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FEASIBILITY AND CONCEPTUAL REMEDIATION DESIGNS FOR PRIORITY CONTAMINATED MINE DRAINAGE SITESIN THE BIG SOUTH FORK NATIONAL RIVER AND RECREATIONAL AREA, KENTUCKY

PHASE III DRAFT REPORT

Gannett Fleming
ENGINEERS AND PLANNERS

January 1998

207 Senate Avenue, Camp Hill, Pennsylvania, 17011 • (717) 763-7211

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ENGINEERS AND PLANNERS

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February 17, 1998

Mr. Steven Bakaletz
Big South Fork National
River & Recreation Area
Route 3, Box 401
Oneida, TN 37841

Subject: Feasibility and Conceptual Remediation Designs for Priority Contaminated Mine Drainage Sites in the Big South Fork National River and Recreation Area, Kentucky
Phase III Draft Report

Dear Mr. Bakaletz:

Enclosed please find the above mentioned report. Note that this is a draft and we have prepared it in black and white. Color will be added in the final report to all pages with photographic plates and to figures where appropriate and beneficial. We will wait for your technical review and re-issue this report within 30 days from receipt thereof.

Sincerely,

GANNETT FLEMING, INC.

Jonathan M. Dietz
Environmental Scientist

Enclosure

cc: Mr. Gary Rosenlieb, w/enclosure
cc: Mr. David Hyman, w/enclosure

FEASIBILITY AND CONCEPTUAL REMEDIATION DESIGNS FOR PRIORITY CONTAMINATED MINE DRAINAGE SITES IN THE BIG SOUTH FORK NATIONAL RIVER AND RECREATION AREA, KENTUCKY

PHASE III DRAFT REPORT

Prepared For:

National Park Service
Southeast Region
Atlanta, Georgia 30303

Prepared By:

Gannett Fleming
ENGINEERS AND PLANNERS

January 1998

207 Senate Avenue, Camp Hill, Pennsylvania, 17011 • (717) 763-7211

EXECUTIVE SUMMARY

Conceptual remediation designs were developed for priority abandoned coal mining sites that are contributing contaminated mine drainage to the Big South Fork National River and Recreation Area (BSFNRRA). Conceptual remediation designs were developed for 13 individual discharges/sites using a variety of passive treatment technologies and reclamation techniques. Preliminary cost estimates were prepared based on the conceptual remediation designs for each of the sites. Anticipated water quality from the proposed remediation designs vary from compliance of the effluent with ambient water quality criteria (AWQC) and protection of sensitive species (EC_{20}) to compliance of the Big South Fork River with ambient water quality criteria (AWQC) and protection of sensitive species (EC_{20}).

- Based on assessment and prioritization previously completed by SSP and presented in

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LIST OF ACRONYMS

ALD	Anoxic Limestone Drain
AML	Abandoned Mine Lands
AWQC	Ambient Water Quality Criteria
BSFNRRA	Big South Fork National River and Recreation Area
BMP	Best Management Practices
CMD	Contaminated Mine Drainage
EC_{20}	Oak Ridge National Laboratory Water Quality Criteria for Near Complete Protection of Sensitive Aquatic Species
GPS	Global Positioning Survey
OLC	Oxic Limestone Channel

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S. S. PAPADOPULOS & ASSOCIATES, INC.
ENVIRONMENTAL & WATER-RESOURCE CONSULTANTS

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To Gary Rosenlieb	From Jim Lolcama	
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Memo

To: Gary Rosenlieb, NPS - Water Resources Division

From: Jim Lolcama, SSP&A

Subject: Response to Comments on SSP&A Phase II Report on CMD Characterization, BSFNRRA

Date: March 10, 1998

CC: Steve Bakaletz, NPS - Oneida, TN
David Hyman, FETC - Pittsburgh, PA

SSP&A has reviewed the comments received March 3 on the Phase II Draft Report. We appreciate the careful review that the report received by all reviewers. Several of the comments referred to the work of Gannett Fleming and so their input on resolving these issues was solicited. SSP&A will move forward with producing the final report immediately, according to the following plan. The plan that we are proposing will not be to everyones' liking, but a few concessions will be needed on both of our parts. Our goals are to produce two highly useable final reports from SSP&A and Gannett Fleming, to maintain a high technical standards in their production, while trying to minimize a serious and growing budget shortfall.

1. Seaming of the Phase I, II, and III Reports: SSP&A will incorporate a written overview of the Phase I results into the Phase II report. This will include an inventory of the Phase I sites, and a map showing the locations of sites and their Type-designation, as an Appendix. We ask that the NPS not expect the Phase II and Phase III reports to be seamed together under one report, for reasons of the amount of time that would be required to re-edit and re-write the reports into a single report format. Our budgets cannot support this work.

2. Further Discussion of the Toxicity: SSP&A will append the section on Downstream Toxicity Index (DTI) with text relating the results to numbers of exceedences by chemical constituents. This will provide a more relevant discussion for management.

3. Algorithms: The algorithms do have a basis of application, and this will be introduced in the text.

1.1.3 Mine Seals

Mine seals are used to exclude passage of air to the deep mine preventing oxygen from contacting acid-producing minerals where CMD can be produced. They are also used to prevent or control the flow of water at deep mine openings. Mine seals can be either dry or wet and are used for sealing slope entries, drift entries, shafts, and boreholes that are opened to deep mine workings. They are often constructed as a safety precaution to prevent entrance to open mine entrances by individuals and to control the escape of methane gas.

Dry Seals - Dry seals are placed in openings to prevent air and water passage into the mine. These seals are suitable for openings where there is no discharge water flow that can result in hydrostatic pressure and failure (blow-out) of the mine seal. Dry seals are often constructed on vertical shafts that were built into mine workings to provide ventilation and access.

Wet Seals - Wet seals are designed to prevent the passage of air into the mine while allowing normal mine discharge to flow through the discharge outlet. The discharge outlets in the wet seal are provided with air traps to prevent inflow of air. Wet seals can also be designed to control the discharge flow from a mine opening and are often used in combination with treatment systems.

Hydraulic Wet Seal - A variation to the wet seal is a hydraulic seal which prevents air and water flow in either direction. The intent of the hydraulic seal is to flood the mine workings saturating the acid-producing materials in an anoxic environment, thereby reducing the formation of CMD and preventing it from discharging from the mine workings. Failure of a hydraulic seal can result in catastrophic impacts to receiving waters and could potentially be a safety hazard. As a result, this seal is only a viable alternative where hydraulic pressures are nominal (e.g., less than 50 feet).

1.1.4 Subsurface Injection

Subsurface injections are used in underground mines, spoil materials and refuse piles. Typical uses are as follows:

Deep Mine Injection - Surface subsidence of abandoned underground mines is typically stabilized by injection of cementacious materials at the mine level to fill mine voids. Injected materials will often prevent subsidence and has recently been found to inhibit CMD production. Fly ash is often used for this purpose because of its relatively low cost, flowability, natural pozalonic properties and alkaline characteristics. Filling of the mine void will provide support to the overburden, act as hydraulic barriers to flow in the mine, and add alkalinity to contact water. In certain conditions, injection of concrete and limestone gravel columns is employed for roof support of the mine from the surface through boreholes. The technique is currently under investigation for its potential water quality benefits because of the reactivity of the highly

alkaline injection material with water in the deep mine complex, thereby inhibiting CMD production and/or neutralizing CMD in the deep mine pool.

Overburden Grouting - Pressurized grouting of rock and soil overburden can be performed to consolidate materials and fill fractures. Overburden grouting can provide additional stability to the overburden, but is primarily used to limit groundwater flow and prevent infiltration. Overburden grouting can be performed using various cement or chemical grouts, depending on applications and conditions.

Toxic Material Encapsulation - Fly ash or other materials can also be injected into mine spoils and refuse materials to encapsulate pockets containing high acid-producing materials. This will reduce acid output by buffering the pyrite oxidation reactions and inhibiting water from contacting the acid-producing minerals.

1.1.5 Bacterial Inhibitor Application

Bacterial inhibitors can be applied to mine spoil to lower acid production by killing the bacteria *(Thiobacillus ferroxidans)* known to be critical in the catalytic pyrite oxidation process. The bacterial inhibitors include bactericides, detergents and organic sludge. This technique is most frequently used in situations where immediate control of CMD formation is important. This BMP is temporary and without frequent application the CMD formation will reoccur.

1.2 Chemical Treatment of Mine Drainage

Chemical treatment of mine drainage can be used solely or in conjunction with site reclamation BMPs, if reclamation is inadequate to eliminate the production of mine drainage. Conventional chemical treatment systems use mechanical feeders, mixers and settling basins in various combinations to provide CMD treatment. Different chemicals are used for treatment in these systems depending on various factors such as water chemistry, effluent requirements, handling and material costs, site conditions and treatment duration. Systems are typically classified based on the chemical used for treatment. Four chemicals are typically used in treating CMD: calcium carbonate (limestone), calcium hydroxide (hydrated lime), sodium carbonate (soda ash or briquettes) and sodium hydroxide (caustic soda). Anhydrous ammonia is also being used to a limited extent to treat CMD. The four typical treatment chemicals can be evaluated by their basic components, i.e. calcium vs. sodium and carbonate vs. hydroxide.

1.2.1 Calcium vs. Sodium

Calcium compounds (e.g., $CaCO_3$ and CaO) are typically less expensive than sodium compounds (e.g., NaOH), but have slower reaction rates. They are also easier to handle and require few safety precautions. Subsequently, they are usually used in large treatment systems along with aeration and mixing units. Conversely, sodium compounds are very reactive and typically used in short term applications or remote locations.

1.2.2 Carbonate vs. Hydroxide

Lower

The pH of the water during treatment has a significant role in the effectiveness of a particular chemical compound for CMD treatment. Carbonate compounds can be limited in their ability to raise the pH, usually less than 9, sufficiently neutralize acidity and precipitate metals; some metals, e.g., manganese, require pH greater than 10 for precipitation to occur rapidly and to low concentrations. Hydroxides can easily raise the pH of treated water to 10 or higher permitting precipitation of these type of metals. However, over application of these compounds can produce an unwanted effect, releasing soluble metal hydroxides and caustic water that is toxic to aquatic life. The relationship between pH and the occurrence and precipitation of most metals in CMD affected waters will often dictate the choice of the treatment chemical.

1.3 In Stream Alkaline Addition

In stream alkaline addition systems are relatively new treatment techniques in which limestone aggregates are mechanically abraded to provide slurry dosing directly to CMD affected streams. These systems are usually designed to provide only alkalinity addition to neutralize acidity in affected waters and typically do not provide for metal removal.

1.3.1 Diversion Well Systems

The diversion well is a limestone dosing system designed to add alkalinity through a fluidized bed of limestone. Fluidization occurs through a cylindrical well filled with crushed limestone aggregate that receives water through an influent pipe at the bottom of the well. The influent water has sufficient head to rise upward through the well, fluidizing the aggregate and forcing abrasion and dissolution of the limestone. Water from the well is then discharged over the lip of the well and back to the source. Head is provided by constructing an impoundment upstream from the well and diverting water through a pipe to the base of the well.

1.3.2 Rotary Drum Systems

Rotary drum limestone slurry dosers are water powered cylindrical containers filled with limestone aggregate. The water for the system is diverted from the stream and rotates the drums where the limestone is ground and mixed into a fine slurry. The slurry is then reintroduced and mixed with the stream water. The system can be adjusted to maintain dosing and water quality goals during various levels of flow, however, design and operation can be limited by minimum flow requirements (depending on the amounts of limestone and number of drums used). The system also requires construction of an impoundment on the watercourse.

1.3.3 Limestone Fine Dosing

Limestone fine dosing is a relatively new and inexpensive treatment method that arose from the drum system technology (Zurbuch *et al.* 1997). The system uses sand sized limestone

particles that are "dumped" into streams at strategic points in affected watersheds. The fines are then carried through the stream course and mixed in with the stream substrate. Since trucks are used to transport the limestone to the application sites, this treatment type requires good access and roads in a treatment area. Given the dynamic and unpredictable nature of stream flows, it is unclear if limestone fines can provide consistent, long term neutralization in CMD affected streams. Limestone fines would have to be applied at least once per year, and possibly more frequently.

1.4 Passive (Wetland) Treatment

Passive systems for the treatment of CMD represent a number of viable treatment technologies which have been developed within the last fifteen years. Passive systems use a variety of substrates, plants, and hydraulic/hydrologic designs to remediate mine drainage via a number of chemical (e.g., precipitation, oxidation, and hydrolysis) and biological processes (e.g., microbial oxidation and reduction). The various passive treatment designs are capable of lowering metal concentrations (e.g., aluminum, iron, manganese and trace metals) and/or acidity from the mine drainage. Subsequently, these systems can provide long term, low maintenance treatment and stream restoration.

Four passive treatment methods are typically appropriate for consideration with mine drainage discharges. These methods are the aerobic surface flow wetlands, anaerobic surface flow wetlands, vertical flow wetland and anoxic limestone drain. A brief description of each system is provided below. Figure 1 provides a schematic profile and Table 1 lists the design limitations of each system.

1.4.1 Aerobic Surface Flow Wetlands

Aerobic surface flow wetlands are systems normally employed to oxidize, hydrolyze and precipitate metals (e.g., iron and manganese) from alkaline mine waters. This type of system has also been successful at decreasing metals in acidic mine drainage; although rates of removal require substantially larger surface areas. Aerobic wetlands employed by Brodie (1993) contain open water and emergent vegetation (e.g., cattails and rushes) planted in inert soils. Recently constructed systems evaluated by Hedin *et al.* (1994) and by Dietz (1993) have employed inert stone as the only substrate and have been successful at removing manganese in alkaline discharges and iron from acidic mine waters.

1.4.2 Anaerobic Surface Flow Wetlands

Anaerobic surface flow wetlands are systems that have been successful at removing metals (i.e., aluminum and iron), similar to aerobic surface flow wetlands, and have also had limited success at reducing acidity from mine waters (Hedin *et al.* 1994; and Dietz *et al.* 1993b). Anaerobic surface flow wetlands contain an organic substrate (e.g., spent mushroom compost) planted with emergent vegetation and variable standing water from one inch to one foot. A number of processes including oxidation, sulfide precipitation, hydrolysis, and absorption have

been suggested as being important in metal removal within this type of system. Microbial sulfate reduction has been identified as the principal process producing alkalinity.

1.4.3 Vertical Flow Wetlands

Vertical flow wetlands, also known as alkalinity producing systems, are a relatively recent development in passive treatment technology to remediate acidic mine waters. This type of wetland has achieved substantial acidity removal and alkalinity production for applications in highly acidic (greater than 200 mg/L as $CaCO_3$)mine waters (Dietz and Stidinger 1996; and Kepler and McCleary 1994). This wetland design has also been successful in removing iron and aluminum from highly acidic mine waters. Vertical flow wetlands consist of an organic substrate layer (e.g., spent mushroom compost) placed over a limestone layer. An underdrain piping system placed beneath the limestone layer collects the water that has passed through the substrate layers. The systems can be provided with a bypass system which allows medium to large flows to bypass the underdrain system and mix with treated waters later in the system. Vertical flow wetlands may or may not be planted with emergent vegetation and contain standing water from less than one, to greater than three feet. Processes previously mentioned for anaerobic surface flow wetlands, as well as limestone dissolution, have been identified as important mechanisms of mine water remediation in vertical flow wetlands. A typical section of a vertical flow wetland embankment and bypass system is provided as Figure 2.

1.4.4 Anoxic Limestone Drains

Anoxic limestone drains (ALDs) have been used almost exclusively in remediating CMD. ALDs studied by Hedin *et al.* (1994) and Brodie *et al.* (1991) have produced substantial alkalinity which is important in neutralizing acidity and in the hydrolysis and precipitation of iron and aluminum, although ferric iron (greater than 2 mg/L) and aluminum (greater than 5 mg/L) have been found to be detrimental to the long term performance of ALDs. The systems consist of trenches or basins filled with limestone that are sealed and buried to prevent oxygenation of the mine drainage that can cause armoring of the limestone and/or clogging of the ALD. Mine drainage passes through the trench or basin where calcium carbonate is solubilized from the limestone producing the alkalinity responsible for neutralization of mine water acidity and precipitation of iron and aluminum. ALDs are typically used in combination with aerobic and anaerobic surface flow wetlands which hydrolyze and precipitate iron from the CMD.

1.4.5 Oxic Limestone Channels

Oxic limestone channels (OLCs) are a relatively recent development in passive treatment technology that has been found to improve pH and remove iron and aluminum from CMD discharges (Ziemkiewicz *et al.* 1996). The technology uses an a conventional channel design containing high quality limestone rip rap through which the CMD is directed. Ziemkiewicz *et al.* evaluated a number of constructed channels and found the OLCs to neutralize acidity and precipitate iron and aluminum in the CMD which the investigators attributed to limestone

solubilization, even in the presence of armoring. However, none of the OLCs studied completely removed acidity nor provided an effluent with low metal concentrations. Therefore, this technology should be considered for sites that are not suitable for any other passive treatment option.

1.5 Implications of Toxic Metals on Selection of Remediation BMP

of aluminum, iron, and mangan

CMD most commonly contains high concentrations, in excess of 1 mg/L, of three metals which are aluminum, iron and manganese. CMD will also contain various levels of other trace metals that are contained in minerals associated with coal, spoil materials, and contact rock strata. The trace metals can be released by a number of process including oxidation of sulfide minerals, solubilization by the low pH associated with CMD, and cation exchange processes for soluble iron in the CMD. A number of trace metals including arsenic, chromium, copper, lead and zinc were detected in samples collected from CMD discharges in the BSFNRRA.

Ambient water quality criteria (AWQC) to protect aquatic life have been established by the U.S. Environmental Protection Agency (U.S. EPA) for trace metals (U.S. EPA 1986), summarized in Table 2 for the 10th percentile of the average hardness reported for the Big South Fork River. Use of this infrequent hardness should result in AWQC concentrations that are very protective of aquatic life in the Big South Fork River, particularly since hardness is typically flow dependent, with low hardness concentrations occurring during higher flows that have greater dilution for CMD inputs. Table 2 also contains the lowest observed chronic toxicity values for daphnids (a known sensitive species), as reported in the individual water quality criteria documents, and concentrations for near complete protection of sensitive aquatic species (EC_{20}). The lowest observed chronic daphnid values for the toxic metals closely approximate the low hardness AWQC, except for lead, which is about an order of magnitude greater because the AWQC incorporates a bioaccumulation factor. The reported EC_{20} concentrations are less than the AWQC for all toxic metals and in some cases are an order of magnitude lower, e.g., cadmium, chromium (III) and copper. The EC_{20} values are estimated from a number of biological indicators, such as breathing rates (i.e., gill movements) and histopathological changes, that may only be indirectly related to survival, growth and/or reproduction effects on individuals or populations. The EC_{20} values may be restrictive for the BSFNRRA without sound basis.

Table 2 also contains the lowest reported detection limits from the Phase I and II studies in the BSFNRRA. The detection limit for cadmium is greater than all three benchmark concentrations, the detection limits for copper is greater than the EC_{20} benchmark, and the detection limit for lead is greater than the AWQC and EC_{20} benchmarks. This could be a complicating factor for the treatment technology selection process and for evaluating potential effluent quality of the conceptual designs with the benchmarks, particularly where concentrations for a CMD station are below the detection limits for the above parameters. In such cases, CMD concentrations for the above parameters will be evaluated based on other detected trace metals, e.g., zinc and copper; copper and zinc are the two toxic trace metals most frequently encountered in CMD in the BSFNRRA. Effluent quality for the above parameters will be evaluated using estimated removal for a surrogate parameter; zinc will be used because it is typically found at concentrations well above detection limits when other trace metals are not detected. This

approach was developed based on a study by Unz and Royer (1997) that found influent zinc concentrations and percent removal in CMD wetland treatment systems to strongly correlate with other trace metals including copper.

The National Park Service has established a number of goals for the remediation projects developed to address the CMD discharges based on removal of elevated toxic metals (e.g., copper and zinc) which are present in a number of the CMD discharges located in the BSFNRRA. The remediation performance goals are, in order of priority:

to meet

1. Compliance with the EC_{20} benchmark at the effluent from the remediation project;

2. Compliance with the EC_{20} benchmark within the Big South Fork River;

3. Compliance with AWQC at the effluent from the remediation project; and

4. Compliance with AWQC within the Big South Fork River.

The control BMPs applied at the source (discussed above in Section A) can have beneficial effects on CMD discharge flow and/or decreases in the CMD strength (Robertson and Barton-Bridges 1990); however, there are no studies available that evaluate the long term effect of control at source BMPs on trace metal concentrations. The incremental decreases in CMD flow though water control would likely have corresponding decreases in toxic metal loading to the Big South Fork River unless the CMD strength increased proportional to the decrease in flow; a possibility given the longer retention time within the spoil. A decrease in CMD strength (i.e., pH and acidity) from site remediation should result in a corresponding decrease in concentrations of toxic metals because low pH and high iron and aluminum are the likely causes of trace metal solubilization from contact minerals. Using information contained in Robertson and Barton-Bridges (1990) and other sources, compliance with the above criteria will be qualitatively assessed to evaluate beneficial effects of this type of BMP on toxic metal loading decreases and water quality improvements.

Trace metal removal has been documented for active chemical treatment systems where the pH is increased with chemical agents such as sodium hydroxide (Watzlaf 1988; and Going 1980). The majority of trace metals (copper, zinc and chromium) will co-precipitate with iron oxides as the pH approaches neutrality which can be achieved using a number of chemicals, e.g., hydrated lime ($CaO \cdot nH_2O$). Some trace metals (e.g., manganese and nickel) were found to require pH above 8 for complete precipitation which would require more caustic chemical agents, e.g., sodium hydroxide (NaOH), to achieve this elevated pH. However, the stability of the trace metals in the sludge is of concern since Watzlaf (1988) indicates the trace metals are re-solubilized if the pH decreases to less than 6.5. The Watzlaf (1988) study found that chemical treatment achieved greater than 90 percent removal for most trace metals which will be used to evaluate effluent quality where this technology is selected to remediate a CMD discharge.

Trace metal removal in wetland treatment systems has been documented by a number of investigators. Eger and Lapakko (1989) found natural wetlands to reduce concentrations of

nickel by 80 percent and copper to less than analytical detection limits in mine drainage from tailings and stockpiles associated with a mineral mining operation. In a subsequent project, Eger *et al.* (1994) found a constructed wetland treatment system to successfully lower nickel, copper, cobalt and zinc from a neutral mine drainage. In a laboratory study using wetland sediments, Fyson *et al.* (1994) reported enhanced arsenic and nickel removal in sediments amended with organic substrates which was concluded due to development of anaerobic conditions.

Two recent studies by Sikora *et al.* (1996) and Rightnour and Hoover (1997) examined trace metal removal employing multi-unit systems. Sikora *et al.* (1996) found pilot-scale anaerobic wetland units containing an organic compost substrate to effectively remove copper, nickel, lead and zinc as sulfides, typically greater than 99 percent reductions, from simulated CMD; trace metal removal was substantially lower in wetland units that did not contain the organic substrate and only anoxic or aerobic conditions. Sikora *et al.* (1996) reported effluent concentrations for the trace metals that were in or near compliance with AWQC. Rightnour and Hoover (1997) evaluated trace metal removal in a full-scale system containing organic substrate units that was constructed to treat leachate from a fly-ash disposal site. The results indicate the system effectively lowered a number of trace metals, including arsenic, nickel and zinc by as much as 93 percent with resulting effluent concentration near or less than AWQC.

The importance of the organic substrate and reducing environments at removing divalent metals, e.g., iron, copper and zinc, is demonstrated by the following reaction in which sulfide and the metal form an insoluble metal sulfide:

$$H_2S + M_{etal}^{2+} \rightleftarrows M_{etal}S + 2H^+$$

The effectiveness of sulfide in the removal of trace metals to very low concentrations is supported by the experimental solubilities for metals (Stumm and Morgan 1981):

- Iron: log $K_{@\,25°C}$ = -18.1
- Zinc: log $K_{@\,25°C}$ = -24.7
- Lead: log $K_{@\,25°C}$ = -27.5
- Copper: log $K_{@\,25°C}$ = -36.1

were the more negative the value, i.e., log $K_{@\,25°C}$, the lower the solubility. The low metal solubilities indicate anaerobic environments supporting sulfate reduction can be effective at lowering trace metal concentrations present in the CMD to levels in compliance with the benchmark criteria established for the BSFNRRA remediation projects. However, trace metal removal design guidance and field-scale performance for anaerobic wetland treatment systems is not currently available in the literature. Therefore, design of the systems will be based on known design guidance (e.g., hydraulic loading and iron or acidity removal rates), and effluent trace metal levels will only be qualitatively evaluated for compliance with the benchmark criteria.

1.6 Remediation Evaluation for Priority Sites

The reconnaissance and monitoring program identified a number of priority sites contributing to water quality degradation of the Big South Fork River. A global positioning survey (GPS) study was conducted at each of the priority sites to determine areas where the point or multi-point source discharges could be treated or the extent of mine spoil generating the diffuse mine drainage. Figure 3 shows the locations of the priority sites in the BSFNRRA and the GPS surveyed areas. The remediation evaluation for each priority site included:

- Identification and selection of the most appropriate remediation approach;
- Development of a conceptual designs for the identified remediation approach;
- Estimation of preliminary construction costs for the identified remediation approach; and
- Evaluation of anticipated effluent water quality from the remediation approach with respect to the benchmark criteria.

Each site is individually discussed below according to their ranking in the Phase II Report. A certain amount of redundancy occurs in the site evaluations which was necessary to have each site be a stand-alone document. This approach will ease the extraction of individual sites from the document if the National Park Service selects only one or several sites for remediation.

2.0 ROARING PAUNCH CREEK

The Roaring Paunch Creek site contains four separate CMD discharges that contribute pollutants indirectly to the Big South Fork River through Roaring Paunch Creek (Figure 3). Three of the discharges, station numbers SSPII RP02, SSPII RP03 and SSPII RP04, are point discharges from collapsed mine entrances or portals that are located on private land in the Barthell Mine area, a historic mining town currently under restoration (Figure 4). The fourth discharge, station number SSPII BTH03, is a diffuse discharge that emanates from the cut slope along the access roadway to Blue Heron Recreation Area and is conveyed via a stormwater culvert to Roaring Paunch Creek. The discharges will be discussed separately below.

Water quality data at the mouth of the Roaring Paunch Creek from the Phase I and II monitoring program was summarized in the Phase II Report. The monitoring results indicate pH varied from 6.5 to 7.4, contains alkalinity in excess of 20 mg/L as $CaCO_3$, and no detectable acidity. Aluminum, manganese were present in Roaring Paunch Creek at concentrations less than 0.1 mg/L, and iron was typically less than 1 mg/L. Zinc was the only trace metal detected in all samples but at concentrations less than 0.01 mg/L. Copper and lead were detected in several samples but at concentration near analytical detection limits.

2.0.1 Barthell Mines Site No. 1 (SSPII RP02)

The Barthell Mines Site No. 1 (SSPII RP02) discharge, is the largest mine drainage input, 25 to 50 gpm, to the Roaring Paunch Creek in the vicinity of the BSFNRRA. The discharge depicted on Plate 1 emanates from a collapsed mine entry located just north of the mining town along the railroad (see Figure 4). As can be seen, this discharge is located in close proximity to a reconstructed building in Barthell. Water quality data from the discharge sampling location from the Phase I and II monitoring program are summarized in Table 3. The monitoring results indicate pH is typically less than 3 with acidities in excess of 400 mg/L as $CaCO_3$.

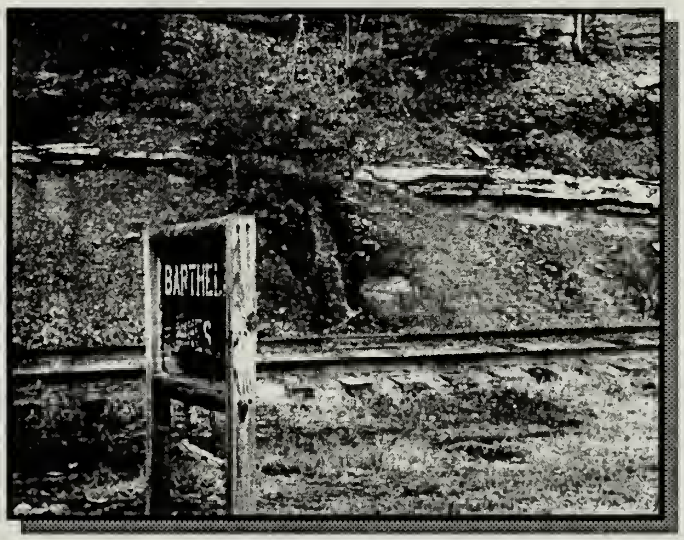


Plate 1. Barthell Mines Site No. 1 (SSPII RP02) CMD discharge located near the town of Barthell.

Aluminum and iron are present in the discharge at elevated levels in excess of 25 mg/L and 60 mg/L. The majority of the iron present in this discharge is in the oxidized ferric iron, comprising greater than 90 percent of the iron. The trace metals chromium, copper and zinc were detected in all samples and at concentrations well above analytical detection limits.

2.0.2 Barthell Mines Site No. 2 (SSPII RP03)

The Barthell Mines Site No. 2 (SSPII RP03) CMD discharge, depicted on Plate 2, is a mine drainage input to Roaring Paunch Creek with flows less than 10 gpm (gallons per minute) that emanates from a collapsed mine entry or portal located on the hill slope in Barthell. The discharge is in close proximity to a number of reconstructed miner huts (see Figure 4); to be used as lodging cabins. The discharge flows down slope, to the railroad and is conveyed in a culvert under the railroad to Roaring Paunch Creek. Water quality data from the discharge sampling location from the Phase I and II monitoring program are summarized in Table 4. The monitoring results indicate pH of the discharge is approximately 3 with acidities in range of 200 to 300 mg/L as $CaCO_3$. Aluminum and iron are present in the discharge at elevated levels in excess of 15 mg/L and 25 mg/L. The majority of the iron present in this discharge is in the oxidized ferric iron, comprising greater than 90 percent of the iron. The trace metals chromium, copper and zinc were also detected in most of the samples collected, but at concentrations much lower than observed at SSPII RP02.

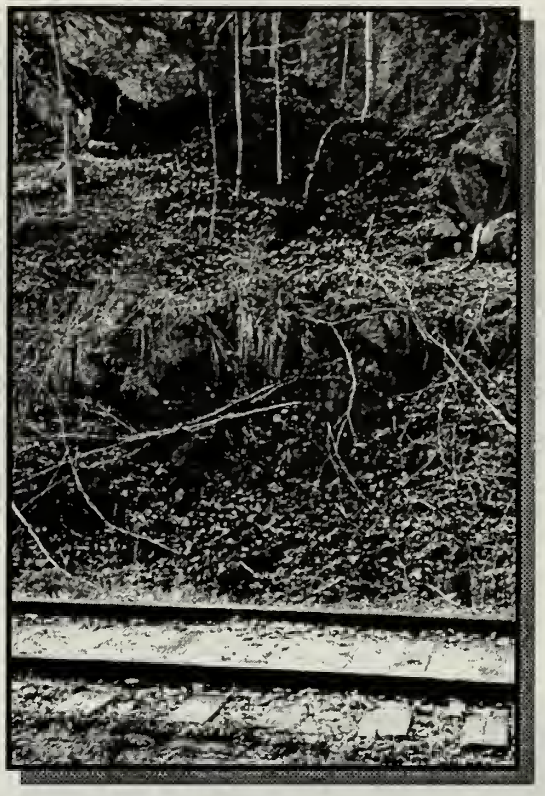


Plate 2. Barthell Mines Site No. 2 (SSPII RP03) CMD discharge located on the side slope in the town of Barthell.

2.0.3 Barthell Mines Site No. 3 (SSPII RP04)

The Barthell Mines Site No. 3 (SSPII RP04) CMD discharge, is a mine drainage input to Roaring Paunch Creek with flows less than 10 gpm that emanates from a collapsed mine entry or portal located on the hill slope in an area just south of Barthell (see Figure 4). The discharge flows down slope, depicted on Plate 3, to a flat area adjacent to the railroad that may have formerly been a coal stock pile area. The discharge infiltrates into this flat area with no observable discharge point to Roaring Paunch Creek. Water quality data from the discharge sampling location from the Phase I and II monitoring program are summarized in Table 5. The monitoring results indicate pH is approximately 2.9 with acidities in range of 300 to 350 mg/L as $CaCO_3$, very similar to SSPII RP03. Aluminum and iron are present in the discharge also at elevated levels in excess of 15 mg/L and 40 mg/L. The majority of the iron present in this discharge is also in the oxidized ferric iron, comprising greater than 90 percent of the iron. The trace metals chromium, copper and zinc were also detected in most of the samples collected and at concentrations similar to observed at SSPII RP02.

2.0.4 Roaring Paunch Site (SSPII BTH03)

The Roaring Paunch Site (SSPII BTH03) CMD discharge, is a mine drainage input to Roaring Paunch Creek with flows less than 10 gpm that emanates from a road cut along the access roadway to the Blue Heron Recreation Area; however, no source could be identified for the discharge. The discharge is conveyed from the roadway and down slope in a stormwater culvert to Roaring Paunch Creek and is depicted on Plate 4. This location is on the opposite stream bank of the previously described Roaring Paunch Creek mine drainage discharges (see Figure 4). No water quality data was obtained from this discharge location, but the discharge has a flow of less than 5 gpm and the appearance of an acidic mine drainage; based on the presence of red-brown iron deposits in the pipe and where it enters a quiescent backwater pool in Roaring Paunch Creek.

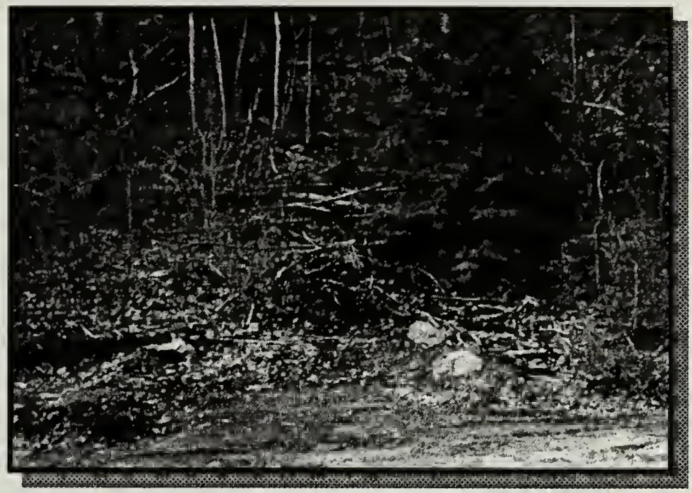


Plate 3. SSPII RP04 CMD discharge located on the side slope near the town of Barthell.

2.1 <u>Remediation Recommendations</u>

The possible remediation methods available for resolving the water quality impacts on the Big South Fork River associated with the Roaring Paunch Creek are limited to treatment BMPs for each of the identified discharges to Roaring Paunch Creek. The dilute nature and high flows of the CMD once co-mingled with uncontaminated Roaring Paunch Creek would prohibit treatment and removal of acidity and metals. Site remediation BMPs would likely involve mine seals to which would likely have limited success in reducing CMD flow and/or strength. The similarity of the water quality data (i.e., high acidity, aluminum, ferric iron and trace metals) indicate similar treatment BMPs would be required to treat the individual discharges. The identified BMPS for the Roaring Paunch discharges include:

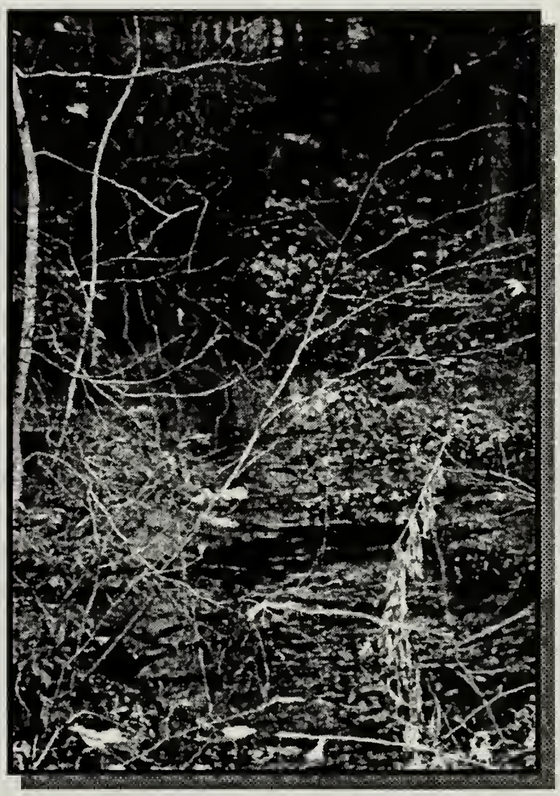


Plate 4. SSPII BTH03 CMD discharge located on the side slope of Roaring Paunch Creek.

- Active treatment systems of each discharge (e.g., chemical dosers); and

- Treatment of each discharge using passive wetland treatment systems (e.g., vertical flow wetlands).

Active treatment of the Roaring Paunch Creek discharges is a viable alternative if a settling basin is provided in the active treatment design. Active treatment with settling will remove iron and aluminum as well as trace metals from the Roaring Paunch Creek CMD discharges. Operation and maintenance limitations, similar to discussed for instream active treatment, and also including periodic dredging of settling pond, may be of concern. However, locations of the discharges are easily accessed (except possibly the Roaring Paunch Site - SSPII BTH03) which would not prohibit the use of active treatment.

Passive wetland treatment has been found to provide successful treatment of CMD with characteristics similar to that of the degraded water quality found in the Roaring Paunch CMD discharges. Treatment of the CMD discharge can be accomplished by collecting the discrete points and conveying them to a common location or treating them separately; such as at the identified potential treatment areas (see Figure 4).

Treatment of the Roaring Paunch Creek CMD discharges will require passive treatment systems capable of generating alkalinity and removing trace metals. Alkalinity generating treatment technologies identified in Section 1.4 include ALD, surface flow anaerobic wetland and anaerobic vertical flow wetland designs. The elevated aluminum (> 15 mg/L) and high ferric iron (> 25 mg/L) measured in the discharges indicates the ALD technology would be inappropriate. The anaerobic surface flow wetland design would be capable of providing alkalinity but the required treatment area for this design would likely exceed available area. The remaining technology, anaerobic vertical flow wetland, is capable of treating the acidity levels found in the Roaring Paunch Creek discharges and providing excess alkalinity. In addition, the anaerobic conditions provided in this design have been found to lower trace metal concentrations.

Based on the above evaluation the anaerobic vertical flow wetland design is recommended as the technology of choice to treat the Roaring Paunch Creek CMD discharges. Site conditions should be adequate for construction of the technology at the Barthell Mine (SSPII RP02, SSPII RP03, and SSPII RP04) discharge locations, identified areas are gently sloping, open and/or forested, and above the stream channel. However, the steeply sloping topography at the Roaring Paunch site (SSPII BTH03) would likely prohibit construction of a vertical flow wetland and will require use of an innovative technology that may be less effective at treating this discharge. For this discharge a new technology, known as oxic limestone channels (OLC), is recommended because ditch construction may be feasible for the site conditions. OLCs have been found to remove acidity and precipitate aluminum and iron, but would have limited success in removing trace metals.

2.2 Conceptual Design

Conceptual designs were developed for the four Roaring Paunch Creek discharges based on available water quality, discharge rates and site conditions. The conceptual designs for the anaerobic vertical flow wetlands to treat the Barthell Mine CMD (SSPII RP02, SSPII RP03 and SSPII RP04) discharges and the OLC to treat the Roaring Paunch site CMD (SSPII BTH03) discharge are discussed below.

Three of the four Roaring Paunch Creek discharges were sampled for water quality, and flow for 3 months. The CMD discharge flow rates averaged approximately 10 gpm for the Barthell Mines Site No. 1 (SSPII RP02) CMD discharge, 25 gpm for the Barthell Mines Site No.2 (SSPII RP03), and 15 gpm for the Barthell Mines Site No. 3 (SSPII RP04). The CMD discharge flow rate for the Roaring Paunch Site (SSPII BTH03) is assumed to be 10 gpm. Water quality for the Roaring Paunch Site (SSPII BTH03) is assumed to be similar to the average of the other three discharges in the Roaring Paunch Creek. Monitoring will be necessary to characterize the Roaring Paunch Site (SSPII BTH03) discharge and flow prior to final design to insure proper sizing and design of the treatment system. The above information will be used to develop the conceptual design and estimate costs of treatment.

2.2.1 Barthell Mines Site No. 1 (SSPII RP02)

. The conceptual design for the Barthell Mines Site No. 1 (SSPII RP02) discharge is depicted in Figure 5. As indicated in the plan view, a channel and culvert will convey the CMD discharge to the anaerobic vertical flow wetlands and includes conveyance underneath the existing railroad. The conveyance channels will be a geotextile-lined channel containing limestone material and will have a cross-section similar to the lined channel depicted in Figure 6, except the LLDPE liner will be excluded. The culvert is a galvanized steel or PVC pipe sized with adequate volume to convey the discharge and allow for accumulation of metal deposits. Efforts will be made to prevent stormwater from mixing with the discharges.

Applying the 10 gpm flow rate to the average acidity of 550 mg/L for the Barthell Mines Site No. 1 (SSPII RP02) discharge results in an acid loading of 30,000 GPD (grams per day) which was used to determine the treatment area required for the vertical flow wetland treatment system. Acid loading was used because acid removal is the only parameter for which design information for vertical flow wetlands is available. An acidity removal rate of 25 GDM (grams per day per square meter) was used to determine total treatment area size. Employing the design model developed by Gannett Fleming results in a single cell, vertical flow wetland treatment system area of 11,000 ft^2 to achieve an alkalinity greater than 0 mg/L. However, due to area constraints at Barthell Mine Site No. 2, the treatment system at the Barthell Mine Site No. 1 was sized to produce a discharge with excess alkalinity to mitigate the partially treated water at Barthell Mine Site No. 2, as well as upstream input outside the BSFNRRA. A multi-cell vertical flow wetland that would achieve a high effluent alkalinity would consist of two cells of varying size; Cell 1 containing 10,000 ft^2 and Cell 2 containing 7,500 ft^2. Cell 3, an aerobic wetland cell containing 7,500 ft^2 of treatment area, was included to assist in removing the high level of iron

associated with this discharge. The two-cell design contains redundant components which should improve the long term operation and treatment effectiveness of the system.

2.2.2 Barthell Mines Site No. 2 (SSPII RP03)

The conceptual design for the Barthell Mines Site No. 2 (SSPII RP03) discharge is depicted in Figure 7. As indicated in the plan view, a channel and culvert will convey the CMD discharge to the anaerobic vertical flow wetlands which includes conveyance down slope and underneath the existing railroad. The conveyance channels will be a geotextile-lined channel containing limestone material and will have a cross-section similar to the lined channel depicted in Figure 6, except the LLDPE liner will be excluded. The culvert is a galvenized steel or PVC sized with adequate volume to convey the discharge and allow for accumulation of metal deposits. Efforts will be made to prevent stormwater from mixing with the discharges.

Applying the 25 gpm flow rate to the average acidity of 265 mg/L for the Barthell Mines Site No. 2 (SSPII RP03) discharge results in an acid loading of 36,100 GPD which was used to determine the treatment area required for the vertical flow wetland treatment system. The design model estimated a single cell, vertical flow wetland treatment system area of 11,250 ft^2 of treatment area to achieve an alkalinity greater than 0 mg/L. However, available area between the railroad and high water levels of Roaring Paunch Creek is limited and inadequate to treat the discharge. A two-cell anaerobic vertical flow system with Cell 1 containing 5000 ft^2 and Cell 2 containing 2500 ft^2 of treatment area is recommended to provide partial treatment of the discharge. The two-cell design is recommended over a one cell design because it contains redundant components which should improve the long term operation and treatment effectiveness of the system.

2.2.3 Barthell Mines Site No. 3 (SSPII RP04)

The conceptual design for the Barthell Mines Site No. 3 (SSPII RP04) discharge is depicted in Figure 8. As indicated in the plan view, a channel and culvert will convey the CMD discharge to the anaerobic vertical flow wetlands which includes conveyance down slope to the proposed area. The conveyance channels will be a geotextile-lined channel containing limestone material and will have a cross-section similar to the lined channel depicted in Figure 6, except the LLDPE liner will be excluded. Efforts will be made to prevent stormwater from mixing with the discharges.

