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A POST-RECLAMATION WATER QUALITY ASSESSMENT  
OF THE MONAHAN OUTDOOR EDUCATION CENTER

A Thesis Submitted to the Graduate School  
in Partial Fulfillment of the Requirements  
for the Degree of  
Master of Science

By  
Sally Ann Imhof

Pittsburg State University

Pittsburg, Kansas

May 1994



## ACKNOWLEDGMENTS

I wish to express my gratitude to all those who have assisted with this project: to those who helped install the weirs in the hot Kansas sun and to those who supported me through their patience and prompting.

A special thank you to my father-in-law, Leonard Imhof, whose influence and knowledge have guided me through this project. Thank you to Murray Balk, and other members of the Surface Mining Section for their support and input, and to the Crawford County SCS office for contributing information.

Thank you to my thesis advisor Dr. Joseph Arruda and committee member Dr. James Triplett. Their dual advice and encouragement have helped throughout this project. And thank you to committee member Dr. Alexander Bednekoff.

A WATER QUALITY ASSESSMENT  
OF THE MONAHAN OUTDOOR EDUCATION CENTER

An Abstract of the Thesis by

Sally Ann Imhof

Before the Monahan Outdoor Education Center became established, a portion of the area was abandoned mine land and a portion of the area was an abandoned coal processing plant. Before reclamation in the mid 1980s, the project site was a concern for the health and safety of residents in the surrounding area, and environmentally there was concern caused by the acid mine drainage originating from abandoned coal waste. This acid mine drainage not only affected the project site itself but also contributed to off-site pollution downstream in Brush Creek.

The purpose of this study was twofold: (1) to determine if the water quality on the Monahan site and the quality of the water leaving the site had improved after the initial reclamation, and (2) to evaluate the physical integrity of the project site.

Water was collected at eight sites and sampled every two weeks for two months, beginning on June 6th, 1990. Thereafter samples were collected following every substantial rainfall through Nov. 18, 1991. The parameters selected for determining water quality were: pH, conductivity, total iron,

sulfates, alkalinity, and hardness. Discharge was recorded at five sites; three of the sites were weirs and two were culverts.

The study site had been abandoned for over 40 years and the pre-reclamation environmental study indicated that the existing acidic condition would persist without reclamation. In the pre-reclamation study, pH readings were taken of the water on site in several different places. At the seep issuing from a gob pile on site the pH was 2.5. After reclamation the last pH reading at that same site was 3.5. The discharge from the Monahan still degrades water flowing into a tributary of Brush Creek located east of the project site.

The continuing acid drainage needs correction for the long term integrity of the site. Other abandoned mined land areas similar to the Monahan have had similar problems in their reclamation processes. Treatments used at some of these sites were reviewed and recommendations are given for possible use on the Monahan site. These recommendations include installation of additional drainage systems along with construction of additional wetlands. Continuing the reclamation process through a maintenance plan will increase productivity of the Monahan as well as improve the water quality both on and off the study area.

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## CHAPTER I

### INTRODUCTION

There is evidence that coal was used in China as early as 1100 B.C., and according to Aristotle's writings coal was being used by smiths in the year 350 B.C. However, it was not until firebricks were invented in the late 1400's that coal was used to heat homes or buildings. Then around 1570, because of the demand for metal goods, coal became a popular and well established commodity and a much demanded resource (Lindbergh and Provorse 1977).

By the 1800's people were interested in recovering resources in the easiest and most economical way. They gave little thought to the small sections of the environment that were being destroyed for their overall comfort. Consequently, the coal mining practices of the 1800's and early 1900's were examples of how land could be devastated without thought to the future. The long-term effects of the coal mining practices used at that time were not understood. The problems left from those early coal mining practices have made us more aware of the balance in our environment, particularly the balance between land and water. Since the late 1960s, coal mining practices are quite different. State laws passed in the 1960s and Federal laws passed in the 1970s have made reclamation a natural sequence of coal mining.



Before laws were passed in the 1960s, one of the prevalent problems occurring at abandoned mined land sites and the abandoned coal processing sites was acid mine drainage. Acid mine drainage is pollution that not only kills surrounding vegetation but it can negatively impact streams and other bodies of water in its path.

The goal of this project was to assess the success of reclamation of a pre-law site. Pre-law designates mining activities prior to the 1968 Kansas Coal Mining and Reclamation Act. The pre-law site to be assessed is now called the Monahan Outdoor Education Center and is being developed for educational purposes. The assessment of the study area was done by monitoring the quality of water on-site and off-site, and by evaluating the physical integrity of the site. Suggestions will be made for continued improvement of the water quality at the Monahan Outdoor Education Center.

## CHAPTER II

### PREVIOUS MINING ACTIVITIES IN THE STUDY AREA

Coal mining in Kansas was limited to the southeast corner of the state, with most of the activity in Crawford and Cherokee Counties. Southeast Crawford County is classified as the Cherokee lowlands. It has a relatively flat topography with a MSL of 930-940 feet (USDA 1981a). Historically, beds of coal are common occurrences within sequences of sedimentary rocks that formed in the floodplain environments (Freeze 1979). Southeast Kansas had such an environment.

Coal mining in Kansas began about 1872. Early production of coal in Kansas was mostly from underground mines (Marcher et al. 1984). According to Lindbergh and Proverse (1977), peak coal production for the country was in 1920, while peak production in Kansas occurred about 1918. After the country's peak during the 1920's, coal production decreased, except for a temporary increase during World War II, and a lesser increase in the 1970's due to the oil shortage (Marcher et al. 1984).

Since the early 1900's the extraction of coal by the traditional underground mining methods has given way to newer methods. Coal is still taken from deep mines in some parts of the country, but from the 1930's through the present, the most common method of extracting coal in Kansas

is by strip mining (Marcher et al. 1984).

Strip mining of coal involves stripping away any material covering the coal seam, starting from the surface and working towards the coal (Thrush et al. 1990). The material covering the coal seam is called overburden. The overburden varies in composition depending on the location of the coal. Removal of the overburden exposes the coal and makes it accessible to the miners and their equipment.

Strip mining became the desired method of extracting coal in Kansas because of the location of the coal seams. Strip mining was more economical than deep mining and safer (Marcher et al. 1984). Some of the coal seams being mined were not deep enough or thick enough to leave a safe roof in the traditional 'room and pillar' method of underground mining. Instead the overburden was stripped by power shovels of various types and sizes. Some of the shovels had booms more than 100 feet in length and dippers that could hold 50-60 tons (Wells 1950).

Between 1910 and 1920 the Monahan site located in southeast Kansas (Figure 1), was deep mined (underground mined). The coal seam that was deep mined was the Weir-Pittsburg coal bed, which occurred about one hundred feet below ground surface and was approximately three feet thick (Figure 2). Later, in the mid-1930s until the early-1940s, the same area was strip mined. The coal mined this time was the Mineral coal seam. It was 25 feet below the ground and

was 18 inches thick (USDA 1981a) (Figure 2).

Figure 1. Vicinity Map

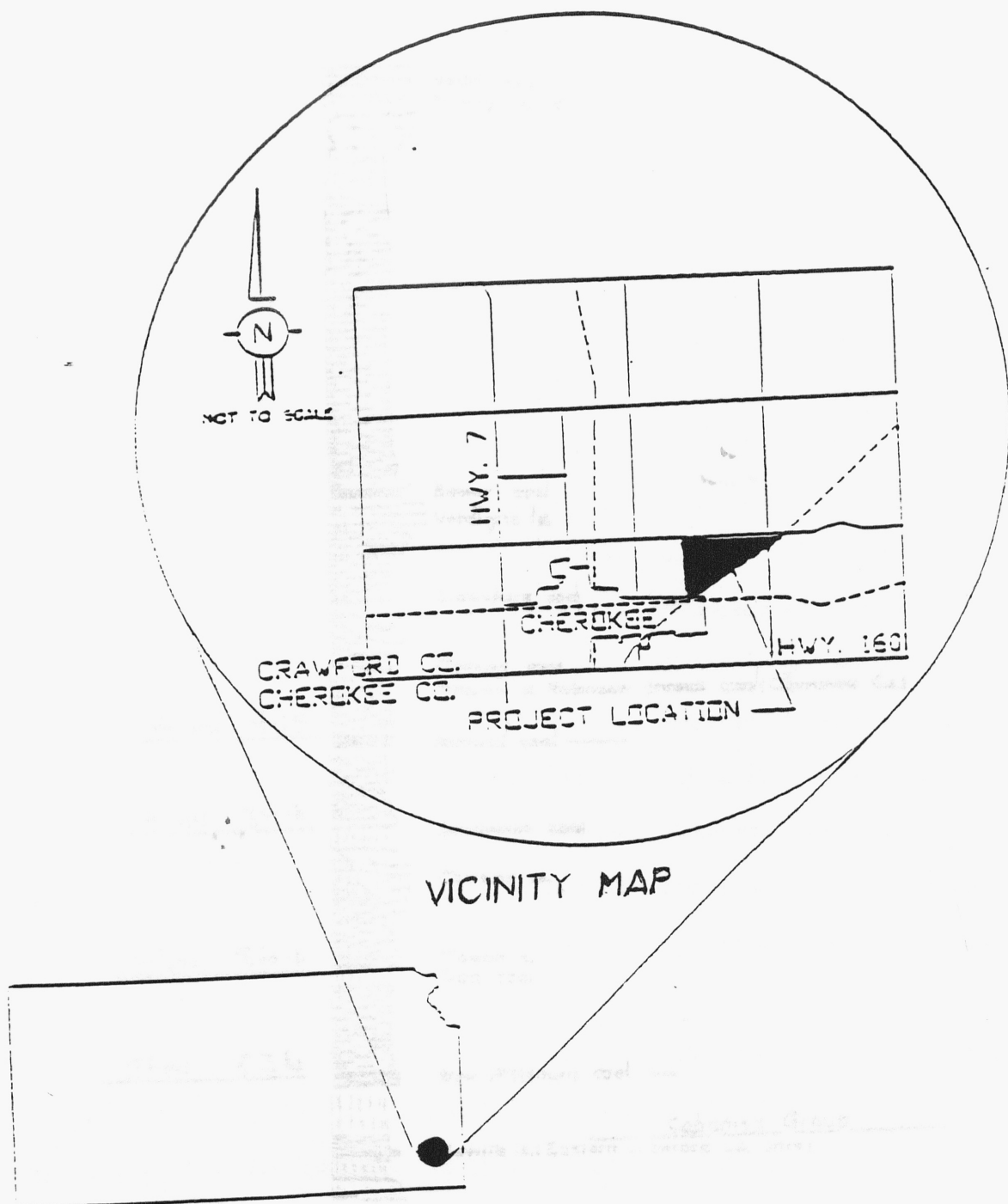
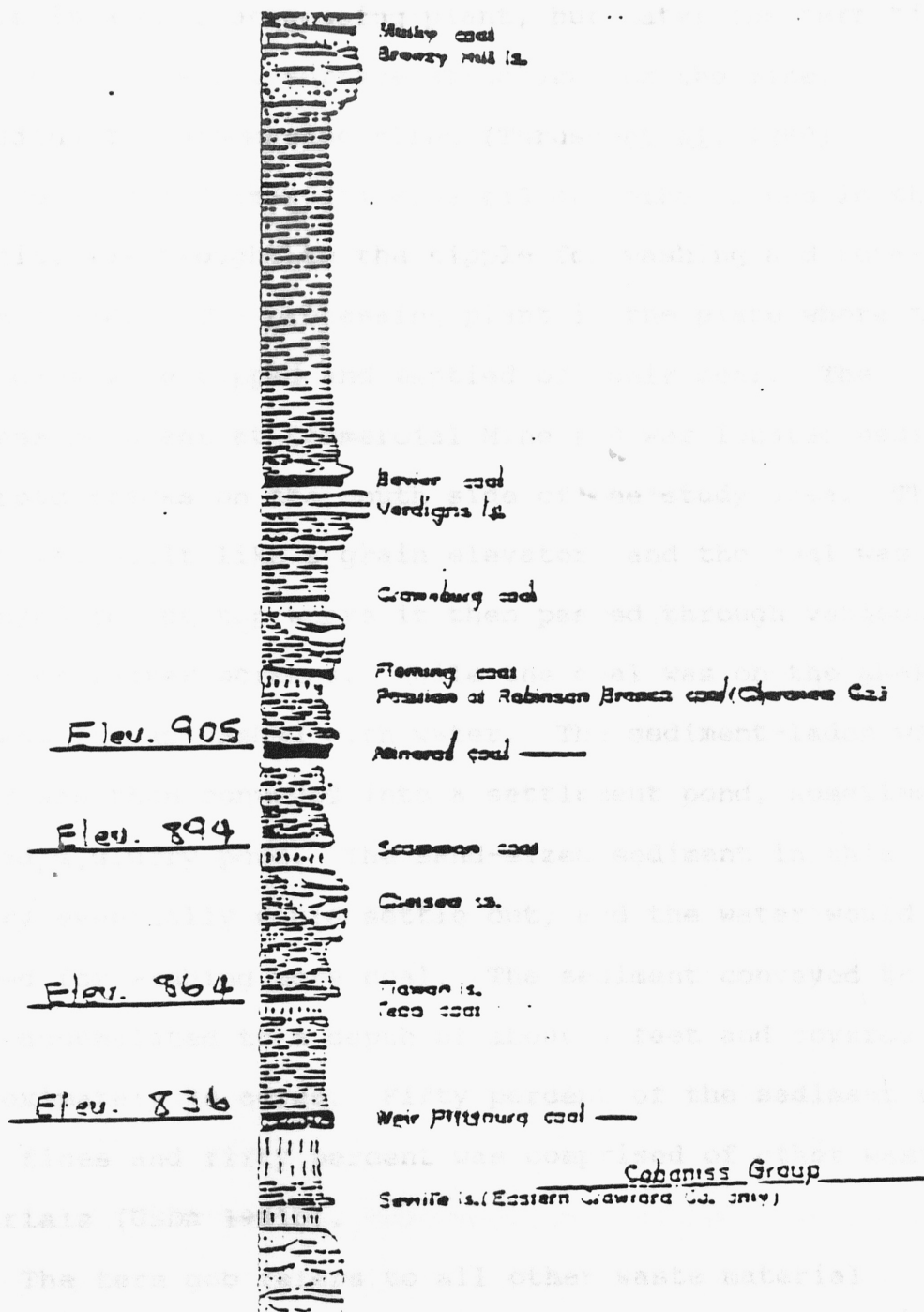


Figure 2. Stratigraphy at the Monahan



During the time of strip mining activity, the study area was called Commercial Mine #10 (Leonard Imhof, personnel communication). This area was also the site of a tipple. A tipple is a coal processing plant, but later the term tipple came to include all surface structures of the mine, including the processing plant (Thrush et al. 1990).

Coal from Commercial Mine #10 and other mines in the vicinity was brought to the tipple for washing and screening (USDA 1981b). The processing plant is the place where the mine cars were tipped and emptied of their coal. The processing plant at Commercial Mine #10 was located near the railroad tracks on the south side of the study area. The plant was built like a grain elevator, and the coal was conveyed to the top where it then passed through various sizes of shaker screens. While the coal was on the shaker screens it was washed with water. The sediment-laden wash water was then conveyed into a settlement pond, sometimes called a slurry pond. The sand-sized sediment in this slurry eventually would settle out, and the water would be reused for washing more coal. The sediment conveyed to the pond accumulated to a depth of about 6 feet and covered approximately 30 acres. Fifty percent of the sediment was coal fines and fifty percent was comprised of other waste materials (USDA 1981b).

The term gob refers to all other waste material separated from the coal but too large to be carried away in

the wash water. This waste material was hauled to a dump area to the northwest of the tippie and eventually covered 17 acres to a height of 20 to 30 feet. Consequently, the relatively flat pre-mined topography was replaced with a large pile of gob which soon eroded into hills and valleys (USDA 1981a).

Most of the hills left from coal mining activity are called mine dumps and are usually well vegetated with both ground cover and plenty of trees. The dumps consist of the overburden, the material which is removed from above the coal seam to gain access to the coal. This material includes the soils and may include some calcareous materials such as limestone, which would aid in natural revegetation (Thrush et al. 1990). Under usual circumstances, when mining activities ceased, the mine dumps would revegetate rather quickly. But gob, like that at the Commercial Mine #10 is different.

The gob pile at the tippie site consisted of those substances that were separated from the coal itself, which meant there were virtually no calcareous materials present. Instead gob, or as it is sometimes called, mine refuse, consisted of shales, pyrites, and small particles of coal (Thrush et al. 1990).

According to local residents, the gob pile at the Monahan burned for many years. Gob often burns because of the heating and slow combustion of the coal and coal



materials. This is initiated by the absorption of oxygen. When air leaks through the coal and shale material and supplies the needed oxygen for combustion, and conditions do not allow dissipation of heat, there is a subsequent rise in temperature. This rise in temperature ignites the coal and shale materials (Thrush et al. 1990). Evidence that spontaneous combustion had occurred at the Monahan was present at the time of study and investigation. A substance called "red dog" was found over much of the gob pile area. Red dog is a material of reddish-brown color resulting from the combustion of shale and other mine wastes (Thrush et al. 1990).

Depending upon parent rock, gob consists of different proportions of shales, coal, and pyrites. The gob pile at the Monahan contained an abundance of pyrite and virtually no limestone (USDA 1981a). Pyrite is found within shale, sometimes running vein-like between layers of the rock (Pulford et al. 1986). The chemical composition of pyrite is  $\text{FeS}_2$ . When this is buried beneath the earth's surface it is stable, but when it is exposed to oxygen either from the atmosphere or from water, pyrite oxidizes (Caruccio and Geidel 1984). Physical characteristics can also contribute to the amount of oxidation reactions. The gob pile was a 50/50 percent mixture of fine-grained and coarse-grained material (USDA 1981a). The 50% fine-grained or framboidal form, has a diameter of less than 1mm. Because of the large

surface area supplied by this fine granularity, it is the most reactive of all pyrite types (Caruccio and Geidel 1984).

The oxidation reaction as taken from Pugh et al. (1984) is as follows:



As the sulfides are oxidized to soluble sulfates and hydrogen ions evolve, the pH is reduced (Caruccio & Geidel 1984). In addition, as ferrous iron is produced as a by-product, a biological reaction begins involving the iron-loving bacteria Thiobacillus ferrooxidans. The catalytic action of the bacteria results in the following reaction taking place at a much faster rate (Kleinmann 1986).



When the system is so acid that ferric ions remain in solution, meaning there is a decrease in iron hydroxide precipitation, the  $\text{Fe}^{3+}$  acts as the oxidizing agent on the remaining pyrite, thus enhancing the oxidation rate and further decreasing the pH (Pugh et al. 1984).



Once the above reactions are in progress, a cycle forms, and within this cycle other mine spoil constituents can react. If the material was spoil there would likely be limestone or other calcareous material to buffer the acid

produced by the weathering of pyrite. But the gob having virtually no calcareous material was more likely to produce metal leaching than to naturally neutralize the acid.

Surface water running over and through spoil material might be neutralized and have a low metal concentration (Caruccio and Geidel 1984). But surface water at the Monahan was highly acid, with high concentrations of iron and sulfate (USDA 1981b).

