ABSTRACT

Three separate large-scale field demonstration projects begun within the last five years at abandoned mines, have involved in one way or another, the application of both flue gas desulfurization (FGD) and fluidized bed combustion (FBC) residues in mine land reclamation. The first, at Forsythe-Energy, used FGD residues as well as fly ash as substitute fill to a surface mine pit; the second, at Thunderbird, created seven caps composed of varying proportions of FBC fly and bottom ashes; and the third, at Harco, involved amending coal processing waste with FGD residues to control infiltration and to induce alkaline recharge. Previous studies monitored all three demonstration sites for short term performance, and in general, no significant environmental impacts were detected. The long-term capacity of the residues to control acid mine drainage and their long-term impact on the environment, however, are unknown. Changes in regulations that would allow the widespread application of the residues in reclamation as well as industry acceptance of these methods hinges on the long-term behavior. The first year of this two year project continued monitoring the performance and environmental impacts of the different reclamation strategies applied at the three sites. Geochemical results collected over the past year suggest that the residues can ameliorate groundwater impacted by mining activities. In addition, to date, leachate generated by the residues has not degraded groundwater or surface water quality. The final analysis of the data collected over the two year project period will include an evaluation of the effectiveness of each reclamation technique, as well as environmental impacts originating with the FBC and FGD residues, if any. In addition, data collected will be used to adjust groundwater flow and contaminant transport models at each site. The final report will synthesize the results with earlier research at all three sites.
EXECUTIVE SUMMARY

Three separate large-scale field demonstration projects begun within the last five years at abandoned mines, have involved in one way or another, the application of both flue gas desulfurization (FGD) and fluidized bed combustion (FBC) residues in mine land reclamation. The first, at Forsythe-Energy, used FGD residues as well as fly ash as substitute fill to a surface mine pit; the second, at Thunderbird, created seven caps composed of varying proportions of FBC fly and bottom ashes; and the third, at Harco, involved amending coal processing waste with FGD residues to control infiltration and to induce alkaline recharge. Previous studies monitored all three demonstration sites for short term performance, and in general, no significant environmental impacts were detected. Long-term impacts and long-term performance of FBC and FGD residues in preventing acid mine drainage, on the other hand, are unknown. Industry and regulatory agency acceptance of new reclamation strategies employing FGD or FBC residues hinges on an analysis of long-term environmental impacts. This report summarizes continued environmental monitoring for the past year at all three demonstration sites.

The monitoring network at the Forsythe-Energy site has only monitoring wells (including a drain beneath the residues). The network at Thunderbird includes a rain gauge, monitoring wells, survey points, lysimeters and surface water sampling points along Briar Creek. The network at Harco, once reclamation work is completed, will include a rain gauge, monitoring wells, suction and free-drainage lysimeters, infiltrometers, tensiometers, and TDR probes. Progress made this past year can be divided into work completed in order to prepare a site for long-term sampling and a preliminary analysis of surface and groundwater quality at the Forsythe-Energy and Thunderbird sites.

Site Preparation Work

Reclamation has altered groundwater flow directions away from wells originally installed to monitor downgradient groundwater quality at the Forsythe-Energy site. Other wells now downgradient are too far from the residue fill to detect leachate. A new well was installed immediately downgradient of the fill in December, 1996 following accepted standard practices. Groundwater sampling at the Forsythe-Energy began once this well was installed.

The dedicated sampling system originally intended for the wells at the Thunderbird site requires access to the well head with a vehicle that can carry the heavy and bulky gas cylinders used to drive the pumps. Access roads to the Thunderbird site were removed just before the start of this project. A wet autumn then prevented access to the monitoring wells with a vehicle. Fortunately, an alternative sampling system became an option when another project, funded by the US Department of Energy, allowed the Department of Geology to acquire an actuator for driving inertial pumps. The relatively light weight actuator can be carried to remote sites. Dedicated inertial pumps were installed at Thunderbird after acquisition of the actuator in the spring, 1997. Groundwater sampling began at Thunderbird in June, 1997.
At the time this project began, the contractor retained by the Illinois Abandoned Mine Land Reclamation Division of the Illinois Department of Natural Resources to reclaim the Harco site still had not completed the work. Because of this, groundwater monitoring wells still needed to be installed, a task not originally planned for this project. Three groundwater monitoring wells were installed at the site in May and July, 1997; one upgradient and two downgradient of soil amendments with FGD residues. Additional wells will be installed as the contractor completes reclamation adjacent to the test plot in the coming year. No groundwater samples were collected at Harco. The first set of samples will be collected the first quarter of the second year of the project.