Applying the 15 gpm flow rate to the average acidity of 325 mg/L for the Barthell Mines Site No. 3 (SSPII RP04) discharge results in an acid loading of 26,600 GPD which was used to determine the treatment area required for the vertical flow wetland treatment system. The design model estimated a single cell, vertical flow wetland treatment system area of 8,800 ft^2 of treatment area to achieve an alkalinity greater than 0 mg/L. A multi-cell systems containing two cells with approximately 8,000 ft^2 would achieve an alkalinity greater than 0 mg/L. The surface area of the treatment system cells are 6,000 ft^2 in Cell 1 and 2,500 ft^2 in Cell 2 which total 8,500 ft^2. The total area was increased to provide excess alkalinity greater than 40 mg/L to assist in neutralizing the Barthell Mines Site No. 2 discharge and upstream inputs of CMD. The two cell

system will contain redundant components which should improve the long term operation and treatment effectiveness of the system.

2.2.4 Roaring Paunch Site (SSPII BTH03)

The conceptual design for the OLC to be employed at the Roaring Paunch Site (SSPII BTH03) is depicted in Figure 9. The OLC will consist of a constructed channel as depicted in Figure 6 containing limestone. The culvert conveying the discharge down the slope will be modified to direct the discharge into the beginning of the OLC which will be in close proximity to the retaining wall from which the culvert emanates.

The recommended passive treatment system for the Roaring Paunch Site (SSPII BTH03) discharge is an open limestone channel (OLC) constructed on the slope between the retaining wall and Roaring Paunch Creek. The acid load for this discharge was assumed to be similar to SSPII RP04 which had and acid load of 17,700 GPD. Ziemkiewicz *et al.* (1996), used as guidance to determine size and length of the channel required, indicate the acidity removal rate is between 0.029 and 1.77 percent per linear foot of OLC; a significant uncertainty exists regarding this technology because none of the OLCs in the study produced net alkalinity and were only effective at reducing acidity, iron and aluminum. The data from Ziemkiewicz *et al.* was used to determine an acidity removal rate of 230 GDLM (grams per day per linear meter), which was the average of removal rate from all the OLCs examined in the study, excluding a channel constructed with sandstone. Using this acidity removal rate, the dimensions of the OLC required to produce a zero acidity discharge is determined to be 255 feet in length, 3 feet in width, and 2 feet in depth.

2.3 <u>Preliminary Construction Costs</u>

Construction costs for the passive treatment systems will include: mobilization and demobilization; care of water during construction; clearing and grubbing; grading associated with channel and treatment cell construction; piping (e.g., underdrain system); limestone and an organic substrate (e.g., spent mushroom compost); miscellaneous materials; seeding of exposed soils; and erosion and sedimentation control measures. Tables 6 through 9 summarize the preliminary estimated costs for the four Roaring Paunch Creek projects which are based on engineering estimates from several recent projects. The total cost for passive treatment of the four CMD discharge in the Roaring Paunch Creek is estimated to be $367,890. No cost estimates are provided for required fill for construction of the treatment system and/or disposal of excess material since these quantities are unknown (determined during final design). Estimated costs for the projects may be significantly higher if only an individual project is undertaken.

2.4. <u>Anticipated Effluent Quality</u>

The passive treatment systems for the Barthell Mine Site (SSPII RP02, SSPII RP03, and SSPII RP04) discharges utilize the anaerobic vertical flow design capable of removing acidity and producing excess alkalinity. Acidity was used as the design parameter for the conceptual

systems because it is the only available guidance for design of this technology. The number of cells and size of the conceptual designs were developed to produce net alkaline water at average loading conditions, except for the Barthell Mine Site No. 2 (SSPII RP03) which was only partially treated. Barthell Mine Site No. 1 and 3 (SSPII RP02, and SSPII RP04) should achieve alkalinity in excess of 100 mg/L and 40 mg/L, respectively. The two treatment systems should also produce a circumneutral pH, an aluminum concentration less than 0.1 mg/L and iron less than 0.5 mg/L. The partial treatment of the Barthell Mine Site No. 2 (SSPII RP03) discharge by the passive treatment system will likely achieve an effluent acidity less than 75 mg/L, iron concentration of less than 5 mg/L and decreases in aluminum. Trace metals will be removed in the anaerobic environment of the vertical flow treatment cells and based on the flow passing through the systems underdrain, a minimum of 90, 60 and 70 percent removal of the trace metals (i.e., copper, chromium (III) and zinc) will be removed by the Barthell Mine Site No. 1, 2 and 3 passive treatment systems, respectively.

The passive treatment system for the Roaring Paunch Site (SSPII BTH03) discharge employs a new OLC design for which there is minimal design and performance information. The treatment system can be expected to lower acidity levels, raise pH, and decrease aluminum and iron concentrations, thereby improving the effluent quality. However, it is not likely that the system will provide a net alkaline water nor circumneutral pH based on field results achieved by Ziemkiewicz *et al.* (1996). In addition, the effectiveness of the system at lowering trace metals is uncertain because there is no information on trace metal precipitation for this technology. Some trace metal precipitation in this aerobic environment may occur as acidity, aluminum and iron concentrations but will be much less than observed in anaerobic environments in the presence of sulfide.

Treatment of the Roaring Paunch Creek discharges will lower metal concentrations in the Roaring Paunch Creek and will lower the amount of contaminants entering the Big South Fork River. It is anticipated the level of treatment provided by the proposed treatment systems, if implemented jointly, will at a minimum achieve water quality observed in Roaring Paunch upstream of the Barthell Mine area. Water quality may actually be improved to levels exceeding this upstream quality by allowing natural remediation processes provide additional removal of concentrations observed. Based on this comparison the proposed remediation will likely achieve and exceed the AWQC benchmarks for the Roaring Paunch Creek. The EC_{20} benchmarks may also be achieved for some parameters (e.g., pH, aluminum, iron, copper and zinc), but can not be evaluated for others due to the benchmark concentration being less than analytically quantifiable concentrations (e.g., cadmium and lead).

3.0 DEVILS CREEK SITE

The Devils Creek site is located on the western side of the Big South Fork River in the vicinity of Blue Heron (see Figure 3). The diffuse CMD discharges enter Devils Creek a short distance, approximately 300 feet, upstream of the confluence with the Big South Fork River (see Figure 10). The Devils Creek multi-point discharges associated with mine spoil and historic deep mining openings are located on the side slope of the watershed (see Plate 5).

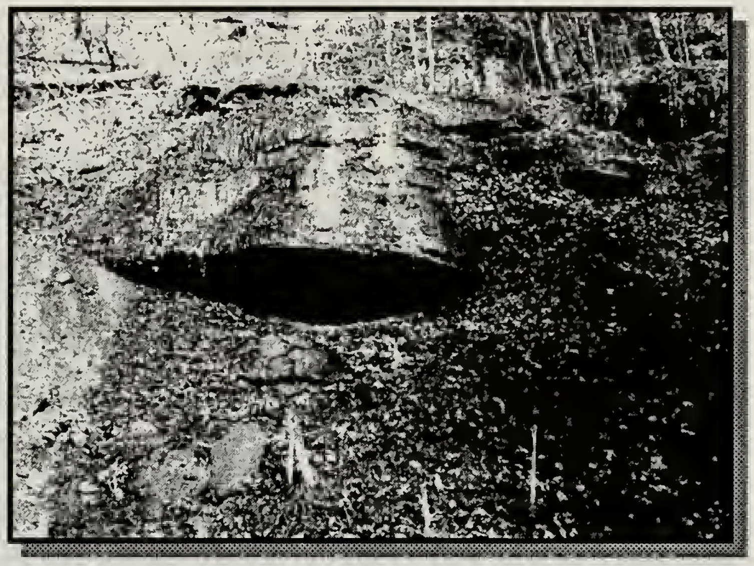


Plate 5. CMD discharges located on the side slope above Devils Creek.

Water quality data at the mouth of the Devils Creek from the Phase I and II monitoring program, summarized in Table 10, indicate pH varies from 3.1 to 6.9 and appears to be related to stream flow with low pHs occurring during low flows similar to observed in the Laurel Branch Creek. Acidity, aluminum, iron, manganese also appear to be related to discharge flow with higher concentrations at lower flows. The trace metals copper and zinc were repeatedly detected at the Devils Creek station at concentrations greater than aquatic life criteria.

The higher pH at higher flows and the presence of macroinvertebrates immediately upstream of the CMD inflow point suggests the primary source of CMD impacts to Devils Creek are associated with multi-point discharges that enter Devils Creek near its confluence with the Big South Fork River. Examination of the multi-point discharge area indicates the CMD emanates from primarily two discrete locations well up slope of the Devils Creek stream channel (see Figure 10). The source of the CMD appears to be from several drift mine openings and mine spoil on the side slope. A water quality sample from the discharge collected during the Phase I investigation indicates the multi-point discharge has a low pH (less than 2.7) and is moderately acidic with a reported value of 360 mg/L as $CaCO_3$. Zinc concentrations were very high and approached 0.2 mg/L, well above the estimated water quality criteria for the Big South Fork River.

3.1 <u>Remediation Recommendations</u>

The possible remediation methods available for resolving the water quality impacts on the Big South Fork River associated with the Devils Creek discharge are limited to treatment BMPs. Site remediation BMPs would likely involve removal of spoil and mine seals which would likely

have limited success in reducing CMD flow and/or strength. The treatment BMPs identified for the Devils Creek discharge include:

- Instream treatment of Devils Creek using active treatment systems (e.g., chemical dosers);
- Instream treatment of Devils Creek using passive treatment systems (e.g., limestone sand dosing);
- Treatment of the multi-point discharges using active treatment systems (e.g., chemical doser);
- Treatment of the multi-point discharges using passive wetland treatment systems (e.g., vertical flow wetlands);

Operation and maintenance limitations of instream active treatment discussed for the Laurel Branch Creek site also apply to Devils Creek. The Devils Creek flow is also inadequate to support use of a rotary-drum system which requires a minimum of 0.1 cfs to operate on a continuous basis (Zurbuch *et al.* 1996). Instream active treatment will result in precipitation of metals (primarily iron and aluminum) in the stream where the solids can accumulate in the substrate and potentially impact benthic habitat. Trace metals (e.g., copper and zinc) in the CMD may be co-precipitated with iron and aluminum or remain in solution where they may remain potentially toxic to fish and benthic macroinvertebrates. The short distance from the discharge location to the Big South Fork River suggests the metal precipitation would likely occur within the river potentially impacting water quality, benthic habitat, and aesthetics within the river. Based on the above limitations, instream active treatment are not recommended as a remediation methods for the Devils Creek.

Active treatment of the multi-point discharge is a viable alternative if a settling basin is provided in the active treatment design. Active treatment with settling will remove iron and aluminum as well as trace metals from the Devils Creek CMD discharge. However, operation and maintenance limitations, similar to discussed for instream active treatment, but also including periodic dredging of settling pond, would prohibit the use of active treatment of the discharge at a remote location such as the Devils Creek location.

Instream passive treatment employing a periodic limestone sand application to a location downstream of the discharge to Devils Creek would be affected by the short distance to the Big South Fork River and could result in significant accumulation of metals in the river. In addition, the short distance may be insufficient for the limestone sand to completely react with the acidity in Devils Creek resulting in water quality impacts. Limited access to the Devils Creek site may also create problems in replenishing the limestone sand on a periodic basis.

Passive wetland treatment has been found to provide successful treatment of CMD with characteristics similar to that of the degraded water quality found in the Devils Creek CMD multi-point discharges. However, passive treatment is not recommended to treat co-mingled CMD discharge flow and Devils Creek flow because of the stream flow variability that has been

observed for Devils Creek which could jeopardize the treatment effectiveness of a passive wetland treatment system. Treatment of the multi-point CMD discharge can be accomplished by collecting the discreet points and conveying them to a common location; such as the identified potential treatment area (see Figure 10).

Treatment of the Devils Creek CMD discharges will require a passive treatment system capable of generating alkalinity. Alkalinity generating treatment technologies identified in Section 1.4 include ALD, surface flow anaerobic wetland and anaerobic vertical flow wetland designs. In addition to alkalinity generation, the passive treatment system must be capable of lowering the trace metal concentrations; chromium, copper and zinc that were found at concentrations greater than the detection limits in Devils Creek. The limitations of each technology is presented in Table 1. The elevated aluminum (2.8 mg/L) and high ferric iron (61.6 mg/L) measured in the discharge indicates the ALD technology would be inappropriate. The anaerobic surface flow wetland design would be capable of providing alkalinity but the required treatment area for this design would likely exceed available area. The remaining technology, anaerobic vertical flow wetland, is capable of treating the acidity levels found in the Devils Creek discharge and providing excess alkalinity. In addition, the anaerobic conditions provided in this design have been found to lower trace metal concentrations. Therefore, the anaerobic vertical flow wetland design is recommended as the technology of choice to treat the Devils Creek CMD discharge; the high influent ferric iron should be lowered to acceptable levels in the inflow limestone channel.

3.2 Conceptual Design

Based on the above evaluation, only passive wetland treatment is suitable to address the Devils Creek CMD discharge to the Big South Fork River. Of the passive wetland treatment technologies available, anaerobic vertical flow wetland design is most appropriate to treat the Devils Creek CMD discharge.

The conceptual design for the anaerobic vertical flow wetland is depicted in Figure 11. As indicated in this plan view a collection channel will convey the multi-point CMD discharge across the slope to the anaerobic vertical flow wetland located at the potential treatment area, a distance of approximately 200 feet. The conveyance channel will be a geotextile-lined channel containing limestone material.

The Devils Creek CMD discharge (SSPII DC03) was sampled once during the BSFNRRA characterization study (Phase I Report) and three times during the Phase II study. Additional sampling may be necessary to characterize the discharge prior to final design. The flow rate monitored for the SSPII DC03 discharge ranged from 10 to 20 gpm this data and a discharge flow rate of 45 gpm was estimated based on data collected from Devils Creek, the CMD discharge chemistry and employing a mass balance equation. The 45 gpm flow was used to develop the Devils Creek passive treatment system because of diffuse nature of the discharges on the slopes above Devils Creek and the likelihood of infiltration of the CMD into the soil, entering the creek as seepage. Applying this flow rate to the CMD water chemistry data for the discharge results in an acid loading of 88,300 GPD which was used to determine the treatment area required for the vertical flow wetland treatment system. Acid loading was used because acid

removal is the only parameter for which design information for vertical flow wetlands is available. An acidity removal rate of 25 GDM was used to determine total treatment area size. A design model developed by Gannett Fleming was used to determine optimal number of cells and treatment area in each cell within the vertical flow system. The model considers acid loading, hydraulic detention time and effluent quality from the vertical flow wetland treatment cell; with an assumed alkalinity of 100 mg/L from the underdrain of vertical flow wetland treatment systems.

A single cell, vertical flow wetland treatment system would require 30,000 ft^2 of treatment area to adequately treat (i.e., acidity = 0 mg/L and alkalinity > 0 mg/L) CMD discharge on Devils Creek. A multi-cell vertical flow wetland that would achieve this same effluent alkalinity would consist of three cells of varying size; Cell 1 containing 7500 ft^2, Cell 2 containing 10,500 ft^2, and Cell 3 containing 11,000 ft^2. The total treatment area of the multi-cell system is 29,000 ft^2 a slight reduction in treatment area which will likely reflect a decrease in project cost. However, this multi-cell design will yield substantially greater effluent alkalinity and will lower trace metals to lower levels than a single cell design. In addition, the long term operation and treatment effectiveness is likely to be improved in a multi-cell system containing redundant components.

3.3 Preliminary Construction Costs

Construction costs for this remediation will include: mobilization and demobilization; care of water during construction; clearing and grubbing; grading associated with channel and treatment cell construction; piping (e.g., underdrain system); limestone and an organic substrate (e.g., spent mushroom compost); miscellaneous materials; seeding of exposed soils; and erosion and sedimentation control measures. Table 11 summarizes the anticipated costs for the Devils Creek project which are based engineering estimates from several recent projects. No cost estimates are provided for required fill for construction of the treatment system and/or disposal of excess material since these quantities are unknown, determined during final design.

3.4 Anticipated Effluent Quality

The passive treatment systems for the Devils Creek CMD discharges utilizes the anaerobic vertical flow design capable of removing acidity, producing excess alkalinity and removing trace metals. Acidity was used as the design parameter for the conceptual systems because it is the only available guidance for design of this technology. The number of cells and size of the conceptual designs were developed to produce net alkaline water at average loading conditions, which will also result in complete removal of acidity, a circumneutral pH and iron and aluminum less than 1 mg/L. Trace metals will be removed in the anaerobic environment of the vertical flow treatment cells. Based on the flow passing through the underdrains, 35 gpm at average flow, the proposed treatment system will lower the trace metal concentrations by a minimum of 75 percent as measured at the effluent from the system. Compliance of copper and other non-detected metals (e.g., cadmium) with the EC_{20} is possible, but can not be evaluated because of the concentrations are less than analytical quantification levels.

The level of treatment should potentially lower chromium (III), copper and zinc concentrations to less than the AWQC benchmarks, thereby resulting in the majority of parameters to be in compliance with the AWQC benchmarks, as measured at the effluent from the system. A number of the parameters will also be in compliance with the EC_{20} benchmarks, e.g., aluminum and zinc, but it is not likely that all parameters, e.g., copper and iron, will meet EC_{20} benchmarks. Compliance of other non-detected metals (e.g., cadmium) can not be evaluated because the concentrations are less than analytical quantification levels.

4.0 LAUREL BRANCH CREEK SITE

Plate 6. Mine spoil, waterfalls and associated CMD discharges on the Laurel Branch Creek.

The Laurel Branch Creek site is located near the southern border of the BSFNRRA CMD study area (see Figure 3). The Laurel Branch Creek contributes pollutants to the Big South Fork River from diffuse discharges associated with historic deep mine spoil on the side slope of the watershed (see Figure 12). The mine spoil from this mining is located down slope of a mine opening and includes a large section of the stream channel that was deliberately placed across the channel and used as bridge during active mining. The bridge foundation has washed away leaving mine residues in the channel that has created a waterfall on the Laurel Branch that is approximately 20 feet in height (see Plate 6).

Water quality data at the mouth of the Laurel Branch from the Phase I and II monitoring program, summarized in Table 12, indicate pH varies from 3.5 to 5.5 and appears to be related to stream flow with low pHs occurring during low flows. Acidity, aluminum, iron, manganese and zinc are also related to discharge flow with higher concentrations occurring at lower flows. Phase I sampling also included an upstream station (i.e., above the mine spoil) which contained water quality reflecting the absence of mine drainage impacts; the upstream water quality had a pH greater than 6, conductivity less than 50 μmhos/cm, and sulfate less than 10 mg/L. The monitoring results suggest the source of the CMD to the Laurel Branch is the mine spoil.

Examination of the mine spoil and man-made waterfall indicated CMD was emanating at several locations at the base of the waterfall. This suggests that upstream, uncontaminated water infiltrates into the mine spoil located in and adjacent to the stream channel where this water reacts with the acid-forming minerals of the mine spoil. The flow dependent water quality at the mouth supports this conclusion because the infiltration capacity of the mine spoil represents only a small portion of the total flow at high flows but increases in proportion to the total flow as the stream flow decreases.

4.1 Remediation Recommendations

A number of possible site remediation and treatment BMPs are available for resolving the water quality impacts on the Big South Fork River associated with the Laurel Branch discharge. The BMPs identified include:

- Instream treatment of Laurel Branch using active treatment systems (e.g., chemical dosers);

- Instream treatment of Laurel Branch using passive treatment systems (e.g., limestone sand dosing);

- CMD discharge treatment using passive wetland treatment systems (e.g., vertical flow wetlands);

- Elimination of CMD source areas via removal of mine spoil from the site; and

- Reduction of CMD production by construction of a stable lined stream channel to minimize infiltration of stream into the mine spoil.

Most of the active treatment systems available require a high degree of operation and maintenance to sustain treatment, such as electricity and chemical feeding. The rotary-drum system is a lower maintenance (requires no electricity and manual feed once every one to two weeks) active treatment that has been successfully employed to treat CMD impacted streams in West Virginia, but requires a minimum of 0.1 cfs to operate which is not present on a continuous basis in the Laurel Branch Creek (Zurbuch *et al.* 1996). Long term operation records for many of the active treatment systems indicate mechanical failures occur resulting in loss of treatment and water quality impacts on the receiving stream biota. Instream treatment also results in precipitation of metals (primarily iron and aluminum) in the stream where the solids can accumulate in the substrate potentially impacting benthic habitat. Trace metals (e.g., copper and zinc) in the CMD may be co-precipitated with iron and aluminum or remain in solution where they may remain potentially toxic to fish and benthic macroinvertebrates. The short distance from the discharge location to the Big South Fork River suggests the metal precipitation would likely occur within the river potentially impacting water quality, benthic habitat, and aesthetics within the river. Based on the above limitations, instream active treatment is not recommended as a remediation method for the Laurel Branch Creek CMD discharge.

Instream passive treatment employs a periodic limestone sand application to one or several locations within an impacted watershed. The limestone sand is applied directly into stream channels where the stream water contacts the limestone slowly dissolving it or carrying and distributing the sand throughout the stream length where it becomes incorporated in the stream bed. The limestone sand will slowly dissolve over time providing alkalinity to increase pH and neutralize acidity. The changes in pH result in the in precipitation of pH solubility dependent metals such as iron (ferric) and aluminum. This is a relatively new remediation technique that has gained interest in a number of states for treatment of CMD and acid deposition impacted waters. No long term studies have been conducted to determine frequency of sand application, number of locations, impacts on benthic communities, and effects of flood events on sustaining water quality conditions. In addition, this is an instream treatment which may have similar problems related to metal removal that was discussed above for instream active treatment.

Passive treatment has been found to provide successful treatment of CMD with characteristics similar to that of the degraded water quality found in the Laurel Branch Creek at low flows. However, passive treatment has not been employed to treat co-mingled CMD in a stream with flow variability that is likely to occur in the Laurel Branch Creek. High flows associated with storm events could result in hydraulic overloading, accumulation of eroded sediments in the system, wash-out of substrates, and/or damage to the passive treatment system. Collection of the diffuse CMD discharges emanating from the spoil from un-contaminated stream flow would be difficult. However, the entire flow, at low stream flow, could be conveyed to a location away from the stream channel and treated with an alkalinity generating vertical flow wetland treatment system. The estimated area of a vertical flow treatment system to treat flows of 0.3 cfs and 50 mg/L acidity would be approximately 8,000 ft^2 at a cost likely to exceed $100,000 at the identified location; based on remote location, distance of conveyance and size of a treatment system to achieve a net alkaline discharge. This alternative would only be capable at treating stream flows up to 0.3 cfs with stream flows in excess of this flow remaining untreated. This would result in some untreated CMD entering the Big South Fork River, although the dilution in Laurel Branch Creek and the river would minimize the impact of the untreated CMD.

Removal of the mine spoil is a remediation method which would remove the production of CMD by eliminating the source area. The highly acidic nature and trace metal composition of the mine spoil may require disposal at a hazardous waste facility which can have tipping fees as high as $100.00 per ton. The mine spoil could be excavated from the site, hauled off-site and disposed of at a location (e.g., capped, reclaimed mine site) where the spoil can be isolated and any CMD produced can be treated. The costs associated with a small disposal amount produced at this location would likely result in excessively high costs. However, if this removal were part of a much larger disposal project, e.g., one of the proposed options for the Blue Heron site (see Chapter 5.0), the costs of the disposal could be dramatically reduced. For example, the proposed disposal and reclamation option for the Blue Heron site resulted in a $7.50 per cubic yard estimated cost which would likely approximate the costs for the Laurel Branch Creek site if the disposal and remediation option for the Blue Heron site was implemented. Applying this cubic yard cost results in an estimated project cost of $125,000 to dispose of the estimated 17,000 cubic yards of spoil. The complete removal may eliminate the CMD discharge from this location if the CMD is solely the result of spoil leaching.

The remaining remediation technique identified is a lined stream channel to convey the stream on top of the spoil, preventing infiltration of stream water into the mine spoil. This remediation technique employs construction of a stream channel that contains an impervious synthetic (e.g., LLDPE) or geo-synthetic (GSL) liner and limestone rock. The impervious liner will prohibit stream water from infiltrating into the mine spoil where it can contact acid-bearing minerals producing the CMD. Preventing infiltration should minimize the CMD produced from site; some CMD may be produced from precipitation falling directly onto the mine spoil. Costs of a lined stream channel typically are within the range of $10 to $25 per linear foot which results in an estimated project cost of approximately $25,000 for a 100 ft channel. This option would eliminate infiltration of the stream flow into the spoil, decreasing CMD production by nearly 100 percent. Some CMD, estimated at less than ½ gpm based on up slope catchment areas, would

continue to be produced from precipitation infiltrating the up slope areas; limestone included in the channel should provide alkalinity sufficient to neutralize this CMD input.

Based on the above evaluation three alternatives are suitable to address the Laurel Branch site CMD discharge in the BSFNRRA, which are: passive treatment employing vertical flow wetland design; removal of the mine spoil from the Laurel Branch Creek channel and adjacent slopes; and construction of a lined channel on top of the mine spoil. Of the three options the lined channel appears to be the most cost effective alternative for the site and should achieve the desired water quality objectives.

4.2 Conceptual Design

The conceptual design for the constructed lined channel is depicted in Figure 13. As indicated in this plan view the channel would be located across the existing mine spoil only which is approximately 100 feet in length. A typical cross-section of a lined channel is depicted in Figure 6.

This construction will likely require removal of a small amount of mine spoil to grade a channel with a stable slope (i.e., no waterfall) which can be properly disposed in adjacent areas. The recommended liner for the channel is a linear low density polyethylene (LLDPE) material with a thickness of 40 mm with a geotextile fabric placed on top. An LLDPE liner is preferred over a geosynthetic liner (GSL), a clay impregnated geotextile fabric, because of potential reactivity of acid materials in the spoil with the clay in the GSL. The liner will be anchored into the subgrade on each side of the channel as well as the upstream and downstream ends. Limestone will be placed in the channel to provide roughness and stability. This limestone should also provide alkalinity to the contact water which will aid in neutralizing any acid inputs from the mine spoil (i.e., surface runoff and/or seepage).

4.3 Preliminary Construction Costs

Construction costs for this remediation will include: mobilization and demobilization; diversion of water during construction; clearing and grubbing; grading of stream channel; disposal of excess mine spoil (if off-site); materials including LLDPE liner, geotextile fabric and limestone; installation of the LLDPE liner, geotextile and limestone, seeding, and erosion and sedimentation control measures. The total cost, summarized Table 13, for the construction of the Laurel Branch Creek project is estimated to be $25,500 and is based on engineering estimates from several recent projects.

4.4 Anticipated Water Quality

The lined stream channel will eliminate contact of the Laurel Branch Creek stream flow with mine spoil that covers the area and will decrease acid production from this spoil. Water quality data at low stream flow (see Table 12) indicates the proposed remediation should substantially improve water quality and will likely eliminate acidity, lower iron to less than 0.5 mg/L, and lower aluminum to less 0.5 mg/L, thereby lowering loading to the Big South Fork

River. The limestone in the lined channel should add alkalinity to neutralize acidity inputs from the mine spoil and upstream sources of CMD that can not be eliminated and could raise the pH to greater than 6.5. Trace metal concentrations, e.g., copper and zinc, may be lowered to levels less than concentrations reported for Laurel Branch Creek discharge rates greater than 3 cfs (see Table 12), which are less than detection for copper and less than 0.01 mg/L for zinc. This level of treatment or pollutant reduction indicates the proposed remediation could achieve compliance with the AWQC benchmarks and approach EC_{20} benchmarks, the later are difficult to evaluate for a number of parameters because the benchmarks are less than quantifiable concentrations.

5.0 BLUE HERON SPOIL

The Blue Heron Spoil site is located to the south (upstream) of the Blue Heron Recreation area in the southern section of the study area and is visible from the BSFNRRA overlook (see Figure 3). The spoil in this area is associated with discarded mine wastes from a number of historic deep mines that were located well up on the side slopes of the watershed. Historical information also indicates that area of the mine spoil may have been pyrolized in fires in the mine spoil. The Blue Heron Spoil site, depicted in Figure 14, is approximately 17 acres in size (the largest mine spoil area in the BSFNRRA) and is comprised of three distinct spoil disposal areas which are Blue Heron-North, Blue Heron-South and Blue Heron-Pine Plantings. The mine spoil is located adjacent to the Big South Fork River and comprises the river bank in several areas (see Plate 7). CMD discharges enter directly into the river from diffuse discharges located along the river bank and at the base of the spoil areas. The mine spoil at Blue Heron-North and Blue Heron-South has been graded and has well established herbaceous vegetation. The only open spoil areas are along a steeply sloped area adjacent to the Big South Fork River. The Blue Heron-Pine Plantings contains 10 to 20 year old planted scotch pine, however, the site is poorly graded with erosion gullies and exposed spoil are present throughout.

Plate 7. Blue Heron Spoil area located on the side slope of the Big South Fork River.

Water quality data at the various Blue Heron seeps along the Big South Fork River from the Phase I and II monitoring at sampling station numbers SSPII BH01, SSPII BH02N, SSPII BH02 and SSPII BH04 are summarized in Tables 14-17. The results indicate the pHs of the discharges ranged in the mid- to upper twos with moderate to high acidities ranging from 300 to 5,000 mg/L. Both pH and acidity appear to have a seasonal variability with the lowest pHs and highest acidities occurring during mid- to late summer; possibly associated with minimum discharge flows or highest spoil temperatures. Aluminum and iron were elevated at all the monitoring locations with maximum concentrations exceeding 100 mg/L and 1,000 mg/L, respectively. The trace metals arsenic, cadmium, chromium, copper, lead and zinc were measured in samples at all Blue Heron locations with maximum concentrations well above detection limits.

Examination of the mine spoil area indicate the CMD emanates at several locations near the base of the spoil and in areas that are subject to flooding by seasonal high waters in the Big South Fork River. The Blue Heron-North and Blue Heron-South areas have been graded to gentle slopes to minimize erosion and aid in establishing the herbaceous cover. The side-slopes

adjacent to the river are 20 to 30 feet high barren spoil that appear to be severely eroded by river storm flows. The Blue Heron-Pine Planting spoil area has not been graded and contains flat, sloping areas and erosion gullies with barren spoil distributed throughout the area.

Two surface waters were identified on and adjacent to the Blue Heron site which may be sources of water infiltrating into the spoil and contribute to migration of CMD from the spoil. A constructed channel borders the Pine Plantings area and conveys a perennial spring from up slope of the Blue Heron Spoil to the Big South Fork River. The channel is unlined and contains gravel and soil areas that may permit infiltration of water into adjacent spoil areas. Flow in the channel appeared to decrease in a downstream direction but no flow measurements have been made to verify this observation. An open water pond (possibly a former settling pond), that collects and stores stormwater generated from up slope areas, is located along the northern edge of the Blue Heron-North area. In addition, numerous swales were observed on undisturbed up slope areas adjacent to the Blue Heron Spoil that may convey overland runoff from adjacent up slope areas permitting infiltration into the mine spoil where the uncontaminated water can react with the acid-forming minerals of the mine spoil and contribute to the discharges at the Blue Heron Spoil site.

5.1 Remediation Recommendations

The possible remediation methods available for resolving the water quality impacts on the Big South Fork River associated with the Blue Heron Spoil are limited to site reclamation and water source control activities. The location of the discharges on the stream banks of the river and below the high river stage elevation prohibit treatment and/or collection of the discharge (for treatment at another area). The identified site reclamation and water source control BMPs for the Blue Heron discharges include one or several of the following:

- Removal of the acid-producing materials through excavation and disposal of mine spoil from the site; and
- Regrading and revegetation of mine spoil areas (or the site after the acid-producing materials have been removed);
- Placement of a dry (e.g., geomembrane, fly ash, clay and/or soil) cover on top of the mine spoil;
- Elimination and diversion of surface water, the spring and pond, from the mine spoil;
- Construction of stormwater interceptor channels to collect and divert runoff from the mine spoil; and
- Installation of a vertical barrier (e.g., injected grout) along the exposed face of the mine spoil.

Because of the complexity of the Blue Heron site one or many of the above identified alternatives could be used singly or in conjunction with one another. As a result a different approach was undertaken in development of a conceptual design(s) for the Blue Heron site. The possible alternatives, called actions, were individually evaluated creating a list of possible options and there likely effects at reducing pollutant loading from the site through either decreases in acid production and/or flow.

5.1.1 Action 1 - Removal of Spoil

Removal of the spoil from the Blue Heron site was identified as an alternative by the Steering Committee. This option would involve: excavation of all mine spoil from the site, down to pre-mining grades; regrading and revegetation of the Blue Heron site once the spoil has been removed; and regrading, dry cover placement (geomembrane liner), and revegetation of the identified disposal site. The disposal site identified by the Committee is a 30 acre abandoned surface mine located within 60 miles of the Blue Heron site.

Removal of the spoil from the Blue Heron site would involve excavation and hauling of the spoil in methods similar to surface mining or gravel excavation. The volume of the material to be excavated is approximately 600,000 cubic yards; based on the total surface area of 17 acres for the Blue Heron site and an estimated average spoil depth of 25 ft, estimated from spoil height adjacent to the Big South Fork River and surrounding topography. The project will also incur costs associated with, construction of a roadway to the Blue Heron site, clearing and grubbing of the Blue Heron and disposal sites, revegetation of the Blue Heron site, regrading and revegetation of the disposal site, placement of a dry cover at the disposal site and placement of a soil cover on the disposal site (and possibly on the Blue Heron site).

The preliminary total cost estimates for the spoil removal action are $3.6 million dollars and the breakdown of the costs are summarized in Table 18. As can be seen the majority of the costs for this action are associated with excavation and hauling of the spoil. Other significant contributions to the cost estimate are the geomembrane and soil cover for the disposal site to prohibit oxygen and water infiltration into the spoil which would produce CMD. The cost estimate did not consider temporary and/or permanent treatment of leachate that may be produced from the disposal site during and after construction.

5.1.2 Action 2 - Partial Regrading and Revegetation

This action is for the Blue Heron site only and considers only partial site activities where required by the site conditions. The lack of a herbaceous cover in the Pine Plantings along with erosion gullies indicates that regrading and revegetation to eliminate barren spoil will be beneficial in reducing discharge flow by lowering infiltration of water and oxygen into the spoil, increasing water retention in the soil layer, increasing evapotranspiration, and lowering decreasing the oxidation of pyrite by lowering oxygen and spoil temperatures. Robertson and Barton-Bridges (1990) indicate that a 1½ and 3 ft soil cover would lower acid generation by approximately 30 and 50 percent, primarily through lower infiltration of water into the spoil. Reclamation of Blue Heron-North and -South would require additional evaluation to characterize

the conditions of the soil, however, extensive reclamation does not appear to be warranted because of previous actions that have resulted in a well established herbaceous layer on the sites. Addition of alkaline materials to the soils on Blue Heron-North and -South may be beneficial, particularly if soil analysis indicates acid conditions, and would provide a source of buffering to infiltrating waters.

Reclamation at the Blue Heron-Pine Plantings area would require clearing and grubbing of existing vegetation which could be mulched and incorporated into the soil cover. Regrading would involve earthmoving of existing spoil to obtain a stable slope that minimizes erosion while inhibiting infiltration and standing water. A 1½ ft soil cover would be placed on top of the regraded site which could be developed from low cost materials such as fly ash and/or waste organics (e.g., paper mill, vegetable tanning and municipal wastewater stabilized sludge). The site would be seeded with a grass and herbaceous seed mix to permit rapid revegetation, thereby, stabilizing slopes and minimizing erosion losses. Agricultural fertilizers and limestone should be applied during seeding and periodically after reclamation to maintain an adequate vegetative cover. The alkaline material could also be beneficial in buffering infiltrating water which would slow the acid-producing reactions and neutralizing acidity that is produced.

The costs for this action are summarized in Table 19 with a preliminary total cost estimate of $160,000. Placing a soil cover on the Blue Heron-Pine Planting area was the highest cost item associated with this action

5.1.3 Action 3 - Dry Cover Placement

This action involves placement of a geomembrane liner on top of the spoil throughout the Blue Heron site. Placement of the liner would minimize the vertical infiltration of water and oxygen into the mine spoil, but would not effect lateral groundwater and oxygen transport through the spoil. The effectiveness and long term integrity of a liner on slopes subject to high floodwater and erosional forces along the banks of the Big South Fork River would have to be evaluated.

Liner installation will require a soil cover, to be placed on top of the liner, to protect the liner from environmental forces (e.g., UV breakdown) and prevent tearing and punctures of the exposed liner. A soil cover depth of 3 ft is recommended to ensure the liner remains covered over the entire site. The slope of the spoil adjacent to the Big South Fork River may prohibit installation of a liner, as well as the liner may eventually become exposed and destroyed along this highly unstable slope. In addition, liner installation will not lower CMD produced from lateral transport of river water into the spoil during high flow events or groundwater flow to the spoils. The action will also require clearing and grubbing, regrading and revegetation of the Blue Heron Site.

The costs for this action are summarized in Table 20 with a preliminary total cost estimate of $1.4 million. The geomembrane liner and soil cover account for over $1 million of the total estimate for this action on the Blue Heron site.

5.1.4 Action 4 - Removal and Diversion of Surface Water

The presence of water (i.e., spring and pond) in close proximity and on the spoil may contribute water to the acid-producing spoil. The close proximity of the surface pond to the Blue Heron-North discharge suggests this activity may be beneficial. In addition, the qualitative observation of decreasing flow in the constructed channel along the edge of the Pine Plantings suggest construction of a lined channel may reduce the CMD flow associated with several of the discharges from the Pine Plantings and Blue Heron-South. The Blue Heron site also lacks control of surface runoff that may enter the site from up slope undisturbed areas and infiltrate into the spoil, adding to the volume of CMD produced by the site. Measures to control the infiltration of uncontaminated water into the Blue Heron Spoil through may help reduce the volume of CMD produced by the site. The effectiveness types of measures are dependent on the volumes of water infiltrating into the spoil, currently unknown, but surface water control measure have successfully reduced CMD production at other sites from 10 to 100 percent.

This action would require three separate control measures including: 1) filling the pond in the Blue Heron-North area; 2) construction of a lined conveyance channel to transport the uncontaminated spring located along the edge of the Blue Heron-South and Pine Plantings area to the Big South Fork River; and 3) construction of interceptor channels at the edge of the spoil, along the steeply-sloped undisturbed areas, to capture surface runoff and convey it away from the spoil and down slope to the Big South Fork River. The pond would be filled with alkalinity generating materials and a top soil cover.

The costs for this action are summarized in Table 21 with a preliminary total cost estimate of $106,000. The construction of the two channels constitute over 60 percent of the total estimate for this action on the Blue Heron site.

5.1.5 Action 5 - Installation of Vertical Barrier

The open spoil along the Big South Fork River may permit infiltration of uncontaminated water from the river, during flood conditions, into the spoil where it may be substantially degraded upon contact with acid-bearing rock material. The open face is likely a major contributor of oxygen, a necessary agent in the oxidation of pyrite, to the spoil resulting in the production of CMD and may also contribute to higher spoil temperatures (and pyrite oxidation rates) by allowing cooler ground temperatures to escape from the spoil. Formation of a vertical barrier along this face using an impermeable blanket, permeation grouting or cut-off wall (see Figures 15 through 17) may provide substantial reduction in CMD production. The impermeable blanket was not considered as an alternative for the Blue Heron Site because of the erosional forces of the Big South Fork River which could expose and destroy this type of barrier.

The vertical barrier would have a lower permeability than existing spoil conditions, thereby inhibiting water from the Big South Fork River from infiltrating into the spoil. The vertical barrier could also decrease water movement from the spoil and increase saturated conditions in the spoil, thereby decreasing the oxidation of pyrite in the spoil and CMD production. The alkaline nature of the grout, used in permeation grouting, could also neutralize acidity in CMD that contacts it.

In permeation grouting the spoil face would be drilled to develop a line of bore holes at regular intervals (10 to 20 ft) along the face of the spoil. Each bore hole would be injected with a liquid grout, to permit the material to fill the voids in the spoil, that is comprised of fly-ash, concrete, water and solidifying agents. The number of wells required to develop the vertical barrier will likely range between 80 and 120 with an average depth of 50 ft. The expected width of the vertical barrier would be approximately 5 to 10 feet. The costs for the permeation grouting vertical barrier is summarized in Table 22 with a preliminary total cost estimate of $546,000. The costs are evenly distributed across well drilling, grout material and injection.

The cut-off wall is another vertical barrier developed along the face of the spoil to depth of less than 50 feet. The cut-off wall is developed by excavating a trench in the spoil and placing a material, e.g., cement-bentonite slurry, into the excavated trench. The material would solidify in the trench forming a near impervious barrier. The width of cut-off walls vary between 5 and 10 feet. The costs for the cut-off wall barrier is summarized in Table 23 with a preliminary total cost estimate of $458,500. The costs are evenly distributed across excavation and slurry material.

5.1.6 Action 6 - Groundwater Control

The contact of the spoil with bedrock along the up slope areas may result in lateral movement of uncontaminated groundwater into the spoil where it may be substantially degraded upon contact with acid-bearing rock material. Isotope analysis conducted during Phase II attributed a substantial amount of discharge flow to groundwater; however, the isotope analysis could not differentiate between up slope springs (groundwater) that infiltrate into the spoil and lateral subsurface groundwater infiltration into the spoil. The presence of several up slope springs conveyed to or adjacent to the spoil suggests that the former may be a significant portion of this groundwater contribution which can be addressed employing Action 4 (section 5.1.4). Minimizing the lateral groundwater infiltration to prevent formation of CMD production will require installation of an up gradient groundwater interception control measure. Several approaches include groundwater pumping or a vertical barrier, similar to the barrier walls described in section 5.1.5.

The groundwater pumping alternative would require installation of approximately 20 wells that would be continuously pumped at low rates (e.g., 1 gpm). The pumped groundwater would be conveyed away from spoil in a conveyance channel to the Big South Fork River or to a passive treatment system if water is CMD contaminated. This alternative would cost approximately $600,000 to drill wells and construct the conveyance channel; additional costs would be incurred if treatment is required. Annual operation costs would include well maintenance and electricity; the electricity requirement may prohibit implementation of this alternative.

The vertical barrier would have a lower permeability than existing spoil conditions, thereby inhibiting groundwater from infiltrating into the spoil. Groundwater impounded behind the barrier would likely be discharged through outlets adjacent to the spoil. Permeation grouting of the bedrock or installation of a cut-off wall, depicted in Figure 16 and 17, are options for

development of a vertical barrier; the cut-off wall may be limited because of depths required. Installation and costs would be similar to the vertical barriers discussed in section 5.1.5.

5.2 Conceptual Design

The recommended remediation measures for the Blue Heron site include regrading and revegetation of the Pine Plantings area, diversion and control of surface and groundwater inputs and development of a vertical barrier. These actions will likely reduce CMD production by the Blue Heron site by 60 to 80 percent for a total cost estimate of $699,400. The first two may be completed initially and evaluated to determine whether the vertical barrier is warranted. In addition, groundwater interception measures may be implemented if the above actions have limited success. More aggressive actions including spoil removal, and dry cover placement do not appear to be warranted because of the high cost to achieve additional CMD decreases over the recommended actions; the additional 20 to 40 percent would require additional expenditures in excess of $3 million.

The conceptual design for the Blue Heron site is depicted in Figure 18 and includes Pine Plantings regrading and revegetation, removal of the Blue Heron-North surface pond, construction of a lined conveyance channel, and construction of stormwater interceptor channels. A vertical, grout barrier is also depicted on Figure 18 and has been included as an additional remediation alternative.

5.3 Anticipated Water Quality

It is anticipated that the remediation methods will effect the Blue Heron CMD discharges by lowering their volume and strength. However, remediation methods success are highly variable and difficult to quantify.

The recommended removal and diversion of surface water could lower CMD discharge volumes by 10 to 25 percent, if up slope springs are a major source of groundwater recharge to the spoil. The recommended remediation methods for the Pine Plantings area should lower the CMD discharges from this area by between 50 and 70 percent which equates to a 20 to 40 percent reduction in flow from the Blue Heron site, based on the Pine Plantings comprising 20 percent of the site. Lowering CMD volumes should reduce CMD loading to the Big South Fork River.

