DEMONSTRATION OF COAL ASH FOR
FEEDLOT SURFACES

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DEMONSTRATION OF COAL ASH FOR FEEDLOT SURFACES

PROJECT SUMMARY

The Energy & Environmental Research Center, the Carrington Research Extension Center (CREC), and Power Products Engineering (PPE) collaborated in a research effort to demonstrate the environmental, engineering, and technical feasibility of utilizing fly ash as a method to improve soils for use as a surface in animal feeding operations. Funding for this effort was provided by Great River Energy, Otter Tail Power Company, the U.S. Department of Energy National Energy Technology Laboratory, the North Dakota Industrial Commission, and the North Dakota State Board of Agricultural Research and Education.

The components of this program were laboratory material characterization for engineering and environmental performance; field demonstrations and performance evaluations, including animal performance; economic comparisons with other surface types; and technology transfer, which focused on work with NDDH and owners of animal feeding operations.

Preliminary laboratory tests indicated the appropriate engineering and environmental performance of the coal ashes selected for the project. Full-scale field plots were designed and constructed at an existing bison research facility located at CREC. The objectives of the field program were to demonstrate fly ash–soil mixture placement under field conditions, simulate and monitor the environmental stability of fly ash–soil mixtures at the field scale, and evaluate the performance of the surfaces for durability and potential for impact to ground and surface water.

The results obtained from the field program were consistent with those from the laboratory testing. The chemical responses for all of the pens were nearly identical, with the small differences between leachate qualities being attributed to natural variability in the soils used in pen construction. The geotechnical testing program identified that the fly ash–soil mixtures exhibit good engineering characteristics when compared to the native soils currently used for feedlots.

The pens were monitored over 3 years, and no impact to groundwater was noted. Runoff was generally found to exhibit similar quality for test surfaces and the control surfaces. Ash–soil surfaces exhibited superior performance over the soil controls. During the wet season and following rainfall events, the treated surfaces dried more quickly by supporting runoff.

The project team worked with the North Dakota Department of Agriculture to convey project results and the potential for North Dakota animal feeding operations to NDDH. As a result, NDDH has approved the use of the fly ash from the sources studied in feedlot surfaces at approved feedlots in North Dakota. The project team produced a manual for feedlot operators with guidance on the appropriate use of these fly ashes, and several demonstrations were done on commercial sites as a closeout activity of the project. The project team anticipates that this use of fly ash will benefit both the fly ash producers and the animal feeding industry in North Dakota.
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DEMONSTRATION OF COAL ASH FOR FEEDLOT SURFACES

EXECUTIVE SUMMARY

The Energy & Environmental Research Center, the Carrington Research Extension Center (CREC), and Power Products Engineering (PPE) collaborated in a research effort to demonstrate the environmental, engineering, and technical feasibility of utilizing fly ash as a method to improve soils for use as a surface in animal feeding operations. Funding for this effort was provided by Great River Energy, Otter Tail Power Company, the U.S. Department of Energy National Energy Technology Laboratory, the North Dakota Industrial Commission, and the North Dakota State Board of Agricultural Research and Education. The result of this effort was the approval of the use of four regional coal combustion fly ashes for use in feeding area surfaces at North Dakota Department of Health (NDDH)-approved animal feeding operations.

Background information from similar studies performed in North Dakota and elsewhere was used to understand the needs associated with feeding operations and to provide an assessment of engineering and environmental performance and behavior of fly ash. This information supported the request for fly ash–soil mixtures to be allowed for use in feedlot surfacing as an application requiring no special use permits. To obtain this approval from NDDH and to facilitate NDDH’s general understanding of coal combustion by-product use, the project team performed an extensive series of laboratory and field activities.

While the use of regional coal combustion fly ash for soil stabilization has been demonstrated and documented, it had not previously been demonstrated in animal feeding areas. Since agriculture is prevalent in the region and the potential for coal ash use in agriculture-related applications is high, this effort was developed with the objective of demonstrating the use of ash in feedlot surfacing, with the intent of applying information gained to other agriculture-related ash use applications.

To achieve the project objectives, the engineering and environmental properties of fly ash–soil mixtures were evaluated, and a comprehensive laboratory environmental characterization program was developed in consultation with NDDH. The components of this program were laboratory material characterization for engineering and environmental performance; field demonstrations and performance evaluations, including animal performance; economic comparisons with other surface types; and technology transfer, which focused on work with NDDH and owners of animal feeding operations.

Preliminary laboratory tests indicated the appropriate engineering and environmental performance of the coal ashes selected for the project. The laboratory phase was followed by an extensive field effort. Full-scale field plots (12 soil–ash-surfaced pens and four control pens in which no fly ash was present) were designed and constructed at an existing bison research facility located at CREC. The objectives of the field program were to demonstrate fly ash–soil mixture placement under field conditions, simulate and monitor the environmental stability of fly ash–soil mixtures at the field scale, and evaluate the performance of the surfaces for durability and potential for impact to ground and surface water.
The results of the laboratory materials characterization program indicate that the fly ash geochemical behavior and chemical characteristics are in good agreement with observations made in earlier fly ash–paste and fly ash–soil studies. For a large number of constituents, the leaching behavior can be explained by assuming relatively simple mineralogical controls, which in turn allows for prediction of metals released under a wide variety of environmental conditions using general geochemical principles.

The results obtained from the field program were consistent with those from the laboratory testing. The chemical responses for all of the pens were nearly identical, with the small differences between leachate qualities being attributed to natural variability in the soils used in pen construction. All constituents that could be influenced by leaching of fly ash–soil were also detected in the control pens at comparable concentrations, indicating that groundwater interaction with fly ash–soil is indistinguishable from groundwater interaction with soils in the control pens. The geotechnical testing program identified that the fly ash–soil mixtures exhibit good engineering characteristics when compared to the native soils currently used for feedlots. Strengths obtained from the fly ash–soil mixtures were higher than those found in the natural soils. Permeabilities of the fly ash–soil mixes are similar to those found in the native soils.

The pens were monitored over 3 years, and the results from the fly ash–soil field-scale tests indicated that no impact to groundwater was noted over the duration of monitoring. Runoff was found to exhibit similar quality for test surfaces and the control surfaces and, with one exception, boron, met North Dakota surface water limits. The boron levels were higher in runoff pens with ash added, but were still within the limits for water to be used for irrigation, which is the generally accepted use for stored runoff water.

In evaluating the physical and engineering performance of ash–soil mixtures used in the field trials, it was evident that the ash–soil surfaces exhibited superior performance over the soil controls. During the wet season and following rainfall events, the treated surfaces dried more quickly by supporting runoff. The benefits of using fly ash in combination with local soils over current feedlot practices can be described as follows:

- Reduced animal stress due to wet soil conditions
- Improved animal weight gains
- Improved environmental stability of the feedlot surface
- Full-cycle utilization of mined materials
- Reduced handling and disposal cost of fly ash

In summary, the present study, in conjunction with previous studies conducted on raw fly ash and fly ash–soil mixtures, has produced a preponderance of evidence that the fly ash–soil mixture utilized in feedlot surfacing has numerous characteristics that make it an environmentally benign material that will not contaminate water or form a contaminated leachate and can be utilized by farmers and ranchers in North Dakota without the need for special use permits.

The project team was successful in working with the North Dakota Department of Agriculture to convey to NDDH the results of this study and the potential for North Dakota animal feeding operations. As a result, NDDH provided a letter approving the use of the fly ash from the sources
studied in feedlot surfaces at approved feedlots in North Dakota. The project team produced a manual for feedlot operators with guidance on the appropriate use of these fly ashes, and several demonstrations were done on commercial sites as a closeout activity of the project. The project team anticipates that this use of fly ash will benefit both the fly ash producers and the animal feeding industry in North Dakota.
DEMONSTRATION OF COAL ASH FOR FEEDLOT SURFACES

INTRODUCTION

Self-cementing coal fly ash has been used effectively for stabilization of soils for a variety of reasons, including drying soil, improving shrink–swell properties of clay soils, increasing strength, improving shear strength of soils, and reducing the compressibility of cohesive soils and granular materials (1). Fly ash-stabilized soils are comparable in performance to those stabilized with lime or cement, but fly ash is generally more economical. In the upper Midwest and northern Great Plains regions, it is most frequently used in confined applications such as under roads, runways, buildings, and parking lots to stabilize soils used as bases for these applications. Nineteen states either allow or authorize the use of coal ash in road base or subbase.

