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RPA

# PRELIMINARY ENGINEERING REPORT

# WETLANDS DESIGN FOR TREATMENT OF ACID MINE DRAINAGE

## JOHNSON FIELDS AREA
## SAND COULEE, MONTANA

APRIL, 1986

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# JOHNSON FIELDS AREA, SAND COULEE, MONTANA

## LITERATURE REVIEW

Using wetlands for wastewater treatment is a recent development. Only within the past ten years have researchers turned their attention to wetlands, both natural and artificial, as passive water treatment facilities (Tilton et al., 1976; Seidel, 1976; Stanlick, 1976). Researchers are now applying this purification capability of wetlands [defined as ". . . land where the water table is at, or above the land surface for long enough each year to promote the formation of hydric soils and to support the growth of hydrophytes as long as other environmental conditions are favorable" (Cowardin et al.)] to the treatment of acid mine discharge, especially in the eastern coal fields (Mitsch et al., 1985; Kleinmann et al., 1983; Weider and Lang, 1984; Snyder and Aharrah, 1984; Kleinmann et al., 1985). Passive mine drainage systems are also being used in Colorado (Holm and Jones, 1985; Guertin et al., 1985). A conference devoted solely to wetlands and mined lands has been conducted (Brooks et al., 1985), and the Department of the Interior continues to fund passive mine drainage treatment research (research proposals on file, Abandoned Mine Lands Bureau, Montana Department of State Lands).

Regardless of the geographical area, mine drainage treatment systems are designed and constructed to: (1) remove metals from mine water, and (2) neutralize acidity. The systems consist of two components: (1) a Sphagnum moss bog or cattail (Typha sp.)-dominated wetland; (2) a limestone neutralization channel. Studies have shown that both Sphagnum and Typha systems will reduce metal concentrations in the discharge (Huntsman et al., 1978; Weider et al., 1982; Kleinmann et al., 1985; Snyder and Aharrah, 1984). The metals are removed from acid water by a variety of mechanisms including adsorption (especially ion exchange), assimulation, precipitation, and simple filtration. Sphagnum with its large surface area is very effective as an ion exchange medium and as a filter for ferric hydroxide particulates (Kleinmann et al., no date). Apparently the properties of Sphagnum favor the removal of iron rather than manganese (Kleinmann et al., 1985; Weider et al., 1982). In contrast, Typha do not have a lot of surface area but accumulate iron and manganese, especially in the rhizome tissue (Snyder and Aharrah, 1984). Both wetland types are also inhabited by a variety of microorganisms which will remove metals. Again, the removal process may be direct assimulation into biomass or oxidation to an insoluble species.

In other experimental systems, limestone rock has been used in the wetland to raise wetland pH and thus discharge pH. However, ferric hydroxide armoring of the limestone rapidly occurs and reduces the neutralization capability of the system. To handle this problem a limestone-filled channel will be constructed below the wetland. Iron oxides should precipitate out or complex in the wetland so the primary function of the channel is neutralization of the discharge pH. Drop structures are incorporated to increase turbulence. The turbulence will exsolve carbon dioxide and increase the pH (Guertin et al., 1985).

## DESCRIPTION OF PROPOSED WETLANDS

The passive mine discharge treatment (PMDT) system proposed for the Johnson Field adits (referred to as the east and south adits) will be composed of:

1. Two peat Typha (cattails) wetlands; one wetland for each discharge.

2. A limestone-lined neutralization channel containing up to three drop structures.

### A. Pond Size

A wetlands construction handbook (Kleinmann et al., no date) is the basis for the following wetlands construction proposal. The suggested wetlands size is a minimum of 200 square feet per gallon per minute (gpm) of flow. Therefore, the south adit (which flows at about 15 gpm) wetlands should have a surface area of 3,000 square feet, and the east adit (which flows at about six gpm) should have a surface area of 1,200 square feet. The actual pond dimensions will depend upon the topography of the areas and engineering constraints. The slope of the wetlands from inlet to outlet should reduce water velocity to a maximum of 0.1 feet per second. Water retention time and, hence, contact time within the system should be maximized to allow maximum metals removal (Kleinmann et al., 1983). Kleinmann et al. (no date) suggests a slope no greater than five degrees, whereas Holm and Jones (185) used a slope of two and one-fourth degrees (20:1). Refer to Figures 1 and 2.

A channel should be constructed to increase contact time and to prevent "short-circuiting" of the system (Figure 3). The channels should be shallow (maximum six inches deep) and relatively wide (one and one-half to two and one-half feet).

The design should reflect the following considerations:

FIGURE 1.

