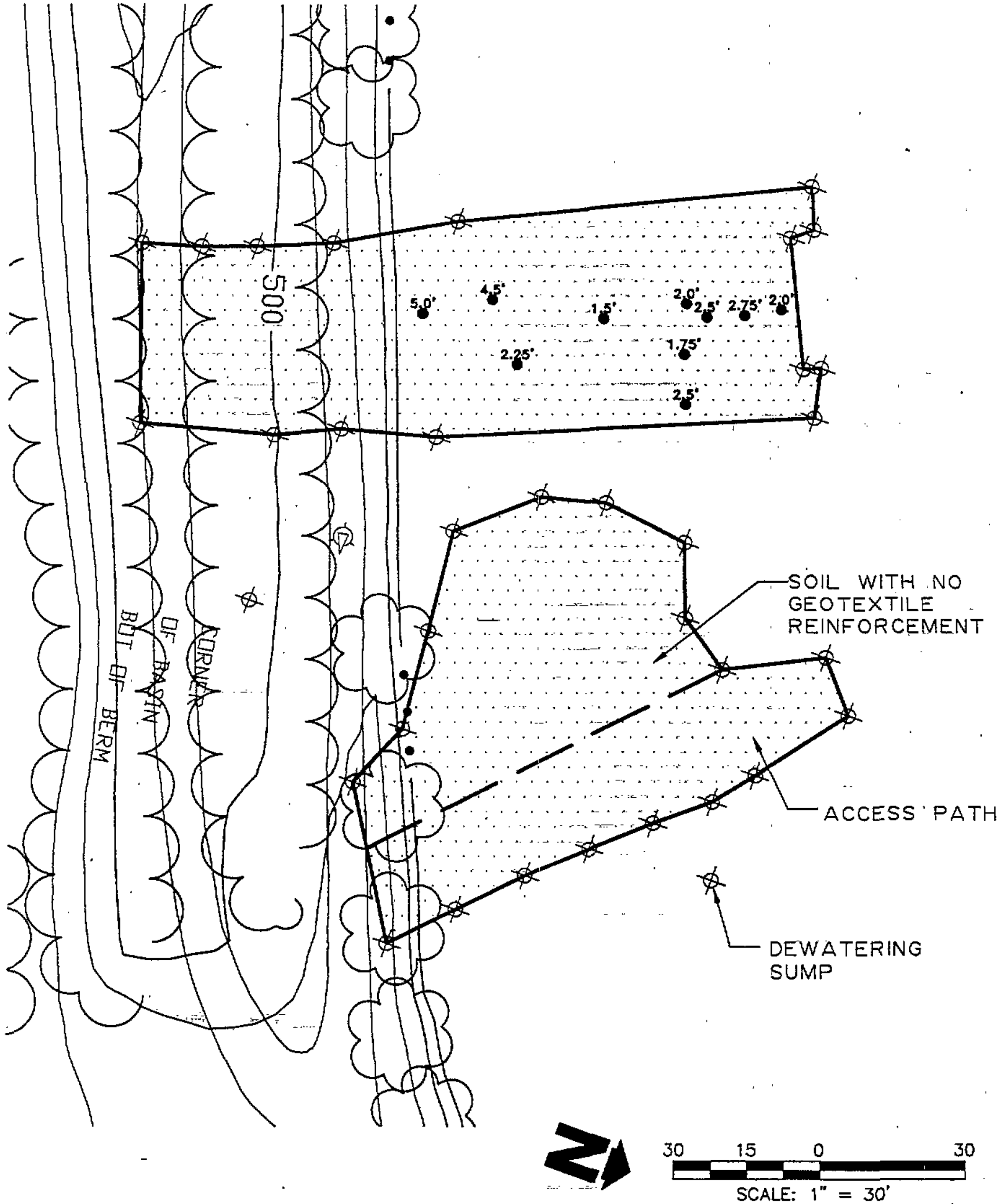


Figure C-7
Test Pad 3 (Sulfate Basin 3)
Transverse Cross-Section Over Time
Avtex Fibers Superfund Site
Front Royal, Virginia

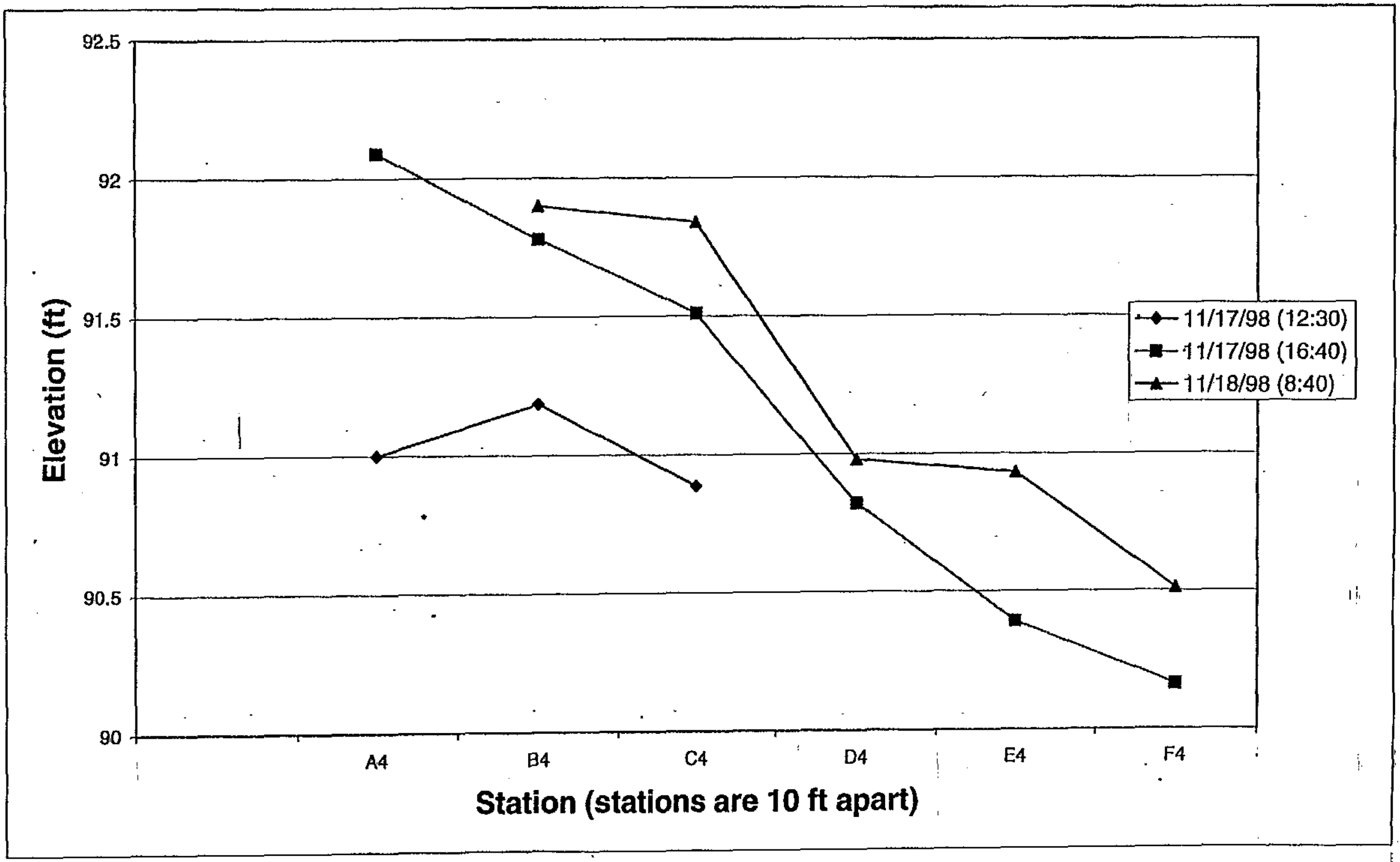
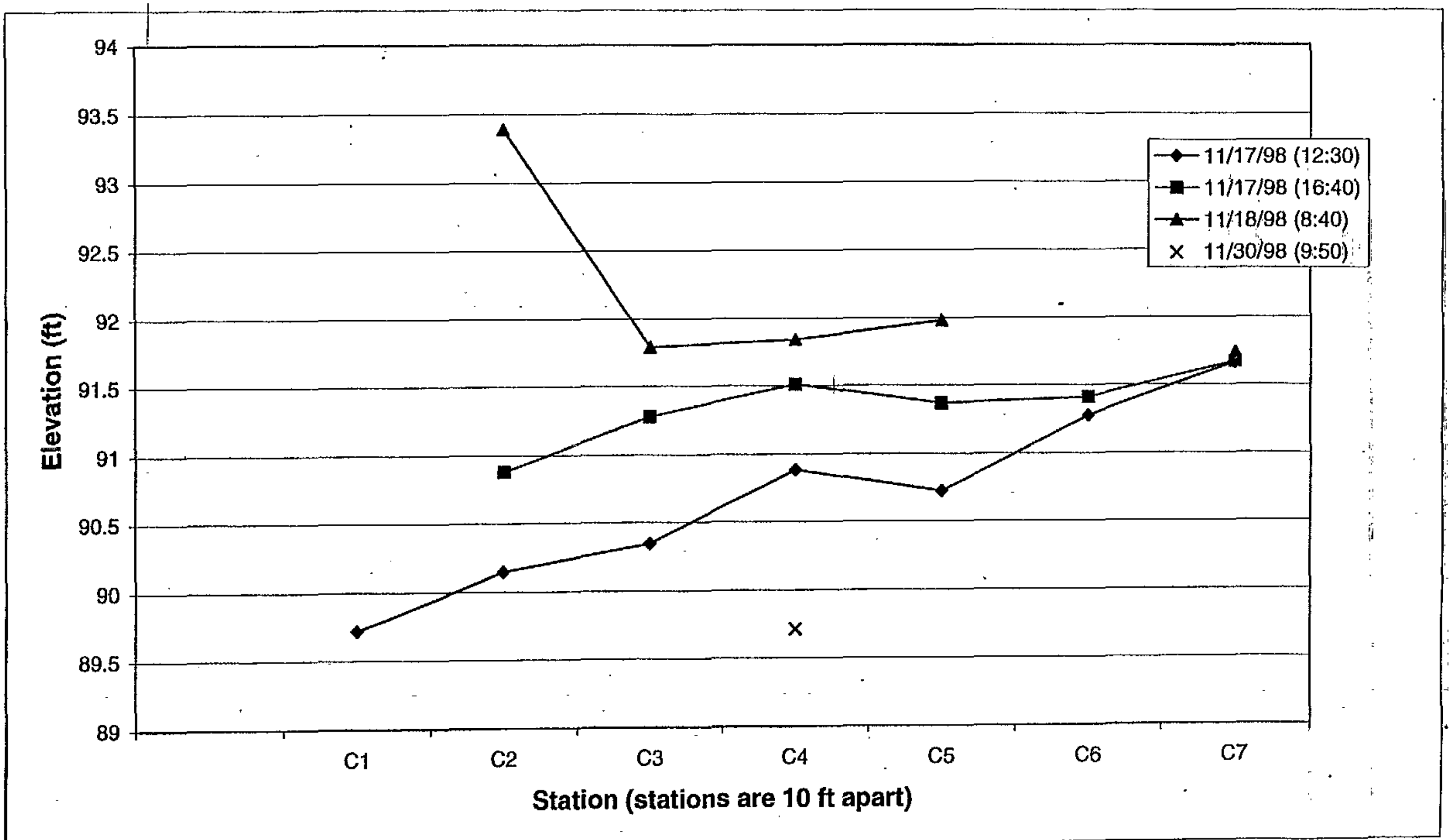


Fig C-8
Test Pad 3 (Sulfate Basin 3)
Longitudinal Cross-Section Over Time
Avtex Fibers Superfund Site
Front Royal, Virginia



The 11/30/98 (9:50) elevation presented was estimated from the SP-2 settlement plate elevation, located near the C4 survey location.
The 11/17/98 (12:30) elevations presented are approximately the original sludge surface elevations.

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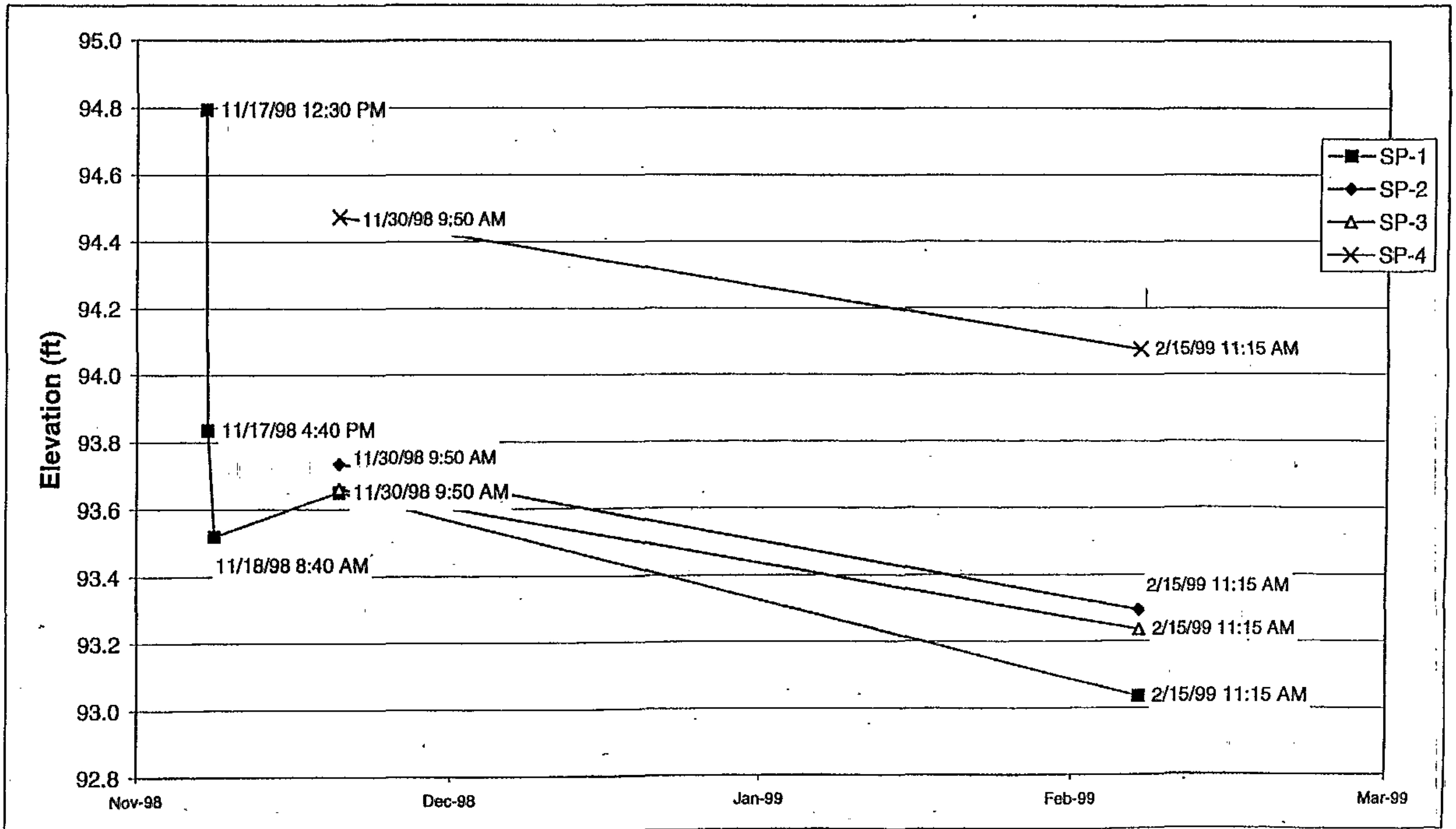
Fi C-9
Test Pad 3 (Sulfate Basin 3)
Settlement Plate Elevations vs. Time
Avtex Fibers Superfund Site
Front Royal, Virginia



The test pad was constructed on 17 November and 18 November 1998.

AR106537

Figure C-10
Sulfate Basin Field Density, Moisture Content and Vane Shear Test Locations
Avtex Fibers Superfund Site
Front Royal, Virginia

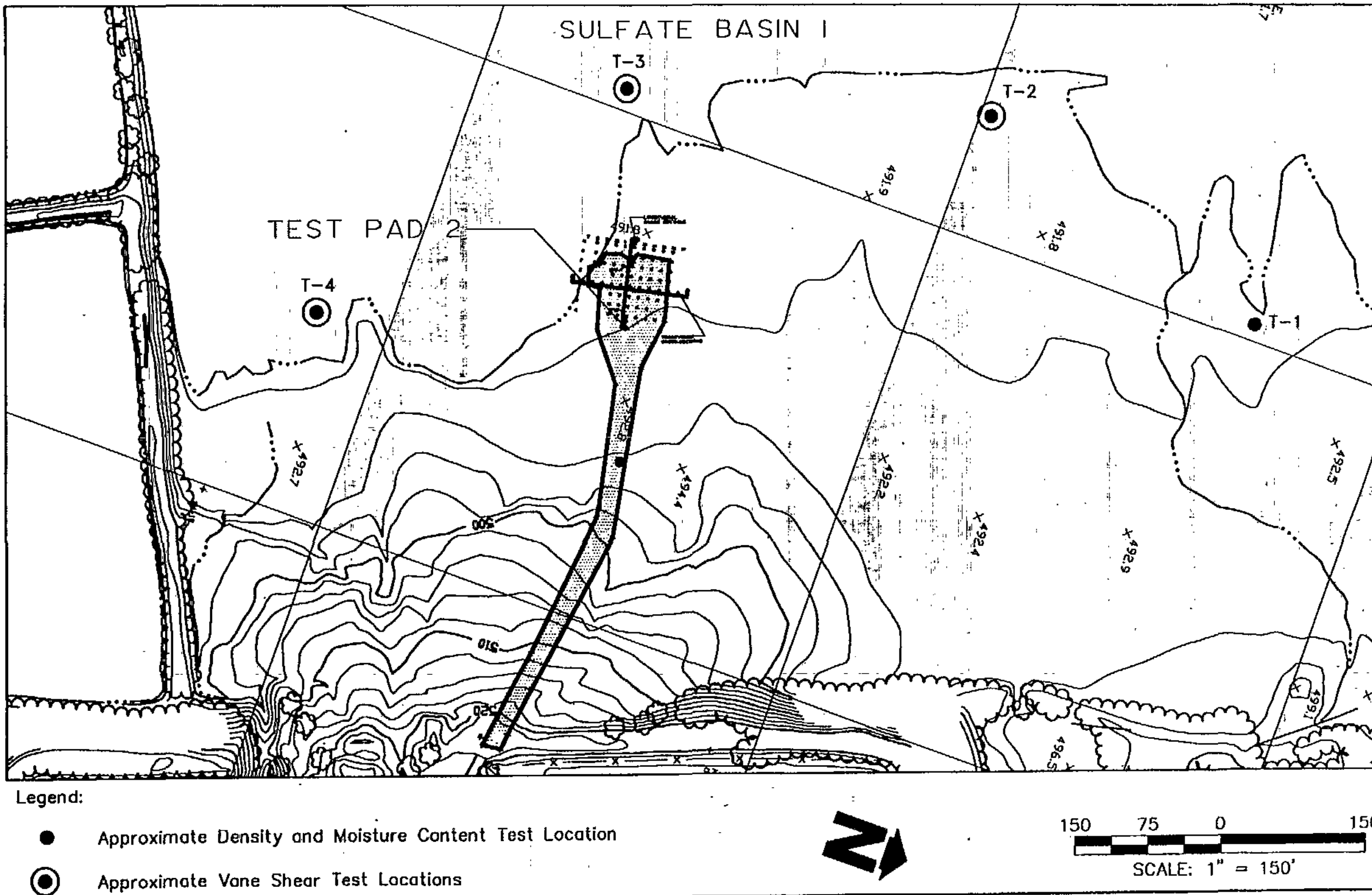


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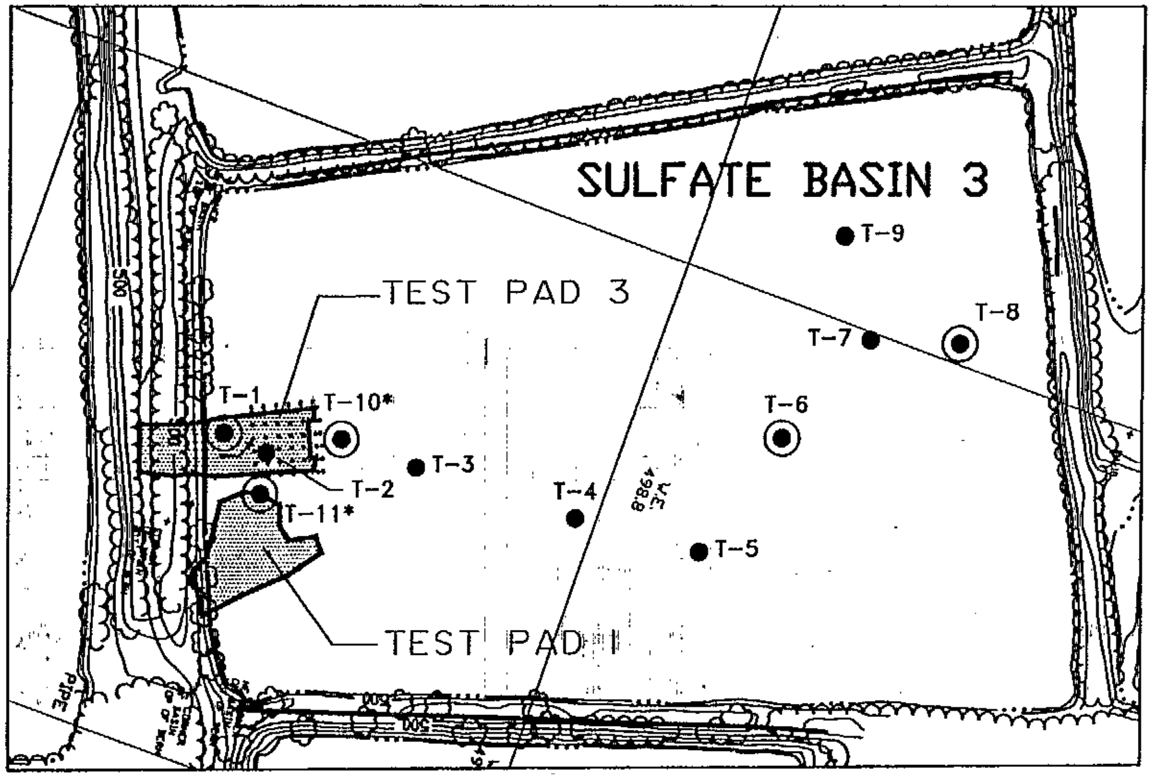
Figure C-11
Sulfate Basin 3 Field Density, Moisture Content and Vane Shear Test Locations
Avtex Fibers Superfund Site
Front Royal, Virginia



Legend:

- ● Approximate Density and Moisture Content Test Location
- ◉ Approximate Vane Shear Test Locations
- * Vane Shear Test Performed on 2/15/99 (all other vane shear tests performed on 11/30/98 and 12/1/98)

