ABANDONED COAL MINE LANDS RESEARCH PROGRAM

FOURTH-SEMI ANNUAL PROJECT REVIEW SEMINAR

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STRATEGIES FOR ESTABLISHMENT OF BIG SAGEBRUSH (*Artemisia tridentata* spp. *wyomingensis*) ON WYOMING MINED LANDS

G.E. SCHUMAN, D.T. BOOTH, AND J.R. COCKRELL

Strategies for Establishment of Big Sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) on Wyoming Mined Lands.

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Introduction

Wyoming big sagebrush is one of the most widely distributed and adapted shrub species in Wyoming and the region. Although considerable debate has surrounded its value, and the need for re-establishment during mined land reclamation, the fact remains that reclamationists are often advised and sometimes required to restore sagebrush to mined lands at densities that approximate predisturbance conditions. In light of this, methods for establishment of big sagebrush are an important area of revegetation research and technology development. Sagebrush is well adapted and persistent when mature, but establishment from seed has proven difficult. Problems include low seedling vigor, seedling inability to compete with herbaceous species, poor seed quality and/or ecotypic adaptation, inability of agronomic seeding methods to meet seed microsite requirements, and effects of altered soil conditions on establishment of the effective vesicular-arbuscular mycorrhizal (VAM) associations that are important to sagebrush seedling survival.

A research study was initiated in January 1991, to test several cultural approaches so as to define effective strategies for obtaining stands of big sagebrush on mined lands. Specific objectives include:

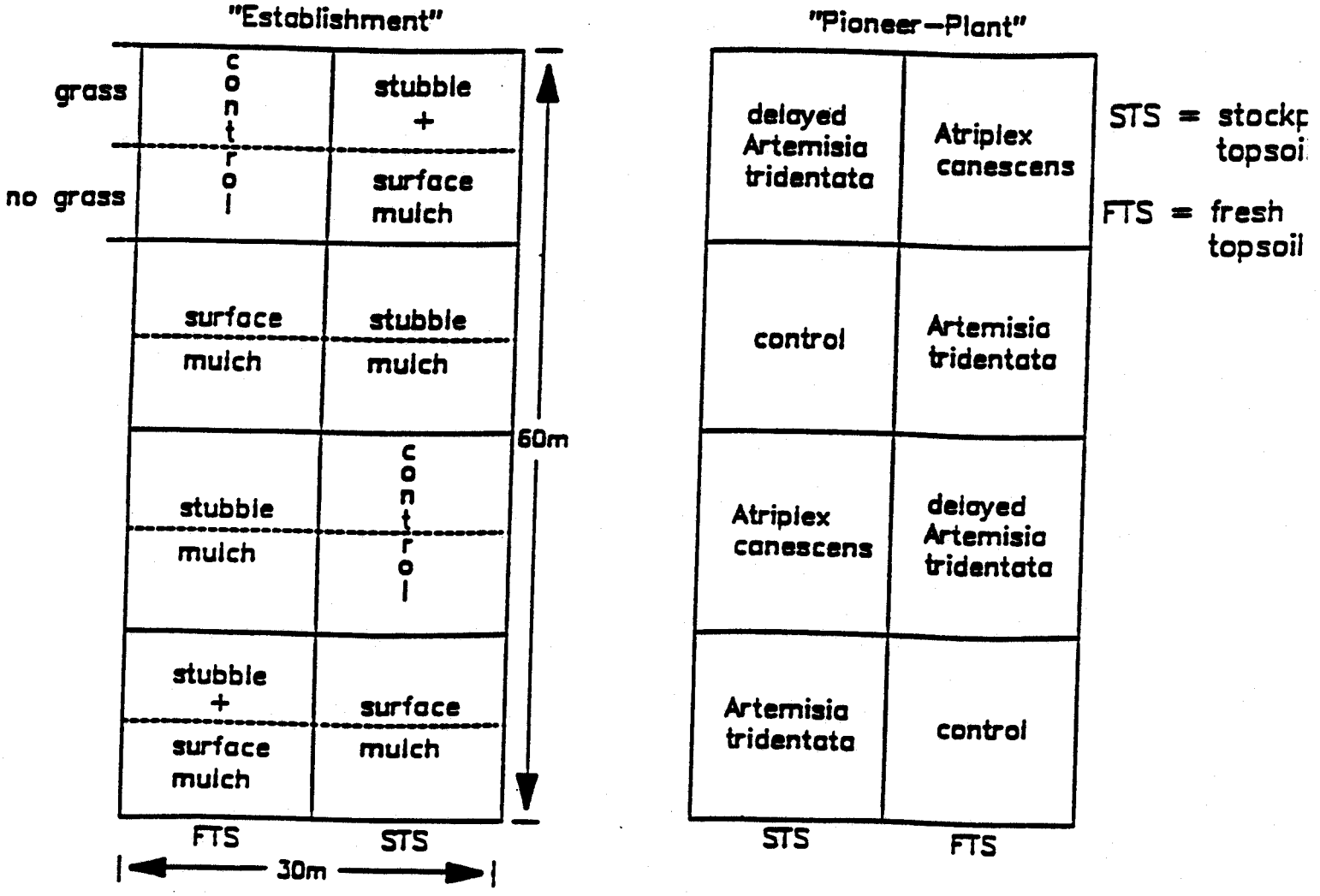
1. Efficacy of direct-applied topsoil for enhanced sagebrush stand establishment through effects of VAM and the topsoil as a seed source.
2. The value of a stubble mulch crop of annual grain for sagebrush establishment through effects on snow catchment and microsite modification.
3. The usefulness of surficially applied hay/straw mulch in improving sagebrush establishment through seed/seedling protection and microsite modification.
4. The effect of competition from concurrently seeded herbaceous species on establishment of sagebrush, and
5. The value of seeding fourwing saltbush as a pioneer species for enhancing soil biological properties leading to the natural recruitment of sagebrush.