Aerial View of South Adit Wetland Area

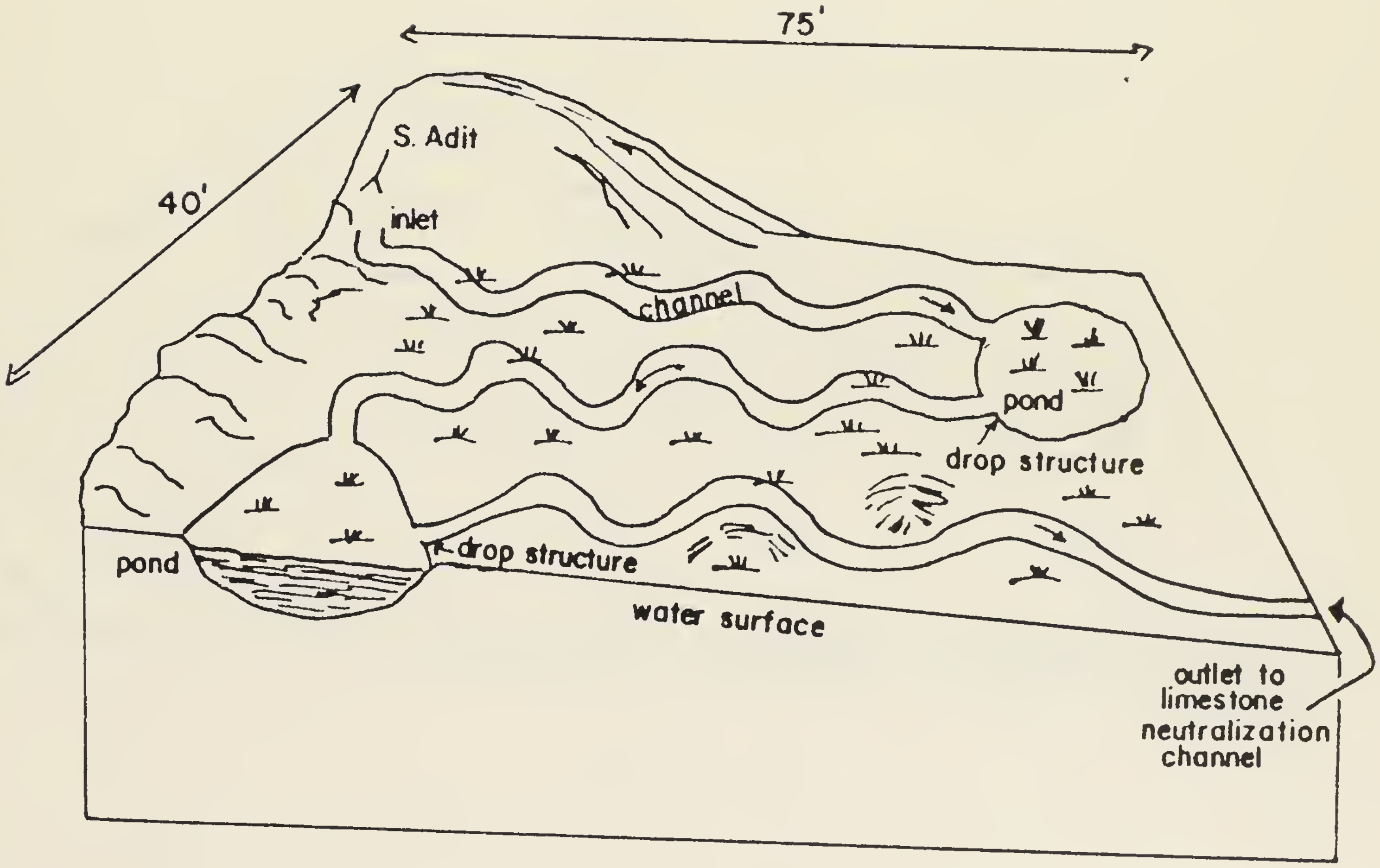


**FIGURE 2.**

Aerial View of East Adit Wetland Area

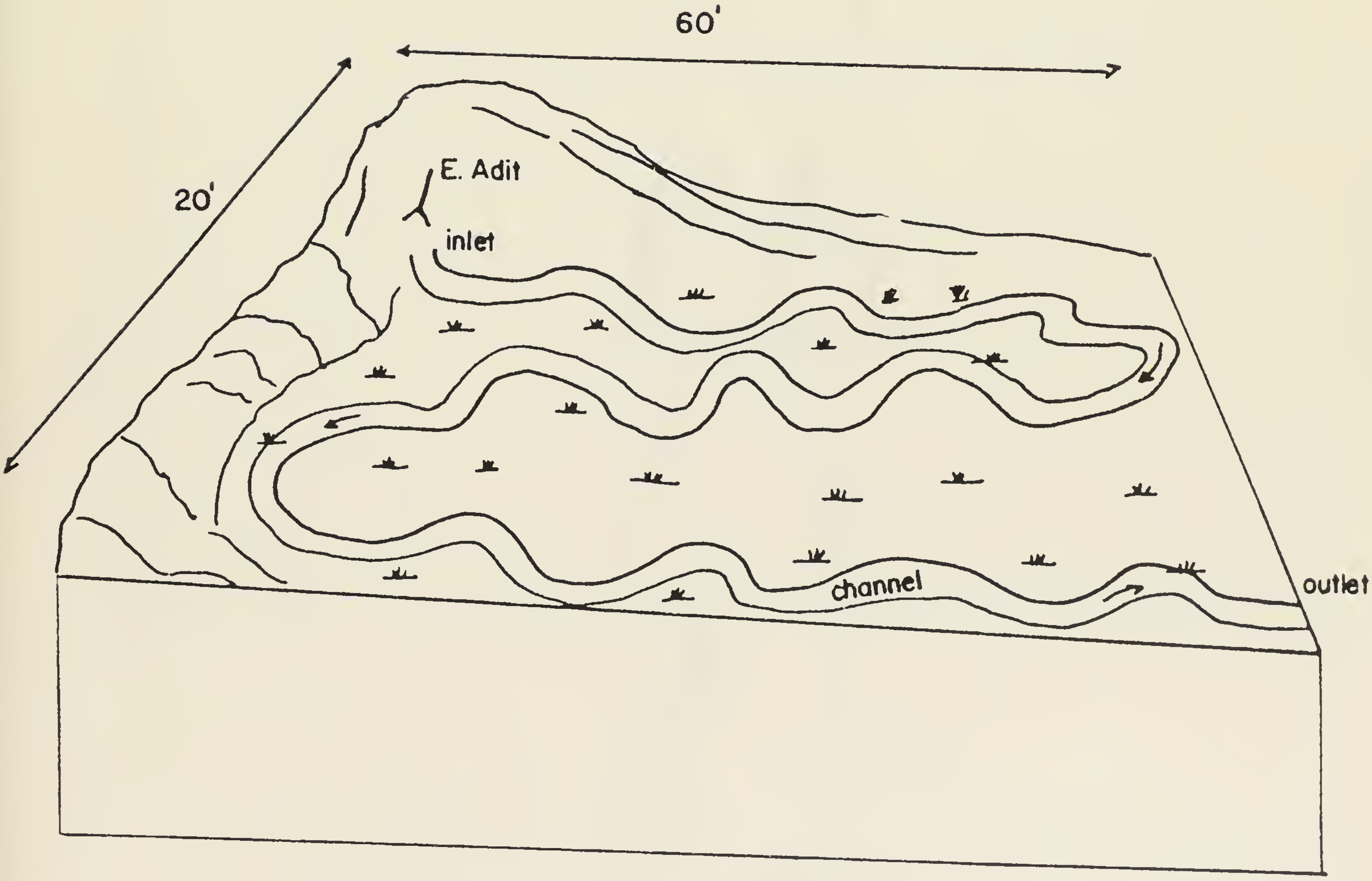
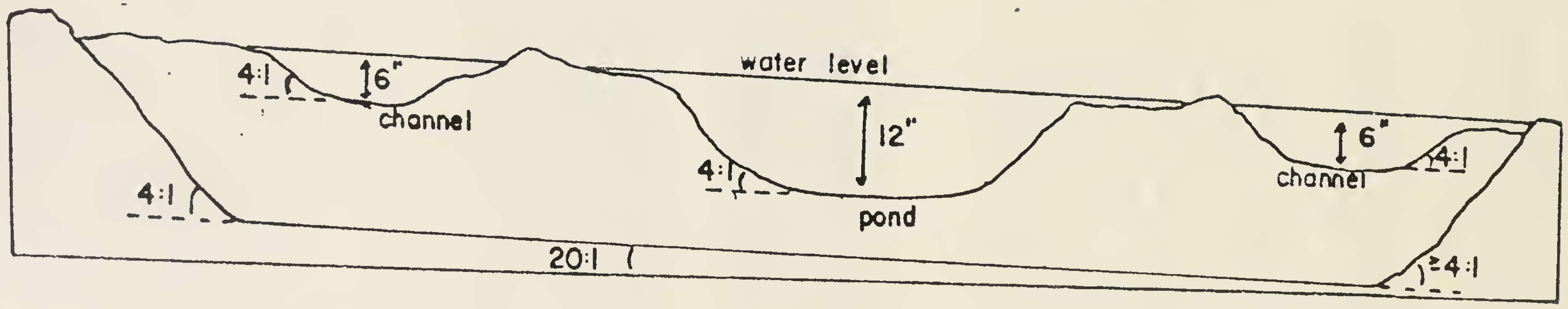


