# CONTROLLING ACID SEEPAGE FROM BURIED COAL WASTES THROUGH GROUNDWATER INUNDATION AND WETLANDS[1]

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Abstract. -- A system consisting of an underground dike, subsurface drain and wetland was designed and installed to control expected acid mine drainage originating from reclaimed coal mine tipple facilities located in Vernon County, Missouri. Design parameters were based upon field and laboratory investigations of the characteristics of coal refuse (slurry and gob), mine spoil and clay cover materials.

## INTRODUCTION

Acid mine drainage (AMD) has placed significant limitations on the long-term success of reclamation of abandoned coal mine sites, especially sites with large concentrations of pyritic coal slurry or gob. The Robinson Branch and Panama tipple sites located in Vernon County, Missouri (fig. 1) were typical of abandoned mine land (AML) coal disposal sites that discharged large quantities of AMD and coal refuse into local streams. Oxidation of pyritic material found in coal wastes and mining overburden produced tons of acid and iron precipitates that entered Robinson Branch and tributary streams. Conventional reclamation approaches used previously at similar sites in Staunton, Illinois, and other places have indicated that acid seeps will continue to develop at mid and bottom slopes, causing mortality of vegetation and severe erosion. Conventional methods of covering these acid materials with clay soils were not deemed adequate to prevent or control AMD. Therefore, additional reclamation alternatives were considered necessary to control AMD and associated erosion problems, and to achieve permanent reclamation.

Understanding several hydraulic and geochemical processes was considered vital for design of a long-term reclamation scheme. These processes included: infiltration into the buried mass including percolation rates and effects of final grades; controlling discharge from a perched groundwater system; chemical oxidation of pyrite in the buried mass; and the movement of groundwater within a perched, buried mass.

Research performed by the Argonne National Laboratory at the Staunton 1 Reclamation Demonstration Project (1979) revealed problems with continued seepage from a buried mass. Other sites in Illinois (Mele and Prodan, 1983) Kansas and Iowa (personal observation) have developed similar problems which can lead to complete reclamation failure or continued costly maintenance. Olsen (1979) described how acid seepage and resultant erosion of cover material

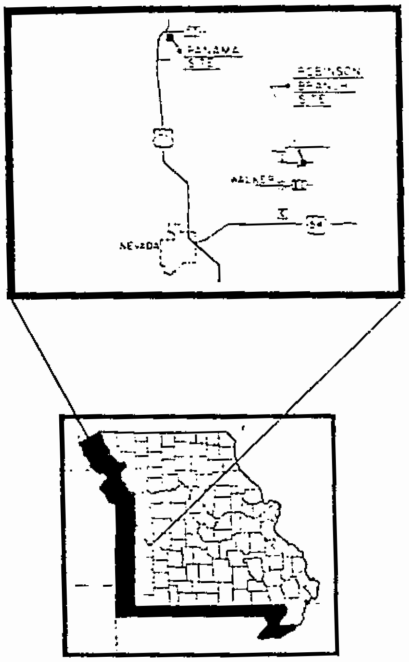

Figure 1. -- Projects Location Map.

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had a significant negative impact on surface water quality. Schubert and Prodan (1979) reported that water was perching on the gob-soil cover interface. They attributed this effect to inadequate mixing of the lime buffer zone which caused formation of a caliche layer on the gob surface.

Research performed on slope angle and erosion rates (Wilkey, 1979) indicated no significant difference between slopes of 33.3%, 20% and 14.3% on erosion rates for sites with similar cover thickness. Rainfall: runoff data collected on the reclaimed New Kathleen site in Illinois showed that R/R ratios increased with lower grades after reclamation (Mele and Prodan, 1983). This was attributed to compaction of the coal refuse during construction and permeabilities of the cover material which were lower than the coarse refuse material.