In 1996, the University of North Dakota (UND) Energy & Environmental Research Center (EERC) reported that lignite fly ash had potential to be used effectively in soil stabilization applications (2). Fly ash samples evaluated in the 1996 study exhibited appropriate engineering and environmental performance for this type of application. Falkirk Mining Company demonstrated the successful use of fly ash in haulroad construction (3). The results of a recent EERC study indicated that fly ash exhibited appropriate environmental characteristics for use in soil stabilization applications (4). Associated work in Minnesota indicated that the engineering performance of these fly ash samples was also appropriate to soil stabilization applications. In North Dakota and surrounding states, numerous self-cementing fly ashes are produced that do not meet existing American Society for Testing and Materials (ASTM) or American Association of State Highway and Transportation Officials (AASHTO) specifications for use as a mineral admixture in concrete but are appropriate for other uses such as soil stabilization or other geotechnical applications.

In 1998, the North Dakota State University (NDSU) Carrington Research Extension Center (CREC) initiated construction of a bison research facility based on North Dakota Department of Health (NDDH) specifications. The CREC bison research facility was designed to meet total containment requirements, as many other North Dakota livestock and dairy producers are required to do. The majority of North Dakota’s 12,000 beef producers and 800 dairy producers have at least some drylot areas subject to concentrated livestock traffic. Earthen pens and laneways do not withstand this animal-based pressure, particularly when the surface remains wet for any length of time such as during spring thaw. As the integrity of the pen or laneway surface breaks down, deep mud and poor drainage reduce animal performance and health (as indicated by poor weight gain), increase odor emissions, and prevent regular maintenance operations such as manure removal. Commonly, the soil–manure interface layer is damaged, resulting in deeper leaching of nutrients and an increased risk of groundwater pollution.

Improved feedlot surfaces provide benefits for any livestock facility, and CREC researchers identified coal ash as an option for improving feedlot surfaces in various research projects (5–8). The EERC then teamed with CREC in 1999 to demonstrate the use of regional fly ash to improve feedlot surfaces.
BACKGROUND

There were several research and demonstration projects related to the use of coal ash in agriculture and feedlot applications. Researchers at Texas A&M University placed two types of ash (crushed ash and hopper ash) into feedlot pens in 1993. Pen conditions were evaluated visually for 2 years following placement. The crushed ash treatment proved superior to the control (earthen surface) for all four thicknesses tried. Crushed ash at 6- and 8-inch depths performed better than other treatments (although there was little difference between the two thicknesses). The hopper ash treatment (tilled into fill) deteriorated at areas of high pressure: feed bunks and water troughs (5).

In 1993, fluidized-bed combustor (FBC) ash was used to stabilize soil in a feedlot in Iowa (6). The study compared FBC-stabilized soil with nonstabilized soil by measuring strength, ability to withstand immersion in water, freeze–thaw resistance, and cone index. The results indicated that treated soil had greater strength than untreated soil, with one exception (air-dried cylinders of soil underwent an unconfined compression test, with the untreated sample exhibiting greater strength; the authors suggest that this anomaly is due to the high organic matter content in the soil). Three freeze–thaw cycles reduced the compression strength of all samples. Treated samples were better able to withstand immersion in water. The feedlot pen treatments were completed using machinery normally available locally at a cost of $0.23/ft² (the fly ash was provided free of charge).

Another Iowa project was the subject of an ash-marketing bulletin (9). The ash marketer combined reclaimed Class C fly ash, with the consistency of aggregate, with fresh Class C fly ash and placed the mixture directly on the surface of the feedlots. The combined material was conditioned with water, disced, and compacted to provide a dry solid platform for the feedlot. Two months of monitoring indicated good performance.

An Ohio feedlot project initiated in 1992 used lime-enriched flue gas desulfurization (FGD) material to construct both livestock pads and hay storage pads (7, 8). Placement activities varied, but in many cases, farmers were able to place the material using their own standard equipment. The demonstrations have been highly successful, and in 1997, 24 commercial pads were constructed after American Electric Power, the FGD producer, received a permit-to-install from the Ohio Environmental Protection Agency (EPA). Farmers are not required to obtain any further authorization to install pads covered by the Ohio EPA permit. The cost of the FGD pads is estimated to be 25% to 65% less expensive than that of concrete or stone aggregate.

Stout (10) investigated the use of FBC ash on an experimental dairy farm in Pennsylvania. Monitoring of heavy metal levels in the leachate under the pavement indicated these parameters were at or below acceptable levels.

OBJECTIVES

The primary goal of this project was to demonstrate the use of ash in feedlot surfacing. Supporting objectives included the following:

- Develop durable, easy-to-place ash-based feedlot surfaces.
• Demonstrate placement techniques, using conventional farm equipment where possible.
• Monitor engineering and environmental performance of the feedlot surfaces.
• Perform an economic evaluation of the various surfaces demonstrated.
• Produce a “how to” manual for use with various ashes and placement methods.
• Report all information to North Dakota feedlot operators.
• Obtain approval from NDDH for unlimited use in feedlot settings.

METHODOLOGY

The project was developed as a 3-year effort, including laboratory and field components. A timeline of the project and field reports can be found in Appendix A. Two of the project sponsors, Great River Energy (GRE) and Otter Tail Power Company (OTPC), provided fly ash and bottom ash from their regional power plants to use in laboratory and field tasks.

The coal combustion by-products (CCBs) identified for study by the project sponsors are listed in Table 1.

Table 1. CCBs Used in CREC Demonstration

<table>
<thead>
<tr>
<th>Utility Owner</th>
<th>Unit Name</th>
<th>Coal Source (mine)</th>
<th>Coal Type</th>
<th>Boiler Type</th>
<th>Emission Control System Type</th>
<th>MW</th>
</tr>
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<tbody>
<tr>
<td>GRE</td>
<td>Coal Creek Units 1 and 2</td>
<td>Falkirk</td>
<td>Lignite</td>
<td>Pulverized tangential</td>
<td>ESP¹/WS²</td>
<td>1200</td>
</tr>
<tr>
<td>GRE</td>
<td>Stanton</td>
<td>Coteau</td>
<td>Lignite</td>
<td>Pulverized tangential</td>
<td>SD³/BH⁴</td>
<td>200</td>
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<tr>
<td>OTPC</td>
<td>Coyote</td>
<td>Beulah</td>
<td>Lignite</td>
<td>Cyclone</td>
<td>SD/BH</td>
<td>400</td>
</tr>
<tr>
<td>OTPC</td>
<td>Hoot Lake 2</td>
<td>Spring Creek</td>
<td>Subbituminous</td>
<td>Pulverized tangential</td>
<td>ESP</td>
<td>53.5</td>
</tr>
<tr>
<td>OTPC</td>
<td>Hoot Lake 3</td>
<td>Spring Creek</td>
<td>Subbituminous</td>
<td>Side wall-fired</td>
<td>ESP</td>
<td>66</td>
</tr>
</tbody>
</table>

¹ Electrostatic precipitator.
² Wet scrubber.
³ Spray dryer.
⁴ Baghouse.

To accommodate questions from NDDH and to optimize the use of project funds, the methodology as outlined in the original project proposal was modified (see Appendix B). The project included several parallel tasks.

**Task 1: Laboratory Development and Field Placement**

EERC and CREC research staff collected and evaluated literature to determine the engineering properties required for the feedlot surfaces. Data on ash characteristics were also assembled from reports of previous work and from industrial partners. From this information, several potential surfacing techniques were identified that would take advantage of the CCBs selected for the study.
Because assembled data provided very complete physical and engineering characterization profiles for the samples of interest, no further laboratory characterization on the materials was required.

Considering the available materials and needs for feedlot surfaces based on input from CREC staff, several concepts for feedlot surfacing were proposed including:

- Stabilized soil surfaces.
- Flowable concretelike mixtures.
- Roller-compacted fly ash–bottom ash mixtures.