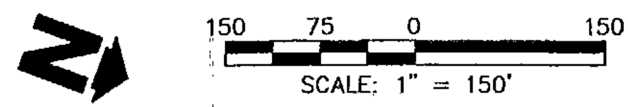


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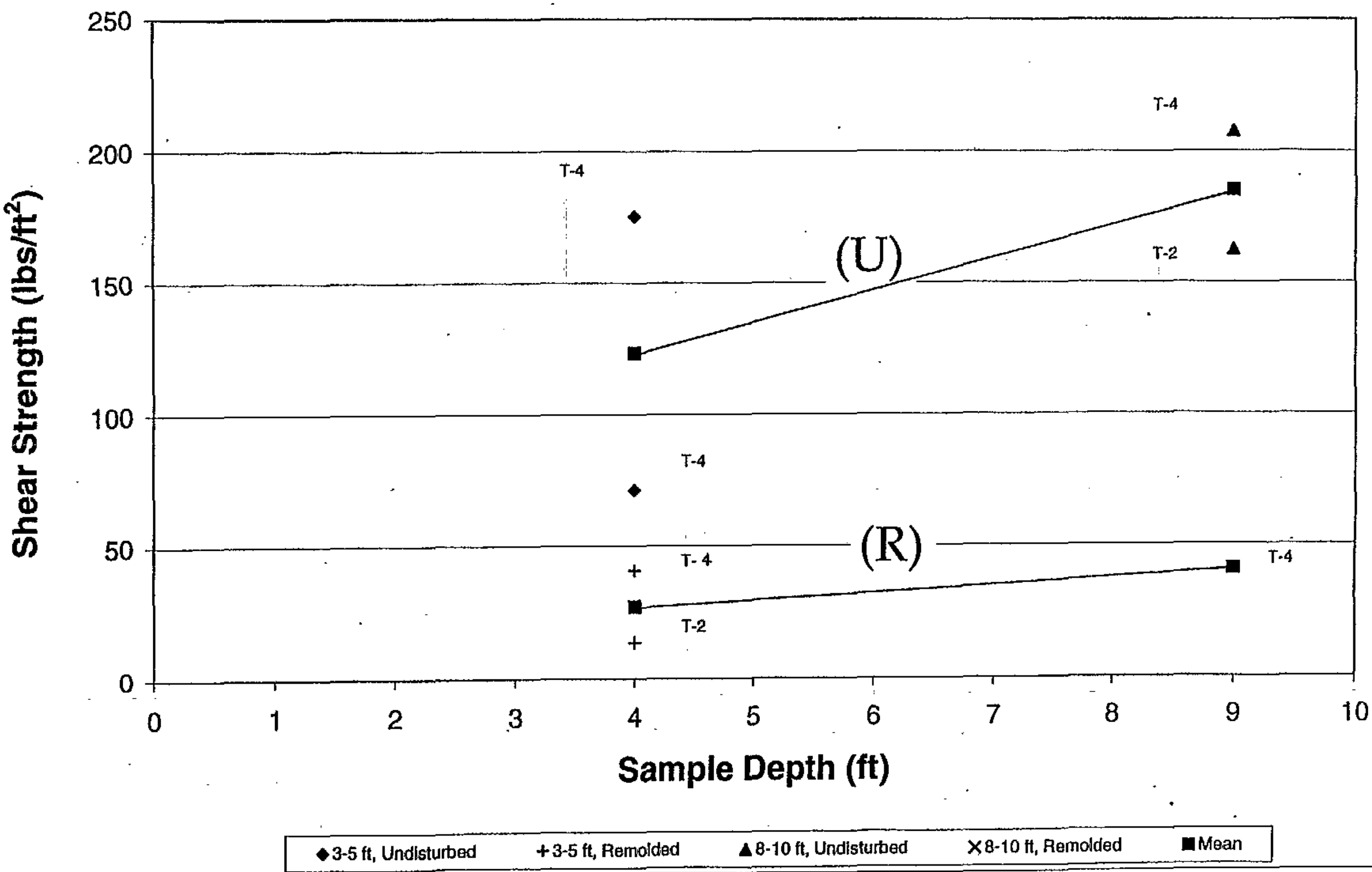
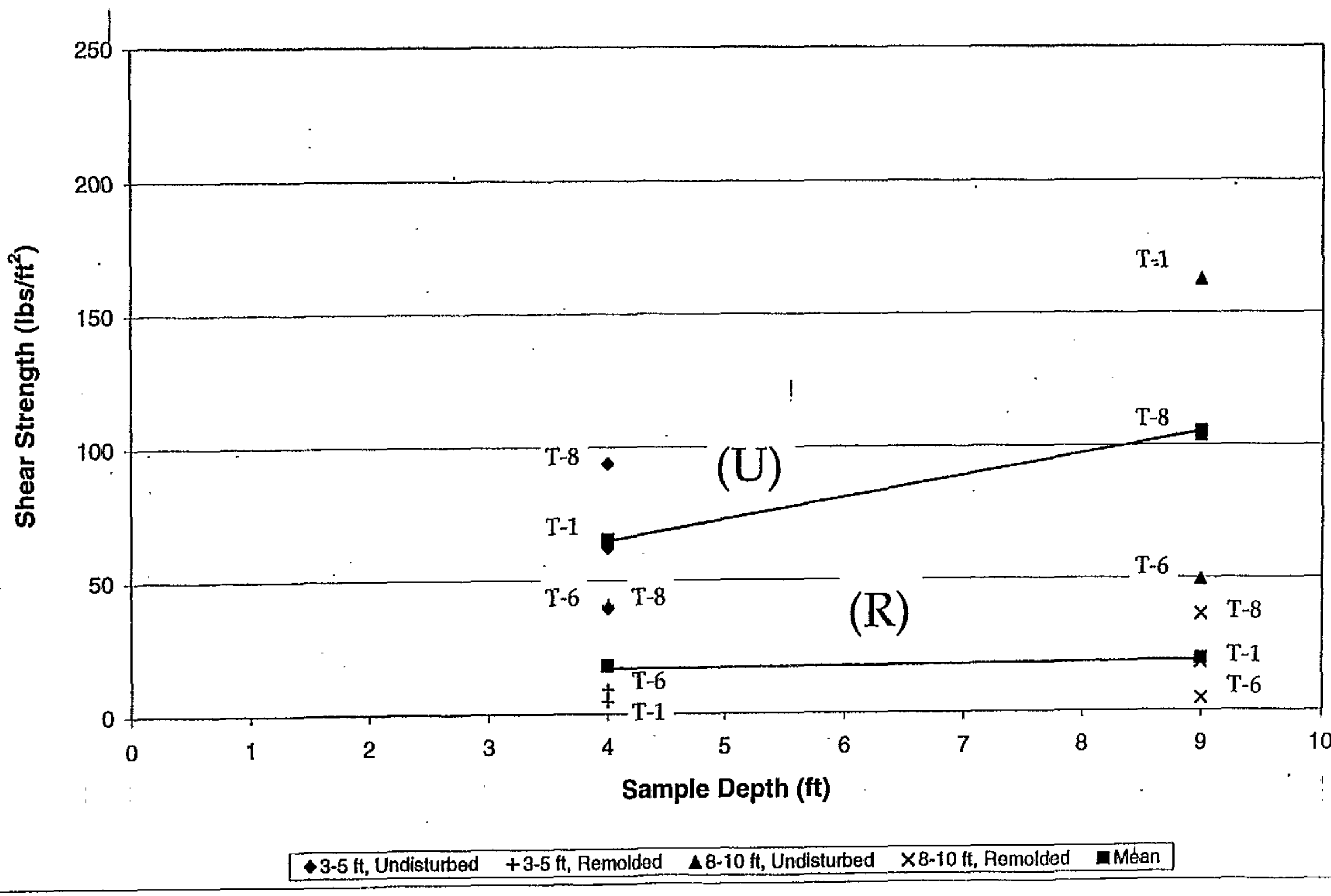
Figure C-12 Shear Strength vs. Depth for SB 1



T-2, T-3, and T-4 were performed in SB1
T-1, T-6, and T-8 were performed in SB3
(U' 'sturbed
(R .olded

AR106540

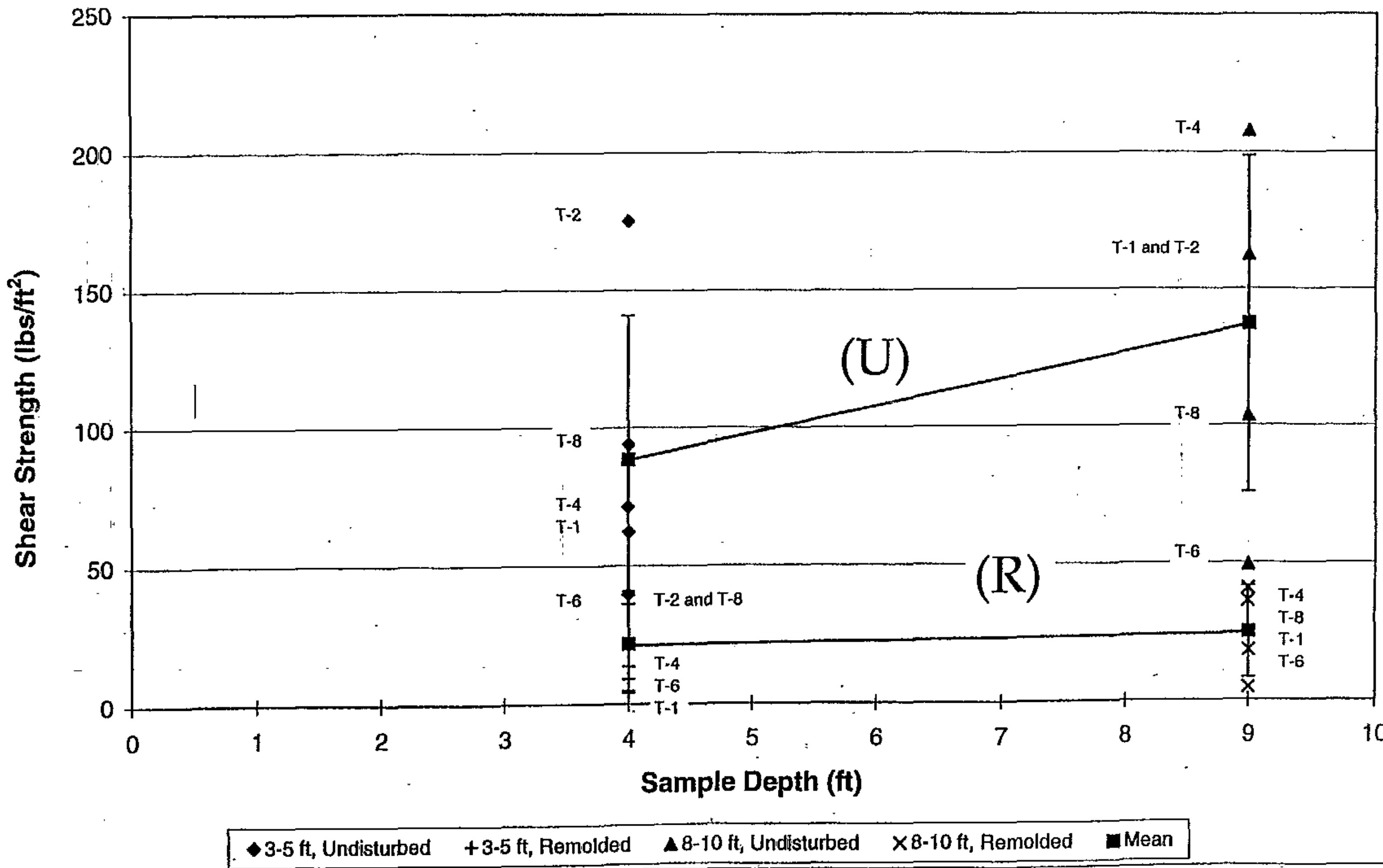
Figure C-13 Shear Strength vs. Depth for SB 3



T-2, T-3, and T-4 were performed in SB1
T-1, T-6, and T-8 were performed in SB3
(U) Undisturbed
(R) Remolded

AR106541

Figure C-14 Shear Strength vs. Depth for SB 1 and SB 3



T-2, T-3, and T-4 were performed in SB1
T-' T-6, and T-8 were performed in SB3
disturbed
emolded

AR106542

Attachment 1
Project Photographs

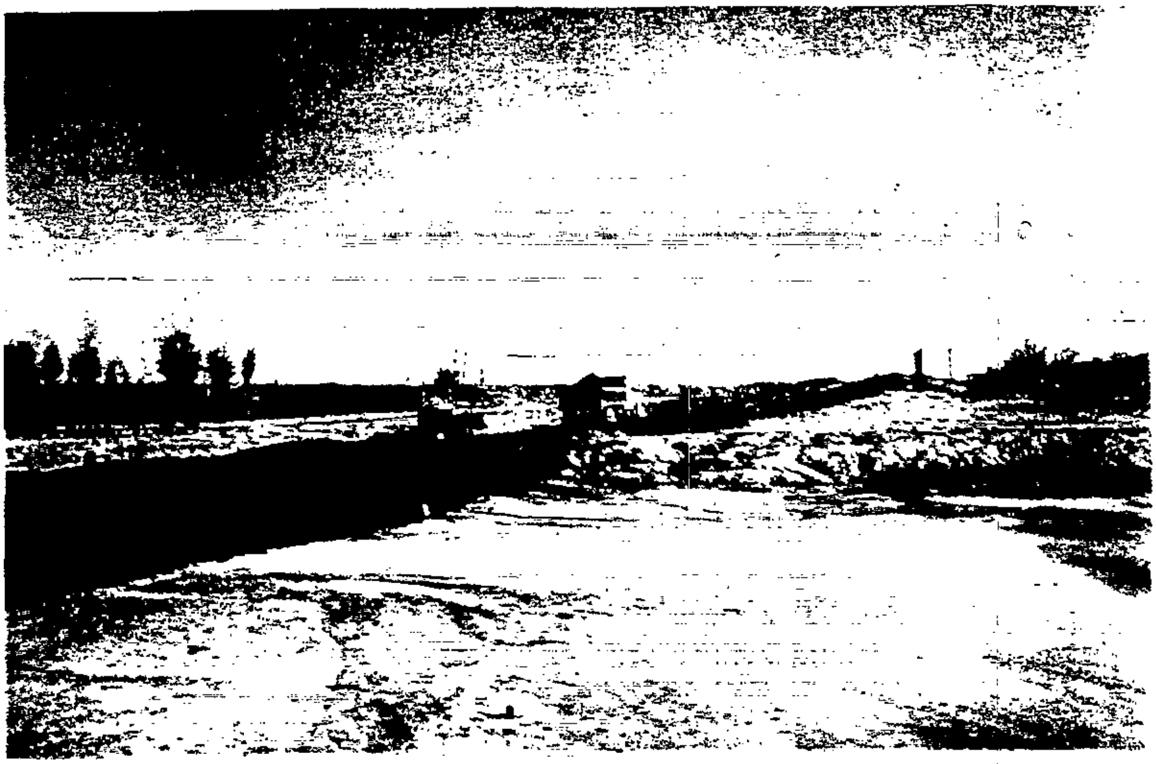


Photo 1: Construction of Access Road for Test Pad 2 (Sulfate Basin 1).

Photo 2: Test Pad 2 geotextile preparation for soil placement (Sulfate Basin 1).

Photo 3: Test Pad 2 under construction (Sulfate Basin 1).

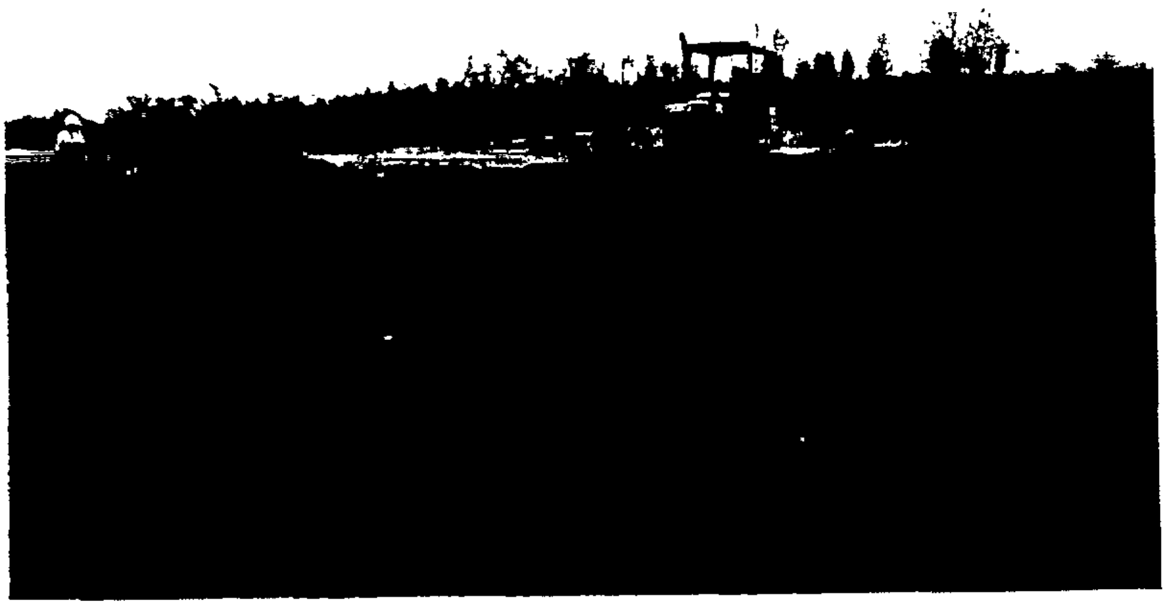


Photo 4: Soil and fly ash placement on Test Pad 2 (Sulfate Basin 1).

Photo 5: Area of Test Pad 3 prior to construction (Sulfate Basin 3).

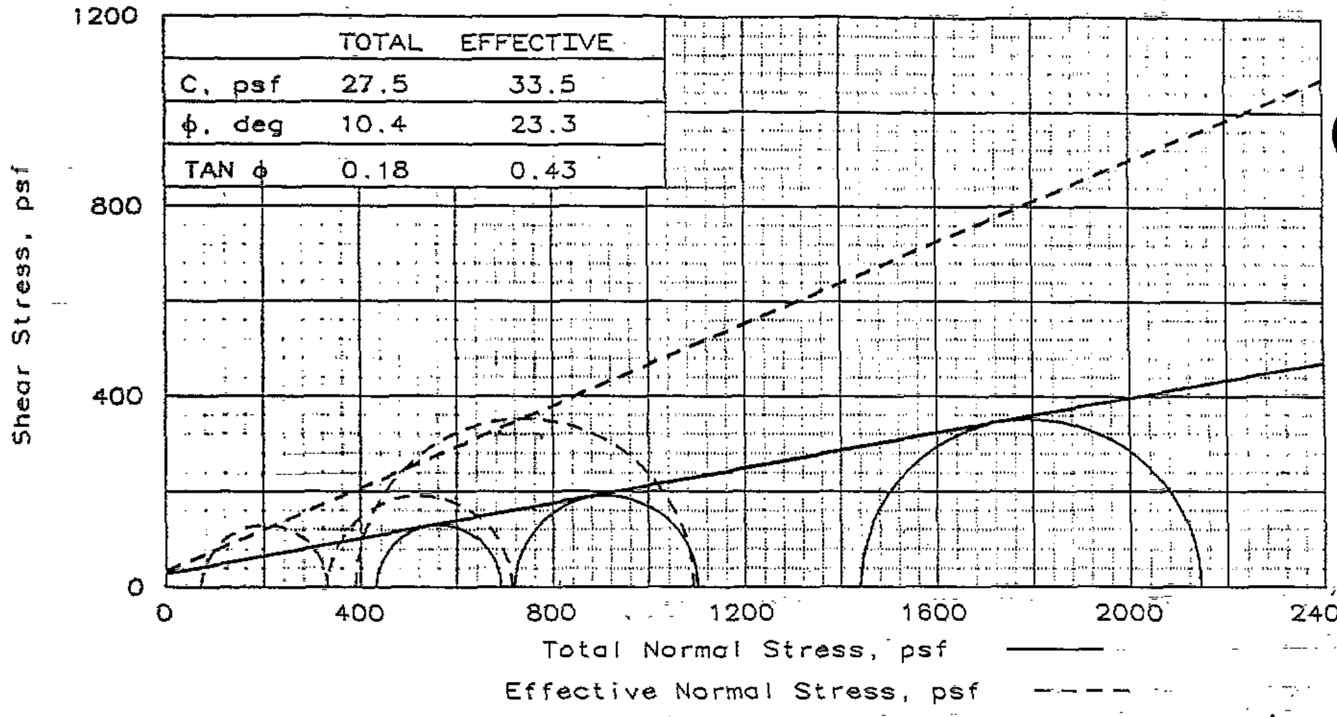
Photo 6: Placement of initial 10 to 13 feet of soil using excavator bucket for Test Pad 3 (Sulfate Basin 3).

Photo 7: Soil anchor being placed on sides of Test Pad 3 (Sulfate Basin 3).

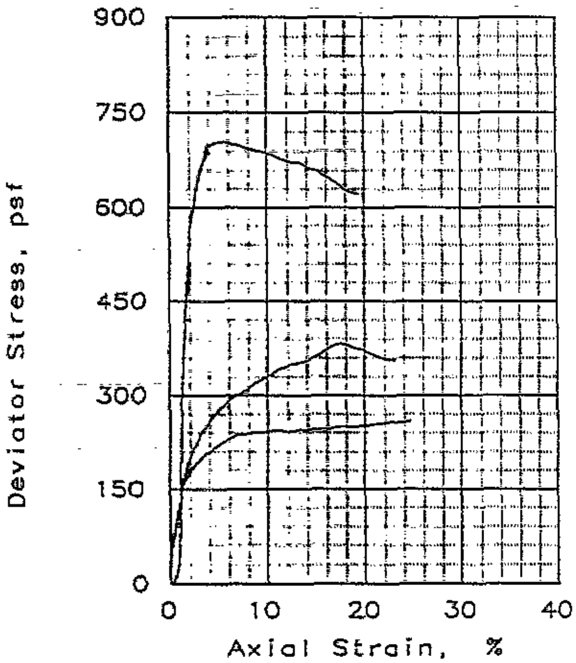
Photo 8: Completed Test Pad 3 (Sulfate Basin 3).