The preceding information explains why the slurry pond and gob pile never revegetated, and why there was a problem with acid mine drainage. Grasses, shrubs, and trees are not tolerant of these conditions, conditions that cause not only a very low pH, but also a high concentration of metals. After years of continuous oxidation of the pyrite and the burning out of the exposed coal and shales, the surface had improved very little (USDA 1981b).

## CHAPTER III

### REGULATIONS

As strip mining operations increased during the early and mid-1900s, more and more land was taken out of production, and more and more streams were affected by acid mine drainage. People became concerned about the future of the environment. This concern prompted the early years of reclamation. Studies took place in order to gain knowledge of such things as spoilbank structure, spoil texture, acidity and alkalinity in spoil, and the nutrient content of spoil (Wells 1953). Also, comparative studies of plant production on partially leveled versus undisturbed spoilbanks were implemented using various tree, shrub, and grass species (Wells 1953).

Local agencies quickly became involved with these efforts. This included groups such as the Reclamation Committee of the Pittsburg Chamber of Commerce, and some of the local coal companies such as the Mulberry Coal Company and The Clemens Coal Company (Rogers 1947). State and national groups included the Civilian Conservation Corps, the Soil Conservation Service, and the United States Forest Service (Wells 1953).

The early years of reclamation spanned from the late-1930s through the early-1950s (Wells 1953). By the 1960s, state governments were becoming involved in reclamation efforts. In 1968 the state of Kansas passed the Mined Land

Reclamation and Conservation Act (State Geological Survey 1972). This act provided regulatory guidelines for reclamation of land mined after January 1, 1969 (State Geological Survey 1972).

In 1969, Governor Docking appointed an Action Task Group, which was in charge of encouraging redevelopment of approximately 50,000 acres that had been strip-mined for coal prior to the 1968 Act. Cost-sharing of the program was aided by grants from the Ozarks Regional Commission to the Kansas Geological Survey, the See-Kan RC&D, and the Soil Conservation Service's REAP Program (State Geological Survey 1972). The establishment of these programs showed regard for both presently mined land and for problem areas left by pre-law mined lands.

In the early-1970s the energy crisis brought about a new interest and surge in coal mining. The output of surface mines rose a dramatic 46% from 1976-1984 (Conservation Foundation 1987). Also on the rise was a people more aware of the environment and more concerned about its welfare. How could strip-mining for coal be justified if it involved the destruction of land and the degradation of quality in our ground water and streams? In 1977, Public Law 95-87 the Surface Mining Control and Reclamation Act (SMCRA) was passed (Conservation Foundation 1987). The main objectives of SMCRA were to regulate present mining operations and to reclaim those abandoned

mine lands that were a danger to the public.

Objectives for new and present mining were: avoid loss of site productivity, maintain energy-efficient agriculture production, and prevent off-site environmental problems. It was thought that if the soil was returned to its prior productivity, then mine-related environmental problems would cease (McCormack 1986). The passage of SMCRA required miners to fill in excavated mines with the original overburden stripped from them and to return the land to its approximate original contour (Conservation Foundation 1987). This practice has eliminated most of the acid mine drainage from newly mined sites (Kleinmann and Erickson 1986).

Title IV, Section 401 of SMCRA, concerns the reclamation of abandoned mine lands (AML Program). Under Title IV, a fund was set up which allows states to receive funding to help with their reclamation projects (U.S. Dept. of the Interior 1988). 80% of the reclamation funds are used to reclaim those areas that endanger the health and safety of the public. Under Section 406, 20% of the funds are transferred to the Secretary of Agriculture. These funds are used to provide control and prevention of erosion and sediment damages and to improve water quality and aesthetic values in both pre-law and post-law coal mined lands.

Under the Surface Mining Control and Reclamation Act of 1977, the Monahan was a prime candidate to receive Title IV

funds. There were hazardous toxic wastes, an unstable gob pile with steep banks, and several small, acid water impoundments (USDA 1981b). The site presented a hazard to local residents, as well as being aesthetically unattractive. A water sample taken in the preliminary study from the drainage ditch running along the north boundary of the property, had a pH of 2.1. This drainage ultimately empties into Brush Creek which was void of aquatic life for a mile downstream (USDA 1981b). Gore and Bryant (1988) contend that the reestablishment of good water quality is a prime concern to stream restoration, and they further rationalize that a desirable aquatic community will follow the attainment and maintenance of good water quality.

The gob pile was the source of the toxic wastes and highly acid material that contaminated the water both on the project site and the water in the surrounding area. After being a continuing source of contamination for more than 40 years it was time to remediate the acid mine drainage and reclaim the Monahan site.

## CHAPTER IV

### THE STUDY SITE

#### A. Pre-Reclamation Conditions

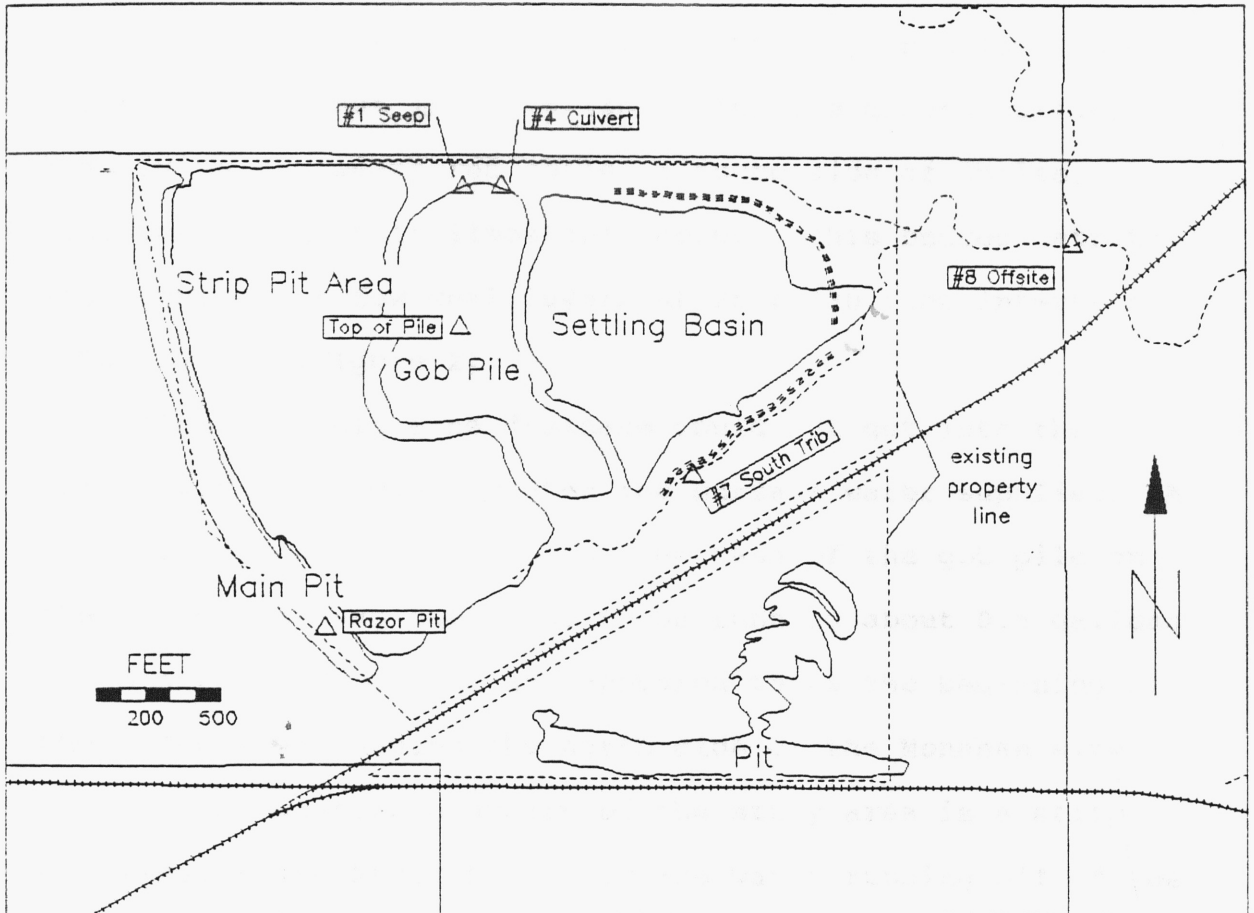
The Monahan Outdoor Education Center was developed on an abandoned mine land site located in southeast Crawford County, approximately one-half mile north and one-half mile east of the town of Cherokee (NE 1/4 of S17, T31S, R24E) (Figure 1).

When the Monahan site was first assessed for reclamation the site was described (USDA 1981b) in the following manner. There were approximately 80 acres of barren refuse, coal slurry and mine spoils. Between the gob pile and the dumps that separated Razor Pit, there were several small acid pits. And on the south border, the remains of the coal processing plant still lay close to the railroad tracks (Figure 3).

At the time of the assessment, weathering and erosion had occurred for about forty years, leaving a number of steep and unstable slopes. There was no vegetation because of the acid conditions and because an iron hydroxide crust had formed on the gob pile making it impossible for plant roots to penetrate the surface and become established (USDA 1981a). East of the gob pile lay the slurry pond, which was also void of vegetation. A dike had been built around the slurry pond to keep the slurry in place, and this dike and everything east to the property fence was revegetated.



Figure 3. Pre-Reclamation Map



The acid water produced was not a threat to deep water supplies since the ground directly under the gob had not been strip mined and the subsurface materials were not permeable. The subsurface materials underlying the gob pile included a deep residual clay soil extending from the ground surface to a depth of about 15 feet. Under the clay soil is a weathered clay shale, brown to light gray in color, which extends from about 15 to 25 feet below the ground surface. Underlying the weathered shale, a succession of shales, sandstones, and thin limestones occur. This bedrock strata also contains a few coal layers at 25 to 30 foot intervals (USDA 1981a) (Figure 2).

Although acid mine drainage could not get into the ground water, it did threaten the surface water supplies. A concentrated seep issuing from the base of the gob pile on the north side was estimated to be running about 0.5 gallons per minute (USDA 1981a) and appeared to be the beginning of the tributary draining the north side of the Monahan site.

On the western boundary of the study area is a strip pit lake, named Razor Pit. Surface water running off of the gob pile gathered into several small pits east of this large strip pit lake. The water in the small pits was highly acid, pH 2.2 to 2.6 (USDA 1981b). There were a few vegetated dumps between the small acid pits and the large pit. These dumps, and the slope of the land kept Razor Pit from being affected by the acid drainage. According to the

environmental assessment (USDA 1981b), Razor Pit was high in sulfates, but had a fairly diverse aquatic ecosystem.

Some of the surface water infiltrated the gob and some formed the small acid pits on top of the gob pile, the remaining surface water either emptied into the south drainage tributary or the north drainage tributary. Both of these eventually drain off-site. The drainage tributary on the north received surface water runoff and water from the seep. The drainage ditch on the south side received surface water runoff and over-flow from Razor Pit. Cattails were growing in the marshy area at the south end of Razor Pit, approximately 2.7 acres in area. The marsh conformed into the south drainage ditch, which continued to support the growth of cattails until it received too much acid runoff from the gob pile for them to tolerate. The two streams flow east and merge just off-site. From there the water flows into a tributary of Brush Creek. According to the environmental assessment (USDA 1981b), this tributary was void of life from below the site to its confluence with Brush Creek two miles east.

Still without vegetation after 40 years of lying idle, visitors to the area viewed the Monahan as aesthetically unpleasant. However, local residents called the abandoned Commercial Mine #10 "Devil's Mesa", or "The Desert". There were deep ravines eroded in the surface and small pools of red water. The hydroxide crust made the surface crunchy and

mineral salts crystallized into pure whites and yellows. Numerous fossils could be found in the weathered shales, and people liked to walk there, drive their off-road vehicles there, and take target practice against the gob pile. It was not aesthetically pleasing to visitors, but local residents utilized the site as it was.

#### B. Reclamation of the Monahan

The Monahan was reclaimed under an interagency agreement between the Office of Surface Mining and the Soil Conservation Service. Funds were provided through the Office of Surface Mining, under Public Law 95-87 and in accordance with Section 601 of the Economy Act (31 UCS 686). The Soil Conservation Service provided the design and construction through contract, and inspected the reclamation of the Monahan site (Interagency Agreement # J6601019, 1980).

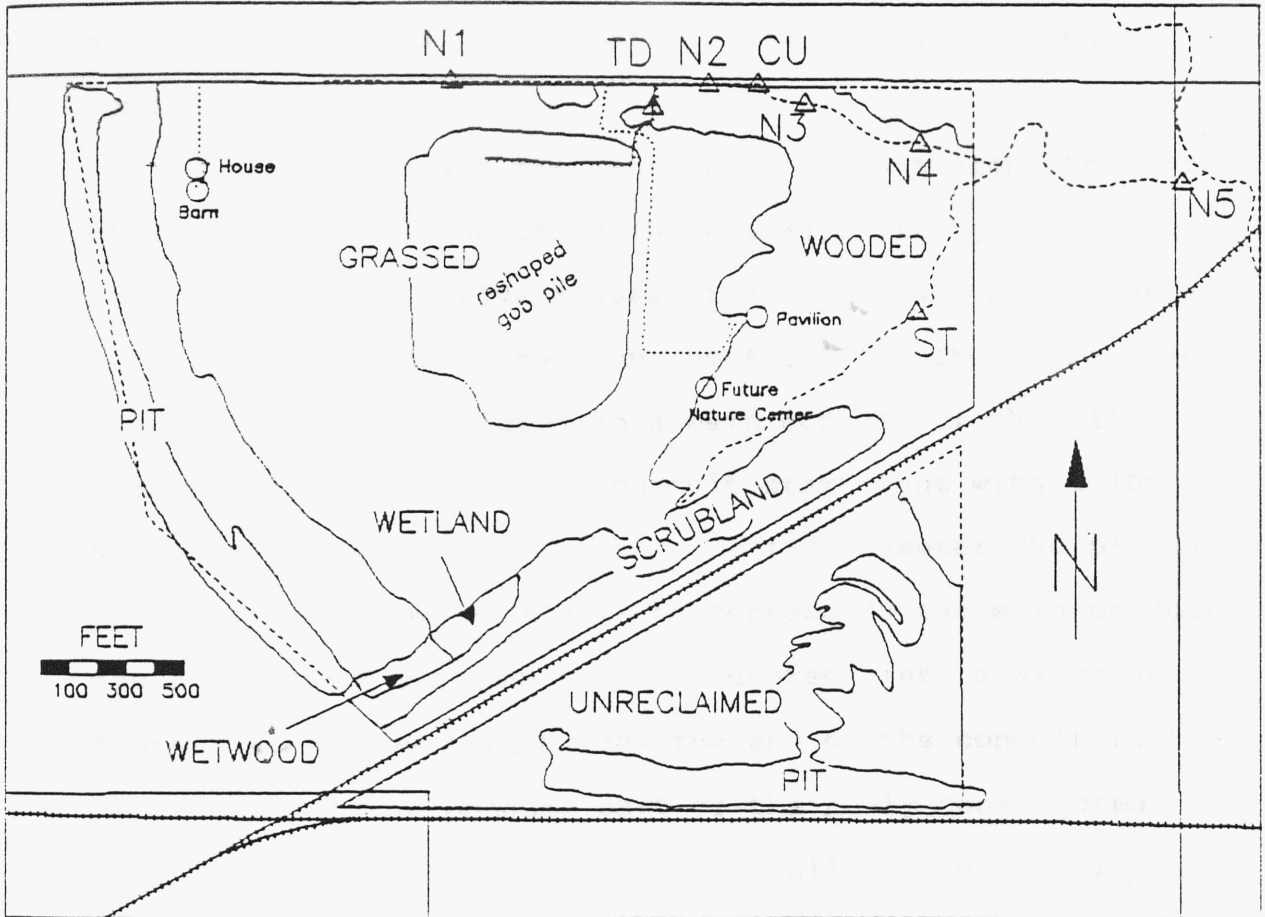
Reclamation began in 1984 and ended eight months later in the spring of 1985. According to the Soil Conservation Service, the sequence of events were:

1. Construct an erosion control dam.
2. Cover exposed concrete, cleanup the tippie site, and construct diversions.
3. Remove brush from acid pit area.
4. Pump acid water from small pits and spray over gob pile.
5. Fill acid pits with gob from reshaping.

6. Construct main drainage ditch on west side of site.
7. Shape gob pile to 3% slope to the east.
8. Place 1 foot of "topsoil" over non-productive areas.
9. Place 1 foot of crushed limestone over 34 acres which was underlain with gob material (17,000 tons used).
10. Place 1 foot additional topsoil over crushed rock.
11. Construct 5 tile outlet terraces two feet below ground surface.
12. Disc, fertilize and plant oats for a cover crop.
13. Construct a fence.
14. Plant trees, shrubs and grass in spring of 1985.

The topsoil in the preceding list meant mine spoil. This mine spoil came from spoil dumps that were between the gob pile and Razor Pit. Upon completion of these events the gob pile was reshaped and the tile drainage system was in place (Figure 4).

Figure 4. Post-reclamation Map



The tile drainage system was put on a foot of mine spoil then topped with a foot of limestone and another foot of mine soil. Total depth from surface to tile drainage system is two feet. The tiles direct surface water away from the gob and into a drain outlet. The drainage system along with the limestone and mine spoil cap and seeding of native grasses stabilized the top of the gob pile and helped to control erosion.

The gob pile was flattened from a 1.5:1 slope to a 3:1 slope, making a grade of 2% (USDA 1983). The gob pile was then terraced into five ridges with the height not to exceed nine inches before compaction (USDA 1983). There are five terrace outlets connected to a main conduit of the tile drainage system. The main conduit starts out with a 10" diameter PVC pipe and changes to a 12" diameter PVC pipe at terrace #3. From terrace #1 to terrace #5 the main conduit has a 3% grade and then turns 45 degrees into a 6% grade. Another 45 degree turn brings the end of the conduit to the north side of the Monahan east of the newly constructed pavilion road (USDA 1983). At the valley of each terrace, rising about 2.5 feet above the ground, is a pipe 8" in diameter that is connected 2 feet underground with the main conduit. The part of the pipe that is exposed above ground is perforated. These pipes were installed in trenches that had been cleared of vegetative matter for at least an 8" diameter from the pipe (USDA 1983). The trenches are

supposed to encourage surface waters to run into the tile outlet and keep the water from contacting buried waste material.

The grasses planted were a mixture of native species. This included Little Bluestem, Big Bluestem, Sideoats Grama, Wheatgrass, Switchgrass, Buffalograss, Prairie Coneflower, Purple Prairie Clover, and Prairie Sunflowers. Planting the native mixture was a fairly new venture as most reclamation projects at this time were planted to fescue. Trees and shrubs planted were Pin Oak, Russian Mulberry, Walnut, Pines, Sumac, Autumn Olive, Plum, and Cherry (USDA 1983).

#### C. Post Reclamation Conditions

In the spring of 1987, two years after the Monahan site had been planted with a native grass mixture, the dominant plant was sweet clover. Sweet clover was not in the original seed mixture but must have invaded from neighboring fields. The clover grew to a height of five feet tall over much of the site. The majority of shrubs and woody plants did not survive because of lack of water and being damaged by wildlife. By the next growing season in the spring 1988, the native grasses became well established. Deer used the area, as well as many smaller mammals, and a variety of birds could be found on the study site including large coveys of quail.