FIGURE 3.

End On View of South Adit Wetland Area



1. Overall drop from inlet to outlet, maximum 1:20;

2. Channel gradient, maximum one percent; and

3. Channel sinuosity of two to two-and-one-half.

$$\text{Sinuosity} = \frac{\text{total channel length (centerline)}}{\text{total straight line channel length}}$$

For example, for three wetland crossings (south adit wetland) total linear channel length would equal about 225 feet so channel length with the prescribed sinuosity would range from about 450 to 560 feet provided that channel gradient is equal to or less than one percent. To enhance diversity in both water depth and velocity in the south adit wetland, it is proposed to construct two ponded areas (see Figure 1) totaling about 10 to 12% of the area. These should be 12-18 inches deep with gradually sloping sides (maximum 15°). Baffling of one larger contiguous wetland area could be used to provide similar performance to a series of linked ponds and channels.

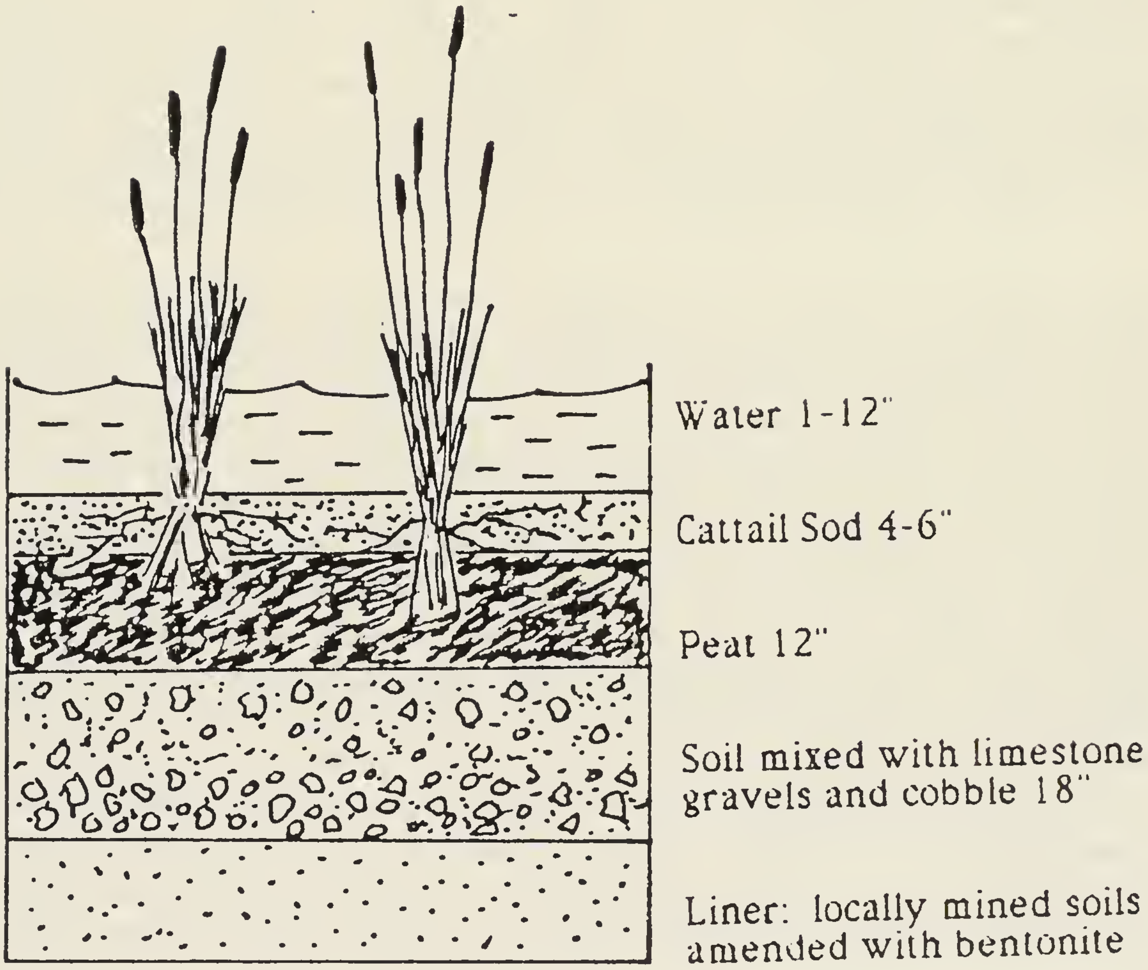
Drop structures may be necessary at pond outlet(s). All cross-sectional slopes of the wetlands (Figure 3) should be less than 15°. This maximum 15° slope would provide suitable conditions for establishment of the emergent *Typha* (Kleinmann *et al.*, no date) plus allow a water saturation gradient along the cross-sectional profile.