## The Sites

### Panama

The Panama Site (fig. 2) and surrounding areas have had a long history of coal mining. By 1896 annual coal production in Vernon County, primarily from underground methods, had reached a peak of 303,886 tons (10th Annual Report-State Mine Inspector). From that peak, coal production levels declined steadily until a new, large surface mine was opened at the Panama site in 1914. Surface mining at the site was short lived however. The mine apparently began along a coal outcrop near a natural drainage and progressed for a short distance before stopping due to increasing overburden depths or the presence of underground mines. The site was later used as a coal refuse disposal site during the 1940's. Approximately twenty-six acres were affected by surface coal refuse. An additional six acres of gob-covered haul roads also produced acid runoff.

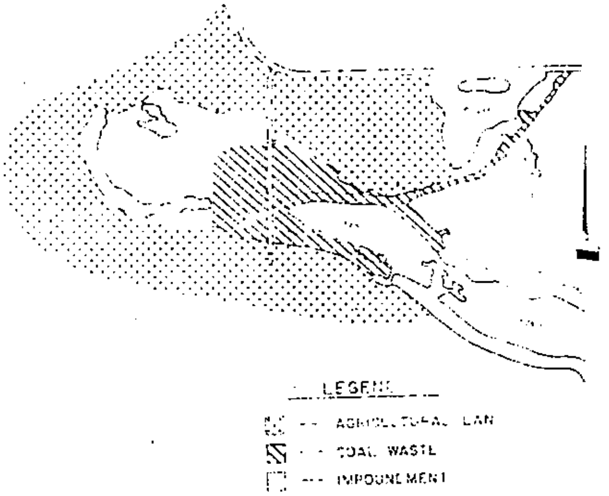

Figure 2. -- Panama site rendering showing relative position of materials. Planned wetland located along stream course on northern boundary of coal waste and agricultural land.

The main gob/slurry deposits were placed in a semicircular fashion around partially vegetated spoil. The site is virtually surrounded by cultivated cropland. A tributary to the Little Osage River received AMD and coal refuse sediment from the site. Sediment had been deposited several miles downstream, impacting cropland and commercially producing native pecan trees.

A good quality final cut impoundment was located a few hundred yards upstream (west) from the Panama AML reclamation site. This area supported a rich wetland habitat consisting of willow (*Salix* spp.), rice cutgrass (*Leersia oryzoides*), water primrose (*Jussiacea* spp.), cattails (*Typha angustifolia*) and other species.

### Robinson Branch

The Robinson Branch site (fig. 3) consisted of an abandoned tipple facility which was operated by Pittsburg and Midway Coal Company from 1942 to 1949. The area designated for reclamation consisted of a five-acre acid impoundment, a five-acre, forty-foot high gob pile, a ten-acre slurry pond and ten-acre shop, yard and tipple facility. The tipple site was located adjacent to an expansive area of AML (in excess of 1,000 acres) which had not been reclaimed. For the most part the abandoned spoils supported dense stands of native forest species and were interlaced with good quality impoundments, as evidenced by the area's popularity with fishermen.

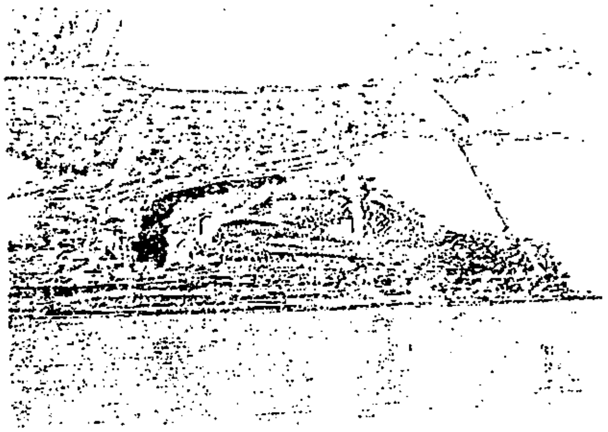

Figure 3. -- Robinson Branch site looking west. Note "L" shaped acid impoundment left center; gob pile center; slurry pond with breaches right center.