The tributary on the south, running from the wetland to the east, had a pH of 5.4 and was clear during periods of



high precipitation but was yellow during periods of low precipitation. The tributary draining the south side of the study area starts as overflow from Razor Pit and flows east. Continuing east, it receives runoff from the south side of the recontoured gob pile and from the naturally revegetated portion of the Monahan site on the east end of the study area. The tributary then turns north and travels approximately 1000 feet to meet with the tributary which drains the north side of the Monahan site. The tributary on the north side starts at the base of the reclaimed gob pile, beginning as a seep, and also flows east. Water from the tile drainage system is added to the tributary as well as surface water from the study area itself and from the field across the road north of the study area at sample site CU. There is also an intermittent tributary draining the old slurry pond area on the east fourth of the property which would affect site N4.

Prior to reclamation the Monahan site belonged to William J. Reals M.D. of Wichita, Kansas. The site had been owned by his wife's father, Francis A. Monahan, whom at one time had interest in the coal mining business. On December 30, 1986 the ownership of the study site changed from Dr. Reals to Pittsburg State University. The site was a joint project between the University and the Crawford County Conservation District to be used for outdoor education. Eventually a nature center will be built on the Monahan, but

until that time the site is used for day camps, nature hikes and other learning experiences.

#### A. Site Selection

Eight sites were chosen to collect data for water quality analysis (Figure 1).

Site N1 is at the base of the existing sand covered grass pile on the north side of the Monahan site.

Site TP is the outlet from the tile drainage system.

Site N2 is east of the drainage tile outlet.

Site CV is at the mouth of a culvert, under the east-west county road, as the water enters the Monahan site. The culvert drains the field north of the site into the tributary on site.

Site N3 is one of the constructed weirs. This site combines water from Site CV, the field, and sites above N2.

Site N4 is another weir located east and downstream from Site N3.

Site ST is also a weir, located on the tributary draining the south side of the Monahan site.

Site N5 is located on the County road off the project area to the east of the Monahan site. Samples were collected at the end of a culvert running under the road. Site N5 combines all of the surface drainage from the study area, plus the drainage from a small area east of the Monahan site.

## CHAPTER V

### MATERIALS AND METHODS

#### A. Site Selection

Eight sites were chosen to collect data for water quality analysis (Figure 4).

Site N1 is at the toe of the resloped and covered gob pile on the north edge of the Monahan site.

Site TD is the outlet from the tile drainage system.

Site N2 is east of the drainage tile outlet.

Site CU is at the mouth of a culvert, under the east-west county road, as the water enters the Monahan site. The culvert drains the field north of the site into the tributary on site.

Site N3 is one of the constructed weirs. This site combines water from Site CU, the field, and sites above N2.

Site N4 is another weir located east and downstream from Site N3.

Site ST is also a weir, located on the tributary draining the south side of the Monahan site.

Site N5 is located on the County road off the project area to the east of the Monahan site. Samples were collected at the end of a culvert running under the road. Site N5 combines all of the surface drainage from the study area, plus the drainage from a small area east of the Monahan site.

## B. Weir Construction and Flow Measurement

Monitoring stream flow provides a better understanding of the downstream impact that the acid mine drainage might be causing. Flow was measured at 5 of the 8 sampling sites. Sites N2 and N5 are culverts and use of a flow meter helped determine volume of flow through these culverts. Later, pre-calculated charts were used (Appendix A). Sites N3, N4 and ST are weirs, which had to be constructed across the stream beds. The location of the weirs was chosen after considering the watershed of the property.

The first step in constructing the weirs was making cross-sections of the stream bed at the three designated sites. After cross-sections were made the designs were drawn. Railroad ties were used for the construction of the weirs. The ties were 8 inches x 10 inches in width and height. The bottom tie was placed in the stream so that only one to two inches were exposed. A second tie was notched in the middle to a 45 degree angle and placed on the bottom tie, then a third tie was placed on the second with a much wider area left open for water flow. The railroad ties were secured to each other with rebar (Appendix A).

A rain gauge was placed behind the house trailer on the west side of the Monahan site. This rain gauge, along with information from the university physical plant, provided a record of precipitation for the duration the project.

water can also affect stream flow by limiting numbers of

### C. Sampling Design and Water Quality Analysis

Each site was sampled for water quality every two weeks from June 1990 to Nov. 1990. Thereafter, they were sampled when precipitation was sufficient, through November of 1991. Duplicate samples were collected.

Water samples were analyzed for pH, conductivity, alkalinity, hardness, iron and sulfates. Usually pH and conductivity were taken at the time of collection. If the remaining tests could not be performed immediately, the samples were refrigerated for no longer than 24 hours. pH was measured using a Fisher pH meter model 150. Low pH is one of the first indications of acid mine drainage. As the history of the Monahan project reveals, the material underlying the gentle sloping hill consists of a large amount of pyrite. When pyrite is exposed to oxygen in air or water it releases sulfuric acid ( $H_2SO_4$ ). This release of sulfuric acid along with the further oxidation of iron, decreases the pH of any contacting waters (Marcher et al. 1984).

Conductivity was measured with a Fisher Conductivity Meter, model #152. Measuring conductivity is a short-cut to measuring total dissolved solids (TDS). Specific conductivity indicates the degree of mineralization in water, thus giving evidence that sulfates, iron and other mineral contents are high. The total dissolved solids in water can also affect stream biota by limiting numbers of

organisms as well as diversity of organisms (EPA 1976).

Total iron was measured using the Hach 1,10-Phenanthroline method. Measuring total iron is another good indicator of acid mine drainage. Iron comes from the weathering of the pyrites that were disturbed during mining. In the presence of oxygen, iron from acid mine drainage can form precipitates in the form of  $\text{Fe}(\text{OH})_3$  yellowboy, or  $\text{Fe}_2\text{O}_3$  which gives the red color to many streams. Both of these compounds can form gels or flocs that may cover the gills of fish and therefore be detrimental to them and other aquatic life (EPA 1976).

Sulfate was measured using the Hach turbidimetric method. This uses barium chloride, which when added to the sulfate ion forms barium sulfate crystals that can be measured for light absorbance.

Sulfate is the best indicator of acid mine drainage in the area (Marcher et al. 1984). The source of sulfate is the oxidation of pyrite,  $\text{FeS}_2$ , to sulfuric acid. Concentrations of sulfate are greatest during low flow, when contact time with spoil has been fairly long, and the water draining from spoil material may constitute a greater part of the flow. Concentrations are less during high flow when contact time is short and dilution occurs (Marcher et al. 1984). The EPA's recommended limit for sulfate concentration is 250 milligrams per liter in water intended for human consumption (Marcher et al. 1984).

Alkalinity was measured using Standard Methods #403 (ASTM 1985). Alkalinity of water is a measurement of the quantity and kinds of compounds that shift pH to the alkaline side, or in other words, its buffering capacity. It is expressed as milligrams of  $\text{CaCO}_3/\text{L}$  (Wetzel 1983). Alkalinity is important to freshwater life because it buffers pH changes that occur naturally. Components of alkalinity such as carbonate and bicarbonate will complex some heavy metals and reduce their toxicity (EPA 1976).

During the data collecting period, the pH was lower than 4.5. At this low pH, it is difficult to get a color change in the alkalinity test, because the indicator used was to be titrated to 4.5. Therefore, few readings of alkalinity were recorded.

Total hardness was measured by the EDTA titration method #314B, Standard Methods (ASTM 1985). Waters which contain polyvalent metals and require large amounts of soap to lather, or upon evaporation form a deposit are referred to as being hard (Wetzel 1983). In most fresh water, hardness is caused by calcium and magnesium ions, although, iron and manganese can contribute to an appreciable extent (EPA 1976). The effects of hardness on fresh water aquatic life seem to be related to the ions that cause the hardness and not to the hardness itself (EPA 1976). Because of low pH and high iron interference the EDTA titration method did not always give results.

## CHAPTER VI

### RESULTS AND DISCUSSION

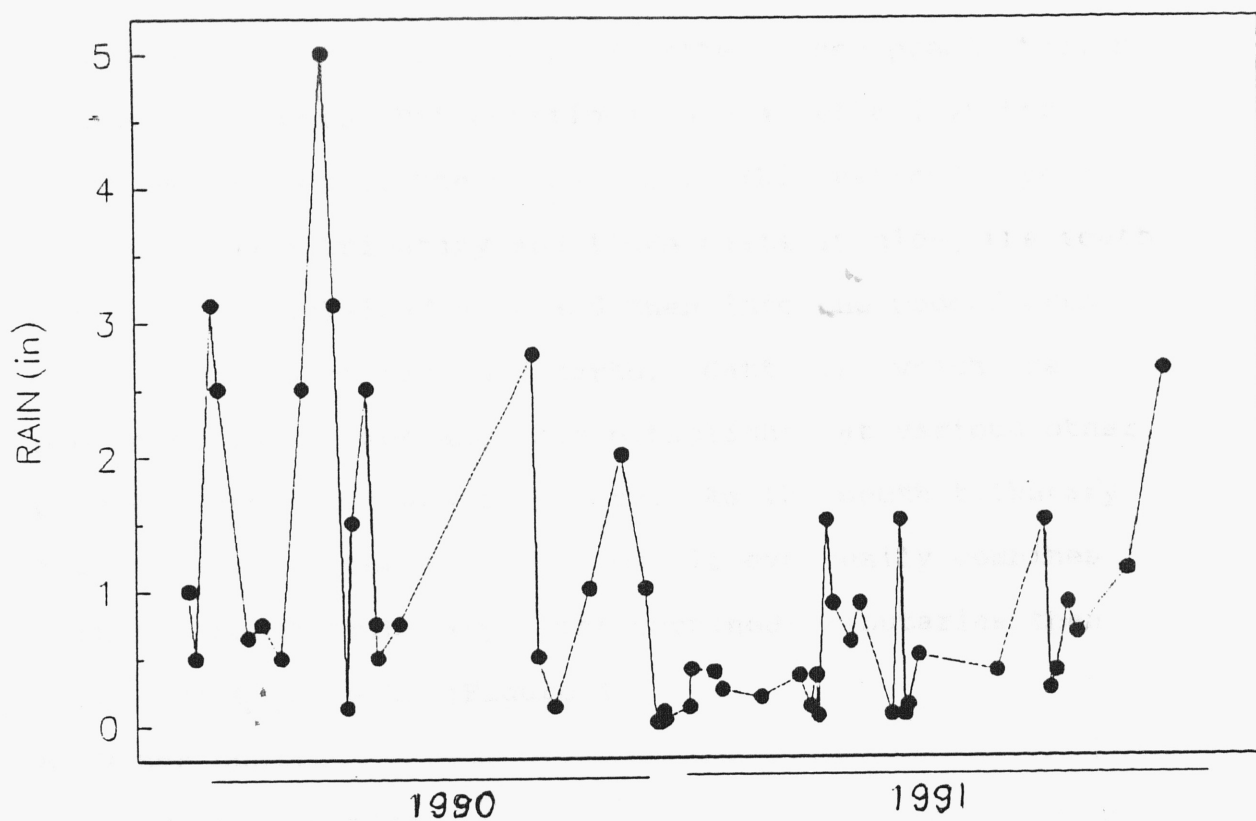
#### A. Hydrology

Average annual rainfall for the study area is 42 inches (Marcher et al. 1984). Rainfall from October 6, 1990 to November 17, 1991 was 32.6 inches, which was 30% below the average rainfall. The weirs were completed at the end of October 1990, but lack of rain (Figure 5) hampered the accumulation of substantial flow data at the weirs and at the culvert site CU (Appendix B).

The weir at site ST was 15 feet long and every time it rained the water washed under the bottom railroad tie. Attempts were made to correct this problem, but they were unsuccessful. Therefore, no data was collected at site ST. There was never enough flow at site CU to collect any data and only enough flow for one reading at site N3. Four readings were collected at site N4. Flow data had been collected for culvert site N5 a number of times before the weirs were installed. Drainage at site N5 is a combination of water draining the Monahan Project with a few acres of water draining from the property directly east of the study site. Between March and mid-June of 1990, the area received about 20 inches of precipitation, which is about average spring rainfall. Discharge from the culvert at site N5, was the greatest on June 21, 1990, and Oct. 16, 1990. On both dates the reading was 3.7 cfs.



Figure 5. Precipitation



Site N1, at the foot of the gob pile, is the beginning of the north tributary. Site N1 had water in it even in dry periods during which site N2 and N3 had no water. This would indicate that the seep mentioned in the geology report had reestablished itself.

The south tributary collects surface water drainage from the south side of the study site. When precipitation is abundant, Razor Pit overflows into a wetland at the southwest corner of the study area. This wetland tapers into the south tributary and flows easterly along the south side of the reclaimed area and then into the wooded area where it meanders east and north. Cattails, which are prominent in the wetland, are established at various other places along the south tributary. As the south tributary takes a more northerly direction, it eventually combines with the north tributary. The combined tributaries then flow east to site 5N (Figure 4).

## B. Water Quality

### 1. Overall pattern

Table 1 lists the mean of pH, conductivity, iron, and sulfates for all eight sites. The mean pH ranged from 3.0 to 3.5 in the north drainage tributary at the Monahan project site. The south tributary had a mean pH of 5.3 and at the off-site discharge site N5, the mean pH was 4.7. This data suggests that because of low precipitation during

the sampling period the only dilution to the off site water was from the south drainage of the Monahan. Conductivity data followed the same pattern. At site N1 the mean was 8005 umhos/cm, and sites TD through N3 ranged from 4154 umhos/cm to 5178 umhos/cm. Site N4 had a mean conductivity of 3243 umhos/cm, while the south trib and off project sites were in the 2000's.

Sulfates again were highest at site N1 having a mean of 4139 mg/l. The other sites on the north side ranged from 1552 mg/l to 3697 mg/l. The south tributary site ST, had a mean of 1030 mg/l and the off-site point N5, 756 mg/l. Water in the drainage on the north side was in contact with acid forming materials and because there was little flow the contact was for a longer period of time than normal. This raised the amount of sulfates in the water.

Iron was highest at site N4, 191 mg/l and ranged from 74 mg/l to 134 mg/l on the other north side sites. Iron had a higher mean at N4 because the site was added, so there fewer samples taken there, and it was at a time of extremely low precipitation. The south trib had a mean iron reading lower than the off-site point, these were 11 mg/l and 12 mg/l respectively. Again the south tributary diluted the water off-site to a better quality than it would otherwise be.

At times of moderately high to high rainfall there is an intermittent stream that flows into the north drainage

tributary before it reaches site N4. At first glance, it might be thought that there was influence from the old slurry that further degraded the north tributary. However, there had been below normal rainfall after the site N4 had been added to the sampling points and the intermittent stream was not flowing. The reason that the pH was lower and the iron and sulfates higher must be do to longer contact time with the acid forming materials and a greater concentration of the iron and sulfates because of lack of dilution from surface runoff. On the other hand, water from the south tributary is helping to dilute the water in the north tributary and enhances the water quality of the water discharging off-site.

In reviewing the means for each site it is evident that there are still water quality problems at the Monahan site. Disturbance of the land by reclamation temporarily increases sedimentation which in turn raises the conductivity and concentrations of iron and sulfate in the surface water. Most of these increases reach maximum level during the period immediately following reclamation. As vegetation becomes established and the land surface reaches equilibrium, these levels should decrease towards pre-mine conditions (Clemens Coal Co. 1993).

Data collected five and six years after the completion of reclamation should reflect these improved conditions. As the land surface settles and the soil compacts there is less

pore space for water and air to collect in and the vegetation cover should be aiding in erosion and sedimentation control. If the reclamation was successful there would be a decrease in conductivity and in the iron and sulfate content of the surface water.

Table 2 is a list of pH readings from samples collected during the preliminary study of the project site. These pre-reclamation collection sites correlate to some of the same locations as data taken for this research. The post-reclamation data shows little change from the pre-reclamation pH readings. Again, this data verifies continuing water quality problems on the project site.

Sulfates									
mean	4139	3845	3021	1835	2552	509	1040	725	
(mg/l)	12	11	9	5	11	4	12	10	
SE	1132	1071	754	454	660	1342	350	303	
-----									
Iron									
mean	334	34	34	103	25	101	12	22	
(mg/l)	12	12	9	12	11	4	11	10	
SE	46.1	34.5	45.1	32.3	24.2	31.5	4.2	4	
-----									

Table I. Summary of Water Quality Data

Parameter	N1	TD	N2	CU	N3	N4	ST	N5
pH	mean 3.1	3.2	3.5	3.3	3.4	3.0	5.3	4.7
(standard N	13	12	7	11	11	4	11	11
units)	SE 0.21	0.27	0.33	0.32	0.33	0.18	0.23	0.44
Conduct.	mean 8005	4803	4154	5178	4868	3243	2413	2025
(umhos)	N 11	11	7	10	10	4	11	11
/cm)	SE 1915	1493	1679	1416	1351	1699	382	444
Sulfates	mean 4139	2865	3527	1635	1552	3697	1030	756
(mg/l)	N 12	12	6	11	11	4	11	11
	SE 1122	1075	1916	358	360	1682	350	308
Iron	mean 134	77	154	103	75	191	11	12
(mg/l)	N 12	11	6	11	11	4	11	10
	SE 46.1	24.5	65.1	32.1	24.3	53.5	4.1	6

Table II. Pre/Post-reclamation Data

<u>Pre-Reclamation #s</u>	<u>Pre pH</u>	<u>Post-Reclamation #s</u>	<u>Post pH</u>
11	6.8	Razor Pit	
10	2.2	Top of Gob Pile	
8	2.7	N1 Seep	3.1
6	2.3	CU Culvert	3.5
7	3.0	ST South Trib.	5.3
5	2.5		-
4	7.0	N5 Site	4.7

## 2. Selected Site-specific pattern

N1: The first pH collected at site N1 was 5.2. This was the highest reading at this site for the duration of the project (Figure 6). The higher pH was probably a result of surface water dilution. Another slightly higher reading was on Jan. 31, 1991 (Figure 6). This was most likely due to the low temperature inhibiting bacterial growth. A temperature of between 22 and 25 degrees Celsius is required for maximum growth of the iron-loving bacteria, Thiobacillus ferrooxidans (ASTM 1985).

Conductivity at site N1 kept going up until it peaked in March of 1991 and then went down somewhat the last three samplings (Figure 6). Readings of both sulfates and iron kept getting higher and higher throughout the duration of the project (Figure 7). There was too much iron interference to get hardness or alkalinity readings.

SITE TD: This is the tile outlet drain. When water was flowing from the drain pipe the water samples were collected directly from the pipe. However, most of the samples were collected from the pool directly under the drain pipe because of little precipitation during the study period. Overall the site has low pH, high conductivity, and a high sulfate and iron content (Figures 8 and 9). One sample, collected from the drain pipe itself in Nov. 1991, had a pH of 4.5. Although still low, it is considerably higher than



the average pH of 3.2 at site TD. The drainage system is probably keeping water from prolonged exposure with the acid forming materials. However, there is still a high sulfate and high iron content which could be caused by high sedimentation (Figure 9). When there was no flow from the outlet pipe itself and the samples were collected from the pool beneath the pipe, there was prolonged exposure to acid forming materials and no dilution from surface runoff water. Overall at site TD the conductivity, iron, and sulfates were lower than at site N1 or site N2.