Application of limestone to the sites will provide alkalinity to lessen the rate of CMD production and neutralize CMD produced with an assumed long term CMD concentration reduction of 10 to 20 percent; long term effectiveness may require periodic application of limestone. Construction of a vertical barrier to prevent river water infiltration, reduce oxygen infiltration, elevate the water table in the spoil, and lower spoil temperatures should effect both CMD strength and flow. It is anticipated this remediation could decrease the CMD strength by between 30 and 50 percent, similar to the difference observed between warm and cold season discharge chemistry (see Tables 15 and 17). Based on the seasonal differences of chromium and lead, the remediation could lower concentrations to below detection limits and copper and zinc concentrations could be lowered by approximately 60 to 90 percent.

Based on the above evaluation the recommended remediation and control measures for the Blue Heron site could lower acidity loading from the Blue Heron Spoil by an estimated 50 to 90 percent and trace metal loading decreases could approach 100 percent, depending on the specific trace metal. Evaluating performance of remediation based on water quality monitoring results may not be permissible because one or more of the proposed actions described may change flow patterns and eliminate some discharges while creating new discharge points. In addition, the variability in water quality data from the monitoring studies was considerable (for example: acidity varied from 340 to 5000 mg/L at SSPII BH02) and may mask actual beneficial improvements.

The types of discharges and improvements associated with the proposed actions also effect evaluation of compliance with the water quality benchmarks. Upstream and downstream samples in the Big South Fork indicate the presence of several trace metals at levels exceeding the AWQC and EC_{20} benchmarks. Based on the above evaluation, the proposed remediation actions will lower the impacts of the Blue Heron Site on the Big South Fork River water quality possibly decreasing presently measured concentrations incrementally closer to instream compliance with AWQC and EC_{20} benchmarks.

6.0 THREE WEST HOLLOW

Three West Hollow is a tributary to the Big South Fork River located on the western side of the watershed in the vicinity of Blue Heron (see Figure 3). Mine drainage enters Three West Hollow in diffuse discharges from mine spoil located on the slopes, approximately ½ mile up the stream, and from collapsed mine portals (Mine #45, 46 and 47) located about 50 feet on the side slope near the flood plain of the river (see Figure 19). At normal flows Three West Hollow Creek flows subsurface, through mine spoil deposited in the stream channel, for several thousand feet before emerging in the floodplain of the Big South Fork River (see Plate 8).

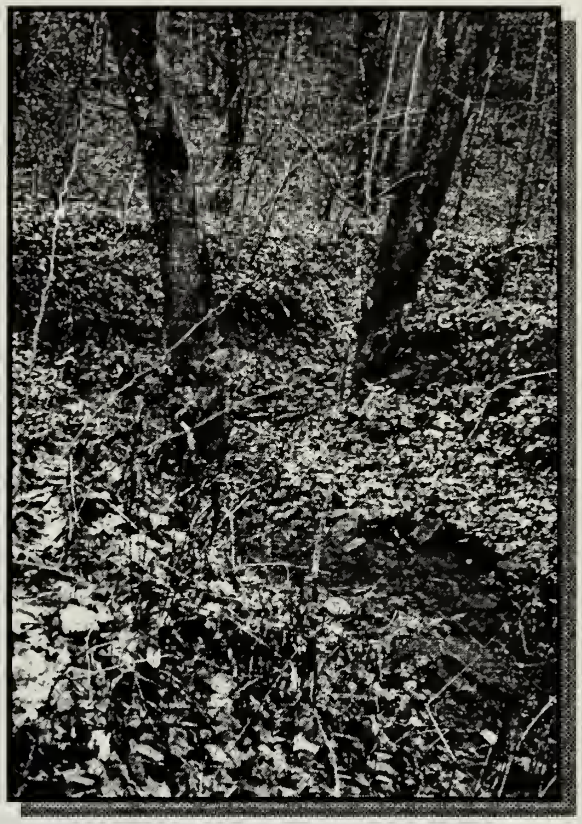


Plate 8. Three West Hollow and CMD discharge emanating from spoil.

Water quality data collected at the mouth of Three West Hollow, station number SSPII TWH01, from the Phase I and II monitoring program are summarized in Table 24. Monitored pH varied from 4.7 to 6.0, contained both non-detectable levels of alkalinity (less than 20 mg/L) and acidity (less than 20 mg/L). Reported iron, aluminum and manganese concentrations were all well less than 1 mg/L. Zinc was the only trace metal repeatedly detected at the Three West Hollow monitoring point, but a concentrations less than 0.025 mg/L. Copper was the only other trace metal measured, but only on three occasions and at concentrations near analytical detection limits.

6.1 <u>Remediation Recommendations</u>

The remediation methods available for mitigating the water quality impacts on the Big South Fork River associated with the Three West Hollow CMD discharges include both site remediation and treatment BMPs. The multiple discharges from mine spoil well up in the Three West Hollow watershed would make site remediation and treatment of individual discharges costly and difficult, due to the limited accessibility to this area. In addition, site remediation may only have limited success in reducing CMD flow and/or strength. Therefore, treatment and site remediation BMPs identified for the Three West Hollow are for the stream and CMD discharge in close proximity to the river's floodplain. The identified BMPs include:

- Reduction of CMD production by construction of a stable lined stream channel to minimize infiltration of the stream into the mine spoil;

- Instream treatment of Three West Hollow using active treatment systems (e.g., chemical dosers);

- Instream treatment of Three West Hollow using passive treatment systems (e.g., limestone sand dosing);

- Treatment of the lower discharges (i.e., Mine #s 45, 46 and 47) using active treatment systems (e.g., chemical doser);

- Treatment of the lower discharges (i.e., Mine #s 45, 46 and 47) using passive wetland treatment systems (e.g., vertical flow wetlands);

Operation and maintenance limitations of instream active treatment were discussed for the Laurel Branch Creek. The absence of year round access is the major factor that eliminates the use of a passive hydraulic systems in Three West Hollow; rotary-drums and diversion wells require periodic limestone replenishment to maintain treatment. Based on the access limitations, instream active treatments are not recommended as remediation methods for the Three West Hollow. Two of the other alternatives, instream passive treatment employing a periodic limestone sand application and active treatment of the stream and discharge would also be prohibited because of remoteness of this location.

Passive wetland treatment has been found to successfully treat CMD, however the high pH (greater than 6), absence of acidity and low metals (less than 1 mg/L total iron) of the discharges in the lower area (Mine #s 45, 46, and 47), as indicated by station number SSP46, suggest that passive treatment would be of little value. In addition, passive wetland treatment is not recommended for co-mingled CMD discharge flow and stream flow because the stream flow variability could jeopardize the treatment effectiveness of a passive wetland treatment system. Therefore, passive wetland treatment is not recommended for Three West Hollow.

Based on similarity of water samples collected during the Phase I study at an upstream location (SSP5001) and the downstream location (SSPTWH) , presented in Table 25, preventing the stream from entering the spoil would not have a substantial effect on improving water quality; may only lower than amount of dissolved solids in the water. However, a lined stream channel containing limestone may be beneficial in improving water quality by neutralizing the pH acidity and precipitating metals present in the stream flow. This remediation technique involves construction of a new stream channel that contains an impervious synthetic (e.g., LLDPE) or geo-synthetic liner and limestone rock. The impervious liner will prohibit stream water from infiltrating into the mine spoil and permit the low pH stream water to contact the limestone ($CaCO_3$), thereby providing neutralization of the low pH and metals present in the stream water. Armoring of the limestone is not of concern because of the low metal concentrations in Three West Hollow. Studies by Ziemkiewicz *et al.*(1994) of open limestone

channels indicate the limestone in the channels would continue to provide neutralization after armoring.

6.2 Conceptual Design

Based on the above evaluation, the only alternative suitable to address the Three West Hollow site CMD discharge in the BSFNRRA is construction of a lined channel on top of the mine spoil. This remedial actions will be evaluated for cost and treatment effectiveness (with respect to the water quality objectives).

The conceptual design for the constructed lined channel is depicted in Figure 20. As indicated in this plan view the channel would be located across the existing mine spoil which is approximately 1000 feet in length. This construction will likely require removal of a small amount of mine spoil to grade a channel with a stable slope. A typical cross-section of a lined channel was depicted in Figure 6. The liner costed for this conceptual design is a linear low density polyethylene (LLDPE) material with a thickness of 40 mm with a geotextile fabric placed on top and on the subgrade. The liner will be anchored into the subgrade on each side of the channel as well as the upstream and downstream ends. Limestone will be placed in the channel to provide roughness and stability. The limestone will also provide alkalinity to the contact water, aiding in neutralizing acidity and precipitating metals in the stream water from upstream CMD discharges.

6.3 Preliminary Construction Costs

Construction costs for this remediation will include: mobilization and demobilization; diversion of water during construction; clearing and grubbing; grading of stream channel; disposal of excess mine spoil (if off-site); materials including LLDPE liner, geotextile fabric and limestone; installation of the LLDPE liner, geotextile and limestone, seeding, and erosion and sedimentation control measures. The total construction cost for the Three West Hollow Project, summarized in Table 26, is estimated to be $109,100, based engineering estimates from several recent projects. No cost estimates are provided for removal and disposal of mine spoil since the data in Table 25 indicate the spoil does not negatively impact the water quality in Three West Hollow; therefore, does not pose a toxicity risk to the Big South Fork River.

6.4 Anticipated Water Quality

The lined stream channel will eliminate contact of the Three West Hollow stream with mine spoil which will decrease acid production from this spoil. Data in Table 25 indicates eliminating contact will have a nominal improvement on water quality. However, the limestone in the lined channel will also neutralize acidity from CMD, raise the pH of the water to greater than 6, and maintain aluminum concentrations at less than 0.1 mg/L. Effects of the remediation on trace metal concentrations is uncertain because trace metals were not detected in the discharge, except zinc which was typically found at concentrations less than 0.020 mg/L.

However, increases in pH from the limestone channel and precipitation of iron and aluminum could aid in precipitating trace metals.

Based on the potential performance of the proposed remediation approach for the Three West Hollow CMD discharge, the effluent from the lined channel could comply with all the AWQC benchmarks, except possibly for pH. A number of the parameters including zinc could also comply with the EC_{20} benchmarks. However, parameters including copper and iron are not likely to be lowered to concentrations below EC_{20} benchmarks. In addition, a number of parameters (e.g., cadmium) can not be effectively evaluated because the benchmarks are less than quantifiable concentrations.

7.0 BLAIR CREEK

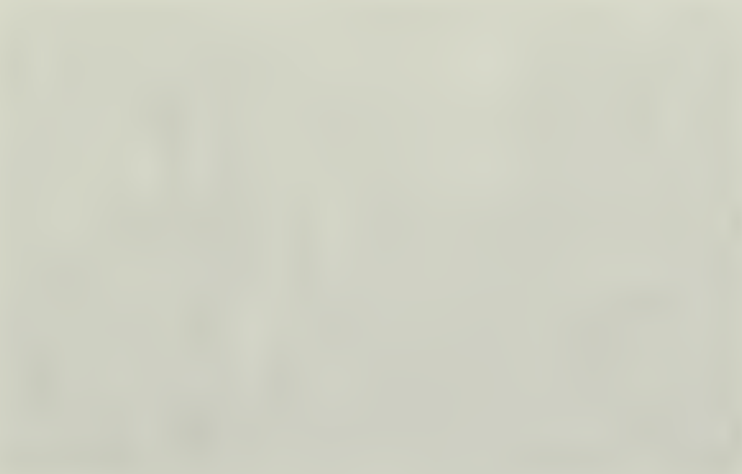
Plate 9. CMD impacted Blair Creek near its confluence with the Big South Fork River.

Blair Creek (see Plate 9) is a tributary to the Big South Fork River located on the eastern side of the watershed in the southern (upstream) portion of the BSFNRRA CMD study area (see Figure 3). Mine drainage in the Blair Creek watershed is from spoil and deep mine areas located approximately ½ mile upstream from the stream's confluence with the river. The mine drainage enters Blair Creek at this location and is conveyed by the stream channel through a densely forested, narrow gorge. Blair Creek contains some brownish-orange colored iron oxide deposits characteristic of an acidic discharge. Site conditions near the confluence of Blair Creek and the Big South Fork River is depicted in Figure 21.

Water quality data collected at the mouth of Blair Creek, station number SSPII BLC01, from the Phase I and II monitoring program are summarized in Table 27. Monitored pH varied from 3 to 5.5 and contained acidity ranging from less than detection to 170 mg/L. Both pH and acidity are related to stream flow with lowest pHs and highest acidities occurring during low flows (similar to Laurel Branch). Aluminum, iron and manganese concentrations appear to be related to discharge flow as well, with higher concentrations occurring at lower flows; reported aluminum, iron and manganese concentrations exceeded 8 mg/L, 20 mg/L and 3 mg/L at the lowest flow, respectively. The trace metal zinc was detected in all samples collected at the Blair Creek location with maximum reported concentrations of 0.11 mg/L occurring during low flows. Copper was also detected in several samples at concentrations well above analytical detection limits. Chromium was detected in several samples but at concentrations near the analytical detection limits.

7.1 Remediation Recommendations

The remediation methods available for mitigating the water quality impacts on the Big South Fork River associated with the Blair Creek discharge are limited to treatment BMPs. The diffuse and multi-point and the remoteness of the discharges in the Blair Creek watershed would likely make site remediation methods very costly and may not successfully reduce CMD flow and/or strength. The treatment BMPs identified for the Blair Creek discharges include:



- Instream treatment of Blair Creek using active treatment systems (e.g., chemical dosers);

- Instream treatment of Blair Creek using passive treatment systems (e.g., limestone sand dosing);

- Treatment of the multi-point discharges using active treatment systems (e.g., chemical doser);

- Treatment of the multi-point discharges using passive wetland treatment systems (e.g., vertical flow wetlands);

Operation and maintenance limitations of instream active treatment were discussed for the Laurel Branch Creek. The Blair Creek flow is also adequate to support use of a passive hydraulic systems such as diversion wells and rotary-drum systems, exceeding the 0.1 cfs minimum (Zurbuch *et al.* 1996). Instream active treatment will precipitate metals (primarily iron and aluminum) in the stream where the solids can accumulate in the substrate and potentially impact benthic habitat. Trace metals (e.g., chromium, copper and zinc) in the CMD may be co-precipitated with iron and aluminum or remain in solution where they may remain potentially toxic to fish and benthic macroinvertebrates. The short distance from the discharge location to the Big South Fork River suggests the metal precipitation would likely occur within the river potentially impacting water quality, benthic habitat, and aesthetics. In addition, the remoteness of the Blair Creek site would limit access for replenishing limestone making continuous treatment highly unpredictable. Therefore, instream active treatment is not recommended as a remediation methods for the Blair Creek.

Active and passive treatment are typically viable alternatives for individual discharges. The Blair Creek discharges are located greater than 2000 ft away from the nearest access point and down a steeply sloped (greater than 10 percent) gorge. Therefore, the remoteness and inaccessibility to the discharge locations prohibits consideration of any treatment at the discharge locations.

Instream passive treatment employing a periodic limestone sand application to an accessible location upstream of the Blair Creek discharge points would provide alkalinity that would neutralize acidity in the discharges. The distance from the discharge points to the mouth of Blair Creek would permit the precipitation of metals (primarily iron and aluminum) in the Blair Creek stream bed. Trace metals may also be co-precipitated or removed through natural attenuation processes in Blair creek , if circumneutral conditions are achieved. However, the solids could be suspended during stormflows in Blair Creek and transported into the Big South Fork River where they may impact benthic communities.

Passive wetland treatment has been found to provide successful treatment of CMD characteristic of the degraded water quality found in Blair Creek. Passive treatment is typically not recommended to treat co-mingled CMD because high stream flows could jeopardize the treatment effectiveness of a passive wetland treatment system. Therefore, instream passive treatment is not recommended for Blair Creek. Treatment of low flows in Blair Creek could be

accomplished by collecting the Blair Creek flow at an upstream location and conveying it to a protected location away from the stream channel. Unfortunately, the elevation of the identified potential treatment area (see Figure 21) along Blair Creek is greater than 50 ft above the stream channel and would require stream diversion several thousand feet upstream; not likely to be feasible in the very narrow and steep gorge found upstream in Blair Creek.

7.2 Conceptual Design

Based on the above evaluation, the only feasible treatment approach to address the Blair Creek CMD discharge to the Big South Fork River is upstream limestone sand addition. This addition would have to be conducted on an annual or semi-annual basis. The location of the application should be at a readily accessible bridge over Blair Creek where stream flow is sufficient to disperse the limestone sand in a downstream direction. A tentative location on Otter Creek Road, an unimproved dirt road off of State Route 742, has been identified.

The amount of limestone to be applied to Blair Creek is based on information from a study by Zurbuch *et al.* (1997) which applied limestone sand to both acid deposition and CMD impacted streams. The study recommends an annual application rate of two times the acid load for first application and one times the annual acid load for subsequent years. The recommendations appear to assume 100 percent limestone sand utilization with no particulate transport or loss from Blair Creek, an overly optimistic consideration particularly given high velocities that are likely during stormflows. In addition, the calculations assume a high purity limestone approaching 100 percent $CaCO_3$ equivalent which may not be available in close proximity to the project; an 85 percent $CaCO_3$ equivalent limestone was assumed for this study. Therefore, a safety factor of 50 percent was added to the application rates to account for this potential loss which results in a rate of 3 times the annual acid load during the first year and a rate of 1.5 times during subsequent years.

The acidity and flow measured in Blair Creek during the monitoring studies were used to calculate an average annual acid load; additional flow and acidity measurements will be required to obtain a better estimate of the Blair Creek average acid load. The acidity loads estimated for Blair Creek ranged from 22 to 560 lbs/day with an average of 227 lbs/day. This equates to an average annual acid load of 42 tons/year and will require limestone sand addition, using a 85 percent $CaCO_3$ limestone, of 125 tons for the first year and 65 tons for each subsequent year.

7.3 Preliminary Construction Costs

The recommended action will require construction of an access point, consisting of a parking/turn-a-round area adjacent to Blair Creek, and application of the limestone sand to Blair Creek in the first year and an additional 24 years. This will make the costs of this proposed action comparable to passive treatment system designs which are based on a 25 year life span.

Table 28 summarizes the costs for the Blair Creek limestone sand addition project for a 25 year period which total $91,400 in 1997 dollars. The majority of the total project costs is associated with the limestone sand, hauling and application to the proposed Blair Creek site. As a comparison, construction cost estimates for a vertical flow wetland system are summarized in

Table 29. The total costs for a wetland treatment system are $240,000 with approximately $90,000 for the temporary roadway to the site and for construction of the channel to convey Blair Creek to the site.

7.4 Anticipated Effluent Quality

The limestone sand application project proposed for Blair Creek utilizes upstream alkalinity addition to neutralize acidity inputs from various CMD discharges located along the stream, but at an inaccessible downstream location. The application of excess limestone sand may also be adequate to produce excess alkalinity and pH greater than 6 at the mouth of Blair Creek. It is anticipated that iron will be oxidized and precipitated, in the presence of the excess alkalinity, to a soluble concentration of less than 0.5 mg/L and soluble aluminum concentrations are expected to be less than 0.1 mg/L at the mouth of Blair Creek. Trace metals will be removed through co-precipitation with iron and aluminum and through natural amelioration in the stream channel. However, the effectiveness of this treatment approach at lowering trace metals, particularly zinc, is uncertain because no information is available for trace metal removal of this technology and information regarding co-precipitation and substrate absorption of trace metals under aerobic conditions is limited.

Blair Creek water quality (see Table 27) at high flow (> 5 cfs) typically had pH greater than 5 and low trace metals; zinc was the only trace metal detected. If high flow water quality can be used as an indicator of potential water quality during low flow after remediation than the Blair Creek CMD discharge could achieve compliance with AWQC benchmarks for all parameters. Compliance with EC_{20} benchmarks is likely for some parameters, but is difficult to evaluate since the benchmarks are less than quantification levels for a number of parameters including copper and cadmium.

8.0 MINE #88 DISCHARGE

Plate 10. Mine #88 CMD discharge and mine entry on the side slope of the Big South Fork River.

The Mine #88 Discharge is located on the eastern side of the Big South Fork River in the northern portion of the BSFNRRA CMD study area (see Figure 3). The discharge emanates from an historic deep mine opening (see Plate 10), with a visible entrance, on the slopes of the watershed and is conveyed to the river via an existing channel to a ponded area along the abandoned rail road. The discharge travels in a ditch along the railroad, passes under the railroad in culverts, and discharges into the river at two separate locations. The mine entrance is approximately 5 feet high and slopes downward from the entrance, along the existing coal seam, and is flooded a short distance from the mine entrance. The entrance is protected from entry by steel bars. Site conditions in the vicinity of the Mine #88 CMD discharge are depicted in Figure 22.

Water quality data at the Mine #88 Discharge from the Phase I and II monitoring program are summarized in Table 30. The pH of this deep mine discharge varied from 5 to 5.5 with acidities ranging 300 to 500 mg/L. Aluminum concentrations were less than 1 mg/L, a result of the relative high pH of the discharge. Iron concentrations were high exceeding 200 mg/L in all samples which based on the pH of the samples would likely be predominately in the form of ferrous iron. Manganese was found at moderately low concentrations in the range of 10 mg/L. The only trace metal detected in all samples was zinc at concentrations of approximately 0.1 mg/L. Arsenic, chromium and copper were detected in one or more samples but at concentrations in the vicinity of analytical detection.

8.1 Remediation Recommendations

The possible remediation methods available for resolving the water quality impacts on the Big South Fork River associated with the Mine #88 discharge are limited to treatment BMPs capable of generating alkalinity and removing iron. Treatment BMPs capable of generating alkalinity to neutralize acidity in the Mine #88 discharge include:

- Treatment of the Mine #88 CMD discharge using active treatment systems (e.g., chemical doser);

- Treatment of the Mine #88 CMD discharge using passive wetland treatment systems (e.g., ALD and/or vertical flow wetlands); and

- A wet mine seal.

Active treatment of the Mine #88 discharge is a viable alternative if a settling basin is provided in the active treatment design. Active treatment with settling will remove iron and aluminum, as well as trace metals from the Worley Branch CMD discharge. However, the high degree of operation and maintenance to sustain treatment, such as electricity and chemical feeding would limit the success of this alternative. In addition, the flow is insufficient to drive more passive systems, e.g., rotary drum and diversion wells. Most of the active treatment systems available also require periodic dredging of settling ponds, which may prohibit the use of active treatment at limited access location such as the Mine #88 location.

Passive wetland treatment has been found to provide successful treatment of CMD characteristic of the degraded water quality found in the Mine #88 CMD discharge. However, the site characteristics (i.e., steeply sloped embankments, existing railroad and Big South Fork River floodplain) limit the available area for treatment. Passive treatment of the Mine #88 CMD discharge will require a passive treatment system capable of generating alkalinity as well as oxidizing and precipitating high iron concentrations. Alkalinity generating treatment technologies identified in Section 1.4 include ALD, surface flow anaerobic wetland and anaerobic vertical flow wetland designs.

The low aluminum (less than 1 mg/L) and high ferrous iron ratio (approaches 100%) measured in the Mine #88 discharge indicates the ALD technology would be appropriate. However, acidity levels reported for the Mine #88 discharge exceed the alkalinity generating potential of an ALD by more than 250 mg/L and, therefore, would only partially treat the Mine #88 CMD discharge; unless an ALD is used in conjunction with some other alkalinity generating system (e.g., anaerobic surface flow and vertical flow wetlands). In addition, an ALD of approximately 0.2 acres would be required to treat the Mine #88 flow which is in excess of the area available outside the floodplain. Therefore, the ALD technology can not be recommended as a viable treatment option

The anaerobic vertical flow wetland design would be capable of providing alkalinity and treating the acidity levels found in the Mine #88 discharge. Anaerobic conditions provided in the vertical flow design will also be required to lower trace metal concentrations; zinc was found at concentrations greater than the detection limits in the Mine #88. However, the required treatment area for this technology would be 1.2 acres if employed alone, and 0.7 acres if employed in conjunction with an ALD, both of which exceed available area. In addition, the high iron concentrations, in excess of 100 mg/L, would require additional area for pre-treatment to lower iron concentrations to levels that will not interfere with the vertical flow design. This indicates the vertical flow technology, as well as other passive wetland treatment technologies, is not a viable treatment option for the Mine #88 discharge.

A mine seal is also a possible remediation alternative for the Mine #88 discharge because it is associated with an open sloped mine entry. A wet mine seal would allow passage of water from the mine pool while preventing oxygen from entering the mine complex where it can

oxidize ferrous iron to ferric iron. However, a wet mine seal would do little to change discharge flows or water quality of the Mine #88 discharge because field observations indicate the mine entry is flooded a short distance from the entryway. A hydraulic mine seal, discussed in section 1.1.3, would prevent flow from the mine entry and, thereby, would eliminate the Mine #88 discharge. However, release of this discharge at another location is possible (and likely) if the Mine #88 complex is inter-connected with other deep mines or contains airway or portals and would require additional remedial activities. Additional, hydrogeologic investigations would be required to evaluate the appropriateness of the hydraulic mine seal alternative. In the absence of this required information, the hydraulic mine seal will not be considered further.

8.2 Conceptual Design

The above evaluation indicates there is insufficient area to apply any of the passive treatment technologies to treat the Mine #88 discharge. However, there has been some recent research conducted by Rose *et al.* (1996) that may be applicable to completely or partial remediate the Mine #88 discharge. The Rose *et al.* study injected organic waste into an open mine shaft and found this approach to lower ferric iron and aluminum of the discharge to levels that would permit use of the ALD technology. In addition, this study also demonstrated the approach lowered the strength of the mine drainage by raising pH and decreasing acidity which was attributed to the reducing environment and sulfate reduction created by the organic substrate. This indicates that injecting organic substrate into the mine complex would have beneficial effects on the discharge water quality.

A modification of this approach would be to inject an organic substrate and limestone mixture into the mine entry in an amount adequate to treat the discharge. Treatment would be accomplished by sulfate reduction to precipitate iron as a sulfide and by solubilizing limestone to produce alkalinity. Each 1 mg/L of iron removed as an insoluble sulfide mineral would have a corresponding 1½ to 2 mg/L decrease in acidity. In addition, the decomposition of the organic substrate would release carbon dioxide that would increase the solubility of limestone and result in higher alkalinity than typically released by ALDs. A wet mine seal would also be constructed on the mine entrance to flood the remainder of the mine complex and prohibit oxygen from entering the mine where it could affect the anaerobic processes.

No design information is available for this innovative approach, but design information from ALD and vertical flow technologies can be applied to provide approximate estimates of the volume of material to be used and the length of the mine entry that will be filled in this approach. The design guidance for ALDs have between 8 and 16 hours of contact time to achieve alkalinities approaching maximum concentrations (Hedin *et al.* 1994). Subsurface flow wetland treatment systems typically have 16 to 48 hours detention time in the organic and limestone layers to remove acidity and generate alkalinity (Dietz *et al.* 1993a). Based on this information the organic substrate and limestone material sufficient to have an initial 16 hour detention time would be 360 yd^3 (270 m^3) and 400 tons (363 metric tons), respectively. The total volume of material to be placed in the mine entry would be approximately 760 yd^3 (570 m^3); actual amounts of materials will be based on mine entry dimensions. Because of the uncertainty associated with this experimental approach, volumes of limestone and organic substrate were not increased to

account for annual substrate losses, typically considered in ALD and vertical flow wetland design.

It is likely this approach will remove acidity and iron from the Mine #88 CMD discharge and produce alkalinity sufficient to produce a circumneutral pH discharge. However, complete removal of iron is unlikely and will require a settling pond for oxidation and precipitation of iron, as an oxide, to lower iron to levels that will minimize impacts on the Big South Fork River. In addition, because of uncertainties associated with acidity removal, an open limestone channel is recommended to convey the discharge from the settling pond to the river. This later component should provide additional alkalinity to neutralize acidity and precipitate iron remaining in the Mine #88 CMD discharge.

The conceptual design for this approach is depicted in Figure 23. The area depicted in the Mine #88 entry for placement of the organic substrate and limestone mixture is presented for conceptual purposes only and does not represent actual mine entry configuration; Mine #88 configuration would be estimated during final design. A settling pond would be located at the base of the slope, open water with approximately 4 to 5 feet depth, and contain a surface area of 2,500 ft^2 (230 m^2); sufficient to provide approximately 24 hours detention time. An open limestone channel would be similar in cross-section to the lined channel depicted in Figure 6 and would be approximately 1,000 feet in length.

8.3 Preliminary Construction Costs

Construction costs for this remediation will include: mobilization and demobilization; construction of an access road to the site; care of water during construction; clearing and grubbing; injection of organic substrate and limestone mixture into the Mine #88 entry; installation of a wet mine seal; grading associated with settling pond and limestone channel construction; limestone and an organic substrate (e.g., spent mushroom compost); miscellaneous materials; seeding of exposed soils; and erosion and sedimentation control measures. Table 31 summarizes the anticipated costs for the Mine #88 project which total $215,350 in 1997 dollars. The majority of the total project costs is associated with the limestone, organic substrate and injection of the mixture into the mine entry.

8.4 Anticipated Effluent Quality

The innovative passive treatment approach proposed for Mine #88 discharge utilizes an anaerobic/alkalinity addition process in the mine entry, a precipitation and settling basin for iron removal, and an open limestone channel for alkalinity addition and iron removal. Because the proposed remediation activity for the mine entry employs an untried and unproven approach, the performance of is unknown and effluent quality can not be determine, however, the proposed remediation will, at a minimum, significantly lower the acidity and iron contained in the CMD discharge. In addition, trace metals will be removed in the anaerobic conditions of the mine entry, potentially lowering trace metals to less than water quality standards at the effluent; removal amounts could approach documented removal for anaerobic wetland treatment systems.

The proposed passive treatment system also employs a settling pond and the new OLC design for which there is minimal design and performance information. These two components of the treatment system can be expected to remove acidity, raise pH, and decrease iron concentrations, thereby further improving effluent quality. However, the effectiveness of these two components will be effected by of the mine entry component performance. Therefore, there is considerable uncertainty regarding this innovative technology's ability at achieve effluent performance goals.

It is anticipated that effluent trace metal quality from the proposed remediation may comply with AWQC benchmarks and at a minimum the proposed remediation could successfully achieve AWQC in the Big South Fork River for all parameters. Compliance with EC_{20} benchmarks may be achieved in the Big South Fork for a number of parameters including pH, aluminum, and zinc, but not for parameters including iron. A number of parameters can not be evaluated for compliance because the benchmarks are less than quantifiable concentrations.

9.0 LAUREL BRANCH SPOIL

The Laurel Branch Spoil site is located to the north (downstream) of Laurel Branch Cr in the southern section of the study area (see Figure 3). The site contributes CMD pollutants directly to the Big South Fork River from diffuse discharges associated with discarded mine spoil from historic deep mining that occurred well up on the side slopes of the watershed. The mine spoil is located adjacent to the river, comprising the stream banks in several areas, and is approximately 1 to 2 acres in total area (see Plate 11). The mine spoil at this site is moderately to poorly vegetated with steeply sloping areas containing barren spoil in both up slope area and areas adjacent to the river. In addition, evidence of pyrolized spoil at the base of unpyrolized spoil is in contact with river water; visible at low river stage.

Plate 11. Laurel Branch Spoil area along the banks of the Big South Fork River.

Water quality data at the Laurel Branch Spoil from the Phase I and II monitoring at sampling station number SSPII LBC01 are summarized in Table 32. The results indicate pH varied from 2.5 to 3 with moderate to high acidities ranging from 300 to 1300 mg/L. Aluminum and iron were both elevated in the discharge exceeding 10 and 75 mg/L, respectively. The trace metals chromium, copper, lead and zinc were measured in all samples at this location at concentrations well above detection limits. Cadmium and lead were detected on several dates at this location but at levels near detection limits.

Examination of the mine spoil area indicate the CMD emanates from several locations near the base of the spoil in areas that are subject to flooding by seasonal high waters of the Big South Fork River. The spoil area above the river channel is relatively flat and contains planted 10 to 20 year old scotch pine. Upslope areas are steeply sloped and poorly vegetated with some unstable areas subject to erosion and mass wasting. The spoil areas may receive direct precipitation and overland runoff from adjacent upslope areas which can infiltrate into the mine spoil. This uncontaminated rainwater and runoff would infiltrate into the mine spoil where reactions with the acid-forming minerals in the mine spoil could result in the CMD discharges identified at the Laurel Branch Spoil site.

9.1 Remediation Recommendations

The possible remediation methods available for resolving the water quality impacts on the Big South Fork River associated with the Laurel Branch Spoil are limited to site reclamation and

water source control activities. The location of the discharge on the stream bank of the river is below the high water river stage and prohibits treatment and/or collection of the discharge for treatment at another area. The identified site reclamation and water source control BMPs for the Laurel Branch Spoil discharge include one or several of the following:

- Removal of the acid-producing materials through excavation and disposal of mine spoil from the site; and
- Regrading and revegetation of mine spoil areas (or the site after the acid-producing materials have been removed);
- Placement of a dry (e.g., geomembrane, fly ash, clay and/or soil) cover on top of the mine spoil;
- Construction of stormwater interceptor channels to collect and divert runoff from the mine spoil; and
- Installation of a vertical barrier (e.g., injected grout) along the exposed face of the mine spoil.

One of the above identified alternatives could be used singly or in conjunction with others for the Laurel Branch Spoil. For this evaluation the possible alternatives, called actions, were individually evaluated creating a list of options and there likely effects at reducing pollutant loading from the site through either decreases in acid production and/or flow.

9.1.1 Action 1 - Removal of Spoil

Removal of the spoil from the Laurel Branch Spoil site was identified as an alternative by the Steering Committee. This option would involve: excavation of all mine spoil from the site, down to pre-mining grades; regrading and revegetation of the Laurel Branch Spoil site once the spoil has been removed; and regrading, dry cover placement (geomembrane liner), and revegetation of the identified disposal site. The disposal site identified by the Committee is a 30 acre abandoned surface mine located within 60 miles of the Laurel Branch Spoil site.

Removal of the spoil from the Laurel Branch Spoil site would involve excavation and hauling of the spoil in methods similar to surface mining or gravel excavation. The volume of the material to be excavated is approximately 40,000 cubic yards; based on the total surface area of 1 acres and an estimated 25 feet average spoil depth; based on observed spoil height adjacent to the Big South Fork River and surrounding topography. The project will also incur costs associated with: construction of a roadway to the Laurel Branch Spoil site; clearing and grubbing of the Laurel Branch Spoil and disposal sites; revegetation of the Laurel Branch Spoil site; regrading and revegetation of the disposal site; placement of a dry cover at the disposal site; and placement of a soil cover on the disposal site. Activities at the disposal site were prorated based on the amount of material to be disposed.

The preliminary total cost estimates for the spoil removal action are approximately $300,000, based on a disposal cost of $7.25 per cubic yard that was developed for the Blue Heron Spoil site. This estimate is appropriate if this proposed removal alternative occurs as part of the removal alternative at the Blue Heron Spoil site. Costs of removal and disposal would be substantially higher if this project were undertaken solely without the Blue Heron disposal alternative.

9.1.2 Action 2 - Regrading and Revegetation

The Laurel Branch Spoil is dominated by mature evergreens with canopy coverage approaching 100 percent. However, the underlying soil is poorly vegetated or barren. The Laurel Branch Spoil also contains level areas where stormwater may collect and infiltrate into the spoil. Regrading of the site to minimize infiltration and revegetation with herbaceous plants to eliminate barren spoil will be beneficial in reducing discharge flow by lowering infiltration of water and oxygen into the spoil, thereby increasing water retention in the soil layer, increasing evapotranspiration, and decreasing pyrite oxidation. Robertson and Barton-Bridges (1990) indicate that a 1½ and 3 ft soil cover would lower acid generation by approximately 30 and 50 percent, primarily through lower infiltration of water into the spoil.

Reclamation at the Laurel Branch Spoil area would require clearing and grubbing of existing vegetation which could be mulched and incorporated into the soil cover. Regrading would involve earthmoving of existing spoil, including excavation of spoil from up slope areas, to obtain stable slopes that minimize erosion while inhibiting infiltration and standing water, and removal of spoil from the river bank to lessen contact with the river. A 1½ ft soil cover would be placed on top of the regraded site which could be developed from low cost materials such as fly ash and/or waste organics (e.g., paper mill, vegetable tanning and municipal wastewater stabilized sludge). The site would be seeded with a grass and herbaceous seed mix to permit rapid revegetation, thereby, stabilizing slopes and minimizing erosion losses. Agricultural fertilizers and limestone would be applied during seeding and periodically after reclamation to maintain an adequate vegetative cover. The alkaline material could also be beneficial in buffering the small amount of infiltrating water that passes through the soil cover.

Based on the cost estimate for the Blue Heron Spoil area, reclamation costs per acre are approximately $40,000. This indicates the total costs for reclamation of the 1 to 2 acres at the Laurel Branch Spoil site would be between $40,000 and $80,000 depending on the total area requiring reclamation and soil cover.

9.1.3 Action 3 - Dry Cover Placement

This action involves placement of a geomembrane liner on top of the spoil throughout the Laurel Branch Spoil site. Placement of the liner would minimize the vertical infiltration of water and oxygen into the mine spoil, but would not effect lateral water and oxygen transport through the spoil face along the river. The effectiveness and long term integrity of a liner on slopes subject to high floodwater and erosional forces along the banks of the Big South Fork River would have to be evaluated.

Liner installation will require a soil cover, to be placed on top of the liner, to protect the liner from environmental forces (e.g., UV breakdown) and prevent tearing and punctures of the exposed liner. A soil cover depth of 3 ft is recommended to ensure the liner remains covered over the entire site. The slope of the spoil adjacent to the Big South Fork River may prohibit installation of a liner, as well as the liner may eventually become exposed and destroyed along this highly unstable slope. In addition, this action will not lower CMD produced from lateral transport of river water into the spoil and the horizontal recharge of groundwater from surrounding areas. The action will also require clearing and grubbing, regrading and revegetation of the site.

Based on the Blue Heron Spoil site, a cost of $80,000 per acre of spoil receiving a dry cover would be representative. This equates to an estimated total cost of between $80,000 and $160,000 for this action at the Laurel Branch Spoil site.

9.1.4 Action 4 - Removal and Diversion of Surface Water

The presence of near level and standing water on the Laurel Branch Spoil may contribute water to the acid-producing spoil. The Laurel Branch Spoil site also lacks control of surface runoff that may enter the site from up slope undisturbed areas and infiltrate into the spoil, adding to the volume of CMD produced by the site. Measures to control the infiltration of uncontaminated water into the Blue Heron Spoil through may help reduce the volume of CMD produced by the site. The effectiveness of the measures are dependent on the volumes of water infiltrating into the spoil, estimated at approximately 5 gpm in the Phase I report (Appendix C). Surface water control measures have successfully reduced CMD production at other sites from 10 to 100 percent.

This action would require two separate control measures: 1) grading to minimize standing water and promote runoff; and 2) construction of interceptor channels at the edge of the spoil, along the steeply-sloped undisturbed areas, to capture surface runoff and convey it away from the spoil and down slope to the Big South Fork River. The grading component would be included as part of the Regrading and Revegetation Action. The interceptor channels will be similar in cross-section as depicted in Figure 6 and will include limestone as the rock material.

The costs for this action involves channel construction, approximately 400 linear feet, and minor grading to improve drainage from the site. Based on cost estimates for the Blue Heron diversion of surface water action, the costs for the Laurel Branch Spoil site would be between $20,000 and $40,000.

9.1.5 Action 5 - Installation of Vertical Barrier

The open exposed spoil along the Big South Fork River may permit infiltration of uncontaminated water from the river, during high river stage, into the spoil where it may be substantially degraded upon contact with acid-bearing rock material. The open face is likely a major contributor of oxygen, a necessary agent in the oxidation of pyrite, to the spoil resulting in the production of CMD and may also contribute to higher spoil temperatures (and pyrite oxidation rates) by allowing cooler ground temperatures to escape from the spoil. Formation of a

vertical barrier, through injection of grout, along this face may provide substantial reduction in CMD production.

The action would create a vertical concrete barrier that would have a lower permeability than existing spoil conditions, thereby inhibiting water from the Big South Fork River from infiltrating into the spoil. The vertical barrier could also decrease water movement from the spoil which would increase saturated conditions in the spoil and decrease CMD production by decreasing the oxidation of pyrite in the spoil. The alkaline nature of the grout would also neutralize acidity in CMD that comes in contact with it.

The spoil face will be drilled to develop a line of bore holes at regular intervals (10 to 20 ft) along the face of the spoil. Each bore hole will be injected with a liquid grout, to permit the material to fill the voids in the spoil, comprised of fly-ash, concrete, water and solidifying agents. The number of wells required to develop the vertical barrier will likely range between 30 and 40 with an average depth of 50 ft. The vertical barrier would have an approximately width of 5 to 10 feet and 300 to 500 ft length along the river.

Based on the Blue Heron Spoil site the total costs for this action at the Laurel Branch Spoil site are estimated to be $60,000 to $100,000.

9.2 Conceptual Design

The recommended remediation measures for the Laurel Branch Spoil site include diversion and control of surface waters, regrading and reclamation. These actions will likely reduce the CMD produced by the Laurel Branch Spoil site by 60 to 80 percent for a total cost estimate of $60,000 to $120,000. More aggressive actions including spoil removal, dry cover placement, vertical barrier do not appear to be warranted because of the high cost to achieve additional CMD decreases over the recommended actions; the additional 20 to 40 percent would require additional expenditures in excess of $250,000.

9.3 Anticipated Water Quality

It is anticipated that the remediation methods will effect the Laurel Branch Spoil discharge by lowering their volume and strength. However, remediation methods success are highly variable and difficult to quantify.

The recommended removal and diversion of surface water action could lower CMD discharge volumes by 10 to 25 percent. Reclamation methods could lower the CMD discharges from the site by between 30 and 50 percent. Overall, the remediation methods could lower CMD volumes by between 40 and 75 percent, thereby, reducing CMD loading to the Big South Fork River. Application of limestone to the site will provide alkalinity to buffer the rate of CMD production and neutralize CMD produced with an assumed long term CMD concentration reduction of 10 to 20 percent. It is anticipated this remediation could decrease the CMD strength by between 25 and 50 percent with chromium and lead lowered to below detection limits and copper and zinc concentrations lowered by approximately 50 to 80 percent, levels that would approach but not achieve compliance with AWQC.

Based on the above evaluation the recommended remediation and control measures for the Laurel Branch Spoil site could lower acidity loading from the sites by 50 to 95 percent and trace metal loading will decrease by up to 100 percent, depending on the specific trace metal. Evaluating performance of remediation based on water quality monitoring results may not be permissible because one or more of the proposed actions described may change flow patterns in the spoil and the variability in water quality data from the monitoring studies (for example: total iron varied from 11 to 360 mg/L at SSPII LBC01) may mask actual beneficial improvements.

The types of discharges and improvements associated with the proposed actions also effect evaluation of compliance with the water quality benchmarks. Upstream and downstream samples in the Big South Fork indicate frequent to occasional aluminum, copper and iron levels that exceed the AWQC and EC_{20} benchmarks. Based on the above evaluation, the proposed remediation actions will lower the impacts of the Laurel Branch Spoil Site on the Big South Fork River water quality possibly decreasing presently measured concentrations incrementally closer to instream compliance with AWQC and EC_{20} benchmarks.

10.0 NANCY GRAVES CREEK

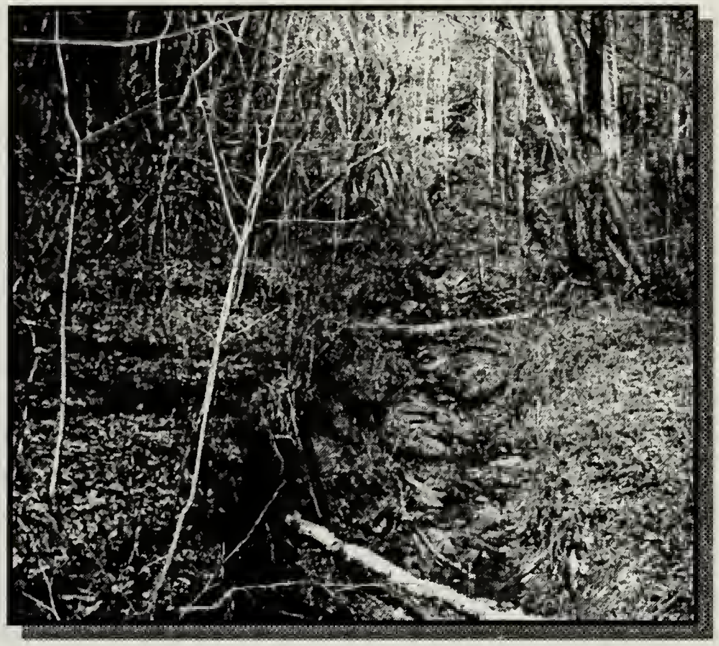


Plate 12. One of the CMD discharge to Nancy Graves Creek.