The tipple facility itself was located on unmined land adjacent to the coal outcrop. Undisturbed cropland bordered the site on the north, south and east. Robinson Branch, a tributary to the West Fork of Clear Creek, bisected the site on the west. Two breaches in the slurry pond dike allowed for direct deposition of highly pyritic coal refuse into the stream. In addition, the five-acre acid impoundment (pH 2.4) periodically discharged. The impact was predictable, with large volumes of coal fines in the stream channel, reducing channel capacity. During heavy storm events Robinson Branch frequently overtopped its banks depositing coal fines and AMD onto cultivated fields.

## INVESTIGATION RESULTS AND DISCUSSION

Studies were begun in August 1983 to determine the extent and characteristics of coal wastes, native soil, groundwater and AMD. Numerous test pits and hand borings were excavated to determine depth of coal wastes and elevations of undisturbed soils. Pit and boring logs were recorded and representative samples of materials were obtained. Field paste pH were recorded and samples split with one half bagged for laboratory analysis and the other half stored for future reference.

Surface water samples were obtained from all surface impoundments, streams and seeps within the study area. Field pH, redox potential, electrical conductivity and dissolved oxygen were measured with portable field instruments. Samples were split for later laboratory analysis.

### Soils/Spoil Investigation

#### Panama

A total of 26 Phase I test pits, 20 Phase II test pits and 15 surface holes were excavated at Panama. Eighty-seven field pH's were measured, seventy-two samples collected and twenty-eight samples tested by a laboratory.

In general, Phase I test pits indicated spoil materials to be extremely diverse, with the interior rows of piled spoils more acid than the exterior or what appeared to be box-cut spoils. Many interior spoils consistently had pH's below 3.0, which are not normally considered treatable (table 1). These materials are a major contributor of acid mine drainage and are not considered suitable as cover. The box-cut spoils appear to be treatable with lime and are considered acceptable cover.

Additional cover material that was generally uncontaminated was located in the creek bottom and along the perimeter of the project site. This cover material extended six to ten feet below existing ground elevations. Approximately two feet of contaminated soil or coal waste overtopped this material necessitating segregation.

Table 1.--Selected spoil sample results from the Panama site.

| Sample | pH | Total S (gms/100 gms) | Mg (lbs/acre) |
|---|---|---|---|
| 1-A | 2.6 | 8.24 | 2054 |
| 1-B | 3.6 | 5.49 | 754 |
| 2 | 6.0 | 2.53 | 1036 |
| 2-A | 3.9 | 8.56 | 936 |
| 2-D | 3.3 | 7.26 | 1049 |

Haul roads contained several feet of contaminated but treatable soil underlying one to two feet of highly acidic coal waste. After removal of coal waste, soils could be treated in place with lime, or used as cover material. A moderate (10 tons per acre) to high (20 tons per acre) lime requirement was estimated for almost all proposed cover material to be disturbed within the project area.

A high salt formation potential was anticipated in proposed cover material requiring high amounts of agricultural limestone. Test results indicated naturally high levels of magnesium (rates exceeding 500 lbs/acres) in proposed cover material. Combined with the high levels of sulfates indicated in some samples, formation of plant toxic levels of $M_gSO_4$ or severe Ca:Mg imbalances were of concern (Evangelou, 1983). It was recommended that non-dolomitic limestone be used to help avoid toxic salt build-up.

#### Robinson Branch

A total of 18 Phase I test pits, 15 Phase II test pits and 25 surface holes were excavated at the Robinson Branch site. Ninety-nine field pH's were measured, ninety-nine samples collected and thirty-eight samples tested by a laboratory.