The use of bottom ash or bottom ash modified with fly ash was also considered for feed roads and laneways. These ash-based surfaces and mixtures are good candidates for numerous agriculture-related applications such as silage, hay, sugar beet, or other crop storage areas.

Because of past projects involving similar soil stabilization laboratory efforts using regional fly ash, a limited set of soil–fly ash mixtures (four) were prepared and evaluated. All four were mixed with soil from the site at 15%–20% addition rates. The test matrix included 16 mixes, two moisture levels, and evaluation of strength at 7 and 14 days. Optimum moisture and maximum dry density were also determined.

Since the types of ash surfaces under consideration require a cementitious binder, it is preferable to use a cementitious fly ash to minimize cost. The four fly ash samples were evaluated qualitatively for reactivity by addition of water and empirically evaluating the heat generated, as well as observing whether or not the fly ash hardened on sitting.

Total concentrations of major and trace constituents were determined on one series of samples from the four ash sources. Concentrations of major constituents were determined by ASTM Method D 4326 using x-ray fluorescence. Trace constituents were determined on solutions from standard dissolution techniques and appropriate spectroscopy techniques.

With input from NDDH, an environmental monitoring plan was developed early in the project. Background leaching data were collected from various sources, and additional leaching information was generated as needed. The monitoring plan included sampling of both groundwater and runoff. The parameters for evaluation were determined with assistance from NDDH and are noted in Table 2.

Laboratory evaluations included short- and long-term leaching, in addition to analyzing leachates for the suite of elements recommended by NDDH (Table 2). The synthetic groundwater leaching procedure (SGLP), developed at the EERC (11), uses a 20-to-1 liquid-to-solid ratio and end-over-end mixing. For this study, distilled, deionized water was used as the leaching solution, and the short-term experiment was run for 18 hours. Long-term experiments were run for 30- and
Table 2. Analytical Parameters for Laboratory Ash Leachate, Groundwater, and Other Environmental Samples

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conductivity</th>
<th>pH</th>
</tr>
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<td>Alkalinity</td>
<td>Conductivity</td>
<td>pH</td>
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<tr>
<td>Aluminum</td>
<td>Copper</td>
<td>Phosphorus</td>
</tr>
<tr>
<td>Ammonia</td>
<td>Dissolved solids</td>
<td>Potassium</td>
</tr>
<tr>
<td>Antimony</td>
<td>Fluoride</td>
<td>SAR&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>Arsenic</td>
<td>Hydroxide</td>
<td>Selenium</td>
</tr>
<tr>
<td>Barium</td>
<td>Iron</td>
<td>Silicon</td>
</tr>
<tr>
<td>Beryllium</td>
<td>Lead</td>
<td>Silver</td>
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<tr>
<td>Bicarbonate</td>
<td>Manganese</td>
<td>Sodium</td>
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<tr>
<td>Boron</td>
<td>Mercury</td>
<td>Sulfate</td>
</tr>
<tr>
<td>Cadmium</td>
<td>Nickel</td>
<td>Thallium</td>
</tr>
<tr>
<td>Carbonate</td>
<td>Chloride</td>
<td>Zinc</td>
</tr>
<tr>
<td>Chloride</td>
<td>Nitrate + nitrite</td>
<td></td>
</tr>
<tr>
<td>Chromium</td>
<td>Percent sodium</td>
<td></td>
</tr>
</tbody>
</table>

<sup>1</sup> Sodium adsorption ratio.

60-days. The data obtained from this leaching allow the evaluation of changes in leaching profiles for elements of interest. Several series of leaching evaluations were performed on fly ash and bottom ash from the four power stations participating in the demonstration and on soil from the CREC site.

Final ash feedlot surface treatments were identified and placed at the bison research facility at CREC, as shown in Figure 1. The facility includes the sloped feedlot area (16 pens, each pen 60 × 70 ft), feeding/watering areas, runoff collection systems, feed and work alleys, and groundwater monitoring wells. As indicated in Figure 1, one set of four pens served as a project control for various performance criteria. This set of pens (B5–B8) was partly surfaced with concrete in the feeding/watering areas, and the remainder of the pens in this series were compacted soil. The remaining 12 pens were used to demonstrate the placement and performance of a variety of soil–ash mixtures. The field demonstrations included the placement of two surface types. The primary surface placed was the soil–fly ash mixture. The second surface type was a flowable mixture of fly ash, bottom ash, sand, cement, and water.

Additionally, two or three commercial feedlots were identified through the NDSU Extension Service as candidates for additional demonstration and technology transfer sites.

Task 2: Environmental Monitoring

The CREC facility was well designed to accommodate environmental monitoring. The groundwater monitoring wells and runoff collection systems are indicated in Figure 1. Separate wells and runoff holding ponds serve a series of four pens each. Two sets of background samples were collected and analyzed from the site prior to placement of the ash surfaces.
Groundwater and runoff water were monitored at the CREC site through Year 3. NDDH provided the input for any parameters that no longer needed to be monitored or those that might be added from earlier in the project. Samples were collected at intervals throughout the first 3 years of the project.
Task 3: Performance Monitoring

The engineering performance of the placed surfaces and animal performance were monitored both by observation by CREC staff during daily activities at the bison research facility and by periodic testing and evaluation on-site by EERC researchers and the consulting engineer. The engineering performance monitoring continued throughout the duration of the project. Observational monitoring included surface conditions, cracking, impact of cleaning procedures, and other general wear-related information. Animal weights were recorded quarterly, and upon slaughter, carcasses were examined.

Task 4: Technology Transfer

CREC staff collected material for a video and “how-to” manual outlining ash utilization in feedlots. This information was developed to show feedlot operators how ash is being used in the demonstration project and make them aware of the potential for their operations.

It was decided not to produce the video; however, a manual was produced describing how to best use fly ash for feedlot surfacing, including information on mix design, mixing methods, and placement techniques using conventional farm equipment.

With the assistance of the NDSU Extension Service, feedlot operators were invited to visit the CREC site to see for themselves how the placements had performed. Two demonstrations were performed to introduce operators to the techniques of ash placement.

Task 5: Economic Evaluation of the Feedlot Placements

An economic evaluation was completed comparing the costs of placement using ashes and concrete. Construction costs included materials and the equipment needed for the placements. The economic benefits for animal weight gain were also evaluated.

RESULTS AND DISCUSSION

Task 1: Laboratory Development and Field Placement

Literature Review

Several previously completed studies provided background for this study. Utilizing similar materials, the physical, chemical, and environmental data support the use of fly ash in soil stabilization applications while addressing environmental concerns and providing recommendations for future uses of fly ash.

In a study entitled “Demonstration of North Dakota Lignite Fly Ash in Haulroad Construction,” the Falkirk Mining Company tested the physical and engineering performance of fly ash-stabilized soil in a haulroad setting, using similar materials to those in the this study. The study concluded: “Overall, the strength gains achieved for the laboratory mixes far exceed the expectations
of the project team, thus verifying that Coal Creek Station (CCS) fly ash can be beneficial for soil enhancement” (3).

EERC final reports provided more data with collaborating conclusions. In 1993, “The Characterization of Coal Creek Station Fly Ash for Utilization Potential” found that CCS fly ash (one of the regional fly ashes evaluated in the feedlot study) is appropriate for use in soil stabilization applications (12). “Use of Bottom Ash in Rammed-Earth Construction” provides documentation on increased strength of soil–fly ash mixtures over soil alone (13). Results of a study completed in 1996 entitled “Survey and Demonstration of Utilization Potential of North Dakota Lignite Ash Resources” indicated “excellent potential for utilization [of North Dakota Lignite (NDL) by-products] in road-building applications such as concrete, controlled low-strength materials, soil stabilization, and permeable base course” (2).

While different types of CCBs were tested, studies found that the materials were consistent in their physical, chemical, and environmental behavior and thus should be approved for a variety of use applications (14). Similar conclusions of the consistency of fly ashes were discovered in the September 2000 EERC study (13). The 1993 EERC study provides data on the physical, chemical, and environmental characterization of ash that is comparable to the feedlot and other studies (15).