Figure 6. pH and Conductivity at Site N1

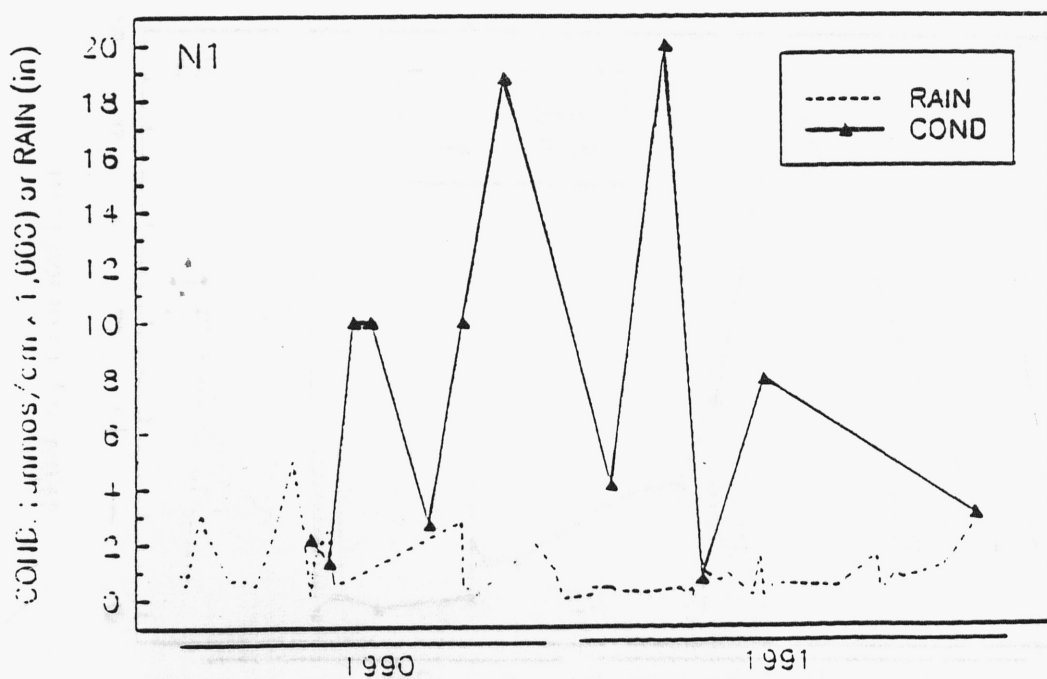
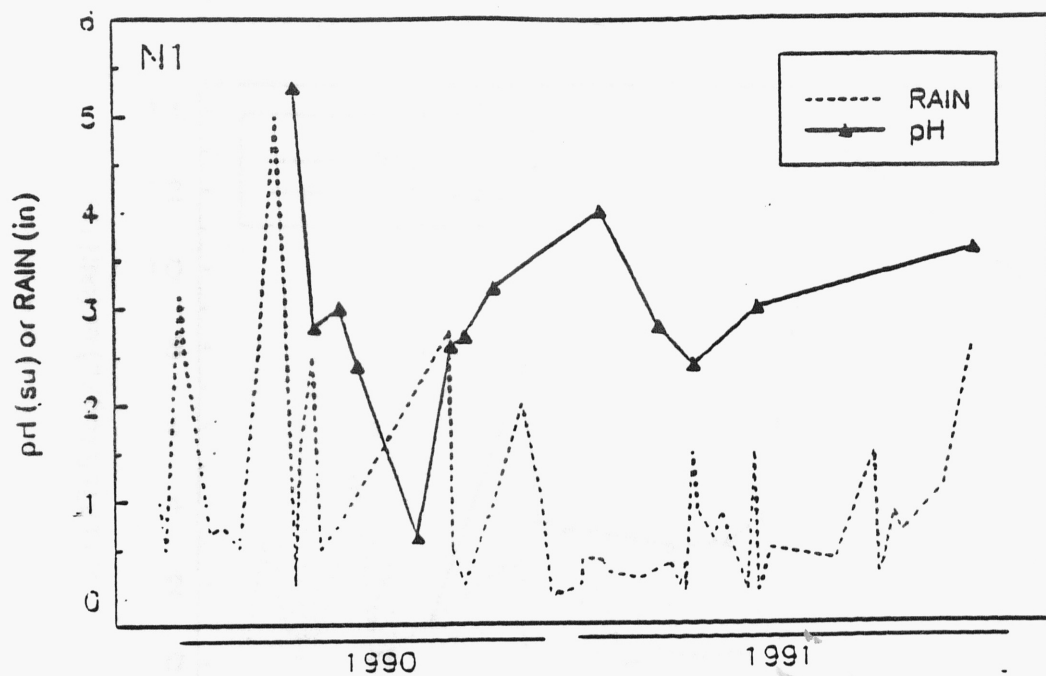


Figure 7. Sulfates and Iron at Site N1

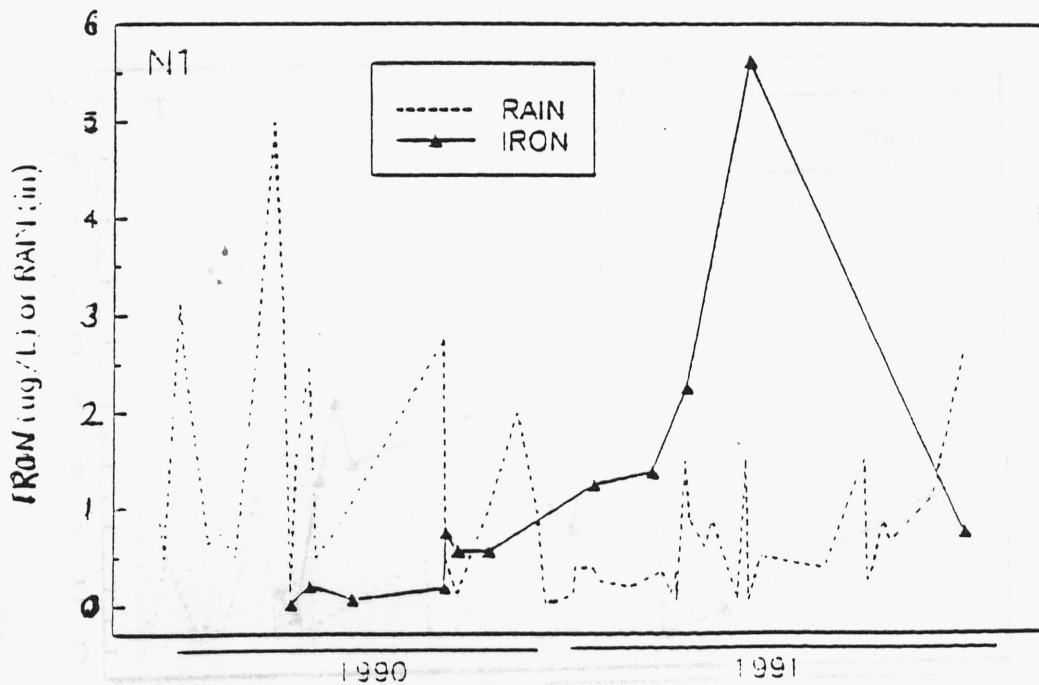
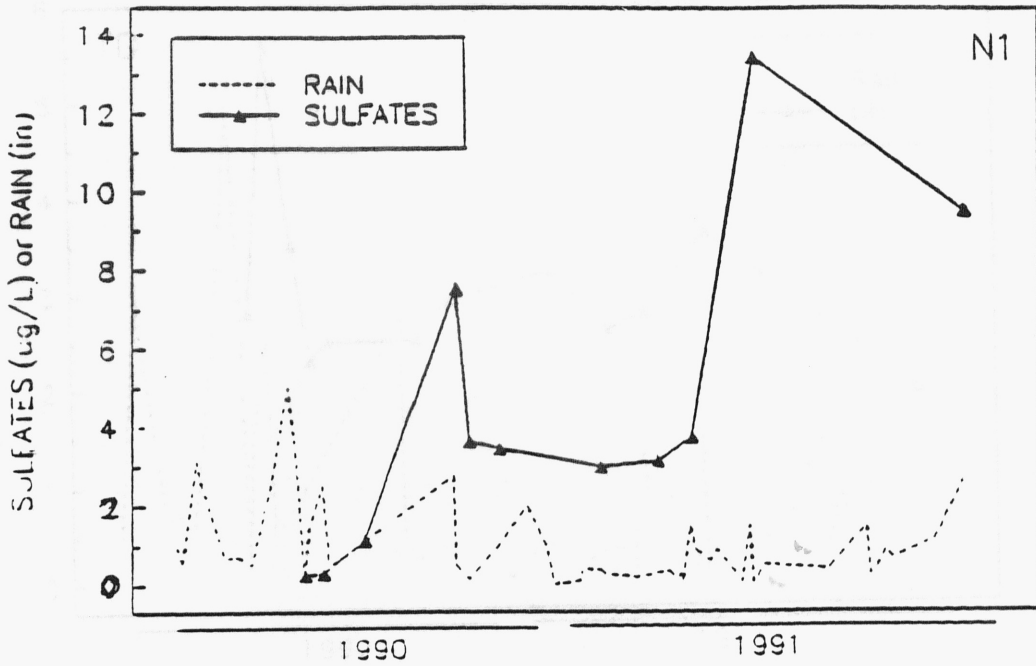


Figure 8. pH and Conductivity at Site TD

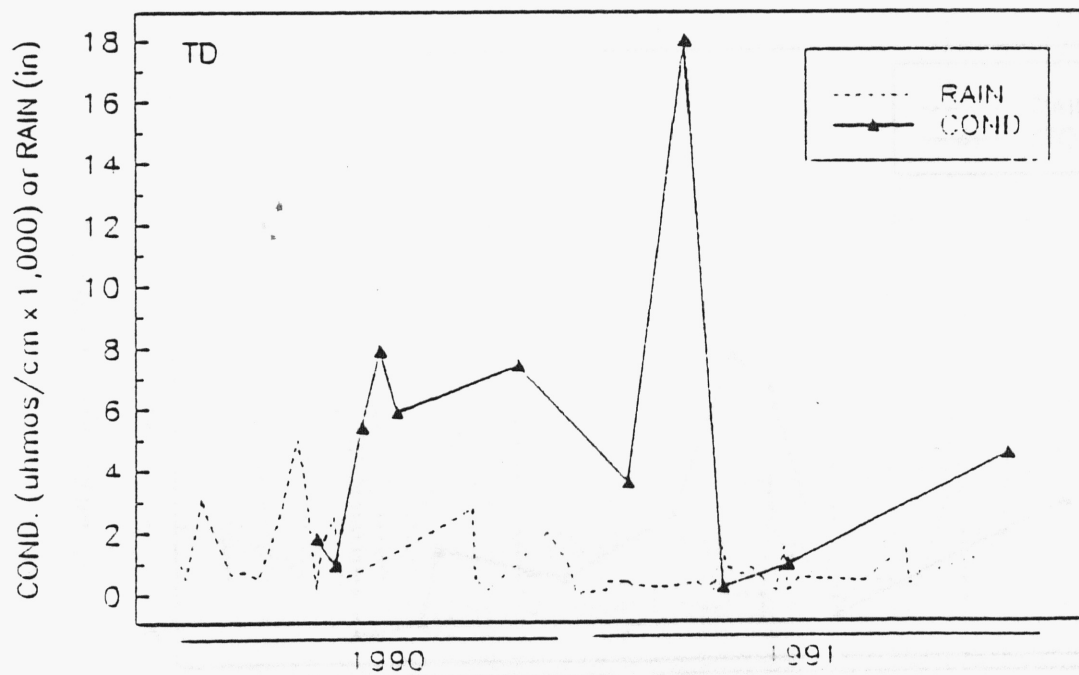
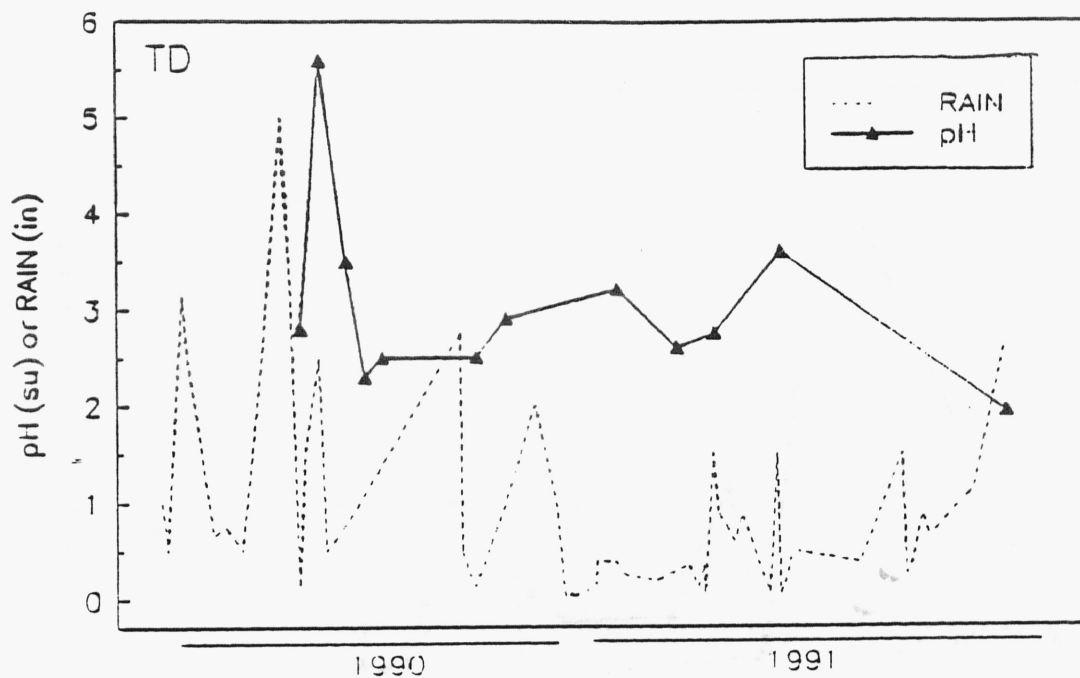
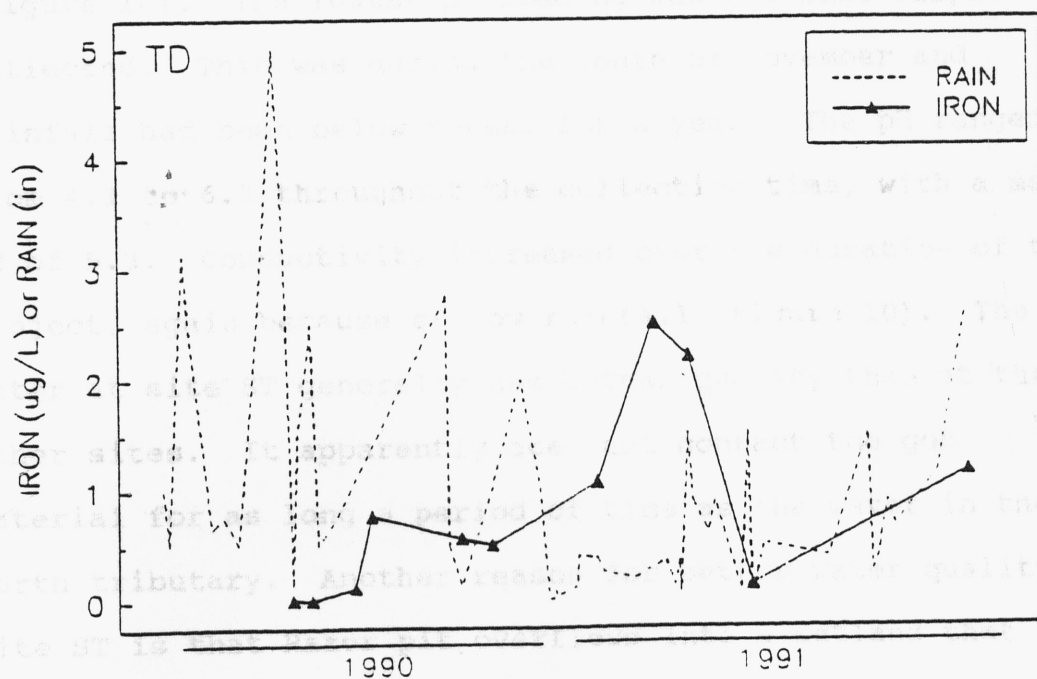
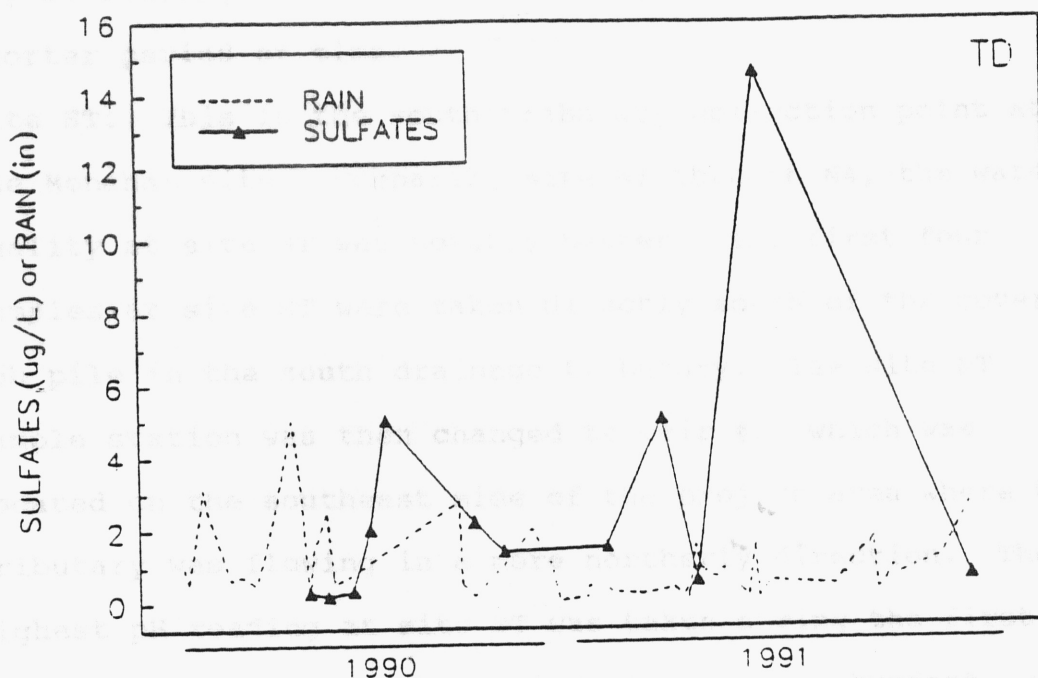


Figure 9. Sulfates and Iron at Site TD



This may be due to the drainage system catching enough surface water to dilute the water in the pool, or the water may be staying in contact with the gob material for a shorter period of time.