Average water depth within the wetlands should be no more than 18 inches with most of the wetlands covered by only six inches or less. Depths could range up to two feet. Variations in depth would tend to maximize habitat diversity. Colonization of the various niches would increase biological activity which in turn would increase metals removal. Shallow waters are considered optimal for iron and manganese removal (Kleinmann *et al.*, no date).

## B. Wetlands Bottom Composition

Figure 4 illustrates the vertical profile of the proposed wetlands. The bottom layer of the basin should contain two to six percent bentonite, a sufficient amount to seal the basin (Hard Rock Bureau, Department of State Lands, personal communication). A mixed soil/limestone layer totaling about 18 to 24 inches should be placed over the liner. The bottom topography (i.e., channels, ponds, and raised ground) will be formed in this material. Soil textures should range from sandy loam, loam, silt loam, sandy clay loam, clay loam, and silty clay loam with 15 to 35% clay. If available, soils rich in decomposed organic matter are desirable. Limestone gravels and cobbles (i.e., up to eight inches in diameter) with a high calcium to magnesium ratio should be mixed with the

**Figure 4.**
Vertical Profile of Cattail Pond



soil such that coarse fragment content increases from top to bottom. This layer is critical for the south adit discharge since the pH is about 2.5. Cattails may not survive in this acidic water and a pH increase to about 3.5 would be desirable. Typha has been found to grow and even flourish at this level of hydrogen ion concentration (Mitsch et al., 1985; Snyder and Aharrah, 1984). Mixing limestone with contoured soil for the east adit is optional.

One foot of peat should be placed over the soil/limestone layer (Kleinmann et al., no date). Peat is known for its ability to sequester metals (Lapakko and Eger, 1981; Gorham, 1953). The peat would also serve as substrate for not only the Typha but also a variety of microorganisms, which can play a major role in metals removal (Jennet et al., 1983). The underlying limestone may also increase the pH of the peat, increasing the metals removal capability (Vuceta and Morgan, 1978).

The cattails will then be planted directly on the peat. A four-to-six inch deep layer of the cattail marsh, which includes the soil and cattail rhizome/root zone, can be removed from the adjacent wheat field and transported immediately to the prepared sites. Other cattail sources may need to be procured. The large clumps should be spaced on the peat substrate to give a plant density of 0.3-to-one plant per square foot (Kleinmann et al., no date). Regeneration of the rhizomes is optimum when they are covered by about one inch of water; this depth can be increased if the rhizomes remain attached to the dead stems (Bedish, 1976). Typha mortality may be high due to transplant shock. The plants are now growing in pH 7 water and will be placed in pH 2.5 mine drainage. Kleinmann et al. (no date) state that the pH difference should be no greater than two units. It is hoped the incorporated limestone will raise the south adit wetland pH enough to allow successful establishment. The east adit discharge water has a pH of about four. So, although the added limestone would benefit Typha establishment, it would not be necessary as it is for the south adit wetlands.

To prevent disturbances during sampling of the system, sampling platforms or catwalks should be constructed for the wetlands. For the south adit wetland two are needed: one over one pond and one about in the middle to sample the channel and surrounding sediments and vegetation. The east adit would require only one platform placed near the middle.

## C. Limestone Neutralization Channel

Although water discharged from the wetlands should contain greatly reduced metals concentrations, the pH would still be very acidic (Mitsch et al., 1985). Therefore, the water (combined discharge from both

wetlands) will be routed through a limestone-filled trench to neutralize the acid (Kleinmann et al., 1983; Holm and Jones, 1985).

The amount of limestone necessary to raise the pH of the discharge a given amount is calculated using the formula and figures in Guertin et al. (1985):

$$W = LpQd$$

where:

$W$ = quantity of crushed limestone in tons
$L$ = load factor
$p$ = percentage of magnesium carbonate in the limestone
$Q$ = streamflow in cfs
$d$ = stone size in inches

for the combined adits discharge:

$L$ = 100 (from Guertin's Figure 10-raising the pH from 2 to 6 with drop structures)
$p$ = 1.5 (Continental Lime, Townsend, Montana, personal communication)
$Q$ = 15 gpm x 1 cfs/449 gpm = .03 cfs
$d$ = .75
$L$ = 100 (from Guertin's Figure 10-raising the pH from 2 to 6 with drop structures

therefore:

$W = (100)(1.5)(.03)(.75) = 3.4$ tons of limestone.

To increase the pH to 6.5 would require about 14 tons of limestone. Therefore, a discharge of pH 6.0 appears the better alternative.