Geochemistry

Water quality sampling for this project followed accepted standard practices to effectively guarantee reliable field geochemical and hydrologic data. In the course of the past year, 68 samples were collected at the three sites from surface and groundwater monitoring points. Three samples were collected from each field instrument during a sampling event; one for cations, one for anions, and one for alkalinity. The alkalinity tests were performed using a Mettler Auto Titrator in the Mining Engineering Environmental Laboratory. The remaining tests were performed in the Mining Engineering Carterville Laboratories, or the joint water chemistry lab operated by Mining Engineering and Geology. Anions were determined potentiometrically or by Liquid Ion Chromatography using a Dionex 10. Cations were determined by ICP with more precise measurements for lead, arsenic and selenium made by graphite furnace or hydride formation AA.

An analysis of the samples collected at each site seeks an answer to two questions; Does leachate generated by the FBC and FGD residues impact groundwater or surface water quality? and, Do these residues mitigate acid mine drainage? The critical indicators of acid mine drainage are elevated concentrations of iron, magnesium, manganese, and sulfate. The fly ash which composed part of the fill at the Forsythe-Energy site generates high concentrations of boron in its leachate. The FBC residues at Thunderbird and the FGD residues at Forsythe-Energy and Harco produce high concentrations of sodium and potassium in their leachate.

Samples at the Forsythe-Energy site collected from a sand filter installed horizontally at the base of the residue fill consistently contain high concentrations of boron, and reduced levels of iron, manganese, magnesium, and sulfate relative to the native groundwater. Boron is the best indicator of residue leachate at this site. This constituent, however, is not detected in wells located downgradient at concentrations significantly different than those in wells upgradient of the residue fill. In addition, iron, magnesium, manganese, and sulfate, traditional indicators of acid mine drainage, have reduced levels in downgradient wells when compared to upgradient wells.

The Thunderbird site also showed positive effects of the FBC caps, both in groundwater and stream samples. Many factors can influence the geochemistry of stream water other
than drainage across the reclaimed mine site, including the duration and intensity of recent storm events. The concentration of some constituents tends to fluctuate from one sample event to another because of these factors. Certain trends in the Briar Creek data, however, are evident. Sodium and potassium, indicators of leachate generated by the FBC residues at this site, are not detected in concentrations downstream from the test plots in levels significantly different than those upstream.

Upgradient wells at the Thunderbird site have high concentrations of iron, manganese, magnesium and sulfate and low pH levels relative to the wells located downgradient of the residues. Preliminary groundwater data, therefore, suggests some ameliorating effects of the residues. Sodium and potassium concentrations in the downgradient wells also do not exceed those detected in the upgradient wells, indicating that at the present time leachate generated by the residues has not reached groundwater.

Plans for the Second Year of the Project

Environmental monitoring will continue during the second year of the project. The final analysis of the data collected over the two year project period will include an evaluation of the effectiveness of each reclamation technique, as well as environmental impacts originating with the FBC and FGD residues, if any. In addition, data collected will be used to adjust groundwater flow and contaminant transport models at each site. The final report will synthesize the results with earlier research at all three sites.
OBJECTIVES

The purpose of this project is to evaluate the effectiveness and, more importantly, the long-term stability of sites reclaimed with a mixture of fluidized bed combustion (FBC) or flue gas desulfurization (FGD) residues and mine spoil or mine processing wastes. The two year program continues water quality monitoring at a network of instruments established during three previous projects; at the abandoned Forsythe-Energy, Thunderbird, and Harco Mines. Assessment of the hydrologic data collected at the mines will ultimately include groundwater flow and contaminant transport models of site conditions.

INTRODUCTION AND BACKGROUND

Under the terms of the Clean Air Act, there is little doubt that most use of Illinois coal will be linked to some form of sulfate control technology or practice, either on the specific boiler burning the Illinois coal, or on another facility from which emission allowances are transferred. Only two sulfate control technologies have found full scale commercial use in Illinois; FBC boilers and wet scrubbers. Both of these technologies produce significant volumes of residues.