Nancy Graves Creek is a tributary to the Big South Fork River located on the western side of the watershed in the northern (downstream) portion of the BSFNRRA CMD study area (see Figure 3). Mine drainage enters Nancy Graves Creek from three sources, a channel that flows overland from an up slope mining area along the north slope of the stream (see Figure 24), Mine #60 drainage on the north slope, and overland flow from the Mine #59 spoil on the south slope. The channel conveys mine drainage from a collective collapsed mine and spoil area located well up on the slopes to Nancy Graves (Plate 12). The Nancy Graves Creek channel contains brownish-orange colored iron oxide deposits characteristic of an acidic discharge.

Water quality data collected at the mouth of Nancy Graves Creek, station number SSPII NGC01, from the Phase I and II monitoring program are summarized in Table 33. Monitored pH varied from 2.8 to 4.1 and contained varying levels of acidity (18 to 270 mg/L) that appears to be related to stream flow with lowest pHs and highest acidities occurring during low flows. Aluminum, iron and manganese concentrations also appear related to discharge flow with higher concentrations occurring at lower flows; reported aluminum, iron and manganese concentrations exceeded 10 mg/L at the lowest flows. The trace metals zinc and copper were repeatedly detected at the Nancy Graves location with maximum reported concentrations of 0.21 mg/L and 0.015 mg/L, respectively. Chromium was also detected from the Nancy Graves station but only in one sample and at a concentration near the detection limit.

10.1 Remediation Recommendations

The remediation methods available for mitigating the water quality impacts on the Big South Fork River associated with the Nancy Graves discharge are limited to treatment BMPs. The diffuse and multi-point discharges at the Nancy Graves site would likely make site remediation methods very costly and may only have limited success in reducing CMD flow and/or strength. The treatment BMPs identified for the Nancy Graves discharges include:

- Instream treatment of Nancy Graves using active treatment systems (e.g., chemical dosers);
- Instream treatment of Nancy Graves using passive treatment systems (e.g., limestone sand dosing);
- Treatment of the multi-point discharges using active treatment systems (e.g., chemical doser);
- Treatment of the multi-point discharges using passive wetland treatment systems (e.g., vertical flow wetlands);

Operation and maintenance limitations of instream active treatment were discussed for the Laurel Branch Creek. The Nancy Graves flow is also inadequate to support use of a passive hydraulic systems such as diversion wells and rotary-drum systems; rotary-drums require a minimum of 0.1 cfs to operate on a continuous basis (Zurbuch *et al.* 1996). Instream active treatment will result in precipitation of metals (primarily iron and aluminum) in the stream where the solids can accumulate in the substrate and potentially impact benthic habitat. Trace metals (e.g., copper and zinc) in the CMD may be co-precipitated with iron and aluminum or remain in solution where they may remain potentially toxic to fish and benthic macroinvertebrates. The short distance from the discharge location to the Big South Fork River suggests the metal precipitation would likely occur within the river potentially impacting water quality, benthic habitat, and aesthetics. Based on the above limitations, instream active treatment is not recommended as a remediation method for the Nancy Graves Creek.

Active treatment of the multi-point discharge is a viable alternative if a settling basin is provided in the active treatment design. Active treatment with settling will remove iron and aluminum as well as trace metals from the Nancy Graves CMD discharge. However, operation and maintenance limitations, similar to discussed for instream active treatment, but also including periodic dredging of settling pond, would prohibit the use of active treatment of the discharge at this remote location.

Instream passive treatment employing a periodic limestone sand application to a location downstream of the discharge to Nancy Graves would likely result in significant accumulation of metals in the Big South Fork River. In addition, the short distance to the river may be insufficient for the limestone sand to completely react with the acidity resulting in water quality impacts. Limited access to the Nancy Graves location may also create problems in replenishing the limestone sand on a periodic basis.

Passive wetland treatment has been found to provide successful treatment of CMD characteristic of the degraded water quality found in the Nancy Graves discharges. However, passive treatment is not recommended to treat co-mingled CMD discharge flow and stream flow because the stream flow variability could jeopardize the treatment effectiveness of a passive wetland treatment system. Treatment of the multi-point CMD discharge can be accomplished by collecting the discrete points and conveying them to a common location; such as the identified potential treatment area (see Figure 24).

Treatment of the Nancy Graves CMD discharges will require a passive treatment system capable of generating alkalinity and removing conventional (i.e., iron and aluminum) and trace (e.g., copper and zinc) metals. Alkalinity generating treatment technologies identified in Section 1.4 include ALD, surface flow anaerobic wetland and anaerobic vertical flow wetland designs. The elevated aluminum (17 mg/L) and high ferric iron (20 mg/L) measured in the discharge indicates the ALD technology would be inappropriate. The anaerobic surface flow wetland design would be capable of providing alkalinity but the required treatment area for this design would likely exceed available area. The remaining technology, anaerobic vertical flow wetland, is capable of treating the acidity levels found in the Nancy Graves discharge and providing excess alkalinity. In addition, the anaerobic conditions provided in this design have been found to lower the trace metals copper (0.015 mg/L) and zinc (0.2 mg/L) present in this discharge. Therefore, the anaerobic vertical flow wetland design is recommended as the technology of choice to treat the Nancy Graves discharge.

10.2 Conceptual Design

Based on the above evaluation, only passive wetland treatment is suitable to address the Nancy Graves Creek CMD discharge. Of the passive wetland treatment technologies available, anaerobic vertical flow wetland design is most appropriate to treat the Nancy Graves CMD discharge.

The conceptual design for the anaerobic vertical flow wetland and conveyance channel is depicted in Figure 25. As indicated in this plan view a collection channel will convey the diffuse and multi-point CMD discharges across the slope to the anaerobic vertical flow wetland located at the potential treatment area, a distance of approximately 200 feet. The proposed conveyance channel will be a geotextile-lined channel containing limestone material, similar to the channel depicted in Figure 6. In addition limestone will be added to the Nancy Graves Creek channel to provide neutralization of CMD entering the creek from the southerly slope, Mine #60 discharge.

The three Nancy Graves CMD discharges were sampled only during the BSFNRRA characterization study (Phase I Report). Phase II sampling focused on water quality of the Nancy Graves Creek downstream of the various CMD inflow points; sample from 10/17/96 during the Phase II may be representative of the CMD discharge. Additional sampling will be necessary to characterize the discharges prior to final design. In the absence of this data, a CMD discharge flow rate of 30 gpm will be used to develop the conceptual design; estimated based on data collected from Nancy Graves Creek, the CMD discharge chemistry and employing a mass balance equation. Applying this flow rate to the CMD water chemistry data for the discharge results in an acid loading of 44,150 GPD which was used to determine the treatment area required for the vertical flow wetland treatment system. Acid loading was used because acid removal is the only parameter for which design information for anaerobic vertical flow wetlands is available. An acidity removal rate of 25 GDM was used to determine total treatment area size. A design model developed by Gannett Fleming was used to determine optimal number of cells and treatment area in each cell within the vertical flow system. The model considers acid loading, hydraulic detention time and effluent quality from the vertical flow wetland treatment

cell (assumed alkalinity of 100 mg/L from the underdrain of vertical flow wetland treatment systems).

A single cell, vertical flow wetland treatment system would require 14,000 ft^2 of treatment area to adequately treat (i.e., acidity = 0 mg/L and alkalinity > 0 mg/L) CMD discharge on Nancy Graves Creek. A multi-cell vertical flow wetland that would achieve this same effluent alkalinity would consist of two cells, each cell containing 6,250 ft^2. The total treatment area of the multi-cell system is 12,500 ft^2 a greater than 10 percent reduction in treatment area which will likely be reflected in a decrease in project cost. In addition, the long term operation and treatment effectiveness is likely to be improved in a multi-cell system containing redundant components.

10.3 Preliminary Construction Costs

Construction costs for this remediation will include: mobilization and demobilization; care of water during construction; clearing and grubbing; grading associated with channel and treatment cell construction; piping (e.g., underdrain system); limestone and an organic substrate (e.g., spent mushroom compost); miscellaneous materials; seeding of exposed soils; and erosion and sedimentation control measures. Table 34 summarizes the anticipated costs for the Nancy Graves project which are based engineering estimates from several recent projects. No cost estimates are provided for required fill for construction of the treatment system and/or disposal of excess material since these quantities are unknown and determined during final design.

10.4 Anticipated Water Quality

The passive treatment systems for the Nancy Graves discharge utilizes the anaerobic vertical flow design capable of removing acidity and producing excess alkalinity. Acidity was used as the design parameter for the conceptual systems because it is the only available guidance for design of this technology. The number of cells and size of the conceptual designs were developed to produce net alkaline water at average loading conditions, which should result in complete removal of acidity, a circumneutral pH, and aluminum less than 0.1 mg/L. It is anticipated that iron will be decreased to less than 0.5 mg/L in the multi-cell design. Trace metals will be removed in the anaerobic environment of the vertical flow treatment cells and based on the flow passing through the underdrains, approximately 25 gpm of the discharge flow, copper and zinc concentrations will be decreased by more than 75 percent.

The level of treatment should result in the majority of parameters, including copper and zinc, to be in compliance with the AWQC benchmarks, as measured at the effluent from the system. A number of the parameters will also be in compliance with the EC_{20} benchmarks, e.g., aluminum and zinc, but it is not likely that all parameters, e.g., copper and iron, will meet EC_{20} benchmarks. Compliance of other non-detected metals (e.g., cadmium) can not be evaluated because the concentrations are less than analytical quantification levels.

11.0 WORLEY MINE #86 SITE

Plate 13. Mine #86 discharge to Worley Branch Creek.

The Worley Mine #86 Site is located on the eastern side of the Big South Fork River at the northern (downstream) boundary of the BSFNRRA study area (see Figure 3). The Mine #86 CMD discharge enters Worley Branch a short distance, approximately 600 feet, upstream of the confluence with the Big South Fork River (see Figure 26). The Mine #86 CMD discharge is associated with a collapsed deep mine entry from historic mining that is located near the stream elevation on the southern side slope of the Worley Branch (see Plate 13).

Water quality samples collected from the Mine #86 discharge during the Phase I and II investigation indicates the discharge has a high pH (greater than 5.5) and is moderately acidic with a reported values ranging from 100 to 250 mg/L as $CaCO_3$ (see Table 35). Iron is elevated with concentrations exceeding 100 mg/L and is almost entirely in the form of ferrous iron. Aluminum concentrations in the discharge are very low (less than 1 mg/L) which is likely due to the elevated pH of the discharge; aluminum has a pH dependent solubility.

The pH at the mouth of the Worley Branch from the Phase I and II monitoring program is relatively constant ranging from 5.5 to 6.5 and unlike the other streams (i.e., Laurel Branch and Devils Creek) does not appear to be related to stream flow. Acidity, iron, manganese and zinc show a slight relationship with flow with higher concentrations occurring at lower stream flows. Aluminum is well below 1 mg/L which is the result of the higher pH of the stream and the CMD discharge. The presence of macroinvertebrates immediately upstream of the Mine #86 CMD inflow point suggests the primary source of CMD to Worley Branch is the Mine #86 discharge. The high pH in the Worley Branch, the presence of moderate acidity, and iron as primarily ferrous iron indicates the distance (travel time) to the Big South Fork River is too short to adequately oxidize the ferrous iron and precipitate iron oxide, which would cause a corresponding decrease in pH.

11.1 <u>Remediation Recommendations</u>

The possible remediation methods available for resolving the water quality impacts on the Big South Fork River associated with the Worley Branch discharge include both site remediation and treatment BMPs. The BMPs include:

- Instream treatment of Worley Branch using active treatment systems (e.g., chemical dosers);
- Instream treatment of Worley Branch using passive treatment systems (e.g., limestone sand dosing);
- Treatment of the Worley Mine #86 CMD discharge using active treatment systems (e.g., chemical doser);
- Treatment of the Worley Mine #86 CMD discharge using passive wetland treatment systems (e.g., ALD and/or vertical flow wetlands); and
- A wet mine seal.

Operation and maintenance limitations of instream active treatment discussed for the Laurel Branch Creek site also apply to Worley Branch. The Worley Branch flow is also inadequate to support use of a rotary-drum system which requires a minimum of 0.1 cfs to operate on a continuous basis (Zurbuch *et al.* 1996). Instream active treatment will also result in precipitation of metals (primarily iron and aluminum) in the stream where the solids can accumulate in the substrate and potentially impact benthic habitat. Trace metals (e.g., copper and zinc) in the CMD may be co-precipitated with iron and aluminum or remain in solution where they may remain potentially toxic to fish and benthic macroinvertebrates. The short distance from the Worley Mine #86 discharge location to the Big South Fork River suggests that the metal precipitation would likely occur within the river, potentially impacting water quality, benthic habitat, and aesthetics within a portion of the river that already exhibits considerable degradation. Based on the above limitations, instream active treatment methods are not recommended as a remediation method for the Worley Branch.

Active treatment of the Worley Mine #86 discharge is a viable alternative if a settling basin is provided in the active treatment design. Active treatment with settling will remove iron and aluminum, as well as trace metals from the Worley Branch CMD discharge. However, operation and maintenance limitations, similar to discussed for instream active treatment, and also including periodic dredging of settling pond, may prohibit the use of active treatment at limited access location such as the Worley Branch location.

Instream passive treatment employing a periodic limestone sand application to a location downstream of the discharge to Worley Branch would be affected by the short distance to the Big South Fork River, which could result in significant accumulation of metals in the river. The high pH and high ferrous iron concentration at the Worley Branch sampling location provides evidence regarding the limited oxidation and precipitation that would likely occur with alkaline addition. In addition, the short distance to the river may be insufficient for the limestone sand to completely react with the acidity in Worley Branch resulting in water quality impacts to areas within the river. Limited access to the Worley Mine #86 Site may also create problems in replenishing the limestone sand on a periodic basis.

Passive wetland treatment has been found to provide successful treatment of CMD characteristic of the degraded water quality found in the Worley Branch CMD discharge. Passive treatment is not recommended to treat co-mingled CMD discharge flow and Worley Branch flow because of the stream flow variability that has been observed for Worley Branch could jeopardize the treatment effectiveness of a passive wetland treatment system. However, the site characteristics (i.e., narrow, steeply sloped channel) limit the available area for treatment if areas in the vicinity of the stream channel are excluded. Therefore, treatment of the Worley Mine #86 CMD discharge will be accomplished within the existing stream channel and by providing bypass of the stream flow (except extreme storm events) around the treatment system.

Treatment of the Worley Branch CMD discharge will require a passive treatment system capable of generating alkalinity as well as oxidizing and precipitating high iron concentrations. Alkalinity generating treatment technologies identified in section 1.4 include ALD, surface flow anaerobic wetland and anaerobic vertical flow wetland designs. The low aluminum (less than 1 mg/L) and high ferrous/ferric iron ratio (approaches 100%) measured in the Mine #86 discharge indicates the ALD technology would be appropriate. However, acidity levels reported for the Mine #86 discharge occasionally approach and/or exceed the alkalinity generating potential of an ALD. This indicates the ALD will have to be used in conjunction with some other alkalinity generating system (e.g., anaerobic surface flow and vertical flow wetlands).

The anaerobic surface flow wetland design would be capable of providing alkalinity but the required treatment area for this design would likely exceed available area. The anaerobic vertical flow wetland is capable of treating the acidity levels found in the Worley Branch Mine #86 discharge, but may be affected by the high iron concentrations which exceed 100 mg/L; therefore use of vertical flow treatment will require pre-treatment to lower iron concentrations. The anaerobic conditions provided in the vertical flow design will also be required to lower trace metal concentrations; zinc was found at concentrations greater than the detection limits in Worley Branch discharge. Therefore, the anaerobic vertical flow wetland design is recommended as the alkalinity generating technology to be used in conjunction with an ALD to treat the Worley Branch CMD discharge.

Pre-treatment to remove iron prior to the anaerobic vertical flow passive treatment system can be accomplished in an aerobic surface flow wetland as long as sufficient oxygen and alkalinity is present to oxidize and precipitate the ferrous iron. Therefore, an aerobic surface flow wetland is also recommended for the passive treatment system as a pre-treatment system before the anaerobic vertical flow wetland.

In addition to the multi-system passive treatment, a wet mine seal is recommended for the Mine #86 discharge because of the presence of ferric iron (occasionally reported for the discharge) which could reduce the effectiveness of the ALD. A wet seal would allow passage of water from the mine pool while preventing oxygen from entering the mine complex where it can oxidize ferrous iron to ferric iron. The mine seal could also aid in stabilizing discharge flows which appear to vary, possibly from clogging of the discharge point in the mine opening with iron oxides.

11.2 Conceptual Design

Based on the above evaluation, a mine seal and passive wetland treatment system appear suitable to address the Worley Branch CMD discharge to the Big South Fork River. As indicated above, the complex nature of the discharge will require use of several types of passive wetland treatment technologies, i.e., ALD, aerobic wetland and anaerobic vertical flow wetland. The conceptual passive treatment system for the Mine #86 discharge is depicted in Figure 27.

The Worley Branch CMD discharge was sampled during the BSFNRRA characterization study (Phase I Report) and the Phase II monitoring. Based on this data, the Mine #86 discharge flow rate averaged 50 gpm and ranged from 10 to 180 gpm. The acidity of the discharge averaged 165 mg/L with a range of 0 to 240 mg/L. Applying the Mine #86 average and maximum flow rate and assumptions and design guidance in Hedin *et al.* 1994 an ALD size was estimated 45,000 ft^2, which was configured as depicted in Figure 27. This ALD would be expected to provide a minimum alkalinity of 150 mg/L over its greater than 25 year life expectancy.

An open limestone channel is located after the ALD to provide aeration of the discharge prior to the aerobic wetland. The aerobic wetland was located following the open limestone channel. The aerobic wetland, containing approximately 10,000 ft^2, was sized based on an average flow, an influent concentration of 100 mg/L, an effluent iron concentration of 30 mg/L (limitation of the vertical flow wetland), and an iron removal rate of 20 GDM (Hedin *et al.* 1994) which is for alkaline waters. The recommended aerobic wetland will be an open water system with approximately 6 feet of depth for long term storage of iron oxide precipitates.

The anaerobic vertical flow wetland is located after the aerobic wetland and will function for additional alkalinity generation and removal of trace metals (e.g., zinc) remaining in the water after the aerobic wetland. The vertical flow wetland was size of 6,250 ft^2 was based on an average acidity load 14,000 GPD remaining after the ALD, an acidity concentration of approximately 50 mg/L, a flow of 50 gpm, and the acidity removal rate of 25 GDM (Dietz and Stidinger 1996). The vertical flow wetland size also has a flow capacity of 100 gpm for its underdrain system, based on a permeability of 0.001 cm/sec for the organic layer, which reflects the volume of water that can be treated for trace metals. The effluent from the underdrain should contain an alkalinity of at least 100 mg/L which should be adequate to neutralize any acidity remaining in the discharge. The optimal depth of the limestone layer in the vertical flow wetland was determined to be three feet, based on a hydraulic detention time of 16 hours.

The final component of the conceptual design is a stream flow bypass system which consists of a settling/diversion pond, an emergency spillway and an underground stream bypass pipe. This unit will collect stream flow and convey it underneath the treatment system to prohibit co-mingling of the stream and discharge which could result in hydraulic overloading and failure of the passive treatment units (i.e., aerobic and anaerobic vertical flow wetlands) located down gradient of the stream flow. The pond and bypass pipe will be designed to convey stream flows up to a certain storm flow (e.g., 10 or 25 year flow events). Flows exceeding this amount will be conveyed over the emergency spillway of the diversion pond and the spillways of the aerobic and anaerobic vertical flow wetlands.

11.3 Preliminary Construction Costs

Construction costs for this remediation will include: mobilization and demobilization; care of water during construction; mine seal installation, clearing and grubbing; grading associated with treatment cell construction; piping (e.g., underdrain system); limestone and an organic substrate (e.g., spent mushroom compost); miscellaneous materials; installation of stream bypass pipe; seeding of exposed soils; and erosion and sedimentation control measures. The total estimated construction costs of $291,750, summarized Table 36, for the Worley Branch project are based engineering estimates from several recent projects. No cost estimates are provided for required fill for construction of the treatment system and/or disposal of excess material since these quantities are unknown, and would be determined during final design.

11.4 Anticipated Water Quality

The innovative passive treatment approach proposed for Worley Mine #86 discharge utilizes an combination passive treatment system incorporating an ALD, aerobic wetland and vertical flow wetland for iron removal and alkalinity addition. Acidity and iron were used as the design parameters for the conceptual system to obtain a net alkaline and low iron effluent (< 1 mg/L) at average flow and concentration conditions. Copper and zinc, two trace metals detected in the discharge may be removed in several of the units within the proposed treatment system including the aerobic wetland unit as co-precipitates with iron oxides, and the anaerobic environment of the vertical flow treatment cells in the presence of sulfide. Based on the flow passing through the underdrains, 15 gpm at average flow, the proposed treatment system will lower the trace metal concentrations by a minimum of 50 percent.

It is anticipated that the effluent from the proposed treatment system could comply with AWQC benchmarks for all parameters. Compliance with EC_{20} benchmarks could also be achieved by the proposed treatment system for a number of parameters including pH, aluminum, and zinc, but not for parameters including copper and iron. A number of parameters including cadmium and lead can not be evaluated for compliance because the benchmarks are less than quantifiable concentrations.

12.0 SLAVEY HOLLOW

Slavey Hollow is a tributary to the Big South Fork River located on the western side of the watershed in the northern (downstream) portion of the BSFNRRA CMD study area (see Figure 3). Mine drainage enters Slavey Hollow via a black PVC pipe that extends out from an existing coal seam, probably an historic portal, located on the side slope of the watershed (Plate 14). Mine spoil deposits located on the slopes of Slavey Hollow are also likely contributors of mine drainage to Slavey Hollow. The mine drainage enters the stream, approximately ¼ mile upstream from the confluence with the Big South Fork River, and flows over a 15 foot natural waterfall before entering the river. The Slavey Hollow stream channel and natural waterfall contain deposits of bright orange colored iron oxide deposits, an indicator of an alkaline discharge. Site conditions of the Slavey Hollow site are depicted in Figure 28.

Plate 14. Slavey Hollow waterfall downstream of CMD discharge that emanates from a black PVC pipe.

Water quality data collected at the mouth of Slavey Hollow, station number SSPII SH02, from the Phase I and II monitoring program are summarized in Table 37. Monitored pH varied from 6.5 to 7.5, contained high levels of alkalinity (greater than 50 mg/L) and no acidity; indicated the discharge is alkaline. Reported iron concentrations were elevated exceeding 10 mg/L in all but one sample. Both aluminum and manganese concentrations were below 5 mg/L. Zinc was the only trace metal detected at the Slavey Hollow monitoring point, but a concentrations less than 0.060 mg/L. A single copper measurement of 0.14 mg/L is likely a result of sample contamination or analytical error since all other samples contained copper less than 0.0029 mg/L.

12.1 <u>Remediation Recommendations</u>

The possible remediation methods available for resolving the water quality impacts on the Big South Fork River associated with the Slavey Hollow discharge are limited to treatment BMPs capable of removing iron only since the discharge contains alkalinity and high pH. Site remediation would be limited to a mine seal which would likely have limited success in reducing CMD flow. Treatment BMPs capable of removing high iron concentrations include:

- Instream settling, and possibly chemical addition, to Slavey Hollow flows;
- Instream treatment of Slavey Hollow using passive wetland treatment systems; and
- Treatment of the Slavey Hollow low flows using passive wetland treatment systems (e.g., aerobic wetlands) constructed adjacent to the Slavey Hollow channel.

Instream active and passive treatment will result in precipitation of metals (primarily iron) in the settling pond or wetland preventing solids from accumulating in the river bed of the Big South Fork River. However, instream active and passive treatment would be subject to high stormflows that are transported from upslope areas in the Slavey Hollow channel; flows in excess of 10 cfs are likely. These high stormflows could result in scouring and washout of iron deposits from the treatment system into the river. Therefore, instream treatment is not recommended for Slavey Hollow. In addition, operation and maintenance limitations involving periodic dredging of settling ponds of sediment and iron deposits would prohibit the use of instream treatment at a remote location such as the Slavey Hollow location.

Passive wetland treatment has been found to provide successful treatment of CMD characteristic of the degraded water quality found in Slavey Hollow discharge. However, access and available area in close proximity to the discharge location is limited requiring conveyance of the discharge to a location downstream of the discharge point, such as the potential treatment area identified on Figure 28. Treatment of the Slavey Hollow CMD discharge can be accomplished by conveying the discharge in the existing channel and constructing a small impoundment to re-direct the discharge to an aerobic wetland treatment system while permitting bypass of elevated flows associated with a storm event.

Treatment of the Slavey Hollow Creek CMD discharge will require a passive treatment system capable of removing iron. The limitations of each technology presented in Table 1 indicate that this can be accomplished with an aerobic wetland treatment system which will oxidize ferrous iron and precipitate the insoluble iron oxide. The only trace metal present in the discharge is zinc which was found at concentrations (0.030 mg/L) below AWQC. Some removal can be expected in the aerobic wetland treatment system as a co-precipitate with iron oxide. Therefore, the aerobic wetland design is recommended as the technology of choice to treat the Slavey Hollow Creek CMD discharge.

12.2 Conceptual Design

Based on the above evaluation, only passive wetland treatment is suitable to address the Slavey Hollow CMD discharge to the Big South Fork River. The aerobic vertical flow wetland design was identified as the most appropriate passive wetland treatment for this discharge.

The conceptual design for the aerobic wetland is depicted in Figure 29. As indicated in this plan view a collection channel, approximately 200 feet in length, will convey the CMD discharge from a small impoundment constructed on the Slavey Hollow Creek to the wetland

treatment system. The impoundment will be necessary to limit the amount of flow that will enter the channel and the wetland treatment system, thereby, protecting the treatment system from hydraulic overloading. The conveyance channel will be a geotextile-lined channel similar to the lined channel depicted in Figure 6.

The Slavey Hollow creek was sampled during the both the Phase I and II studies which included both water quality and flow. Additional sampling may be necessary to further characterize the discharge and stream characteristics prior to final design. Based on the available flow and water quality data a flow rate of 200 gpm was used to develop the conceptual design; based on low flow conditions measured at the mouth of Slavey Hollow. Applying this flow rate to the total iron concentration of 15 mg/L for Slavey Hollow results in an iron loading of 12,800 GPD which was used to determine the treatment area required for the aerobic wetland treatment system. An iron removal rate of 10 GDM was used to determine total treatment area size. A single cell, aerobic wetland treatment system would require 28,000 ft^2 of treatment area to achieve adequate iron removal (i.e., total iron < 1 mg/L). It is recommended the treatment system consist of two cells each containing 14,000 ft^2. Cell 1 would contain an inert substrate planted with wetland vegetation (e.g., cattails) and Cell 2 would contain non-acidic rock (R-3), such as a poor quality limestone ($CaCO_3$ content less than 80 percent).

12.3 Preliminary Construction Costs

Construction costs for this remediation will include: mobilization and demobilization; care of water during construction; clearing and grubbing; grading associated with impoundment, channel and treatment cell construction; limestone; miscellaneous materials; seeding of exposed soils; and erosion and sedimentation control measures. The anticipated construction costs, summarized in Table 38 for the Slavey Hollow project total $149,400 and are based engineering estimates from several recent projects. No cost estimates are provided for required fill for construction of the treatment system and/or disposal of excess material since these quantities are unknown, determined during final design.

12.4 Anticipated Water Quality

The conceptual design for the Slavey Hollow discharge was designed to remove iron only because of the alkaline condition in this discharge. The aerobic treatment system proposed could effectively remove iron from the CMD discharge to concentration less than 1 mg/L, on an average basis. The treatment system may also lower manganese present in the discharge but with lower effectiveness than iron. Aerobic systems may also effect copper and zinc concentrations by precipitation as oxides or absorption to iron precipitates.

The proposed treatment system will likely produce an effluent in compliance with the AWQC benchmarks for all the parameters. In addition, the proposed treatment system could achieve compliance with many of the EC_{20} benchmarks with the possible exceptions of copper and iron. Several of the parameters including cadmium can not be evaluated for compliance because the benchmarks are less than quantifiable concentrations.

13.0 SUMMARY

Conceptual remediation designs and preliminary cost estimates were developed for the prioritized CMD discharge sites in the BSFNRRA study area, which included all three categories of CMD discharges, i.e., Type I, Type II and Type III. A number of BMPs, including site remediation and passive treatment, were evaluated and considered for development of conceptual remediation designs for each of the CMD discharges. Selection was based on discharge type, discharge water quality and flow rate, site characteristics, and water quality benchmarks to be achieved for the CMD discharge. Table 39 summarizes the remediation methods, preliminary cost estimates and compliance levels for the priority CMD discharge sites.

Passive (wetland) treatment technologies were identified and selected for the Type I discrete discharge points at the Barthell Mine sites, Devils Creek, Nancy Graves Creek, Worley Mine #86 and Slavey Hollow, where site conditions would permit construction of an adequately sized system; creek discharges were excluded because of the high and variable storm flows that would jeopardize stability and performance of passive treatment systems. Conceptual designs varied considerably, but all CMD discharges with elevated trace metals incorporated the anaerobic vertical flow wetland technology because this technology has demonstrated its ability to remove trace metals to concentrations below AWQC benchmarks. Several passive treatment systems also incorporated aerobic wetland and ALD technologies which were included in conceptual designs to remove iron and add alkalinity to the discharges, necessary to achieve compliance with established benchmarks.

Stream lined channels were recommended for two creek discharges, Laurel Branch Creek and Three West Hollow, because site evaluation indicated stream flow was infiltrating mine spoil deposits in and along the stream channel. The lined stream channels will minimize infiltration of stream flow into the mine spoil, thereby reducing CMD generation. In addition, limestone included in the stream lined channel could add alkalinity to neutralize upstream CMD, minimal at both sites, and any downstream CMD inputs associated with the spoil. Blair Creek, the third creek discharge, utilizes upstream limestone fines addition to neutralize CMD inputs that could not be treated using passive treatment due to their remote and inaccessible locations. This approach will add alkalinity to the stream that could neutralize CMD inputs and permit natural amelioration processes to lower pollutant loading to the Big South Fork River.

Two CMD discharge sites, Roaring Paunch (an individual site in the Roaring Paunch Creek site) and Mine #88, were in locations with inadequate area for treatment and/or site conditions that would prohibit construction of a passive treatment system. An OLC design, a new and untested technology, was recommended for the Roaring Paunch site which should at a minimum lower pollutant loading to the Roaring Paunch Creek. An innovative conceptual design using an organic/limestone mixture placed in the mine entrance was developed and recommended for the Mine #88 CMD discharge to lower acidity and trace metals in the discharge. This recommended approach should be considered experimental with an uncertain performance. The settling pond and OLC also included in this design will, at a minimum, lower pollutant loading to the Big South Fork River.

Control at source BMPs were recommended for the Blue Heron-North, Blue Heron-South, Blue Heron-Pine Plantings (grouped together due to proximity of sites and their likely

interactions) and Laurel Branch Spoil Type III CMD discharge sites. Recommended conceptual remediation designs included site reclamation, water control and vertical barriers to reduce CMD flow and strength, thereby lowering pollutant loading to the Big South Fork River. Spoil removal was considered as an option, but was determined to be too costly for the benefits achieved.

14.0 BIBLIOGRAPHY

Brodie, G.A. 1993. Staged, aerobic constructed wetlands to treat acid drainage: Case history of Fabius impoundment 1 and overview of the Tennessee Valley Authority's program. In Constructed Wetlands for Water Quality Improvement, ed. G.A. Moshiri, Lewis Publishers, Boca Raton, FL.

Brodie, G.A., C.R. Britt,, T.M. Tomaszewski, and N.H. Taylor. 1991. Uses of passive anoxic limestone drains to enhance performance of acid drainage treatment wetlands. In Proceedings of Reclamation 2000: Technologies and Successes.

Dietz, J.M. and D.M. Stidinger. 1996. Acidic mine drainage abatement in an anaerobic sub-surface flow environment - Case history of the treatment system at Corsica, PA. pp. 531-540 In The 1996 American Society of Surface Mining and Reclamation Proceedings, Knoxville, TN, May 15-20, 1996.

Dietz, J.M. 1993a. Personal data on the performance of the Township Road treatment system at the Potato Ridge Mine, Ohiopyle, PA.

Dietz, J.M., J. Gruver and D.M. Stidinger. 1993a. Technical investigation of the abatement of acid mine drainage in a sub-surface wetland environment. Report to the U.S. Bureau of Mines, Pittsburgh, PA.

Dietz, J. M., R.G. Watts and D.M. Stidinger. 1993b. Evaluation of wetlands constructed for the treatment of acidic mine drainage. Commonwealth of Pennsylvania, Department of Environmental Resources, Publication ISBM No. 0-8182-0186-X.

Eger, P. and K. Lapakko. 1989. Nickel and copper removal from mine drainage by a natural wetland. pp301-309, In Proceedings of the American Society for Surface Mining Reclamation, Pittsburgh, PA. U.S. Bureau of Mines Circular IC9183.

Eger, P., J. R. Wagner, Z. Kassa, and G. D. Melchert. 1994. Metal removal in wetland treatment systems. pp.80-88 In Proceedings of the 1994 International Land Reclamation and Mine Drainage Conference.

Fyson, A., M. Kalin and L.W. Adrian. 1994. Arsenic and nickel removal by wetland sediments. pp.109-118 In Proceedings of the 1994 International Land Reclamation and Mine Drainage Conference.

Going, J.E. 1980. Priority pollutant removal from mine drainage. U.S. Environmental Protection Agency Report No. 600/7-80-121

Hedin, R.S., R.W. Nairn and R.L.P. Kleinman. 1994. Passive treatment of coal mine drainage.
Kemp, P.H. 1971. Chemistry of Natural Waters - 1, "Water Research, Vol. 5, pp297.

Kepler, D.A. and E.C. McCleary. 1994. Successive alkalinity producing systems (SAP's) for the treatment of acidic mine drainage. pp.195-204 In Proceedings of the 1994 International Land Reclamation and Mine Drainage Conference.

Rightnour, T.A. and K.L. Hoover. 1997. An application of phased element removal technology for passive treatment of fly ash leachate contaminants. The Environmental Professional, Vol. 19, pp. 201-208.

Robertson, A.M. and J. Barton-Bridges. 1990. Cost effective methods of long term acid mine drainage control from waste rock piles. pp. 153-174 In Proceedings of the GAC-MAC Conference on AMD, Vancouver.

Rose, A.W., J. Stalker and L.H. Michaud. 1996. Remediation of acid mine drainage within strip mine spoil by sulfate reduction using waste organic matter. pp. 321-336 In The 1996 American Society of Surface Mining and Reclamation Proceedings, Knoxville, TN, May 15-20, 1996.

Sikora, F.J., L.L. Behrends, G.A. Brodie, and M.J. Bulls. 1996. Manganese and trace metal removal in successive anaerobic and aerobic wetlands. pp. 560-579 In The 1996 American Society of Surface Mining and Reclamation Proceedings, Knoxville, TN, May 15-20, 1996.

Stumm, W. And J.J. Morgan. 1981. Aquatic Chemistry: An introduction emphasizing chemical equilibria in natural waters. John Wiley & Sons, New York. 766p.

United States Environmental Protection Agency (U.S. EPA). 1986. Quality Criteria for Water - 1986 (Gold Book). U. S. EPA, Office of Water, Regulations and Standards, Wachington, DC. EPA 440/5-86-001

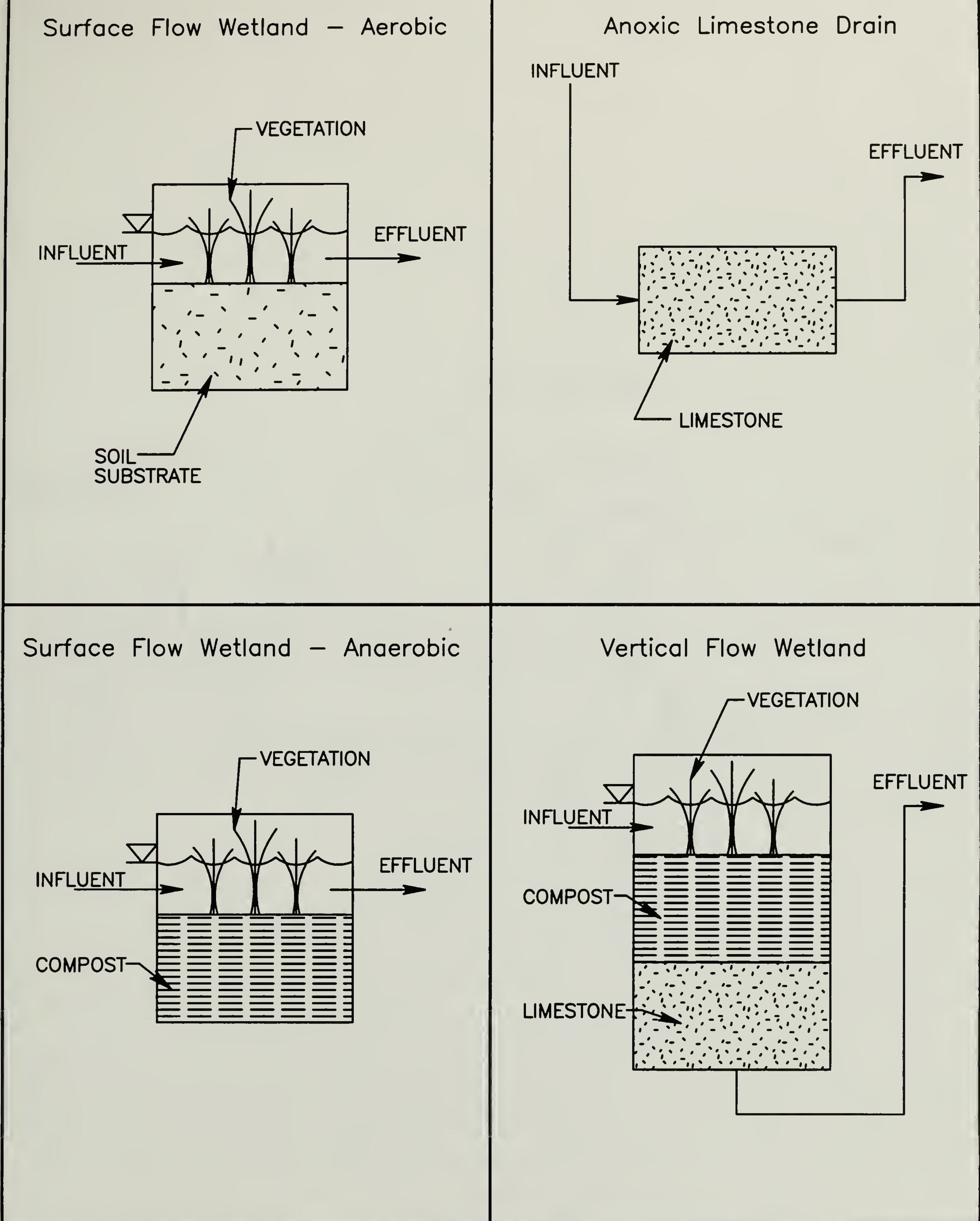
Unz, R.F. and E. Royer. 1997. Validity of manganese as a surrogate of heavy metal removal in constructed wetlands treating acidic mine waters. Final Report - National Mined Land Reclamtion Center Project, The Pennsylvania State University, Project PSU-19.

Watzlaf, G.R. 1988. Chemical stability of manganese and other metals in acid mine drainage sludge. pp. 83-90. In Mine Drainage and Surface Mine Reclamation. Vol I, Mined Land Reclamation, Abandoned Mine Lands and Policy Issues, IC 9184, Bureau of Mines Circular 1988, United States Department of the Interior.

Ziemkiewicz, P.F., D.L. Brant, and J.G. Skousen. 1996. Acid mine drainage treatment with open limestone channels. pp. 367-374 In The 1996 American Society of Surface Mining and Reclamation Proceedings, Knoxville, TN, May 15-20, 1996.

Zurbuch, P.E., R. Menendez, and J.L. Clayton and S.A. Miller. 1997. Restoration of two West Virginia rivers from the effects of acid mine drainage. Presented at the 19th Annual Conference of the Association of Abandoned Mine Land Programs, Canaan Valley, WV.

Zurbuch, P.E., R. Menendez, and J.L. Clayton. 1996. Limestone neutralization of Dogway Fork, West Virginia, by means of a rotary-drum system. Restoration Ecology, 4:206-219.