Three drop structures should be constructed in the limestone trench. The turbulence caused by these structures will allow exsolution of carbon dioxide ($CO_2$). Without such turbulence, the dissolved $CO_2$ would form carbonic acid and buffer the solution at a maximum pH of 6.0 to 6.5 (at the pH when calcium carbonate reaches saturation equilibrium). Removal of $CO_2$ with turbulence allows the pH to increase above 6.5 (Guertin et al., 1985). A drop structure incorporated above the wetland may also aid in promoting metal (iron and manganese) oxidation and precipitation prior to metal removal in the wetlands (Holm and Jones, 1985), although it is not contemplated in the initial preliminary design.

## ENGINEERING CONSIDERATIONS

Projects incorporating biological treatment of wastewater and engineering aspects present interesting and sensitive engineering constraints. Special design considerations relative to flow collection, soil permeability, wetland hydraulics, water quality, and field constructability are warranted.

### A. Flow Collections

At both adits, flow gradients of ground water (mine drainage) and hydraulic gradients in the ponds are low. Therefore, some backup of the mine drainage could occur at certain times of the year resulting in acid waters bypassing the ponds. During low flow periods insufficient drainage to the ponds could occur.

A collector system would minimize the effects of low and high flows and substantially decrease the probability of acid contamination of adjacent lands. The collector system may have the configuration illustrated in Figure 5.

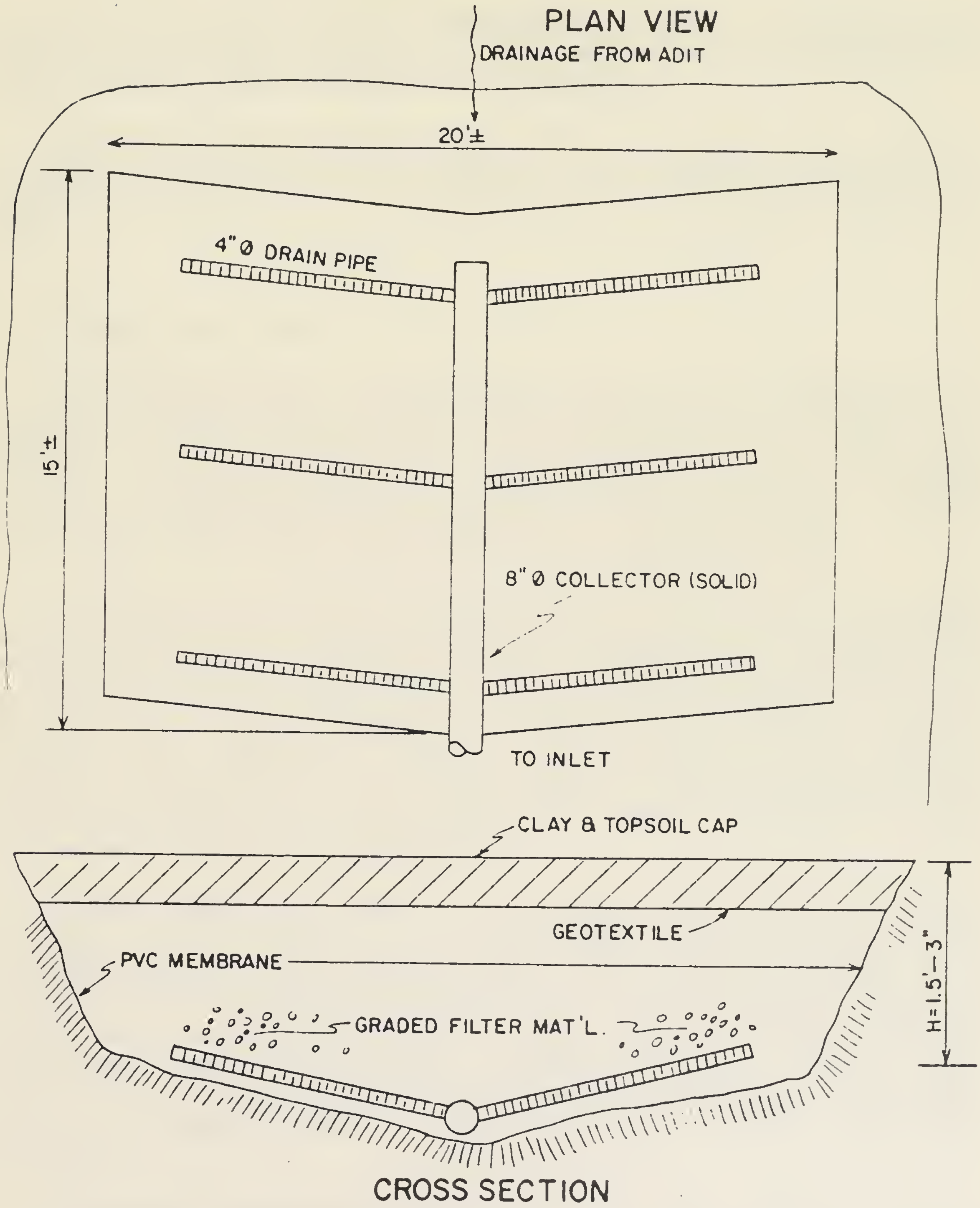
It is important to note that a significant mine drainage loss appears to be taking place at the south adit. During earlier reclamation work, a drain, line, and manhole with flow measurement were installed in the coulee. However, a hand auger hole excavated just east of the manhole suggests that flow is bypassing the drain and exiting to the sandstone just down gradient from the manhole. In addition the soils appear to be loose, highly compressible silty sands.

We suggest that six borings to depths of 10 to 15 feet be drilled in a rectangular pattern in the vicinity of the proposed bog. Piezometers would be installed in at least four borings to determine the amount of flows passing under the site. The borings would also provide data on which to base settlement estimates for embankment construction.