Innovative reclamation strategies with FGD and FBC residues can provide a beneficial outlet for these materials. In reclamation, the residues replace the agricultural limestone that is commonly used to neutralize the potential acidity in acid forming materials at the site. But the use of FGD and FBC residues at the mine site can also reduce soil hydraulic conductivity. This enables the residues to function simultaneously as an infiltration barrier and as a source of alkaline recharge at the same time.

Large-scale field demonstration projects at the Forsythe-Energy, Thunderbird, and Harco Mines, have involved in one way or another, the application of both FGD and FBC residues in mine land reclamation. The Illinois Abandoned Mine Land Reclamation Division (IALMRLD) of the Illinois Department of Natural Resources retained contractors to complete reclamation at all three sites. Preliminary environmental monitoring suggests that combustion residues can effectively control acid mine drainage when incorporated in soils, used as liners, or as substitute fill in surface mined land. No environmental impacts originating from the residues were detected in groundwater resources at the time of the initial studies.

The current project continues the environmental monitoring at all three sites and addresses an often overlooked aspect of large scale field demonstration projects; long-term performance and environmental impacts. Changes in regulations that would allow the widespread application of FBC and FGD residues in reclamation as well as industry acceptance of these methods hinges on the long-term behavior of the residues in large field scale demonstration projects.

Forsythe-Energy Project
Five years ago, the National Mine Land Reclamation Center (NMLRC) funded a three year project at the abandoned Forsythe-Energy Mine. A final cut strip pit at the site was filled with unoxidized sulfite rich scrubber sludge mixed with fly ash (Southern Illinois Power, Marion Station) over a two year period. The residues acted as a structural fill to stabilize an adjacent roadway. A network of monitoring wells was installed in the field and laboratory column studies were begun to determine potential environmental impacts from the residues one year prior to placement of the fill. A drain was installed directly beneath the fill to collect leachate before attenuation or dilution in the environment. Column studies suggested that the FGD residues actually cleaned the native groundwater, and that laboratory tests could be devised to predict field leaching and groundwater cleaning performance. Preliminary groundwater flow and contaminant transport models of the site were developed.

No leachate from the residues was detected downgradient from the residues, but the samples from the drain beneath the fill do indicate a distinctive quality to the leachate associated with the fill. In addition, a shift in groundwater flow as a result of the new topography indicated that the existing monitoring well network was inadequate.

Thunderbird Project

The Illinois Clean Coal Institute (ICCI) funded a two year study at the abandoned Thunderbird mine. The objective here was to test, on a large scale, if FBC combustion residues mixed with native soils can form an infiltration barrier as effective as the clay liners required under RCRA. Seven plots were established, each with a different composition of FBC fly and bottom ashes. Thirty-two lysimeters were installed prior to placement of the liners, but heavy equipment took its toll, damaging many of the instruments. Twelve replacement lysimeters under six of the test plots and a network of monitoring wells were then installed to assess environment impacts. In addition, the quality of the water in nearby Briar Creek has been monitored regularly since the study began.

The Briar Creek sample network is important both as a means of verifying the elimination of acid drainage from the GOB filled pit, and for determining that the quality of water running off of the site has not been adversely affected by trace metals in the ash. Even if the cap is completely successful as an infiltration barrier, the question of whether the ash contaminates the surface run-off must be addressed.

Harco

The ICCI also funded a one year study at the abandoned Harco Mine. The reclamation involved amending coal processing waste with FGD residues to control infiltration and to induce alkaline recharge. Previous studies characterized the material used in the Harco reclamation, finding a laboratory hydraulic conductivity of 1E-5 cm/sec that has been confirmed in the field. Ten lysimeters were installed prior to this project, but delays in
reclamation work at the site have impacted the environmental studies. The installation of the complete monitoring network including a rain gauge, groundwater monitoring wells, suction lysimeters, infiltrometers, tensiometers, and TDR probes must wait until reclamation is complete.

**EXPERIMENTAL PROCEDURES**

In our earlier research, the hydrology of the sites was assessed through a brute force, multidirectional approach. Instrumentation for monitoring infiltration includes free-drainage and suction lysimeters, infiltrometers, tensiometers, and time domain reflectometry (TDR) stations. In addition, shallow monitoring wells provide information on groundwater flow and quality at the site and rain gauges capture precipitation. This approach yields data on changes in site hydrology immediately after reclamation as well as a means of evaluating the advantages and disadvantages of the different reclamation strategies.