Attachment 2
Reduced Geotechnical Laboratory Data

AR106548



	TOTAL	EFFECTIVE
C, psf	27.5	33.5
ϕ, deg	10.4	23.3
TAN ϕ	0.18	0.43



	SAMPLE NO.:	1	2	3
INITIAL	WATER CONTENT, %	206.3	198.9	197.8
	DRY DENSITY, pcf	22.4	25.5	25.2
	SATURATION, %	88.6	99.9	97.9
	VOID RATIO	5.124	4.378	4.446
	DIAMETER, in	2.86	2.83	2.83
	HEIGHT, in	4.92	4.92	4.92
AT TEST	WATER CONTENT, %	210.2	196.1	196.9
	DRY DENSITY, pcf	22.4	25.5	25.2
	SATURATION, %	90.3	98.5	97.4
	VOID RATIO	5.124	4.378	4.446
	DIAMETER, in	3.19	3.14	3.09
	HEIGHT, in	3.95	4.00	4.12
	Strain rate, in/min	0.0200	0.0200	0.0200
	BACK PRESSURE, psf	1872	720	4320
	CELL PRESSURE, psf	2304	1440	5760
	FAIL. STRESS, psf	259	382	704
	TOTAL PORE PR., psf	2232	1109	5371
	ULT. STRESS, psf	258	381	699
	TOTAL PORE PR., psf	2218	1051	5472
	$\bar{\sigma}_1$ FAILURE, psf	331	714	1093
	$\bar{\sigma}_3$ FAILURE, psf	72	331	389

TYPE OF TEST:
CU with Pore Pressures
SAMPLE TYPE: Remolded
DESCRIPTION: Sulfate Sludge

SPECIFIC GRAVITY= 2.2
REMARKS:

Fig. No.: 1

CLIENT: FMC Corporation

PROJECT: Front Royal Sulfate Sludge

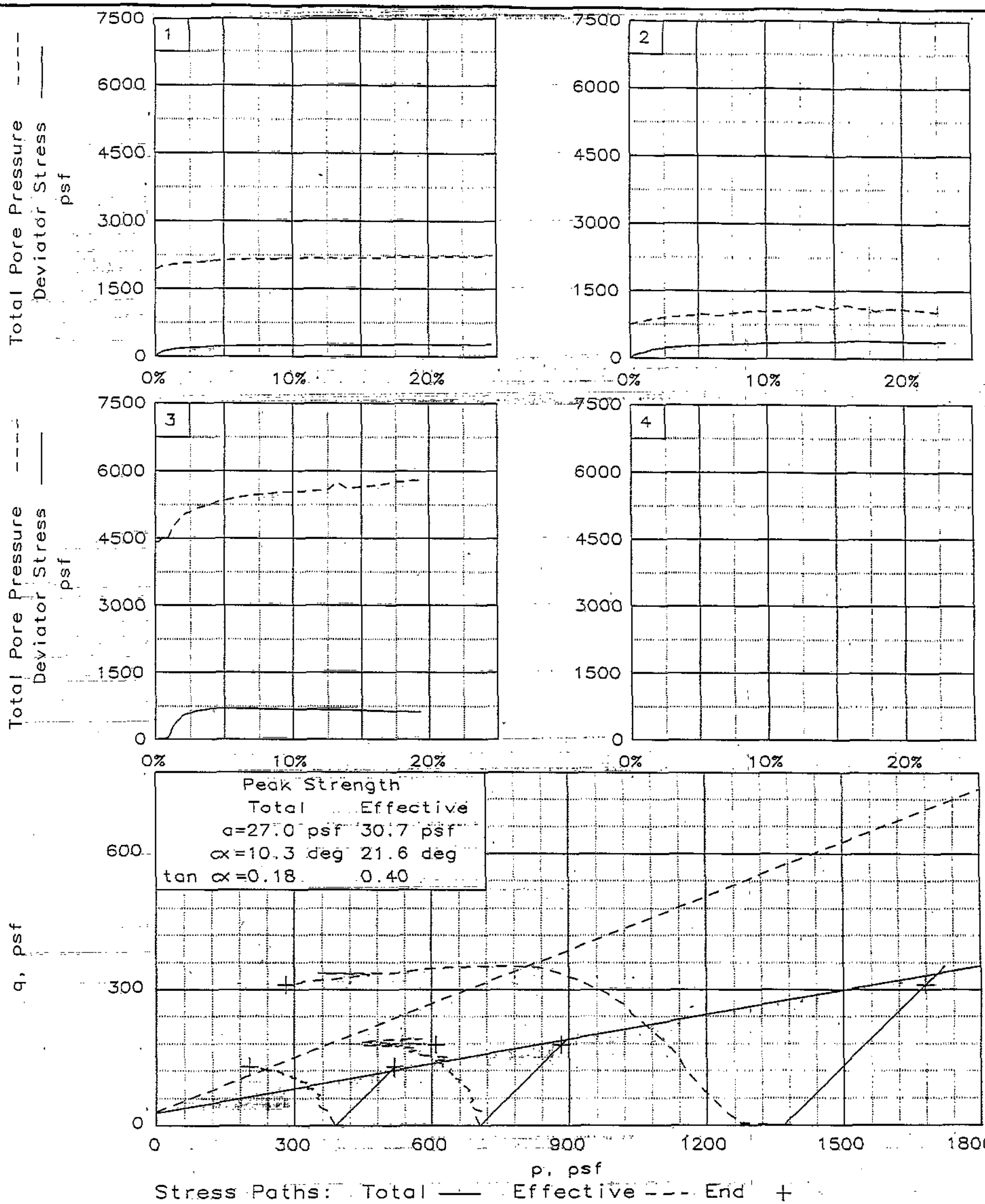
SAMPLE LOCATION: Sulfate Basin 1

PROJ. NO.: 10556.61.01 DATE: 7 October 19

TRIAXIAL SHEAR TEST REPORT

THE ERM GROUP

AR106549



Peak Strength	Total	Effective
a=	27.0 psf	30.7 psf
α=	10.3 deg	21.6 deg
tan α=	0.18	0.40

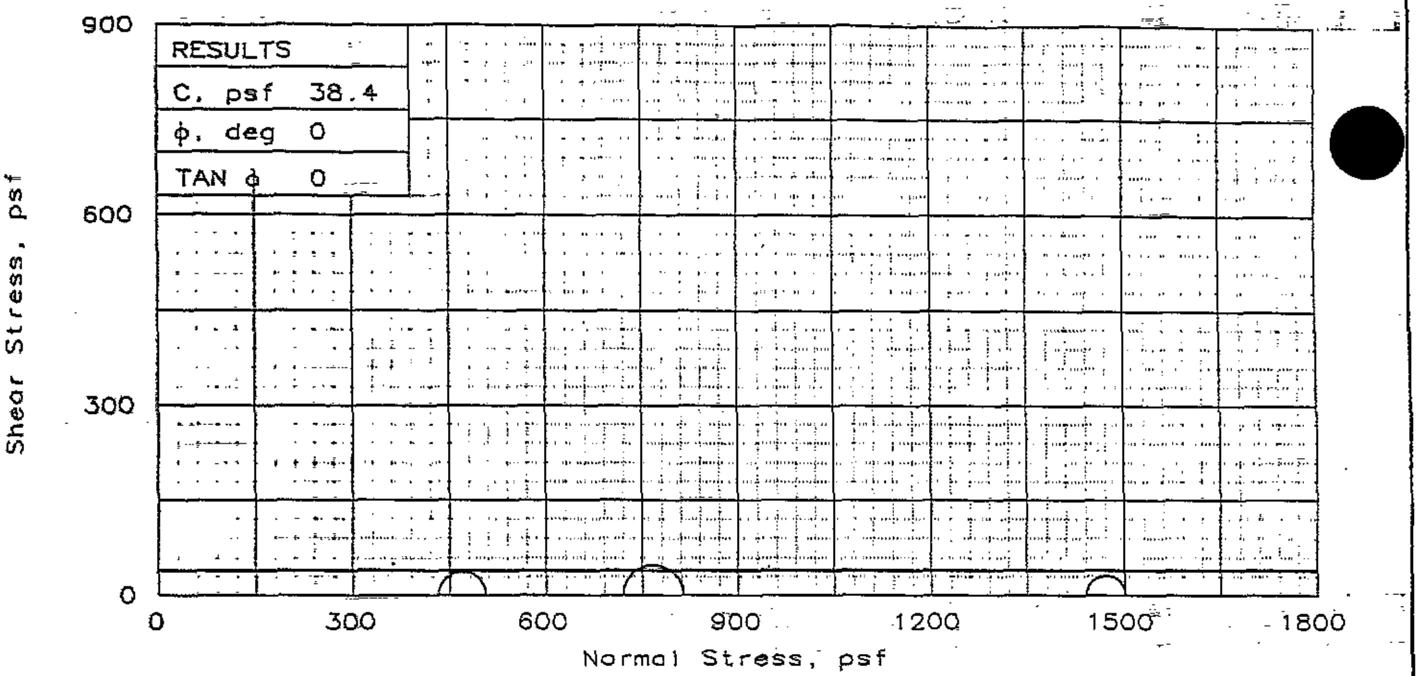
Client: FMC Corporation

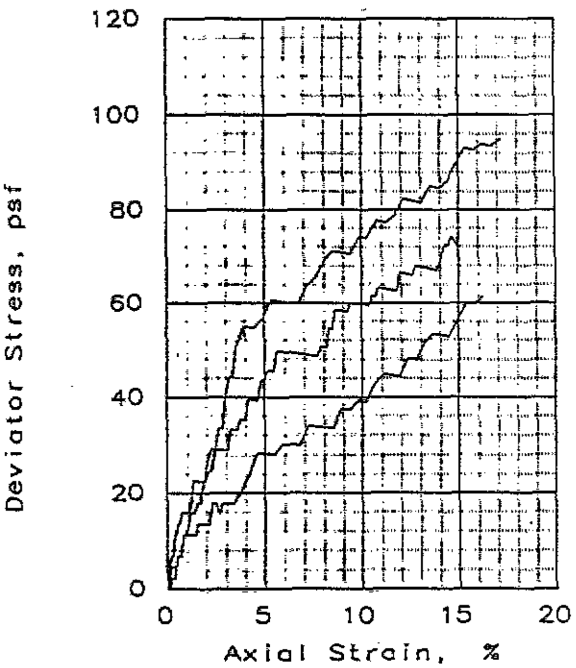
Project: Front Royal Sulfate Sludge

Location: Sulfate Basin 1

File: FMCCU1 Project No.: 10556.61.01 Fig. No.: ____

AR106550





	SAMPLE NO.:	1	2	3
INITIAL	WATER CONTENT, %	226.4	235.6	245.3
	DRY DENSITY, pcf	22.9	21.3	21.4
	SATURATION, %	99.9	94.9	99.6
	VOID RATIO	4.987	5.461	5.420
	DIAMETER, in	2.83	2.83	2.83
	HEIGHT, in	6.31	5.51	5.82
AT TEST	WATER CONTENT, %	225.4	241.2	232.2
	DRY DENSITY, pcf	22.9	21.3	21.4
	SATURATION, %	99.4	97.2	94.3
	VOID RATIO	4.987	5.461	5.420
	DIAMETER, in	2.83	2.83	2.83
	HEIGHT, in	6.31	5.51	5.82
	Strain rate, in/min	0.0200	0.0200	0.0200
	BACK PRESSURE, psf	720	720	720
	CELL PRESSURE, psf	1152	1440	2160
	FAIL. STRESS, psf	74	95	61
	ULT. STRESS, psf	72	95	61
	σ_1 FAILURE, psf	506	815	1501
	σ_3 FAILURE, psf	432	720	1440

TYPE OF TEST:
Unconsolidated Undrained

SAMPLE TYPE: Remolded

DESCRIPTION: Sulfate Sludge

SPECIFIC GRAVITY= 2.2

REMARKS:

CLIENT: FMC Corporation

PROJECT: Front Royal Sulfate Sludge

SAMPLE LOCATION: Sulfate Basin 1

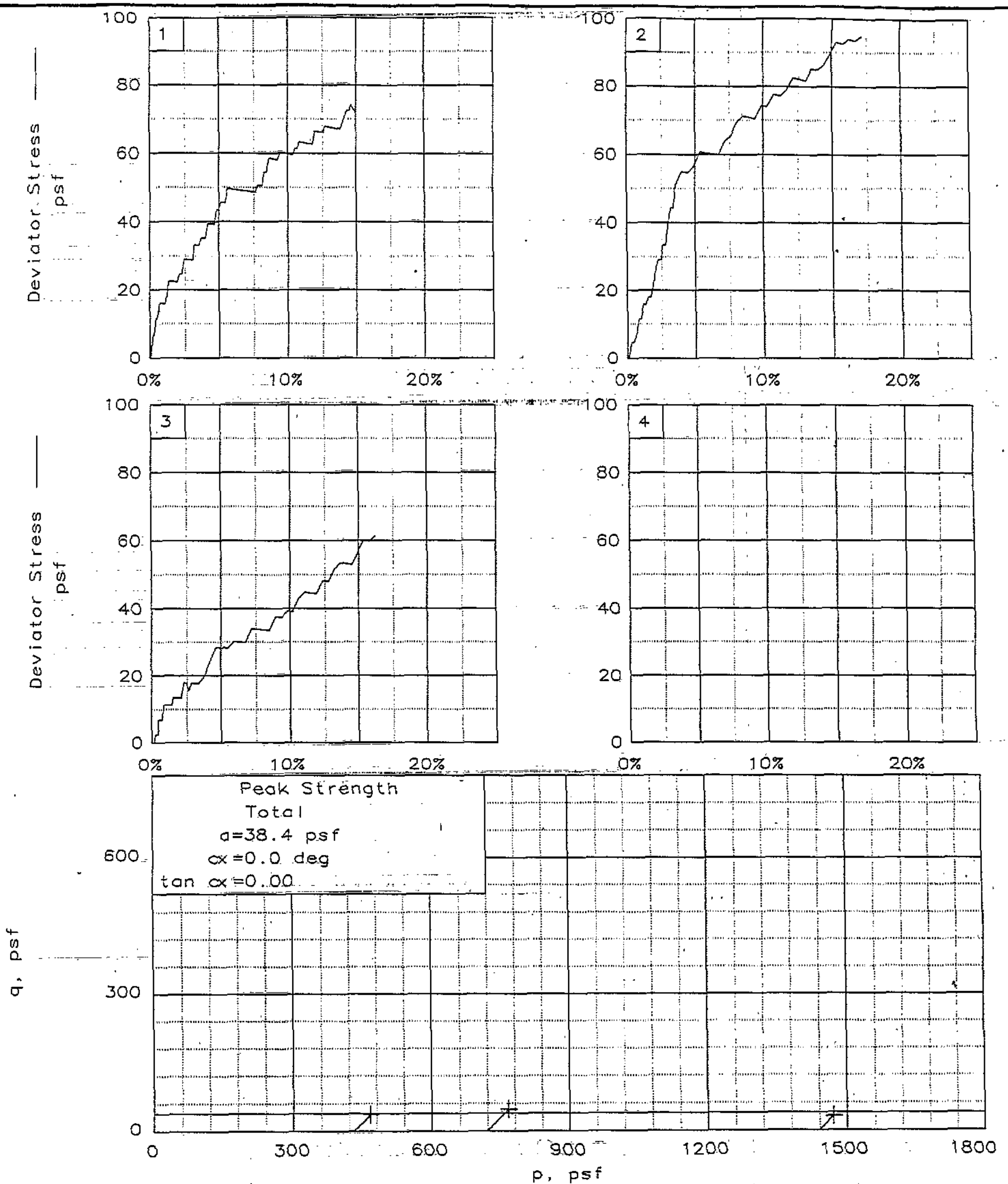
PROJ. NO.: 10556.61.01 DATE: 7/10/98

TRIAXIAL SHEAR TEST REPORT

THE ERM GROUP

Fig. No.: 1

AR106551



Stress Paths: + indicates end

Client: FMC Corporation
Project: Front Royal Sulfate Sludge
Location: Sulfate Basin 1
File: FMCUU1 Project No.: 10556.61.01 Fig. No.: ____

AR106552

Table C-A2-1 *Test Pad Geotechnical Testing*
Summary of Soil Laboratory Tests

Test Pad No.	Sample No.	Sample Type	Description of Specimen According to ASTM D-2487	Nat. Moist (%)	Perm-eability (cm/sec)	Atterberg Limits			% Pass No 200 Sieve	Max. Dry Den. (lb/ft3)	Opt. Moist. Cont. (%)	Remarks
						LL	PL	PI				
3	TP-3, 0.0	Bulk Soil	Silt with sand (ML)	16	$2.7*10^{-06}$	34	25	10	77.3	108.7	18.0	See attached gradation and density curves.

Notes:

1. Tests in accordance with applicable ASTM Standards
2. Classifications in accordance with ASTM and Unified Soil Classification System.
3. Key to abbreviations: LL = Liquid Limit; PL = Plastic Limit; PI = Plasticity Index.
4. Soil tests were conducted by: EVK and PSC

SUMMARY OF TRIAXIAL PERMEABILITY
TEST RESULTS
ASTM D-5084

Client:	FMC Avtex	Report Date:	14-Jan-99
ERM Project Number:	10556.62.01	Test Date:	14-Jan-99
Project/Location:	Sludge Basin Test Pad 3	Sampling Date:	8-Jan-99
Sample Location:	TP3	Tested By:	PSC
Sample Description:	Test Pad Cover Soil		
Notes:	Sample was recompacted to density observed in the field		

Physical Property Data

Sample Type:	Remolded		
Initial Height (in):	4.02	Final Height (in):	4.01
Initial Diameter (in):	2.80	Final Diameter (in):	2.80
Initial Wet Weight (g):	745.00	Final Wet Weight (g):	813.00
Wet Density (pcf):	115.1	Wet Density (pcf):	125.9
Moisture Content:	14.9%	Moisture Content:	24.2%
Dry Density (pcf):	100.1	Dry Density (pcf):	101.3
		Saturation:	102%

Test Parameters

Cell Pressure (psi):	69.0	Fluid:	Deaired Water
Head Water (psi):	66.0	Cell Number:	A-2
Tail Water (psi):	66.0	Temperature (°C):	20
Max. Consol. Stress (psi):	3.0	Min. Consol. Stress (psi):	3.0

Reduced Permeability Data

Change in Time (min)	Head Across Sample (in) Average	Gradient (h/l) Average	Change in Flow (cc)	Raw Permeability (m/sec)
24	20.5	5.1	1.0	3.4E-08
34	19.7	4.9	1.0	2.5E-08
54	18.6	4.6	1.6	2.7E-08
60	17.5	4.4	1.2	1.9E-08
22	16.7	4.2	0.6	2.7E-08

Computed Permeability

Permeability : 2.7E-08 (m/sec) at 20° C

2.7E-06 (cm/sec) at 20° C

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EVK 1/19/99

AR106554

Job No. 10556.62.01 Date 1/19/99

Project FMC - Avtex Fibers - Front Royal, VA

Source of Material TP3 0.0

Description of Material SILT with SAND ML

Test Pad 3 Soil

Test Method ASTM D-695

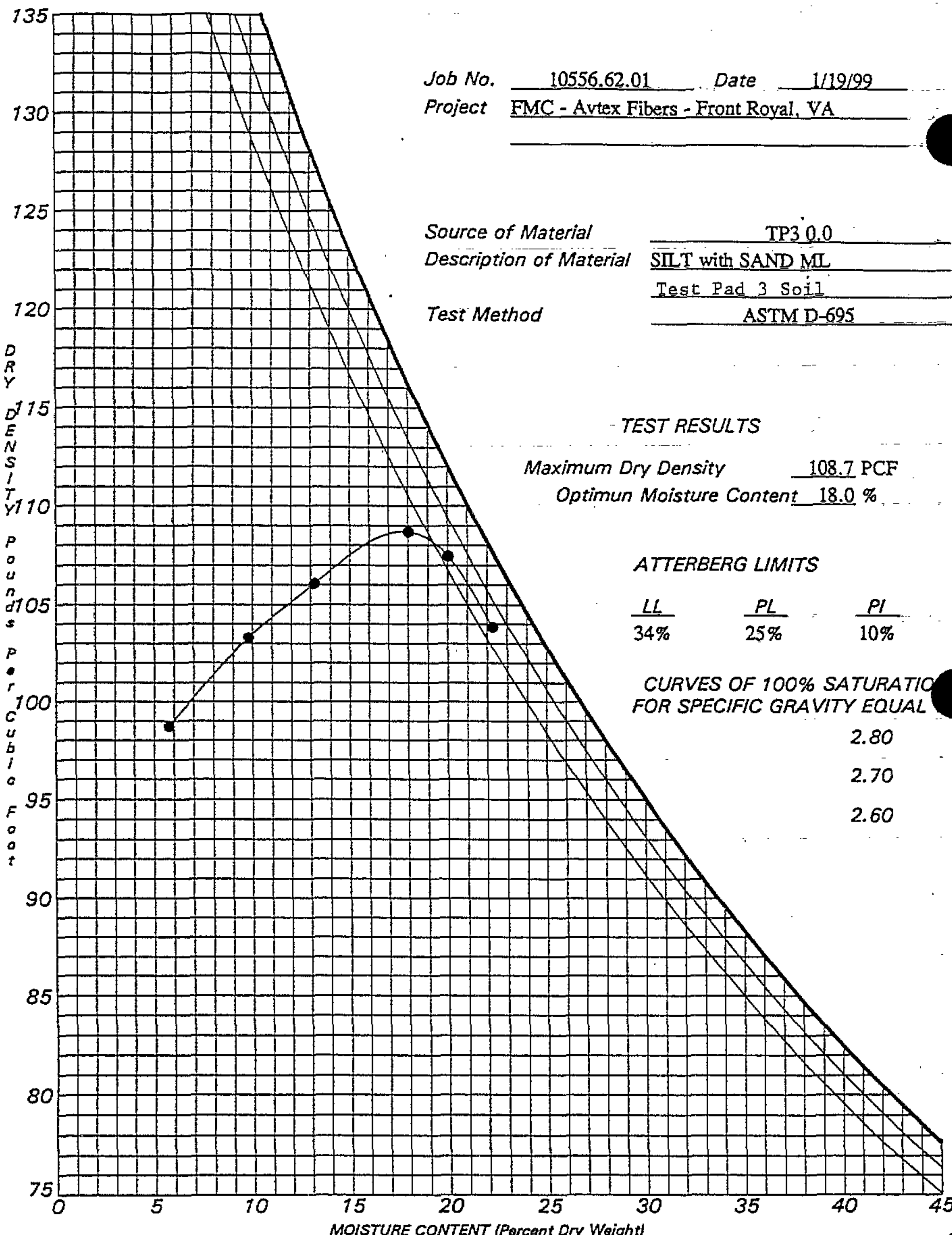
TEST RESULTS

Maximum Dry Density 108.7 PCF

Optimun Moisture Content 18.0 %

ATTERBERG LIMITS

LL	PL	PI
34%	25%	10%



MOISTURE-DENSITY RELATIONSHIP

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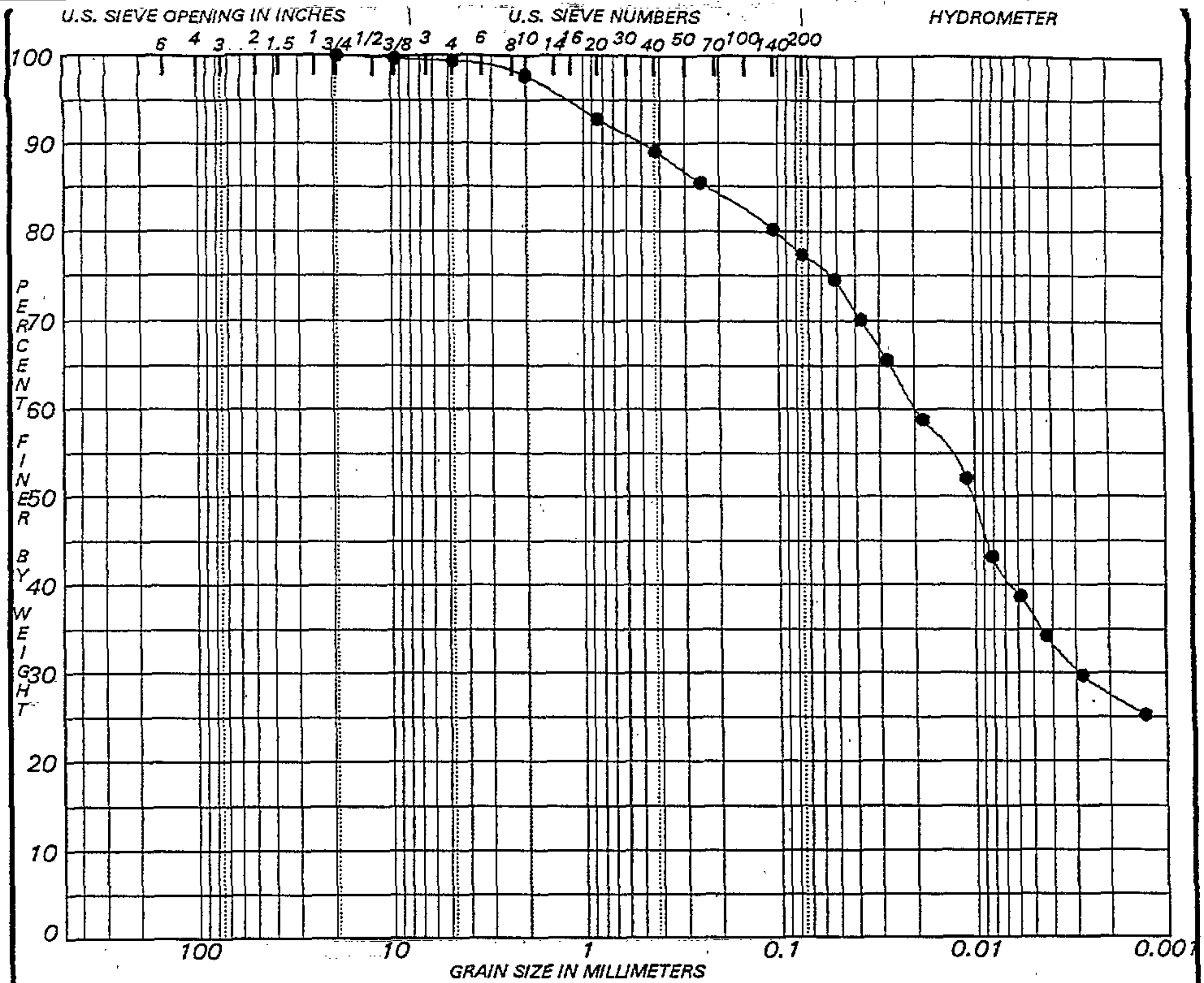
AR106555