### B. Soil Characteristics and Permeability

Pond liners and embankments can probably be constructed from on-site materials. Soils at the east adit range from a moderately plastic clay to a clayey sand. Based on visual observations and previous experiences, the clay can be amended with high swell bentonite (two to six percent generally) to provide a high quality liner. Expected permeability would be less than $1.0\text{x}10^{-7}$ cm/sec. The clayey sands will compact easily to form an erosion resistant channel.

FIGURE 5
Flow Collector At Adits



Soils at the south adit are clayey sands (natural) and silty sands (fill). The clayey sands appear to have characteristics similar to those at the east adit and should be suitable for embankments and channels. Clay ~~would~~ have to be transported from the east adit for liner construction. Alternatively, a synthetic membrane can be used for the liner.

Earthwork should be as balanced as possible, considering the biologic and hydraulic constraints of the bogs. Since the quantities are relatively small, absolute balance is not essential.

Slopes of the embankments and channels will require some laboratory testing before they can be finalized. For preliminary purposes, we suggest 4.0 horizontal to 1.0 vertical and in no case steeper than 2.5 to 1.0.

## C. Wetland Hydraulics

The reaction kinetics of both desired water quality reactions of interest in the acid mine drainage (pH neutralization and precipitation/adsorption removal of metals) most closely follow first-order rates. This is due to eventual limitation of these reactions by lack of useable reactants (neutralization and precipitation) or reaction sites (adsorption). Thus, each is essentially limited by a "single" substrate.

Recognizing the continual flow input intended for the treatment wetlands, this suggests that a plug flow, first-order reactor model would best characterize their behavior. In such a reactor the concentration of pollutant(s) exhibits a gradient in the longitudinal dimension of the reactor with little gradient occurring in the transverse direction. By increasing reactor length and, hence, reactor residence time, treatment efficiency is improved. Such a model would accurately describe the removal of pollutants from or neutralization of acid mine drainage influent in a wetlands channel or impoundment.

Besides being well suited to the metals removals and pH neutralization desired, first-order, plug flow kinetics lend themselves well to this application in that residence time is very easily controlled (at a given flow rate) by channel length. Thus, the contemplated system of interconnected ponds and channels or a larger baffled contiguous pond is appropriate. Using the previously mentioned hydraulic loading of one gallon per minute flow per 200 square feet and an average water depth of 15 inches, approximately 1.5 days of hydraulic detention time will be provided.

Hydraulic considerations of the wetlands design suggest that two inclusions are important: (1) arrangement or partitioning of the wetland impoundments to provide a linear flow path insuring plug flow

conditions, and (2) a method for adjusting the detention time via adjustment of flow path length and/or water depth. In view of biological considerations, adjustment by either method may be important. Radical water depth changes may not be beneficial for the species of interest, but periodic flow fluctuations may necessitate handling without undue loss of the hydraulic detention time provided. Manual slide gates installed in outlet dams or dikes would be the most convenient means of adjusting water depth. Intermediate structures with similar gates along the course of the wetlands or channels would allow diversion of flow to adjust the length of flow path.

To maintain accurate measurement of flow through the wetlands systems and permit calculation of metals removals, etc., primary flow control devices such as vee-notched weirs should be provided at the inlet and outlet to each system. Permanent staff gages will permit periodic flow measurement, and continuous flow recorders can be employed as desired. The existing flow-recording manhole near the south adit is already equipped with the necessary weir and recorder and may be reuseable at this location provided system hydraulics can be made to fit the inverts elevation of its inlet line(s).

## D. Water Quality

Typical water quality for the acid mine drainage from the two adits is included in Appendix A. Aside from the previously discussed difference in pH, the two waters are similar in their high iron, aluminum, magnesium, and sulfate contents. In addition to the obvious ramifications to biological species to be placed in these waters, the unusual chemistry dictates certain engineering allowances.

Any concrete used in drop structures or other hydraulic control devices will be vulnerable to acid and sulfate attack. Consequently, concrete should be mixed using either Type 5 cement or a minimum of 6.0 sacks per cubic yard of Type 1-2 cement. This will prolong durability.

The acidic conditions will likewise jeopardize any unprotected metal used for hydraulic control devices (slide gates, staff gages, etc.). The use of stainless steel or epoxy coating on carbon steel or aluminum will maximize life. Where possible, redwood or other noncorrosive materials would be preferred in construction.

Since centralized collection and discharge now exist for the drainage from each adit by virtue of an earlier improvements project, no new discharges will be created. Hence, National Pollutant Discharge Elimination System discharge permits should not be required for the discharge from the two wetlands.

## E. Field Constructability

Figure 6 shows in schematic fashion the wetland treatment system components suggested at each adit site. The existing site topography should allow construction of the impoundments and channels using on-site material for the bulk of the earthwork. The decision as to use of the separated ponding areas with interconnecting channels or a baffled contiguous impoundment would affect the final development scheme for each site.

Key aspects of the construction sequence are anticipated to include the following items:

- Final site topographic survey, soil test borings, and engineering design.

- Removal and stockpiling of topsoil, vegetation, and debris from the wetlands sites. Topsoil free of vegetative material will be reused as a final cover for non-wetlands portions of the structures (dike slopes, etc.).