**Monitoring Well Installation**

Well installation followed accepted guidelines (USEPA, 1986). All boreholes were drilled with a Mobile B53 drill rig driving a hollow stem auger. All monitoring well casings were installed in a six inch (minimum) diameter hole. The casing was constructed of 2 inch ID threaded schedule 40 PVC pipe. PVC is considered an acceptable well casing material when aggressive organic leachate mixtures will not be contacted (Barcelona and others, 1985). No solvent cement was used; instead pipe junctions were sealed with an O ring to ensure against leakage. The monitoring wells installed this past year have prepacked five foot long screens. A prepacked screen is composed of a two inch slotted screen (0.01 inch) installed in a six inch diameter perforated outer casing lined with pelon fabric (polyester). Ottawa quartz sand fills the annulus between the two casings. A borehole drilled into saturated spoil or coal processing waste tends to collapse before an effective sand pack can be constructed in the hole. Prepacked screens ensure an effective filter between the well and the surrounding sediment.

After placing the prepacked screen at the desired depth, sand is added to the hole to a minimum of 30 cm above the top of the screen to minimize interference from the overlying grout. A minimum of 1.5 m of hydrated bentonite filled the annulus above the sand. A mixture of cement and bentonite (5% dry weight bentonite added to cement after mixing with water) filled the annulus above the bentonite plug to just below the frost line. Concrete filled the remaining annulus to a point above grade to minimize surface water interference. An external plastic locking casing was set in the concrete to protect the plastic well casing at the surface. The wells were developed by overpumping and surging. Water yielded from the wells contains little visible suspended solids. At the present time, the top of the plastic inner well casings has not been surveyed to a common datum at each site. Well completion diagrams will be prepared once surveying is complete.
Hydrologic Monitoring

Esling and Caudle (1990) described the design of the rain gauges and free-drainage lysimeters installed at both the Thunderbird and Harco sites. A free-drainage lysimeter is a device installed below the surface which traps infiltrating water. A pan buried in soil is an example of a type of free-drainage lysimeter. The principle is simple; infiltrating water on its way to the groundwater system collects in the pan. The natural attraction of water to soil particles, however, will hold and keep infiltrating water from entering a cavity. In fact, water enters a subsurface cavity only after a saturated zone (perched system) develops and the pressures in this perched zone exceed the pressure in the cavity (the pressure in the cavity will be equivalent to atmospheric pressure if the cavity is vented to the surface). Before the pressures in the perched zone above the lysimeter cavity exceed the pressure in the cavity, water may actually flow laterally, bypassing the lysimeter. The lysimeters at both the Thunderbird and Harco sites minimize this problem. Brammer and Esling (1989) demonstrated that the diameter of a free-drainage lysimeter should exceed 25 cm to effectively trap infiltrating water in fine-textured materials. All lysimeters at the demonstration sites have diameters in excess of 25 cm. Each lysimeter consists of a plastic cylinder with a sealed end filled with a layer of silica sand and spoil, emplaced below grade in a manner that should minimize disturbance to the surrounding material. The lysimeter directs flow to a sump connected to a standpipe. It is important to note that if the residue caps are functioning as designed, little or no water will collect in the sump. Work at Thunderbird, however, suggests that at least during the period immediately after placement of the cap, significant infiltration can find its way into the lysimeters. By measuring the amount of water collected relative to the magnitude of a precipitation event, the permeability and integrity of the liner can be determined.

Two test plots with detailed instrumentation will be established at Harco once reclamation is completed. Each test plot will include two free drainage lysimeters, three suction lysimeters, three TDR probes, three tensiometers, and one large diameter infiltrometer. The infiltrometer will artificially induce infiltration at the site and will provide a means of testing the performance of the other instruments. The suction lysimeters can sample moisture in soil for water quality determinations. The tensiometer measures soil suction, or negative pressures in the vadose zone. The TDR unit monitors moisture content at regular short intervals under the test plots.
Water Quality Monitoring: General Procedures

Water quality sampling follows stringent U.S. Environmental Protection Agency (USEPA) procedures (USEPA, 1979; 1984a; 1984b; 1986) in order to effectively guarantee reliable field geochemical and hydrologic data. Field personnel assemble all sampling instruments and containers the day prior to each sample trip. The transportation containers (ice chests) are prepared in areas remote from reagent or solvent storage on the day of the sample trip. The field personnel prepare a trip blank, just before leaving for the field. This blank serves a singular purpose; to document how preservation chemicals, sample container, or handling procedures affect sample analyses. The trip blanks contain deionized water.