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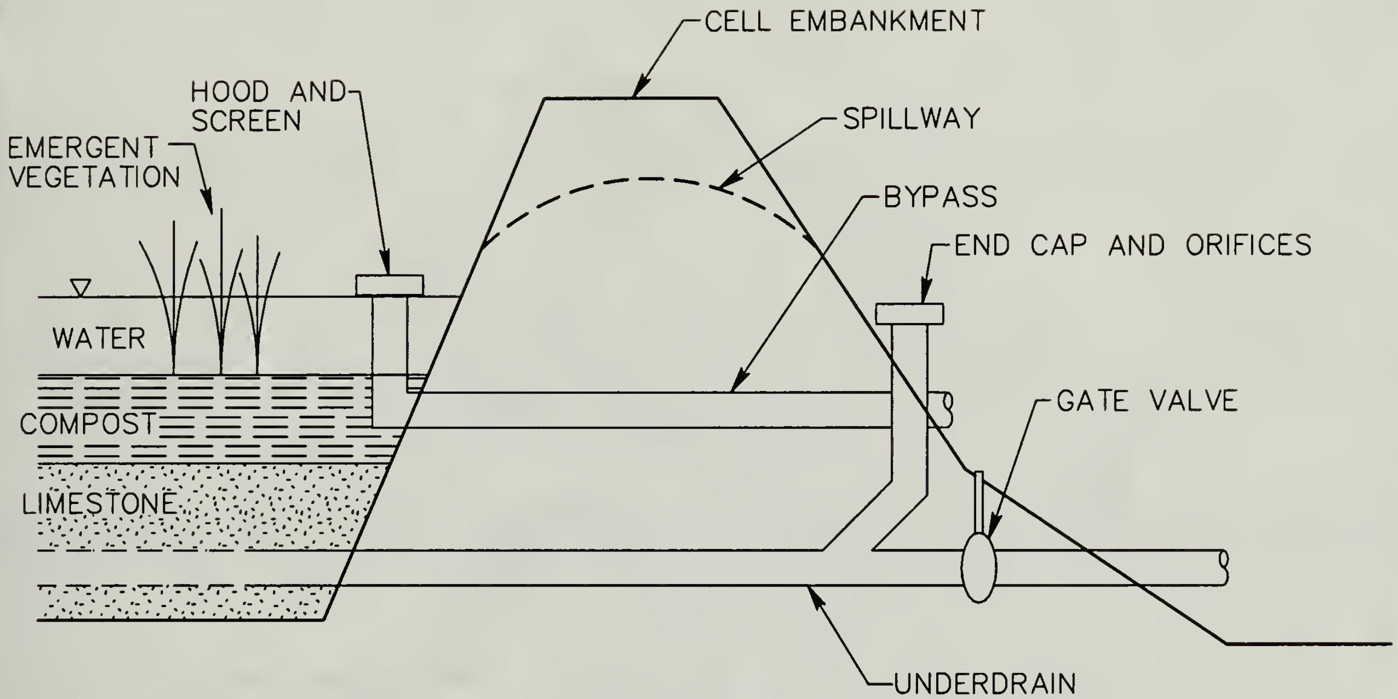
BIG SOUTH FORK NATIONAL RIVER
RESTORATION STUDY

SCHEMATIC PROFILES OF
PASSIVE TREATMENT SYSTEMS

NO SCALE

FIGURE
1



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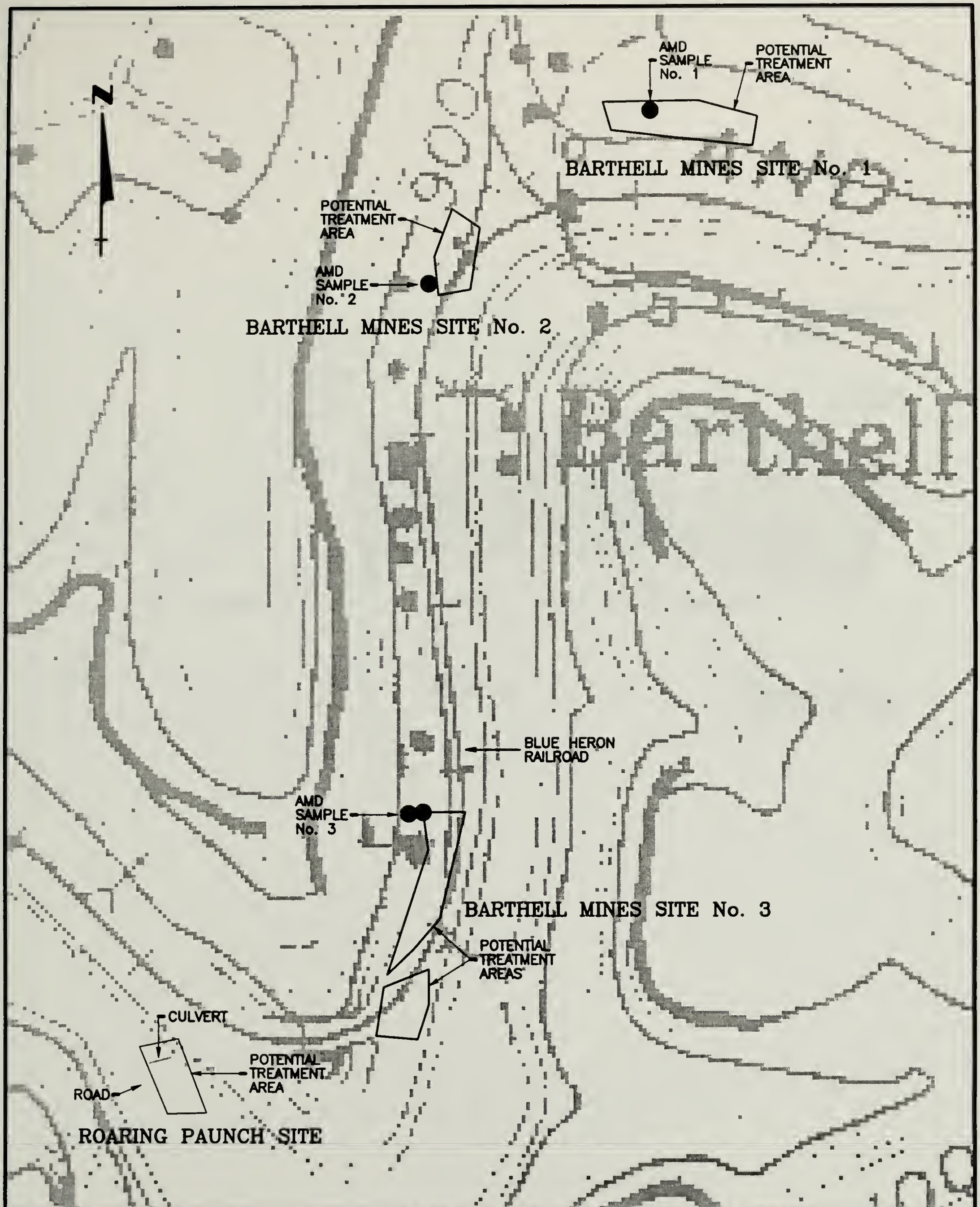
RESTORATION STUDY

VERTICAL FLOW WETLAND
CONCEPTUAL TREATMENT CELL
EMBANKMENT CROSS SECTION

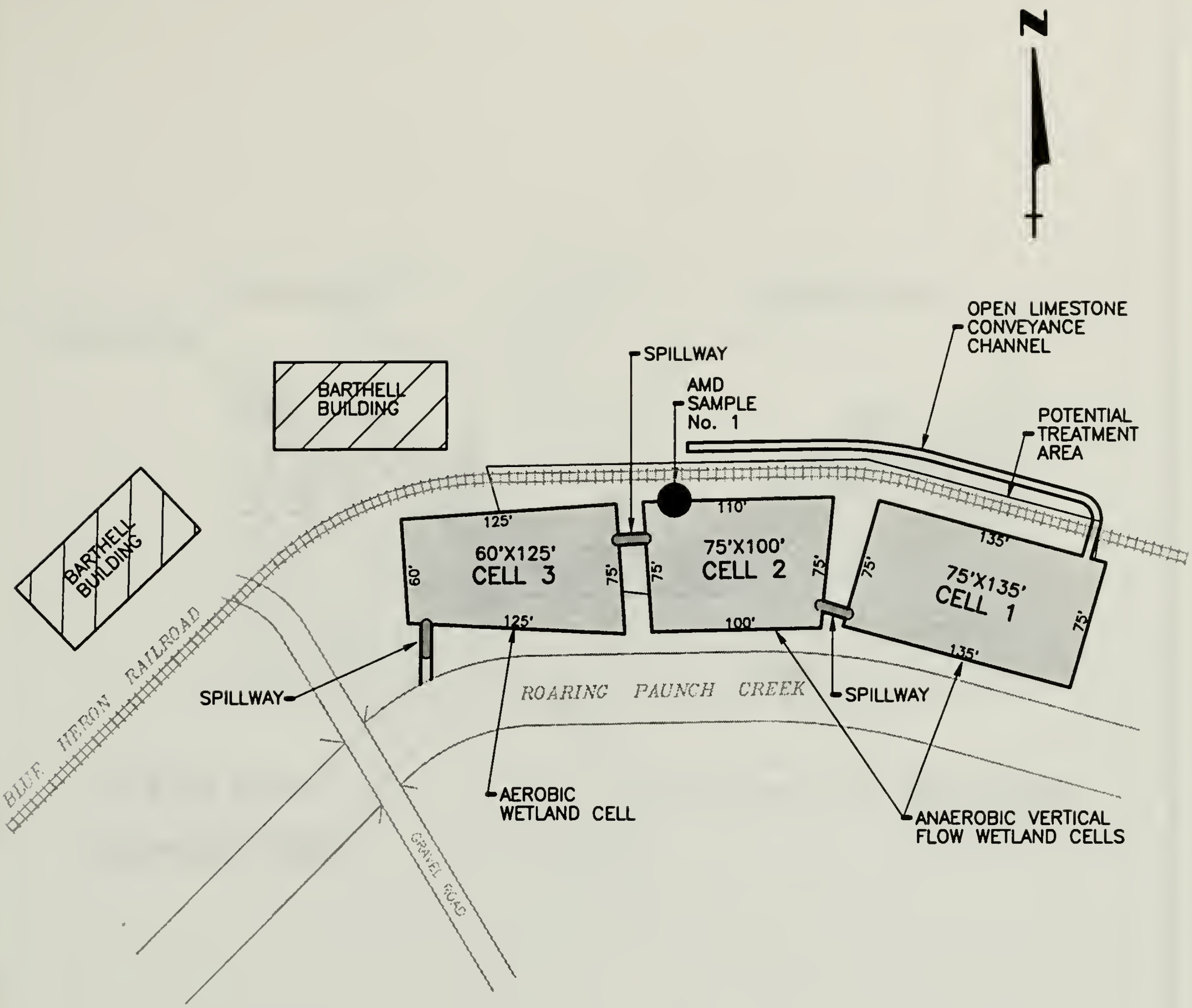
NO SCALE

FIGURE
2

GANNETT FLEMING, INC. ENGINEERS AND PLANNERS HARRISBURG PENNSYLVANIA	NATIONAL PARK SERVICE, SOUTHEAST REGION **BIG SOUTH FORK NATIONAL RIVER RESTORATION STUDY**	SCALE 1'=2000'
	PROJECT LOCATION MAP	FIGURE 3



GANNETT FLEMING, INC. ENGINEERS AND PLANNERS HARRISBURG PENNSYLVANIA	NATIONAL PARK SERVICE, SOUTHEAST REGION BIG SOUTH FORK NATIONAL RIVER RESTORATION STUDY BARTHELL MINES SITES No. 1, No. 2 AND No. 3 AND ROARING PAUNCH SITE SITE CHARACTERISTICS	SCALE 1'=300' FIGURE 4



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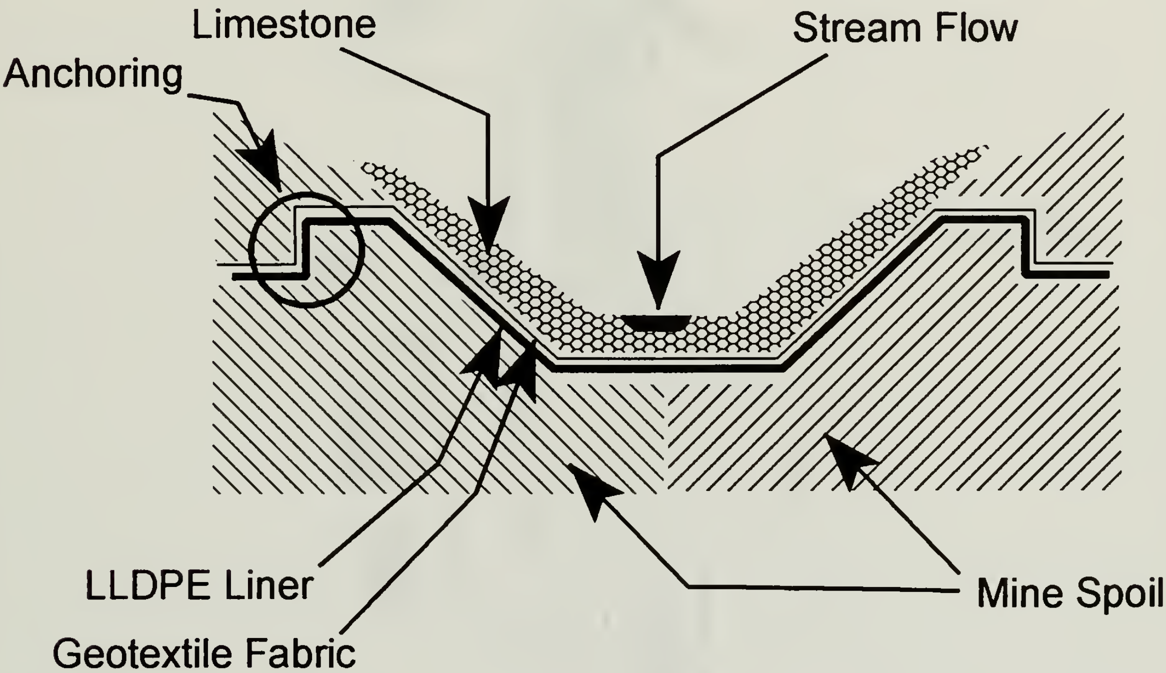

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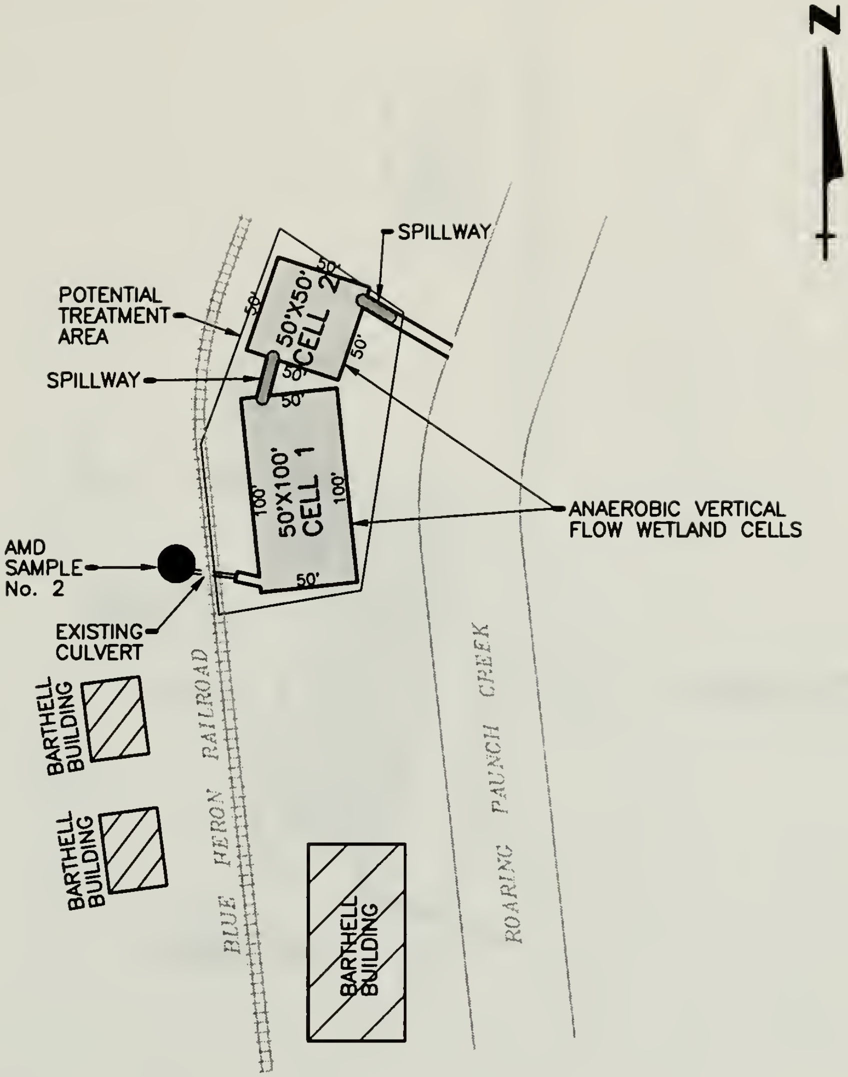
BIG SOUTH FORK NATIONAL RIVER
RESTORATION STUDY

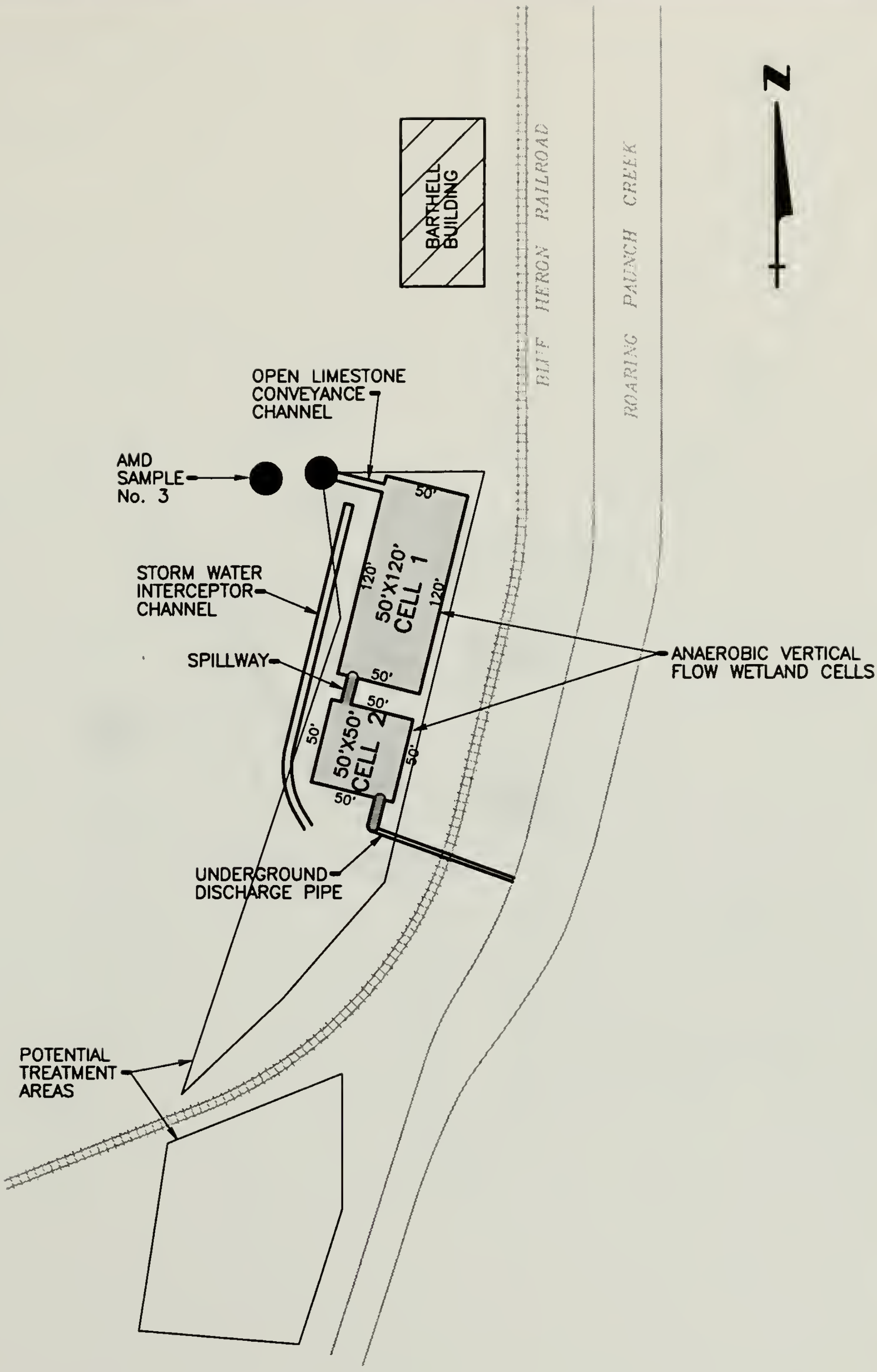
TYPICAL LINED CHANNEL CROSS-SECTION

No Scale

Figure 6



GANNETT FLEMING, INC. ENGINEERS AND PLANNERS HARRISBURG PENNSYLVANIA	NATIONAL PARK SERVICE, SOUTHEAST REGION BIG SOUTH FORK NATIONAL RIVER RESTORATION STUDY BARTHELL MINES SITE No. 2 CONCEPTUAL REMEDIATION DESIGN	SCALE 1'=100' FIGURE 7



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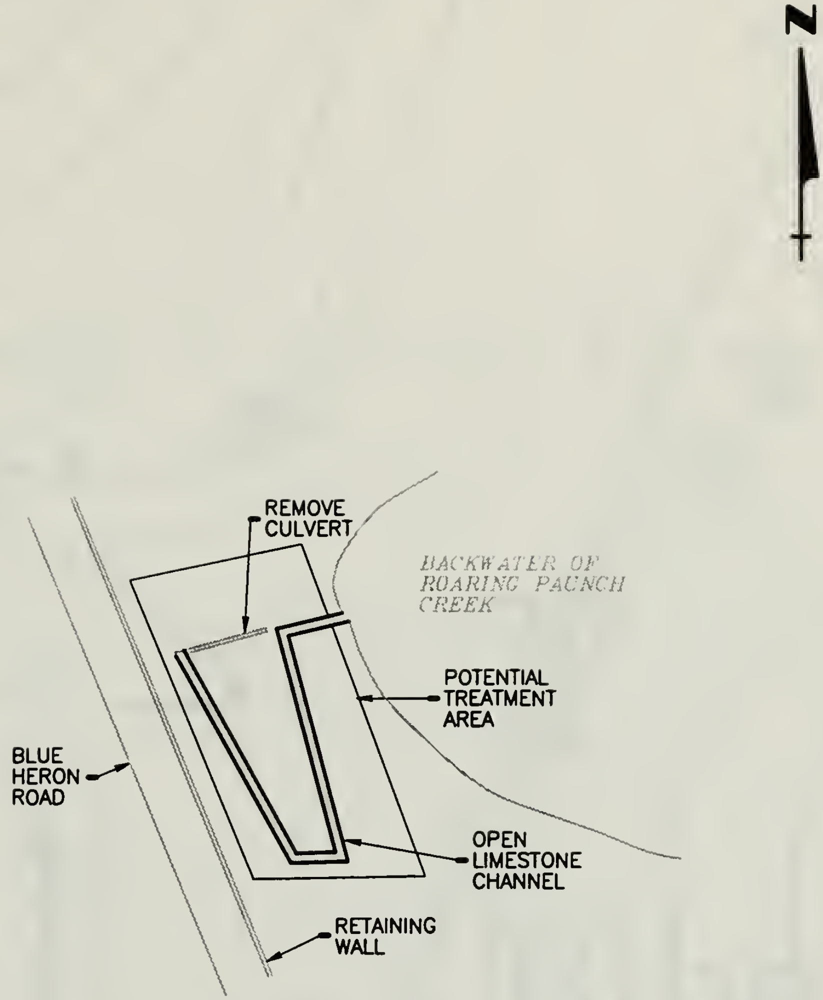
BARTHELL MINES SITE No. 3
CONCEPTUAL REMEDIATION DESIGN

SCALE
1'=100'

FIGURE
8



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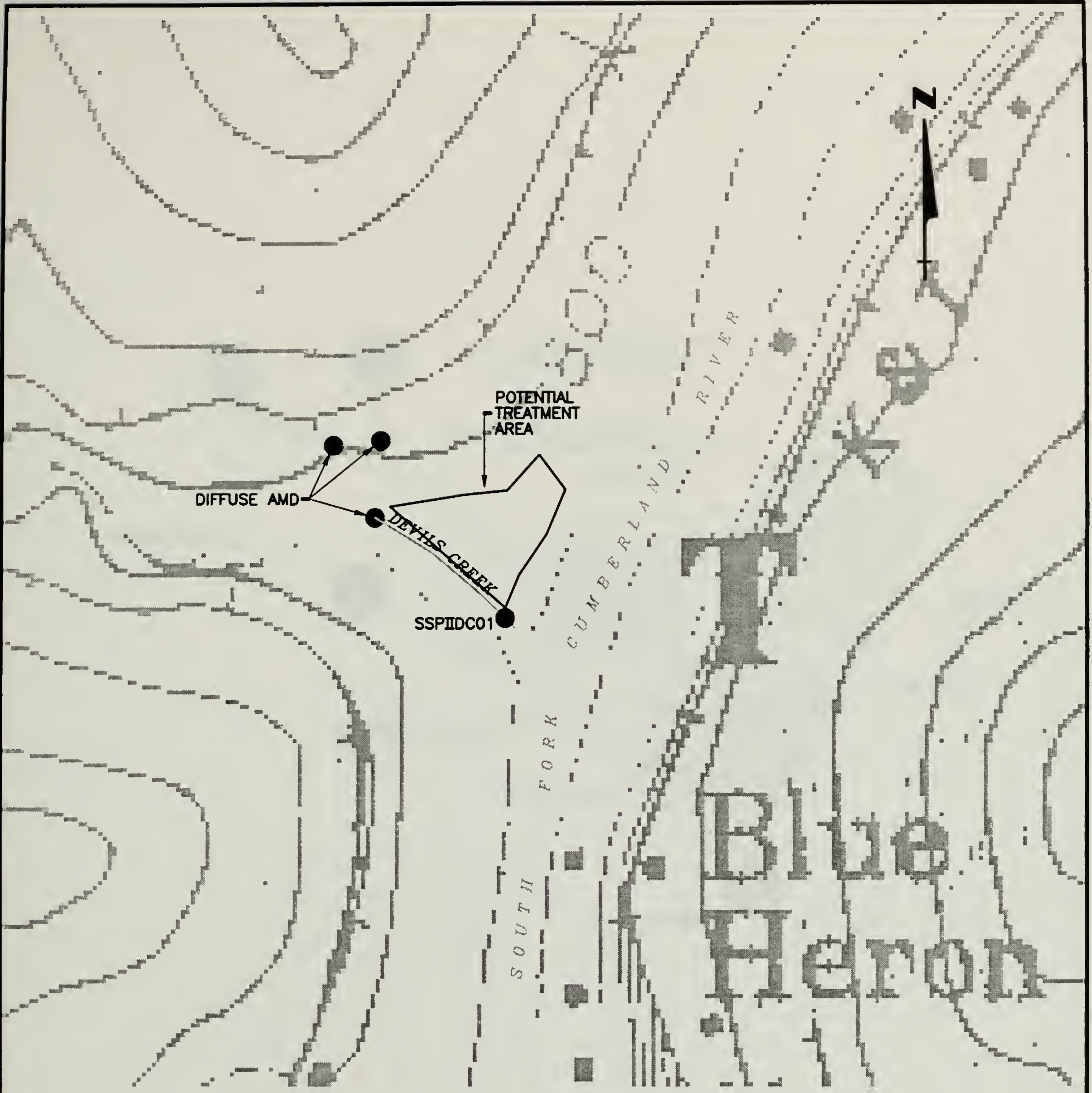
ROARING PAUNCH SITE

CONCEPTUAL REMEDIATION DESIGN

SCALE 1'=100'

FIGURE 9



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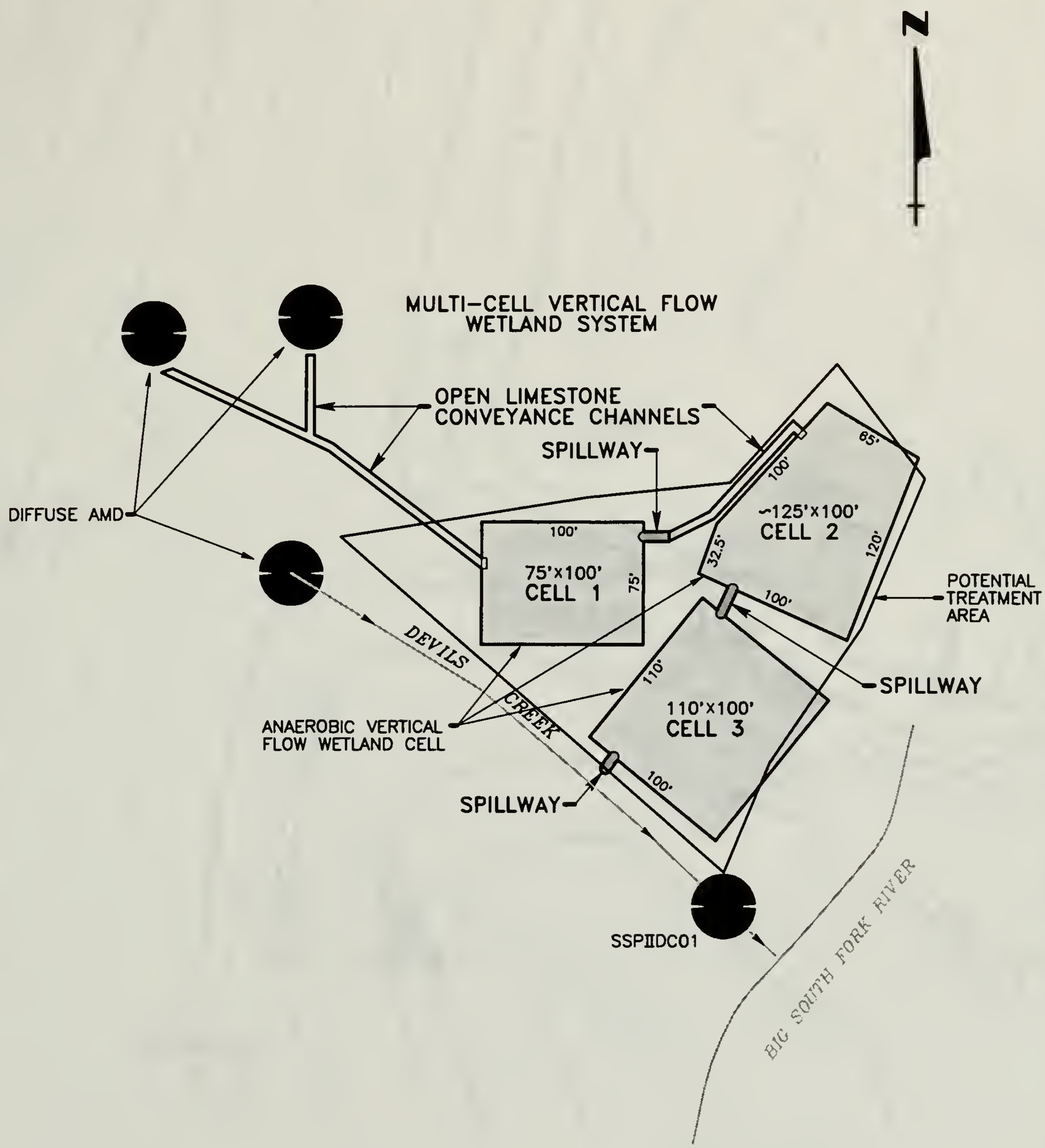
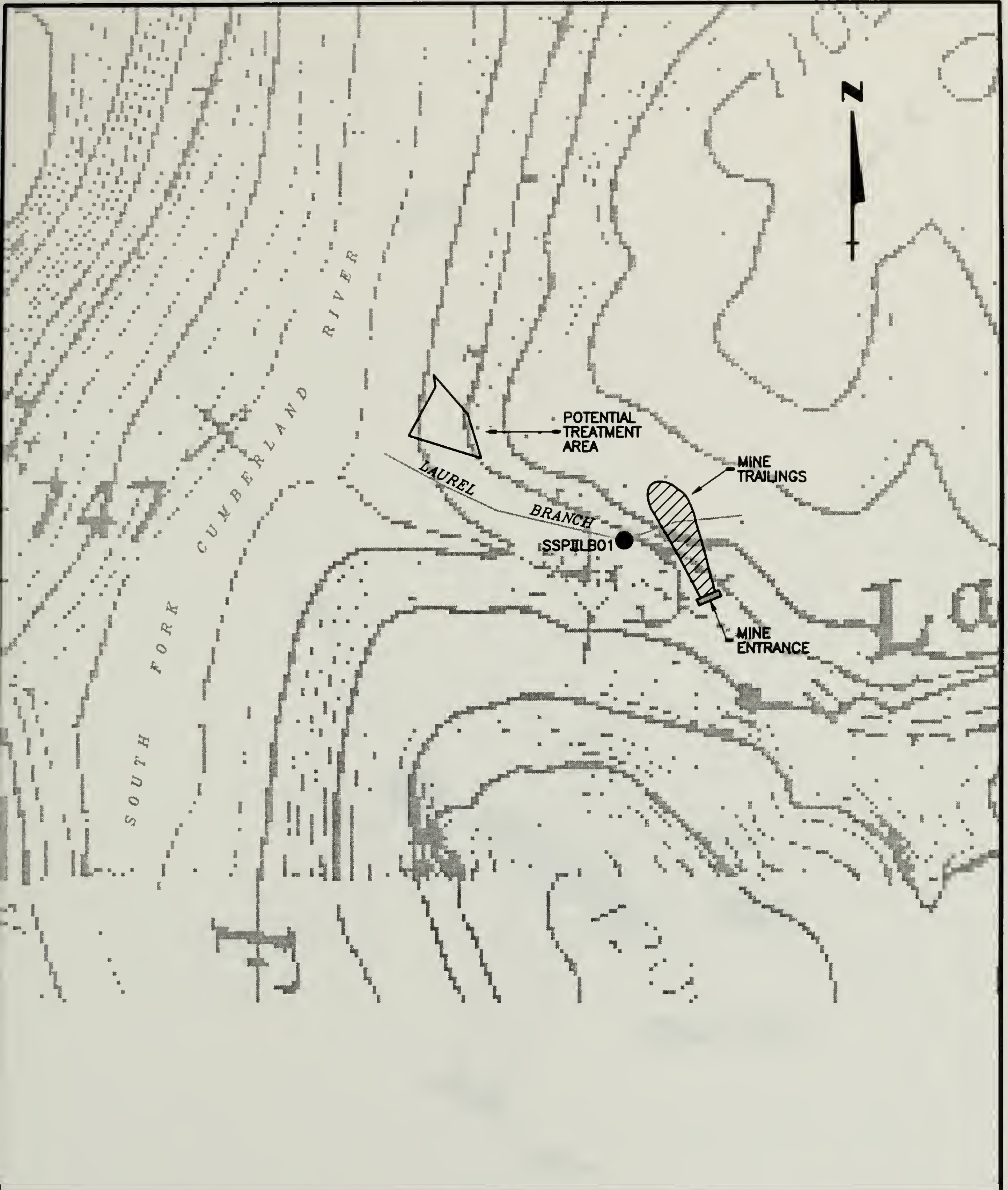
BIG SOUTH FORK NATIONAL RIVER
RESTORATION STUDY

DEVILS CREEK SITE
SITE CHARACTERISTICS

SCALE	1'=300'
FIGURE	10



GANNETT FLEMING, INC. ENGINEERS AND PLANNERS HARRISBURG PENNSYLVANIA	NATIONAL PARK SERVICE, SOUTHEAST REGION BIG SOUTH FORK NATIONAL RIVER RESTORATION STUDY DEVILS CREEK SITE CONCEPTUAL REMEDIATION DESIGN	SCALE 1'=100' FIGURE 11



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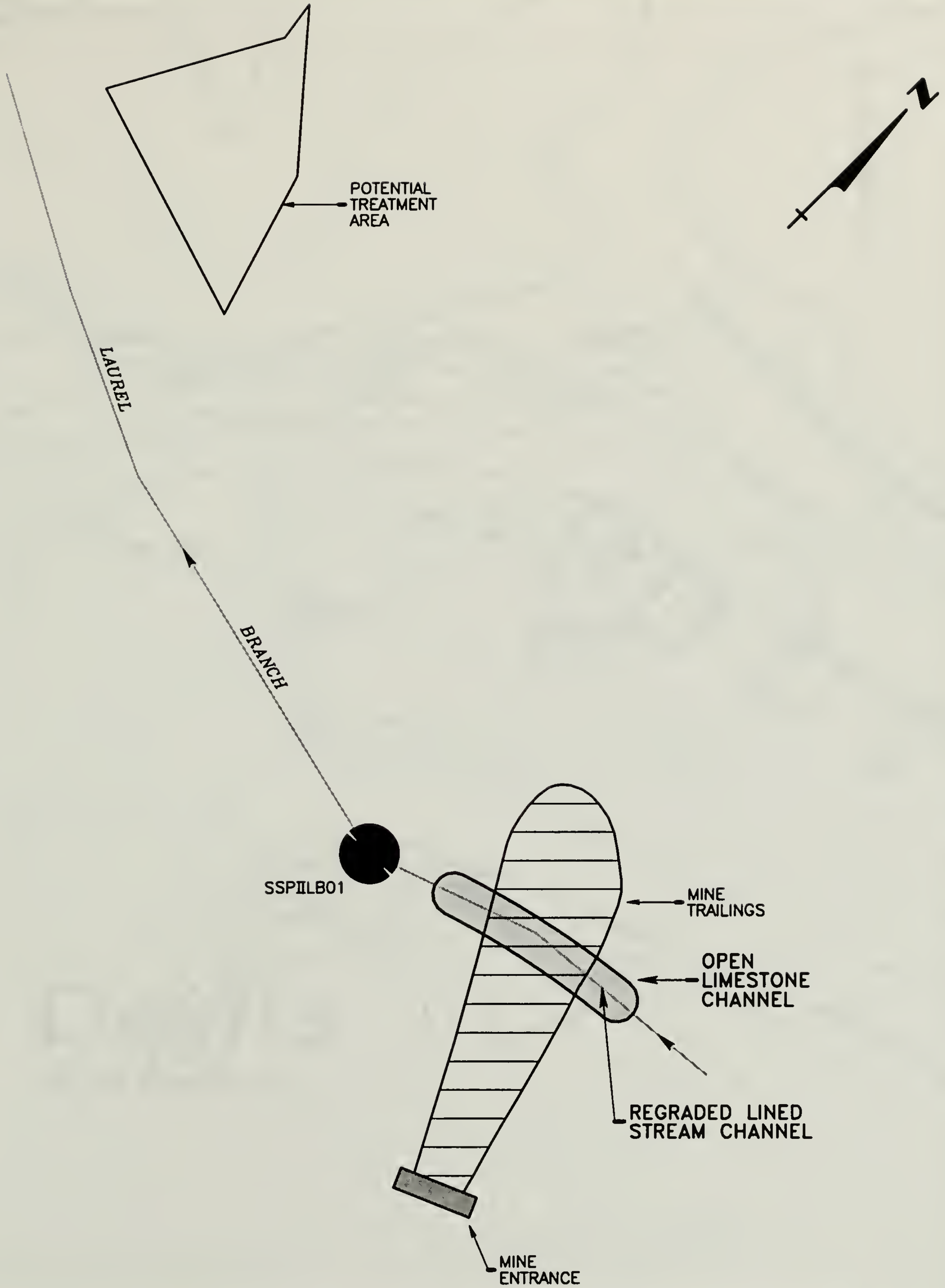
BIG SOUTH FORK NATIONAL RIVER
RESTORATION STUDY

LAUREL BRANCH SITE

SITE CHARACTERISTICS

SCALE
1'=300'

FIGURE
12



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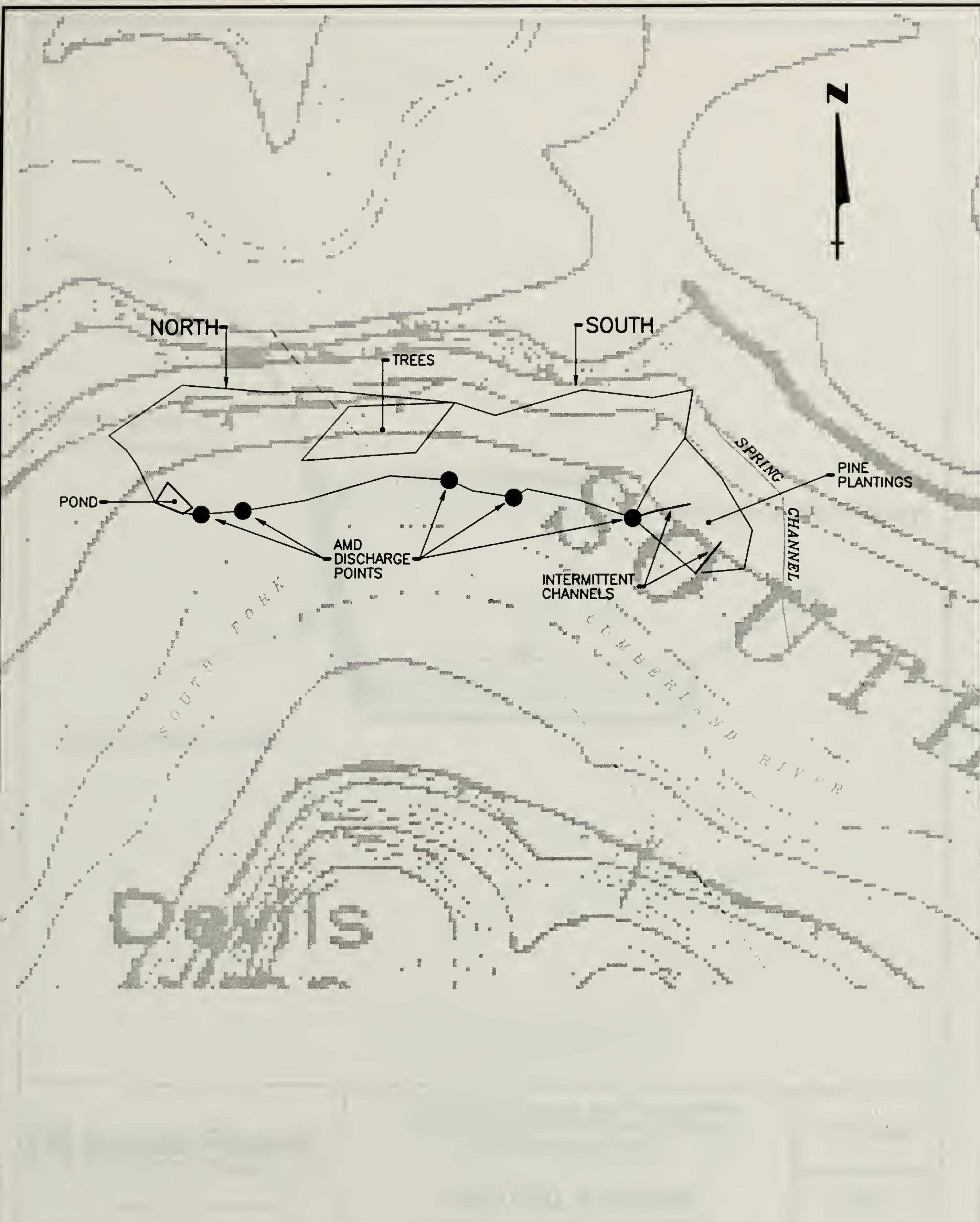
BIG SOUTH FORK NATIONAL RIVER
RESTORATION STUDY

LAUREL BRANCH SITE
CONCEPTUAL REMEDIATION DESIGN

SCALE
1'=100'

FIGURE
13



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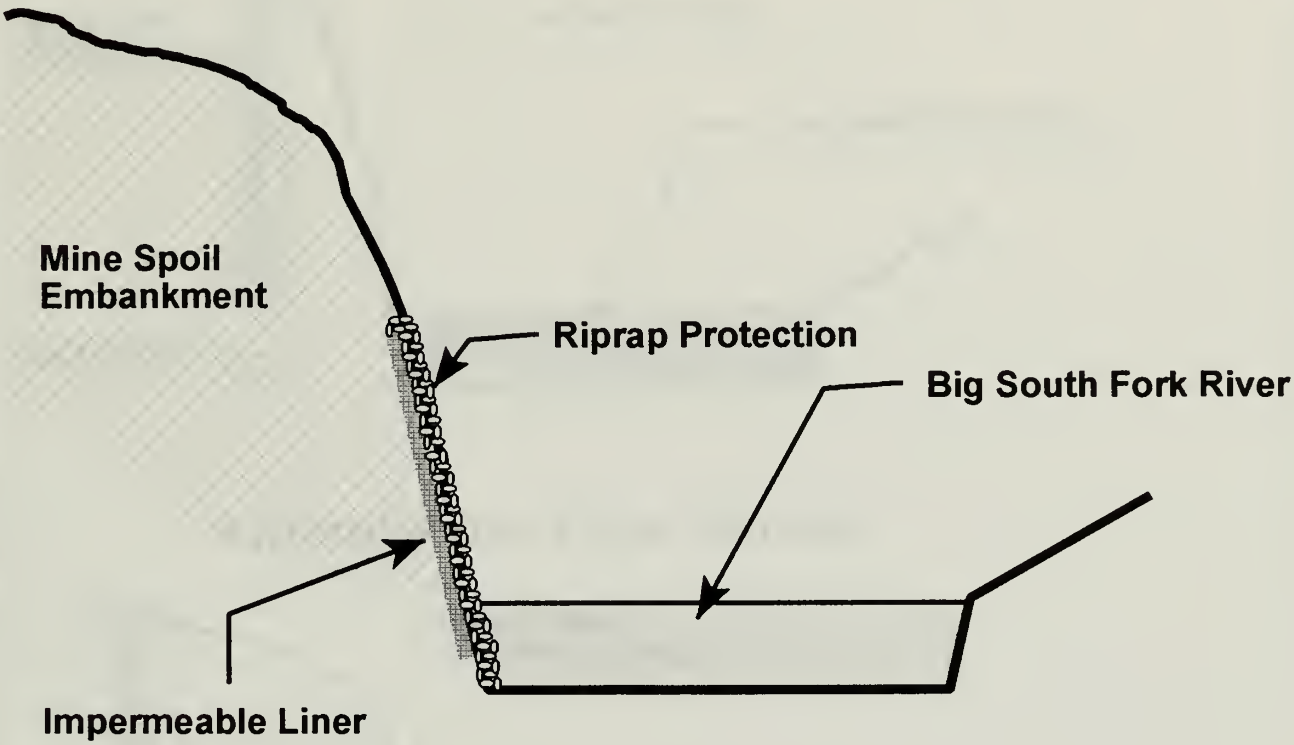
BIG SOUTH FORK NATIONAL RIVER
RESTORATION STUDY