Phase I spoil test pits on the west side of the site generated extremely low pH's and were considered to be unsuitable cover material. Underlying box-cut spoils would provide adequate cover but were buried too deep (in excess 10 feet) and therefore were not considered economically recoverable. Spoil piles east of the "L"-shaped acid pit were found to be suitable for cover requiring moderate levels of agricultural limestone. The coal waste in the slurry pond, stream and haul roads was extremely acidic and required removal and/or burial. Phase I test pits also indicated that native, but contaminated, soils were located beneath the slurry pond area.

Phase II test pits of the unmined areas and slurry pond verified that adequate quantities of suitable cover material were available within the project limits. Unmined areas could be excavated ten to twelve feet and would require low levels of treatment with lime. Soils underlying the slurry pond were within three to five feet of the surface and required moderate levels of treatment with lime.

## Surface Water Hydrology

Surface-water-related information was separated into two segments: 1) determining watershed characteristics and peak flows for selected drainage areas in the watershed and 2) water quality.

### Watershed Characteristics

Early in the project the watersheds containing the AML reclamation sites were investigated in an effort to gather information pertaining to how these sites had affected the hydrologic structure of the watersheds. Specific geomorphic information that ultimately was used in developing a conceptual model of the watersheds was collected as well as data related to hydraulic performance of channels and structures. A conceptual model was then run in digital format on computer to predict flow in channels and through various impoundments for four storm events. The magnitude of storms simulated were for a six-hour event with recurrance intervals of 2, 10, 25, and 100 years.

Based on the modeling results, AML-affected watersheds performed in two distinctly opposite ways. The AML coal refuse sites produced runoff very quickly, and were highly acid and sediment laden. On the other hand, the majority of the AML spoils in the watershed produced very little direct runoff due to numerous basins of internal drainage and large final cut impoundments through which most spoil runoff and upland water were routed.

Watershed modeling at Robinson Branch showed that all AML spoil produced runoff during the 100-year event. Two sites produced runoff during the 25-year event. These were the areas north of Highway C and one impoundment discharging to Robinson Branch near the southern edge of the project. The same two areas discharged insignificant amounts during the 2 and 10-year events.

The Panama AML site differed because it was separated from upland watersheds to the south by final cut impoundments. As a result, all flows were routed through the final cut impoundments which serve as detention basins. Peak flows for the 100-year event were reduced by approximately 75%.

The routing of upland water through final cuts at the Panama site significantly reduced downstream impact. Long after storm water had ceased to flow from the site, the impoundments continued to flow, spreading much of the sediment downstream to the wetlands near the Osage River, and diluting AMD. The opposite occured on Robinson Branch, where the watershed runoff had been effectively reduced by retention of water on upland AML sites. Due to the alteration of the Robinson Branch watershed, the managing of discharge rates at the site was an important factor in improving water quality after precipitation events and during periods of drought.

### Water Quality

The water quality segment consisted of 45 sampling stations, 53 field pH tests and 23 complete water samples from water bodies. Also, the pH of surface materials at 45 locations in and near the AML sites was measured. Sampling of stream courses was limited due to the prolonged drought conditions that persisted through the late summer and early fall of 1983. However, a clear understanding did emerge as to the distribution of poor quality water, and the source of the majority of the poor quality water (Table 2).

Poor quality water was defined as water with a pH less than 5.5 standard units and/or dissolved iron in excess of 10 mg/l. It is evident that exposed acidic spoil materials produce acid runoff and generate seeps through-out the watersheds of the AML sites. The AML sites included in this project are unique in their respective watersheds due to the ease by which acid sediments leave the sites. This, coupled with a disproportionate amount of excessively acid coal waste material that is exposed over wide areas, results in large amounts being redistributed by erosion and subsequent deposition.

The three main sources of acid water originating from acidic spoil and wastes were direct runoff from the sites, overflowing acid water from impoundments, and generation of acid water from off-site depositional areas. Because coal wastes are higher in pyritic forms of sulfur than spoil, they produce acids at a very high rate after being transported off site.