While the utilization of CCBs raises questions of negative environmental effects, the studies completed have demonstrated downward trends in almost all areas of environmental concern (3). Laboratory results in the 1996 EERC study indicated, “the NDL by-products evaluated contained extremely low concentrations of most regulated trace elements” (2). A study entitled “Reclassification of CCS Fly Ash Paste as Inert Waste” found that “CCS fly ash paste has numerous characteristics that make it environmentally benign material.” The study also concluded “little or no potential for impacts to groundwater exists” (14). The EPRI Final Report also states, “The groundwater monitoring has shown no adverse environmental impacts.”

Each study completed on the use of ash as a soil stabilizing agent has provided similar data and conclusions and as a result, similar recommendations for action. The Falkirk Mining Company felt that the NDDH should prepare guidelines for the use of fly ash in mine settings, a conclusion paralleling that of the feedlot study (3). In the April 1996 EERC Final Report, the EERC recommended “that the NDSDH consider development of standards for preapproved uses for recycled lignite combustion by-products in road-building and other use applications” (2). The 1993 study recommended that coal combustion fly ash “be monitored regularly for appropriate physical and engineering properties and for chemical constituents and leaching behavior,” thus prompting the continuing study of the uses of fly ash in the feedlot study. These studies were summarized for NDDH to facilitate discussions of broader approval of coal ash use and development of a beneficial use rule for ash-stabilized soil for feedlot surfaces.

Laboratory Activities – Physical and Engineering Performance

Results of empirical evaluation of cementitiousness indicated that all fly ash samples exhibited cementitious behavior, making them candidates for surface treatments identified.
At the initiation of this project, the CREC feedlot pen surfaces were constructed of compacted soil. A sample of the soil was collected from the site for use in laboratory development of the stabilized soil mixes and for comparative purposes. Laboratory specimens of soil–ash mixtures were prepared to mimic potential surfaces and tested for moisture, dry density, and strength. Complete physical engineering laboratory results are included in Appendix C. A summary of strength data is shown in Table 3. Results were typical of those from previous ash–soil stabilization efforts, providing a range of increased strengths over soil (~160%–500%) depending on the individual ash tested.

**Table 3. Laboratory Data/Strengths, psi**

<table>
<thead>
<tr>
<th>Ash-to-Soil Ratio</th>
<th>20%</th>
<th>15%</th>
<th>15%</th>
<th>20%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly Ash Source</td>
<td>Stanton</td>
<td>Coyote</td>
<td>Hoot Lake</td>
<td>Coal Creek</td>
</tr>
<tr>
<td></td>
<td>7-day</td>
<td>14-day</td>
<td>7-day</td>
<td>14-day</td>
</tr>
<tr>
<td></td>
<td>121</td>
<td>141</td>
<td>119</td>
<td>173</td>
</tr>
<tr>
<td></td>
<td>195</td>
<td>227</td>
<td>133</td>
<td>213</td>
</tr>
<tr>
<td>Fly Ash Average</td>
<td>158</td>
<td>184</td>
<td>126</td>
<td>193</td>
</tr>
<tr>
<td>100% Soil Average</td>
<td>55*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase over Soil</td>
<td>288%</td>
<td>336%</td>
<td>230%</td>
<td>352%</td>
</tr>
</tbody>
</table>

* 100% soil average strength was calculated using these five values: 66, 50, 54, 50, and 50.

These data indicated that soil–fly ash mixtures in the range of 15%–20% fly ash addition exhibit a significant increase in strength over 100% soil and are consistent with data from previous studies. It was concluded from these results and historical data that additions of fly ash from approximately 15%–25% were appropriate for use in stabilizing the soils in the loafing areas of the feedlots at the CREC site.

A different, flowable concretelike material was proposed for feeding and watering areas because animals tend to congregate in these areas, requiring added durability over the loafing areas. The flowable concretelike mixture is made up of bottom ash, fly ash, and small amounts of cement. This material had been tested extensively in both the laboratory and field and used by members of the research team in separate studies. The advantages of this mixture are potentially reduced cost as compared to standard concrete, durable surface with strengths approaching 1000 psi, and simple placement because it flows and self-levels requiring minimal surface finishing. In this study, laboratory testing was not performed before field placement, as this material is a near-commercial application.

Another proposed ash-based surface type, roller-compactred fly ash–bottom ash mixtures, was under consideration but omitted from further consideration for use in field trials because the soil–ash mixtures and the flowable ash-based material were easier to place. In the case of the soil–ash mixtures, feedlot operators would need delivery of only one material to mix with existing soils. While researchers agreed that the roller-compactred fly ash-bottom ash mixture would be better suited to applications where a more durable surface is required such as the feeding/watering areas, the placement of the flowable ash-based material was deemed to be more efficient.
**Laboratory Activities – Chemical and Environmental Characterization**

The chemical and environmental characterization involved several components. Samples of the fly ash and bottom ash to be used in the demonstration were collected on a regular basis. Laboratory chemical and environmental characterization focused on bulk analysis of trace elements and short- and long-term leaching. Both the laboratory and field generated samples were analyzed for an extensive list of trace elements (see Table 2). These elements were of environmental interest to the NDDH, and NDDH was instrumental in developing the list.

**Bulk Chemical Characterization**

Complete results of the bulk chemical characterization are included in Appendix D. These data are consistent with data from previous studies, as shown in Figure 2. Using data from this and previous studies, the limited variability of the major trace elements of materials from single sources is shown in Figure 3.

Total trace composition data were also available for some samples from previous studies. This data also indicated consistency for individual samples. Total trace composition data were also consistent with previous studies in that the concentration of many trace elements was higher in the fly ash than in the bottom ash. This was particularly noteworthy for arsenic, copper, lead, nickel, and zinc.

![Figure 2. Bulk chemical variability.](image-url)
The fly ash total trace element concentrations were used to estimate the fly ash contribution to the trace element content of the soil–ash mixtures at the CREC site as a means of addressing questions regarding the disposition of soil–ash mixtures when an ash-stabilized feedlot might be taken out of use. The trace element contribution of the fly ash to the ash–soil mixtures was calculated using the total concentrations in the individual fly ash samples and the highest percentage of fly ash addition used at the site (28%). This use of total values, assuming total dissolution of the ash, is an unattainable worst-case scenario. The actual contribution of trace elements from ash would be fractional in the short term (years), although total release is theoretically possible in geologic time. As shown in Appendix D, in the table entitled “Calculated Trace Element Content in Manure and Ash–Soil Mixtures,” the calculated values indicate that the ash–soil mixtures would be appropriate based on the land application guidelines noted in Land Application of Sewage Sludge: A Guide for Land Applicators on the Requirements of the Federal Standards for the Use or Disposal of Sewage Sludge, 40 CFR Part 503 (16). Additional discussions between researchers and NDDH indicated that when a feedlot is taken out of use, the feedlot surfaces would typically be left in place. Further data presented in Appendix D indicate that the ash–soil mixtures could either be land-applied or left in place at the site.

**Laboratory Leaching**

The detailed data set is included in Appendix D. Figure 4 shows variability of 100% ash leachate concentrations for select trace elements. These data indicate very limited variability of samples from individual sources and, for many elements, between sources. The leaching data are also consistent with data from previous regional studies (see Appendix E).
Laboratory leaching was also performed on soil–ash mixtures (75% soil–25% fly ash). Results are also included in Appendix D.

Several observations are evident from the laboratory leaching data:

- Many leachate concentrations were less than the lower limit of quantitation (LLQ). Eight of 22 elements were below the LLQ for soil–ash leachates and primarily below the LLQ for the 100% ash leachates.

- For individual materials from a single source, leaching results were consistent, indicating limited variability.

- The majority of leachate concentrations (both 100% ash and soil–ash mixtures) were within the range of the groundwater concentrations at the site for 14 of 22 elements. These elements are antimony, arsenic, beryllium, cadmium, copper, iron, manganese, mercury, nickel, potassium, silver, sodium, thallium, and zinc.

- 100% bottom ash leachate concentrations are generally lower than those of 100% fly ash and soil–ash mixtures. This is consistent with the lower total concentrations of many trace elements in bottom ash as compared to fly ash from the same source.
• Soil–ash mixture leachate concentrations were generally lower than 100% fly ash leachate concentrations; however, the reduced concentrations cannot be correlated to percentage of ash used.

• 100% ash and soil–ash leachate concentrations were consistently higher than site groundwater concentrations for aluminum, boron, chromium, selenium, and sulfate.