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

	Specimen Identification		Classification	MC%	LL	PL	PI	Cc	Cu
●	TP3	0.0	SILT with SAND ML	16	34	25	10		
	Test Pad 3 Soil								

	Specimen Identification		D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	TP3	0.0	19.00	0.02	0.003		0.7	22.0	41.0	36.3

PROJECT FMC - Avtex Fibers - Front Royal, VA

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DATE 1/19/99

GRADATION CURVES - ASTM

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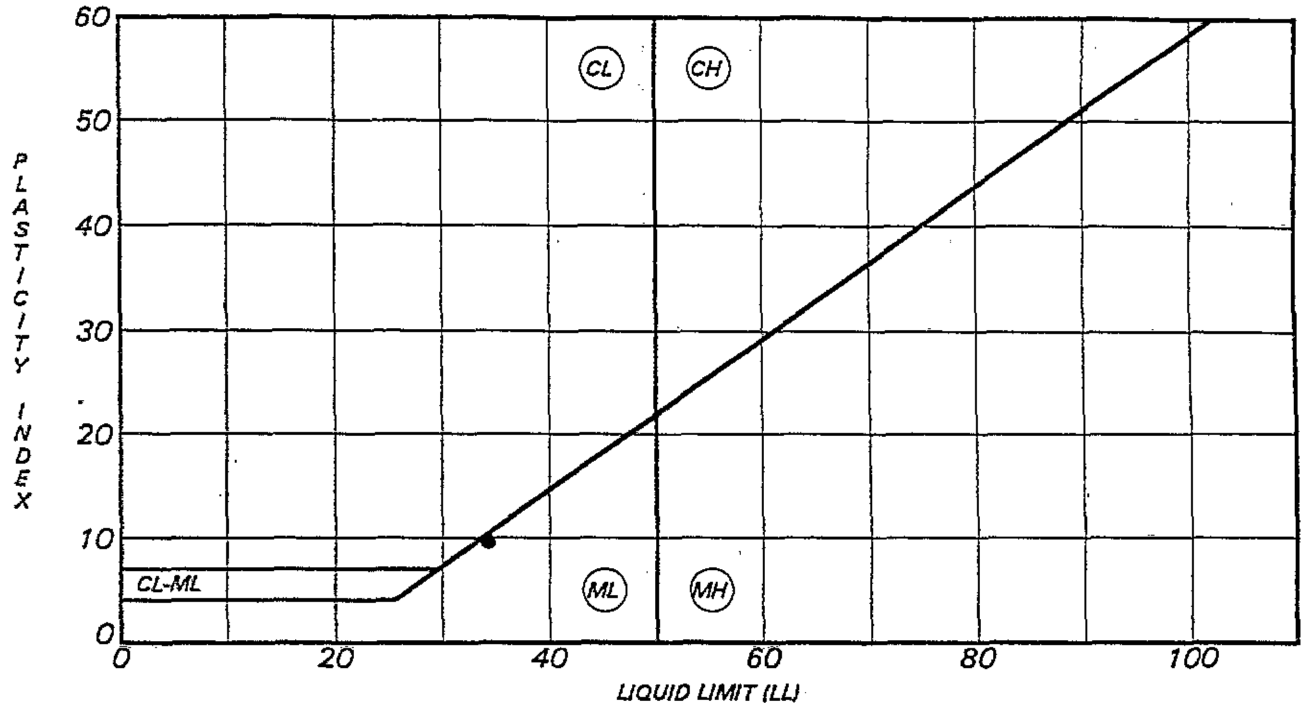
EVK 1/19/99

AR106556



	Specimen Identification		LL	PL	PI	Fines	Classification
●	TP3	0.0	34	25	10	77.3	SILT with SAND ML
	Test Pad 3 Soil						

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DATE 1/19/99

ATTERBERG LIMITS' RESULTS

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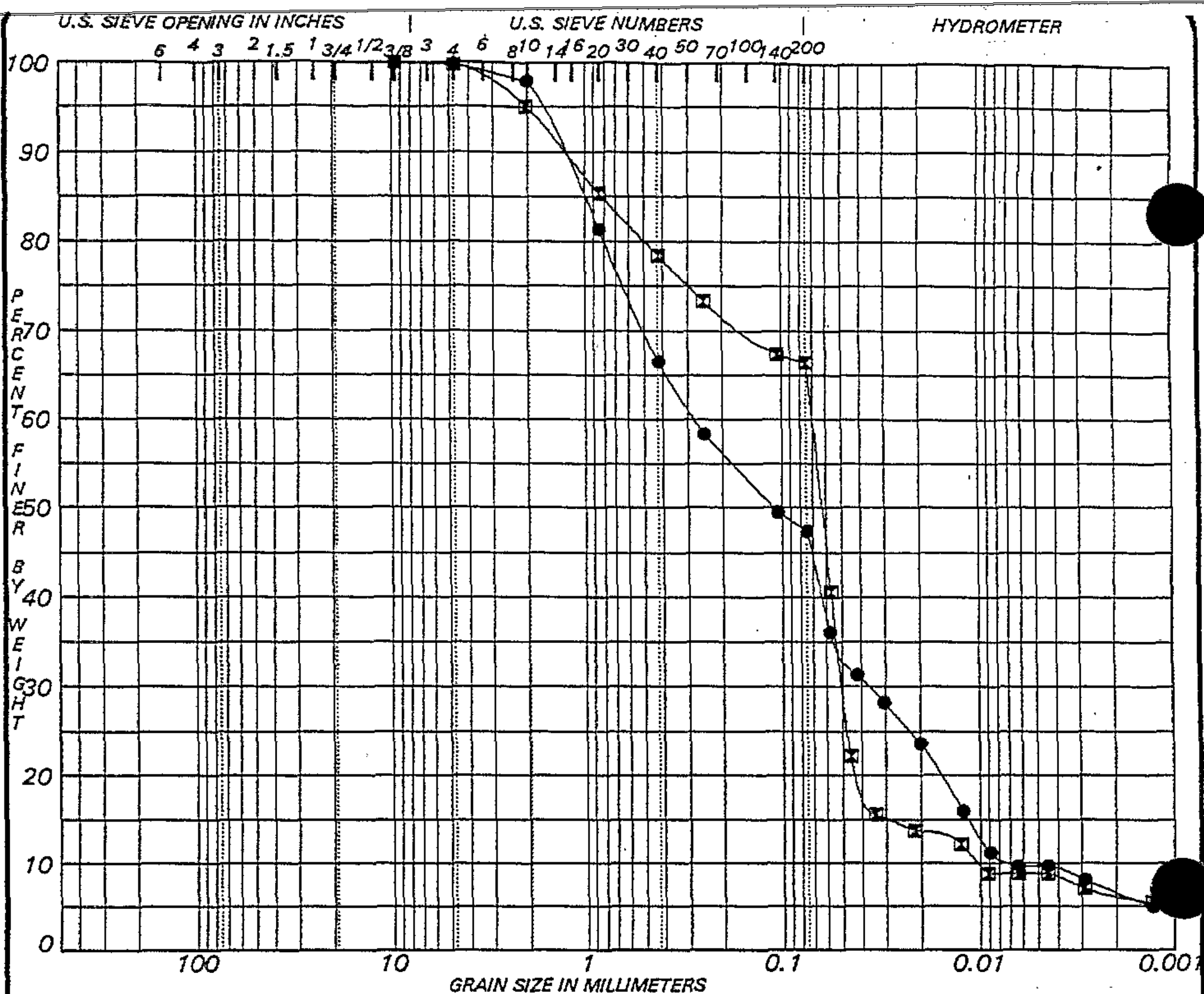
AR106557

Table C-A2-2 *Sulfate Basin Geotechnical Testing*
Summary of Sulfate Sludge Laboratory Tests

Sulfate Basin No.	Sample No.	Sample Type	Description of Specimen According to ASTM D-2487	Nat. Moist (%)	Perm-eability (cm/sec)	Atterberg Limits			% Pass No 200 Sieve	Max. Dry Den. (lb/ft3)	Opt. Moist. Cont. (%)	Remarks
						LL	PL	PI				
1	Basin-1 1.0	Bulk Sludge	Silty sand (SM)	111		NP			47.4			See attached gradation curve. This material was dry prepared
1	Basin-1 2.0	Bulk Sludge	Sandy silt (ML)	201		NP			66.4			See attached gradation curve. This material was dry prepared
2	Basin-2 1.0	Bulk Sludge	Silt with sand (ML)	144		NP			79.6			See attached gradation curve. This material was dry prepared
3	Basin-3 1.0	Bulk Sludge	Silty Sand (SM)	144		NP			24.7			See attached gradation curve. This material was dry prepared
3	Basin-3 1.1	Bulk Sludge	Silt (ML)			NP			>95			See attached gradation curve. This material was wet prepared.
3	Basin-3 2.0	Bulk Sludge	Silty Sand (SM)	209		NP			17.9			See attached gradation curve. This material was dry prepared
3	Basin-3 2.1	Bulk Sludge	Silt (ML)			NP			>95			See attached gradation curve. This material was wet prepared.

Notes:
1. Tests in accordance with applicable ASTM Standards
2. Classifications in accordance with ASTM and Unified Soil Classification System.
3. Key to abbreviations: LL = Liquid Limit; PL = Plastic Limit; PI = Plasticity Index.
4. Soil tests were conducted by: EVK and PSC



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Specimen Identification			Classification	MC%	LL	PL	PI	Cc	Cu
●	BASIN-1	1.0	SILTY SAND SM	111	NP	NP	NP		
⌧	BASIN-1	2.0	SANDY SILT ML	201	NP	NP	NP		
	Sludge Samples								

Specimen Identification			D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	BASIN-1	1.0	9.50	0.28	0.037	0.0068	0.2	52.4	37.7	9.7
⌧	BASIN-1	2.0	9.50	0.07	0.050	0.0102	0.3	33.3	57.6	8.8

PROJECT FMC - Avtex Fibers - Front Royal, VA

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DATE 1/19/99

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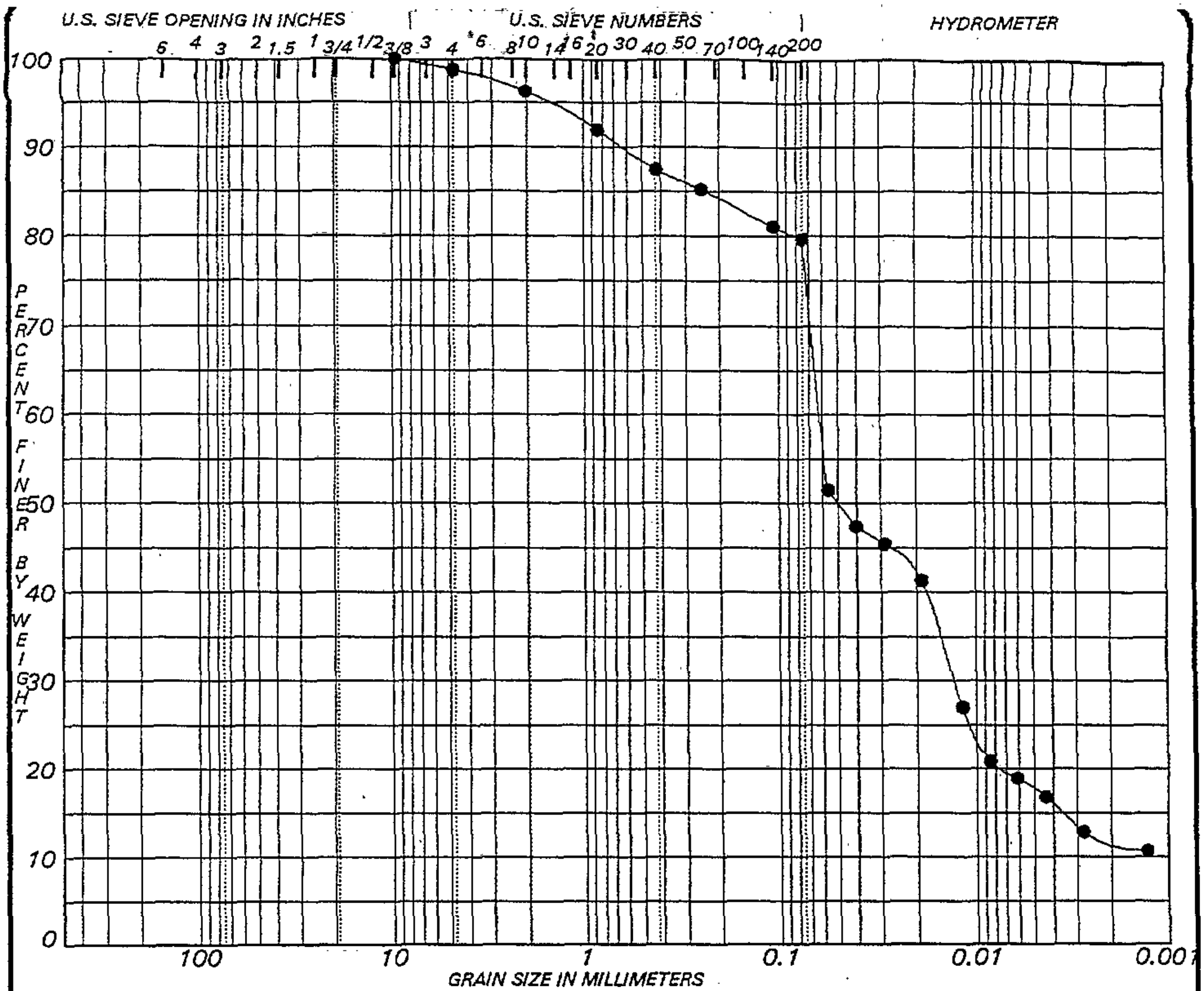

COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

	Specimen Identification		Classification	MC%	LL	PL	PI	Cc	Cu
●	BASIN-2	1.0	SILT with SAND ML	144	NP	NP	NP		
	Sludge Sample								

	Specimen Identification		D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	BASIN-2	1.0	9.50	0.06	0.013		1.2	19.2	62.0	17.6

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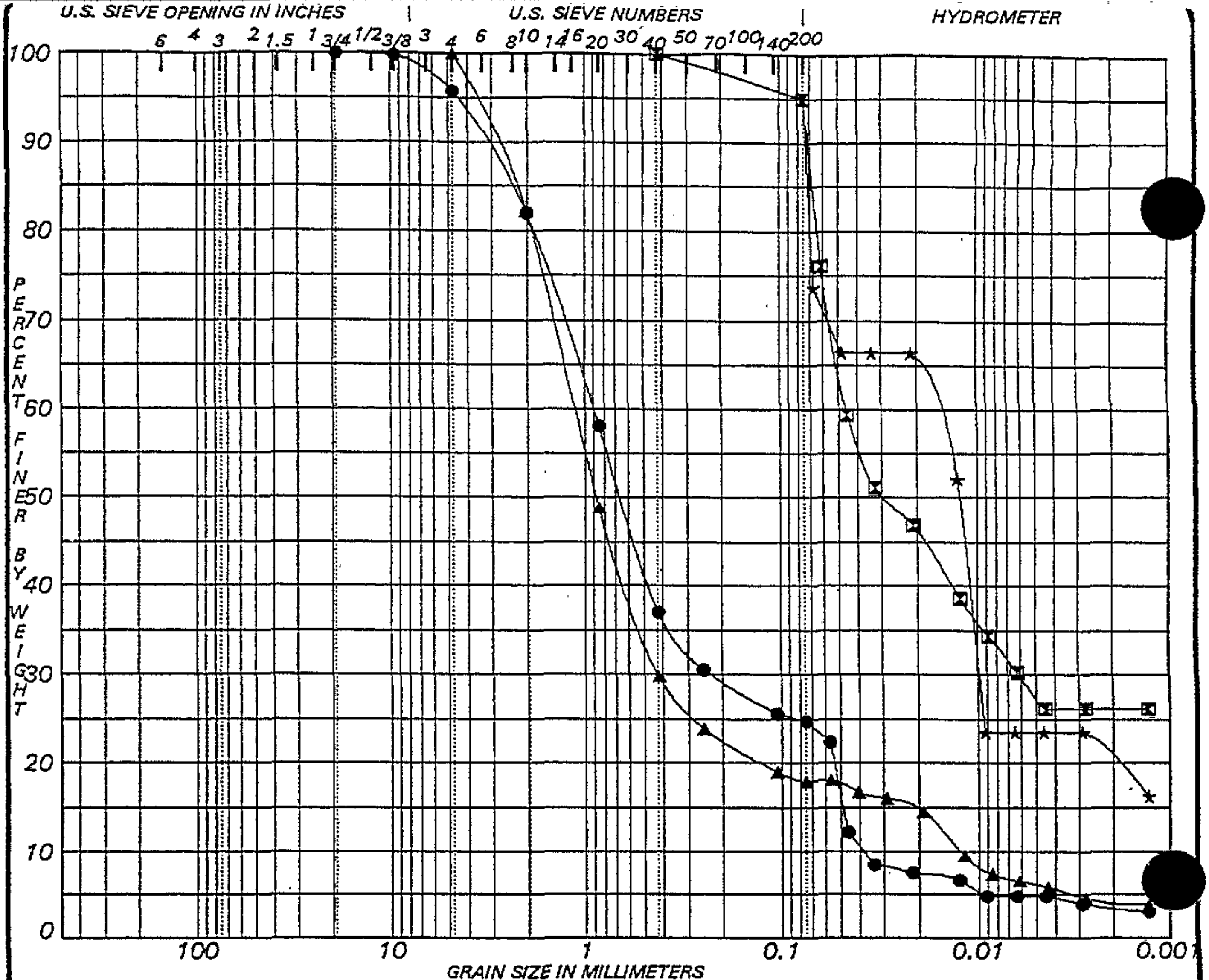
EWK 1/19/99

AR106560



<table>
<tr><td rowspan="2">COBBLES</td><td colspan="2">GRAVEL</td><td colspan="3">SAND</td><td rowspan="2">SILT OR CLAY</td></tr>
<tr><td>coarse</td><td>fine</td><td>coarse</td><td>medium</td><td>fine</td></tr>
</table>

Specimen Identification			Classification	MC%	LL	PL	PI	Cc	Cu
●	BASIN-3	1.0	SILTY SAND SM	144	NP	NP	NP		
⌧	BASIN-3	1.1	SILT ML		NP	NP	NP		
▲	BASIN-3	2.0	SILTY SAND SM	209	NP	NP	NP		
★	BASIN-3	2.1	SILT ML		NP	NP	NP		
	Sludge Samples								

Specimen Identification			D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	BASIN-3	1.0	19.00	0.91	0.229	0.0383	4.3	71.0	19.9	4.8
⌧	BASIN-3	1.1	0.43	0.05	0.006		0.0	5.0	67.6	27.4
▲	BASIN-3	2.0	4.75	1.13	0.428	0.0124	0.0	82.1	11.7	6.2
★	BASIN-3	2.1	0.43	0.02	0.010		0.0	5.0	71.6	23.4

PROJECT FMC - Avtex Fibers - Front Royal, VA

JOB NO. 10556.62.01

DATE 1/19/99

GRADATION CURVES - ASTM

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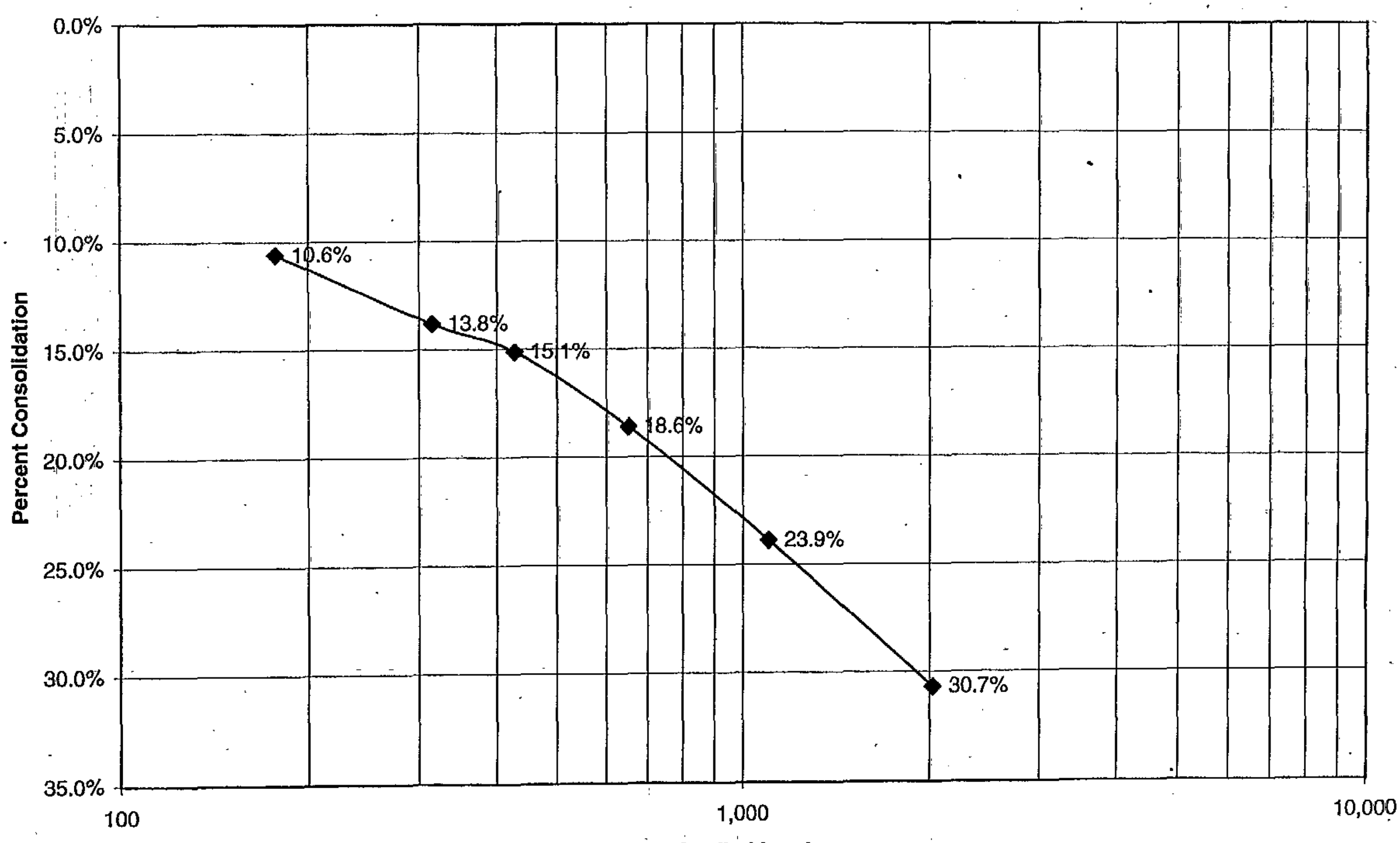
AR106561

Sulfate Sludge Consolidation Test Results
Avtex Fibers Superfund Site
Front Royal, Virginia



Note: Sludge sample taken from Sludge Basin #3

Appendix D
Analysis of Storm Water Management Options

AR106563

The following provides the initial conceptual evaluation of the storm water management options that may be implemented during remediation of the Avtex Fibers Superfund Site (Site). In order to confirm the conclusions of this conceptual evaluation, FMC will perform an additional, more detailed evaluation prior to closure of the sulfate basins. The more detailed evaluation will identify a storm water management alternative that provides appropriate control and treatment of contaminated or potentially contaminated storm water until it is demonstrated that such control is no longer necessary. The proposed scope of the detailed evaluation is described at the end of this appendix.