The research will allow evaluation of the primary questions and interactive effects among treatments in a manner to suggest an optimal combination of methods to enhance sagebrush revegetation. It is anticipated that application of technology developed from this project will directly benefit entities involved in western mined land reclamation.

Project Description

This project is composed of two compatible studies that are being conducted simultaneously. These are identified as the "Establishment Study" and "Pioneer Plant Study" (Figure 1). The Establishment Study will test techniques for sagebrush establishment, and will be fully completed during the three year term of this project. The Pioneer Plant Study will be a longer-term investigation of plant succession manipulation intended to enhance sagebrush establishment. Initial results of the pioneer Study will be available by year three of the present project, but several additional years of monitoring will be necessary for full evaluation of treatment effects.

Figure 1. Field plot diagram of a representative block of the "Establishment" and fourwing saltbush "Pioneer Plant" studies; each block has been replicated three times with main treatments (Table 1) randomly assigned within the split-plot experimental design.



Establishment Study

This study is evaluating three sets of main treatment variables (Table 1): topsoil salvage procedures (fresh vs. stored), mulch method (stubble, surface, stubble + surface, and non-mulched), and level of herbaceous species competition (concurrently seeded grasses vs. no seeded grasses). Sagebrush was seeded similarly within all combinations of the above main treatments using broadcast methods. Figure 1 portrays the field plot design. Each block is divided into two topsoil treatment plots, each of which is split into four stubble treatments plots; each stubble treatment plot is further divided into three grass seeding-rate treatment plots.

The two topsoil treatments are included to evaluate the hypothesis that sagebrush establishment will be enhanced by use of fresh-stripped topsoil instead of stored topsoil (i.e., topsoil that had been stockpiled at least 5 years prior to respreading on mine spoils). It is postulated that freshly stripped topsoil will have a minimum loss of fertility, VAM and, possibly, viability of seed bank sagebrush seeds, and therefore, a higher potential for natural establishment of sagebrush than stored soil.

The mulch treatments are to test the hypothesis that modifications of seedbed conditions will improve establishment of surficially seeded sagebrush. Mulches are known to modify the seedbed microclimate with regard to temperature and moisture. Two mulches are being tested, alone and in combination: a grain stubble and a surface application of hay/straw mulch. Grain stubble has been found effective in trapping snow, modifying diurnal temperature fluctuation, and increasing water infiltration and storage in the soil. Because of these benefits, researchers found stubble mulching to result in greater grass seedling establishment than that with other mulching practices; the same results would be expected for sagebrush, particularly when surface seeded. The surficially applied hay/straw mulch will likely have little effect on snow accumulation, but may beneficially modify seedbed microclimate through water conservation and temperature moderation; it also may protect sagebrush seeds and seedlings from physical and desiccative effects of wind and/or insolation.

The grass seeding treatments are to evaluate the hypothesis that sagebrush will be more effectively established in absence of competition from concurrently seeded herbaceous species. The three treatments are absence and two seeding rates of a mixture of vigorous cool-season, native perennial grasses.