The laboratory leaching protocol used for ash characterization was designed to characterize the materials used and was not intended to predict elemental concentrations of field runoff, groundwater, or leachate. Laboratory leaching does not account for natural attenuation mechanisms that impact actual field concentration in a specific environment. These attenuation mechanisms include dispersion, diffusion, precipitation, redox reactions, bacterial action, and sorption. The laboratory leaching results were intended to support the use of leaching characterization to qualify coal ash for use in commercial applications by indicating leaching potential. The laboratory leaching data assembled for this work provide a solid base of information on leaching variability and direction for development of a guideline on limits for leachate concentrations that may be adopted by a regulatory entity to simplify approval of specific ashes for use.

Field Placement

During Year 1, several field placement activities were performed at the CREC bison research facility. Figure 1 on page 6 illustrates the layout of the CREC bison research facility and indicates the control pens and various ash placements. Field reports detailing activities are included in Appendix A.

All pens have identical sloping, and each set of four pens has a runoff collection and storage area. Each pen is 60 × 70 ft and holds 10–12 bison for a variety of feeding studies being conducted by CREC researchers. The general feedlot design was facilitated by NDDH. The soil was brought in from an outside location to develop the appropriate sloping for the feedlot. The control pens (B5–B8) have concrete (20% fly ash) around the feeding and watering areas. The remainder of surfacing in the control pens is compacted soil.

Pens B1–B4 have a 50% fly ash concrete on the feeding/watering areas using one of the project fly ash samples. The same fly ash was also used to stabilize the remaining soil in those pens at the varying levels noted in Table 4. Pens B9–B12 shown in Figure 1 have a flowable mixture of fly ash–bottom ash–cement–water of approximately 1000 psi around the feeding/watering areas, while the remaining pen area was stabilized with a second regional fly ash at various percentages as noted in Table 5. Pens B13–B16 shown in Figure 1 have the same flowable mixture of fly ash–bottom ash–cement–water of approximately 1000 psi around the feeding/watering areas, while the remaining pen area was stabilized with a third regional fly ash at various percentages as noted in Table 6.

Conventional farm tractors and equipment were used to place ash for the stabilized soil surfaces as noted in Tables 4–6.
Table 4. Fly Ash Placement Information for Soil Stabilization Pens B1–B4

<table>
<thead>
<tr>
<th>Pen</th>
<th>Ash Addition, %</th>
<th>Mixing</th>
<th>Compaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>12</td>
<td>Disc + rototiller</td>
<td>Tractor</td>
</tr>
<tr>
<td>B2</td>
<td>12</td>
<td>Disc + rototiller</td>
<td>Tractor</td>
</tr>
<tr>
<td>B3</td>
<td>18</td>
<td>Disc + rototiller</td>
<td>Tractor</td>
</tr>
<tr>
<td>B4</td>
<td>25</td>
<td>Disc + rototiller</td>
<td>Tractor</td>
</tr>
</tbody>
</table>

Table 5. Fly Ash Placement Information for Soil Stabilization Pens B9–B12

<table>
<thead>
<tr>
<th>Pen</th>
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<th>Mixing</th>
<th>Compaction</th>
</tr>
</thead>
<tbody>
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<td>Tractor</td>
</tr>
<tr>
<td>B10</td>
<td>12</td>
<td>Disc</td>
<td>Rubber tire compactor</td>
</tr>
<tr>
<td>B11</td>
<td>16</td>
<td>Disc + rototiller</td>
<td>Rubber tire compactor</td>
</tr>
<tr>
<td>B12</td>
<td>22</td>
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<td>Tractor</td>
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</table>

Table 6. Fly Ash Placement Information for Soil Stabilization Pens B13–B16

<table>
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</tr>
</thead>
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<td>14</td>
<td>Disc</td>
<td>Tractor</td>
</tr>
<tr>
<td>B15</td>
<td>28</td>
<td>Disc + rototiller</td>
<td>Tractor</td>
</tr>
<tr>
<td>B16</td>
<td>18</td>
<td>Disc + rototiller</td>
<td>Rubber tire compactor</td>
</tr>
</tbody>
</table>

In June 2000, the first fly ash was placed to stabilize the soil in one set of four pens (B9–B12). The project was initiated in the east series of pens because the fencing had not been installed, allowing the fly ash to be delivered and placed with a bottom-dump grain hopper truck (Figure 5). A total of 70 tons of fly ash was placed in these four pens. The ash was incorporated at a 6–8-in. depth using two different mixing techniques based on the types of equipment expected to be available to most feedlot operators. Compaction was also accomplished using two different types of equipment, again based on expectations of equipment available to feedlot operators (Figure 6). Results of laboratory tests on samples collected in the field and field density and moisture testing are shown in Figures 7 and 8. Field data indicated >100% compaction was achieved. Moisture content ranged from 6.4 to 9.8. Laboratory strengths of field-collected samples approached 200 psi after 28 days of curing.

Fly ash was used to stabilize surfaces in Pens B1–B4 during September 2000. Approximately 70 tons of fly ash was used in these four pens. These pens presented a challenge for placement, mixing, and compaction because all the fencing was already in place, making the working area quite limited for equipment. The fly ash was delivered and placed in the various pens using a pneumatic system. The disadvantage in this placement was that there was significant dusting during placement. The advantage was that the fly ash could be well distributed in the pens. As noted in Table 4, a disc
Figure 5. Photo of a bottom-dump grain hopper truck.

Figure 6. Photo showing the compaction process.
### West Section

<table>
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<td>Fly Ash 1</td>
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<tr>
<td>MC</td>
<td>8.2 %</td>
<td>10.9 %</td>
<td>4.3 %</td>
<td>7.5%</td>
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</table>

**Figure 7.** Laboratory and field test results for stabilized soils: Pens B1–B4.

### East Section

<table>
<thead>
<tr>
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<td>8.7</td>
<td>7.5</td>
<td>9.5</td>
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<td>9.0</td>
<td>7.1</td>
<td>9.3</td>
<td>5.0</td>
<td></td>
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</tbody>
</table>

1 Dry density (DD), pounds per cubic foot
2 Moisture content (MC), %

**Figure 8.** Laboratory and field test results for stabilized soils: Pens B9–B16.
and rototiller were used for mixing the soil and fly ash. A small rototiller was required to incorporate the fly ash at the fence line. A tractor was used for compaction because the rubber tire compactor would not fit into the penned areas. Laboratory and field tests were performed, and preliminary results are noted in Figure 7. Field results indicated >100% compaction and moisture contents ranging from 4.5% to 10.9%. Strength data on samples collected from Pens B3 and B4 indicate strength was nearing 300 psi at 28 days. Some increase in strength is expected with additional curing times. Strength data from Pens B1 and B2 are not available.

Also noted in Figure 7, Pens B5–B8 are the control pens at this site, so no soil modification was performed, and a standard concrete was placed in the feeding–watering areas.

In July, similar techniques and volumes of fly ash were used to stabilize Pens B13–B16 (see Table 6). Similar laboratory and field data were collected and are shown in Figure 8. Again, compaction >100% was achieved.

During August 2000, the feeding and watering areas in Pens B9–B16 were surfaced with a flowable mixture containing bottom ash, fly ash, and cement. The flowable mixture was delivered by a local ready-mix supplier, and the placement procedure is shown in Figure 9. The mix proportions are noted in Table 7.

Cylinders made at the time the flowable fill mixture was placed in the feeding areas indicate that the flowable fill mixture gained strength overtime. Two cylinders were tested at 28 days and had strengths of 212 and 310 psi. A third cylinder was tested at 56 days and exhibited strength of 470 psi.