**Site ST:** This is the south tributary collection point at the Monahan site. Comparing site N1 through N4, the water quality at site ST was notably better. The first four samples at site ST were taken directly south of the covered gob pile in the south drainage tributary. The site ST sample station was then changed to weir #3, which was located on the southeast side of the project area where the tributary was flowing in a more northerly direction. The highest pH reading at site ST was taken during the first two months of the project when rainfall was more abundant (Figure 10). The lowest pH reading was the last sample collected. This was during the month of November and rainfall had been below normal for a year. The pH ranged from 4.1 to 6.3 throughout the collection time, with a mean pH of 5.3. Conductivity increased over the duration of the project, again because of low rainfall (Figure 10). The water at site ST generally has better quality than at the other sites. It apparently does not contact the gob material for as long a period of time as the water in the north tributary. Another reason for better water quality at site ST is that Razor pit overflows into a wetland that tapers into the south drainage tributary. Cattails present

in the wetland and in some areas along the south tributary take up iron and manganese into their tissue, which helps to enhance the water quality. Although the sulfate and iron content was too high to meet EPA "Quality Criteria for Water" (1976) standards, the data collected at site ST was showed better water quality than at the other sample sites (Figure 11).

**SITE N5:** The first five samples collected at site N5 had a pH ranging from 5 to 7 (Figure 12). The sulfate and iron readings were also lowest at these collection times which was during average precipitation (Figure 12 and 13).

Figure 10. pH and Conductivity at Site ST

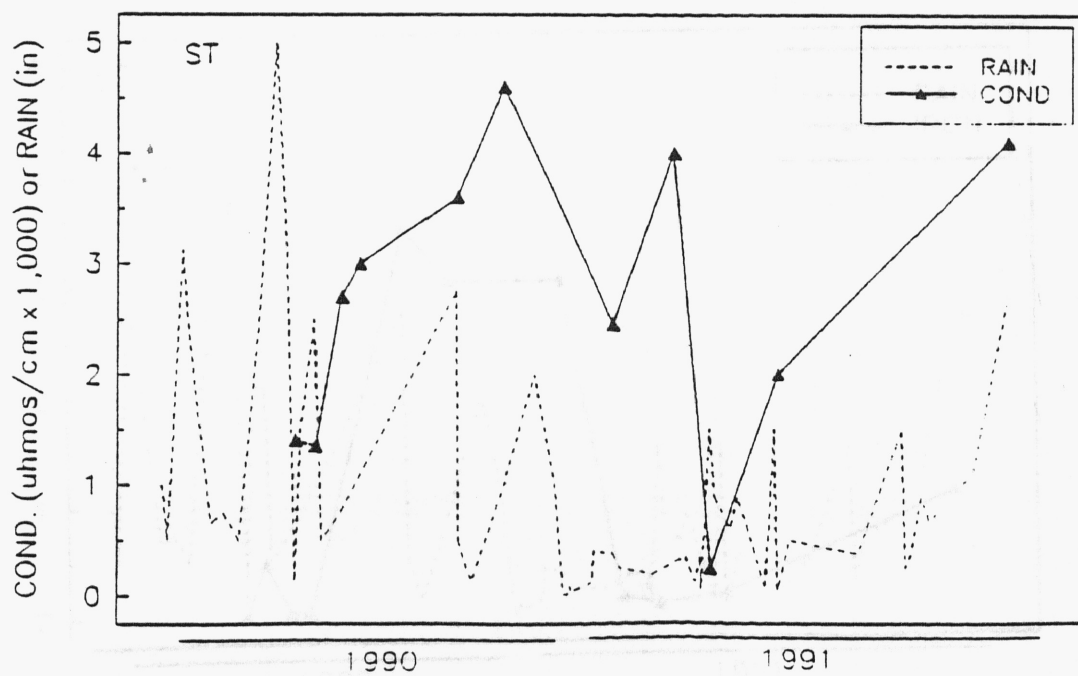
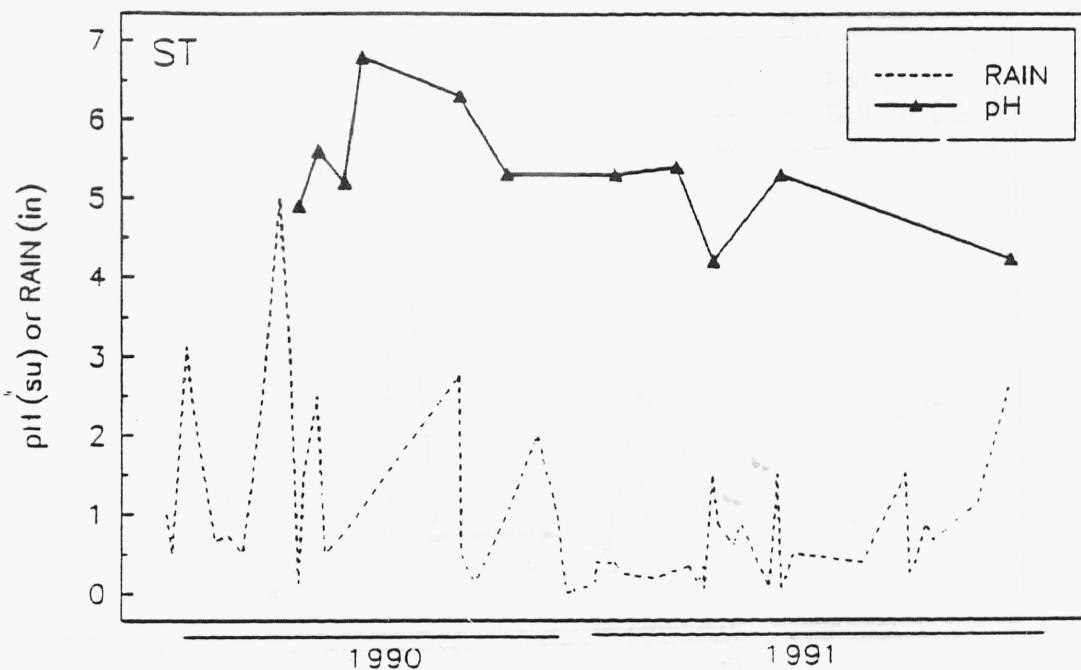




Figure 11. Sulfates and Iron at Site ST

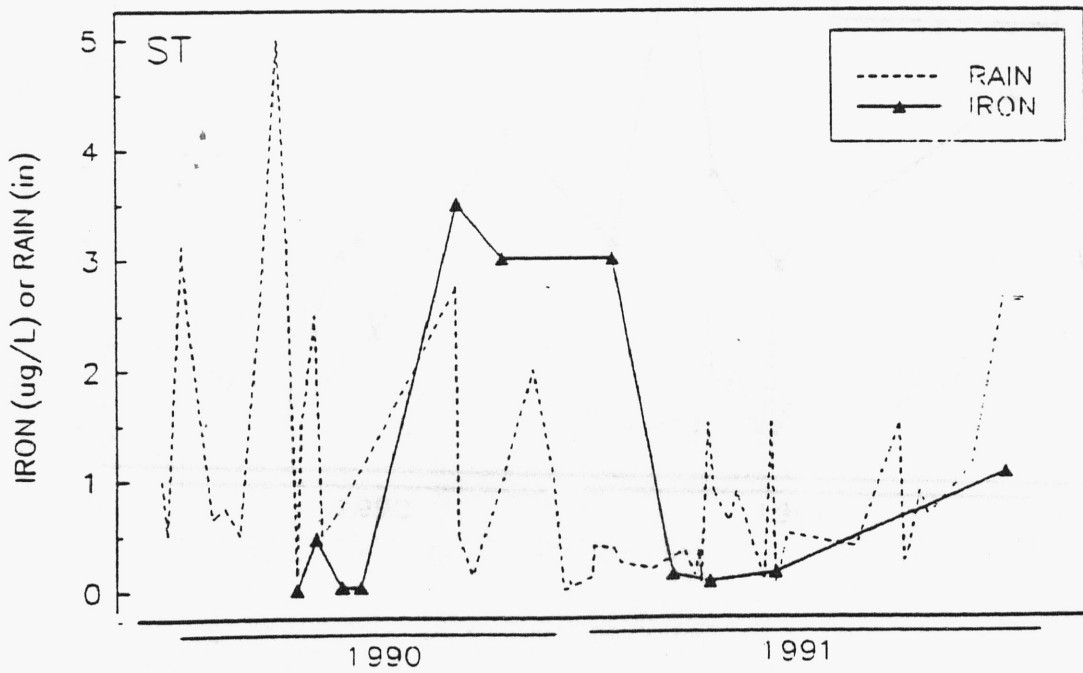
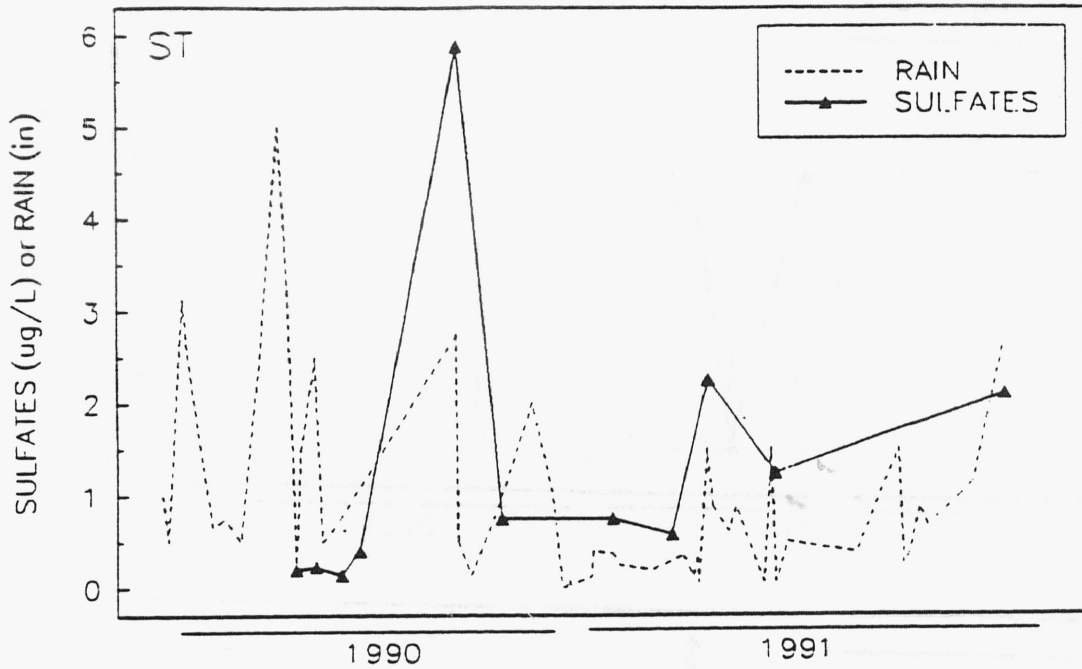


Figure 12. pH and Conductivity at Site N5

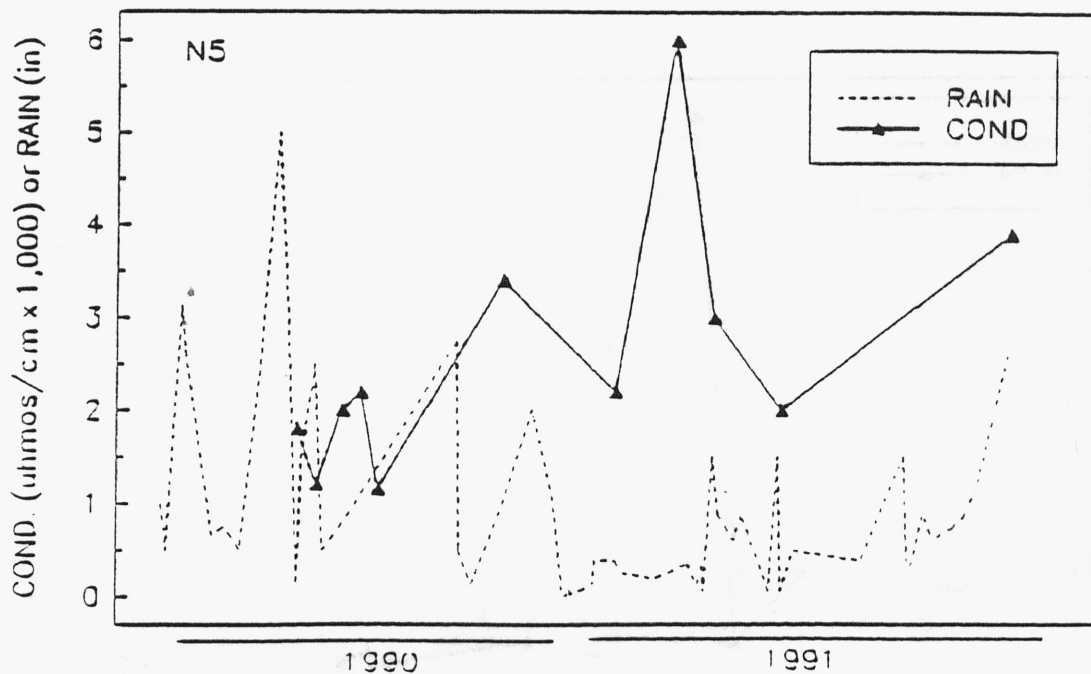
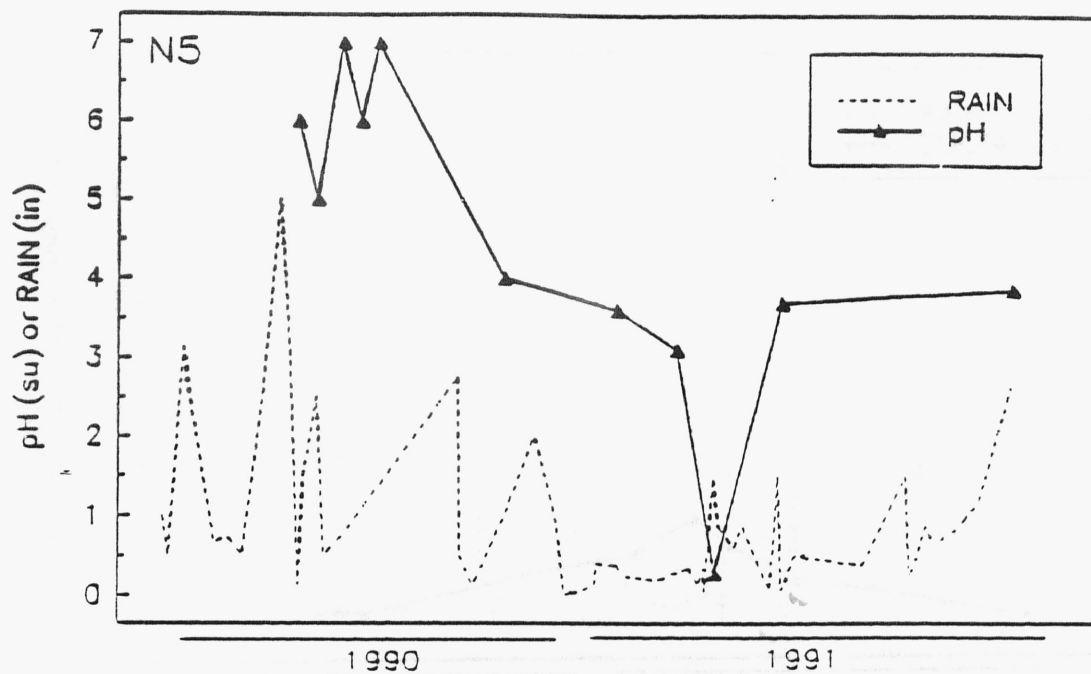
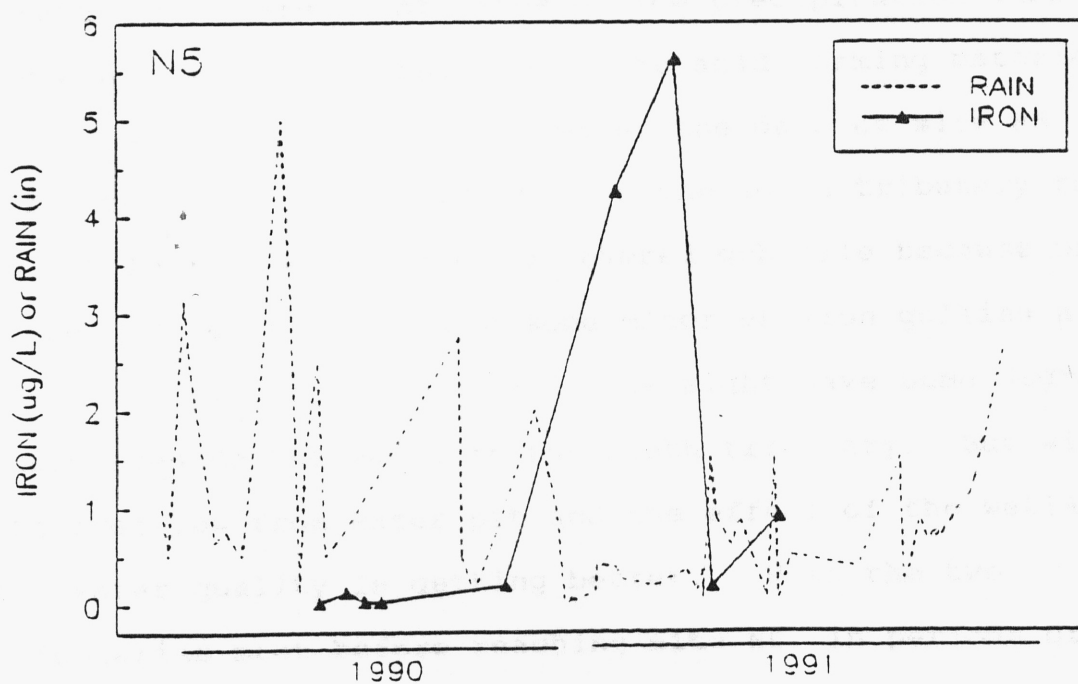
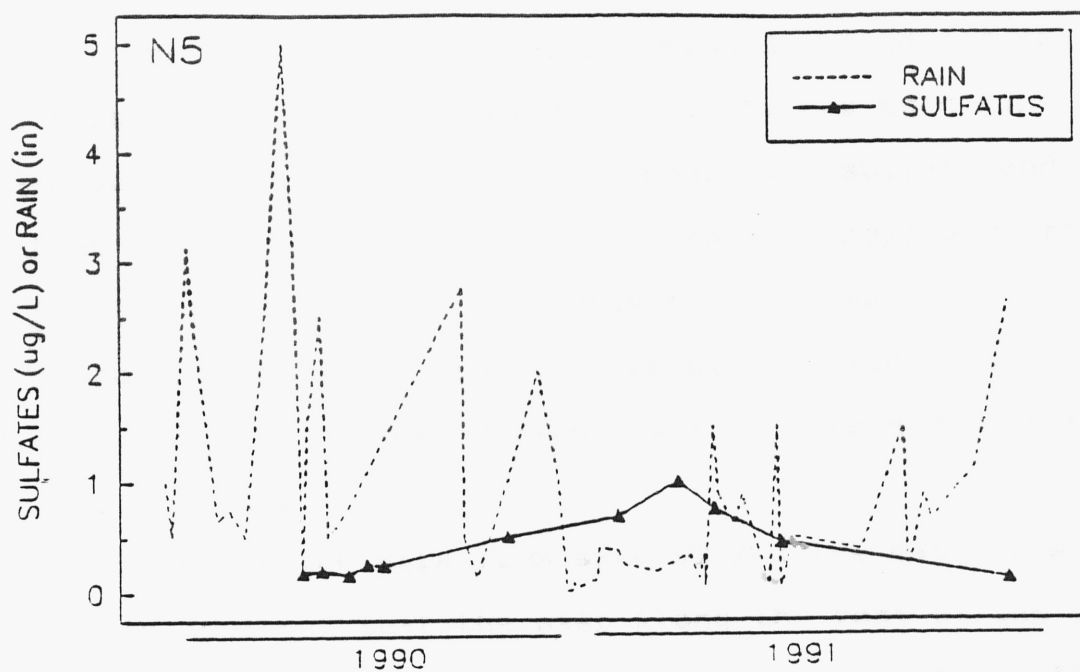


Figure 13. Sulfates and Iron at Site N5



During high flow the readings were closer to standard, sulfate in the 200 mg/L to 250 mg/L range, and iron between 0.1 mg/L to 1.3 mg/L. As precipitation declined and there was little surface runoff water to dilute the acid mine drainage, water quality also declined. The sulfate and iron content rose, sulfate going as high as 3875 mg/L and iron up to 56 mg/L (Figure 13). Conductivity at N5 was also influenced by dilution from surface waters (Figure 12). Conductivity was highest during low flow when sedimentation was concentrated.