1.0 BACKGROUND

Pursuant to the Administrative Order for Removal Response Activities, dated February 2, 1990 (Order), issued by the United States Environmental Protection Agency (EPA) to FMC Corporation (FMC), storm water runoff from the Site must be collected and treated prior to discharge to the South Fork of the Shenandoah River (River), if necessary to meet established standards. FMC has complied with the Order by operating the existing on-site wastewater treatment plant (WWTP). Although the need for treatment is intermittent based on influent water quality to the WWTP, this operation is expected to be maintained until the remediation of the areas on the east side of the railroad tracks (e.g., plant buildings, associated sewers, and impacted soils) and closure of the Sulfate Basins (SBs), Fly Ash Units, and WWTP Basins (WWBs) are completed. Once these remedial activities are completed, it is anticipated that storm water runoff will not require collection or treatment, from a water quality perspective, and FMC may petition EPA to terminate the Order.

Currently, the SBs at the Site provide hydraulic capacity for storm water retention prior to treatment in the WWTP. The proposed remedy for the SBs, which includes a soil cover and lowering of the basin dikes, will reduce and eventually eliminate this hydraulic capacity. During closure of the SBs, the hydraulic storage capacity may still be utilized for storm water that falls directly into the basins. Once the SBs are closed, they will not collect storm water and runoff from the area will be directed through sedimentation controls, if necessary, to the River. However, since the remediation of the east side of the railroad tracks or other areas of the Site may not be completed prior to closure of all the SBs, it may be necessary to have replacement hydraulic storage capacity to maintain appropriate storm water control.

2.0 *EVALUATION OF STORM WATER RUNOFF AND COLLECTION*

An evaluation of the potential storm water generation during a 10-year, 24-hour storm was performed to determine the total replacement storm water storage capacity needed during remedial activities. This evaluation was performed in accordance with the United States Department of Agriculture Soil Conservation Service's "Urban Hydrology for Small Watersheds," Technical Release 55, June 1986 (TR-55).

The Site was divided into two major storm water categories for this evaluation: runoff areas and collection areas. As shown on Figure D1, the estimated runoff areas include the areas west of the railroad tracks (i.e., Viscose Basins (VB) 1 through 8, and Fly Ash Basin (FAB) 3), the plant area, and the southwest plant grounds. The collection areas include SBs and the WWBs (i.e., Polishing Basins (PB) 1 and 2, and the Emergency Lagoon (EL)).

VB 9 through 11 are not included in either category since, based on their construction and characteristics, they do not appear to represent a runoff area or a significant collection area. The existing berm elevations of VB 9 through 11 prevent storm water runoff to other areas. The porosity of the surface limits the amount of storm water collected during a storm event, and the nominal amount of storm water that may collect in these basins may be pumped directly to the WWTP. Therefore, additional storage capacity should not be necessary for storm water runoff from these basins since their discharge to the WWTP can be controlled and managed until hydraulic capacity is available.

The volume of potential runoff during a 10-year storm was calculated for the subject areas in accordance with TR-55, considering total acreage, and soil and cover conditions. As provided in TR-55, the soil and cover conditions were used to estimate Runoff Curve Numbers (CN). In general, soil was considered to be Type C - Sandy clay loam for the runoff areas. Composite CN's for the runoff areas ranged from 70 to 85 depending on cover conditions. The total amount of runoff generated during a 10-year storm for the runoff areas was calculated to be approximately 14.4 million gallons in a 24-hour period. The runoff calculation for each subject area is provided in Table D1.

The volume of storm water collected in the collection areas during a 10-year storm was calculated based on acreage and total inches of rainfall during a 10-year storm: 5.3 inches (Figure B-5 in TR-55). As a conservative estimate, evaporation and infiltration were not considered in the volume calculations for the collection areas. The total amount of storm water collected in the WWBs and the SBs was calculated to be approximately 576,000 and 8.98 million gallons, respectively. The storm water collection calculation for each subject area is provided in Table D2.

Based on the calculated storm water runoff and collection volumes during a 10-year storm event, the total combined estimated replacement storm water storage capacity needed is approximately 15 million gallons, shown on Table D3. This capacity considers that the SBs may be used as storage units for direct rainfall until they are closed. Therefore, based on this estimate, it will be necessary to maintain storm water storage capacity of at least 15 million gallons during remedial activities to ensure that storm water can be appropriately managed.

3.0 *EVALUATION OF REPLACEMENT STORM WATER STORAGE CAPACITY OPTIONS*

A conceptual evaluation of potential replacement storm water storage capacity options indicated that the three existing WWBs (i.e., PB 1 and 2, and the Emergency Lagoon) may be used to replace the lost capacity from closing the SBs. The current hydraulic storage capacity of the WWBs is approximately 9 million gallons. However, each basin contains sludge and is underlain contaminated soil, If the sludge and contaminated soil are removed from all the WWBs, the capacity of these three basins increases significantly.

Two replacement storm water capacity options were considered. The first option simply would require removing all the sludge from the three WWBs and operating each as an individual retention basin. The second option also involves removing all the sludge from the three basins, but also includes the removal of the dike separating PB 1 and 2 to provide additional storage capacity and simplify water management operations.

As shown on the table below and Table D4, Option 1 should provide sufficient storage capacity for a 10-year storm. Once the sludge is removed from the WWBs, the maximum total capacity is estimated to increase to approximately 17.6 million gallons, and the normal operating capacity (i.e., maintaining at least two feet of freeboard) is estimated to be approximately 15.7 million gallons. As an alternative, Option 2 will provide an additional 1.1 million gallons of storage capacity. Although this additional capacity is not needed based on the calculations above, this alternative may simplify water management operations, as well as provide an additional safety factor.

	Option 1		Option 2	
Storage Capacity Required (million gal)	Maximum Capacity[1] (million gal)	Operating Capacity[2] (million gal)	Maximum Capacity[1] (million gal)	Operating Capacity[2] (million gal)
15	18	16	19	17

1 - Maximum Capacity represents total capacity to the top of the dike.

2 - Operating Capacity represents total capacity maintaining at least 2 feet of freeboard.

Given that the WWBs can provide the necessary storage capacity, the existing WWTP may continue to be used to treat the storm water. The current maximum throughput of the WWTP is approximately 2,000 gallons per minute (gpm), or approximately 2.9 million gallons per day. This flow rate is based on the operation of one treatment train and the limitation imposed by the pumping capacity of the pit between the primary clarifier and the aeration basin. The hydraulic capacity of each side of the WWTP is 3,500 gpm. This throughput rate should be sufficient to maintain basin levels and allow appropriate treatment of the storm water throughout remedial activities.

4.0 *FURTHER EVALUATION*

Mitigating the potential uncontrolled release of hazardous substances at this Site is more significant compared to typical construction sites. Furthermore, the effluent limits for the WWTP are a critical ARAR that will need to be met during EE/CA implementation. Therefore, FMC will perform further, more detailed evaluation of the potential storm water runoff volume and WWTP capacity to confirm the conclusions presented herein and refine, modify, and/or redevelop appropriate storm water control alternatives, prior to the closure of the SBs.

There are several areas of uncertainty in the conceptual evaluation presented above, including the actual drainage acreage, the actual reasonably expected worst-case runoff volumes, the capacity of the WWTP, and closure sequencing logistics. To resolve these and other storm water control uncertainties, FMC will perform the following concurrent with the design phase for the closure of the SBs:

- Survey of the site drainage areas and calculation of runoff volumes during reasonably expected worst case scenarios and consecutive storms;

- Identification of historic rainfall data to estimate the amount of rainfall that has historically occurred during consecutive storms;
- Assessment of the WWTP capacity and necessary modifications/ upgrades to increase the capacity, if necessary;
- Evaluation of alternatives to manage and minimize accumulated rainfall on the SBs prior to closure;
- Calculation of potential water generated from both dewatering and runoff from the closed sulfate basins that would require management; and
- Evaluation of the EE/CA unit closure sequence to ensure that appropriate storm water and leachate management is provided during the implementation of closure activities and in the future.

These issues are described below.

Drainage Acreage

As presented in Figure D1 and Tables D1, D2, and D3, the drainage/collection area for the site, excluding the sulfate basins, is estimated at approximately 174 acres. This estimate was based on an evaluation of topography, basin characteristics, and existing drainage ways that convey runoff. However, more detailed survey of Site will be performed to further identify and more accurately quantify the portions of the Site providing runoff that will require management. This drainage acreage will be used to refine the storm water runoff volume estimates.

Design Storm

The conceptual evaluation presented above was performed using the 10-year, 24-hour design storm and runoff calculations specified in TR-55. However, to ensure that the selected storm water management alternative provides a higher degree of safety, the potential for consecutive storms will be considered as part of the additional detailed evaluation. FMC will use historic rainfall data from both the Site and the Front Royal area to estimate the amount of rainfall that has historically occurred during consecutive storms, and will calculate the potential runoff volumes resulting from these events.

WWTP Capacity

Based on the conceptual evaluation, FMC anticipates that the WWTP currently has sufficient hydraulic/throughput capacity to provide sufficient and timely treatment of storm water runoff during a design storm. However, the WWTP can be upgraded to handle greater throughput if necessary. The future detailed evaluation will include an assessment of the feasibility of increasing the throughput, and will also consider the possibility of a process or component failure that would decrease the WWTP throughput. The evaluation will identify any repairs, modifications, and/or upgrades necessary to achieve the necessary hydraulic capacity, in consideration to the revised estimated storm water runoff volume, revised designed retention capacity alternatives, and treatment requirements to meet the discharge limits.

Accumulated Rainfall on SBs

The SB soil cap field pilot study, performed in November 1998, demonstrated that soil cap construction is more efficient on drier sulfate sludge. Therefore, to improve SB soil cap construction during the EE/CA implementation, FMC will remove and treat the standing water from the SBs, and will attempt to minimize the amount and/or duration of accumulated rainfall in the SBs prior to closure. As part of the additional evaluation, FMC will evaluate potential alternatives for maintaining the SBs as dry as possible prior to closure. One possible alternative to be considered is the installation of temporary vegetative cover in the SBs, which would reduce the amount of standing/infiltrating rainfall by enhancing transpiration.

Runoff and Leachate from Closed SBs

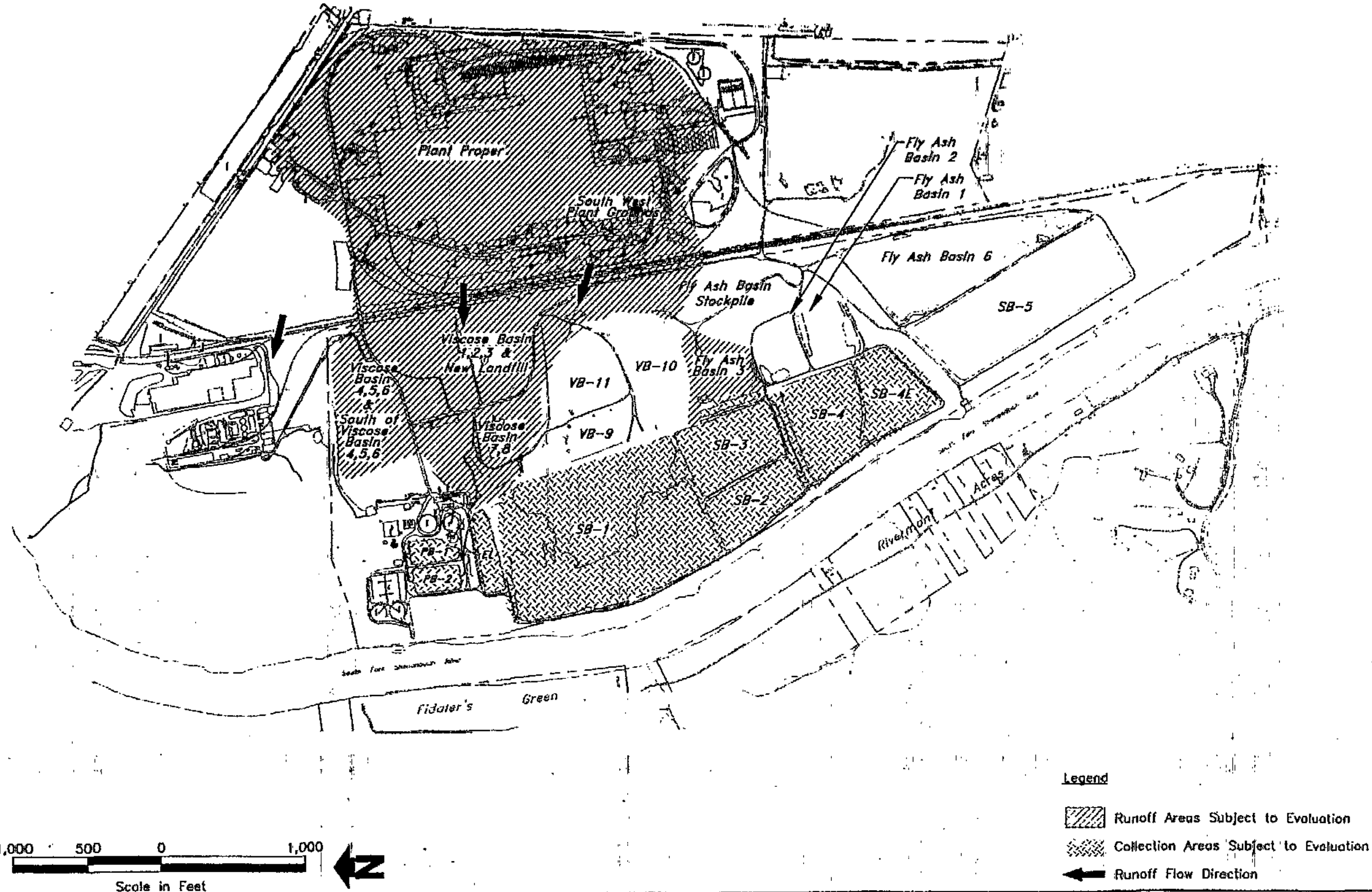
FMC will further evaluate both near term and long term water generation from the SBs, and whether treatment is necessary. Although it is reasonable to assume that surface runoff from the closed basins would not contact any contaminated material, and therefore would not require treatment, the water may require retention in accordance with State or local storm water and sedimentation control regulations prior to discharge. In addition, leachate generated from dewatering of the SBs will need to be retained and run through the WWTP until proven clean. Therefore, as part of the future detailed evaluation, FMC will evaluate the volume and rate of run-off and leachate generation from the closed SBs and incorporate these estimates into the evaluation of storm water management alternatives.

Closure Sequencing

FMC will further evaluate the EE/CA unit closure sequence to ensure that appropriate storm water and leachate management is provided during the implementation of closure activities and in the future. FMC assumes that storm water derived from the plant area will continue to be retained and treated by the WWTP to meet discharge requirements until it is shown that the storm water is uncontaminated. However, FMC anticipates that there will be reductions in the amount of storm water that requires treatment over time. For example, the plant sewer system will be decommissioned during the Non-Time Critical Removal Action (anticipated to be within the next three years). Once this occurs, the conduit for storm water runoff to the retention basins will be severed, and storm water that falls in the plant area will primarily infiltrate into the ground or evaporate. Additionally, after the SBs are closed, rainfall on this area will infiltrate, evaporate, transpire, and runoff. Since the EE/CA units will be capped with two feet of clean soil and vegetation, any runoff that occurs should be clean and acceptable for direct discharge to the River, provided sedimentation is appropriately controlled. As part of the further evaluation, FMC will consider the sequence and effects of the EE/CA and future activities on the storm water management requirements, and estimate a reasonable closure schedule for the WWTP.

In summary, the conceptual storm water management alternative described herein appears to be a practical and feasible approach for the EE/CA implementation. However, as a logical next step in the evaluation process, FMC will perform a detailed evaluation, as described above, to support the proposed alternative and/or develop new alternatives, as appropriate.

Figure D1
Major Storm Water Runoff and Collection Areas
Avtex Fibers Superfund Site
Front Royal, Virginia



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10556.64.01/12.04.98-SCH/12.07.98-CMP/A102-1F

AR106571

Table D1 - Total Volume of Storm Water Runoff During a 10-Year Storm
Avtex Fibers Superfund Site, Front Royal, Virginia

RUNOFF AREAS	AREA (acres)	Runoff Curve Number - CN [2]	CN*A	Potential Max. Retention - S [3] (in)	Runoff - Q_{10} [4] (in)	Runoff Volume - V_{10} [5] (gal)
Areas West of Railroad Tracks[1]						
Viscose Basin No. 4, 5, 6	17.34	70	1213.8	4.29	2.26 in	1.06E+06
Viscose Basin No. 3/New Landfill	13.8	70	966	4.29	2.26 in	8.47E+05
Viscose Basin No. 8	17.4	75	1305	3.33	2.69 in	1.27E+06
South of Viscose Basin No. 4, 5, 6	7.47	70	522.9	4.29	2.26 in	4.59E+05
Viscose Basin No. 1, 2	6.84	70	478.8	4.29	2.26 in	4.20E+05
Viscose Basin No. 7	3.79	75	284.25	3.33	2.69 in	2.77E+05
Flyash Basin No. 3	5.95	70	416.5	4.29	2.26 in	3.65E+05
Plant Proper	81.3	85	6910.5	1.76	3.65 in	8.05E+06
Southwest Plant Grounds	16.8	85	1428	1.76	3.65 in	1.66E+06
Totals	170.69					**1.44E+07**

Notes:

1) The volumes associated with direct rainfall into the Sulfate Basins and Wastewater Treatment Plant Basins are addressed in Table 2.
2) The Runoff Curve Numbers (CN) calculated based on the methodologies provided in the US Dept. of Agriculture Urban Hydrology for Small Watersheds, Technical Release 55, 1986 (TR-55).
3) The Potential Maximum Retention (S) was calculated per TR-55 using the equation $S=(1000/CN)-10$.
4) Inches of runoff (Q_{10}) was calculated per TR-55 using the equation ($Q_{10}) = (P-0.2S)^2/(P+0.8S)$, where P=5.3 inches for 10-yr storm event (Figure B-5 in TR-55).
5) Volume of runoff (V_{10}) is equal to the total subject area (ft^2) multiplied by Q_{10}

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Table J2 - Total Storm Water Volume in Collection Areas During a 10-Year Storm
Avtex Fibers Superfund Site, Front Royal, Virginia

Unit Area	Drainage Area (acres)	Rainfall - 10-Yr Storm - Q_{10} [1,2] (in)	Storm Water Volume - V_{10} (gal)
Sulfate Basins & Associated Unit			
SB-1	32.7	5.3	4.71E+06
SB-2	6.0	5.3	8.63E+05
SB-3	7.8	5.3	1.12E+06
SB-4 & 4E	14.9	5.3	2.14E+06
Lagoon West of Flyash Basin No. 3	1.0	5.3	1.44E+05
Wastewater Treatment Basins			
Emergency Lagoon	1.8	5.3	2.59E+05
Polishing Basin No.1	1.2	5.3	1.73E+05
Polishing Basin No.2	1.0	5.3	1.44E+05
Totals Excluding Sulfate Basins [3]	4.0		5.76E+05

Notes:

1) The amount of rainfall during a 10-year storm event was obtained from US Dept. of Agriculture "Urban Hydrology for Small Watersheds," Technical Release 55, 1986 (TR-55).
2) Rainfall = runoff for the purpose of this evaluation.
3) The total volume of storm water excluding the sulfate basins is provided because during an emergency storm event these basins may be used to provide hydraulic capacity (i.e., as they are currently used). Once a sulfate basin is closed, the hydraulic capacity will be lost, but storm water runoff associated with the area will be directed to the River and it will not be necessary to collect or treat this runoff.

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Table D3 - Total Storm Water Volume Requiring Replacement Storage Capacity During a 10-Year Storm Event Avtex Fibers Superfund Site, Front Royal, Virginia

Unit Area	Drainage Area (acres)	Runoff - 10-Yr Storm - Q_{10} (in)	Storm Water Volume - V_{10} (gal)
Runoff Areas West of Railroad Tracks [1]	72.6	2.39	4.71E+06
Plant Proper	81.3	3.65	8.05E+06
Southwest Plant Grounds	16.8	3.65	1.66E+06
Wastewater Treatment Basins	4.0	5.3	5.76E+05
Total Replacement Capacity Required			**1.50E+07**

Notes:

1) The amount of runoff (Q_{10}) from the Areas West of Railroad Tracks provided above is a weighted average of all the units shown on Table D1, and was calculated per the methods in the US Dept. of Agriculture "Urban Hydrology for Small Watersheds," Technical Release 55, 1986 (TR-55).
2) The total volume of storm water excludes the sulfate basins because during an emergency storm event these basins may be used to provide hydraulic capacity (i.e., as they are currently used). Once a sulfate basin is closed, the hydraulic capacity will be lost, but storm water runoff will be directed to the River and it will not be necessary to treat this runoff in the wastewater treatment plant.

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Table D4 - Storm Water Capacity of Wastewater Treatment Basins
Avtex Fibers Superfund Site, Front Royal, Virginia

Wastewater Treatment Basin [1]	Area (ft^2)	Total Depth [2] (ft)	Operating Depth [3] (ft)	Maximum Emergency Capacity [4] (gal)	Normal Operating Capacity [5] (gal)
Option #1					
Emergency Lagoon	79,000	14	12	8.27E+06	7.43E+06
Polishing Basin #1	54,000	12.5	10.5	5.05E+06	4.45E+06
Polishing Basin #2	44,000	13	11	4.28E+06	3.79E+06
Total Storage Capacity				**1.76E+07**	**1.57E+07**

Option #2					
Emergency Lagoon	79,000	14	12	8.27E+06	7.43E+06
Combined Polishing Basin	114,000	12.5	10.5	1.07E+07	9.38E+06
Total Storage Capacity				**1.89E+07**	**1.68E+07**

Notes:

1) Option #1 assumes that the wastewater treatment basins would be used as currently constructed; Option #2 assumes that the berm separating Polishing Basins #1 and #2 would be removed to create a combined basin.
2) Total depth of the basins assumes that the sludge is removed from the basin.
3) Operating depth assumes that under normal circumstances at least 2 feet of freeboard will be maintained in each basin.
4) Maximum Capacity provides the total available capacity that would be available during an emergency storm event (i.e., no freeboard).
5) Operating Capacity provides the total available capacity, maintaining 2 feet of freeboard.