Figure 9. Photo showing the flowable mixture used.
Table 7. Mix Proportions

<table>
<thead>
<tr>
<th>Materials</th>
<th>Quantities</th>
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</thead>
<tbody>
<tr>
<td>Bottom Ash</td>
<td>2700 lb</td>
</tr>
<tr>
<td>Fly Ash</td>
<td>300 lb</td>
</tr>
<tr>
<td>Portland Cement</td>
<td>150 lb</td>
</tr>
<tr>
<td>Water</td>
<td>416 lb</td>
</tr>
<tr>
<td>Air-Entraining Agent</td>
<td>10.3 lb</td>
</tr>
<tr>
<td>3-day Strength</td>
<td>900 psi</td>
</tr>
</tbody>
</table>

Also in September 2000, the flowable mixture used at the CREC site was placed at an additional site near Mandan, North Dakota, for a base in a silage bunker. The bunker had sidewalls in place, and the flowable mixture was poured directly from the ready-mix trucks onto the earthen floor and allowed to self-level. This site has been monitored visually for engineering performance over the duration of the project. To date, the site has performed well, and the silage is much cleaner and more accessible.

On request of NDDH, the remaining work was limited to investigation of the fly ash-stabilized surfaces. Plans to use bottom ash in laneways or other areas on the CREC site were abandoned to limit experimental variables, and additional testing of the fly ash–bottom ash flowable mixture was limited to visual inspection, which indicated that ash-based concrete gains strength over extended time frames (>1 yr).

Task 2: Environmental Monitoring at the CREC Site

Groundwater Monitoring

On-site environmental monitoring, including groundwater and runoff monitoring, has been conducted since initiation of the project. The CREC bison research facility was well designed to facilitate environmental monitoring, with sloped surfaces and associated runoff-holding ponds for each set of four pens (Figure 1). The groundwater monitoring system installed by the North Dakota State Water Commission (NDSWC) consists of eight nests of three staggered wells each. Two sets of nested monitoring wells were also placed at the base of each set of four pens, which are downgradient from the bison pens. Each nest includes three monitoring wells screened at 9–16 ft (shallow), 16–38 ft (medium), and 30–58 ft (deep) below surface to allow for monitoring of potential leachate migration and its vertical hydrochemical distribution.

The EERC sampling program was initiated on December 9, 1999, with focus on acquisition of background information on groundwater chemistry prior to ash placement. Subsequent sampling was conducted on June 26, 2000; January 9, 2001; July 25, 2001; and November 19, 2001. A total of 36 samples were analyzed for the basic elemental chemistry and trace metals to date (excluding Quality Assurance/Quality Control [QA/QC]). In addition, two samples were collected and analyzed from near NDSWC monitoring wells. Because of the high costs associated with sampling and analyses for all monitoring wells (two nests of three under each pen), the early interpretive effort focused on the selection of the most indicative wells that would provide reliable results in a reasonable time frame.
With respect to the aquifer homogeneity and analogous chemistry in all wells at the subject site, including older wells northeast of the site monitored by NDSWC, it was suggested to continue monitoring only for the shallowest wells that would represent the worst-case scenario. Following that, the most recent sampling events on July 25, 2001, and November 19, 2001, targeted one shallow well under each set of pens.

Late in 1999, background groundwater samples were collected just prior to the introduction of bison to the set of control pens. Groundwater quality data are included in Appendix D. To date, no changes to groundwater quality have been noted.

The aquifer immediately underlying the constructed pads consists of relatively homogeneous sandy sediments with an unconfined water table at a depth of about 3–5 feet below ground. Only minimal fluctuation of up to 1 foot depending largely on the water level in an adjacent slough has been observed in monitoring wells to date.

The analytical results for all collected samples are presented in Appendix D. The groundwater at the site is calcium–magnesium bicarbonate-type averaging 450 mg/L of total dissolved solids (TDS), and CaCO₃ hardness of 390 mg/L. Groundwater chemistry is representative of shallow permeable aquifers with relatively short retention time. The basic chemistry of wells monitored by NDSWC is similar with higher average values for TDS (900 mg/L) and hardness (400 mg/L) reflecting greater depth (37, 80, and 100 ft).

The groundwater chemistry for monitoring wells confirms hydraulic homogeneity of the monitored aquifer with minor differences attributed mostly to the depth of wells. Variability between wells targeting the same depth all over the site is typically smaller than differences between wells within the respective nests installed at different depths. Seasonal water-table fluctuations resulting in frequent changes of the geochemical and biological conditions at the interface between the vadose and saturated zone affect the shallow wells the most with expected highest elemental concentration variability. Overall elemental concentrations and physical parameters for individual monitoring wells are very stable and do not exhibit significant trends that would exceed typical elemental variability. Concentration values for respective trace elements are low and well within the expected ranges typically influenced more by sampling and laboratory procedures than natural changes. NDSWC well DDD3 sampled two times for the project had considerably higher TDS and concentrations of sulfate and iron than all previous analyses from the same well and other wells onsite. It is not possible to conclude whether documented high concentrations are caused by upgradient contamination or well aging. Based on experience and because the new wells have better quality, deterioration of water quality in the older monitoring well is likely associated with bacterial growth in oxidative processes in and around the well screen.

Analytical results for 38 samples collected indicated that the overall elemental concentrations and physical parameters for individual monitoring wells at the subject site are very stable and do not exhibit significant trends that would exceed typical elemental variability.
Runoff Monitoring

Runoff sampling was dependent upon availability of runoff in the holding ponds at the CREC site. During each runoff-sampling event, one sample was collected from each of the runoff holding ponds. Runoff samples were evaluated for suspended solids and the same parameters as the laboratory samples and the groundwater samples were. Two runoff-sampling events were accomplished in 2001, and one sampling event was accomplished in Spring 2002. NDDH performed a runoff sampling and associated analyses in March 2003.

A summary of runoff quality data is shown in Table 8. Additional runoff data can be found in Appendix D. Runoff from fly ash-treated surfaces contained less suspended solids. The runoff from treated and control pens is of similar quality and meets the most stringent North Dakota surface water standards for nearly all parameters evaluated. While concentrations of some parameters were higher than concentrations in local groundwater, these were consistently elevated in runoff from treated and control pens. Only boron concentrations were slightly elevated in runoff from treated pens compared to runoff from control pens. Boron can be a phytotoxin inhibiting plant growth when present in high concentrations in water. Runoff from this site and other anticipated feedlots would be applied as irrigation water. Measured runoff concentrations of boron at the CREC site generally meet the short-term irrigation limit of 2 ppm, making the runoff suitable for irrigation.

Table 8. Summary of Runoff Holding Pond Results

<table>
<thead>
<tr>
<th>Fly Ash: Pen</th>
<th>Coal Creek B1–B4</th>
<th>Control B5–B8</th>
<th>Hoot Lake B9–B12</th>
<th>Stanton B13–B16</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arsenic (As)</td>
<td>µg/L</td>
<td>9.63–63.5</td>
<td>4.96–30.6</td>
<td>1.7–16.9</td>
</tr>
<tr>
<td>Barium (Ba)</td>
<td>µg/L</td>
<td>52.5–271</td>
<td>27.4–543</td>
<td>95.3–534</td>
</tr>
<tr>
<td>Boron (B)</td>
<td>mg/L</td>
<td>0.44–3.13</td>
<td>0.148–0.731</td>
<td>0.246–1.36</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>µg/L</td>
<td>&lt;1–1.31</td>
<td>&lt;1–1.65</td>
<td>&lt;1–2.34</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>µg/L</td>
<td>&lt;1–1.94</td>
<td>&lt;1–1.19</td>
<td>&lt;1–1.54</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>µg/L</td>
<td>3.09–23.4</td>
<td>1.33–16.9</td>
<td>2.07–29.1</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>µg/L</td>
<td>&lt;1–1.55</td>
<td>&lt;1–1.01</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>µg/L</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>Nickel (Ni)</td>
<td>µg/L</td>
<td>14.2–26.0</td>
<td>8.84–16.6</td>
<td>1.88–16.2</td>
</tr>
<tr>
<td>Selenium (Se)</td>
<td>µg/L</td>
<td>2.19–3.87</td>
<td>&lt;1–3.48</td>
<td>&lt;1–3.43</td>
</tr>
<tr>
<td>Sulfate (SO₄)</td>
<td>mg/L</td>
<td>11.3–330</td>
<td>24.4–150</td>
<td>39.3–155</td>
</tr>
<tr>
<td>Zinc (Zn)</td>
<td>µg/L</td>
<td>4.00–43.7</td>
<td>&lt;1–32.1</td>
<td>1.46–44.0</td>
</tr>
</tbody>
</table>

Individual Pen Runoff Study

NDDH indicated an interest in determining individual pen contributions to the bulk runoff collected from the holding ponds. The EERC constructed a temporary system to collect runoff from individual pens during summer 2001. The collection system consisted of hand-dug trenches in the laneway just below the pens. The trenches were intended to direct water from the pens to a collection
bottle (see Figure 10). Pens B1–B8 had bison present during this time, and Pens B9–B16 did not have bison present, nor were any animals on those pens at any time from placement in 2000 until after this runoff experiment was completed.