Pioneer Plant Study

This study involves two sets of main treatment variables (Table 1): topsoiling procedures (fresh vs. stored, for the same purposes described in the Establishment Study), and shrub seeding procedures. Mulch method (grain stubble) and level of seeded herbaceous species competition (no seeded grasses) is held constant under all main treatment combinations. The shrub seeding treatments imposed on each topsoil treatments are: a) seeded to sagebrush, b) seeded to fourwing saltbush, c) one year delayed seeding of sagebrush, and d) an unseeded control. After the first growing season for seeded shrubs, treatments a), b) and c) will be over-seeded annually with sagebrush to assure that viable seed is present each spring. The experimental design (Figure 1) divides each block into two topsoil treatment plots, each of which are further split into four shrub seeding treatment plots.

Table 1. Treatments applied in "Establishment" and fourwing saltbush "Pioneer Plant" studies. All combinations of main treatments will be implemented within each study.

Treatments	Establishment Study	Fourwing Saltbush Pioneer Plant Study
TOPSOIL	1. Fresh Topsoil 2. Stored Topsoil	1. Fresh Topsoil 2. Stored Topsoil
MULCH	1. Stubble Mulch 2. Surface Mulch 3. Stubble + Surface Mulch 4. Control (no mulch)	Not varied (Stubble mulching will be practiced on all treatment combinations)
COMPETITION	1. Seeded Cool-Season Grass Mixture 2. Control (no seeded grasses)	Not varied (No grasses will be seeded)
SHRUB SEEDING	Not varied (sagebrush will be seeded on all treatment combinations)	1. Fourwing saltbush seeded Year 1 and overseeded with sagebrush Years 2 and 3. 2. Sagebrush seeded Year 1 and overseeded with sagebrush in Years 2 & 3. 3. Delayed seeding: no shrubs seeded Year 1, sagebrush initially seeded in Year 2 and overseeded in Year 3. 4. Control (no shrubs seeded)

The topsoil and shrub seeding treatments allow testing for two contrasting hypotheses. The first, hereafter referred to as the "exclusion" hypothesis, is that fourwing saltbush seeding rates greater than 2.2 kg/ha (26 seeds/m^2) result in monotypic stands that exclude invasion of other species, particularly climax shrubs such as sagebrush. It has been suggested that if seed mixtures contained more sagebrush and less fourwing saltbush, more sagebrush would establish on reseeded mined lands.

The contrasting view, hereafter referred to as the "pioneer plant" hypothesis, is that planting sagebrush and other climax plants before sufficient soil improvement (biological and physical) has occurred predestines poor survival of climax plant seedlings. It is postulated that fourwing saltbush is a pioneer species that can be used to prepare the site for the later-seral species big sagebrush. Saltbush densities of one plant/m^2 may not exclude sagebrush, but instead may promote the soil improvement necessary for sagebrush to establish and survive. If this hypothetical relationship is valid, the most successful and economical method of obtaining healthy stands of sagebrush may be to initially plant a suitable pioneer species such as fourwing saltbush. The rationale for this view is: a) the perceived need for disturbed soils to regain, through effects of the pioneer species, predisturbance levels of VAM and other developmental attributes required to support sagebrush populations, and b) the beneficial modification of seedbed microclimate that may occur with the establishment of a pioneer shrub species. Fourwing saltbush has been previously proposed and justified as an effective pioneer species that will promote the desired soil and microclimate changes.

Comparisons of vegetation responses among the various treatment combinations will allow us to evaluate sagebrush establishment, survival and plant succession with and without fourwing saltbush as a pioneer species. If the exclusion hypothesis is true, there will be little interaction between topsoil and shrub seeding treatments. Plots seeded to sagebrush only will have the greatest, and plots seeded to fourwing saltbush will have the least sagebrush development. Conversely, there will be significant topsoil and shrub seeding treatment interactions if the pioneer plant hypothesis is true. In that case, sagebrush development on stored topsoil should be greater where fourwing saltbush was established than where it was not. Sagebrush should also have greater development on the fresh topsoil than on stored topsoil. In all treatments, survival of sagebrush seedlings should increase as soils and plant communities develop. Proper evaluation of the pioneer plant theory will require additional years beyond the period covered by this proposal.

Progress Report

This project was initiated January 1, 1992 and is being carried out in cooperation with North Antelope Coal Company, north of Douglas. Mr. Scott Belden, Environmental Supervisor with North Antelope Coal Co., is our site coordinator and cooperator. The seedling establishment phase of the "Establishment" project is complete and seedling density, mortality and establishment are being evaluated. Early phases of the "Pioneer" study have also been completed.

Establishment Study

Topsoil source had a significant affect on sagebrush emergence and first season survival. Fresh topsoil resulted in 1.52 sagebrush seedlings/m^2 compared to 0.02 seedlings/m^2 for the stored topsoil during our June observations. A similar trend was evident for the October observations with fresh topsoil having 1.26 and the stored topsoil having 0.04 sagebrush seedlings/m^2. Summer mortality was only 17%.