Looking at the data from site ST and the data from site N5, it is apparent that the seep along the foot of the gob pile has a significant effect on the water quality on the Monahan study area. At times of low precipitation when there was prolonged exposure to the acid forming materials and no dilution from surface water the data at site N5 reflected poor water quality. On the south tributary there is little influence from the covered gob pile because of the slope. However, there are some minor erosion gullies along the south side of the gob and this might have some degrading influences on the water in the south tributary. But with the overflow from Razor pit and the effect of the wetland the water quality is getting better. When the two tributaries meet before reaching site N5, in periods of low or no surface runoff, then the influence from the north tributary degrades the quality of the water leaving site N5.

According to the EPA's "Quality Criteria for Water" (1976), 1.0 mg/L of iron is the maximum for freshwater aquatic life, and sulfates should be 250 mg/L or less. When there was not enough precipitation to allow for surface runoff, the influence of the water from the seeps on the Monahan degraded the quality of the water which flowed from the culvert, Site N5, toward Brush Creek.

### C. Physical Integrity

In the preliminary study, acid mine drainage was the prevalent problem existing at the Monahan Site. Because of the amount and nature of the gob present at the Monahan Site, care needed to be taken to use the most appropriate reclamation techniques. New reclamation techniques, dealing with the abatement of acid mine drainage are being tried continuously. After considering different methods of reclamation, the plan accepted for the specific problems present at the Monahan Site was to reduce the slope of the gob pile from a 1.5:1 slope to a 3:1 slope, cover the gob with some of the revegetated spoil located on site, and install a tile drainage system.

It was expected that the physical disturbance of the gob pile would hinder improvement of the water quality for a short time following reclamation (USDA 1981a). It was further expected that improvement of water quality would come with the compaction, settling, covering, and

revegetation of the gob pile. This along with the tile drainage system should have kept surface water away from the acid forming materials. As it was, reclamation had been completed for five years at the start of this project, and it was evident that seeps were reforming on the north side of the Monahan as the drainage ditch re-established itself.

Many of the goals set to be accomplished by the reclamation of the Monahan Site have been met. There are no longer any dangerous embankments or unstable slopes. The small acid pits are gone and aesthetically the Monahan looks like a well maintained prairie. Yet the data collected shows little improvement in the quality of the water on or directly off site. Where the acid mine drainage is originating and how to remediate it is the issue to be discussed.

As reported by Vickers (1989), the initial growth of grasses and forbes on the Monahan Site was good. However, if individual plants in each of the grids was counted, the percent of ground covered was low. This means that the erosion control and sod forming capability of the plants was minimal. The terrace/tile drainage system, installed during reclamation is keeping some of the surface water away from the pyritic materials found in the gob pile. Nevertheless, seasonal weather conditions and lack of vegetation establishment has allowed erosion gullies to form on the top and on the sides of the cap covering the gob. This means

that much of the surface water is entering the gob pile through infiltration of the erosion gullies.

Another source of water available for recharging the system may come from below. Not mentioned in the assessment, but written in the USDA Geology report (1981b), was the fact that a perched water table existed under the old slurry pond and the gob pile. Because the less consolidated gob sits on top of unmined ground, conditions are right for a build-up of a slight water mound, or perched water table, under the gob pile. Freeze and Sherry (1979) explain that such a water mound would cause an artificial recharge to take place in a horizontal, unconfined aquifer, bounded at the base by an impermeable formation. The impermeable formation in this case would be the unmined ground on which the gob pile sits. According to the report, the water table over the site area ranged from less than a foot below ground level to about five feet below ground level. This high water table can rise into the gob through capillary action (Foth 1984) and then ooze out at the seep. This artificial aquifer could be recharged by the infiltrating surface waters, from the strip pit lakes in the area, or from the slope of adjacent land. Once the aquifer is to its full capacity the water finds the path of least resistance and moves to the foot of the slope.

Whatever the source of water coming into contact with the gob pile, there is oxygen affiliated with it. And this

oxygen reacts with the pyritic material to become acid mine drainage. All vegetation in the path of the acid mine drainage is a target for destruction. It is not uncommon under these conditions to see whole sides of slopes with dying vegetation (Leonard Imhof 1991). This can happen as the seeps seal and acid mine drainage finds another path or opening further up slope. As the surrounding ground becomes saturated with acid mine drainage the vegetation dies from toxic conditions. While the loss of moisture through evapotranspiration is decreased in one part of the area because of dying vegetation, saturation increases its boundaries and effects more vegetation. This is what is occurring on the north side of the study area.



## CHAPTER VII

### Conclusions

The water quality at the Monahan site has not improved, and the water leaving the site can still have a negative impact on the tributary which subsequently flows into Brush Creek.

While it is true that many of the original structural and physical problems leading to the reclamation of the Monahan Site have been corrected, other problems persist. The vegetation has little chance to survive if the seep is not remediated and the breaks in the cap of the gob pile are not addressed. As the vegetation dies and erosion continues, improved water quality will not be attained and site failure will occur.

A management plan is necessary for the long term success of the Monahan Reclamation Project. First, the water issuing from the seep and surface water flowing in the tributaries should be treated to improve the water quality leaving the study site. Secondly, a goal for optimum plant growth, on the top and on the slopes of the gob pile, will keep erosion to a minimum and cut back on the amount of surface water that contacts the underlying gob.

## CHAPTER VIII

### RECOMMENDATIONS

Appendix D presents a discussion on acid mine drainage abatements tried at various other project sites. Incorporating some of these treatments with other recommendations, led to three possible approaches to correcting the acid mine drainage on the north side of the Monahan Site.

Solution #1. A bentonite clay trench with a wetland. A trench 6" x 4' would be placed ten feet south of the existing tributary on the north side of the Monahan Site. This trench would start at the northwest end of the gob pile in the ditch, run parallel to it and end in a wetland located east of the gob pile along the existing berm. The property was surveyed for elevations to support this plan. It was found that the grade is sufficient to carry the surface water to the wetland (Figure 14). The trench would be lined with bentonite. Bentonite is a clay that has high colloidal properties (Thrush 1990), which means the clay can absorb large amounts of water accompanied by an increase of about 36 times its volume (American Colloid Co. 1991). With the absorption of water, bentonite becomes jell-like and creates a barrier (Thrush 1990), which will not allow additional water to move through it. The trench can then direct water into the wetland, where it will come into contact with cattails and can be treated with lime if

necessary.

**Solution #2. Additional drainage system.** A trench would be dug along the foot of the gob pile on the north side (Figure 15). The trench lined with stone aggregate would house a



Figure 14. Option 1 Map

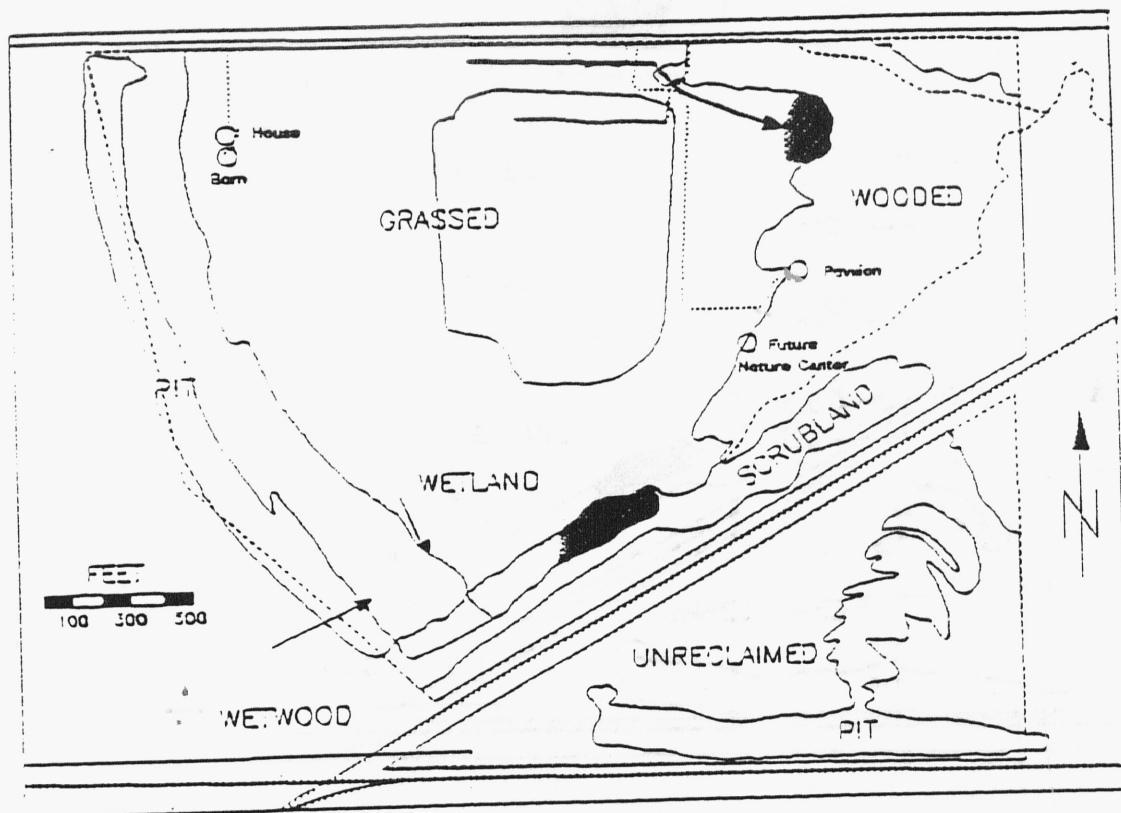
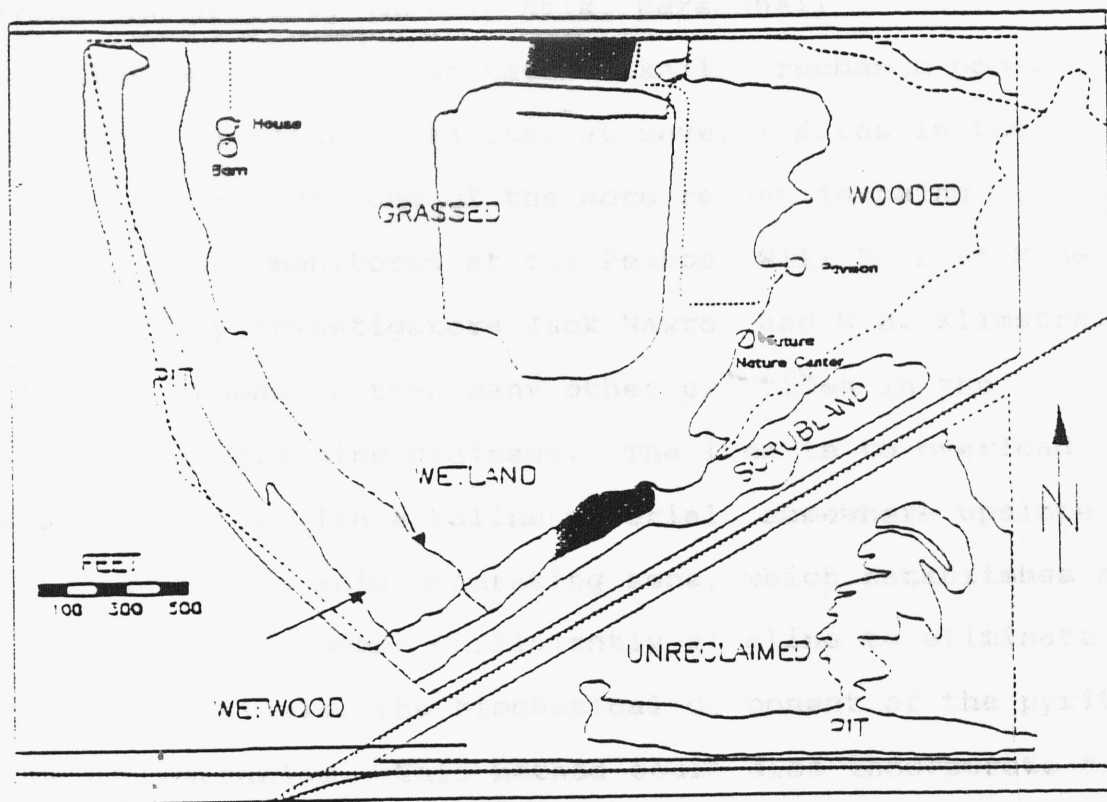


Figure 15. Option 2 Map



perforated pipe. Four other rock lined trenches would connect in a T fashion, housing four plain pipes attached to the perforated pipe. These would extend to the existing drainage ditch, by-passing the vegetation on the slope. The water can then be treated in the existing tributary before leaving the property (Murray Balk, personnel)

**Solution #3. Concentrated alkaline recharge pool.**  
This method is being researched at several sites in the eastern coal region, one of the more recent is being implemented and monitored at the Peabody Will Scarlet Mine in Illinois by investigators Jack Nawrot and W.B. Klimstra. It is less expensive than many other practices in the treatment of acid mine drainage. The idea is to overload the ground water with alkaline materials somewhere upslope of the subsurface acid generating zone, which establishes a groundwater environment sufficiently alkaline to eliminate bacterial catalysis, the biochemical component of the pyrite oxidation mechanism. This method could also incorporate the use of the sodium lauryl sulfates (SLS) and or lime.

To correct the acid mine drainage on the south side of the Monahan Site the following recommendation could be used with any of the preceding solutions. It is suggested that the existing wetland be extended further east (Figure 6 & 7). The slope on the south side is not as steep and the drainage area is not as large, therefore there is not as much seepage from the gob pile entering the south tributary

as there is the north tributary. Because of the conditions already present, extending the wetland on the south side of the Monahan Site would bring the pH of the water in that tributary up to a reasonable level with little or no addition of lime. Presently, the water here is diluted by the pit directly west of the Monahan Site. The strip pit drains into the existing wetland which has a considerable stand of cattails growing in it. The cattails have become established towards the east and occupy most of the tributary draining the south side of the property. Cattails take up a considerable amount of the iron in the acid mine drainage, thus improving the pH (Kleinmann 1986) (Appendix D). This along with the dilution factor of the water entering from the pit keeps the water on the south side of the site less acid.

The preceding recommendations are only preliminary and would require additional surveying and design in order to implement them. However, immediate attention needs to be given to the patch of erosion and to the dying vegetation on the north side of the property that is working its way up the slope. These places should have lime amended into the first six inches of soil, about 80 tons per acre (Bill Joseph personnel). The lime should remain for about a year and then mulch heavily with organic material. After an additional four to six months the area should be re-seeded, and again covered with an organic mulch (Bill Joseph

personnel). Whenever a new problem area is noticed the process should be repeated.

Maintenance is constant and the resultant cost will depend on the number of acres being treated. Overall the grass cover looked sufficient, but the actual ground cover when last looked at in 1988 was just over ten percent (Vickers 1989). With good management, whether it be burning or mowing or enhancing with organic fertilizer, the ground cover can ultimately be brought up to standard. When the grass cover becomes heavier the root zone will trap more water and evapotranspiration from increased foliage surface area will keep that water from reaching the unreactive pyritic zone. This will keep a significant amount of surface water from infiltrating the gob, thus decreasing the acid runoff, which is our number one goal.



## CHAPTER IX

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APPENDIX A

## Discharge of culverts and weirs

velocity of the water in the large culverts. At the Monahan site, we measured several times with a flow meter. The flow meter measures velocity of the water in feet per second (Barfield & Turner 1964). Volume of water (discharge) can be measured by multiplying the area of the culvert which it flows through by the velocity. When the water is channeled through a known circular area, the discharge can be found by using Manning's equation (Figure 16). Once this is known then a chart of discharge (Channel Rating) can be used to find discharge at varying depths (Figure 16).

## APPENDIX A Discharge

To find discharge of the weir we use Bernoulli's equation (Table IV). The notch in the weir is at a 45 degree angle and the depth of water over the notch was measured. A table was used to help calculate the volume of water flowing through the weir (Table V). If the water flows over the notch the area can be found by using the upper level of the weir in the same manner. If the water is not contained in the upper level, then it would be recorded as a flood condition. The data produced by these procedures are found in Tables VI and VII.

## Discharge of culverts and weirs

Velocity at Site N5 the large culvert east of the Monahan site, was measured several times with a flow meter. The flow meter measures velocity of the water in feet per second (Barfield & Warner 1983). Volume of water flowing (discharge) can be measured by multiplying area through which it flows times the velocity. When the water is channeled through a known circular area, then full capacity discharge can be found by using Manning's Equation (Table III). Once this is known then a chart of Circular Channel Ratios can be used to find discharge at varying depths (Figure 16).

To find discharge at the weirs we use Bernoulli's equation (Table IV). The notches in the weirs are at a 45 degree angle and the depth of water going through the notch was measured. A table could then be set up to calculate the volume of water flowing through the weirs (Table V). If the water flows out of the notch the area can be found by using the upper level of the weir in the same manner. If the water is not contained in the upper level, then it would be recorded as a flood condition. The data produced by these procedures are found in Tables VI and VII.