Samples are collected through filters (0.45 micron) into sample bottles to overflowing. One 250 ml sample and two 500 ml sample are collected and preserved following USEPA (1979; 1984a; 1984b) guidelines (Table 1). The samples are placed in an ice bath immediately after collection and kept cold for transport to SIUC within 24 hours. The tentative parameters (Table 1) should cover any contaminants originating from the FBC and FGD residues.

Water Quality Monitoring: Groundwater Sampling

Table 1. Proposed cations and anions for laboratory analysis, analysis method, and sample preservation method. All samples are filtered through a 0.45 micron in-line filter. All containers and caps are polyethylene, polypropylene, or borosilicate glass. One 500 ml bottle contains the sample for cations; one 250 ml bottle contains the sample for anions; one 500 ml bottle contains the sample for alkalinity titrations.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Method</th>
<th>Preservation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cations: Al, B, Ba</td>
<td>ICP</td>
<td>Cooled to 4 Degrees C</td>
</tr>
<tr>
<td>Be, Ca, Cd, Co, Cr, Cu, Fe</td>
<td>Filtered, Acidified to pH less than 2 with Nitric Acid</td>
<td></td>
</tr>
<tr>
<td>Hg, K, Mg, Mn, Na, Ni, Zn</td>
<td>Cooled to 4 Degrees C</td>
<td></td>
</tr>
<tr>
<td>Cations: Pb, Se, As</td>
<td>ICP\AA</td>
<td>Filtered, Acidified to pH less than 2 with Nitric Acid</td>
</tr>
<tr>
<td>Anions: Cl, F, NO₃, SO₄</td>
<td>IC</td>
<td>Cooled to 4 Degrees C</td>
</tr>
<tr>
<td>Alkalinity: HCO₃, CO₃</td>
<td>Titration</td>
<td>Filtered</td>
</tr>
</tbody>
</table>
Each sampled well is equipped with a dedicated gas-driven bladder pump or inertial pump for purging and sampling. The dedicated pumps offer a means of monitoring temperature, conductance and pH during purging with a flow-through cell. The dedicated sampling systems also reduce sampling time and eliminate any possibility of cross-well contamination.

On arrival at the field site, water level elevation is determined three times with a tape, and recorded to the nearest 0.01 ft. In order to obtain representative samples, micro purging techniques are employed (Puls and Barcelona, 1989; Robin and Gillham, 1987; Kearl and others, 1992; Barcelona and others, 1985). When compared to the alternative, purging multiple well volumes with a purge pump and packer, micro purging significantly reduces the cost of sampling. The monitoring wells are purged until stable readings of dissolved oxygen, pH, temperature and specific conductance are obtained (Table 2). Stable readings are defined as any reading within ± 10% of the previous reading with readings taken at 2 minute intervals at the maximum flow rate of the well or a flow rate of 2 gallons per minute, whichever is less. If the well yields are low enough so that the well is pumped dry before parameters stabilize, the field personnel wait for the water levels to recover and then collect the groundwater sample.

**Water Quality Monitoring: Surface Water Samples**

Water samples along Briar Creek at the Thunderbird site are collected according to USEPA approved methods and tested for pH and conductivity in the field using a portable pH meter system. Samples are forced under a vacuum system through a disposable filter pack into the sample bottles. All samples along Briar Creek are collected on the same day.
Table 2. Minimum field parameters measured in groundwater samples, along with the analysis method.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Method</th>
<th>Preservation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Temperature</td>
<td>Flow Through Cell - Single Probe (QED Model FC1000) (0.1 degrees Celsius)</td>
<td>Field Determined Unfiltered</td>
</tr>
<tr>
<td>Specific Conductance</td>
<td>Flow Through Cell - Single Probe (QED Model FC1000) (0.1% of range)</td>
<td>Field Determined Unfiltered</td>
</tr>
<tr>
<td>pH</td>
<td>Flow Through Cell - Single Probe (QED Model FC1000) (pH units 0.01)</td>
<td>Field Determined Unfiltered</td>
</tr>
<tr>
<td>Dissolved Oxygen</td>
<td>Flow Through Cell - Single Probe (QED Model FC1000) (0.1 ppm)</td>
<td>Field Determined Unfiltered</td>
</tr>
<tr>
<td>Hydraulic Head</td>
<td>Electric Tape (within 0.01 feet)</td>
<td>NA</td>
</tr>
</tbody>
</table>