Table 2. -- Chemical analysis of selected sampling points, Robinson Branch site. Point A - Robinson Branch 600 feet downstream; Point B - Storm water runoff; Point C - acid impoundment; Point D - gob pile perennial seep.

| | A | B | C | D |
|---|---|---|---|---|
| pH | 3.2 | 2.6 | 2.1 | 3.1 |
| Acidity (mg/l) | 277 | 22,149 | 5,523 | 754 |
| Sulfate (mg/l) | 448 | 4,481 | 2,704 | 7,696 |
| Total Fe (mg/l) | 12 | 4,250 | 307 | 3,400 |
| Conductivity (mmhos/cm) | 900 | 5,300 | 5,700 | 6,850 |

Consequently, it is important to remove thin veneers of coal waste from depositional areas and road surfaces as well as to treat the large coal waste sources.

## Ground Water Hydrology

The ground water investigation was separated into two segments. The first included well installation and testing, the second covered water quality. The depth of the wells ranged from five feet to a maximum depth of 30 feet. A total of 14 wells were constructed; three to allow pump tests and water samples to be withdrawn, the other 11 for specialized testing of formation permeabilities.

Ground water quality was of concern on both sites because reclamation was expected to alter the present conditions, primarily by influencing the quantity and timing of ground water discharges. The quality of the ground water discharges was estimated to be influenced by two factors: the amount of soluble salts, and the oxidation/reduction state of the ground water. As a rule water will not persist in a strongly oxidized or reduced state as it moves through the environment. At both sites acidic water developed when pyritic materials were exposed to the atmosphere. When acid water (strongly oxidized) moves through the surface water system, the result typically is dissolution of basic materials and metals in the water's path and precipitation of iron as "yellow boy" as oxygen diffusion occurs and pH rises. However, much less is understood about what occurs when similar water infiltrates and travels through a ground water system.

Acid seeps are common and result from conditions not unlike those above ground; however, subsurface oxidation rates of pyritic materials proceed at a much slower rate than on the surface. Conversely, they proceed at a relatively constant rate because moisture and temperature are less variable. Most of the subsurface acid production associated with mining occurs within the vadose zone and the seasonally saturated zone above the water table. While oxidation rates are slower in the subsurface, they also occur vertically as well as horizontally. The result is that, on the surface, the upper crust is the major contributor, while in the subsurface, the entire depth may contribute. For example, if a 10-acre surface area produces 100 tons of acid per year effectively from the upper two inches of surface, this translates to 833 acre feet of material producing the acid.

Assume also that below the upper crust, all infiltrating water discharges as a seep and that acid production proceeds at an average rate 100 times less than on the surface. Under these conditions a 30-foot-deep site would still produce 180 tons of acid annually. In the unsaturated zone precipitation of iron. hydroxide complexes on alkaline surfaces also reduces the ability of the materials to neutralize the acids. However, changes begin to take place when acid waters reach the saturated zone.

At the Panama site pH and redox potentials were taken at three locations beginning with a recharging final cut, ground water from a well, and water discharging to a backhoe pit from ground water. Water movement was from the final cut through the spoil toward the backhoe pits. The pH values were 8.59, 6.75, and 5.67 respectively. The redox potential predictably followed pH with values of 16 mV, 23 mV, and 61 mV. The final sample showed evidence of super saturation of the ground water with carbonic acid as the water effervesced, releasing carbon dioxide. Within 10 minutes the pH of the water had risen to 5.98 and the redox potential dropped to 37 mV. The pH of much of the surface and subsurface materials through which the water moved was in the very acid range (pH 3.0-4.5). However, because the environment below the water table is not oxidizing and is close to a reducing environment, strongly acid solutions are altered in oxidation state and react readily with alkaline fractions in solution.