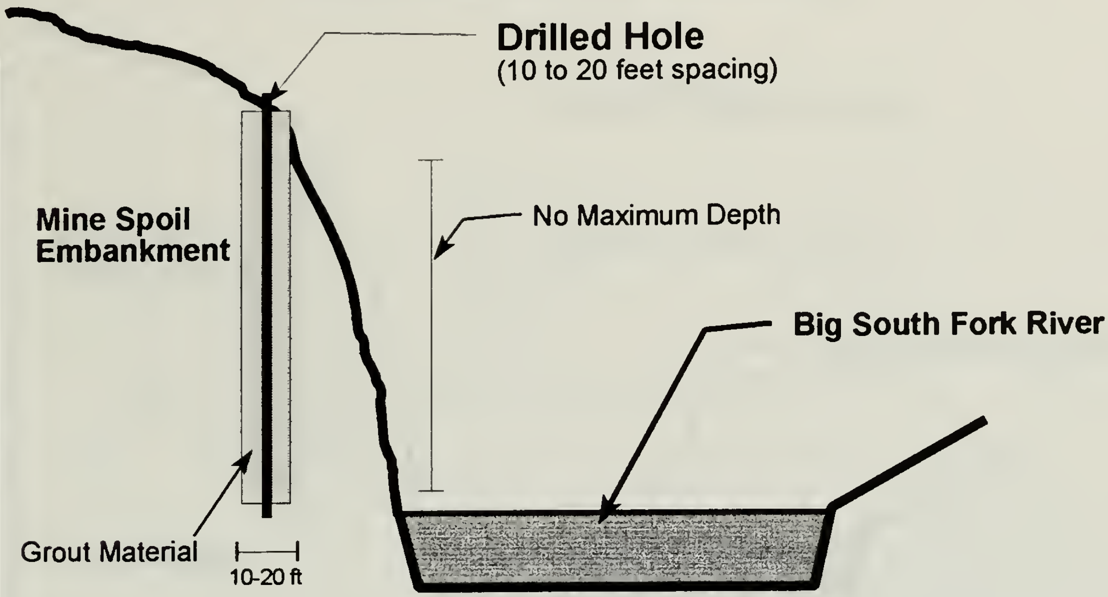
BLUE HERON SPOIL
SITE CHARACTERISTICS

SCALE	FIGURE
1'=300'	14

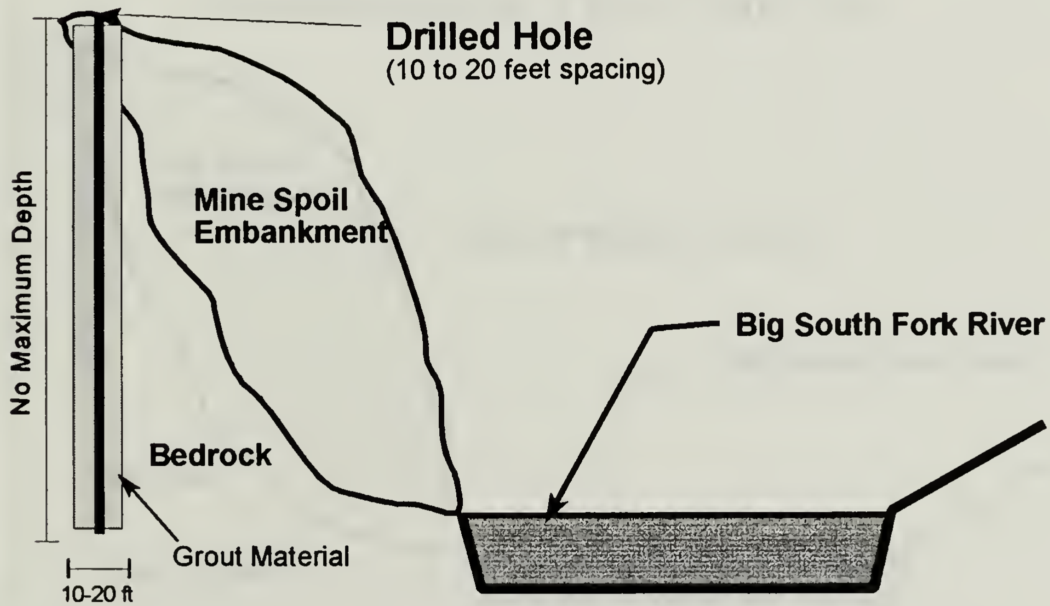


Gannett Fleming ENGINEERS AND PLANNERS HARRISBURG PENNSYLVANIA	NATIONAL PARK SERVICE, SOUTHEAST REGION BIG SOUTH FORK NATIONAL RIVER RESTORATION STUDY **VERTICAL BARRIER IMPERMEABLE LINER**	No Scale Figure 15

Spoil & River Barrier

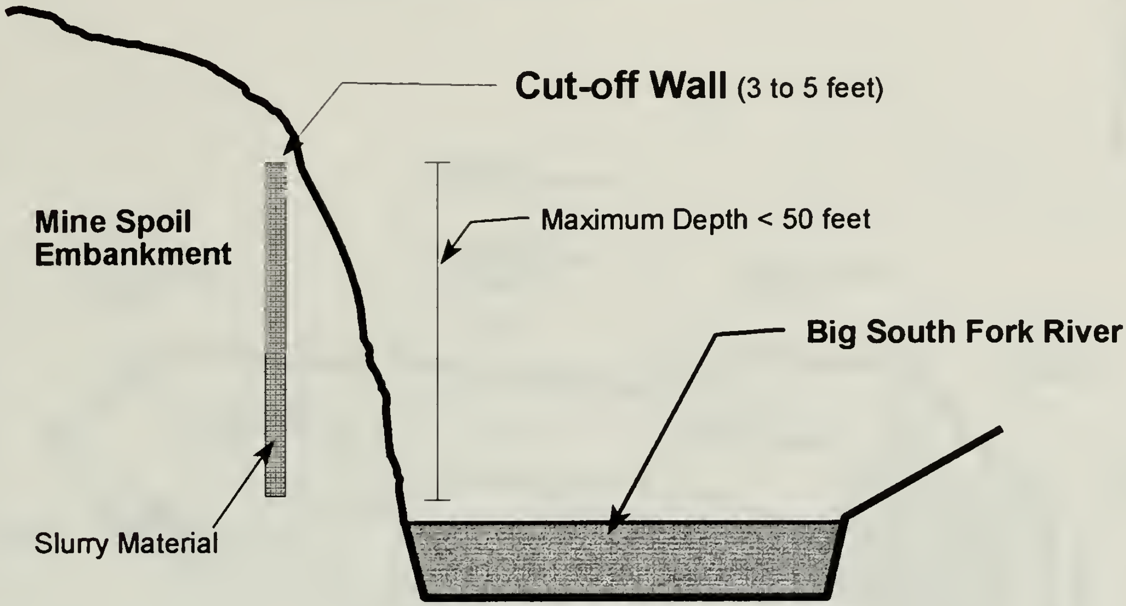


Goundwater Flow Barrier

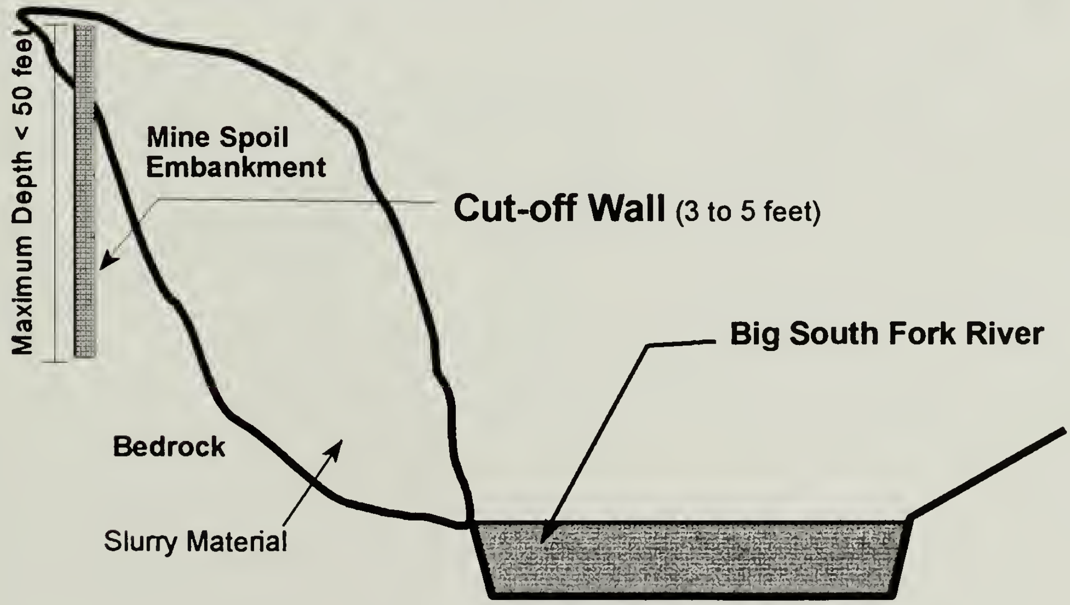


Gannett Fleming ENGINEERS AND PLANNERS HARRISBURG PENNSYLVANIA	NATIONAL PARK SERVICE, SOUTHEAST REGION BIG SOUTH FORK NATIONAL RIVER RESTORATION STUDY VERTICAL BARRIER PERMEATION GROUTING	No Scale Figure 16

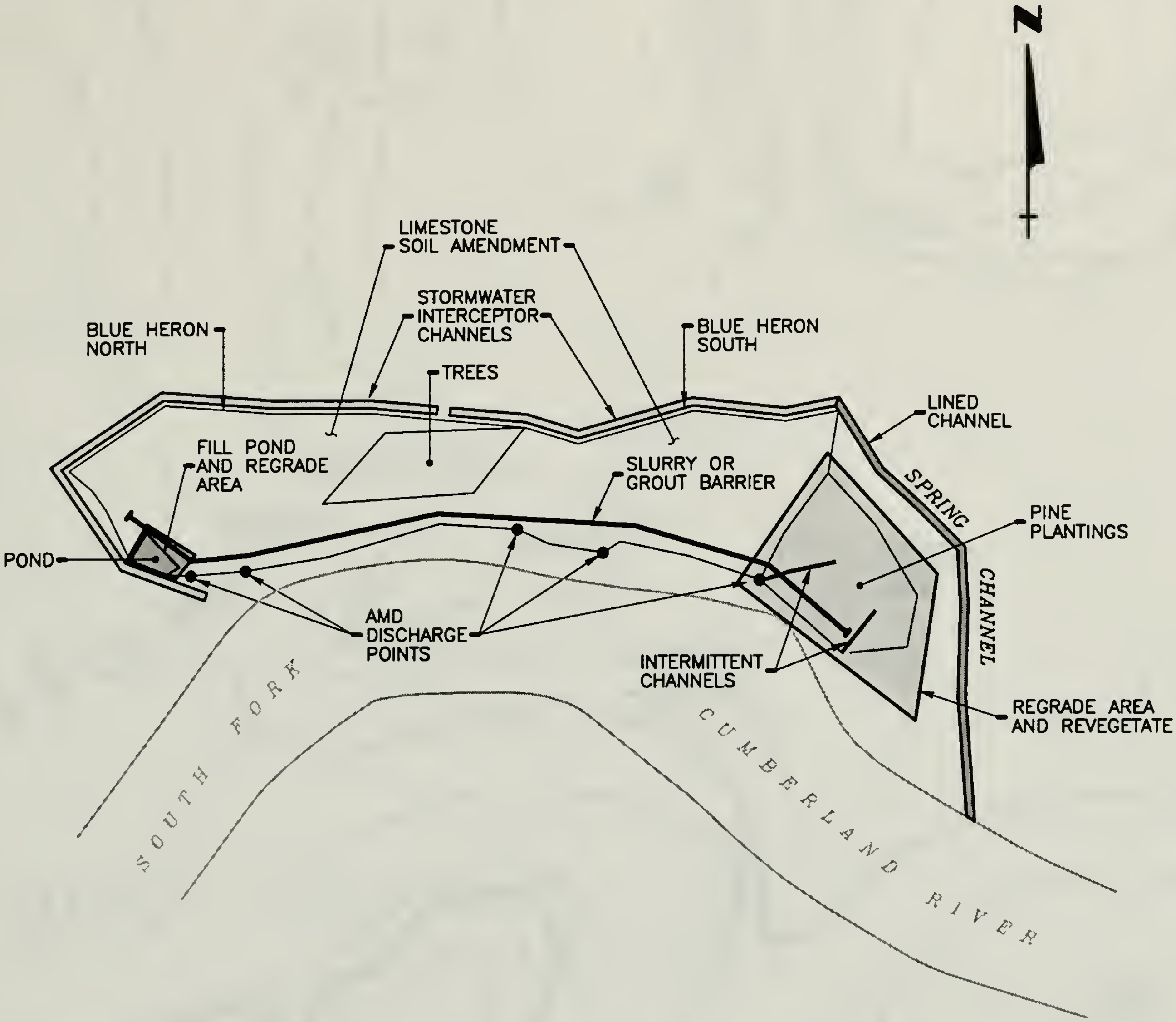
Spoil & River Barrier



Goundwater Flow Barrier



Gannett Fleming ENGINEERS AND PLANNERS HARRISBURG PENNSYLVANIA	NATIONAL PARK SERVICE, SOUTHEAST REGION BIG SOUTH FORK NATIONAL RIVER RESTORATION STUDY	No Scale
	VERTICAL BARRIER CUT-OFF WALL	Figure 17



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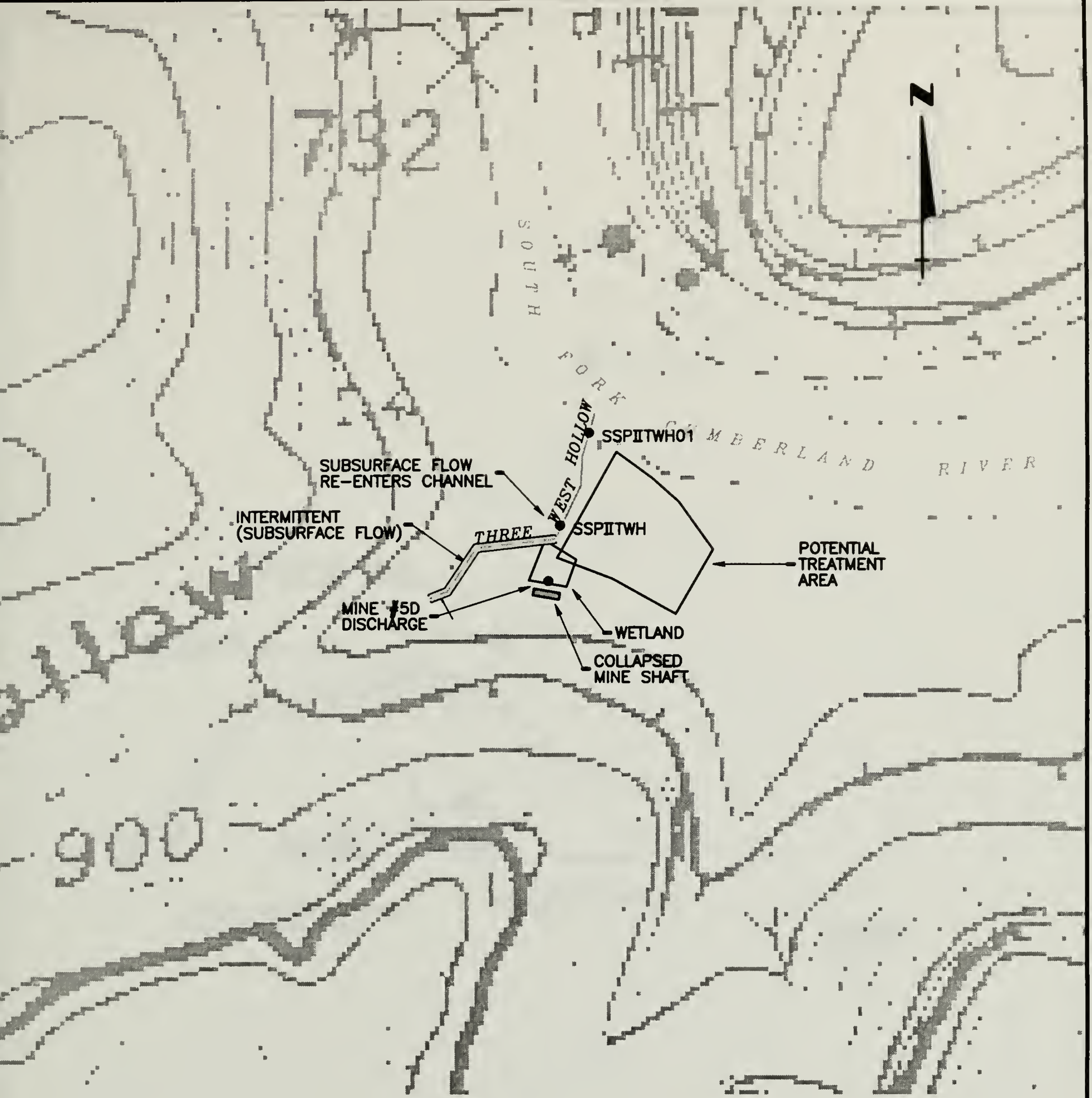
NATIONAL PARK SERVICE, SOUTHEAST REGION
BIG SOUTH FORK NATIONAL RIVER
RESTORATION STUDY

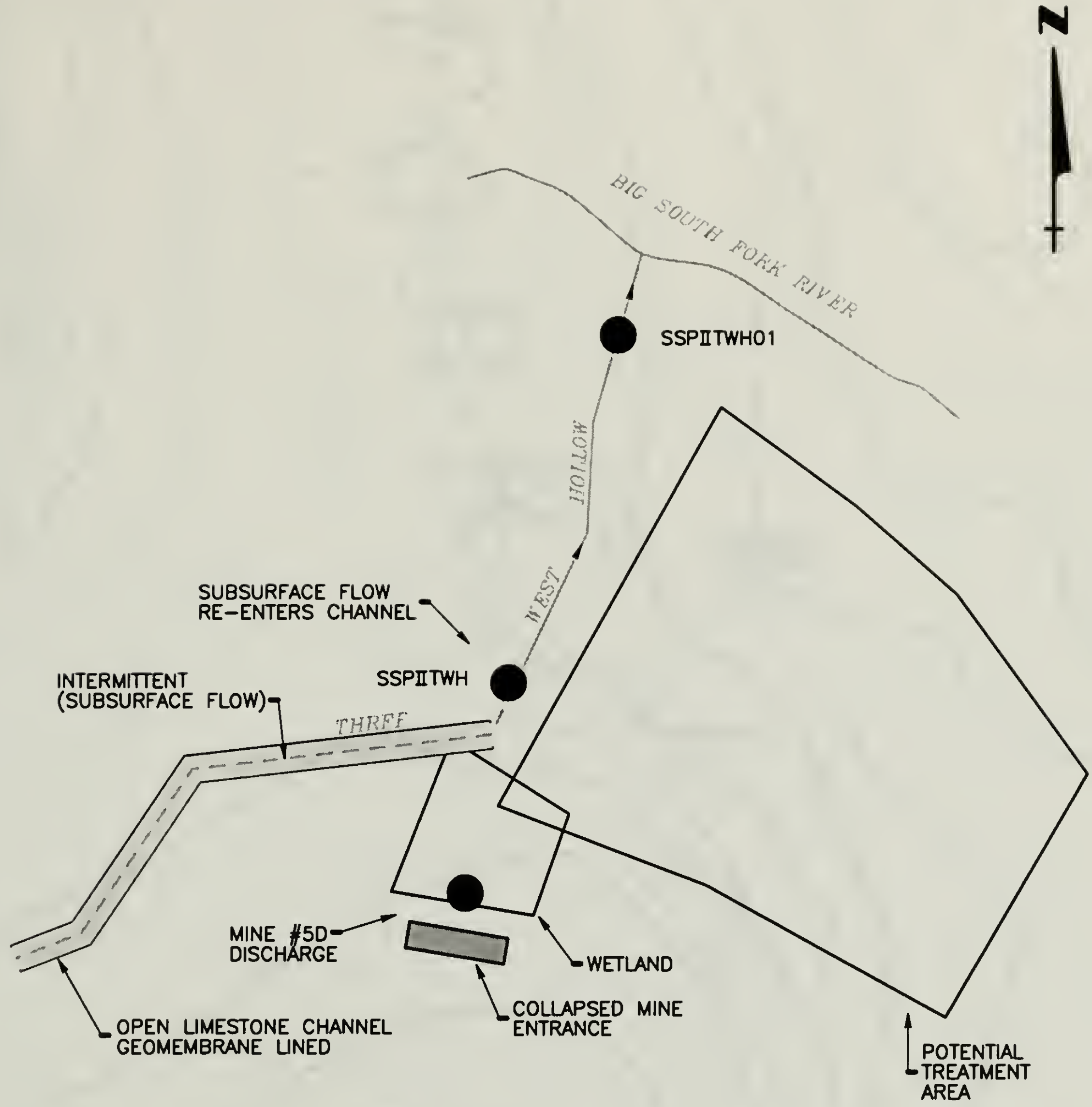
BLUE HERON SPOIL
SITE CHARACTERISTICS

SCALE
1'=300'

FIGURE
14



GANNETT FLEMING, INC. ENGINEERS AND PLANNERS HARRISBURG PENNSYLVANIA	NATIONAL PARK SERVICE, SOUTHEAST REGION BIG SOUTH FORK NATIONAL RIVER RESTORATION STUDY THREE WEST HOLLOW SITE SITE CHARACTERISTICS	SCALE 1'=300' FIGURE 19



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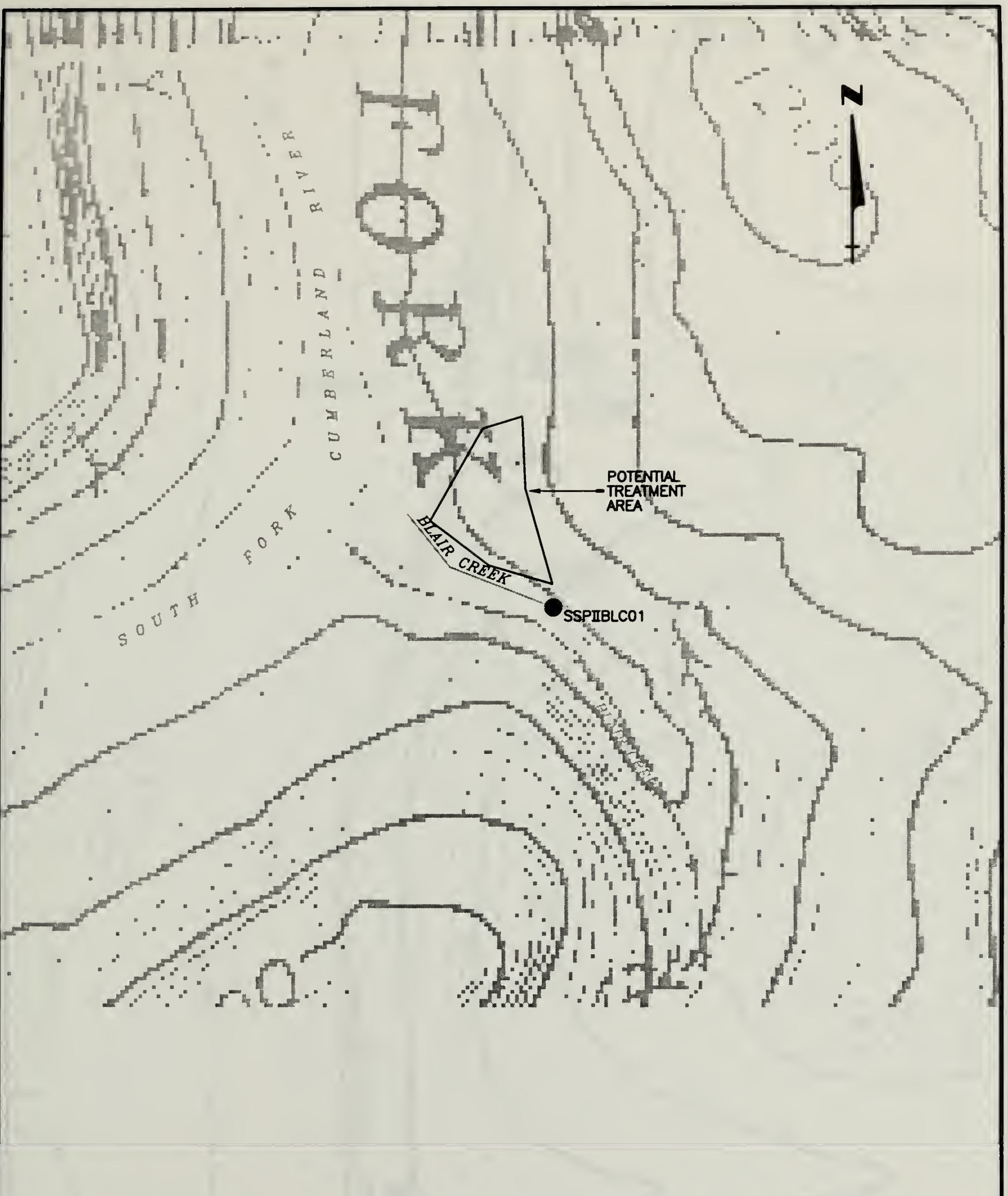
NATIONAL PARK SERVICE, SOUTHEAST REGION
BIG SOUTH FORK NATIONAL RIVER
RESTORATION STUDY
THREE WEST HOLLOW SITE
CONCEPTUAL REMEDIATION DESIGN

SCALE
1'=100'

FIGURE
20



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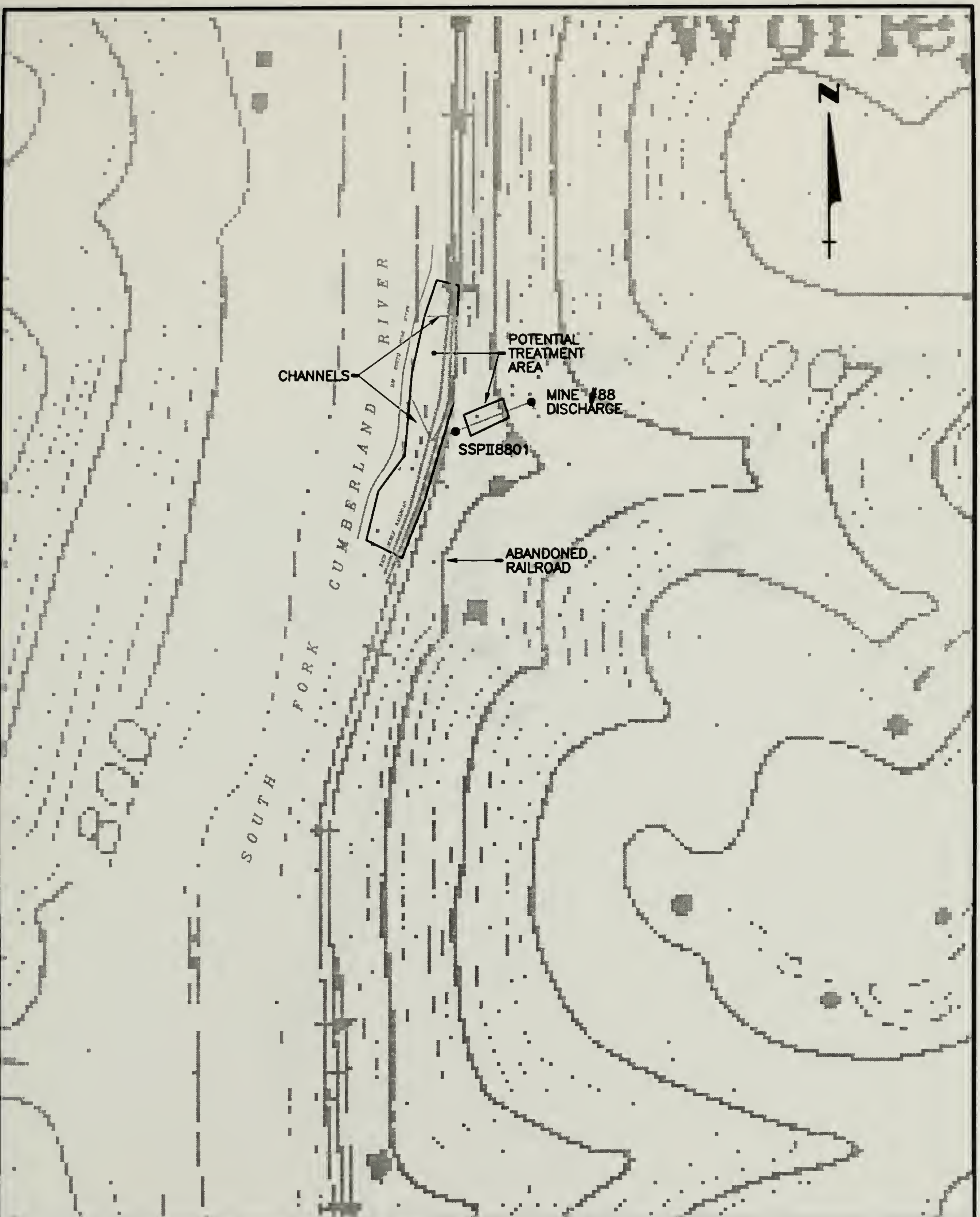
BIG SOUTH FORK NATIONAL RIVER
RESTORATION STUDY
BLAIR CREEK SITE
SITE CHARACTERISTICS

SCALE
1'=300'

FIGURE
21



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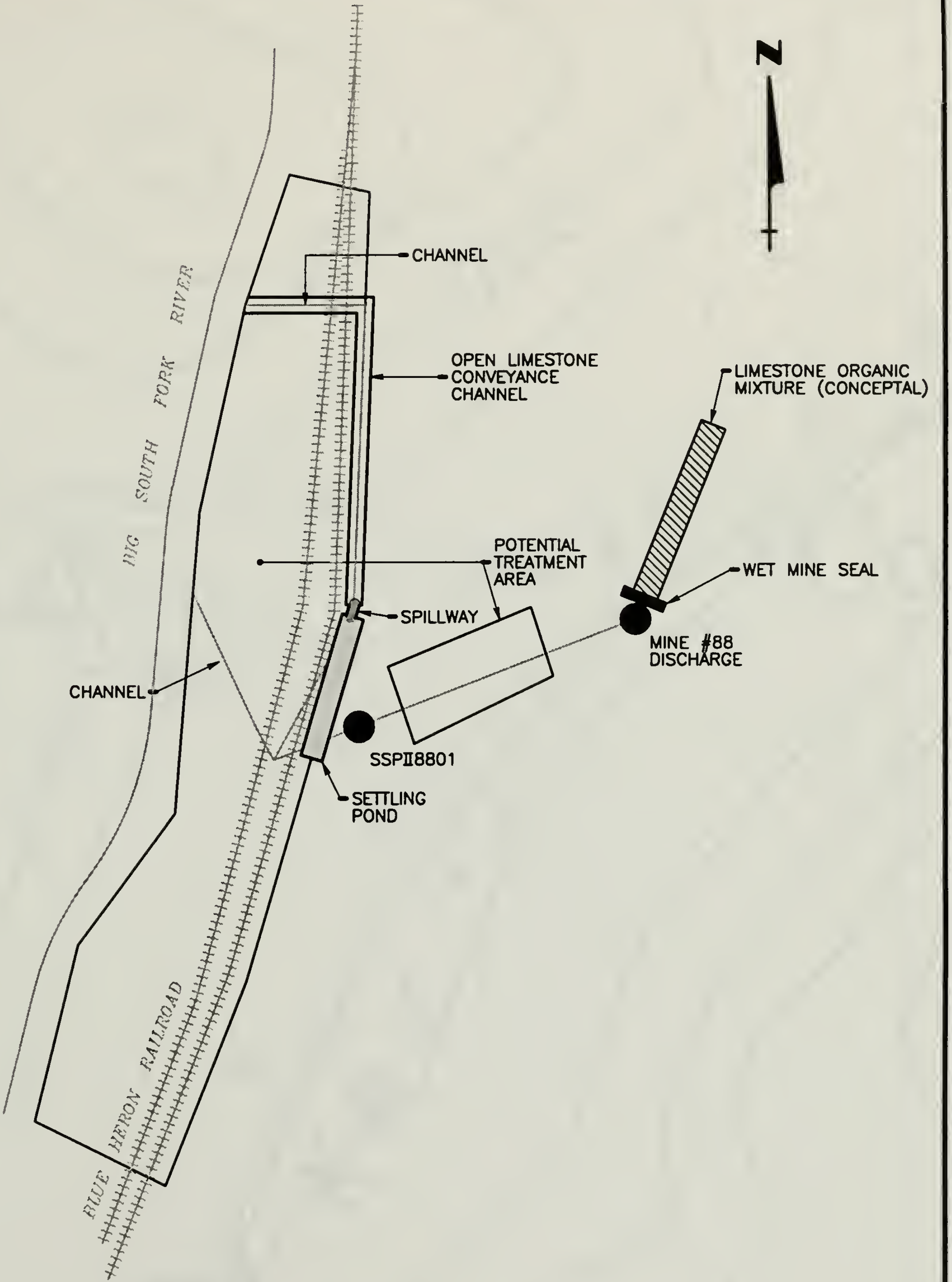
BIG SOUTH FORK NATIONAL RIVER
RESTORATION STUDY

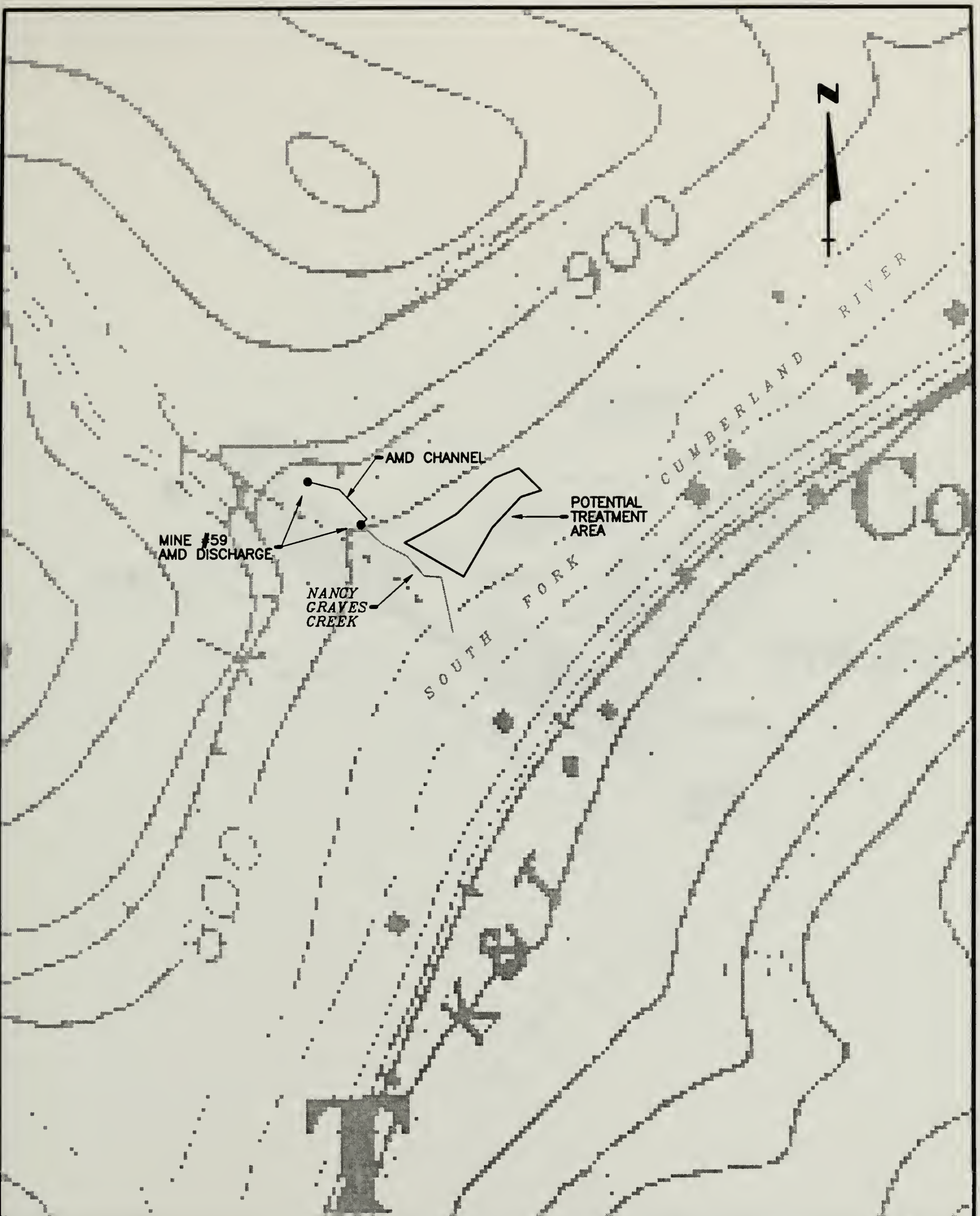
MINE #88 SITE
SITE CHARACTERISTICS

SCALE 1'=300'

FIGURE 22



GANNETT FLEMING, INC. ENGINEERS AND PLANNERS HARRISBURG PENNSYLVANIA	NATIONAL PARK SERVICE, SOUTHEAST REGION BIG SOUTH FORK NATIONAL RIVER RESTORATION STUDY MINE #88 SITE CONCEPTUAL REMEDIATION DESIGN	SCALE 1'=100' FIGURE 23



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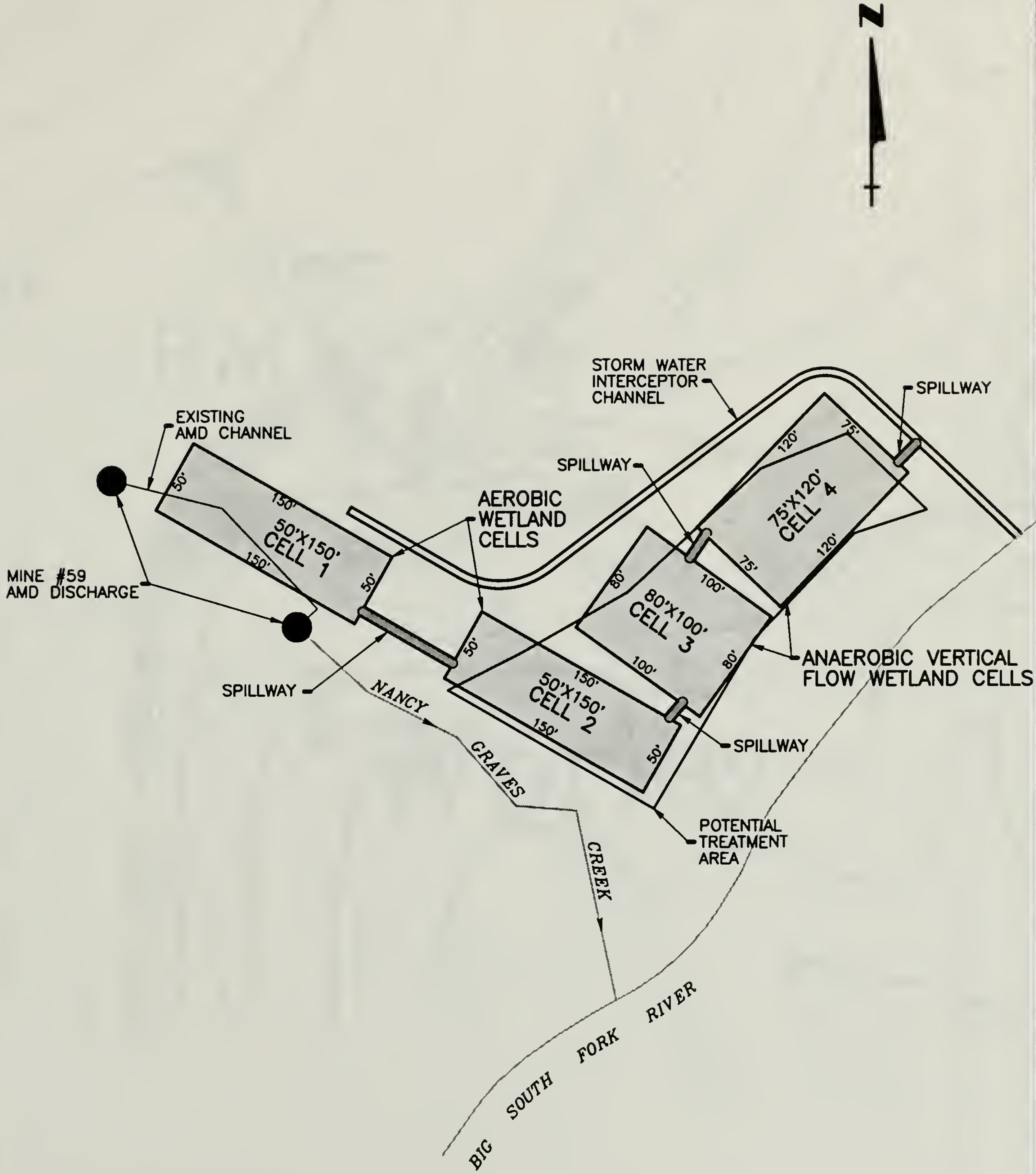
NATIONAL PARK SERVICE, SOUTHEAST REGION
BIG SOUTH FORK NATIONAL RIVER
RESTORATION STUDY

NANCY GRAVES SITE
SITE CHARACTERISTICS

SCALE 1'=300'

FIGURE 24



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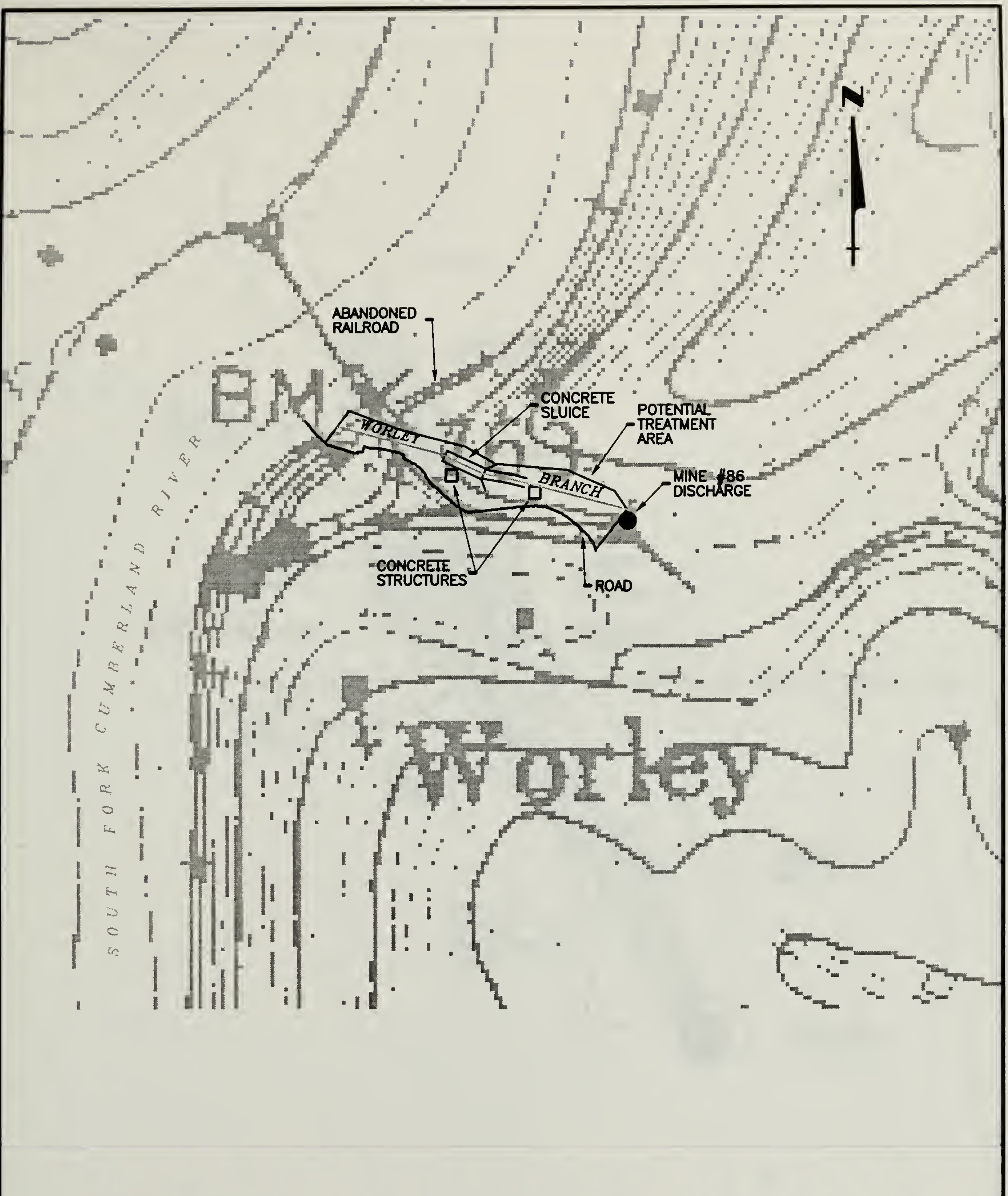
NATIONAL PARK SERVICE, SOUTHEAST REGION
BIG SOUTH FORK NATIONAL RIVER
RESTORATION STUDY
NANCY GRAVES SITE
CONCEPTUAL REMEDIATION DESIGN