Water Quality Monitoring: Water Quality Analyses

Three samples are collected from each field instrument during a sampling event; one for cations, one for anions, and one for alkalinity. The alkalinity tests are performed using a Mettler Auto Titrator in the Mining Engineering Environmental Laboratory. The remaining tests are performed in the Mining Engineering Carterville Laboratories, or the joint water chemistry lab operated by Mining Engineering and Geology. Anions are determined potentiometrically or by Liquid Ion Chromatography using a Dionex 10. Cations are determined by ICP. If more precise measurement for lead, arsenic and selenium are necessary, they are determined by graphite furnace or hydride formation AA.

Data Analyses and Modeling Studies

The final analysis of the data collected over the two year project period will include an evaluation of the effectiveness of each reclamation technique, as well as environmental impacts originating with the FBC and FGD residues, if any. In addition, data collected will be used to adjust groundwater flow and contaminant transport models at each site. The final report will synthesize the results with earlier research at all three sites.
The flow and transport models reflect the conceptual models of the geology and are calibrated to the available hydrologic data. The purpose of the modeling is to experiment with the natural system in order to get a better understanding of the factors controlling groundwater flow and contaminant transport. Specific modeling objectives include: 1) Develop a reliable model of the steady state groundwater flow system at the test sites; 2) Determine weakness in the available data through the calibration and sensitivity analysis of the model, and 3) Apply numeric models of contaminant transport to worse case scenarios, based on the steady state flow system generated through flow modeling efforts.

Flow modeling follows a precise protocol as described by van der Heijde and El Nawawy (1992) and Anderson and Woessner (1992), including conceptual model development, calibration, and sensitivity analysis. Calibration shows weaknesses in the input data or flaws in the conceptual model. In this way, modeling helps improve the overall conceptual model of site conditions. A properly performed sensitivity analysis identifies those parameters most influential in determining the accuracy and precision of the model.

Calibration of the transport models is not possible if no contaminants reach one of the monitoring wells in less than two years of monitoring. Because of this, the main purpose of the contaminant transport modeling is to investigate different scenarios for contaminant migration away from the combustion residues based on a range for each input parameter, including nominal, minimum, and maximum values. The range of values is justified based on field data or published information. Contaminant transport model scenarios will cover time periods of up to 100 years or until a steady state plume develops.

RESULTS AND DISCUSSION

The purpose of this project is fairly straightforward; regularly collect surface and groundwater samples at sites reclaimed with FBC or FGD residues. Accomplishing this task, however, required considerable site preparation work. This section is divided into two parts; one documenting field work that prepared a site for groundwater monitoring and the other describing the geochemistry of the collected samples.

Site Preparation Work

Reclamation had altered groundwater flow directions away from wells originally installed to monitor downgradient groundwater quality at the Forsythe-Energy site. Other wells now downgradient are too far from the residue fill to detect leachate. A new well was installed in December, 1996 at this site immediately downgradient of the fill, following methods described in another section of this report. No samples were taken at the Forsythe Energy site until after the well was installed.

The dedicated sampling system originally intended for the wells at the Thunderbird site requires access to the well head with a vehicle that can carry the heavy and bulky gas cylinders used to drive the pumps. Access roads to the Thunderbird site were removed
just before the start of this project. A wet autumn then prevented access to the monitoring wells with a vehicle. Fortunately, an alternative sampling system became an option when another project, funded by the US Department of Energy, allowed the Department of Geology to acquire an actuator for driving inertial pumps. The fairly light weight actuator can be carried to remote sites. Dedicated inertial pumps were installed at Thunderbird after acquisition of the actuator in the spring, 1997. Groundwater sampling began at Thunderbird in June, 1997.

At the time this project began, the contractor retained by the IAMLRD at the Harco site still had not completed reclamation work. Because of this, groundwater monitoring wells still needed to be installed, a task not originally planned for this project. Three groundwater monitoring wells were installed at the site in May and July of 1997; one upgradient and two downgradient of soil amendments with FGD residues. Additional wells will be installed as the contractor completes reclamation adjacent to the test plot in the coming year. No groundwater samples were collected at Harco. The first set of samples will be collected the first quarter of the second year of the project.