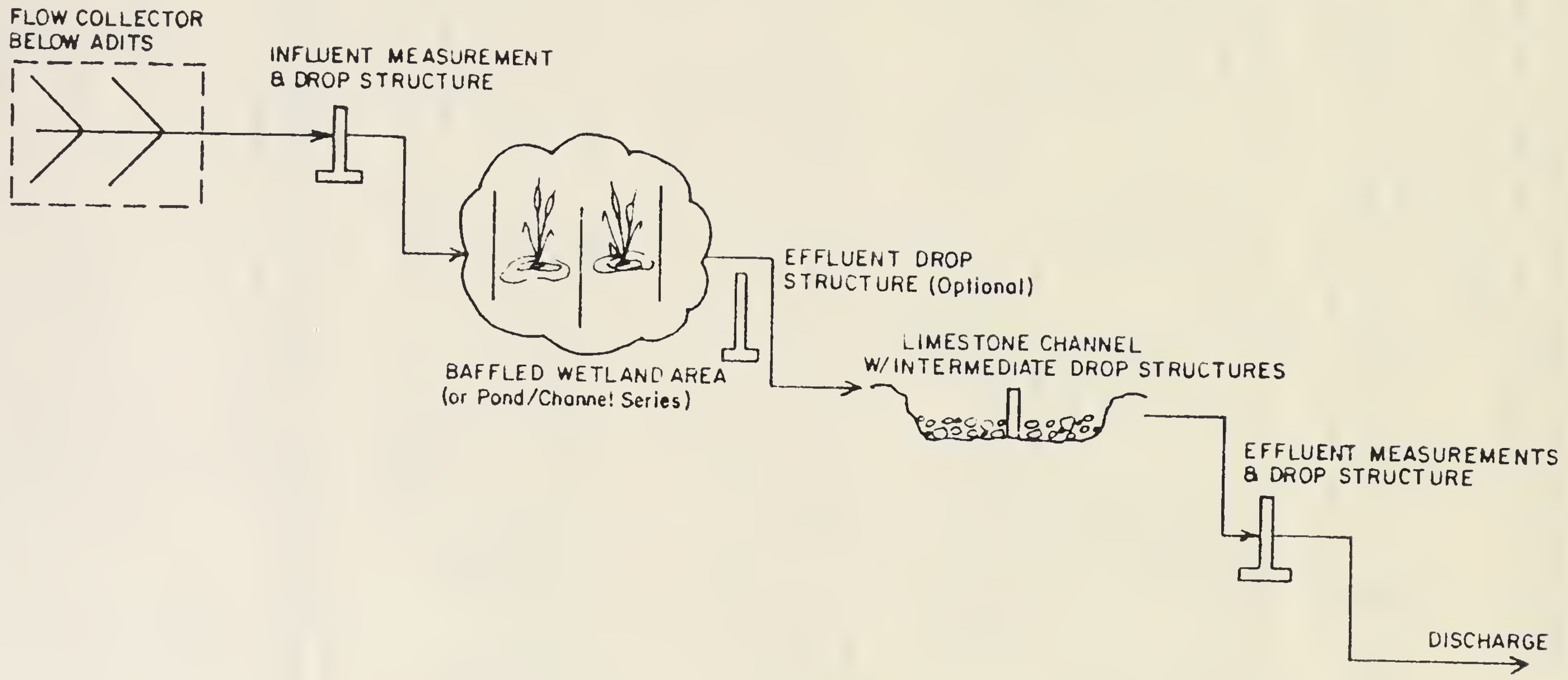
- Excavation, transport, and placement of earth fill to create the necessary pond areas and peripheral dikes. Because of the proximity of cut and fill operations, dozer and blade equipment should be adequate; use of self-loading scrapers would be optional.

- Construction of piping systems, drop structures, and other hydraulic appurtenances can be done in conjunction with or immediately after the general site earthwork is completed.

- Procural and incorporation of bentonite into the impoundment floors to provide an adequate water seal. In cut areas the exposed surface can be scarified for a depth of six to 12 inches, and the bentonite can be applied, incorporated, and compacted. In fill areas, prior to final compaction of the upper strata, bentonite can be likewise applied and the layer compacted.

- Above the seal layer, the mixed layer of soil and limestone (if used) would be placed. Compaction of this zone would not be performed to avoid over-consolidation to the point of limiting contact with the water. Limestone would likely be procured from a supplier in Townsend, Montana, due to the suitability of their product (low magnesium content).

FIGURE 6
Schematic of Wetland
System Components



- * Construction of downstream drop structures and limestone channels can occur as the wetlands site earthwork and floor preparation are proceeding. Downstream structures would likewise be complete and ready to receive flow before vegetation transplant begins, recognizing the imminence thereafter of flow diversion to the systems.

- * Atop the soil/limestone layer, peat would be placed, likely to be obtained from a supplier in the Big Hole Valley. Truck transport of the material will be necessary.

- * The cattail mats, transplanted from adjacent marshland, would be placed in accordance with previously cited spacing recommendations. Because of the proximity of the supply, front-end loader equipment would be suitable for lifting, hauling, and placing the mats. Mat size would be a function of loader bucket size, and the largest manageable size would appear preferable for minimum disturbance of the vegetative structure. Depending on the exact characteristics of the equipment used, an extended "tongue" on the loader bucket and some means of cutting the existing cattail mat may be desirable.

- * Heavy equipment should not run atop the peat or cattail layers to avoid compaction of these materials. Placement of both layers will have to be completed for small portions of the wetlands area before proceeding to adjacent areas to permit equipment access. This can be accomplished by proper planning of the construction sequence.

- * Once the cattail mats are placed, flow diversion through the wetland can be done. During the course of construction it is likely that flow will have to be diverted around the wetland sites to avoid saturation of the worksite. Obviously establishment of flow through the wetland must closely follow cattail transplant to maintain their viability.

- * As flow diversion takes place, initial sampling and flow monitoring can begin. Thereafter data will be accumulated according to a prescribed monitoring plan.

## F. Monitoring Plan

Because the primary parameters of interest from the standpoint of wetlands treatment of the acid mine drainage are hydrogen ion concentration (pH), dissolved iron, and dissolved manganese, these parameters comprise the bulk of the monitoring program. To permit calculation

of the flux of these materials through the systems, influent and effluent flow will both be of interest. Reaction rates and resulting changes in water quality are anticipated to be relatively slow (measurable in days or weeks) in the wetlands systems, and this dictates the frequency of monitoring advisable. A suggested monitoring plan is as follows:

- Measurement of instantaneous influent and effluent flow for each wetland on a bi-weekly basis.