Tests were run to determine hydraulic conductivies of subsurface materials in 12 of the 14 wells drilled. As a rule the permeabilities ranged between 10 exp -5 to 10 exp -6 cm/sec. However, two significant exceptions existed. The first was the subsoil layer underlying the coal waste pile at Robinson Branch (1.9 x 10 exp -9 cm /sec); the second the subsoils at the Panama site (8.08 x 10 exp -8 cm/sec). It was believed that these conditions were influenced by the infiltrating acid water. The specific cause may have been precipitation of iron hydroxides in soil pore spaces, which thereby reduced permeabilities, or disassociation of clay aggregates into a less permeable mass, resulting in acid seeps at the base of the coal refuse. Infiltration rates on the gob pile with the surface crust removed were 77.2 cm/hr; graded spoil at Panama with the crust removed had an a infiltration rate of 21.3 cm/hr. The coal wastes were very permeable and absorbed water readily without a surface crust. Thus they were capable of yielding large amounts of acid water.

From a hydrologic standpoint, it was concluded that control of water quality within the coal waste mass would not be too difficult. By controlling lateral movement of water out of the waste mass, and controlling the maximum elevation of water accumulating in the coal waste, surface seeps could be controlled. Sub-surface drains were considered the most economical means of controlling ground water levels. The best configuration for position of outlets relative to the surface depended upon the total discharges determined during design of such a system.

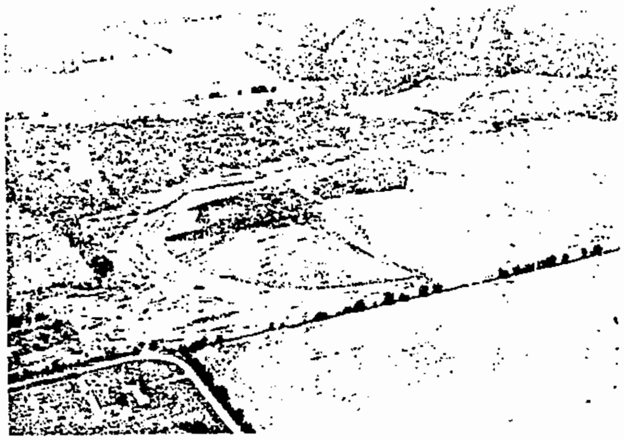

Figure 4. -- Robinson Branch site showing curved dike and coal refuse prior to placement of final cover.

## RECLAMATION PLAN

### Controlling Seepage From Buried Coal Waste

The first design consideration was to reduce the existing high infiltration rates with a clay cap. This eliminated the rapidly fluctuating water table and high discharge rates following precipitation events. When infiltration does result in an excess passing to the water table, it is of lesser magnitude and occurs over longer time spans. The result is that due to the high permeability of the coal waste, the water table tends to rise and fall in a uniform manner.

The second design feature was the grading of the coal waste to relatively flat slopes. This helped ensure that infiltrating water would not respond to heterogeneities in the coal waste mass. It also buffered the discharge response of the water table to infiltrating water. If slopes were too steep, water, traveling under the pressure of higher hydraulic gradients, could emerge horizontally at obstructions as simple as grading planes, resulting in mid-slope seeps.

In addition, the discharge characteristics of a high gradient water table would tend to be more sudden, with higher peaks of shorter duration. A high percentage of the coal waste would also be above the water table, where acid production would proceed at a faster rate.

The third design feature was the use of dikes constructed of clay subsoil material. Figure 4 shows dike installation prior to placement of final cover. The purpose of the dikes was to provide a relatively watertight barrier around the coal waste in order to maintain stable water levels within the coal waste. The dikes were keyed into the strata of lowest permeability and higher ground.

The final design feature was the use of a subsurface drainage tile system around the perimeter of the graded coal waste. Figures 5 and 6 show pre-and post-reclamation cross sections including relative positions of the wetland, dike and tile drain. Tile drains control maximum ground water levels and points of discharge. By keeping the graded coal waste surfaces relatively flat, a much denser subsurface drainage system was avoided. The perimeter drain system was designed to outlet seepage water into adjacent wetland impoundments that were constructed during the course of excavating borrow material. The wetland dilutes the discharge water, and creates a reducing environment that is more tolerant of pH changes than are soil or stream channel systems.