Appendix E
Human Health Risk Assessment for the EE/CA Units

Human Health Risk Assessment for the Sulfate Basins, Wastewater Treatment Plant Basins, Fly Ash Basins, and Fly Ash Stockpile

Avtex Fibers Superfund Site

Front Royal, Virginia

Prepared for
FMC
Philadelphia, Pennsylvania

Prepared by
Gradient Corporation
44 Brattle Street
Cambridge, MA 02138

March 25, 1999

1.0 Introduction

On behalf of FMC, Inc., Gradient Corporation conducted a risk assessment of potential exposures to sulfate sludge and fly ash by a Site trespasser at the Avtex Fibers Superfund Site (Site) in Front Royal, Virginia. This risk assessment was done in support of the Engineering Evaluation/Cost Analysis (EE/CA, ERM 1999) to quantitatively evaluate current and future risks to human health associated with exposure to potential chemicals of concern by a Site trespasser. The purpose of the human health risk assessment was three-fold:

- Identify the chemicals of potential concern (COPCs) using risk-based screening;
- Evaluate current and future potential risks associated with exposure to uncovered sulfate sludge and fly ash; and
- Provide a baseline human health risk estimate in the absence of a response action

1.1 Guidance

U.S. Environmental Protection Agency (U.S. EPA) risk assessment guidelines were used to evaluate risks (U.S. EPA, 1989; 1991; 1994). The risk assessment methodology was consistent with U.S. EPA guidance and employed conservative, default assumptions whenever site-specific data were not available.

1.2 Report Organization

This report is organized into the following sections:

- Section 1 provides the introduction to the risk assessment evaluation;
- Section 2 provides a summary of site information;
- Section 3 describes the steps involved in the screening and identification of chemicals of potential concern;
- Section 4 describes the assessment of carcinogenic risks and noncarcinogenic hazards associated with exposures to arsenic and zinc;
- Section 5 describes the assessment of blood lead levels for an adolescent trespasser; and
- Section 6 summarizes the risk assessment results.

Figures are provided in Appendix A. Detailed data summaries supporting the methodologies and models for the risk assessment are provided in Appendix B.

2.0 Site Information

Three management units at the Site, the Sulfate Basins (SBs), the Wastewater Treatment Plant Basins (WWBs), and Fly Ash Basins (FABs) and Stockpile (FAS), will be closed as a Non-Time-Critical Removal Action. Figure 1 shows the locations of the three units, and each unit is described below.

- The SBs consist of six basins occupying approximately 80 acres. The SBs were used for disposal of an estimated 936,000 cubic yards of sulfate sludge formed during the treatment of plant wastewater in the waste water treatment plant. The sludge is estimated to contain approximately 20 percent (excluding water) zinc, which was used in the rayon manufacturing process. The sulfate sludge also contains calcium sulfate (gypsum), cellulose, and other metals.
- The WWBs consist of the Emergency Lagoon and two Polishing Basins. The three basins cover about four acres. The three basins are estimated to contain a total of 29,000 cubic yards of sulfate sludge of the same type present in the SBs.
- The Fly Ash Management Unit consists of four Fly Ash Basins (FAB 1, FAB 2, FAB 3 and FAB 6) and the FAS (Figure 1). The Fly Ash Basins and Stockpile were used for disposal of an estimated 1,300,000 cubic yards of fly ash. The fly ash is identical to fly ash generated by coal-fired power plants throughout the U.S.

SBs 1 through 4E and the WWBs are located within the boundary of the 100-year floodplain of the South Fork of the Shenandoah River (River). In accordance with the National Contingency Plan (NCP), EPA designated this response action to be a Non-Time-Critical Removal Action because of concern that flooding of the River may cause chemicals present in the sludge (primarily metals) to be released from the SBs and WWBs to the River. The expedited closure of these basins will mitigate the potential threat of release during flooding. Although the FABs and Stockpile are located outside the 100-year floodplain boundary, there is the potential for fly ash migration due to high wind or heavy rain. These units are therefore included in the Non-Time-Critical Removal Action and will undergo a similar response action as the SBs and WWBs.

An EE/CA has been prepared to support the Non-Time-Critical Removal Action and includes an evaluation of the nature and extent of contamination within each unit, an assessment of potential risk to human health and the environment associated with the units, and analysis of the response alternatives for the three management units.

3.0 Screening and Identification of Chemicals of Potential Concern

3.1 Sulfate Basins/Waste Water Treatment Plant Basins

The samples of sulfate sludge collected from the SBs and WWBs were merged into one data set because the sulfate sludge in both units was nearly identical in chemical composition and generated from the same process. In 1993, as part of the Phase 1 remedial investigation, twenty samples were collected from within and below the SBs, and seven samples were collected from within and below the WWBs, and analyzed for the Target Compound List (TCL) and Target Analyte List (TAL) using Contract Laboratory Program (CLP) methods to meet the Level IV analytical option. The data were validated in accordance with EPA protocol. The analytical results indicated the primary chemicals in the SBs and WWBs were metals associated with the sulfate sludge. The constituents occurred consistently and were evenly distributed throughout the sulfate sludge in all the basins. Soil samples from the berms and the soils underlying the sulfate sludge were generally uncontaminated, with detection of slightly elevated metal concentrations above background. Accordingly, the lateral and vertical extent of contamination in the SBs was contained within the sulfate sludge, the 1 to 2 feet of soil underlying the sludge, and the soil in the berms in contact with the sludge.

As the first step to selecting COPCs, 5 soil samples from deeper borings, which consisted of a mixture of sludge and soil, were excluded from the data set used to identify COPCs for the risk assessment. These samples were excluded because there was no potential for direct contact with chemicals in the soil (*i.e.*, samples were collected from approximately 20 feet below sludge surface). As a result, the 27 Level IV samples for the combined SBs and WWBs were reduced to 22 samples. These 22 samples consisted of 15 samples from the six SBs and seven samples from the three WWBs. The data for these 22 samples are presented in Table 1.

The second step was the screening of the constituents detected in the Level IV samples (Table 2). All 22 samples retained in the data set for screening were used for COPC screening. Maximum detected concentrations of chemicals in the sludges from the SBs and the WWBs were compared with Region III Risk-Based Concentrations (RBCs) for industrial soil exposure. Because the Site will never be developed for residential use, screening against industrial RBCs was considered appropriate (and more conservative than the proposed recreational use). Constituents with maximum concentrations exceeding

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the RBCs were retained as COPCs for further evaluation in the risk assessment. These COPCs were identified based on a Hazard Quotient of 0.1 for noncarcinogens (to account for possible systemic effects for non-carcinogens in accordance with EPA Region III guidance), and a risk level of 10^{-6} for carcinogens. Results of the screening are presented in Table 2. The only constituents detected in sulfate sludge that exceeded the Region III RBCs for an industrial soil exposure were arsenic, lead and zinc.

3.2 Fly Ash Basins and Stockpile

Twenty-two samples from the FABs and Stockpile were analyzed for TCL and TAL constituents using CLP methods to meet the Level IV analytical option. The data were validated in accordance with EPA protocol. Some sulfate sludge was observed in samples collected near the bottom elevation of FAB-6, which supported anecdotal information that this basin was originally used to store sulfate sludge.

The Stockpile contains multiple lenses of soil approximately six inches thick that were likely placed as cover material during placement of fly ash in the pile. No other material was found in the borings completed in the stockpile.

For the same reasons previously described for the SBs and WWBs data, samples collected from deep boring soil samples were eliminated from the data set. As a result, the 22 Level IV samples for the FABs and Stockpile were reduced to 14 samples. Of these 14 samples, eight samples were from the FABs 1, 2, 3 and 6, and six samples from the Stockpile. The 14 samples that comprise the data set for the FABs and Stockpile are presented in Table 1.

The constituents detected in the 14 Level IV samples are presented in Table 3. As previously described, COPCs from the FABs and Stockpile were selected by comparing maximum detected concentrations with U.S. EPA Region III RBCs. The screening results for the FABs and Stockpile are presented in Table 3. Only arsenic exceeded the Region III RBCs for an industrial soil exposure.

4.0 Carcinogenic Risks and Noncarcinogenic Hazards for Arsenic and Zinc

This risk assessment evaluated risks to a potential adolescent trespasser for exposures to arsenic and zinc in soil at the combined SBs and WWBs, and for arsenic in the FABs and Stockpile. Current and future risks are assumed to be the same in the absence of a response action. The 95% upper confidence limits of the mean (UCLM) for arsenic (SBs/WBBs: 6 ppm; FABs/FAS: 127 ppm) and zinc (SBs/WBBs: 178,000 ppm) were used to estimate risks from ingestion and dermal contact. For inhalation risks, air concentrations of arsenic, lead and zinc were estimated using a modified particulate matter concentration model from EPA's Soil Screening Guidance (1996b). Cancer risk and noncarcinogenic hazards were estimated for potential exposures to arsenic and zinc *via* ingestion, dermal contact, and inhalation using EPA-derived cancer slope factors (CSFs) and reference doses (RfDs). Risks from lead exposure at the combined SBs and WWBs were estimated using the adult lead model (USEPA, 1996a; Bowers *et al.*, 1994) and are discussed in Section 5.0.

4.1 Metal Particulate Concentrations

The estimation of cancer risks and noncancer hazards associated with potential inhalation exposure required the calculation of a particulate emission factor (PEF) that related the concentration of a chemical in soil to the concentration of dust particles in air. The PEF represents an annual average emission rate based on wind erosion. The emission part of the PEF equation is based on the unlimited reservoir model developed to estimate particulate emissions due to wind erosion (USEPA, 1996b). A site-specific dispersion model (Q/C) is then selected that best represents a site's size and meteorological conditions (see Exhibit 11, p.27 in USEPA, 1996b). Tables 4, 5, and 6 show the calculations to derive the particulate air metal concentrations for the combined SBs and WWBs and the FABs and Stockpile.

The combined SBs and WWBs have approximately 65 of its 85 acres under water between the months of February and October, during a significant portion of the exposure period assumed for trespassers. Therefore, time-weighted air concentrations were based on 6 months of exposure occurring when only 20 acres were exposed, and 2 months of exposure occurring when all 85 acres were exposed. Time weighted concentrations for arsenic, lead, and zinc at the combined SBs and WWBs were the sum of the metal-specific concentrations (C_air) from Tables 4 and 5 multiplied by a coefficient representing months under or not under water:

$$C = (C_{20}) * (6/8) + (C_{85}) * (2/8)$$

where:

- C = time-weighted particulate metal concentration
- C_{20} = metal concentrations from Table 4 (20 acres exposed)
- C_{85} = metal concentrations from Table 5 (85 acres exposed)
- 6/8 = 6 months of the 8 months exposure period when 20 acres are exposed
- 2/8 = 2 months of the 8 months exposure period when 85 acres are exposed

Values for exposure parameters and their sources are listed in Table 7. This risk assessment considered a trespasser between the ages of 8 and 17, trespassing on the site during 35 days/year (assumes a trespassing event occurs once/week, for 8 months of the year). Exposure parameters recommended in the Exposure Factors Handbook (US EPA, 1997) were used for body weight, surface soil and fly ash ingestion rate, inhalation rate, and inhalation exposure time. For dermal contact with surface soil and fly ash, soil/skin adherence factor and body surface area exposed to soil were based on values for a soccer player as recommended in the Exposure Factors Handbook.

Toxicity factors are summarized in Table 8. Oral and inhalation cancer slope factors for arsenic were taken from EPA's Integrated Risk Information System (USEPA, 1999). There are no cancer slope factors for zinc as it is not considered a carcinogen *via* oral or inhalation routes. Oral reference doses for arsenic and zinc were also taken from IRIS. There are no reference concentrations for arsenic and zinc to evaluate noncarcinogenic hazards *via* the inhalation route. Although there were no dermal toxicity criteria, oral reference doses (adjusted for dermal absorption) can also be used to estimate risks from dermal exposure.

Calculation of total cancer risks and noncancer hazards for the combined SBs/WWBs and FABs/FAS are presented in Tables 9 through 12, using exposure parameters listed in Table 7, and toxicity factors listed in Table 8. Total cancer risks at the combined SBs/WWBs and FABs/FAS were 1×10^{-7} and 2×10^{-6}, respectively (Table 13). Both values are below or within EPA's target risk goals of 10^{-6} to 10^{-4}. Total noncancer hazard indices for the combined SBs/WWBs and FAB/FAS were 0.06 and 0.04, respectively (Table 14). Both values are less than one, indicating noncancer health effects are not expected.

5.0 Blood Lead Levels

U.S. EPA recommends using blood lead models to evaluate potential exposures to environmental lead. The IEUBK Model is recommended for children younger than 7 years (USEPA, 1994), while a modified version of the Bowers *et al.* (1994) model is recommended for adults (USEPA, 1996a). The adult model was used here to predict blood lead levels for the potentially exposed population of 8-17 year-old adolescents. Children in this age range are more likely to have soil ingestion approximating those of adults rather than toddlers, and Gulson *et al.* (1997) reported that children age 6 and older absorb ingested lead at comparable levels to adults.

First, an average baseline blood lead level was identified to account for continuing exposure to background levels of lead in food, soil, and dust, and pre-existing body burdens due to prior lead exposures. To obtain this baseline blood lead level, the NHANES III data base was queried for blood lead levels for males and females aged from 8 to 17 years living in the South (USPHS, 1997), yielding a geometric mean baseline blood lead level of 1.67 μg/dL and a geometric standard deviation (GSD) of 1.93. The GSD describes the amount of variability in blood lead levels among the exposed population. To this baseline blood lead level, the model added an incremental increase in blood lead levels due to the lead source of interest (in this case, exposure to lead in sludge and particulates at the combined SBs/ WWBs).

Lead uptake from soil and particulates was calculated using the following equation:

$$PbB_{central} = PbB_{baseline} + (BKSF \times \frac{EF}{AT}) \times ((Pb_{soil} \times IR_{soil} \times AF_{soil}) + (Pb_{air} \times IR_{air} \times H \times AF_{air}))$$

where:

$PbB_{central}$ = Blood lead level (calculated)
$PbB_{baseline}$ = Geometric mean baseline blood lead level from NHANES III
BKSF = Biokinetic slope factor (change in blood lead per μg change in daily lead uptake) (0.4 μg/dL per μg/day) (USEPA, 1996a)
EF = Exposure frequency – *i.e.*, number of days per period of duration AT during which an individual is exposed to the lead source being evaluated (35 days) (Table 7)
AT = Averaging time (365 days) (USEPA, 1996a)
Pb_{soil} = Average soil lead concentration (534.8 μg/g)
IR_{soil} = Soil ingestion rate (0.05 g/day) (USEPA, 1996a)
AF_{soil} = Fraction of ingested lead absorbed into the blood stream (0.12) (USEPA, 1996a)
Pb_{air} = Particulate lead concentration (0.23 μg/m^3) (Tables 4 and 5)
IR_{air} = Inhalation rate (14 m^3/day) (Table 7)

H = Event duration (4 hours per day in a 24 hour day) (Table 7)

AF_{air} = Fraction of inhaled lead deposited in and absorbed through the lungs (0.32) (Bowers *et al.*, 1994)

The incremental blood lead due to exposures at the combined SBs/WWBs was added to the baseline blood lead for a total blood lead level that represented an average adolescent. The incremental change in blood lead was 0.13 µg/dL. Thus, the adolescent blood lead level would increase from 1.67 to 1.8 µg/dL. U.S. EPA recommends a target blood lead level for young children and adults based on the likelihood that a blood lead level exceeds 10 µg/dL would be less than 5% (U.S. EPA, 1996a). This target was adopted for adolescents in this risk assessment.

To ensure that the incremental blood lead increase over the baseline blood lead level was protective of 95% of the adolescent population, a target blood lead level was estimated using the following equation (U.S. EPA, 1996a):

$$PbB_{0.95} = PbB_{Central} \times GSD^{1.645} \text{ where:}$$

where:

$PbB_{0.95}$ = The 95th percentile blood lead concentration for adolescents ages 8 to 17 years.

$PbB_{central}$ = Blood lead concentration in adolescents associated with exposures to lead in soil and particulate (1.8 µg/dL).

$GSD^{1.645}$ = Estimated value of the individual geometric standard deviation (1.93). The exponent, 1.645, is the value of the standard normal deviate used to calculate the 95th percentile from a lognormal distribution of blood lead level.

$PbB_{central}$ equaled 1.8 µg/dL as estimated in the first equation. Solving the above equation, a resulting $PbB_{0.95}$ of 5.31 µg/dL was estimated, which was lower than U.S. EPA's target blood lead level of 10 µg/dL (U.S. EPA, 1994). On this basis, it can be concluded that the lead in sludge at the combined SBs/WWBs does not pose an unacceptable risk for potentially exposed adolescents.

6.0 Conclusions

Carcinogenic risks and noncarcinogenic hazards associated with exposures to arsenic and zinc in sludges were evaluated for an adolescent trespasser at the Avtex Fibers Superfund Site (Site) in Front Royal, Virginia. Total cancer risks at the combined SBs/WWBs and FABs/FAS were 1×10^{-7} and 2×10^{-6}, respectively. Both values are below or within EPA's target risk goals of 10^{-6} to 10^{-4}. On this basis, it can be concluded that the arsenic and zinc in soil at the combined SBs/WWBs and FABs/FAS would not be associated with unacceptable risks for potentially exposed adolescents.

Total noncancer hazard indices for the combined SBs/WWBs and FABs/FAS were 0.06 and 0.04, respectively. Both values are less than one, indicating noncancer health effects associated with trespassing activities are not expected at these sites.

The incremental increase in blood lead due to exposures at the combined SBs/WWBs was 0.13 µg/dL, resulting in an increase in the blood lead level from 1.67 to 1.8 µg/dL for the adolescent trespasser. The resulting blood lead level is within U.S. EPA's recommended target blood lead level for young children and adults that the likelihood of a blood lead level exceeding 10 µg/dL would be less than 5% (U.S. EPA, 1996a). To ensure that the incremental blood lead increase over the baseline blood lead level was protective of 95% of the adolescent population, a resulting $PbB_{0.95}$ of 5.31 µg/dL was estimated, which was lower than U.S. EPA's target blood lead level of 10 µg/dL. On this basis, it can be concluded that the lead in sludge at the combined SBs/WWBs does not pose an unacceptable risk for potentially exposed adolescents.

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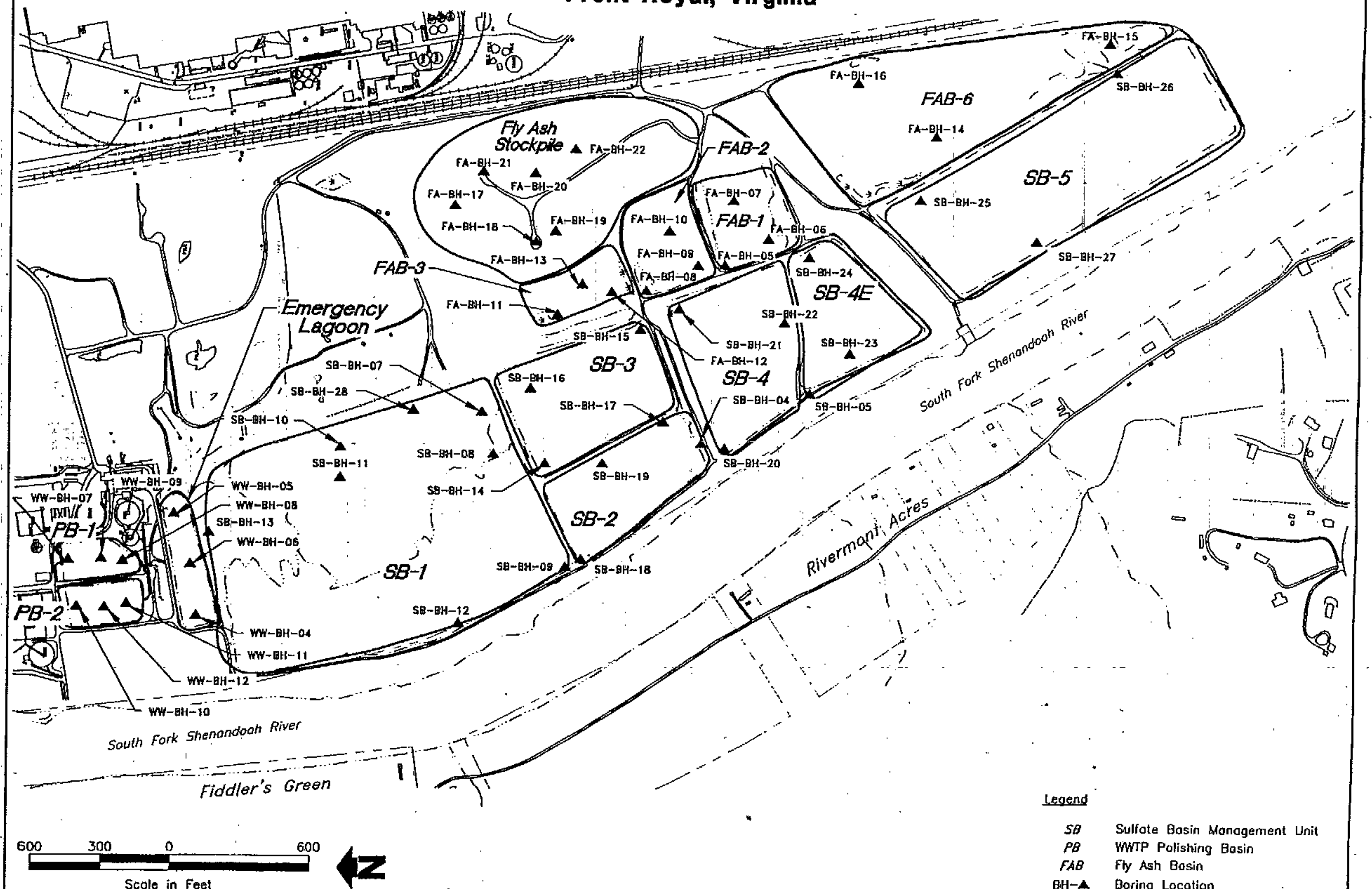
Appendix A

Figures

Figure 1
Sampling Locations for Sulfate Basins, Wastewater Treatment Plant Basins, Fly Ash Basins and Stockpile
Avtex Fibers Superfund Site
Front Royal, Virginia



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Appendix B

Data Summaries and Spreadsheet Calculations

Table 1

Level IV Samples from Sulfate Basins, Wastewater Treatment Plant Basins, Fly Ash Basins, and Stockpile Used for Human Health Risk Assessment

Avtex Fibers Superfund Site, Front Royal, Virginia

Sample Location	Sample ID
Sulfate/Wastewater Treatment Plant Basins (22 samples)	
Emergency Lagoon	AV-WW-BH-05(B)-00
Emergency Lagoon	AV-WW-BH-04-05
Emergency Lagoon	AV-WW-BH-05-00
Emergency Lagoon	AV-WW-BH-05(B)-00D
PB-01	AV-WW-BH-08-00
PB-01	AV-WW-BH-08-00D
PB-01	AV-WW-BH-09-00
SB-01	AV-SB-BH-09-02
SB-01	AV-SB-BH-07-10
SB-01	AV-SB-BH-28-00
SB-01	AV-SB-BH-28-00D
SB-01	AV-SB-BH-10-10
SB-01	AV-SB-BH-13-15
SB-01	AV-SB-BH-08-04
SB-02	AV-SB-BH-17-00
SB-03	AV-SB-BH-15-00
SB-03	AV-SB-BH-16-07
SB-04	AV-SB-BH-23-04
SB-04	AV-SB-BH-22-07
SB-05	AV-SB-BH-27-00
SB-05	AV-SB-BH-27-06
SB-05	AV-SB-BH-25-00
Fly Ash Basins/Stockpile (14 samples)	
FAB-01	AV-FA-BH-06-10
FAB-02	AV-FA-BH-08-00
FAB-03	AV-FA-BH-12-00
FAB-03	AV-FA-BH-13-00
FAB-03	AV-FA-BH-13-00D
FAB-06	AV-FA-BH-14-10
FAB-06	AV-FA-BH-15-15
FAB-06	AV-FA-BH-15-15D
Fly Ash Stockpile	AV-FA-BH-20-00
Fly Ash Stockpile	AV-FA-BH-19-00
Fly Ash Stockpile	AV-FA-BH-18-50
Fly Ash Stockpile	AV-FA-BH-23-30
Fly Ash Stockpile	AV-FA-BH-23-30D
Fly Ash Stockpile	AV-FA-BH-23-00

PB - Polishing Basin

SB - Sulfate Basin

FA - Fly Ash Basin

Note: Last two digits of sample ID indicates the depth to the top of the sampling interval.