A rain event on July 23, 2001, resulted in adequate runoff for collection of samples from 15 of the 16 pens. The collection of runoff from control Pen B6 was unsuccessful because the funnel directing runoff into the sample container was blocked. Samples were prepared with the same protocol as runoff samples collected from the runoff ponds, and a full suite of analyses was performed. Complete analytical results for this sample set are shown in Appendix D.

Because of the nature of the field setting, the experimental setup for the individual pen runoff collection included these additional variables:

- Trench location required collection of limited runoff so freshly disturbed soils were exposed to runoff.
- Animals present in Pens B1–B8 may have influenced the runoff flow path in the pens.
- Bison were present on B1–B8 but not B9–B16.
- Feeding and bedding studies were performed in Pens B1–B8 during the collection period.

Runoff from Pens B1–B8 (bison present) was darker in color, and turbidity was higher than runoff from pens B9–B16 (no bison present). There was wide variability in runoff concentrations
from each set of pens, and the variability was greater where bison were present. Runoff concentrations from fly ash-treated pens were generally lower than or within the concentration range of runoff from the control pen. No correlations between percentage ash addition and runoff quality are evident.

**Pen-Cleaning Analysis**

Typical feedlot management scenarios include cleaning by scraping the accumulated manure in the pen and land-applying it. During the course of this project, most CREC pens were scraped at least once, and manure samples were collected twice. After both pen-cleaning activities, CREC staff noted distinct differences between the ash-stabilized and control pens:

- A smaller volume of manure resulted from scraping the ash-stabilized surfaces as compared to the control pens.
- Associated with the smaller volume of manure removed from the ash-stabilized pens, less soil was incorporated into the scrapings because of the firmer ash-stabilized surface.
- The control pens exhibited more defined wear paths at the pen perimeters than the ash-stabilized pens.

The first manure collection was performed by CREC staff. Separate samples of manure were taken from each of Pens 1–4, and two composite samples were obtained from the control pens (Pens 5–8). Assuming that the samples contained manure, soil, straw, and coal fly ash, EERC staff developed a protocol to determine the concentration of ash present in the samples. The samples were allowed to air dry. Portions of the samples were then heated in a furnace to 800°C. Fired samples were then viewed under an optical microscope, and spherical particles (representing ash) were estimated based on the area that 50–100 particles occupied in the field. The percentages reported (see Appendix D) do not account for sample loss in the firing process or the method bias that excluded visually evaluating portions of the sample that exhibited large particles. The reported values are estimated to be 2–4 times higher than the ash content in the original manure samples.

In order to estimate the trace element contribution to the manure from the fly ash used, a calculation was made using the highest estimated percentage of ash present in the evaluated manure samples, 9.1%. Using the total elemental concentration in the four fly ash samples used in this study, the trace element contribution from the fly ash was calculated and is reported in Appendix D. The table includes the ceiling and monthly average concentrations for elements noted in *Land Application of Sewage Sludge: A Guide for Land Appliers on the Requirements of the Federal Standards for the Use or Disposal of Sewage Sludge*, 40 CFR Part 503 (16), the total fly ash concentrations of those elements, and the calculated trace element contribution to the ash–soil mixtures based on the highest percentage of fly ash addition used at the site (28%). The results show that the manure and ash–soil mixtures both are calculated to be well below the land application limits listed. Even using 100% ash, concentrations fell below the land application limits with the exception of two arsenic values.
NDDH staff collected a second set of manure samples. These samples were also analyzed for trace element content. The results, provided by NDDH, are included in Appendix D, and the ceiling and monthly average concentrations for elements noted in *Land Application of Sewage Sludge: A Guide for Land Appliers on the Requirements of the Federal Standards for the Use or Disposal of Sewage Sludge*, 40 CFR Part 503 (16), are included in the table. The trace element concentrations, with the exception of arsenic, of the manure samples are consistently below the limits by a factor of at least 10. For arsenic, all but one of the manure sample concentrations fall below the ceiling limits by a factor of at least 7.6 while one sample fell below by a factor of only 3.

The NDDH performed a comparison of the metals in the manure from the fly ash-treated pens against the 503 sludge regulations (17). The sludge regulations have limits for concentration and loading rates. NDDH calculated the loading rates for the various metals based on typical manure-to-cropland application rates.

Manure should typically be applied to cropland at rates of about 20 tons an acre; however, the rate is much higher in some instances: 50 to 100 tons an acre. Using the values measured from samples of manure from the fly ash-treated pens, if this manure is applied at rates of 20 tons an acre, it does not exceed the cumulative or annual pollutant loading rate in the sludge regulations. However, if the application rates are very high, such as 74 tons an acre, the arsenic value in the manure from one of the pens would exceed the annual pollutant loading rate.

This same type of calculation was performed for the trace elements from the soil–fly ash mixtures that might eventually be land-applied. In comparing the calculated values for metals for a 28% fly ash application, the arsenic level of one fly ash source would result in a soil–fly ash mixture that would exceed the annual pollutant loading rate in the 503 sludge regulations if it was applied at a rate of 31 tons an acre or higher. NDDH did not indicate any other elements had the potential to exceed the annual or cumulative pollutant loading rates.

The potential issues with land-applying manure or soil–fly ash mixtures are extremely limited as indicated by the project team and NDDH evaluations of the data. CREC research staff highly recommend nutrient management plans for all animal-feeding operations which will encourage the application of manure at rates to protect groundwater, surface water, and the environment.

**Task 3: Performance Monitoring at the CREC Site**

The engineering performance of the ash-treated and control surfaces was monitored through observation, in situ testing, and laboratory evaluations of samples taken from the site. Observational monitoring included surface conditions, cracking, impact of cleaning procedures, and other general wear-related information. In situ testing included density and moisture content. Strength, density, and permeability tests were performed on intact, cored samples. Animal performance was also evaluated under CREC animal research projects. CREC staff evaluated the pen surfaces visually.

In 2001, engineering testing focused on evaluating samples collected at the CREC site. Density, moisture content, and permeability testing were the primary tests planned in an attempt to
quantitate and compare engineering performance of treated and untreated surfaces. In-place nuclear density testing was also performed on the eight treated pens where bison were not present. Results of field and laboratory tests are reported in Appendix D. Data collection was limited to select pens where no bison were present. Results indicated adequate mixing and compaction and are consistent with results from previous projects, showing an improvement in the site soils.

On-site visual evaluations indicated that when conditions were dry, control pens and treated pens look and perform similarly; however, during spring breakup, the treated pens performed much better than the control pens. This can be seen in photographs taken at the site during Spring 2001 (Figure 11). In addition, during rainfall events throughout the summer, the pen conditions were notably better in the treated pens than in the untreated pens. Muddy conditions were reduced by as many as 2–3 days in the treated pens as compared to the untreated pens.

Also, there was far less wear around the fence lines and concrete aprons in the treated pens. At the time of pen cleaning in September 2001, the control pens yielded a much higher volume of material that required removal than did the ash-treated pens. The lower volume of manure requiring removal from the ash-treated pens provided an advantage for material handling and was predicted to increase the time a feedlot could be used before soil usually removed during cleaning must be replaced. While it was speculated that the lower volumes of manure from the ash-treated pens would be higher in nutrient content, the limited data assembled (see Appendix D) indicate the percentages of nitrogen, phosphorus, and potassium were lower in the sample from the ash-treated pens than that from the control pens. Future investigations are required to evaluate the impact of pen scrapings on nutrient value.

Figure 11. Control vs. treated pens.

The use of flowable fill mixture for the feed bunker aprons at the CREC has proven to be a very economical choice. The material was placed easily, the costs were far less than that of concrete,
and to date the performance has been equal to that of the concrete aprons found in the control pens. The silage bunker placed near Mandan has also stood up quite well and provides better performance than the traditional soil floor.