### Wetland Abatement of Controlled Acid Seepage

Utilization of wetland environments was considered essential in order to provide the final control mechanism for planned seepage. The effectiveness of wetlands for controlling AMD is based on the principal of chemical reduction zones due to water saturation and host

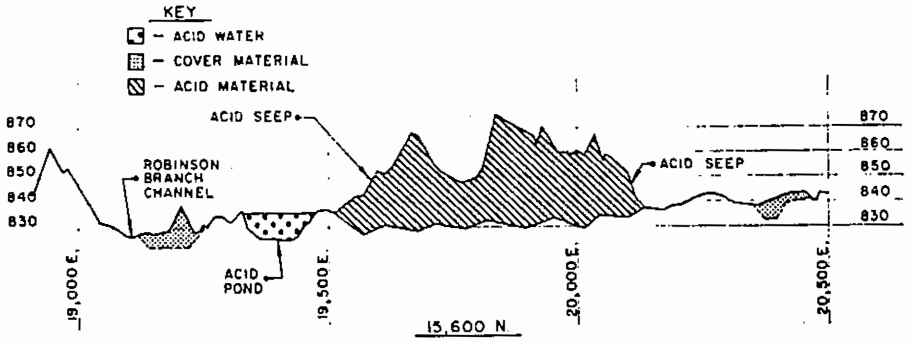

Figure 5. -- Pre-reclamation cross section of Robinson Branch site showing relative position of material types. Seepage points actually located at gob pile-soil interface.

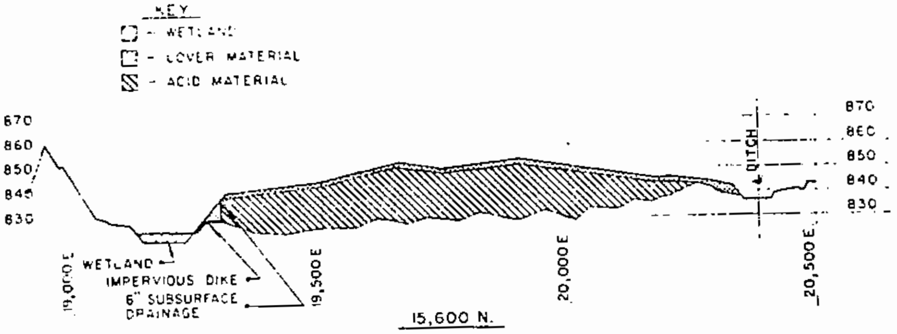

Figure 6. -- Post-reclamation cross section of Robinson Branch site showing position of wetland, dike and subsurface drain.

wetland plant species. Located adjacent to natural drainages, both sites provided excellent opportunities for wetland habitat development.

Upon removal of cover material, the existing drainages were routed through the excavations. Wetland habitat was provided by designing for shallow (littoral) zones on the impoundment perimeter corresponding to subsurface drains from the buried coal refuse. Maximum impoundment depths, ranging from three to six feet, were maintained by concrete overflow structures.

Direct planting of wetland plant species was not required due to an abundance of naturally established wetlands in AML sites located upstream. By the Fall of 1986, the Panama site had been colonized by water primrose (Jussiacea spp.), cattails (Typha angustifolia) smartweeds (Polygonum spp.), and rice cutgrass (Leersia oryzoides) along with thriving stands of switchgrass (Panicum virgatum) and reed canary grass (Phalaris arundinacea) which were seeded along the impoundment shoreline (fig. 7).

## Utilization of Buried Native Soils

Consistent with Missouri Land Reclamation Commission policy, an effort was made to utilize disturbed materials for reclamation. As discussed earlier, both sites were surrounded for the most part by agricultural land. The Robinson Branch site had marginally vegetated spoil bordering on the west. Spoiled overburden at Panama was located in the middle of the coal waste. Although readily available, spoil was eliminated as a cover source for the following reasons: 1) shale and resulting acid levels were unacceptably high and 2) textures were too coarse to provide the desired lower oxygen diffusion rates.