Table 2
Human Health COPC Screening Results for Sulfate and WWTP Basins Sludge
Avtex Fibers Superfund Site, Front Royal, Virginia

Analytes	Frequency of Detection	No. of Samples	Maximum Concentration		Region III Industrial Soil RBC	Industrial Soil RBC Exceeded?
Volatiles						
1,2,4 -Trichlorobenzene	1	20	2.5	J	2000	No
2-Butanone	6	20	1.1		120000	No
2-Hexanone (hexanone)	1	20	0.01	J	16000	No
4-Methyl-2-Pentanone	2	20	0.01	J	16000	No
Acetone	8	20	1.6		20000	No
Ethyl Benzene	6	20	0.009	J	20000	No
Methylene Chloride	1	20	0.005	J	760	No
Toluene	11	20	0.14	J	41000	No
Xylenes (Total)	8	20	0.04	J	410000	No
Semivolatiles						
2-Methylnaphthalene	11	20	3.1	J	4100	No
4-Methylphenol	1	20	0.21	J	1000	No
Acenaphthene	2	20	0.26	J	12000	No
Anthracene	1	20	0.16	J	61000	No
Benzo(a)anthracene	9	20	0.86	J	7.8	No
Benzo(a)pyrene	1	20	0.64	J	0.78	No
Benzo(b)fluoranthene	3	20	1.3	H	7.8	No
Benzo(g,h,i)perylene (pyrene)	1	20	0.36	J	6100	No
Bis(2-ethylhexyl)phthalate	19	20	4.6	J	410	No
Carbon disulfide	15	20	11		20000	No
Chrysene	15	20	6.7	J	780	No
Dibenzo(a,h)anthracene	1	20	0.16	J	0.78	No
Di-n-butylphthalate	2	20	1.2	J	20000	No
Di-n-octylphthalate	3	20	0.88	J	4100	No
Fluoranthene	4	20	1	J	8200	No
Fluorene	8	20	1.6	J	8200	No
Indeno(1,2,3-cd)pyrene	1	20	0.41	J	7.8	No
Naphthalene	2	20	9.8	J	4100	No
N-Nitrosodiphenylamine	1	20	0.75	J	1200	No
Pentachlorophenol	1	20	1.3	J	48	No
Phenanthrene (pyrene)	18	20	5.3	J	6100	No
Phenol	8	20	0.57	J	120000	No
Pyrene	14	20	4.1	J	6100	No
Pesticides/PCBs						
4,4'-DDD	2	22	0.0074	J	24	No
4,4'-DDE	4	22	0.0076	J	17	No
4,4'-DDT	1	22	0.0026	J	17	No
Aldrin	6	22	0.25	L	0.34	No
Alpha Chlordane (Chlordane)	6	22	0.0028	J	16	No
Aroclor 1242	3	24	0.65		2.9	No
Aroclor 1254	1	24	0.2	J	2.9	No
Aroclor 1260	3	24	0.89		2.9	No
Beta-BHC	4	22	0.014	J	3.2	No
Delta-BHC (beta)	2	22	0.0016	J	3.2	No
Dieldrin	4	22	0.024	J	0.36	No
Endosulfan (I)	11	22	0.02	J	1200	No
Endosulfan (II)	1	22	0.0022	J	1200	No
Endosulfan Sulfate (Endosulfan)	1	22	0.01	J	1200	No
Endrin	2	22	0.0013	J	61	No
Endrin Aldehyde (endrin)	3	22	0.027	P	61	No
Endrin Ketone (endrin)	4	22	0.0059	J	61	No
Gamma Chlordane (chlordane)	6	22	0.074	L	16	No
Gamma-BHC (Lindane)	6	22	0.025	L	4.4	No
Heptachlor	3	22	0.28	L	1.3	No
Heptachlor Epoxide	8	22	0.027		0.63	No
Methoxychlor	1	22	0.0086	J	1000	No

Tables prepared by ERM

Table 2 (cont.)

Human Health COPC Screening Results for Sulfate and WWTP Basins Sludge

Avtex Fibers Superfund Site, Front Royal, Virginia

Analytes	Frequency of Detection	No. of Samples	Maximum Concentration		Region III Industrial Soil RBC	Industrial Soil RBC Exceeded?
Metals						
Aluminum	20	20	15300		200000	No
Antimony	2	20	20.9		82	No
Arsenic	19	20	11.8	L	3.8	Yes
Barium	20	20	280		14000	No
Beryllium	11	20	1.1		410	No
Cadmium	18	20	87.8		200	No
Calcium	20	20	177000		N/A *	No
Chromium (as Cr VI)	20	20	338	K	610	No
Cobalt	11	20	13		12000	No
Copper	20	20	179	J	8200	No
Cyanide, Total (as Free)	9	20	3.2		4100	No
Iron	20	20	29500	J	61000	No
Lead	20	20	2240		400^	Yes
Magnesium	20	20	30900		N/A *	No
Manganese	20	20	744		4100	No
Mercury (as Methyl)	18	20	9.8	L	20	No
Nickel	20	20	129		4100	No
Potassium	13	20	1340		N/A *	No
Selenium	3	20	2.3	L	1000	No
Silver	1	20	17		1000	No
Sodium	17	20	16600		N/A *	No
Vanadium	20	20	39.4		1400	No
Zinc	20	20	278000		61000	Yes

Notes:

All concentrations in mg/kg.

Only positively detected constituents listed above.

Data were screened according to USEPA Region III methodology (USEPA, 1993).

RBC - Risk-Based Concentration (USEPA Region III industrial soil; October, 1998). RBCs are based on a noncarcinogenic hazard index of 0.1 and a carcinogenic risk of 1 x 10-6.

Where no RBC criteria are available, constituent shown in parenthases is used as a surrogate.

* - Essential nutrients (calcium, magnesium, potassium, and sodium) were not retained for further consideration in the risk assessment.

^ RBC for lead based on Revised Interim Soil Lead Guidance (USEPA, 1994).

14 out of 19 detections of arsenic exceed the Region III Industrial Soil RBC.

9 out of 20 detections of lead exceed the Region III Industrial Soil RBC.

14 out of 20 detections of zinc exceed the Region III Industrial Soil RBC.

Table 3
Human Health COPC Screening Results for Fly Ash Basins and Stockpile
Avtex Fibers Superfund Site, Front Royal, Virginia

	Frequency of Detection	No. of Samples	Maximum Concentration		Region III Industrial Soil RBC	Industrial Soil Exceeded?
Volatiles						
Acetone	1	14	0.011	J	20000	No
Bromodichloromethane	1	14	0.14	J	92	No
Chloroform	10	14	0.11	J	940	No
Methylene Chloride	2	14	0.048	J	760	No
Toluene	1	14	0.002	J	41000	No
Trichloroethene	1	14	0.004	J	520	No
Semivolatiles						
Carbon Disulfide	2	14	0.055	J	20000	No
Di-n-butylphthalate	1	12	0.08	J	20000	No
Di-n-octylphthalate	1	12	0.13	J	4100	No
Pesticides						
Methoxychlor	1	6	0.017	J	1000	No
Metals						
Aluminum	14	14	16900		200000	No
Arsenic	14	14	193	J	3.8	Yes
Barium	14	14	759	J	14000	No
Beryllium	14	14	5		410	No
Cadmium	9	14	1.5		200	No
Calcium	14	14	21200	J	N/A *	N/A
Chromium (as Cr VI)	14	14	25.2		610	No
Cobalt	14	14	18.2		12000	No
Copper	14	14	54.4		8200	No
Cyanide, Total (as Free)	13	13	3.3		4100	No
Iron	14	14	23400		61000	No
Lead	14	14	22.9	J	400^	No
Magnesium	14	14	2660		N/A *	N/A
Manganese	14	14	152	K	4100	No
Mercury (as Methyl)	14	14	1		20	No
Nickel	14	14	28.8	L	4100	No
Potassium	12	14	3590		N/A *	N/A
Selenium	14	14	12.7		1000	No
Sodium	14	14	777		N/A *	N/A
Thallium	13	14	2.8		14	No
Vanadium	14	14	81.7		1400	No
Zinc	14	14	2870	L	61000	No

Notes:
All concentrations in mg/kg.
Only positively detected constituents listed above.
Data were screened according to USEPA Region III methodology (USEPA, 1993).
RBC - Risk-Based Concentration (USEPA Region III industrial soil; October, 1998). RBCs are based on a noncarcinogenic hazard index of 0.1 and a carcinogenic risk of 1 x 10-6.
Where no RBC criteria are available, constituent shown in parenthases is used as a surrogate.
* - Essential nutrients (calcium, magnesium, potassium, and sodium) were not retained for further consideration in the risk assessment.
^ RBC for lead based on Revised Interim Soil Lead Guidance (USEPA, 1994).
All 14 detections of arsenic exceed the Region III Industrial Soil RBC.

Table 4 Screening Analysis of Particulate Emissions and Ambient On-site Concentrations due to Wind Erosion

SBs/WWBs: Scenario 1 (20 acres unvegetated)

User Defined Constants:

	Value	Data Source
fraction of contaminated surface with vegetative or other cover (V)	0%	Unvegetated site
mean annual wind speed [u]	4.7 m/s	Default:USEPA Soil Screening Guidance (USEPA, 1996b)
source extent (A)	80,929 m^2	Site specific (20 acres)
height above surface (Z)	7 m	Default: NWS weather station sensor height
roughness height (Z_0)	0.05 m	Default: USEPA (1996b)
threshold friction velocity at surface (U_0)	0.5 m/s	Default: USEPA (1996b)

Calculated Parameters:

threshhold value of wind speed at 7 m (U_t)	6.2 m/s	calculated (USEPA, 1996b)
dimensionless ratio (x)	1.2	calculated (USEPA, 1996b)

F(x), for ($0 < x < 0.6$) =	1.9
F(x), for ($0.6 < x < 0.95$) =	1.5
F(x), for ($0.95 < x < 2$) =	1.4
F(x), for ($x > 2$) =	1.2

Appropriate F(x), for calculated (x) 1.4

PM10 emission factor (E10) 6.08E-06 g / m^2-sec

Source Area = Flux Area 80,929 m^2 (20 acres)

Q/C Value = (for Raleigh-Durham, USEPA, 1996b) =	46.51 [g / m^2-sec] / [kg / m^3]		43,560 ft^2/acre
Site Area for this Q/C value =	10 acres	40,465 m^2	3.281 ft/m
Dispersion Factor =	5.31E-04 [g / m^3] / [g / sec]		4,046 m^2/acre

Chemical	Csoil[1] [mg/kg]	C_soil (alpha) [ ]	R_{10} [g /sec]	C_air mg/m^3
Arsenic	6.11	6.11E-06	3.01E-06	1.60E-06
Lead	742.5	7.43E-04	3.65E-04	1.94E-04
Zinc	178257	1.78E-01	8.77E-02	4.66E-02

[1] Concentration is the 95% upper confidence limit of the mean.

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Table 5 Screening Analysis of Particulate Emissions and Ambient On-site Concentrations due to Wind Erosion

SBs/WWBs: Scenario 2 (85 acres vegetated)

User Defined Constants:

	Value	Data Source
fraction of contaminated surface with vegetative or other cover (V)	0%	Unvegetated site
mean annual wind speed [u]	4.7 m/s	Default:USEPA Soil Screening Guidance (USEPA, 1996b)
source extent (A)	343,949 m²	Site specific (85 acres)
height above surface (Z)	7 m	Default: NWS weather station sensor height
roughness height (Z_0)	0.05 m	Default: USEPA (1996b)
threshold friction velocity at surface (U_0)	0.5 m/s	Default: USEPA (1996b)

Calculated Parameters:

threshhold value of wind speed at 7 m (U_t)	6.2 m/s	calculated (USEPA, 1996b)
dimensionless ratio (x)	1.2	calculated (USEPA, 1996b)

PM10 emission factor (E10) 6.08E-06 g / m^2-sec

Source Area = Flux Area 343,949 m^2 (85 acres)

Q/C Value = (for Raleigh-Durham, USEPA, 1996b) 39.64 [g / m^2-sec] / [kg / m^3]

Site Area for this Q/C value = 30 acres 121,394 m^2

Dispersion Factor = 2.08E-04 [g / m^3] / [g / sec]

43,560 ft^2/acre
3.281 ft/m
4,046 m^2/acre

Chemical	Csoil[1]	C_soil (alpha)	R_{10}	C_air
	[mg/kg]	[ ]	[g /sec]	mg/m^3
Arsenic	127.4	1.27E-04	2.67E-04	5.54E-05
Lead	742.5	7.43E-04	1.55E-03	3.23E-04
Zinc	178257	1.78E-01	3.73E-01	7.75E-02

[1] Concentration is the 95% upper confidence limit of the mean.

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Table 6 Screening Analysis of Particulate Emissions and Ambient On-site Concentrations due to Wind Erosion

FABs/FAS (35 acres exposed)

User Defined Constants:

		Data Source
fraction of contaminated surface with vegetative or other cover (V)	95%	Unvegetated site
mean annual wind speed [u]	4.7 m/s	Default:USEPA Soil Screening Guidance (USEPA, 1996b)
source extent (A)	141,626 m^2	Site specific (35 acres)
height above surface (Z)	7 m	Default: NWS weather station sensor height
roughness height (Z_0)	0.05 m	Default: USEPA (1996b)
threshold friction velocity at surface (U_0)	0.5 m/s	Default: USEPA (1996b)

Calculated Parameters:

threshhold value of wind speed at 7 m (U_t)	6.2 m/s	calculated (USEPA, 1996b)
dimensionless ratio (x)	1.2	calculated (USEPA, 1996b)

PM10 emission factor (E10) 3.04E-07 g / m^2-sec

Source Area = Flux Area	141,626 m^2	(35 acres)		
Q/C Value = (for Raleigh-Durham, USEPA, 1996b)	39.64 [g / m^2-sec] / [kg / m^3]		43,560	ft^2/acre
Site Area for this Q/C value =	30 acres	121,394 m^2	3.281	ft/m
Dispersion Factor =	2.08E-04 [g / m^3] / [g / sec]		4,046	m^2/acre

Chemical	Csoil[1]	C_soil (alpha)	R_{10}	C_air
	[mg/kg]	[ ]	[g /sec]	mg/m^3
Arsenic	127.4	1.27E-04	5.49E-06	1.14E-06

[1] Concentration is the 95% upper confidence limit of the mean.

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Table 7
Exposure Parameters, Trespasser/Recreational Scenario for Adolescents (8-17 years), EE/CA for Basins

Parameters common to all exposure routes		
Body Weight (BW)	47 kg	EFH Table 7-3 (a)
Exposure Frequency (EF)	35 days/year	Region 3 (b)
Exposure Duration (ED)	10 years	Region 3 (b)
Averaging Time - Cancer (AT_{cancer})	25550 days	
Averaging Time - Noncancer ($AT_{noncancer}$)	3650 days	
Soil Ingestion		
Soil Ingestion Rate (IR_{soil})	100 mg/day	EFH page 4-20, 4-21
Relative Bioavailability (B)	contaminant-specific	see Table 8
Fraction Ingestion from Site (IF)	0.45	(c)
Dermal Contact		
Total Body Surface Area (SA)	13,170 cm^2	EFH Table 6-6, 6-7 (a)
Fraction Surface Area Exposed (SF)	0.34	EFH Table 6-8 (a,d)
Soil-Skin Adherence (AF)	0.036 mg/cm^2	EFH Table 6-12 (e)
Dermal Absorption (DA)	contaminant-specific	See Table 8
Inhalation of Particulates		
Inhalation Rate (IR)	14 m^3/day	EFH Table 5-26 (a)
Exposure Time (ET)	4 hours/day	EFH Table 15-12 (f)
Fraction Deposited in Lungs	contaminant-specific	

(a) U.S. EPA Exposure Factors Handbook, 1997. Average across mean values for gender and age groups.
(b) Site-specific recommended by Region 3, based on 1 day/week, 8 months/year, ages 8-17.
(c) Assumes 45% soil ingestion occurs outside, while 55% corresponds to indoor dust ingestion (U.S. EPA, 1994, Guidance Manual for the Integrated Exposure Uptake Biokinetic Model for Lead in Children)
(d) Assumes exposure of hands, arms, and one-half of legs.
(e) Assumes Outdoor Soccer No. 1 scenario. Value calculated from body-part weighted average over hands, arms, and legs.
(f) Approximate time spent in recreational activities, (assumed outdoors) ages 6-11.

Table 8
Summary of Toxicity Factors for Arsenic and Zinc

Chemicals of Concern	Oral CSF $(mg/kg\text{-}day)^{-1}$	Chronic C Oral RfD mg/kg-day	Inhalation CSF $(mg/kg\text{-}day)^{-1}$	Oral Absorption (O)	Relative Bioavailability (B)	Dermal Absorption (DA)
Inorganic						
Arsenic	1.5E+00	3.0E-04	1.5E+01	9.5E-01	8.0E-01	3.0E-02
Zinc		3.0E-01		2.5E-01	1.0E+00	1.0E-03

Slope factors and RfDs are from IRIS, current as of 9/30/98
Oral absorption from EPA (1994) for arsenic, and from ATSDR (1992) for zinc
Relative bioavailability from TNRCC (1996) for arsenic. For zinc, use default for inorganics
Dermal abosrption from Gradient (1995) for arsenic, and from EPA (1994) for zinc

Sources:

ATSDR (1992). *Toxicological Profile for Zinc (Draft Update).* Agency for Toxic Substances and Disease Registry
EPA (1994). Letter from J. Hanlon to J. A. Heimbuch, re: Floodplains/Wetlands Cleanup Goals Issue, FieldsBrook Superfund Site, October 20
Gradient (1995). Recommended Values for Three Exposure Variables. Prepared for Fuller and Henry, 6/30
TNRCC (1996). Texas Risk Reduction Program, Volume 2. Appendices I-IV & VI-IX. Office of Waste Management, December 16.

Table 9
Excess Lifetime Cancer Risks
for the Sulfate Basins/Waste Water Treatment Plant Basins

Ingestion of Sulfate Sludge
Intake Factor (1/day): IF = 1.31E-08

Chemicals Evaluated	Surface Soil Concentration (C) (mg/kg)	Relative Bioavailability (B)	Daily Intake DI = C×IF×B (mg/kg·d)	Slope Factor (SF) (kg·d/mg)	Cancer Risk CR = DI×SF	Percent Contribution To Total Cancer Risk
Inorganic						
Arsenic	6.11E+00	8.0E-01	6.4E-08	1.5E+00	9.6E-08	100.0%
Zinc	1.78E+05	1.0E+00	2.3E-03	N/A		
				Total Cancer Risk:	9.6E-08	

Intake Factor (IF) = (IR_{soil} (100 mg/day) x IF (0.45) x EF (35 days/yr) x ED (10 yrs) x 10^{-6} (kg/mg)) / (BW (47 kg) x AT (25550 days))

Dermal Contact with Sulfate Sludge
Intake Factor (1/day): IF = 4.70E-08

Chemicals Evaluated	Surface Soil Concentration (C) (mg/kg)	Dermal Absorption (DA)	Daily Intake DI=C×IF×DA (mg/kg·d)	Slope Factor (SF) (kg·d/mg)	Oral Absorption (O)	Cancer Risk CR=DI×(SF÷O)	Percent Contribution To Total Cancer Risk
Arsenic	6.11E+00	3.0E-02	8.6E-09	1.5E+00	9.5E-01	1.4E-08	100.0%
Zinc	1.78E+05	1.0E-03	8.4E-06	N/A	2.5E-01		
					Total Cancer Risk:	1.4E-08	

Intake Factor (IF) = (AF (0.0362 mg/cm^2) x SA (13170 cm^2/event) x SF (0.34) x EF (35 days/yr) x ED (10 yrs) x 10^{-6} (kg/mg)) / (BW (47 kg) x AT (25550 days))

Inhalation of Outdoor Air
Intake Factor (m³/(kg·day)): IF = 6.80E-04

Chemicals Evaluated	Outdoor Air Concentration (C) (mg/m³)	Fraction Deposited in Lungs (FD)	Daily Intake DI=C×IF×FD (mg/kg·d)	Slope Factor (SF) (kg·d/mg)	Cancer Risk CR=DI×SF	Percent Contribution To Total Cancer Risk
Arsenic	1.86E-06	1.0E+00	1.3E-09	1.5E+01	1.9E-08	100.0%
Zinc	5.43E-02	1.0E+00	3.7E-05	N/A		
				Total Cancer Risk:	1.9E-08	

Intake Factor (IF) = (IR_{air} (14 m^3/day) x ET (4 hrs/day) x EF (35 days/yr) x ED (10 yrs)) / (24 (hrs/day) x BW (47 kg) x AT (25550 days))

N/A = Not available (Zinc is not considered a carcinogen)

Table 10
Excess Lifetime Cancer Risks
for the Fly Ash Basins/Fly Ash Stockpile

Ingestion of Fly Ash
Intake Factor (1/day): IF = 1.31E-08

Chemicals Evaluated	Surface Soil Concentration (C) (mg/kg)	Relative Bioavailability (B)	Daily Intake DI = C×IF×B (mg/kg·d)	Slope Factor (SF) (kg·d/mg)	Cancer Risk CR = DI×SF	Percent Contribution To Total Cancer Risk
Inorganic						
Arsenic	1.27E+02	8.0E-01	1.3E-06	1.5E+00	2.0E-06	100.0%
				Total Cancer Risk:	2.0E-06	

Intake Factor (IF) = (IR_{soil} (100 mg/day) x IF (0.45) x EF (35 days/yr) x ED (10 yrs) x 10^{-6} (kg/mg)) / (BW (47 kg) x AT (25550 days))

Dermal Contact with Fly Ash
Intake Factor (1/day): IF = 4.70E-08

Chemicals Evaluated	Surface Soil Concentration (C) (mg/kg)	Dermal Absorption (AF)	Daily Intake DI=C×IF×A (mg/kg·d)	Slope Factor (SF) (kg·d/mg)	Oral Absorption (O)	Cancer Risk CR=DI×(SF÷O)	Percent Contribution To Total Cancer Risk
Arsenic	1.27E+02	3.0E-02	1.8E-07	1.5E+00	9.5E-01	2.8E-07	100.0%
					Total Cancer Risk:	2.8E-07	

Intake Factor (IF) = (AF (0.0362 mg/cm^2) x SA (13170 cm^2/event) x SF (0.34) x EF (35 days/yr) x ED (10 yrs) x 10^{-6} (kg/mg)) / (BW (47 kg) x AT (25550 days))

Inhalation of Fly Ash
Intake Factor (m³/(kg·day)): IF = 6.80E-04

Chemicals Evaluated	Outdoor Air Concentration (C) (mg/m³)	Fraction Deposited in Lungs (FD)	Daily Intake DI=C×IF×FD (mg/kg·d)	Slope Factor (SF) (kg·d/mg)	Cancer Risk CR=DI×SF	Percent Contribution To Total Cancer Risk
Arsenic	1.14E-06	1.00E+00	7.70E-10	1.50E+01	1.2E-08	100.0%
				Total Cancer Risk:	1.2E-08	

Intake Factor (IF) = (IR_{air} (14 m^3/day) x ET (4 hrs/day) x EF (35 days/yr) x ED (10 yrs)) / (24 (hrs/day) x BW (47 kg) x AT (25550 days))

...le 11
Noncancer Hazard Quotients
for the Sulfate Basins/Waste Water Treatment Plant Basins

Ingestion of Sulfate Sludge
Intake Factor (1/day): IF = 9.18E-08

Chemicals Evaluated	Surface Soil Concentration (C) (mg/kg)	Relative Bioavailability (B)	Daily Intake DI = C×IF×B (mg/kg·d)	Reference Dose (RfD) (mg/kg·d)	Hazard Quotient HQ=DI÷RfD	Percent Contribution To Hazard Index
Inorganic						
Arsenic	6.11E+00	8.0E-01	4.5E-07	3.0E-04	0.0015	1.7%
Zinc	1.78E+05	1.0E+00	1.6E-02	3.0E-01	0.0545	98.3%
				Hazard Index*:	**0.0560**	

Intake Factor (IF) = (IR_{soil} (100 mg/day) x IF (0.45) x EF (35 days/yr) x ED (10 yrs) x 10^{-6} (kg/mg)) / (BW (47 kg) x AT (3650 days))

Dermal Contact with Sulfate Sludge
Intake Factor (1/day): IF = 3.29E-07

Chemicals Evaluated	Surface Soil Concentration (C) (mg/kg)	Dermal Absorption (AF)	Daily Intake DI=C×IF×AF (mg/kg·d)	Reference Dose (RfD) (mg/kg·d)	Oral Absorption (O)	Hazard Quotient HQ=DI÷(RfD×O)	Percent Contribution To Hazard Index
Arsenic	6.11E+00	3.0E-02	6.0E-08	3.0E-04	9.5E-01	0.00021	21.3%
Intake Facto	1.78E+05	1.0E-03	5.9E-05	3.0E-01	2.5E-01	0.00078	78.7%
					Hazard Index*:	**0.00099**	

Intake Factor (IF) = (AF (0.0362 mg/cm^2) x SA (13170 cm^2/event) x SF (0.34) x EF (35 days/yr) x ED (10 yrs) x 10^{-6} (kg/mg)) / (BW (47 kg) x AT (3650 days))

*Hazard Quotients are summed, which likely overestimates total noncancer effects.