The primary and most notable difference between the untreated and treated pens was in animal performance as assessed by CREC researchers according to bison weight gain. Bison in all pens were weighed on a quarterly schedule. During the spring thaw and early summer (April, May, June), bison in the treated pens gained an average of 0.35 pounds a day more than bison in the untreated pens, resulting in a feed savings of $0.13 per pound gained. Feed efficiency improved during spring and summer muddy months from 13.09 to 10.40 lb feed (dry matter) per pound of gain, $P = 0.01$, and over the 6-month feeding period from 10.55 to 9.47, $P = 0.05$. During dry times, the animals on all pens exhibited comparable weight gains. Because bison gain weight slower than beef cattle, it is anticipated that these figures will be even more significant for beef cattle. A complete set of data is included as Appendix F.

**Task 4: Technology Transfer**

Technology transfer for this effort focused on two areas: 1) working with and presenting data to NDDH and 2) promoting the concept of the use of coal ash in agricultural applications, specifically the use of fly ash for stabilizing feedlot surfaces. A comprehensive list of technology transfer activities is included in Appendix G. Promotion of this potential use to livestock and dairy producers has been accomplished primarily through events held at CREC, where regional producers attend briefings on CREC research. The response of regional producers has been positive, and several producers have expressed immediate interest in implementing the use of fly ash for drylots and loafing areas. Producers have also requested information on use of coal ash for laneways and driveways where muddy conditions also exist and for crop storage areas. A key technology transfer activity was the development of a manual for county extension agents and livestock producers (Appendix G). Additionally, livestock operators were invited to visit the CREC site to see for themselves how the placements have performed.

Additional placements at two locations in North Dakota served as training activities. Soil–fly ash mixes were placed in a silage bunker located about 40 miles northwest of Fargo in September of 2003. The three silage pits had fly ash mixed into the existing soil floor, and monitoring of performance will be completed this upcoming spring. A second placement occurred at a feedlot located near Carson. Soil and fly ash were mixed in a windrow, and the material was then placed in front of existing feed bunkers. As with the first placement, performance will be evaluated this spring, although early indications are that the material is not standing up to the very heavy and concentrated activity in the feed row.

**NDDH Correspondence**

Throughout the duration of the project, the project team worked with the NDDH with the goal of developing a rule approving the use of coal ash in feedlot applications. To get the approval and facilitate NDDH’s general understanding of CCBs, the project team performed an extensive series of laboratory and field activities. All data were reported to NDDH through various technology transfer
outlets including meetings, presentations, e-mails, phone conversations, and reports. A Web site was also developed to allow for easy and instant data sharing between the project team, project sponsors, and NDDH.

The project team assembled and documented information on stabilization characteristics of different soils, animal health and exposure to coal ash, and state regulations concerning coal ash for use in feedlots. This information is included as presented to NDDH in Appendix H.

NDDH’s integral participation proved to be detrimental to project progress. On numerous occasions, as documented in Appendix H, NDDH stalled progression by requesting unnecessary tests and by not allowing additional demonstrations to occur. NDDH requests were often perceived by the project team as unwarranted and prejudiced against ash use.

As the project drew to a close, it appeared as though NDDH would not make a determination on the use of coal ash in feedlot applications. Without NDDH approval, there would be no realized benefit for North Dakota farmers and ranchers. The North Dakota Agriculture Commission, Mr. Roger Johnson, was asked to help facilitate an agreement between parties. The NDDH agreed “that the final Manual, if strictly adhered to, will enable beneficial use of the four studied fly ashes within pens of Department-permitted livestock facilities with minimal impacts to human and animal health and the environment.” Currently, only 40 feedlot facilities in North Dakota are NDDH-approved, making the rule only applicable to large operators. The project team plans to pursue a blanket approval for all North Dakota feedlots and for additional feedlot applications, including laneways and feed storage pads.

On a positive note, the project was successful in its technology transfer efforts with NDDH. Some NDDH representatives came to understand the environmental and engineering aspects of the material with regard to its use in feedlot stabilization.

**Task 5: Economic Evaluation of the Feedlot Placements**

*Placement Economics*

It is assumed that coal ash placement in feedlot settings can be completed using conventional farm equipment owned by the livestock producer and labor will not be outsourced. Therefore, in determining the cost for the CREC ash placement, labor and equipment costs were considered to be zero.

The raw material cost of fly ash is estimated to be $25 a ton. Transportation costs are estimated to be $1.00 a mile. Total costs for the construction of a 75 × 100-ft feedlot pen at the CREC site treated to a depth of 6 inches with 20% fly ash (28 tons) located 100 miles from the ash source is estimated to be $800. Pens stabilized at the CREC site are expected to have a surface life of 5 years, making the yearly expense for this placement about $140 per 75 × 100-ft pen.

The raw material cost of a cement-treated feedlot is estimated to be $90 a ton. Transportation costs are estimated to be $1.00 a mile. Total costs for the construction of a 75 × 100-ft feedlot pen
treated to a depth of 6 inches with 20% cement located 100 miles from the source are estimated to be $2620. Pens stabilized at a site are expected to have a surface life of 5 years, making the yearly expense for cement placement $525 per 75 × 100 ft pen.

Animal Benefits

During the spring thaw and early summer (April, May, June), bison in the treated pens gained an average of 0.35 pounds a day more than bison in the untreated pens, resulting in a feed savings of $0.13 per pound gained. Because this difference was not statistically significant throughout the 3-year duration of this project, the applicability of the number to the economics of the placement is inappropriate at this time. It is anticipated that a noteworthy feed savings will result in years with significant rainfall and during spring thaw.

The realized economic advantage of stabilizing feedlots with coal ash will depend on several factors, including maintenance savings, improved manure quality, improved animal health, and other hidden market advantages. Potential returns from increased animal performance appear to outweigh the costs of stabilizing feedlots with coal ash.

Other Issues

If the landowner chooses to use the feedlot site for purposes other than feedlot pens, remedial actions may be required regardless of the surfacing type. These were not considered in this economic evaluation.

CONCLUSIONS

- Stabilizing feedlot surfaces with fly ash offers several advantages including reduced odor, reduced permeability and associated infiltration of water to groundwater, reduced manure handling and pen resurfacing, and increased animal comfort and weight gain.

- Laboratory and field results indicated that use of fly ash to stabilize soil for feedlot surfaces will not generally contaminate water or form a contaminated leachate. Field data indicated no distinguishable impact on resultant groundwater quality.

- Laboratory leaching results demonstrated that the composition of soil–ash leachates fell within the range of local surface and groundwater, even without allowing for the attenuation of the leachate, which will occur in a field setting through dispersion, diffusion, precipitation and coprecipitation, redox reactions, bacterial action, and sorption.

- It is environmentally appropriate to use the fly ash sources evaluated to stabilize feedlot surfaces.

- There is high potential for an economic benefit from use of ash-treated soils for feedlot surfaces based on estimated costs of the surface treatment and limited data on animal weight gains during a single wet season.
The ash stabilized surfaces exhibited decreased wear patterns in pens and facilitated ease of pen cleaning.

Manure removed from ash-treated surfaces was of appropriate quality for land application, and runoff from the treated surfaces was of appropriate quality for irrigation purposes.

Involving the state regulatory agency in this project did not provide the benefits anticipated, and an alternate approach to working toward development of approvals for specific applications or development of more general use rules should be developed in North Dakota.

RECOMMENDATIONS

- The coal ash industry in North Dakota needs to continue to lobby for beneficial ash use rules or policies at the state level taking advantage of user interest in specific applications to facilitate lobbying efforts.

- The project team should continue to work with the NDSU Extension Service for 1–2 years in demonstrating the use of coal ash in feedlots to ensure quality placements.

- The project team should investigate and demonstrate the use of ash-stabilized soil mixtures for additional agricultural applications such as feed storage, compost pads, driveways, etc.

- Future projects should be designed and implemented prior to approaching the NDDH for approvals.

REFERENCES


3. Falkirk Mining Company. Demonstration of North Dakota Lignite Fly Ash in Haulroad Construction; Final Report to Lignite Research Council; FY00-XXXIV-97; Sept. 2001


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- U.S. Department of Energy

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