Test pit and boring data verified the presence of buried native soils underlying refuse deposits on both sites. Upper layers identified as contaminated from sulfur infiltration were disposed of with coal refuse. Remaining materials were treated with agricultural limestone at rates determined by acid-base accounting. Non-dolomitic limestone was specified to avoid build-up of magnesium sulfate salts.

Although primary borrow sources were from the planned wetland excavations, in-place treatment of buried soils underlying the slurry pond at Robinson Branch allowed for a significant reduction in refuse impacted areas. Removal and consolidation of slurry and gob behind the groundwater dike effectively reduced the disposal area by nearly 50 percent (from approximately 19.5 acres to 10 acres).

Figure 7. -- Panama wetland with emerging vegetation one year after completion (Fall 1986). Note dike to right of water.

## Vegetative Establishment

Plant material selection was based on a philosophy of providing a range of vegetative types which could selectively adapt to the varying soil conditions, in addition to providing wildlife habitat (table 3). Two basic mixtures were specified, one for drainages and lowlands, another for upland sites. Western wheatgrass (*Agropyron smithii*) was selected as a salt tolerant cool season grass. Warm season native grass species were selected for relative drought tolerance (due to firm clay soils in this case) and low nutrient requirements. K-31 Tall Fescue (*Festuca arundinacea*) was included due to salt tolerance and a strong Commission tradition.

It was understood when writing contract specifications that the specific seeding dates would not be known. Only two broad dates were specified: Spring, March 15 through May 15; and Fall, August 15 through October 1. Obviously, different species would have competitive advantage depending on which season they were planted, or within a specified season (e.g. early spring vs. late spring) and weather conditions. Therefore, a broad based mixture was expected to ensure desired results. A consequence unforeseen, however, at the Panama site was the contractor's heavy overseeding of tall fescue during the Fall of 1985 in order to achieve cover requirements for final payment.

Table 3. -- Seed mixture for type 1, upland areas and type 2, lowland areas.

| Perennial Grasses: | lbs.PLS[1]/Acre | |
|---|---|---|
| | T-1 | T-2 |
| *Festuca arundinacea* | | |
| K-31 tall fescue | 2.0 | 2.0 |
| *Agropyron smithii* | | |
| w. wheatgrass (Barton) | 4.0 | 4.0 |
| (Pubescent) | 2.0 | 2.0 |
| *Panicum virgatum* | | |
| switchgrass (Blackwell) | 2.0 | 2.0 |
| (Cave-in-Rock) | 1.0 | -- |
| (Kanlow) | -- | 1.5 |
| *Phalaris arundinacea* | | |
| reed canarygrass (Ioreed) | -- | 1.0 |
| *Andropogon gerardi* | | |
| big bluestem (Rountree) | 1.5 | -- |
| *Sorghastrum nutans* | | |
| Indiangrass (Rumsey) | 1.5 | |
| Legumes: | | |
| *Medicago sativa* | | |
| alfalfa (Ranger) | 1.5 | -- |
| *Lotus corniculatus* | | |
| birdsfoot trefoil (Dawn) | 1.5 | 1.0 |
| *Trifolium repens* | | |
| white clover (Ladino) | -- | 1.0 |
| *Trifolium pratense* | | |
| red clover | 1.5 | -- |

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[1] Pure live seed

Despite these drawbacks a diverse variety of seeded species emerged. Tall fescue dominated most areas although densities varied. Western wheatgrass was also observed. Of the warm season species, kanlow switchgrass (*Panicum virgatum*) produced excellent dense stands in waterways and other low lying areas. Reed canarygrass (*Phalaris arundinacea*) was also present in drainages although slower to establish. Some bluestems were observed going to seed during the summer of 1986, the first growing season. All leguminous species were observed with clovers dominating.

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