SCALE	FIGURE
1'=100'	25



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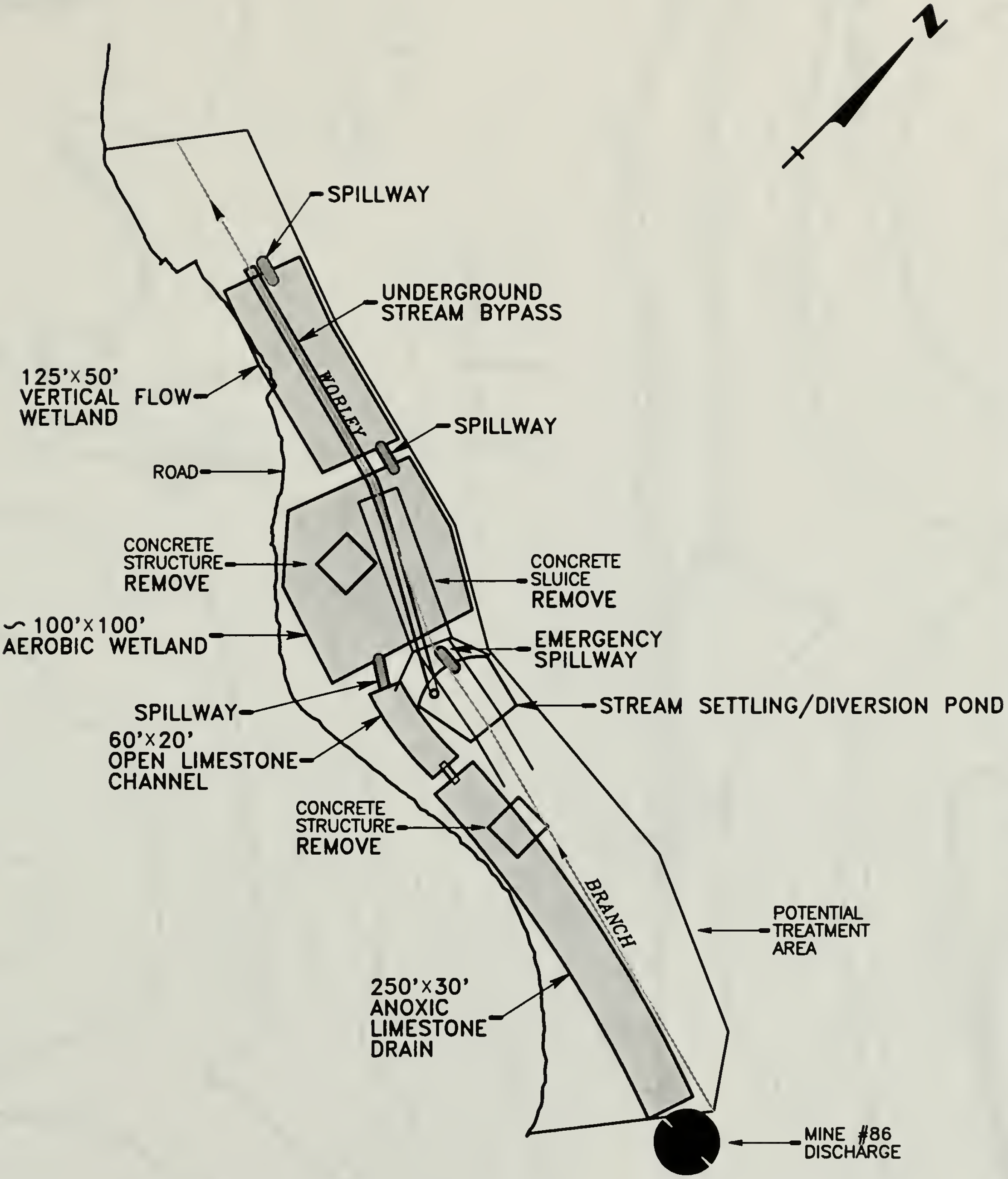
NATIONAL PARK SERVICE, SOUTHEAST REGION
BIG SOUTH FORK NATIONAL RIVER
RESTORATION STUDY

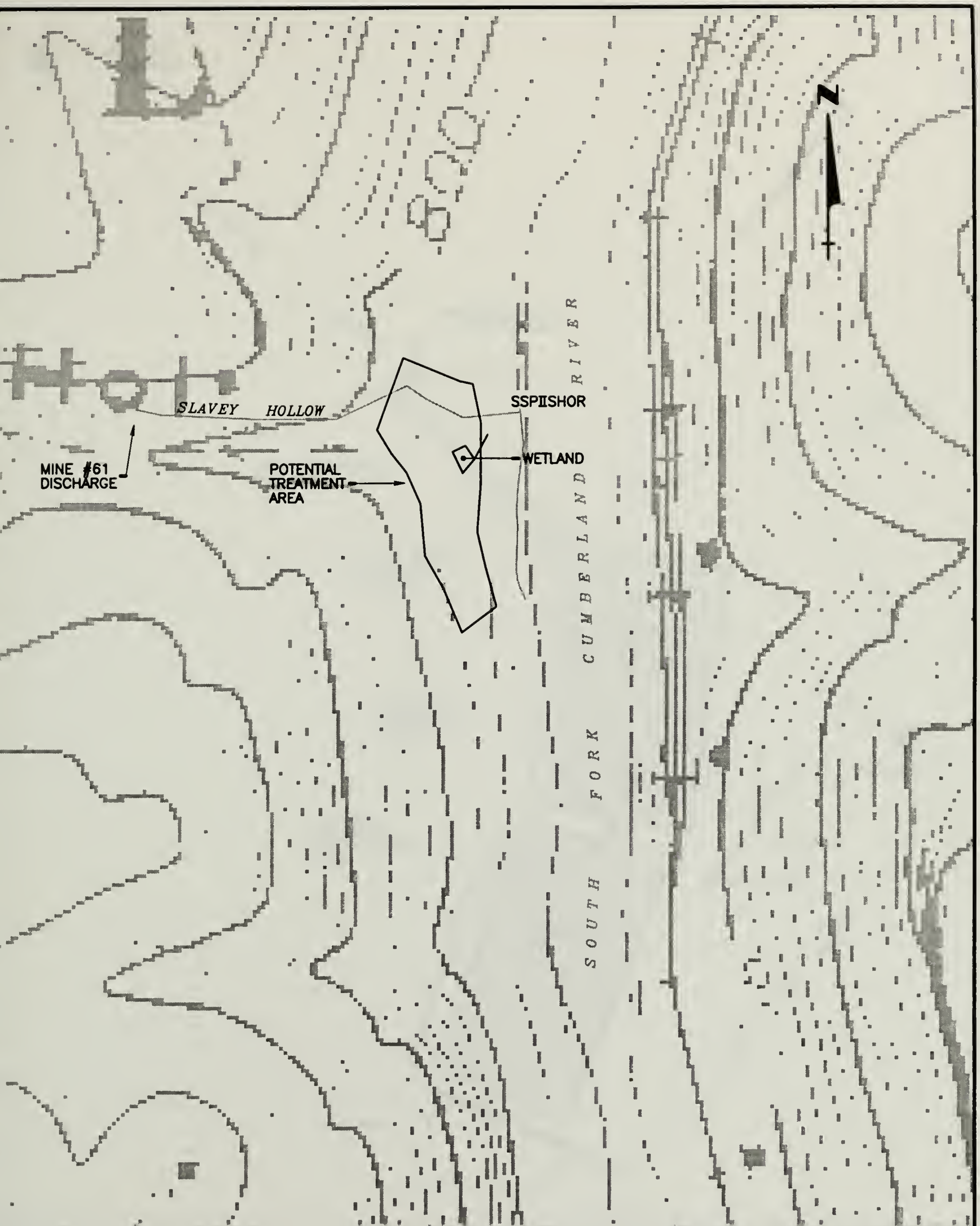
WORLEY MINE #86 SITE
SITE CHARACTERISTICS

SCALE
1'=300'

FIGURE
26



GANNETT FLEMING, INC. ENGINEERS AND PLANNERS HARRISBURG PENNSYLVANIA	NATIONAL PARK SERVICE, SOUTHEAST REGION BIG SOUTH FORK NATIONAL RIVER RESTORATION STUDY WORLEY MINE #86 SITE CONCEPTUAL REMEDIATION DESIGN	SCALE 1'=100' FIGURE 27



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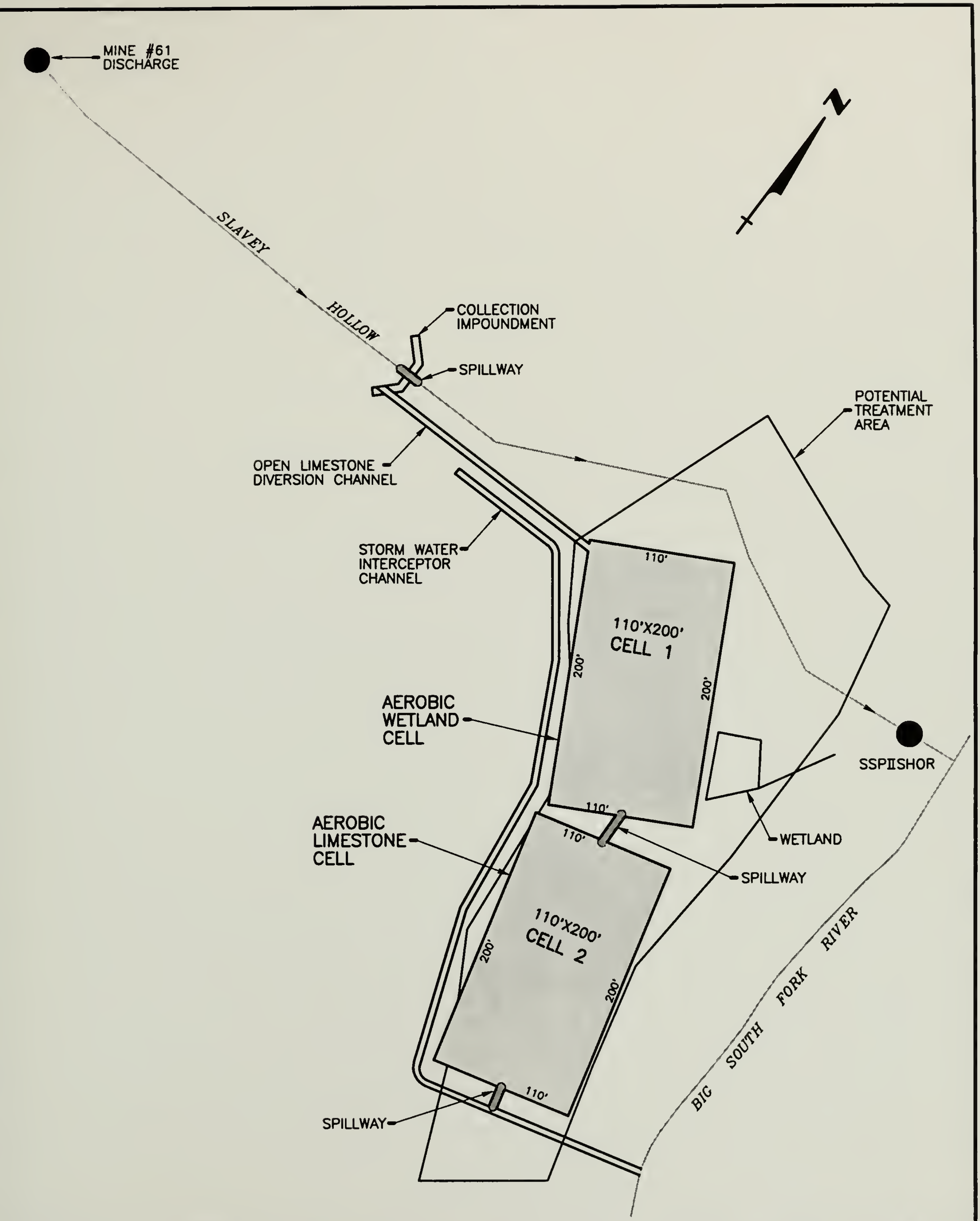
NATIONAL PARK SERVICE, SOUTHEAST REGION
BIG SOUTH FORK NATIONAL RIVER
RESTORATION STUDY

SLAVEY HOLLOW SITE
SITE CHARACTERISTICS

SCALE
1'=300'

FIGURE
28



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NATIONAL PARK SERVICE, SOUTHEAST REGION
BIG SOUTH FORK NATIONAL RIVER
RESTORATION STUDY
SLAVEY HOLLOW SITE
CONCEPTUAL REMEDIATION DESIGN

SCALE
1'=100'

FIGURE
29

Table 1. Limitations of Passive Treatment Systems

Physical Parameter	Treatment Type			
	Aerobic Surface Flow Wetland	**Anaerobic Surface Flow Wetland**	**Anaerobic Vertical Flow Wetland**	**Anoxic Limestone Drain**
Flow (cfs)	Size Dependent	Size Dependent	Size Dependent	<0.5 cfs
pH	>4	>3	NA	>5
Dissolved Oxygen (mg/L)	>2	NA	NA	<2
Acidity (mg/L)	<Alkalinity	Size Dependent	Size Dependent	<100
Alkalinity (mg/L)	>Acidity	NA	NA	<100
Ferric Iron (mg/L)	Size Dependent	Size Dependent	<30	<2
Total Iron (mg/L)	<70 (w/o aeration)	Size Dependent	<30	NA
Aluminum (mg/L)	NA	NA	NA	<5
Site Characteristics	Gently sloping; Large area	Gently sloping; Very large area	Gently sloping; Moderate Area	Moderately sloping; Long narrow area
Other Comments	Influenced be seasonal temperature change			Additional basin required for iron removal

Table 2. Ambient water quality criteria (AWQC) to protect aquatic life and most sensitive species concentration for trace metals monitored in the BSFNRRA.

Parameter	Benchmark Concentrations in mg/L			Lowest Reported Detection Limit
	EPA Ambient Water Quality Criteria	Lowest Observed Chronic Value for Daphnids[1]	Sensitive Species[3] EC_{20}	
Aluminum	0.087	1.9	0.075	0.024
Arsenic	0.190	NA	NA	0.0066
Cadmium[2]	0.00045	0.00015	0.000013	0.00085
Chromium (III)[2]	0.075	<0.044	0.0084	0.001
Copper[2]	0.0043	0.006	0.00026	0.0025
Iron	1.0	NA	NA	0.0043
Lead[2]	0.00070	0.012	0.00035	0.0011
Zinc[2]	0.039	0.047	0.021	0.0014
pH	6.5-9	NA	NA	NA

[1] Values reported in parameter specific Ambient Water Quality Criteria documents.
[2] Hardness variable AWQC estimated using a hardness value of 31 mg/L (10th percentile of sample measurements collected at the USGS station 5130104009.
[3] Oak Ridge National Laboratory's water quality criteria for near complete protection of sensitive aquatic species.

Table 3. Water Quality Data Collected From the Barthell Mines CMD Location 2 at Sample Location Number 09 (SSPIIRP02).

Date Sampled	05/24/96	6/12/96	07/18/96	08/19/96
pH - lab	2.87	2.96	2.70	2.72
pH - field	2.74	N/D	2.54	3.45
Acidity (mg/L CaCO3)	700	430	520	560
Temperature (deg C)	17.6	17.9	17.2	23.1
Conductivity (umhos/cm)	1760	1292	1697	1710
Dissolved Oxygen (mg/L)	NS	10.3	N/A	10.3
Redox Potential (mVolts)	335.0	334.6	195.6	321.6
Alkalinity (mg/L CaCO3)	N/A	NA	-	-
Measured TDS at 180 deg C	1200	700	970	1100
	(mg/L)	(mg/l)	(mg/l)	(mg/l)
Aluminum (Al+3)	40	27	36.00	41
Total Aluminum (Al+3)	40	27	40.00	41
Arsenic (As+3)	<0.0066	< 0.0066	< 0.0066	< 0.0066
Cadmium (Cd+2)	<0.001	0.0025	< 0.0010	< 0.0010
Calcium (Ca+2)	31	31	33	39
Chromium (Cr+3)	0.03	0.023	0.03	0.031
Copper (Cu+2)	0.069	0.045	0.03	0.035
Iron (Fe)	120	68	86.00	95
Total Iron (Fe)	130	72	87.00	90
Lead (Pb+2)	<0.0011	< 0.0011	< 0.0011	<0.0011
Magnesium (Mg+2)	15	13	15.0	17
Manganese (Mn+2)	2	1.6	1.80	2.4
Total Manganese (Mn+2)	2	·1.5	2.00	2.3
Selenium (Se+4)	<0.0033	< 0.0033	< 0.0033	< 0.0033
Sodium (Na+)	1.6	1.5	1.9	2.3
Zinc (Zn+2)	0.27	0.21	0.25	0.28
Chloride (Cl-)	<10	< 10	< 10	<50
Sulfate (SO4-2)	990	670	830	770
Fe+2 field spectroph.	18.00	1.5	1.73	2.11
Fe+3 by difference	102.00	66.5	84.27	92.89

Table 4. Water Quality Data Collected From the Barthell Mines CMD Location 3 at Sample Location Number 10 (SSPIIRP03).

Date Sampled	05/24/96	06/12/96	07/18/96	08/19/96
pH - lab	3.00	3.13	2.96	3.00
pH - field	2.78	2.5	2.75	3.18
Acidity (mg/L CaCO3)	280	250	270	260
Temperature (deg C)	15.1	16.8	15.7	16.0
Conductivity (umhos/cm)	1244	1124	1190	1084
Dissolved Oxygen (mg/L)	NS	10.6	13.2	12.2
Redox Potential (mVolts)	304.4	299.6	234.6	308.6
Alkalinity (mg/L CaCO3)	N/A	NA	-	-
Measured TDS at 180 deg C	640	590	680	720
	(mg/L)	(mg/l)	(mg/l)	(mg/l)
Aluminum (Al+3)	16	15	20	18
Total Aluminum (Al+3)	16	16	21	18
Arsenic (As+3)	<0.0066	< 0.0066	< 0.0066	< 0.0066
Cadmium (Cd+2)	<0.001	0.0033	< 0.0010	< 0.0010
Calcium (Ca+2)	33	34	38	39
Chromium (Cr+3)	0.0077	< 0.0043	0.01	0.0085
Copper (Cu+2)	0.0051	< 0.0029	0.01	0.0071
Iron (Fe)	28	30	47	52
Total Iron (Fe)	29	32	46	52
Lead (Pb+2)	0.0013	0.0028	< 0.0011	< 0.0011
Magnesium (Mg+2)	18	17	20.0	19
Manganese (Mn+2)	1.6	1.7	1.8	1.8
Total Manganese (Mn+2)	1.7	1.6	1.8	1.8
Selenium (Se+4)	<0.0033	< 0.0033	< 0.0033	< 0.0033
Sodium (Na+)	5	4.4	5.1	5.8
Zinc (Zn+2)	0.14	0.14	0.15	0.15
Chloride (Cl-)	<10	< 10	< 10	<50
Sulfate (SO4-2)	490	380	450	430
Fe+2 field spectroph.	0.88	1.67	1	2.08
Fe+3 by difference	27.12	28.33	46	49.92

Table 5. Water Quality Data Collected From CMD Near Barthell Town at Sample Location Number 10a (SSPIIRP04).

Date Sampled	05/24/96	07/18/96	06/12/96
pH - lab	2.90	2.88	NA
pH - field	2.80	2.55	2.5
Acidity (mg/L CaCO3)	350	300	NA
Temperature (deg C)	17.3	25.2	17.6
Conductivity (umhos/cm)	1270	1489	1190
Dissolved Oxygen (mg/L)	NS	N/A	13
Redox Potential (mVolts)	330.2	272.6	232.6
Alkalinity (mg/L CaCO3)	N/A	-	NA
Measured TDS at 180 deg C	590	680	NA
	(mg/L)	(mg/l)	(mg/l)
Aluminum (Al+3)	15	19	12
Total Aluminum (Al+3)	14	21	12
Arsenic (As+3)	<0.0066	< 0.0066	< 0.0066
Cadmium (Cd+2)	<0.001	< 0.0010	0.0026
Calcium (Ca+2)	28	34	29
Chromium (Cr+3)	0.0092	0.01	< 0.0043
Copper (Cu+2)	0.018	0.01	0.0088
Iron (Fe)	42	52	31
Total Iron (Fe)	41	55	31
Lead (Pb+2)	<0.0011	< 0.0011	< 0.0011
Magnesium (Mg+2)	14	15	12
Manganese (Mn+2)	1.3	1.5	1.2
Total Manganese (Mn+2)	1.3	1.6	1.1
Selenium (Se+4)	<0.0033	< 0.0033	< 0.0033
Sodium (Na+)	3.4	4.0	3.2
Zinc (Zn+2)	0.082	0.10	0.086
Chloride (Cl-)	<10	< 10	NA
Sulfate (SO4-2)	510	530	NA
Fe+2 field spectroph.	1.05	2.5	0.69
Fe+3 by difference	40.95	49.5	30.31

Table 6. Preliminary cost estimate for the conceptual vertical flow passive treatment system at the Barthell Mine No. 1 Site CMD discharge.

ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL
1	Mobilization & Demobilization	1	EA	$5,000.00	$5,000.00
3	Clearing & Grubbing	0.75	ACRE	$1,500.00	$1,125.00
4	Diversion of Water	1	EA	$2,500.00	$2,500.00
5	SW Channel Excavation	400	LF	$20.00	$8,000.00
6	Treatment System Grading	6300	CY	$5.00	$31,500.00
7	Misc. Rock Material	50	TON	$30.00	$1,500.00
8	HQ Limestone	1900	TON	$50.00	$95,000.00
9	Spent Mushroom Compost	1400	CY	$30.00	$42,000.00
10	Geonet	2800	SY	$4.00	$11,200.00
11	Underdrain Piping	1	EA	$25,000.00	$25,000.00
12	Wetland Planting	2800	SY	$1.00	$2,800.00
13	Seeding & Mulching	0.25	ACRE	$6,500.00	$1,625.00
14	Erosion and Sedimentation Measures	1	EA	$1,500.00	$1,500.00
	Total Capital Costs				**$228,750.00**

Table 7. **Preliminary cost estimate for the conceptual vertical flow passive treatment system at the Barthell Mine No. 2 Site CMD discharge.**

ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL
1	Mobilization & Demobilization	1	EA	$4,000.00	$4,000.00
3	Clearing & Grubbing	0.3	ACRE	$1,500.00	$450.00
4	Diversion of Water	1	EA	$1,500.00	$1,500.00
5	SW Channel Excavation	200	LF	$20.00	$4,000.00
6	Treatment System Grading	1800	CY	$5.00	$9,000.00
7	Misc. Rock Material	40	TON	$30.00	$1,200.00
8	HQ Limestone	370	TON	$50.00	$18,500.00
9	Spent Mushroom Compost	280	CY	$30.00	$8,400.00
10	Geonet	560	SY	$4.00	$2,240.00
11	Underdrain Piping	1	EA	$7,500.00	$7,500.00
12	Wetland Planting	780	SY	$1.00	$780.00
13	Seeding & Mulching	0.15	ACRE	$6,500.00	$975.00
14	Erosion and Sedimentation Measures	1	EA	$1,000.00	$1,000.00
	Total Capital Costs				**$59,545.00**

Table 8. Preliminary cost estimate for the conceptual vertical flow passive treatment system at the Barthell Mine No. 3 Site CMD discharge.

ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL
1	Mobilization & Demobilization	1	EA	$4,000.00	$4,000.00
3	Clearing & Grubbing	0.3	ACRE	$1,500.00	$450.00
4	Diversion of Water	1	EA	$1,500.00	$1,500.00
5	SW Channel Excavation	200	LF	$20.00	$4,000.00
6	Treatment System Grading	1800	CY	$5.00	$9,000.00
7	Misc. Rock Material	40	TON	$30.00	$1,200.00
8	HQ Limestone	440	TON	$50.00	$22,000.00
9	Spent Mushroom Compost	340	CY	$30.00	$10,200.00
10	Geonet	670	SY	$4.00	$2,680.00
11	Underdrain Piping	1	EA	$8,500.00	$8,500.00
12	Wetland Planting	900	SY	$1.00	$900.00
13	Seeding & Mulching	0.15	ACRE	$6,500.00	$975.00
14	Erosion and Sedimentation Measures	1	EA	$1,000.00	$1,000.00
	Total Capital Costs				**$66,405.00**

Table 9. **Preliminary cost estimate for the conceptual open limestone channel at the Barthell Mine No. 4 Site CMD discharge.**

ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL
1	Mobilization & Demobilization	1	EA	$3,000.00	$3,000.00
2	Clearing & Grubbing	0.3	ACRE	$1,500.00	$450.00
3	Diversion of Water	1	EA	$1,500.00	$1,500.00
4	Channel Excavation	255	LF	$20.00	$5,100.00
5	HQ Limestone	75	TON	$32.00	$2,400.00
6	Piping	1	EA	$1,500.00	$3,500.00
7	Seeding & Mulching	0.3	ACRE	$6,500.00	$1,950.00
8	Erosion and Sedimentation Measures	1	EA	$1,000.00	$1,000.00
	Total Capital Costs				**$18,900.00**

Table 10. Water Quality Data Collected From the Mouth of Devils Creek at Sample Location Number 21 (SSPIIDC01).

Date Sampled	05/09/96	06/13/96	07/17/96	08/21/96	09/23/96	10/17/96	11/19/96	02/18/97	3/21/97	04/17/97
pH - lab	7.04	6.77	3.38	3.42	3.08	3.11	6.71	6.45	6.14	5.65
pH - field	6.31	6.36	4.72	3.71	3.06	3.0	5.61	5.50	· 6.72	6.64
Acidity (mg/L CaCO3)	<10	< 10	48	48	110	140	N/A	N/A	ND	< 10
Temperature (deg C)	14.3	16.9	20.4	21.0	16.4	13.5	8.9	6.9	8.9	9.8
Conductivity (umhos/cm)	44	69	657	616	1119	1191	83	51	35	91
Dissolved Oxygen (mg/L)	9.8	11	11.0	13.0	8.6	8.1	11.2	11.3	ND	10.4
Redox Potential (mVolts)	-8.0	-24.4	-33.4	280.6	291.6	288.6	-50.4	269.4	321.4	407.4
Alkalinity (mg/L CaCO3)	<20	< 20	-	-	-	^-	24	< 20	<20	< 20
Measured TDS at 180 deg C	32	41	370	350	640	530	24	N/A	ND	N/A
Discharge Rate (cfs)	7.290	6.190	0.758	0.157	0.135	0.136	3.753	9.382	28.000	2.278
	(mg/L)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Aluminum (Al+3)	<0.026	0.066	1.3	1.1	2.9	3.2	^<0.024	0.12	< 0.024	< 0.024
Total Aluminum (Al+3)	0.28	0.46	1.5	1.2	2.7	3	0.61	0.32	0.29	0.4
Arsenic (As+3)	<0.0066	< 0.0066	< 0.0066	< 0.0066	^<0.0066	^<0.0066	^<0.0066	<0.0066	< 0.0066	< 0.0066
Cadmium (Cd+2)	<0.001	< 0.001	< 0.0010	< 0.0010	< 0.0010	^<0.0010	^<0.0010	<0.00085	<0.00085	< 0.00085
Calcium (Ca+2)	3.7	6.3	37	39	62	68	6.8	3.7	2.8	8.4
Chromium (Cr+3)	<0.001	< 0.001	< 0.0036 B	< 0.0010	^<0.0010	0.0037	^<0.0010	<0.0042	<0.0042	< 0.0042
Copper (Cu+2)	0.0076	< 0.0029	0.01	0.0077	^<0.018	0.0066	0.019	0.012	0.021	< 0.0025
Iron (Fe)	0.05	0.11	2.4	3.3	13	16	0.37	0.075	<0.022	0.036
Total Iron (Fe)	0.25	0.38	2.8	4.4	14	18	3.1	0.21	0.28	0.33
Lead (Pb+2)	<0.0011	0.013	< 0.0011	<0.0011	< 0.0011	< 0.0011	^<0.0011	0.0028	< 0.0011	< 0.0011
Magnesium (Mg+2)	1.6	2.2	18	16	28	28	2.4	1.7	1.2	3.1
Manganese (Mn+2)	0.1	0.26	6.4	6	11	12	0.4	0.14	0.034	0.51
Total Manganese (Mn+2)	0.11	0.25	6	6.2	11	12	0.44	0.14	0.035	0.47
Selenium (Se+4)	<0.0033	< 0.0033	< 0.0033	< 0.0033	^<0.0033	^<0.0033	^<0.0033	< 0.0066	<0.0066	< 0.0066
Sodium (Na+)	1	1.6	22.0	20	40	39	2.2	1.3	0.73	2.4
Zinc (Zn+2)	0.006	0.0066	0.05	0.055	0.072	0.084	< 0.0016	0.024	0.012	0.013
Chloride (Cl-)	<10	< 10	< 10	<10	^<10	^< 10	^<10	< 10	12	10
Sulfate (SO4-2)	13	19	240	230	400	470	25	11	<11	29
Fe+2 field spectroph.	0.00	0.02	0.83	0.37	1.35	1.58	0.29	NS	0.00	0.00
Fe+3 by difference	0.05	0.09	1.57	2.93	0.00	14.42	0.08	0.08	0.00	0.04

Table 11. Preliminary cost estimate for the conceptual vertical flow passive treatment system for the Devils Creek CMD discharges.

ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL
1	Mobilization & Demobilization	1	EA	$5,000.00	$7,000.00
2	Clearing & Grubbing	2	ACRE	$1,500.00	$3,000.00
3	Diversion of Water	1	EA	$2,500.00	$2,500.00
4	SW Channel Excavation	400	LF	$20.00	$8,000.00
5	Treatment System Grading	4000	CY	$5.00	$20,000.00
6	Misc. Rock Material	140	TON	$30.00	$4,200.00
7	HQ Limestone	2150	TON	$50.00	$107,500.00
8	Spent Mushroom Compost	2000	CY	$30.00	$60,000.00
9	Geonet	3000	SY	$4.00	$12,000.00
10	Underdrain Piping	1	EA	$30,000.00	$30,000.00
11	Wetland Planting	3200	SY	$1.00	$3,200.00
12	Seeding & Mulching	1	ACRE	$6,500.00	$6,500.00
13	Erosion and Sedimentation Measures	1	EA	$3,000.00	$3,000.00
	Total Capital Costs				**$266,900.00**

Table 12. Water Quality Data Collected From the Mouth of Laurel Branch Creek at Sample Location Number 41 (SSPIILB01).

Date Sampled	05/07/96	06/11/96	07/16/96	08/20/96	09/18/96	10/16/96	11/19/96	02/18/97	3/20/97	04/16/97
pH - lab	5.39	5.23	3.38	3.48	3.42	3.44	5.17	5.00	5.15	4.51
pH - field	5.25	5.6	3.97	3.30	3.50	3.69	4.72	5.00	5.86	4.69
Acidity (mg/L CaCO3)	<10	< 10	40	72	78	78	<10	< 10	<10	14
Temperature (deg C)	13.4	14.5	19.4	21.2	15.5	12.9	10.1	9.7	8.9	5.9
Conductivity (umhos/cm)	40	46	387	442	475	492	60	44	35	98
Dissolved Oxygen (mg/L)	10.1	10.8	12.2	10.2	9.2	8.9	11.0	10.5	10.9	11.5
Redox Potential (mVolts)	37.1	-81.4	-33.4	137.6	210.6	187.6	51.6	534.4	328.4	954.4
Alkalinity (mg/L CaCO3)	<20	< 20	-	-	-	^-	20	< 20	<20	< 20
Measured TDS at 180 deg C	29	29	190	230	230	220	56	N/A	ND	N/A
Discharge Rate (cfs)	6.260	4.420	0.354	0.030	0.090	0.058	6.355	3.903	26.075	2.610
	(mg/L)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Aluminum (Al+3)	0.08	0.13	4.6	5.3	5.4	5.6	0.21	0.41	0.12	0.92
Total Aluminum (Al+3)	0.72	0.53	4.1	5.3	5.4	5.8	0.51	0.56	0.47	1
Arsenic (As+3)	<0.0066	< 0.0066	< 0.0066	< 0.0066	^<0.0066	^<0.0066	^< 0.0066	< 0.0066	<0.0066	< 0.0066
Cadmium (Cd+2)	<0.001	< 0.001	< 0.0010	< 0.0010	< 0.0010	^<0.0010	^<0.0010	<0.00085	<0.00085	< 0.00085
Calcium (Ca+2)	2.1	3.4	16	18	16	18	3.8	3.8	2.1	5.8
Chromium (Cr+3)	<0.001	< 0.001	< 0.0036 B	< 0.0010	^<0.0010	^<0.0010	^< 0.0010	<0.0042	<0.0042	< 0.0042
Copper (Cu+2)	0.0074	< 0.0043	0.0083	0.0073	< 0.0029	0.018	^<0.0025	0.012	<0.012	0.019
Iron (Fe)	0.17	0.85	7.3	6.8	7.3	7.2	0.42	1.2	0.15	2.5
Total Iron (Fe)	0.57	1.1	7.4	4.8	7.3	7.8	0.67	1.2	0.36	2.6
Lead (Pb+2)	<0.0011	< 0.0011	< 0.0011	< 0.0011	^<0.0011	< 0.0011	^<0.0011	<0.0011	<0.0011	< 0.0011
Magnesium (Mg+2)	1.2	1.6	7.1	8.7	8.4	8.9	1.6	1.6	1.1	2.6
Manganese (Mn+2)	0.05	0.095	1	1.4	1.3	1.4	0.11	0.13	0.036	0.23
Total Manganese (Mn+2)	0.066	0.1	1.1	1.4	1.2	1.4	0.13	0.12	0.044	0.24
Selenium (Se+4)	<0.0033	< 0.0033	< 0.0033	< 0.0033	^<0.0033	^<0.0033	^<0.0033	<0.0066	< 0.0066	< 0.0066
Sodium (Na+)	1.1	1.4	2.3	2.8	3.1	3.1	1.4	1.4	0.72	1.3
Zinc (Zn+2)	0.0056	0.0051	0.08	0.073	0.06	0.062	0.0068	0.0082	0.01	0.025
Chloride (Cl-)	<10	< 10	< 10	<10	^<10	^<10	^<10	< 10	<10	<10
Sulfate (SO4-2)	12	22	120	130	140	160	19	11	<11	33
Fe+2 field spectroph.	0.1	0.54	2.43	3.21	4.58	4.18	0.4	0.87	0.09	1.6
Fe+3 by difference	0.07	0.31	4.87	3.59	2.72	3.02	0.02	0.33	0.06	0.9

Table 13. Estimates of construction costs for the Laurel Branch Creek lined stream channel.

ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL
1	Mobilization & Demobilization	1	EA	$5,000.00	$5,000.00
2	Diversion of Water	1	EA	$5,000.00	$5,000.00
3	Grading	200	CY	$20.00	$4,000.00
4	LLDPE Liner	150	CY	$30.00	$4,500.00
5	Geotextile Fabric	150	CY	$5.00	$750.00
6	Limestone	140	TON	$25.00	$3,500.00
7	Revegetation	0.5	ACRE	$1,600.00	$800.00
8	Erosion & Sedimentation Control	1	EA	$2,000.00	$2,000.00
	Total Capital Costs				**$25,550.00**

Table 14. Water Quality Data For the Discharge Emanating From the Blue Heron Spoil-Pine Plantings at Sample Location Number 36 (SSPIIBH01).

Date Sampled	05/08/96	06/11/96	11/19/96
pH - lab	2.70	2.48	2.40
pH - field	2.78	ND	2.36
Acidity (mg/L CaCO3)	360	620	860
Temperature (deg C)	10.5	15.7	13.1
Conductivity (umhos/cm)	1400	1956	3430
Dissolved Oxygen (mg/L)	10.3	8.1	7.3
Redox Potential (mVolts)	276.0	307.6	319.6
Alkalinity (mg/L CaCO3)	N/A	-	N/A
Measured TDS at 180 deg C	760	1800	2000
Discharge Rate (cfs)	0.04	0.035	0.04
	(mg/L)	(mg/l)	(mg/l)
Aluminum (Al+3)	19	39	58
Total Aluminum (Al+3)	19	41	53
Arsenic (As+3)	<0.0066		^< 0.0066
Cadmium (Cd+2)	<0.001		< 0.0010
Calcium (Ca+2)	66	120	180
Chromium (Cr+3)	0.0086	0.019	0.02
Copper (Cu+2)	0.036	0.036	0.052
Iron (Fe)	43	74	92
Total Iron (Fe)	43	78	100
Lead (Pb+2)	<0.0011		^<0.0011
Magnesium (Mg+2)	22	42	61
Manganese (Mn+2)	2.9	5.1	6.8
Total Manganese (Mn+2)	3	5.1	6.8
Selenium (Se+4)	<0.0033	< 0.0033	^<0.0066
Sodium (Na+)	4.6	6.2	8.9
Zinc (Zn+2)	0.12	0.21	0.28
Chloride (Cl-)	<10	< 10	50
Sulfate (SO4-2)	680	1200	1600
Fe+2 field spectroph.	2.8	2.24	0.4
Fe+3 by difference	40.2	71.76	91.6

Table 15. Water Quality Data For the Discharge Emanating From the Blue Heron Spoil-South(N) at Sample Location Number 35i (SSPIIBH02N).

Date Sampled	02/18/97	04/16/97	07/16/96	08/20/96	10/16/96	3/20/97	09/23/96
pH - lab	3.03	2.89	2.53	2.62	2.45	2.88	2.39
pH - field	4.00	2.63	2.40	1.77	2.70	3.31	2.67
Acidity (mg/L CaCO3)	280	410	900	740	1500	350	1100
Temperature (deg C)	15.5	19.6	22.5	32.0	24.0	22.3	16.6
Conductivity (umhos/cm)	NS	1715	2480	2100	3950	1453	3420
Dissolved Oxygen (mg/L)	1.9	5.9	3.2	5.0	3.2	6.7	3.9
Redox Potential (mVolts)	659.4	739.4	155.6	250.6	227.6	307.4	200.6
Alkalinity (mg/L CaCO3)	N/A	N/A	-	-	^-	ND	-
Measured TDS at 180 deg C	770	1000	1400	2200	2600	920	2100
Discharge Rate (cfs)							
	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Aluminum (Al+3)	8.6	9.5	25.00	23	68	6.1	47
Total Aluminum (Al+3)	10	9.8	62.00	49	58	7.3	50
Arsenic (As+3)	< 0.0066	< 0.0066	< 0.0066	< 0.0066	^<0.0066	< 0.0066	^<0.0066
Cadmium (Cd+2)	<0.00085	< 0.00085	< 0.0010	< 0.0010	0.0028	<0.00085	0.021
Calcium (Ca+2)	62	130	110	200	130	86	94
Chromium (Cr+3)	0.0091	0.0085	0.02	0.022	0.057	<0.0042	0.017
Copper (Cu+2)	0.012	0.021	0.06	0.038	0.15	0.027	0.14
Iron (Fe)	65	46	120.00	130	340	18	300
Total Iron (Fe)	75	47	210.00	170	380	18	330
Lead (Pb+2)	<0.0011	0.0028	0.01	0.0091	^<0.0011	0.014	0.0073
Magnesium (Mg+2)	24	37	39.0	62	46	29	43
Manganese (Mn+2)	1.3	2.3	3.60	6.2	16	1.2	6
Total Manganese (Mn+2)	1.3	2.1	3.90	6.2	13	1.2	4.1
Selenium (Se+4)	<0.0066	< 0.0066	<0.0033	< 0.0066	^<0.0033	< 0.0066	^<0.0033
Sodium (Na+)	4.9	5	8.2	6.9	5.8	3.2	7.4
Zinc (Zn+2)	0.06	0.071	0.13	0.19	0.31	0.053	0.35
Chloride (Cl-)	< 50	< 10	< 25	<50	140	<10	^<100
Sulfate (SO4-2)	600	760	2000	1500	2100	580	1800
Fe+2 field spectroph.	38.00	2.05	70.50	60.00	67.00	1.30	78.00
Fe+3 by difference	27.00	43.95	49.50	70.00	273.00	16.70	222.00

Table 16. Water Quality Data For the Discharge Emanating From the Blue Heron Spoil-South at Sample Location Number 35 (SSPIIBH02).

Date Sampled	05/08/96	06/11/96	07/16/96	3/20/97	04/16/97
pH - lab	2.84	2.22	2.24	2.49	2.99
pH - field	2.88	ND	2.17	3.08	2.80
Acidity (mg/L CaCO3)	500	2400	5000	1200	340
Temperature (deg C)	14.9	21	21.8	15.0	21.1
Conductivity (umhos/cm)	1190	8480 (?)	7850	2520	1386
Dissolved Oxygen (mg/L)	2.9	1.5	4.0	1.1	7.4
Redox Potential (mVolts)	190.0	110.6	133.6	301.4	714.4
Alkalinity (mg/L CaCO3)	N/A	-	-	ND	N/A
Measured TDS at 180 deg C	1000	12000	9400	1700	650
Discharge Rate (cfs)					
	(mg/L)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Aluminum (Al+3)	15	480	380	25	9.5
Total Aluminum (Al+3)	49	480	430	23	8.1
Arsenic (As+3)	<0.0066	0.19	0.26	0.016	< 0.0066
Cadmium (Cd+2)	<0.001	0.0073	< 0.010	<0.00085	< 0.00085
Calcium (Ca+2)	78	340	400	95	58
Chromium (Cr+3)	0.014	0.42	0.36	0.023	0.0046
Copper (Cu+2)	0.039	0.49	0.30	0.072	0.017
Iron (Fe)	110	1700	1400	150	53
Total Iron (Fe)	170	1700	1600	150	52
Lead (Pb+2)	<0.0011	0.013	0.03	< 0.0011	< 0.0011
Magnesium (Mg+2)	24	97	110	18	22
Manganese (Mn+2)	1.5	11	12	1.6	1.6
Total Manganese (Mn+2)	1.6	12	12	1.5	1.5
Selenium (Se+4)	<0.0033	< 0.033	< 0.0066	<0.0066	< 0.0066
Sodium (Na+)	4.8	15	17	2.4	6
Zinc (Zn+2)	0.071	0.76	1.1	0.1	0.066
Chloride (Cl-)	<10	60	70	<100	< 50
Sulfate (SO4-2)	710	9600	7800	1600	540
Fe+2 field spectroph.	25.5	245	292	82	13.2
Fe+3 by difference	84.5	1455	1108	68	39.8

Table 17. Water Quality Data For the Discharge Emanating From the Blue Heron Spoil-North at Sample Location Number 34 (SSPIIBH04).