### III. Manning's Equation

Manning's Equation  
taken from  
Fluid Mechanics 8th Ed.

by  
Victor Streeter & E. B. Wylie

$$V_{full} = C/n R^{2/3} S^{1/2}$$

V = Velocity

C = a constant in USC units

n = .022 Mannings friction factor 4

S = .001 assumed slope < 10%

R = A/P <sup>2/3</sup>

A = Pipe Cross-sectional area (19.63 ft<sup>2</sup>)

P = Wetted perimeter (15.7 ft.)

$$V_{full} = 1.49/.022 \quad 25^{2/3} \quad .001^{1/2}$$

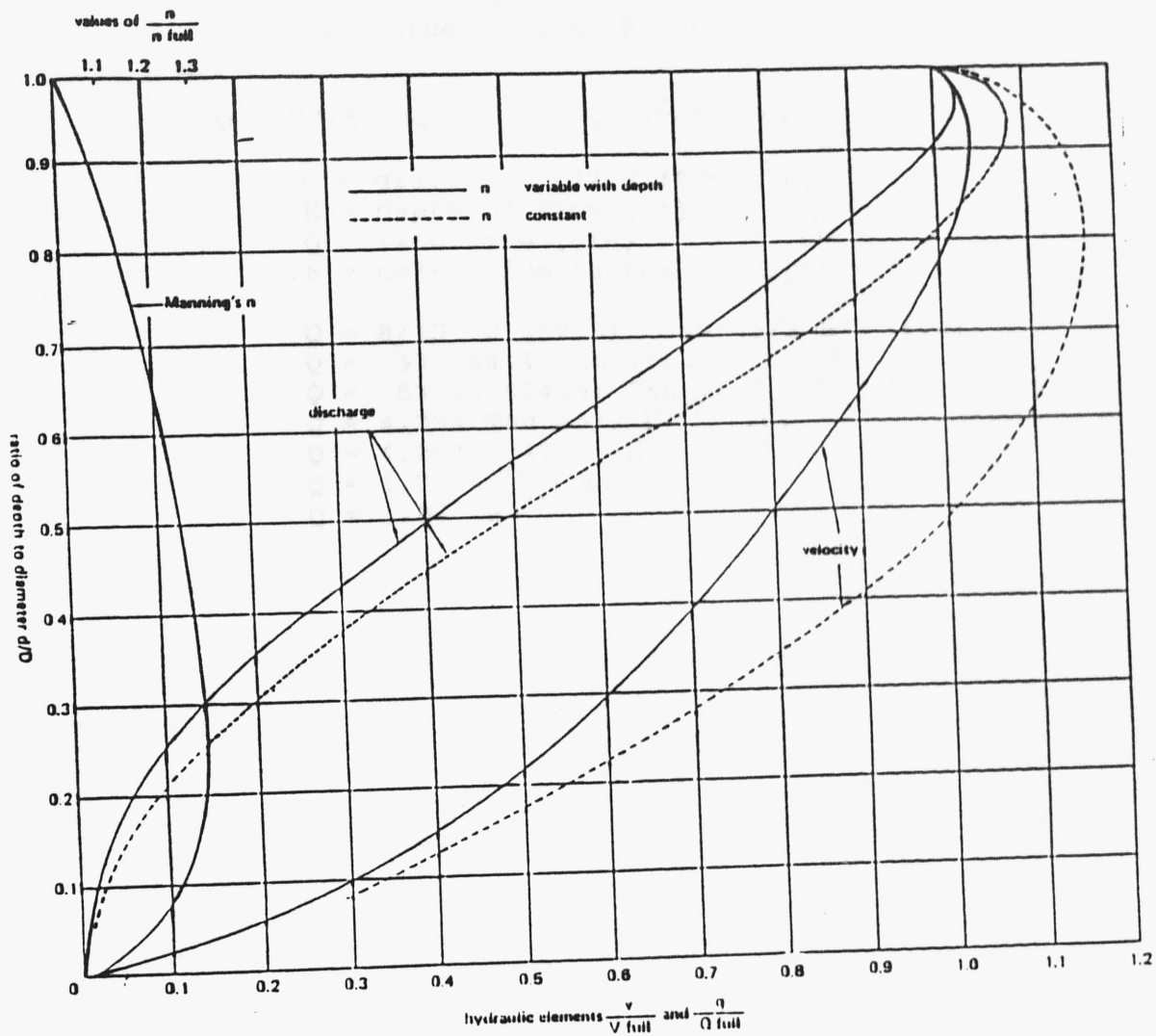
$$V_{full} = 2.51 \text{ f/s}$$

$$Q = VA$$

$$Q_{full} = 2.51 \quad 19.63$$

$$Q_{full} = 49.28 \text{ cfs}$$

Figure 16. Circular Channel Ratios  
Not to scale





# Table III. Bernoulli Equation

Derived from Bernoulli equation  
Fluid Mechanics 8th Ed.

by  
Victor Streeter & E. B. Wylie

$$Q = 8/15 \quad 2g \quad \tan 0/2 \quad H^{5/2} \quad (.6)$$

g = gravity: (32.2 ft/sec<sup>2</sup>)

H = depth of flow (ft)

Q = flow rate (cfs)

.6 = correction factor of nappe

$$Q = 8/15 \quad 2 \quad (32.2) \quad \tan 45/2 \quad H^{5/2} \quad (.6)$$

$$Q = .53 \quad 64.4 \quad \tan 45/2 \quad H^{5/2} \quad (.6)$$

$$Q = .53 \quad (8.02496) \quad \tan 45/2 \quad H^{5/2} \quad (.6)$$

$$Q = 4.253 \quad \tan 45/2 \quad H^{5/2} \quad (.6)$$

$$Q = 4.253 \quad .4142 \quad H^{5/2} \quad (.6)$$

$$Q = 1.77 \quad H^{5/2} \quad (.6)$$

$$Q = 1.06 \quad H^{5/2}$$

Table V. FLOW OVER 45 DEGREE TRIANGULAR NOTCH WEIR  
IN CUBIC FEET PER SECOND

$Q = 1.06 H^{5/2}$

Head in Feet	Head in inches	Flow
.04	0.5	.0032
.083	1.0	.0021
.125	1.5	.0058
.167	2.0	.0121
.208	2.5	.0209
.25	3.0	.0332
.292	3.5	.441
.333	4.0	.0678
.375	4.5	.0913
.417 = NO DATA	5.0	.1190
.458 = NO FLOW	5.5	.1505
.5	6.0	.1874
.542	6.5	.2293
.583	7.0	.2751
.625	7.5	.3273
.666	8.0	.3837
.708	8.5	.4471
.75	9.0	.5163

Table VI. SITE (Depth in inches)

DATE	Site 3	Site 5	6	Site 7	8
Oct. 11, 89	ND	ND	ND	ND	4
Nov. 28, 89	ND	ND	ND	ND	3
Oct. 16, 90	NF	NF	NF	ND	4
Jun. 6, 90	NF	NF	NF	ND	2.5
Jun. 21, 90	NF	NF	NF	ND	4
Jan. 27, 91	NF	NF	NF	ND	2.13
Mar. 18, 91	NF	NF	3.13	ND	3.13
April 15, 91	NF	NF	2.75	ND	NF
May 30, 91	NF	NF	NF	ND	2.88
Nov. 19, 91	NF	7.5	1.25	ND	2.5
Dec. 21, 91	NF	NF	1.5	ND	NF

ND = No Data

NF = No Flow

Table VII. DISCHARGE (cubic feet per second)

DATE		Site N2	Site N3	Site N4	Site ST	Site N5
Oct.	11, 1989	ND	ND	ND	ND	1.23
Nov.	28, 1989	ND	ND	ND	ND	0.74
Jun.	6, 1990	0.0	ND	ND	ND	1.3
Jun.	21, 1990	0.0	ND	ND	ND	3.7
Oct.	16, 1990	0.0	0.0	0.0	ND	3.7
Jan.	27, 1991	0.0	0.0	0.0	ND	0.5
Mar.	18, 1991	0.0	0.0	0.037	ND	0.9
April	15, 1991	0.0	0.0	0.027	ND	0.0
May	30, 1991	0.0	0.0	0.0	ND	0.7
Nov.	19, 1991	0.0	0.301	0.004	ND	0.6
Dec.	21, 1991	0.0	0.0	0.006	ND	0.0

ND = No Data

APPENDIX 3 Precipitation

# Table 11. Precipitation

Date:	Amount:	Date:	Amount:
02-25-90	1.50"	12-10-90	1.03"
03-01-90	1.50"	01-12-91	1.12"
03-12-90	1.50"	01-14-91	1.10"
03-16-90	1.50"	01-26-91	1.18"
04-03-90	1.50"	02-03-91	1.12"
04-12-90	1.75"	03-01-91	1.12"
04-24-90	1.50"	03-27-91	1.32"
05-03-90	2.50"	04-01-91	1.12"
05-23-90	3.00"	04-07-91	1.12"
05-30-90	1.13"	04-08-91	1.04"
06-05-90	1.13"	04-14-91	1.50"
06-10-90	1.53"	04-18-91	1.50"
06-20-90	2.50"	04-22-91	1.50"
06-25-90	1.50"	05-06-91	1.06"
06-26-90	1.50"	05-21-91	1.06"
07-10-90	1.50"		1.50"
10-06-90	1.50"	APPENDIX B Precipitation	
10-03-90	1.50"		
10-18-90	1.50"	06-01-91	1.12"
11-11-90	1.50"	06-04-91	1.50"
12-02-90	1.50"	07-10-91	1.38"
12-12-90	1.50"	08-11-91	1.50"
12-24-90	1.50"	08-13-91	1.25"
12-27-90	1.50"	08-07-91	1.38"
12-29-90	1.50"	09-16-91	1.38"
		09-21-91	1.50"
		10-24-91	1.12"
		11-17-91	2.63"

Table VIII. Precipitation

Date:	Amount:	Date:	Amount
02-25-90	1.00"	12-30-90	.034"
03-01-90	.50"	01-15-91	.12 "
03-12-90	3.13"	01-16-91	.40 "
03-16-90	2.50"	01-26-91	.38 "
04-03-90	.65"	02-05-91	.25 "
04-12-90	.75"	03-02-91	.19 "
04-24-90	.50"	03-27-91	.35 "
05-09-90	2.50"	04-03-91	.12 "
05-23-90	5.00"	04-07-91	.35 "
05-30-90	3.13"	04-08-91	.05 "
06-06-90	.13"	04-14-91	1.50 "
06-10-90	1.50"	04-18-91	.88 "
06-20-90	2.50"	04-30-91	.60 "
06-25-90	.75"	05-06-91	.88 "
06-26-90	.50"	05-21-91	.06 "
07-10-90	.75"	05-27-91	1.50 "
10-06-90	2.75"	05-30-91	.06 "
10-08-90	.50"	06-01-91	.13 "
10-18-90	.13"	06-08-91	.50 "
11-27-90	1.00"	07-30-91	.38 "
12-02-90	2.00"	08-31-91	1.50 "
12-17-90	1.00"	09-03-91	.25 "
12-24-90	.01"	09-07-91	.38 "
12-27-90	.01"	09-15-91	.88 "
12-29-90	.09"	09-21-91	.66 "
		10-24-91	1.13 "
		11-17-91	2.63 "

# Water Quality Data for 06/01

Date	DO	Temp	pH	Salinity	Iron	Ammonia	Alkalinity
060690	(20)	(20)	(20)	(20)	(20)	(20)	(20)
1	5.2	2,000	8.0	2.0	NR	NR	NR
2	5.4	2,000	8.0	2.0	NR	NR	NR
M	5.2	2,000	8.0	2.0	NR	NR	NR
062190	1	2.4	2,000	2.0	25.0	NR	NR
2	2.4	2,000	2.0	17.0	NR	NR	NR
M	2.4	2,000	2.0	22.0	NR	NR	NR
071190	1	3.0	10,000	NR	NR	NR	NR
2	3.0	10,000	NR	NR	NR	NR	NR
M	3.0	10,000	NR	NR	NR	NR	NR
072590	1	2.4	>10,000	1,210	4.0	NR	NR
2	2.4	>10,000	1,210	1.5	NR	NR	NR
M	2.4	>10,000	1,210	6.5	NR	NR	NR
080790	1	NR	NR	NR	NR	NR	NR
2	NR	NR	NR	NR	NR	NR	NR
M	NR	NR	NR	NR	NR	NR	NR
091090	1	2.7	NR	2.0	20	NR	NR
2	2.7	NR	2.0	10	NR	NR	NR
M	2.7	NR	2.0	10	NR	NR	NR
100790	1	2.4	>10,000	7,500	75.0	NR	NR
2	2.4	>10,000	7,500	51.0	NR	NR	NR
M	2.4	>10,000	7,500	60.0	NR	NR	NR
101890	1	2.7	NR	3,000	81.0	NR	NR
2	2.7	NR	3,000	50.0	NR	NR	NR
M	2.7	NR	3,000	56.0	NR	NR	NR
111090	1	3.0	20,000	1,175	63.0	NR	NR
2	3.3	17,600	2,000	50.0	NR	NR	NR
M	3.3	18,000	3,438	6.5	NR	NR	NR

## APPENDIX C Water Quality

# IX. Water Quality Data for Site N1

Date	pH	Conduct.	Sulfates	Iron	Hardness	Alkalinity
(su)	(umhos/cm)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	
060690	1	5.2	2,200	200	3.0	NR
	2	5.4	2,200	300	1.8	NR
	M	5.3	2,200	250	2.4	
062190	1	2.8	1,400	300	25.0	NR
	2	2.7	1,300	275	17.0	NR
	M	2.8	1,350	288	21.0	
071190	1	3.0	10,000	NR	NR	NR
	2	3.0	10,000	NR	NR	NR
	M	3.0	10,000			
072590	1	2.4	>10,000	1,250	6.3	NR
	2	2.4	>10,000	1,000	7.5	NR
	M	2.4	>10,000	1,125	6.9	NR
080790	1	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF
	M					
091090	1	2.7	NR	625	20.0	NR
	2	2.6	NR	625	18.0	NR
	M	2.7		625	19.0	
100790	1	2.6	>10,000	7,500	75.0	NR
	2	2.6	>10,000	7,500	63.0	NR
	M	2.6	>10,000	7,500	69.0	
101890	1	2.7	NR	3,750	63.0	NR
	2	2.7	NR	3,500	50.0	NR
	M	2.7		3,625	56.5	
111090	1	3.0	20,000	4,375	63.0	NR
	2	3.3	17,600	2,500	50.0	NR
	M	3.2	18,800	3,438	56.5	



# IX. Water Quality Data for Site N1 - continued

Date		pH	Conduct.	Sulfates	Iron	Hardness	Alkalinity
		(su)	(umhos/cm)	(mg/l)	(mg/l)	(mg/l)	(mg/l)
013191	1	4.2	4,400	3,000	125.0	NR	NR
	2	3.8	3,800	3,000	125.0	NR	NR
	M	4.0	4,100	3,000	125.0		
031891	1	2.8	18,000	2,500	125.0	NR	NR
	2	2.8	22,000	3,750	150.0	NR	NR
	M	2.8	20,000	3,125	137.5		
041591	1	2.4	710	3,750	300.0	NR	NR
	2	2.4	710	3,750	150.0	NR	NR
	M	2.4	710	3,750	225.0		
053091	1	3.0	8,200	12,500	762.5	NR	NR
	2	3.0	7,600	14,375	362.5	NR	NR
	M	3.0	7,900	13,438	562.5		
111891	1	3.5	3,000	10,000	302.0	NR	NR
	2	3.6	3,000	9,000	359.0	NR	NR
	M	3.5	3,000	9,500	330.5		

NR= no reading

NF= no flow

# X. Water Quality Data for Site TD

Date		pH (su)	Conduct. (umhos/cm)	Sulfates (mg/l)	Iron (mg/l)	Hardness (mg/l)	Alkalinity (mg/l)
060690	1	2.7	1,800	300	0.8	22,982.0	NR
	2	2.8	1,800	250	0.8	24,646.0	NR
	M	2.8	1,800	275	0.8	23,814.0	
062190	1	5.7	1,000	200	0.5	NR	5.0
	2	5.5	900	150	0.5	NR	18.0
	M	5.6	950	175	0.5		11.5
071190	1	3.5	5,400	313	NR	NR	NR
	2	3.5	5,400	313	NR	NR	NR
	M	3.5	5,400	313			
072590	1	2.3	7,800	1,500	7.5	NR	NR
	2	2.2	8,000	2,500	15.0	NR	NR
	M	2.3	7,900	2,000	11.3		
080790	1	2.5	5,800	5,000	76.0	NR	NR
	2	2.5	6,000	5,000	76.0	NR	NR
	M	2.5	5,900	5,000	76.0		
091090	1	NF	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF	NF
	M						
100790	1	NF	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF	NF
	M	NF	NF	NF	NF	NF	NF
101890	1	2.6	NR	2,250	50.0	NR	NR
	2	2.4	NR	2,125	63.0	NR	NR
	M	2.5		2,188	56.5		
111090	1	2.9	7,400	1,250	50.0	NR	NR
	2	2.9	7,400	1,500	50.0	NR	NR
	M	2.9	7,400	1,375	50.0		

# X. Water Quality Data for Site TD - continued

Date		pH (su)	Conduct. (umhos/cm)	Sulfates (mg/l)	Iron (mg/l)	Hardness (mg/l)	Alkalinity (mg/l)
013191	1	3.2	3,600	1,250	62.5	NR	NR
	2	3.3	3,600	1,750	150.0	NR	NR
	M	3.3	3,600	1,500	106.3		
031891	1	2.6	18,000	5,000	250.0	NR	NR
	2	2.6	18,000	5,000	250.0	NR	NR
	M	2.6	18,000	5,000	250.0		
041591	1	2.8	190	400	300.0	NR	NR
	2	2.7	210	700	140.0	NR	NR
	M	2.8	200	550	220.0		
053091	1	3.6	900	14,375	11.3	NR	NR
	2	3.6	960	13,750	14.0	NR	NR
	M	3.6	930	14,063	12.7		
111891	1	4.1	300	2,625	60.8	NR	NR
	2	5.0	1,200	1,250	65.8	NR	NR
	M	4.6	750	1,938	63.3		

NR= no reading

NF= no flow

# XI. Water Quality Data for Site N2

Date		pH (su)	Conduct. (umhos/cm)	Sulfates (mg/l)	Iron (mg/l)	Hardness (mg/l)	Alkalinity (mg/l)
060690	1	5.3	2,400	200	2.0	43,999.0	NR
	2	5.4	2,400	300	1.3	45,360.0	NR
	M	5.3	2,400	250	1.6		
062190	1	3.7	1,800	150	13.0	NR	NR
	2	3.7	1,800	100	6.0	NR	NR
	M	3.7	1,800	125	9.5		
071190	1	NF	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF	NF
	M						
072590	1	NF	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF	NF
	M						
080790	1	NF	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF	NF
	M						
091090	1	NF	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF	NF
	M						
100790	1	NF	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF	NF
	M						
101890	1	NF	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF	NF
	M						
111090	1	2.9	13,600	NR	NR	NR	NR
	2	2.8	14,800	NR	NR	NR	NR
	M	2.8	14,200				

# XI. Water Quality Data for Site N2 - continued

Date		pH (su)	Conduct. (umhos/cm)	Sulfates (mg/l)	Iron (mg/l)	Hardness (mg/l)	Alkalinity (mg/l)
013191	1	NF	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF	NF
	M						
031891	1	3.0	6,000	1,250	80.0	NR	NR
	2	3.0	6,000	1,500	125.0	NR	NR
	M	3.0	6,000	1,375	102.5		
041591	1	2.5	580	2,500	200.0	NR	NR
	2	2.5	580	2,500	200.0	NR	NR
	M	2.5	580	2,500	200.0		
053091	1	3.0	3,400	1,200	212.5	NR	NR
	2	3.0	3,400	26,250	737.5	NR	NR
	M	3.0	3,400	13,725	475.0		
111891	1	3.8	1,200	3,500	117.5	NR	NR
	2	3.9	200	2,875	147.5	NR	NR
	M	3.8	700	3,188	132.5		