- At the time of flow measurements (twice per month), a one-liter grab sample of influent and effluent would be procured. Each sample would be analyzed for pH, dissolved iron, and dissolved manganese at the MDHES analytical lab or a contracted private laboratory.

- Initially at the time of transplant and at three-month intervals thereafter, multiple tissue samples would be obtained from growing _Typa_ specimens from each wetland. The vegetative as well as rhizomous tissues should be analyzed, and a minimum of four plants should be sampled. It may prove of interest to compare specimens growing near the inlet versus the outlet to each wetland. Tissue analyses for iron and manganese would be performed by the Montana State University Extension Service or other private laboratory. Additional trace metals analyses may be desirable, particularly those of known toxilogical properties.

- Sediment core samples would be taken from a minimum of three locations at each wetland on a semi-annual basis. These cores could be located to differentiate between inlet and outlet zones in each wetland and should penetrate through the cattail mat, peat layer, and underlying soil to the top of the bentonite-amended liner. Cores should be analyzed for total iron and manganese and any additional metals of interest. Background concentrations should be established by core sampling during startup to provide a data baseline.

- Periodic grab samples of liquid or solid material from the wetland would be procured for microbial characterization and algal speciation. This would provide additional insight into the species predominance that becomes established. If of interest, liquid samples could be centrifuged, and total iron, manganese, or other metals analyses could be performed on the solids portion to establish concentrations characteristic of microbes and algae.

- At the completion of one year of monitoring, an annual report would be prepared summarizing and interpreting the data

collected. Tentative conclusions would be included along with recommendations regarding apparent adjustments needed in wetland operation, continued monitoring, and applicability of the pilot system to other full-scale situations.

## G. Design and Construction Scheduling

Recognizing the imminence of the construction season and the desirability of transplanting the cattails before prolific seasonal growth occurs, the scheduling of design and construction of the two wetlands systems will necessarily have to be expedited. It is anticipated that construction work will be performed on a direct contract basis with a local contractor. Since the systems are experimental in nature and will require close field supervision during installation with the opportunity for adjustments in design during construction, this is a logical choice.

After distribution of this Engineering Report and comment thereon, a preliminary engineering design for each site will be prepared in blueprint form. The preliminary design should require abut two weeks preparation time; and once available, work sessions between the consultants and the Department of State Lands will be held to critique and revise it as necessary.

Final (revised) engineering design blueprints and specifications will be prepared and distributed for final comment. Once approved, a contractor(s) chosen by the Department of State Lands will be contacted for a pricing commitment for performance of the required work. The design will be thoroughly reviewed with the contractor to insure full understanding of the work to be performed, and contract options will be explored. While a lump sum price for the work may be possible, hourly or unit pricing for labor, equipment, and materials would seem more flexible in permitting interim adjustments to the scope of work.

Once a contractural agreement was reached with the contractor, notice to proceed would be granted immediately; and construction could commence. The consultants, in conjunction with Department of State Lands personnel, will closely supervise the work in the field during construction. A 20-to-30-day construction period is anticipated.

After construction completion, consultant personnel will implement the monitoring program.

# APPENDIX A

# WATER ANALYSES

ENERGY LABORATORIES

ENERGY LABORATORIES, INC.
P.O. BOX 30916 · 1107 SOUTH BROADWAY · BILLINGS, MT 59107-0916 · PHONE (406) 252-6325

## LABORATORY REPORT

To Department of State Lands (1) Lab No. 86-2533B
Address Abandoned Mine Reclamation Date 4-7-86 tab
Capitol Station
Helena, Montana 59620
ATTN: Michael Hiel

## WATER ANALYSIS

Abandoned Mine - Johnson/South
Sampled 3-20-86 @ 1530
Submitted 3-24-86

| CONSTITUENT | MILLIGRAMS PER LITER |
|---|---|
| Potassium | <1 |
| Sodium | 22 |
| Calcium | 159 |
| Magnesium | 129 |
| Sulfate | 2,660 |
| Chloride | 17 |
| Carbonate | * |
| Bicarbonate | * |
| Nitrate as N | * |
| Iron | 279 |
| Total Solids (Calculated) | * |
| Total Hardness as CaCO3 | 928 |
| Specific Conductance @ 25°C | * |
| pH | * |

### METALS

| | |
|---|---|
| Aluminum | 148 |
| Arsenic | 0.080 |
| Barium | <0.1 |
| Cadmium | 0.113 |
| Chromium | <0.02 |
| Lead | 0.03 |
| Mercury | <0.001 |
| Selenium | <0.005 |
| Silver | 0.008 |
| Copper | 0.03 |

*The sample was preserved with nitric acid and these tests could not be performed.

ENERGY LABORATORIES

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ATTN: Michael Hiel

## WATER ANALYSIS

Abandoned Mine - Johnson/East
Sampled 3-20-86 @ 1530
Submitted 3-24-86

| CONSTITUENT | MILLIGRAMS PER LITER |
|---|---|
| Potassium | 6 |
| Sodium | 23 |
| Calcium | 198 |
| Magnesium | 135 |
| Sulfate | 1,660 |
| Chloride | 16 |
| Carbonate | * |
| Bicarbonate | * |
| Nitrate as N | * |
| Iron | 173 |
| Total Solids (Calculated) | * |
| Total Hardness as CaCO3 | 1,050 |
| Specific Conductance @ 25°C | * |
| pH | * |
| METALS | |
| Aluminum | 45.5 |
| Arsenic | 0.006 |
| Barium | <0.1 |
| Cadmium | 0.016 |
| Chromium | <0.02 |
| Lead | 0.01 |
| Mercury | <0.001 |
| Selenium | <0.005 |
| Silver | 0.005 |
| Copper | <0.01 |

*The sample was preserved with nitric acid and these tests could not be performed.

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