Geochemistry

An analysis of the samples collected at each site seeks an answer to two questions; Does leachate generated by the coal combustion and flue gas desulferization residues impact groundwater or surface water quality? and, Do these residues mitigate acid mine drainage? Tables 3 through 8 list the results of geochemical analyses. A large array of numbers can often look confusing, but the critical indicators of acid mine drainage are elevated concentrations of iron, magnesium, manganese, and sulfate. The fly ash which composed part of the fill at the Forsythe-Energy site generates high concentrations of boron in its leachate. The FBC residues at Thunderbird and the FGD residues at Forsythe-Energy and Harco produce high concentrations of sodium and potassium in their leachate. This section presents preliminary findings.

Table 3 summarizes cation concentrations and table 4 summarizes anion concentrations and parameters measured in the field at the Forsythe-Energy site. Well 10 is upgradient, well 14 is the new downgradient well, and wells 9 and 11 are the old downgradient wells. The drain sample is groundwater collected from a sand filter installed horizontally at the base of the residue fill. The drain shows high concentrations of boron, sodium, and potassium and much lower concentrations of the iron, magnesium, manganese, and sulfate relative to background groundwater. Boron, sodium, and potassium are not detected in the downgradient wells in levels significantly different than those in the upgradient wells. The key indicators of acid mine drainage have reduced levels in downgradient wells. The data, therefore, suggest that the FGD/fly ash fill has reduced the concentrations of the main constituents of acid mine drainage and that leachate generated by the residues has not impacted groundwater quality.
Table 5 summarizes cation concentrations and table 6 anion concentrations and parameters measured in the field for Briar Creek at the Thunderbird site. Currently active stream sample stations include site 1, 2-3, 4, 5 and 6; with the stream flowing from site 1 toward site 6. Station 1 and 2-3 are upstream of the residues, station 4 is immediately downstream. Many factors can influence the geochemistry of stream water other than drainage across the reclaimed mine site, including the duration and intensity of recent storm events. The concentration of some constituents tends to fluctuate from one sample event to another because of these factors. Certain trends in the Briar Creek data, however, are evident. Sodium and potassium, indicators of leachate generated by the FBC residues at this site are not detected in concentrations downstream from the test plots in levels significantly different than those upstream. Work continues on relating the geochemistry along Briar Creek to different lower order drainage basins of the reclaimed mine.

Table 7 summarizes cation concentrations and table 8 anion concentrations and parameters measured in the field from groundwater samples collected at the Thunderbird site. Wells 6 and 8 are located upgradient and wells 2, 4, and 5 downgradient of the residues. Upgradient wells at the Thunderbird site have high concentrations of iron, manganese, magnesium, and sulfate and low pH levels relative to the wells located downgradient of the residues. Preliminary groundwater data, therefore, suggests some ameliorating effects of the residues. The downgradient concentration of sodium and potassium, the indicators of residue leachate, do not exceed levels detected in the upgradient wells. Again, this suggests that at the present time, leachate generated by the residues has not reached groundwater.

CONCLUSIONS AND RECOMMENDATIONS

This study suggests that, to date, the reclamation work incorporating FBC and FGD residues at the Thunderbird and Forsyte-Energy sites has not impacted groundwater or surface water quality. In fact, preliminary data suggest an ameliorating effect of the residues on water already degraded by mining. Further monitoring is necessary in order to investigate the long term impact of the new reclamation strategies. During the second year of the project, models developed at the sites and calibrated to field conditions will be used to generate scenarios of the long term impact of the residues on the environment.

The purpose of the modeling is to experiment with the natural system in order to get a better understanding of the factors controlling groundwater flow and contaminant transport. The objective of the contaminant transport modeling is to investigate different scenarios for contaminant migration away from the demonstration sites based on a range for each input parameter, including nominal, minimum, and maximum values. This range of values will be justified with field data or published information. Those individuals most interested in using coal combustion residues in reclamation, or in developing environmental regulations for these materials, will find the results of the scenario simulations valuable.
DISCLAIMER STATEMENT

This report was prepared by Steven Esling of Southern Illinois University with support, in part by grants made possible by the Illinois Department of Commerce and Community Affairs through the Illinois Coal Development Board and the Illinois Clean Coal Institute. Neither Steven Esling of Southern Illinois University nor any of its subcontractors nor the Illinois Department of Commerce and Community Affairs, Illinois Coal Development Board, Illinois Clean Coal Institute, nor any person acting on behalf of either:

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REFERENCES