Date Sampled	05/08/96	06/11/96	07/16/96	08/20/96	09/23/96	10/16/96	11/19/96	02/18/97	3/20/97	04/16/97
pH - lab	2.74	2.58	2.62	2.59	2.59	2.57	2.34	2.77	2.98	2.72
pH - field	2.44	N/D	N/A	1.71	2.79	2.62	2.4	2.50	3.43	2.52
Acidity (mg/L CaCO3)	1300	490	600	3200	780	860	1600	500	350	1200
Temperature (deg C)	12.8	25	27.7	29.5	20.2	22.2	13.7	13.2	17.5	19.3
Conductivity (umhos/cm)	3375	2100	2490	4470	2470	2770	3990	NS	1268	2230
Dissolved Oxygen (mg/L)	0.4	3.5	5.2	0.8	3.7	3.7	4.7	6.9	6.6	7.3
Redox Potential (mVolts)	164.0	212.6	243.6	226.6	213.6	222.6	261.6	734.4	774.4	669.4
Alkalinity (mg/L CaCO3)	N/A	-	-	-	-	^-	N/A	N/A	ND	N/A
Measured TDS at 180 deg C	2000	1300	290	5900	2200	1900	3100	1400	650	1200
Discharge Rate (cfs)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	(mg/L)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Aluminum (Al+3)	74	12	14	200	46	24	48	17	9.5	43
Total Aluminum (Al+3)	75	76	29	240	96	58	56	37	7.8	39
Arsenic (As+3)	0.048	< 0.0066	< 0.0066	0.19	^<0.0066	^<0.0066	0.021	< 0.0066	< 0.0066	0.039
Cadmium (Cd+2)	<0.001	< 0.001	< 0.0010	< 0.010	0.0087	< 0.0010	0.034	<0.00085	<0.00085	< 0.00085
Calcium (Ca+2)	54	160	170	130	200	190	200	150	64	40
Chromium (Cr+3)	0.083	0.0087	0.01	0.27	< 0.0010	0.021	0.032	0.011	<0.0042	0.048
Copper (Cu+2)	0.25	0.037	0.03	0.47	0.053	0.038	0.12	0.034	0.01	0.1
Iron (Fe)	340	68	84	970	130	160	360	62	7.1	210
Total Iron (Fe)	300	140	95	1100	180	190	420	76	8.1	210
Lead (Pb+2)	<0.0011	0.0036	0.01	0.0089	0.0093	0.0041	^<0.0011	0.0049	<0.0011	< 0.0011
Magnesium (Mg+2)	16	44	52	48	68	60	60	44	26	15
Manganese (Mn+2)	3.5	3.3	4	11	9.1	8.4	5.9	3.5	1.2	3.1
Total Manganese (Mn+2)	3.5	4	4	11	8.5	8.2	6.6	3.5	1.2	3.1
Selenium (Se+4)	<0.0033	< 0.0066	< 0.016	< 0.0066	^<0.0033	^<0.0033	^<0.0066	<0.0066	<0.0066	< 0.0066
Sodium (Na+)	1.7	4.8	5.5	7.1	7.5	7.4	5.7	4.6	2.7	2.7
Zinc (Zn+2)	0.26	0.11	0.13	0.89	0.28	0.25	0.24	0.14	0.082	0.2
Chloride (Cl-)	20	< 10	< 10	<100	^<10	55	^<150	< 100	10	< 250
Sulfate (SO4-2)	1900	1300	1100	4400	1600	1800	2700	1000	450	1100
Fe+2 field spectroph.	24.7	17.1	22.6	608	42	50	90	2.1	0.83	106
Fe+3 by difference	315.3	50.9	61.4	362	88	110	270	59.9	6.27	104

Table 18. **Preliminary cost estimate for the conceptual spoil removal action at the Blue Heron Spoil Site.**

ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL
1	Mobilization & Demobilization	1	EA	$100,000.00	$100,000.00
2	Clearing & Grubbing	47	ACRE	$1,000.00	$47,000.00
3	Excavation	600,000	CY	$2.50	$1,500,000.00
4	Hauling @ 50 miles	600,000	CY	$2.00	$1,200,000.00
5	Blue Heron Site Revegetation	17	ACRE	$1,600.00	$27,200.00
6	Disposal Site Regrade	30	ACRE	$2,000.00	$60,000.00
7	Disposal Site Revegetation	30	ACRE	$1,600.00	$48,000.00
8	Dry Cover-Geomembrane	145,000	SY	$5.00	$725,000.00
9	Soil Cover-1.5 feet	72,500	CY	$8.00	$580,000.00
10	Temporary Roadway	1,500	LF	$9.00	$13,500.00
11	Erosion and Sedimentation Measures	1	EA	$50,000.00	$50,000.00
	Total Capital Costs				**$4,350,700.00**

Table 19. Preliminary cost estimate for the conceptual reclamation action at the Blue Heron Spoil Site.

ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL
1	Mobilization & Demobilization	1	EA	$7,500.00	$7,500.00
2	Clearing & Grubbing	4	ACRE	$1,000.00	$4,000.00
3	Earthmoving	19,000	CY	$2.00	$38,000.00
4	Site Regrade	4	ACRE	$2,000.00	$8,000.00
5	Site Revegetation	4	ACRE	$1,600.00	$6,400.00
6	Soil Amendments	13	ACRE	$500.00	$6,500.00
7	Soil Cover-1.5 feet	8,500	CY	$8.00	$68,000.00
8	Temporary Roadway	1,500	LF	$9.00	$13,500.00
9	Erosion and Sedimentation Measures	1	EA	$10,000.00	$10,000.00
	Total Capital Costs				**$161,900.00**

Table 20. **Preliminary cost estimate for the conceptual geomembrane liner installation action at the Blue Heron Spoil Site.**

ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL
1	Mobilization & Demobilization	1	EA	$65,000.00	$65,000.00
2	Clearing & Grubbing	17	ACRE	$1,000.00	$17,000.00
3	Excavation	60,000	CY	$2.00	$120,000.00
4	Blue Heron Site Revegetation	17	ACRE	$1,600.00	$27,200.00
5	Dry Cover-Geomembrane	82,500	SY	$5.00	$412,500.00
6	Soil Cover-3 feet	82,500	CY	$8.00	$660,000.00
7	Temporary Roadway	1,500	LF	$9.00	$13,500.00
8	Erosion and Sedimentation Measures	1	EA	$25,000.00	$25,000.00
	Total Capital Costs				**$1,340,200.00**

Table 21. **Preliminary cost estimate for the conceptual surface water control action at the Blue Heron Spoil Site.**

ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL
1	Mobilization & Demobilization	1	EA	$7,000.00	$5,000.00
2	Pond Excavation	200	CY	$5.00	$1,000.00
3	HQ Limestone	150	Tons	$50.00	$7,500.00
4	Top Soil Cover - 1.5 ft	150	CY	$8.00	$1,200.00
5	Diversion Channel Construction	1,000	LF	$40.00	$40,000.00
6	Interceptor Channel Construction	1,500	LF	$20.00	$30,000.00
7	Revegetation	0.5	ACRE	$1,600.00	$800.00
8	Temporary Roadway	1,500	LF	$9.00	$13,500.00
9	Erosion and Sedimentation Measures	1	EA	$7,500.00	$7,500.00
	Total Capital Costs				**$106,500.00**

Table 22. Preliminary cost estimate for the conceptual permeation grouting barrier installation action at the Blue Heron Spoil Site.

ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL
1	Mobilization & Demobilization	1	EA	$25,000.00	$25,000.00
2	Well Drilling	105	WELLS	$2,500.00	$262,500.00
3	Grout Material	12,000	CY	$20.00	$240,000.00
4	Grout Injection	105	WELLS	$1,500.00	$157,500.00
5	Temporary Roadway	1,500	LF	$9.00	$13,500.00
6	Erosion and Sedimentation Measures	1	EA	$5,000.00	$5,000.00
	Total Capital Costs				**$703,500.00**

Table 23. Preliminary cost estimate for the conceptual cut-off wall barrier installation action at the Blue Heron Spoil Site.

ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL
1	Mobilization & Demobilization	1	EA	$20,000.00	$20,000.00
2	Trench Excavation	12,000	CY	$10.00	$120,000.00
3	Slurry Material	12,000	CY	$25.00	$300,000.00
4	Temporary Roadway	1,500	LF	$9.00	$13,500.00
5	Erosion and Sedimentation Measures	1	EA	$5,000.00	$5,000.00
	Total Capital Costs				**$458,500.00**

Table 24. Water Quality Data Collected From the Mouth of Three West Hollow at Sample Location Number 32 (SSPIITWH01).

Date Sampled	05/09/96	06/13/96	07/17/96	08/21/96	10/17/96	11/21/96	02/18/97	3/21/97	04/17/97
pH - lab	6.43	N/A	5.17	6.07	5.21	5.39	5.36	5.12	4.73
pH - field	5.51	6.18	5.38	5.62	5.09	5.84	5.50	5.34	5.96
Acidity (mg/L CaCO3)	<10	N/A	< 10	-	^<10	^<10	< 10	<10	< 10
Temperature (deg C)	14.1	16	16.7	17.5	14.6	9.0	7.5	9.8	9.0
Conductivity (umhos/cm)	41	49	138	147	193	68	49	31	76
Dissolved Oxygen (mg/L)	9.9	13.2	9.4	8.0	5.2	3.0	10.9	11.0	9.1
Redox Potential (mVolts)	-4.0	-13.4	-154.4	-36.4	-104.4	1.6	160.4	322.4	70.0
Alkalinity (mg/L CaCO3)	<20	NA	< 20	< 20	^<20	^<20	< 20	<20	< 20
Measured TDS at 180 deg C	36	21	82	86	150	65	N/A	14	N/A
Discharge Rate (cfs)	0.830	1.916	0.456	0.016	0.002	3.038	7.595	4.175	0.240
	(mg/L)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Aluminum (Al+3)	0.029	0.05	0.07	< 0.026	0.066	0.076	0.12	0.049	0.076
Total Aluminum (Al+3)	0.42	0.21	0.05	0.2	0.39	0.31	0.12	0.19	0.079
Arsenic (As+3)	<0.0066	< 0.0066	< 0.0066	< 0.0066	^<0.0066	^<0.0066	< 0.0066	< 0.0066	< 0.0066
Cadmium (Cd+2)	<0.001	< 0.001	< 0.0010	< 0.0010	< 0.0010	^<0.0010	<0.00085	<0.00085	< 0.00085
Calcium (Ca+2)	2	2.9	6	8.1	8.1	4.2	2.1	1.6	5.2
Chromium (Cr+3)	<0.001	< 0.001	< 0.0036 B	< 0.0010	< 0.0010	^<0.0010	<0.0042	<0.0042	< 0.0042
Copper (Cu+2)	0.024	< 0.0029	0.01	<0.0029	< 0.0029	^<0.0025	0.012	<0.012	< 0.0025
Iron (Fe)	<0.0052	0.0091	< 0.026	0.023	^< 0.0052	^<0.0043	0.022	0.025	< 0.022
Total Iron (Fe)	0.31	0.2	< 0.026	0.14	0.28	0.1	0.05	0.15	< 0.022
Lead (Pb+2)	<0.0011	< 0.0011	< 0.0011	< 0.0011	< 0.0011	^<0.0011	<0.0011	<0.0011	< 0.0011
Magnesium (Mg+2)	1.4	1.9	4.3	5.2	5.5	2.6	1.4	1.3	3.4
Manganese (Mn+2)	0.03	0.046	0.05	0.025	0.042	0.067	0.038	0.03	0.037
Total Manganese (Mn+2)	0.036	0.047	0.05	0.03	0.048	0.067	0.037	0.025	0.026
Selenium (Se+4)	<0.0033	< 0.0033	< 0.0033	< 0.0033	^<0.0033	^<0.0033	< 0.0066	<0.0066	< 0.0066
Sodium (Na+)	1	0.98	9.8	7.7	16	1.9	0.86	0.62	3.6
Zinc (Zn+2)	0.007	0.0092	0.02	0.018	0.014	0.0069	0.0082	0.0093	0.022
Chloride (Cl-)	<10	< 10	10	<10	17	^<10	< 10	<10	< 10
Sulfate (SO4-2)	13	10	39	36	58	20	11	11	33
Fe+2 field spectroph.	0.03	0	0.00	0.00	0.00	N/C	NS	0.01	0.00
Fe+3 by difference	0.00	0.0091	0.00	0.02	0.00	0.00	0.02	0.02	0.00

Table 25. Summary of water quality data from locations upstream and downstream of the spoil in Three West Hollow

LOCATION	STATION NUMBER	pH	ACIDITY mg/L as $CaCO_3$	CONDUCTANCE μmho/cm	SULFATE mg/L	CALCIUM mg/L	ALUMINUM mg/L	IRON mg/L	ZINC mg/L
Upstream	SSP5001	5.4	<10	31	<10	1.7	0.3	0.34	0.03
Downstream	SSPTWH	5.6	<10	78	25	4.6	0.4	0.21	0.04

Table 26. Estimates of construction costs for the Three West Hollow lined stream channel.

ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL
1	Mobilization & Demobilization	1	EA	$5,000.00	$5,000.00
2	Diversion of Water	1	EA	$5,000.00	$5,000.00
3	Grading	1500	CY	$20.00	$30,000.00
4	LLDPE Liner	1500	CY	$30.00	$45,000.00
5	Geotextile Fabric	1500	CY	$5.00	$7,500.00
6	Limestone	400	TON	$25.00	$10,000.00
7	Revegetation	1	ACRE	$1,600.00	$1,600.00
8	Erosion & Sedimentation Control	1	EA	$5,000.00	$5,000.00
	Total Capital Costs				**$109,100.00**

Table 27. Water Quality Data Collected From the Mouth of Blair Creek at Sample Location Number 43 (SSPIIBLC01).

Date Sampled	05/08/96	06/12/96	07/16/96	08/21/96	09/23/96	10/16/96	11/18/96	02/18/97	3/20/97	04/16/97
pH - lab	5.81	4.74	3.11	3.13	3.00	3.04	4.74	4.84	5.48	4.13
pH - field	5.57	5	3.07	3.96	3.21	3.06	4.37	5.00	6.11	3.87
Acidity (mg/L CaCO3)	<10	< 10	150	120	150	170	10	< 10	<10	22
Temperature (deg C)	14.2	16.2	19.3	18.1	14.6	11.5	9.5	7.3	8.3	6.5
Conductivity (umhos/cm)	43	72	860	901	1160	1221	98	81	33	172
Dissolved Oxygen (mg/L)	10.3	13.8	9.2	10.0	9.0	9.0	11.7	11.2	11.1	11.4
Redox Potential (mVolts)	-39.3	20.6	199.6	280.6	286.6	203.6	80.6	514.4	407.4	1044.4
Alkalinity (mg/L CaCO3)	<20	20	-	-	-	^-	<20	< 20	<20	N/A
Measured TDS at 180 deg C	53	42	370	430	510	570	49	N/A	ND	N/A
Discharge Rate (cfs)	11.790	9.018	0.652	0.033	0.080	0.074	7.445	3.122	20.395	0.632
	(mg/L)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Aluminum (Al+3)	0.047	0.36	5.4	5.7	8.1	8.2	0.26	0.12	< 0.024	0.74
Total Aluminum (Al+3)	0.4	0.59	4.8	5.7	7.9	8.4	0.63	0.38	0.8	0.83
Arsenic (As+3)	<0.0066	< 0.0066	< 0.0066	< 0.0066	^<0.0066	< 0.0066	< 0.0066	< 0.0066	< 0.0066	< 0.0066
Cadmium (Cd+2)	<0.001	< 0.001	< 0.0010	< 0.0010	^<0.0010	< 0.0010	<0.0010	<0.00085	<0.00085	< 0.00085
Calcium (Ca+2)	2.6	5.6	29	33	39	41	6.3	3.7	2.6	6.6
Chromium (Cr+3)	<0.001	< 0.001	< 0.0036 B	0.0027	^<0.0010	0.0029	< 0.0010	<0.0042	<0.0042	< 0.0042
Copper (Cu+2)	<0.0029	< 0.0029	0.025	< 0.0029	0.026	0.0046	<0.0025	0.012	<0.012	0.027
Iron (Fe)	0.32	0.74	12	11	15	19	1	1.4	0.21	4.1
Total Iron (Fe)	0.64	1.7	13	14	17	20	1.6	2	0.73	4.7
Lead (Pb+2)	<0.0011	< 0.0011	< 0.0011	< 0.0011	< 0.0011	< 0.0011	<0.0011	<0.0011	<0.0011	< 0.0011
Magnesium (Mg+2)	1.1	2.1	12	12	16	16	2.1	1.7	1.2	2.8
Manganese (Mn+2)	0.033	0.41	2.3	2.8	3.3	3.6	0.21	0.18	0.098	0.41
Total Manganese (Mn+2)	0.037	0.17	2.4	2.8	3.2	3.5	0.18	0.18	0.089	0.42
Selenium (Se+4)	<0.0033	< 0.0033	< 0.0033	< 0.0033	^<0.0033	^< 0.0033	<0.0033	< 0.0066	<0.0066	< 0.0066
Sodium (Na+)	1.5	3.3	33	37	53	54	4.3	3.3	1.1	6.2
Zinc (Zn+2)	0.0037	0.02	0.11	0.11	0.11	0.11	0.011	0.038	0.014	0.022
Chloride (Cl-)	<10	< 10	19	19	24	29	<10	< 10	<10	< 10
Sulfate (SO4-2)	<10	24	260	270	360	400	32	21	<11	48
Fe+2 field spectroph.	0.35	0.03	2.74	0.28	1.58	2.7	0.97	0.95	0.19	2.15
Fe+3 by difference	0	0.71	9.26	10.72	13.42	16.3	0.03	0.45	0.02	1.95

Table 28. Preliminary cost estimate for conceptual limestone alkalinity addition for the Blair Creek Site CMD discharge.

ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL
1	Mobilization & Demobilization	1	EA	$1,500.00	$1,500.00
2	Turn-Around Grading	700	CY	$5.00	$3,500.00
3	Seeding & Mulching	0.1	ACRE	$6,500.00	$650.00
4	Erosion and Sedimentation Measures	1	EA	$1,500.00	$1,500.00
5	1st Year HQ Limestone	125	TON	$50.00	$6,250.00
6	24 Year HQ Limestone	1560	TON	$50.00	$78,000.00
	Total Capital Costs				**$91,400.00**

Table 29. Preliminary cost estimate for the conceptual vertical flow passive treatment system at the Blair Creek Site CMD discharge.

ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL
1	Mobilization & Demobilization	1	EA	$5,000.00	$5,000.00
2	Temporary Roadway	6000	LF	$9.00	$54,000.00
3	Clearing & Grubbing	0.75	ACRE	$1,500.00	$1,125.00
4	Diversion of Water	1	EA	$2,500.00	$2,500.00
5	SW Channel Excavation	1750	LF	$20.00	$35,000.00
6	Treatment System Grading	2450	CY	$5.00	$12,250.00
7	Misc. Rock Material	260	TON	$30.00	$7,800.00
8	HQ Limestone	1200	TON	$50.00	$60,000.00
9	Spent Mushroom Compost	920	CY	$30.00	$27,600.00
10	Geonet	1850	SY	$4.00	$7,400.00
11	Underdrain Piping	1	EA	$20,000.00	$20,000.00
12	Wetland Planting	1850	SY	$1.00	$1,850.00
13	Seeding & Mulching	0.4	ACRE	$6,500.00	$2,600.00
14	Erosion and Sedimentation Measures	1	EA	$2,000.00	$2,000.00
	Total Capital Costs				**$239,125.00**

Table 30. Water Quality Data Collected From the Mine #88 CMD Discharge at Sample Location Number 05 (SSPII8801).

Date Sampled	05/07/96	06/10/96	07/15/96	08/19/96	09/23/96	10/17/96	11/18/96	02/18/97	3/19/97	04/15/97
pH - lab	5.45	5.33	5.34	5.48	5.37	5.35	5.29	5.38	5.28	5.40
pH - field	5.33	5.46	5.00	* 5.8	* 6.1	5.19	5.30	5.30	5.31	5.15
Acidity (mg/L CaCO3)	340	520	300	510	520	500	500	430	400	470
Temperature (deg C)	14.1	14.7	15.0	15.1	14.9	14.9	13.7	14.4	14.1	14.3
Conductivity (umhos/cm)	2890	2630	3520	3535	3570	3770	3820	3060	2850	3280
Dissolved Oxygen (mg/L)	2.7	N/A	4.0	3.0	1.2	1.4	1.6	5.6	3.3	1.7
Redox Potential (mVolts)	-87.5	N/A	-112.4	-181.4	-173.4	-166.4	-156.4	382.4	442.4	904.4
Alkalinity (mg/L CaCO3)	<20	20	20	24	44	54	48	20	60	30
Measured TDS at 180 deg C	2500	3200	3300	3500	3600	3400	3700	2900	2600	2900
Discharge Rate (cfs)	0.200	0.130	0.184	0.180	0.080	0.248	0.100	0.100	0.063	0.036
	(mg/L)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Aluminum (Al+3)	0.54	0.61	0.39	0.51	0.53	0.5	0.72	0.54	0.41	0.39
Total Aluminum (Al+3)	0.6	0.66	0.41	0.52	0.54	0.49	0.56	0.61	0.51	0.4
Arsenic (As+3)	<0.0066	< 0.0066	< 0.013	0.014	0.015	0.013	< 0.0066	< 0.0066	<0.0066	< 0.0066
Cadmium (Cd+2)	<0.001	< 0.001	< 0.010	< 0.020	0.015	<0.0010	0.011	<0.00085	<0.00085	< 0.00085
Calcium (Ca+2)	140	160	180	190	190	180	240	170	140	150
Chromium (Cr+3)	<0.001	< 0.001	< 0.0036 B	< 0.0010	^<0.0010	< 0.0010	<0.0010	<0.0042	<0.0042	< 0.0042
Copper (Cu+2)	<0.0029	< 0.0043	< 0.0029	< 0.0029	0.01	< 0.0029	< 0.0025	0.012	<0.012	< 0.0025
Iron (Fe)	220	270	310	370	390	330	310	240	210	260
Total Iron (Fe)	210	260	350	330	350	400	320	240	200	260
Lead (Pb+2)	<0.0011	< 0.0022	< 0.0022	< 0.0011	^<0.0011	< 0.0011	<0.0011	< 0.0011	< 0.0011	< 0.0011
Magnesium (Mg+2)	61	69	76	76	80	76	81	64	61	70
Manganese (Mn+2)	8.7	9.8	11	11	11	12	12	8.9	8.6	9.8
Total Manganese (Mn+2)	9.2	10	11	12	11	11	13	9.9	8.4	10
Selenium (Se+4)	<0.0033	< 0.0066	< 0.0066	< 0.0066	^<0.0066	^<0.0033	<0.0066	< 0.0066	< 0.0066	< 0.0066
Sodium (Na+)	390	420	420	500	500	570	500	400	350	610
Zinc (Zn+2)	0.075	0.094	0.12	0.16	< 0.028	0.09	0.12	0.11	0.094	0.092
Chloride (Cl-)	41	50	44	57	60	48	50	54	50	50
Sulfate (SO4-2)	1700	2100	2200	2000	2100	2200	2400	1100	650	1900
Fe+2 field spectroph.	180	133	150	82	82	140	255	NS	147	265*
Fe+3 by difference	40	137	160	288	308	190	55	240	63	0

Table 31. **Preliminary cost estimate for the innovative passive treatment system and wet mine seal at the Mine #88 deep mine discharge.**

ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL
1	Mobilization & Demobilization	1	EA	$15,000.00	$15,000.00
2	Temporary Roadway	2000	LF	$9.00	$18,000.00
3	Clearing & Grubbing	1	ACRE	$1,500.00	$1,500.00
4	Diversion of Water	1	EA	$2,500.00	$2,500.00
5	Injection of Mixture	1	EA	$82,650.00	$82,650.00
6	Installation of Deep Mine Wet Seal	1	EA	$25,000.00	$25,000.00
7	Open Limestone Channel Excavation	1000	LF	$20.00	$20,000.00
8	Treatment System Grading	500	CY	$5.00	$2,500.00
9	Misc. Rock Material	130	TON	$30.00	$3,900.00
10	HQ Limestone	500	TON	$50.00	$25,000.00
11	Spent Mushroom Compost	360	CY	$30.00	$10,800.00
12	Seeding & Mulching	1	ACRE	$6,500.00	$6,500.00
13	Erosion and Sedimentation Measures	1	EA	$2,000.00	$2,000.00
	Total Capital Costs				**$215,350.00**

Table 32. Water Quality Data For the Discharge Emanating From the Laurel Branch Spoil at Sample Location Number 39 (SSPIILBC01).

Date Sampled	05/07/96	06/11/96	07/16/96	08/20/96	09/18/96	10/16/96	11/19/96	02/18/97	3/20/97	04/16/97
pH - lab	2.58	2.69	2.73	2.70	2.72	2.79	2.52	2.72	2.97	2.86
pH - field	2.60	N/D	3.06	* 2.5	2.81	2.62	2.54	2.50	3.35	2.71
Acidity (mg/L CaCO3)	750	510	500	510	570	610	1300	600	300	500
Temperature (deg C)	12.2	15.2	25.3	30.4	22.5	19.2	12.9	14.1	10.1	14.5
Conductivity (umhos/cm)	1736	1285	1395	1730	1751	1395	2780	NS	1003	1443
Dissolved Oxygen (mg/L)	0.8	10.2	1.0	3.2	4.5	2.9	1.5	0.6	7.6	5.3
Redox Potential (mVolts)	-24.0	224.6	173.6	213.6	226.6	207.6	206.6	691.4	754.4	712.4
Alkalinity (mg/L CaCO3)	N/A	-	-	-	-	^-	N/A	N/A	ND	N/A
Measured TDS at 180 deg C	960	770	700	1000	980	930	1700	920	260	580
Discharge Rate (cfs)	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	(mg/L)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Aluminum (Al+3)	39	25	20	25	30	30	89	33	11	18
Total Aluminum (Al+3)	40	32	49	36	40	39	110	35	10	20
Arsenic (As+3)	<0.0066	< 0.0066	< 0.0066	< 0.0066	^<0.0066	^<0.0066	< 0.0066	<0.0066	<0.0066	< 0.0066
Cadmium (Cd+2)	<0.001	< 0.001	< 0.0010	< 0.0010	0.0073	< 0.0010	0.01	<0.00085	<0.00085	< 0.00085
Calcium (Ca+2)	15	13	13	16	18	19	31	16	8.3	11
Chromium (Cr+3)	0.044	0.026	0.02	0.03	0.003	0.028	0.084	0.031	0.0076	0.017
Copper (Cu+2)	0.16	0.071	0.03	0.074	0.036	0.032	0.16	0.062	0.027	0.028
Iron (Fe)	120	96	87	110	120	110	250	130	11	75
Total Iron (Fe)	130	110	230	150	170	130	360	130	11	84
Lead (Pb+2)	<0.0011	< 0.0011	0.0024	0.0025	^<0.0011	^<0.0011	^<0.0011	<0.0011	<0.0011	< 0.0011
Magnesium (Mg+2)	9.1	8.6	8.7	11	13	13	20	9.3	4	8.1
Manganese (Mn+2)	2.1	1.8	2.1	3	3.2	3.1	4.9	2.3	0.59	1.6
Total Manganese (Mn+2)	1.8	1.9	2.2	3	3	3.3	4.6	2.3	0.62	1.5
Selenium (Se+4)	<0.0033	< 0.0033	< 0.0033	<0.0066	^<0.0033	^<0.0033	^<0.0066	<0.0066	< 0.0066	< 0.0066
Sodium (Na+)	1.6	1.9	2.9	3.7	4.4	4.4	4.1	2.3	1.8	2
Zinc (Zn+2)	0.15	0.12	0.11	0.15	0.14	0.14	0.27	0.14	0.061	0.11
Chloride (Cl-)	11	< 10	< 10	<100	^<10	14	^<200	< 50	<10	< 50
Sulfate (SO4-2)	920	67	620	670	690	730	1600	420	210	460
Fe+2 field spectroph.	24.6	19.9	26.1	40	63.6	38	126	71	0.18	27.2
Fe+3 by difference	95.4	76.1	60.9	70	56.4	72	124	59	10.82	47.8

Table 33. Water Quality Data Collected From the Mouth of Nancy Graves Creek at Sample Location Number 15 (SSPIINGC01).

Date Sampled	05/09/96	06/13/96	10/17/96	11/19/96	02/18/97	3/21/97	04/17/97
pH - lab	4.10	3.58	2.85	3.23	3.76	4.11	3.53
pH - field	3.78	4.05	2.76	3.41	3.50	3.70	3.26
Acidity (mg/L CaCO3)	40	90	270	88	32	18	80
Temperature (deg C)	15.2	17.8	14.5	10.6	9.4	11.0	11.2
Conductivity (umhos/cm)	157	410	1591	555	316	127	585
Dissolved Oxygen (mg/L)	9.2	14	8.6	N/C	10.2	10.2	10.1
Redox Potential (mVolts)	117.0	268.6	310.6	276.6	748.4	641.4	658.4
Alkalinity (mg/L CaCO3)	N/A	NA	^-	N/A	N/A	ND	N/A
Measured TDS at 180 deg C	74	180	1200	310	160	67	270
Discharge Rate (cfs)	0.530	0.572	0.005	0.157	0.470	1.133	0.078
	(mg/L)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Aluminum (Al+3)	1.3	2.8	17	4.1	1.7	0.91	3.1
Total Aluminum (Al+3)	1.5	3.1	17	4.3	1.9	1.9	3.2
Arsenic (As+3)	<0.0066	< 0.0066	^<0.0066	^<0.0066	< 0.0066	< 0.0066	< 0.0066
Cadmium (Cd+2)	<0.001	< 0.001	^<0.0010	^<0.0010	<0.00085	<0.00085	< 0.00085
Calcium (Ca+2)	7.4	17	110	19	12	5.9	27
Chromium (Cr+3)	<0.001	< 0.001	0.0064	^<0.0010	<0.0042	<0.0042	< 0.0042
Copper (Cu+2)	0.0046	0.01	0.015	^<0.0025	0.012	<0.012	< 0.0025
Iron (Fe)	0.86	2.1	21	4	1.5	0.54	2
Total Iron (Fe)	1.2	2.6	23	4.7	1.6	1.1	2.3
Lead (Pb+2)	<0.0011	< 0.0011	< 0.0011	^<0.0011	<0.0011	0.0091	< 0.0011
Magnesium (Mg+2)	4.3	8.5	51	9	6.4	3.2	14
Manganese (Mn+2)	1.1	2.8	18	3.1	1.9	0.85	4.1
Total Manganese (Mn+2)	1.1	2.7	18	3.2	1.8	0.83	4.4
Selenium (Se+4)	<0.0033	< 0.0033	^<0.0033	^<0.0033	<0.0066	<0.0066	< 0.0066
Sodium (Na+)	3.1	7.4	65	8.7	5.5	2	14
Zinc (Zn+2)	0.023	0.054	0.21	0.046	0.032	0.019	0.062
Chloride (Cl-)	<10	< 10	^<10	^<10	<10	<10	10
Sulfate (SO4-2)	64	100	980	170	53	44	210
Fe+2 field spectroph.	0.29	0.38	0.73	0.61	NS	0.11	0.52
Fe+3 by difference	0.57	1.72	20.27	3.39	1.50	0.43	1.48

Table 34. Preliminary cost estimate for the conceptual vertical flow passive treatment system at the Nancy Graves CMD discharge.

ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL
1	Mobilization & Demobilization	1	EA	$5,000.00	$5,000.00
2	Clearing & Grubbing	2	ACRE	$1,500.00	$3,000.00
3	Diversion of Water	1	EA	$2,500.00	$2,500.00
4	SW Channel Excavation	500	LF	$20.00	$10,000.00
5	Treatment System Grading	5400	CY	$5.00	$27,000.00
6	Misc. Rock Material	130	TON	$30.00	$3,900.00
7	HQ Limestone	1300	TON	$50.00	$65,000.00
8	Spent Mushroom Compost	1200	CY	$30.00	$36,000.00
9	Geonet	1900	SY	$4.00	$7,600.00
10	Underdrain Piping	1	EA	$20,000.00	$20,000.00
11	Wetland Planting	1200	SY	$1.00	$1,200.00
12	Seeding & Mulching	1	ACRE	$6,500.00	$6,500.00
13	Erosion and Sedimentation Measures	1	EA	$2,000.00	$2,000.00
	Total Capital Costs				**$189,700.00**

Table 35. Water Quality Data Collected From the Worley Mine #86 CMD Discharge at Sample Location Number 04 (SSPII8601).

Date Sampled	05/07/96	06/10/96	07/15/96	08/19/96	09/18/96	10/17/96	11/18/96	02/18/97	3/19/97	04/15/97
pH - lab	5.65	5.39	5.40	5.56	5.62	5.62	6.14	5.69	5.75	5.56
pH - field	5.46	5.41	5.50	7.38	* 7.0	5.14	5.82	5.50	6.12	5.65
Acidity (mg/L CaCO3)	330	420	340	240	120	110	N/A	< 10	<10	210
Temperature (deg C)	13.8	14.5	13.8	15.2	14.5	14.4	12.2	11.6	10.5	14.3
Conductivity (umhos/cm)	2040	1945	2750	2550	2910	1824	1200	150	160	2720
Dissolved Oxygen (mg/L)	3.1	N/A	3.0	1.2	0.6	2.1	1.0	7.8	9.0	0.6
Redox Potential (mVolts)	-75.0	N/A	-122.4	-216.4	-197.4	-164.4	-205.4	516.4	725.4	814.4
Alkalinity (mg/L CaCO3)	<20	< 20	< 20	42	44	66	30	20	22	70
Measured TDS at 180 deg C	1500	2300	2400	2200	1500	1300	140	100	160	1800
Discharge Rate (cfs)	3.024	0.407	0.178	0.053	0.030	0.023	0.063	0.005	0.150	0.108
	(mg/L)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Aluminum (Al+3)	0.085	0.16	< 0.026	0.12	< 0.026	< 0.026	< 0.024	<0.024	< 0.024	0.06
Total Aluminum (Al+3)	0.16	0.16	< 0.026	0.1	0.17	< 0.026	0.24	0.68	1.8	0.068
Arsenic (As+3)	<0.0066	< 0.0066	< 0.0066	< 0.0066	< 0.0066	^<0.0066	<0.0066	< 0.0066	< 0.0066	< 0.0066
Cadmium (Cd+2)	<0.001	< 0.001	< 0.010	< 0.0010	0.0056	^<0.0010	<0.0010	<0.00085	<0.00085	< 0.00085
Calcium (Ca+2)	74	140	170	140	100	91	19	8.3	12	100
Chromium (Cr+3)	<0.001	< 0.001	< 0.0036 B	< 0.0010	< 0.0010	^<0.0010	<0.0010	<0.0042	<0.0042	< 0.0042
Copper (Cu+2)	<0.0029	< 0.0043	< 0.0029	0.0033	0.0086	^<0.0029	< 0.0025	<0.0025	<0.012	< 0.0025
Iron (Fe)	110	210	190	170	110	77	5.1	0.022	0.48	110
Total Iron (Fe)	110	200	220	150	140	95	9	0.96	2.3	100
Lead (Pb+2)	<0.0011	< 0.0022	< 0.0011	< 0.0011	< 0.0011	^<0.0011	<0.0011	< 0.0011	< 0.0011	< 0.0011
Magnesium (Mg+2)	38	59	61	56	45	31	5.8	3.2	4.5	44
Manganese (Mn+2)	6.6	9.2	11	9.6	8.6	7.2	0.71	0.25	0.41	7.7
Total Manganese (Mn+2)	7	9.3	9.9	9.7	8.6	8.1	0.63	0.27	0.45	8
Selenium (Se+4)	<0.0033	< 0.0033	< 0.0033	< 0.0033	^<0.0033	^<0.0033	<0.0033	< 0.0066	< 0.0066	< 0.0066
Sodium (Na+)	220	340	300	330	260	220	21	12	11	330
Zinc (Zn+2)	0.068	0.088	0.12	0.083	0.056	0.033	0.0064	0.0082	0.015	0.07
Chloride (Cl-)	24	32	32	<50	^<10	20	12	< 10	<10	< 50
Sulfate (SO4-2)	1000	1700	1700	1200	900	850	95	48	60	1300
Fe+2 field spectroph.	2.51	63	85	121	103	69	N/C	0	0.41	157*
Fe+3 by difference	107.49	147	105	49	7	8	5.1	0.022	0.07	0

Table 36. **Preliminary cost estimate for the conceptual ALD/vertical flow passive treatment system for the Worley Mine #86 CMD discharge.**

ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL
1	Mobilization & Demobilization	1	EA	$5,000.00	$6,000.00
2	Clearing & Grubbing	2	ACRE	$1,500.00	$3,000.00
3	Diversion of Water	1	EA	$5,000.00	$5,000.00
4	SW Channel Excavation	200	LF	$20.00	$4,000.00
5	Treatment System Grading	6000	CY	$5.00	$30,000.00
6	Misc. Rock Material	250	TON	$30.00	$7,500.00
7	HQ Limestone	2200	TON	$50.00	$110,000.00
8	Spent Mushroom Compost	700	CY	$30.00	$21,000.00
9	Geonet	700	SY	$4.00	$2,800.00
10	Geotextile Fabric	1000	SY	$3.00	$3,000.00
11	LLDPE Liner	900	SY	$10.00	$9,000.00
12	Underdrain Piping	1	EA	$20,000.00	$20,000.00
13	Bypass Piping	1	EA	$30,000.00	$30,000.00
14	Installation of Deep Mine Wet Seal	1	EA	$25,000.00	$25,000.00
15	Wetland Planting	700	SY	$1.00	$700.00
16	Seeding & Mulching	1.5	ACRE	$6,500.00	$9,750.00
17	Erosion and Sedimentation Measures	1	EA	$3,000.00	$5,000.00
	Total Capital Costs				**$291,750.00**

Table 37. Water Quality Data Collected From Slavey Hollow at Sample Location Number 07 (SSPIISH02 and SSPIISH04).

Date Sampled	05/10/96	06/13/96	07/17/96	08/21/96	09/23/96	10/17/96	11/21/96	02/18/97	3/21/97	04/17/97
pH - lab	7.22	6.92	7.04	7.02	7.01	7.04	6.86	6.22	5.95	6.16
pH - field	6.88	7.08	7.34	7.88	7.56	6.75	7.63	6.10	5.70	6.10
Acidity (mg/L CaCO3)	<10	< 10	<10	-	-	^-	N/A	N/A	ND	N/A
Temperature (deg C)	15.1	15.2	16.3	16.5	15.2	14.9	12.0	12.9	13.0	13.5
Conductivity (umhos/cm)	595	892	1255	1192	1148	1181	642	752	750	1019
Dissolved Oxygen (mg/L)	10.0	12.6	10.4	9.2	9.6	9.1	7.2	4.6	4.9	2.5
Redox Potential (mVolts)	-124.0	-263.4	-225.4	-296.4	-319.4	-296.4	-103.4	348.4	263.4	114.4
Alkalinity (mg/L CaCO3)	51	72	180	100	98	110	68	120	62	120
Measured TDS at 180 deg C	370	570	840	840	780	760	450	540	460	650
Discharge Rate (cfs)	0.710	4.125	1.264	0.586	0.325	0.412	0.815	0.645	0.264	0.330
	(mg/L)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
Aluminum (Al+3)	0.062	0.046	< 0.026	0.063	< 0.026	< 0.026	^<0.024	0.12	0.26	< 0.024
Total Aluminum (Al+3)	1.2	1.8	1.8	1.8	2.1	1.8	1.2	0.12	0.82	0.21
Arsenic (As+3)	<0.0066	< 0.0066	< 0.0066	<0.0066	^<0.0066	^<0.0066	^<0.0066	<0.0066	<0.0066	< 0.0066
Cadmium (Cd+2)	<0.001	< 0.001	< 0.0010	< 0.0010	^<0.0010	^< 0.0010	^<0.0010	<0.00085	<0.00085	< 0.00085
Calcium (Ca+2)	25	39	55	61	48	50	28	32	29	42
Chromium (Cr+3)	<0.001	< 0.001	< 0.0036 B	<0.0010	^<0.0010	^< 0.0010	^<0.0010	<0.0042	<0.0042	< 0.0042
Copper (Cu+2)	0.14	< 0.0029	< 0.0029	<0.0029	< 0.0029	^< 0.0029	^<0.0025	0.012	<0.012	< 0.0025
Iron (Fe)	3.3	6.3	8.4	7.1	6.4	6.1	4	6.8	5.7	10
Total Iron (Fe)	5.3	12	16	14	13	15	12	8	6.5	12
Lead (Pb+2)	<0.0011	< 0.0011	< 0.0011	<0.0011	^<0.0011	^<0.0011	^<0.0011	<0.0011	<0.0011	< 0.0011
Magnesium (Mg+2)	11	17	22	21	20	18	12	12	11	17
Manganese (Mn+2)	1.3	2.3	3.5	3.2	2.9	2.9	1.6	1.9	1.8	2.6
Total Manganese (Mn+2)	1.3	2.3	3.1	3.1	2.8	2.8	1.6	1.9	1.6	2.6
Selenium (Se+4)	<0.0033	< 0.0033	< 0.0033	< 0.0033	^<0.0033	^<0.0033	^<0.0033	< 0.0066	<0.0066	< 0.0066
Sodium (Na+)	74	110	200	170	200	160	94	110	96	210
Zinc (Zn+2)	0.024	0.028	0.023	0.037	0.021	0.019	0.055	0.019	0.038	0.02
Chloride (Cl-)	<10	< 10	< 10	10	12	18	^<10	10	12	50
Sulfate (SO4-2)	260	310	520	490	480	480	270	290	290	400
Fe+2 field spectroph.	1.55	2.41	3.52	0.54	3.16	3.72	1.60	NS	4.60	9.70
Fe+3 by difference	1.75	3.89	4.88	6.56	3.24	2.38	2.40	6.80	1.10	0.30

Table 38. Preliminary cost estimate for the conceptual aerobic passive treatment system at the Slavey Hollow Site CMD discharge.

ITEM NO.	DESCRIPTION	QUANTITY	UNIT	UNIT COST	TOTAL
1	Mobilization & Demobilization	1	EA	$5,000.00	$5,000.00
2	Clearing & Grubbing	2	ACRE	$1,500.00	$3,000.00
3	Diversion of Water	1	EA	$2,500.00	$2,500.00
4	Channel Excavation	900	LF	$20.00	$18,000.00
5	Treatment System Grading	6600	CY	$5.00	$33,000.00
6	Misc. Rock Material	180	TON	$30.00	$5,400.00
7	HQ Limestone	1200	TON	$50.00	$60,000.00
8	Spent Mushroom Compost	400	CY	$30.00	$12,000.00
9	Wetland Planting	2500	SY	$1.00	$2,500.00
10	Seeding & Mulching	1	ACRE	$6,500.00	$6,500.00
11	Erosion and Sedimentation Measures	1	EA	$1,500.00	$1,500.00
	Total Capital Costs				**$149,400.00**

Table 39. Summary of the proposed remediation projects for the prioritized CMD discharges in the BSFNRRA.

Priority Rank	CMD Discharge Site	Proposed Remediation Method	Preliminary Cost Estimate	Water Quality Benchmark Compliance Level
1	**Roaring Paunch Creek (Total)**	Individual Discharge Dependent	$367,890.00	Effluent AWQC/Instream AWQC
	Barthel Mines Site No. 1	Multi-cell Vertical Flow Wetland	$183,550.00	Effluent AWQC
	Barthel Mines Site No. 2	Vertical Flow Wetland/Aerobic Wetland	$78,865.00	Effluent AWQC
	Barthel Mines Site No. 3	Vertical Flow Wetland/Aerobic Wetland	$86,575.00	Effluent AWQC
	Roaring Paunch Site	Oxic Limestone Channel	$18,900.00	Instream AWQC
2	**Devils Creek**	Multi-cell Vertical Flow Wetland	$266,900.00	Effluent AWQC
3	**Laurel Branch Creek**	Lined Stream Channel	$25,550.00	Effluent AWQC/EC_{20}
4,5,8	**Blue Heron Spoil** ***South, North & Pine Plantings***	Site Reclamation/Water Control/Vertical Barrier	$699,400.00	Instream AWQC
6	**Three West Hollow**	Lined Stream Channel	$109,100.00	Effluent AWQC/EC_{20}
7	**Blair Creek**	Limestone Fines Addition	$91,400.00	Instream AWQC/Effluent AWQC
9	**Mine #88**	Organic/Limestone Emplacement	$215,350.00	Instream AWQC
10	**Laurel Branch Spoil**	Site Reclamation/Water Control	$120,000.00	Instream AWQC
11	**Nancy Graves Creek**	Vertical Flow Wetland	$189,700.00	Effluent AWQC
12	**Worley Mine #86**	ALD/Aerobic Wetland/Vertical Flow Wetland	$291,750.00	Effluent AWQC
13	**Slavey Hollow**	Aerobic Wetland	$149,400.00	Effluent AWQC
TOTAL BSFNRRA CMD REMEDIATION COST			**$2,526,440.00**	