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Table 12
Noncancer Hazard Quotients
for the Fly Ash Basins/Fly Ash Stockpile

Ingestion of Fly Ash
Intake Factor (1/day): IF = 9.18E-08

Chemicals Evaluated	Surface Soil Concentration (C) (mg/kg)	Relative Bioavailability (B)	Daily Intake DI = C×IF×B (mg/kg·d)	Reference Dose (RfD) (mg/kg·d)	Hazard Quotient HQ=DI÷RfD	Percent Contribution To Hazard Index
Inorganic						
Arsenic	1.27E+02	8.0E-01	9.4E-06	3.0E-04	0.0312	100.0%
				Hazard Index*:	0.0312	

Intake Factor (IF) = (IR_{soil} (100 mg/day) x IF (0.45) x EF (35 days/yr) x ED (10 yrs) x 10^{-6} (kg/mg)) / (BW (47 kg) x AT (3650 days))

Dermal Contact with Fly Ash
Intake Factor (1/day): IF = 3.29E-07

Chemicals Evaluated	Surface Soil Concentration (C) (mg/kg)	Dermal Absorption (AF)	Daily Intake DI=C×IF×AF (mg/kg·d)	Reference Dose (RfD) (mg/kg·d)	Oral Absorption (O)	Hazard Quotient HQ=DI÷(RfD×O)	Percent Contribution To Hazard Index
Arsenic	1.27E+02	3.0E-02	1.3E-06	3.0E-04	9.5E-01	0.0044	100.0%
					Hazard Index*:	0.0044	

Intake Factor (IF) = (AF (0.0362 mg/cm^2) x SA (13170 cm^2/event) x SF (0.34) x EF (35 days/yr) x ED (10 yrs) x 10^{-6} (kg/mg)) / (BW (47 kg) x AT (3650 days))

*Hazard Quotients are summed, which likely overestimates total noncancer effects.

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Table 13

Summary of Total Excess Lifetime Cancer Risk for a Trespasser/Recreator

Sulfate Basins/Waste Water Treatment Plant Basins

Exposure Pathway	Cancer Risk	Percent Contribution
Ingestion of Surface Soil	9.6E-08	64.5%
Dermal Contact with Surface Soil	1.4E-08	15.1%
Inhalation of Outdoor Air	1.9E-08	20.4%
Total Cancer Risk:	1E-07	

Fly Ash Basins/Fly Ash Stockpile

Exposure Pathway	Cancer Risk	Percent Contribution
Ingestion of Surface Soil	2.0E-06	81.7%
Dermal Contact with Fly Ash	2.8E-07	17.6%
Inhalation of Outdoor Air	1.2E-08	0.8%
Total Cancer Risk:	2E-06	

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Table 14
Summary of Total Noncancer Hazard Index*
for a Trespasser/Recreator

Sulfate Basins/Waste Water Treatment Plant Basins

Exposure Pathway	Hazard Index	Percent Contribution
Ingestion of Surface Soil	0.056	98.2%
Dermal Contact with Surface Soil	0.00099	1.8%
Inhalation of Outdoor Air	N/A	
Total Hazard Index:	0.06	

Fly Ash Basins/Fly Ash Stockpile

Exposure Pathway	Hazard Index	Percent Contribution
Ingestion of Surface Soil	0.031	81.2%
Dermal Contact with Surface Soil	0.0044	18.8%
Inhalation of Outdoor Air	N/A	
Total Hazard Index:	0.04	

*Hazard Quotients are summed, which likely overestimates total noncancer effects.
N/A = Toxicity value not available for this pathway

Appendix F
Documentation to Comply with Virginia Regulations for In Place Closure of the EE/CA Units

APPENDIX F - DOCUMENTATION TO COMPLY WITH VIRGINIA REGULATIONS FOR IN PLACE CLOSURE OF THE EE/CA UNITS

9 VAC 20-80-200.D of the Virginia Solid Waste Management Regulations (VSWMR) requires that the party responsible for an unpermitted facility demonstrate that the facility will not pose a threat to human health and the environment when closed in place. The purpose of Appendix F to this EE/CA report is to present the information required by the VSWMR under Section 80-200.D to support the in-place closure of both the sulfate basins and fly ash basins and stockpile.

1.0 TYPE OF WASTE (9 VAC 20-80-200.D.1)

The VSWMR requires the following information under this section:

a. The amount, type, source and generating process of all the waste managed at the facility;

b. Information required under Part VIII of the VSWMR (titled Special Wastes) for any waste that would require a letter of clarification from the director; and

c. A statement that the waste contains no hazardous waste under the VSWMR.

Sections 2.1 and 2.3 of the EE/CA report describe the amount, type, source and generating process of the sulfate sludge and fly ash, and provide the data that indicate there are no hazardous wastes being closed in place. Pertinent information for both the sulfate sludge and fly ash is provided below.

Sulfate Sludge

Amount, type, and generating process of the waste. The Sulfate Basin Management Unit consists of six basins, identified as SB 1, 2, 3, 4, 4E and 5, that are aligned in a predominantly north-south orientation bordering the River. The SBs occupy approximately 85 acres. The basins are unlined and were used for disposal of sludge formed in the primary clarifiers and polishing basins by the neutralization of spent viscose rayon spinning bath with lime in the WWTP. Activated sludge from secondary treatment was also transferred to the Sulfate Basins after undergoing stabilization in an aerobic digester. The basins are estimated to contain 936,000 cubic yards of sludge containing approximately 20 percent (dry weight) zinc in

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the form of zinc hydroxide, zinc sulfate, and zinc carbonate. The sludge also contains gypsum ($CaSO_4 \cdot 2H_2O$), cellulose, iron hydroxide and metal oxides. Placement of sludge from the two polishing basins and the emergency lagoon will add 29,000 cubic yards of sludge to the SB closure.

Part VIII Special Wastes. Part VIII of the VSWMR addresses disposition of special wastes, including asbestos-containing waste materials, wastes containing PCBs (i.e., PCB concentrations greater than 1.0 ppm), liquids, tires, drums, white goods, soil contaminated with petroleum products, and lead acid batteries. Based on visual inspections and the 21 borings completed in the Sulfate Basins during the Phase 1 Remedial Investigation in 1993, these materials (as defined in the VSWMR) are not believed to be present in the basins.

Presence of hazardous waste. The SBs contain no listed or characteristic hazardous waste. There is no information to indicate that contaminants in the sulfate sludge were derived from a RCRA-regulated unit. Low concentrations of CS_2 in the sulfate sludge likely resulted from process wastewater discharged to the WWTP, rather than discharge of the moat water from the CS_2 storage units. Recent EPA guidance (October 1998, *Management of Remediation Waste Under RCRA*) determined that in instances where the source of contamination is uncertain, a waste should not be considered to be a listed waste.

Analytical results for waste characterization show that the zinc sludge in the sulfate basins is not a RCRA hazardous waste based on the Toxicity Characteristics. Nineteen samples of sulfate sludge were collected from the sludge and underlying soil in the SBs and WWBs during the Phase 1 RI in 1993, and analyzed for Toxicity Characteristic Leaching Procedure (TCLP) metals, cyanide and sulfide reactivity, ignitability and corrosivity testing. The metal results indicated barium was detected at concentrations ranging from 0.25 mg/l to 1.4 mg/l, which is well below the regulatory limit of 100 mg/l. There was also one trace detection of chromium and one detection of silver, both of which were well below their respective regulatory limits. All of the other characteristic results were well below regulatory limits. Additional waste characterization samples were also collected in 1997 as part of a pilot test for electrokinetic zinc recovery. These samples also indicated that the sulfate sludge is not a RCRA hazardous waste based on Toxicity Characteristics.

Fly Ash

Amount, type, and generating process of the waste. The Fly Ash Basins and Stockpile Management Unit consists of four fly ash basins (FAB-1, FAB-2, FAB-3, and FAB-6) and the fly ash stockpile. The fly ash basins and stockpile were used for disposal of fly ash generated by the combustion of coal in the on-site power plant. Fly ash was the particulate matter captured in the dust collectors at the boiler house and sluiced in water into the basins. The fly ash in the stockpile was material removed from the fly ash basins. The estimated total volume of fly ash in the four basins and the stockpile is approximately 1,305,000 cubic yards. Fly ash consists of predominately of silica, aluminum and iron oxides, with lesser amounts of calcium, magnesium, potassium, sodium, titanium oxides, and unburned carbon.

Part VIII Special Wastes. Based on visual inspections and the 19 borings completed in the FABs and FAS during the Phase 1 Remedial Investigation in 1993, VSWMR Part VIII wastes are not believed to be present in the fly ash units.

Presence of hazardous waste. The FABs and FAS contain no listed or characteristic hazardous waste. There is no information to indicate that contaminants in the fly ash were derived from a RCRA-regulated unit. Analytical results for waste characterization indicate that the fly ash is not a RCRA hazardous waste based on the Toxicity Characteristics. Four fly ash samples were analyzed for TCLP metals. The results indicate that although leachable concentrations of metals were detected (arsenic at ND-0.192 mg/l, barium at 0.758-2.3 mg/l, cadmium at ND-0.026 mg/l, chromium at ND-0.021 mg/l, lead at ND-0.14 mg/l, and selenium at 0.063-0.067 mg/l), the concentrations in leachate derived from the fly ash were below the respective regulatory limits.

2.0 *COMPLIANCE WITH SITING RESTRICTIONS (9 VAC 20-80-200.D.2)*

The VSWMR requires that the responsible party of the unpermitted facility submit documentation from a registered professional engineer that closure of the facility in place will comply with applicable siting requirements of Part V of the VSWMR. Information regarding the following criteria is required:

a. Airport safety;

b. Floodplains;

c. Unstable areas;

d. Wetlands;

d. Fault areas;

e. Seismic impact zones;

f. Setbacks from surface waters, facility boundaries, sources of drinking water, public road right-of-ways, residences, schools, hospitals, nursing homes, or recreational park areas;

g. Ability to conduct ground water monitoring;

h. Engineering controls to address site specific characteristics that might prevent approval or require limitations on the site.

Pertinent information addressing each of these siting restrictions for both the sulfate sludge and fly ash is provided below.

Sulfate Basin Closure

Airport safety. This VSWMR siting criterion related to airport safety are applicable to sanitary landfills where bird hazards to aircraft are a concern. Therefore, this siting requirement is not applicable to the in place closure of the SBs.

Floodplains. This VSWMR siting criterion requires that owner/operators of landfills located within the 100-year floodplain demonstrate that the facility will not restrict the flow of the 100-year flood, reduce the temporary storage capacity of the floodplain, or result in washout of the solid waste so as to pose a hazard to human health and the environment.

The SBs will be closed within the boundary of the 100-year floodplain. However, the analysis presented in the EE/CA report and Appendix B indicate that the siting criteria will be met and exceeded. The conceptual design includes the reduction of the final elevations of the basins, which increases the flow of the 100-year flood, and increases temporary storage capacity of the floodplain. Flood modeling presented in Appendix B shows that flood flow velocities calculated for this area are sufficiently low (<3.5 fps) that the final vegetated cover would not be eroded by the flow of a 100-year flood. Therefore, the sulfate sludge will not be washed out during a flood, and will not pose a threat to human health and the environment.

Unstable Areas. The VSWMR define unstable areas as areas where local soil, geologic, or man-made features may result in differential settling, sudden or non-sudden events, and subsequent failure of structural components. Unstable areas can include poor foundation conditions, areas susceptible to mass movements, and karst conditions. This VSWMR siting criterion requires that new landfills being placed in unstable areas must demonstrate that engineering measures have been incorporated into the structural components of the facility to compensate for the unstable area. Rader and Webb (1979) report that the Martinsburg Formation that underlies by the SBs provides foundation stability and is not subject to karst conditions. Therefore, the sulfate basins are not located atop an unstable area, as defined by the VSWMR, and this siting criterion does not apply to the closure of the SBs.

Wetlands. This VSWMR siting criterion states that new landfills shall not be located in wetland areas. According to the wetland delineation conducted by Gannett Fleming (1994), the sulfate basins are not wetlands, therefore this siting criteria does not apply to the closure of the basins.

Fault Areas. This VSWMR siting criterion states that new landfills shall not be located within 200 feet of a fault that has had displacement within Holocene time unless it can be demonstrated that the structural integrity of the facility will be protective of human health and the environment. Geologic mapping of the area conducted by Rader and Biggs (1975) indicates that the closest fault to the Site is located over a mile from the SBs, therefore this siting criterion is met for the closure of the SBs.

Seismic Impact Zones. This VSWMR siting criterion states that new landfills shall not be located in seismic impact zones, unless they are designed to maintain their structural integrity. The VSWMR definition for a seismic impact zone is "an area with a 10% or greater probability that the maximum horizontal acceleration in lithified earth material, expressed as a percentage of the earth's gravitational pull (g), will exceed 0.10g in 250 years." By this definition, most of Virginia is within a seismic impact zone. The maximum horizontal acceleration in lithified earth material for the Front Royal area is between 0.15g and 0.20g, as reported by Algermissen *et al* (1990). Therefore, the closed SBs will be designed to maintain their structural integrity.

Setbacks. This VSWMR siting criterion states that new landfills shall not extend closer than:

- 100 feet of a regularly flowing surface water body or river;
- 50 feet from the facility boundary;
- 500 feet from a ground water drinking water source;
- 1,000 feet from a primary highway and 500 feet from a city street; and
- 200 feet from a residence, school, hospital, nursing home or recreational park.

The in place closure of the SBs will meet the applicable setback requirements.

Ground water monitoring. This VSWMR siting criterion states that new landfills shall not located in areas where ground water monitoring cannot be conducted in accordance with 9 VAC 20-80-250.D. This section of the VSWMR requires that the monitoring system consist of the sufficient number of wells at appropriate depths, capable of yielding samples from the uppermost aquifer. The samples must represent background water quality unaffected by the landfill, and the quality of ground water at the unit boundary. Ground water monitoring conducted in the area upgradient and downgradient of the SBs during the Phase 1 RI indicate that these requirements can be met.

Engineering Controls. This VSWMR siting criterion states that the following site characteristics may require substantial limitation or incorporation of sound engineering controls:

- Excessive slopes;
- Lack of available soil cover;
- Seeps, springs or other ground water intrusion into the site;
- Presence of linear infrastructure facilities, such as a gas or electric line under the site; and
- Prior existence of an open dump or unpermitted landfill on the site.

None of the site characteristics are present within the area occupied by the SBs, therefore this siting criterion does not apply to the closure of the SBs.

Fly Ash Unit Closure

Airport safety. For the reason discussed above previously, this siting requirement is not applicable to the in place closure of the fly ash units.

Floodplains. The fly ash units are not located within the boundary of the 100-year floodplain, therefore this siting requirement does not apply to the closure of the fly ash units.

Unstable Areas. For the reasons discussed above, the fly ash units are not located atop an unstable area, as defined by the VSWMR, therefore this siting criterion does not apply to the closure of the SBs.

Wetlands. The fly ash basins contain low value, manmade wetlands. The EPA Ecological Risk Assessment (Sprenger et al, 1999) determined that exposure to the fly ash posed a risk to terrestrial biota. Consequently, the EE/CA report concluded that a response action to mitigate this exposure is warranted, and that response action should consist of covering the FABs with soil. Therefore, this siting criterion does not apply to the closure of the fly ash units.

Fault Areas. Geologic mapping of the area conducted by Rader and Biggs (1975) indicates that the closest fault to the Site is located over a mile from the fly ash units, therefore this siting criterion is met for the closure of the fly ash units.

Seismic Impact Zones. The maximum horizontal acceleration in lithified earth material for the Front Royal area is between 0.15g and 0.20g, as reported by Algermissen *et al* (1990). Therefore, the closed fly ash units will be designed to maintain their structural integrity.

Setbacks. This VSWMR siting criterion states that new landfills shall not extend closer than:

- 100 feet of a regularly surface water body river;
- 50 feet from the facility boundary;
- 500 feet from a ground water drinking water source;
- 1,000 feet from a primary highway and 500 feet from a city street; and
- 200 feet from a residence, school, hospital, nursing home or recreational park.

The in place closure of the fly ash units will meet the applicable setback requirements. Although the closure of FAB 6 will be within 500 feet of a city street, the VSWMR allows for units to be screened by plantings so the unit will not be visible from a city street. The existing vegetation along the railroad tracks adjacent to FAB 6 will meet the requirement for a vegetative screen.

There are multiple residential housing units located within 500 feet of the southeast portion of FAB 6. Based on a survey of water supply wells conducted by the State Water Control Board (SWCB) in support of the 1988 Geraghty and Miller RI Report (1988), there were no reported ground water drinking water sources within 500 feet of FAB 6. Further, is not expected that these residences have installed water supply wells since the time that the SWCB survey was completed because water is available from the Town of Front Royal. Therefore, this setback requirement as it relates to the in place closure of the fly ash units will be met.

Ground water monitoring. Ground water monitoring conducted in the areas upgradient and downgradient of the fly ash units during the Phase 1 RI indicate that this siting requirement can be met.

Engineering Controls. None of the site characteristics listed in the previous section are present within the area occupied by the fly ash units, therefore this siting criteria does not apply to the closure of the fly ash units.

Statement of Compliance with VSWMR Siting Requirements by a Professional Engineer

Ms. Carol Young is currently a registered professional engineer in the Commonwealth of Virginia (registration number 026152). Ms. Young is familiar with the engineering aspects of the flood plain modeling presented in Appendix B of the EE/CA report, and is knowledgeable of the conditions at the Site. By signing below, Carol Young believes that in her professional judgement the documentation presented above indicates that the in place closure of the SBs, FABs, and FAS will comply with the applicable siting requirements of Part V of the VSWMR.

Ms. Carol Young, P.E.

3.0 CERTIFICATION (9 VAC 20-80-200.D.3)

The VSWMR requires that a professional engineer or qualified ground water scientist certify in his professional judgement that the waste can be left in place without posing a threat to human health and the environment. 9 VAC 20-80-10 defines a qualified ground water scientist as "a scientist who has received a degree in the natural sciences and has sufficient training and experience in ground water hydrology and related fields as may be demonstrated by state registrations.... that enable the individual to make sound judgements regarding ground water monitoring, contaminant fate and transport, and corrective action."

Mr. Robert Keating, P.G. is a qualified ground water scientist for the purpose of providing the required certification. Robert Keating holds both a baccalaureate and post-graduate degree in geology, is certified currently as a professional geologist in the Commonwealth of Virginia (license number 2801 000722), and has over 15 years of professional experience in the practice of ground water monitoring and contaminant fate and transport. Robert Keating directed the preparation of the EE/CA report and the Phase 1 RI conducted in 1993 at the Site, and is therefore knowledgeable of the hydrologic conditions at the Site.

The certification that the SBs, FABs and FAS can be closed in place without posing a threat to human health and the environment is based on the following reasons. More detail for each reason is presented in the EE/CA report.

- The risk assessment prepared by Gradient Corporation and presented in the EE/CA report indicates that there are no unacceptable risks to human health from exposure to the sulfate sludge or fly ash associated with trespassing activities.
- The findings of the risk assessment indicate that there will be no unacceptable risk to human health in the future from exposure to the sulfate sludge and fly ash due to recreational use, which is the proposed future site use.
- Based on the baseline ecological risk assessment prepared by EPA, it was concluded that potential ecological risks exist at the Site based on the compounds evaluated under current conditions with the waste material. The proposed response action, consisting of covering the sulfate sludge and fly ash as part of the in place closure, will mitigate the potential ecological risk.
- The sulfate sludge and fly ash need to be contained on the Site to prevent migration during weather events, the most important of which is flooding of the River. Metals in the sulfate sludge, especially zinc, are toxic to fish, therefore, there is a potential risk to fish in the event that future flooding releases sludge to the River. The response action will mitigate the exposure of ecological receptors to the exposed sludge in the basins or to sludge released to the River during flooding.
- Ground water data showed that the sludge and fly ash were not leaching trace metals into the underlying ground water at concentrations that pose an unacceptable risk to human health or ecological receptors.

By signing below, Robert Keating certifies that in his professional judgement, for the reasons stated above, the sulfate sludge and fly ash could be left in place without posing a threat to human health and the environment.

Mr. Robert Keating, P.G.

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