NR= no reading

NF= no flow

# XII. Water Quality Data for Site CU

Date		pH (su)	Conduct. (umhos/cm)	Sulfates (mg/l)	Iron (mg/l)	Hardness (mg/l)	Alkalinity (mg/l)
060690	1	5.6	2,200	300	3.0	44,755.0	NR
	2	5.6	2,400	300	3.0	44,755.0	NR
	M	5.6	2,300	300	3.0	44,755.0	
062190	1	3.7	1,600	100	6.0	NR	NR
	2	3.7	1,600	100	6.0	NR	NR
	M	3.7	1,600	100	6.0		
071190	1	5.2	2,600	150	38.0	NR	1.0
	2	5.2	2,600	80	2.0	NR	2.0
	M	5.2	2,600	115	20.0		1.5
072590	1	2.5	8,800	1,500	13.0	NR	NR
	2	2.5	8,800	2,500	15.0	NR	NR
	M	2.5	8,800	2,000	14.0		
080790	1	2.8	4,800	2,500	75.0	NR	NR
	2	2.9	4,800	2,500	75.0	NR	NR
	M	2.9	4,800	2,500	75.0		
091090	1	NF	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF	NF
	M						
100790	1	NF	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF	NF
	M						
101890	1	2.8	NR	1,625	63.0	NR	NR
	2	2.7	NR	1,625	50.0	NR	NR
	M	2.8		1,625	56.5		
111090	1	2.9	14,000	2,500	63.0	NR	NR
	2	2.9	14,000	2,500	63.0	NR	NR
	M	2.9	14,000	2,500	63.0		

# XII. Water Quality Data for Site CU - continued

Date		pH (su)	Conduct. (umhos/cm)	Sulfates (mg/l)	Iron (mg/l)	Hardness (mg/l)	Alkalinity (mg/l)
013191	1	NF	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF	NF
	M						
031891	1	2.7	12,000	2,500	160.0	NR	NR
	2	2.7	12,000	2,500	160.0	NR	NR
	M	2.7	12,000	2,500	160.0		
041591	1	2.4	580	2,500	125.0	NR	NR
	2	2.4	580	2,500	125.0	NR	NR
	M	2.2	580	2,500	125.0		
053091	1	3.0	3,000	200	318.8	NR	NR
	2	3.0	3,000	250	231.3	NR	NR
	M	3.0	3,000	225	275.1		
111891	1	3.4	2,100	3,750	347.5	NR	NR
	2	3.3	2,100	3,500	316.3	NR	NR
	M	3.3	2,100	3,625	331.9		

NR= no reading

NF= no flow

# XIII. Water Quality Data for Site N3

Date		pH (su)	Conduct. (umhos/cm)	Sulfates (mg/l)	Iron (mg/l)	Hardness (mg/l)	Alkalinity (mg/l)
060690	1	5.7	2,200	250	3.0	32,962.0	NR
	2	5.7	2,200	250	2.0	31,903.0	NR
	M	5.7	2,200	250	2.5	32,432.5	
062190	1	5.5	1,200	200	0.2	NR	6.0
	2	5.5	1,100	200	0.2	NR	5.0
	M	5.5	1,150	200	0.2		
071190	1	3.5	2,600	300	0.3	NR	NR
	2	3.5	2,600	300	8.0	NR	NR
	M	3.5	2,600	300	4.2		
072590	1	2.6	7,400	2,500	5.0	NR	NR
	2	2.6	7,400	2,200	3.0	NR	NR
	M	2.6	7,400	2,350	4.0		
080790	1	NF	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF	NF
	M						
091090	1	NF	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF	NF
	M						
100790	1	NF	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF	NF
	M						
101890	1	2.9	NR	1,500	75.0	NR	NR
	2	2.9	NR	1,000	63.0	NR	NR
	M	2.9		1,250	69.0		
111090	1	2.9	13,600	2,250	50.0	NR	NR
	2	2.9	12,800	2,250	75.0	NR	NR
	M	2.9	13,200	2,250	62.5		



XIII. Water Quality Data for Site N3 - continued

Date		pH (su)	Conduct. (umhos/cm)	Sulfates (mg/l)	Iron (mg/l)	Hardness (mg/l)	Alkalinity (mg/l)
013191	1	3.2	4,800	1,500	62.5	NR	NR
	2	3.2	4,200	1,250	62.5	NR	NR
	M	3.2	4,500	1,375	62.5		
031891	1	2.8	12,000	2,250	160.0	NR	NR
	2	2.8	12,000	2,500	160.0	NR	NR
	M	2.8	12,000	2,375	160.0		
041591	1	2.4	580	2,500	125.0	NR	NR
	2	2.0	580	2,500	125.0	NR	NR
	M	2.2	580	2,500	125.0		
053091	1	3.0	3,000	200	318.8	NR	NR
	2	3.0	3,000	250	231.3	NR	NR
	M	3.0	3,000	225	275.1		
111891	1	3.3	2,100	4,375	65.5	NR	NR
	2	3.3	2,000	3,625	45.5	NR	NR
	M	3.3	2,050	4,000	55.5		

NR= no reading

NF= no flow

# XIV. Water Quality Data for Site N4

Date		pH (su)	Conduct. (umhos/cm)	Sulfates (mg/l)	Iron (mg/l)	Hardness (mg/l)	Alkalinity (mg/l)
031891	1	2.9	8,000	2,000	150.0	NR	NR
	2	2.9	10,000	2,000	125.0	NR	NR
	M	2.9	9,000	2,000	137.5		
041591	1	2.6	420	2,000	400.0	NR	NR
	2	2.5	420	2,000	340.0	NR	NR
	M	2.5	420	2,000	370.0		
053091	1	3.2	2,800	1,225	181.3	NR	NR
	2	3.0	2,000	1,350	156.3	NR	NR
	M	3.1	2,400	1,288	168.8		
111891	1	3.5	1,200	9,500	100.0	NR	NR
	2	3.6	1,100	9,500	78.0	NR	NR
	M	3.5	1,150	9,500	89.0		

NR= no reading

NF= no flow

# XV. Water Quality Data for Site ST

Date		pH (su)	Conduct. (umhos/cm)	Sulfates (mg/l)	Iron (mg/l)	Hardness (mg/l)	Alkalinity (mg/l)
060690	1	4.7	1,400	200	0.0	30,845.0	NR
	2	5.0	1,400	200	0.1		NR
	M	4.8	1,400	200	0.1	30,845.0	
062190	1	5.6	1,400	225	6.7	NR	NR
	2	5.6	1,300	225	2.7	NR	NR
	M	5.6	1,350	225	4.7		
071190	1	5.2	2,400	100	0.2	1,223.0	NR
	2	5.2	3,000	175	0.4	1,150.0	NR
	M	5.2	2,700	138	0.3	1,186.5	
072590	1	6.8	3,000	300	0.3	517.0	NR
	2	6.8	3,000	500	0.2	546.0	NR
	M	6.8	3,000	400	0.3	531.5	
080790	1	NF	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF	NF
	M						
091090	1	NF	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF	NF
	M						
100790	1	6.3	3,600	675	35.0	NR	NR
	2	6.3	3,600	500	35.0	NR	NR
	M	6.3	3,600	588	35.0		
101890	1	NF	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF	NF
	M						
111090	1	5.1	4,600	750	45.0	NR	NR
	2	5.5	4,600	750	15.0	NR	NR
	M	5.3	4,600	750	30.0		

XV. Water Quality Data for Site ST - continued

Date		pH (su)	Conduct. (umhos/cm)	Sulfates (mg/l)	Iron (mg/l)	Hardness (mg/l)	Alkalinity (mg/l)
013191	1	5.2	2,500	750	35.0	NR	8.3
	2	5.3	2,400	750	25.0	NR	11.8
	M	5.3	2,450	750	30.0		10.1
031891	1	5.4	4,000	750	0.7	NR	NR
	2	5.4	4,000	400	2.0	NR	NR
	M	5.4	4,000	575	1.4		
041591	1	4.7	240	3,750	1.4		
	2	3.6	240	750	0.4	NR	NR
	M	4.2	240	2,250	0.9		
053091	1	5.5	2,000	1,050	1.5	NR	NR
	2	5.2	2,000	1,400	1.5	NR	NR
	M	5.3	2,000	1,225	1.5		
111891	1	4.1	1,200	3,750	15.3	NR	NR
	2	4.1	1,200	4,700	26.4	NR	NR
	M	4.1	1,200	4,225	20.9		

NR= no reading

NF= no flow

# VI. Water Quality Data for Site N5

Date		pH (su)	Conduct. (umhos/cm)	Sulfates (mg/l)	Iron (mg/l)	Hardness (mg/l)	Alkalinity (mg/l)
060690	1	6.0	1,800	200	NR	43,848.0	NR
	2	6.0	1,800	150	NR	44,755.0	NR
	M	6.0	1,800	175		44,301.5	
062190	1	5.0	1,200	200	0.2	45.0	5.0
	2	5.0	1,200	200	0.2	8.0	4.0
	M	5.0	1,200	200	0.2	26.5	4.5
071190	1	7.0	2,000	125	2.5	829.0	6.0
	2	7.0	2,000	200	0.1	818.0	6.0
	M	7.0	2,000	163	1.3	823.5	6.0
072590	1	6.0	2,200	300	0.4	847.0	10.0
	2	6.0	2,200	225	0.2	869.0	9.0
	M	6.0	2,200	263	0.3	858.0	9.5
080790	1	7.0	1,200	250	0.3	27.0	10.0
	2	7.0	1,100	250	0.3	26.0	8.0
	M	7.0	1,150	250	0.3	26.5	9.0
091090	1	NF	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF	NF
	M						
100790	1	NF	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF	NF
	M						
101890	1	NF	NF	NF	NF	NF	NF
	2	NF	NF	NF	NF	NF	NF
	M						
111090	1	3.0	3,400	500	2.0	NR	NR
	2	4.0	3,400	500	2.0	NR	NR
	M	3.5	3,400	500	2.0		

## XVI. Water Quality Data for Site N5 - continued

Date		pH (su)	Conduct. (umhos/cm)	Sulfates (mg/l)	Iron (mg/l)	Hardness (mg/l)	Alkalinity (mg/l)
013191	1	3.6	200	625	42.5	NR	NR
	2	3.7	2,200	750	42.5	NR	NR
	M	3.7	1,200	688	42.5		
031891	1	3.1	6,000	1,000	62.5	NR	NR
	2	3.1	6,000	1,000	50.0	NR	NR
	M	3.1	6,000	1,000	56.3		
041591	1	3.0	280	750	1.6	NR	NR
	2	3.0	280	750	2.0	NR	NR
	M	3.0	280	750	1.8		
053091	1	3.7	2,000	450	9.3	NR	NR
	2	3.7	2,000	450	9.3	NR	NR
	M	3.7	2,000	450	9.3		
111891	1	3.9	1,000	6,250	2.0	NR	NR
	2	3.9	1,100	1,500	12.0	NR	NR
	M	3.9	1,050	3,875	7.0		

NR= no reading

NF= no flow

## Treatments

Geis and Bryant (1989) explain that pollution can be identified as either point source or nonpoint source. Nonpoint source pollution arises from diffuse areas and is not well understood. Point source pollution arises from a single identifiable source such as the discharge of effluent into a surface water. Therefore the CDD from a nonpoint source is classified as point source pollution. Point source pollution from point sources are usually more easily controlled than they are also more easily controlled and their location is well defined (Geis and Bryant 1989). There are several ways to treat a point source pollution. One of the ways is to use chemical treatment (Kleinman and Erickson 1984), and one of the easiest and still effective methods is treating the effluent with chemicals. Chemicals are used to neutralize acids chemically using lime. Although this is used as a way to treat an after-the-fact way of treating acid mine drainage (Kleinman and Erickson 1984), the addition of lime can produce an environment unsuitable to aquatic life. Kleinman goes on to say, when the addition of lime increases the availability to excess acidity, the sulfur concentration may increase, but acidification can be postponed or stopped. Limestone is an inorganic calcium carbonate ( $\text{CaCO}_3$ ) which can be used to neutralize acid producing sulfur (Kleinman et al. 1986). The quality of limestone is the key to its

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Gore and Bryant (1988) explain that pollution can be identified as either point source or nonpoint source. Nonpoint source pollution arises from a large area and is not well specified. Point source pollution arises from a single well-defined source such as the drainage from a surface mine. Therefore the AMD from the Monahan would be classified as point source pollution. Pollutants arising from point sources are usually more concentrated, but they are also more easily controlled due to their restricted location (Gore and Bryant 1988). There are several ways to treat a point source pollution. One of the most common control strategies is treatment at the discharge point (Kleinmann and Erickson 1986), and one of the earliest and still widely used methods, is treating the problem chemically. Acid mine drainage is often treated chemically using limestone. Although this is usually thought of as an after-the-fact way of treating acid mine drainage (Kleinmann and Erickson 1986), the addition of lime can produce an environment unfavorable to pyrite oxidation. Kleinmann goes on to say, when the addition of limestone increases alkalinity to exceed acidity, the sulfur concentration may increase, but acidification can be postponed or stopped. Limestone is an impure calcium carbonate ( $\text{CaCO}_3$ ) which can be used to neutralize acid producing pyrite (Nebergall et al. 1980). The quality of limestone is the key to its



performance (Hope 1982). Because limestone is not a uniform product, its effectiveness will vary with its chemical content and its physical characteristics. The effectiveness of limestone is a function of its purity and fineness. Purity is measured by the calcium carbonate equivalent and is expressed as a weight percentage. The presence of other chemicals or contaminants such as clay, dilute the purity of the limestone. Particle size or fineness of grain is the other major factor to performance level. The fineness of grain increases the amount of reactive surface area in a given quantity of limestone. Hope (1982) goes on to say that a one inch cube of limestone has a surface area of six square inches. The same piece of limestone ground to pass a 100-mesh screen has a surface area of 60,000 square inches. Coarse grind limestone last longer, but only because it has less surface area to react with hydrogen in the acid. In their paper, **Control of Acid Mine Drainage**, Kleinmann and Erickson (1986) explore several ways of dealing with AMD. Besides using limestone as a chemical treatment, they explore the use of bacteria inhibitors. Iron-oxidizing bacteria largely control the rate of pyrite oxidation once the system is in a highly acidic state. Laboratory studies show that acid production is reduced by more than half upon elimination of the bacteria Thiobacillus ferrooxidans. Of the many classes of compounds identified to inhibit the bacteria only anionic surfactants have proven to be

effective in the field (Kleinmann and Erickson 1986). The surfactants used were sodium lauryl sulfates (SLS). The first full scale field test used a 30% SLS solution that was sprayed over a coal refuse pile, after a three month lag time, acidity and sulfate concentrations dropped by 60% and iron concentrations decreased by 90%. This single application was effective for approximately 6 months. Using anionic detergents is also discussed in the reclamation techniques of the Office of Surface Mining's environmental impact statement OSM-EIS-11 (1983), and suggest that use of anionic detergents shows promise in the control of acid formation.

In areas where acid mine drainage is a problem, the use of mulches or amendments as a treatment is making a come back. Slick and Curtis (1985) define mulch as any suitable protective layer of organic or inorganic material that is either applied or left on or near the soil surface as a temporary aid in stabilizing that surface. An amendment, they say, is anything incorporated into the soil "root zone" such as lime, fertilizer, or manure used to make the soil productive or more productive.

Conditions detrimental to seed germination are erosion, extreme diurnal surface and soil temperatures, lack of available moisture, and extremes in pH (Slick & Curtis 1985). Mulching and amending have proven to be a way to condition soil for better seed germination and subsequent

plant growth. Mulching and amending not only prevents erosion but also improves the soils microclimatic conditions which helps to establish vegetation.

Mulch has been used for years to protect the soil from erosion and excessive drying not only in agriculture, but also in highway construction and landscape development. In more recent years mulching has been used in surface-mine reclamation to help establish optimum vegetative cover for site stability and productivity (Slick & Curtis 1985). It has been observed that mulching is also valuable in reclamation of abandoned mine lands. Kleinmann and Erickson (1988) conclude that the decomposition of organic mulches helps alleviate oxygen from the pyritic zones, while making conditions more suitable for microbial activities.

Mulching, would therefore modify the microclimate, and make it more favorable for plant establishment and growth (Slick & Curtis 1985). Mulching with organic matter says Grunwald et. al. (1988), is critical for soil moisture retention and for providing a mechanism for the slow release of nutrients. A lot of materials, both organic and inorganic, have been tested for mulching effectiveness. Organic mulches are usually preferred because they are nature's own materials which provide needed micro flora and fauna, seeds, matter and nutrients to the often sterile heterogenous mine soils (Slick & Curtis 1985). Slick and Curtis (1985) in agreeing with Grunwald et. al. say that organic matter is one of the

most important factors in building a good soil structure which is both capable of retaining moisture and providing plant nutrients. Extensive literature exists on the effects of organic mulches on cropland soil conditions, runoff, erosion, and yield of crops, but considerably less information has been published on its use in mine reclamation.

Nawrot, Warburton, and Klimstra (1986), reported the results of study on the direct vegetation of coarse refuse. A gob pile is coal refuse left on the surface (Thrush 1990). During the past 30 years of reclamation demonstration activities, physical and chemical characteristics of both spoils and coal refuse have been evaluated. When first disturbed, coal refuse has an initial acidification generation of  $\text{pH} < 2$  however, the acid-producing potential gradually decreases as the pyrite in the weathered surface zones deplete. According to Nawrot study, this happens gradually in a 5 to 10 year time frame. If the oxidized surface zone is not disturbed after this time frame, then its potential acidity level is treatable (e.g. 10 to 45 tons  $\text{CaCO}_3$  eq/1000 tons), and the underlying unoxidized zone, if not disturbed, remains unreactive. In a demonstration project started in the fall of 1984, Nawrot et. al. (1986) used a limestone amendment along with winter rye for an initial cover crop, to demonstrate that coal refuse could be directly vegetated. The following

spring black locust trees were planted. The second spring, pin oak, sweet gum, sumac and dogwood were planted. The second year locust growth showed greater than 65% survival. The winter rye initially planted provided a mulch that did not compete with the trees for moisture or nutrients. The summer and fall of 1985 brought an emergence of sweet clover and red clover. The clovers added to the organic matter previously provided for by the rye. Switchgrass was then overseeded the next Spring. Three months later samples were collected. Decreased acidity below the weathered zone was evident with a mean pH of 5.7. This site previously had extreme acidic conditions. The study done by Nawrot and his colleagues, suggest that in order to prevent disturbance and re-exposure of previously unoxidized pyritic materials the best approach to liming is "overtreating" the weathered surface zone, this will enhance alkaline flushing of untreated acid materials and better help establish a good root zone for the direct vegetation.

Grits (1987) reports that cattails and hardstem bulrush are the most likely species to survive and establish a wetland in acid mine water because they tolerate a lower pH than most plant species. Since cattails accumulate iron and manganese in their rhizome tissue to as much as 300 ppm iron and 200 ppm manganese, and in their leaves as much as 45 ppm Fe and 52 ppm Mn (Kleinmann 1986), cattails improve water quality. Cattails grow along the south tributary most of

the length of the stream, although there are a few places,  
directly south of the gob pile, where it is too acid to  
support the cattails.