Competition effects on sagebrush emergence and first season establishment were also very evident. Sagebrush seedling density was 1.88, 0.25 and 0.18 sagebrush seedlings/m^2 for the 0, 18, and 36 kg PLS/ha grass seeding rates, respectively, in June. October seedling counts showed a similar summer mortality as observed on the topsoil treatments.

Mulch practice also had significant impact on sagebrush seedling density in both the June and October data. Sagebrush seedling densities were 0.01, 1.25, 1.17, and 0.65 seedlings/m^2 for the control (no mulch), surface straw, stubble mulch, and surface plus stubble mulch in June, respectively. October seedling densities were 0, 1.07, 0.98 and 0.55 seedling/m^2 for the respective mulch treatments.

Grass seedling densities did not exhibit a topsoil or mulch treatment response. The grass seedling densities were 0, 196, and 250 seedlings/m^2 for the 0, 18, and 36 kg PLS/ha grass seeding rates, respectively.

Pioneer Study

Fourwing saltbush seedling density responded to the topsoil source treatment; however, the differences were not as great.

Fourwing saltbush seedling density was 4.69 and 3.94 seedling/m^2 in June for the fresh and stored topsoil, respectively. The October seedling densities were 4.22 and 3.53 seedlings/m^2 for the respective topsoil treatments. Sagebrush establishment on the Pioneer study was considerably more variable than on the Establishment study and responded opposite of the Establishment study to topsoil treatments. Sagebrush density was 0.15 and 1.26 seedlings/m^2 in June for the fresh and stored topsoil, respectively. This trend cannot be explained. Growing season mortality was also much greater. The October seedling density was 0.07 and 0.41 seedlings/m^2 for the respective topsoil treatments.

Future Plans

We will continue to monitor sagebrush seedling survival on the Establishment study in the spring of 1993 and we will also evaluate the percent of VAM infection of the surviving sagebrush.

Soil and spoil samples will also be collected in the spring of 1993 to evaluate biological and chemical qualities of the material.

Sagebrush will be over-seeded this winter on the sagebrush, delayed sagebrush, and fourwing saltbush treatments of the Pioneer study. Final data collection and interpretation of the Pioneer study will be accomplished outside of the time frame of the grant.

THE ROLE OF NATURAL ORGANIC SOLUTES IN THE MOBILITY OF SELENIUM IN COAL MINE BACKFILL-GROUND-WATER SYSTEMS

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SEMI-ANNUAL REPORT #4
THE ROLE OF NATURAL ORGANIC SOLUTES IN THE MOBILITY OF SELENIUM IN COAL MINE BACKFILL-GROUND-WATER SYSTEMS

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INTRODUCTION

Natural organic solutes may play an important role in the mobility of selenium in coal mine backfill ground-water systems. A better understanding of the processes involving organic solute-selenium interactions could provide information for improving coal mining reclamation techniques. The specific objectives of this research are:

1. To characterize inorganic and organic selenium species in coal mine backfill and its associated ground water,
2. To determine the role of natural organic solutes on selenium adsorption/desorption and precipitation/dissolution processes, and
3. To quantify the effects of organic solutes on the mobility of selenium from coal mine backfill to ground water.

The information obtained from this research will increase our understanding of processes that influence the mobility of selenium in coal mine backfill ground-water systems.

SITE SELECTION

Three field sites with existing wells were selected in reclaimed areas at two large surface coal mines in the Powder River Basin. The mines are referred to by letter designation (A and B) throughout this project because of agreements with the companies not to identify the mines by name. Two sites were investigated at mine A (A-1 and A-2) and one site was investigated at mine B (B-1).

FIELD SAMPLE COLLECTION

Spoil Cores

Six spoil cores were obtained during September 1991. Two spoil cores were collected from within approximately a 15-foot radius of the well at each of the three sites. Core holes ranged from 22.5 to 27.5 feet deep and were at least as deep as the associated well.

Ground-Water Samples

Ground-water samples were collected at each well in September, 1991 and July or August 1992. Wells were pumped at approximately 1.2 gallons per minute with a submersible, positive displacement pump until pH, specific conductance, and temperature were stable before samples were collected.

LABORATORY ANALYSES

Quality Assurance

The laboratory quality assurance program used in this study included the use of blanks, standard reference samples and duplicate analyses. A total of 10 to 15 percent of the total analyses were dedicated to quality assurance. A spoil reference sample was developed from excess spoil material collected during the sampling. An additional soil standard reference material was developed by the U.S. Geological Survey using soils from the San Joaquin Valley, California. Water standard reference samples prepared by the U.S. Geological Survey Standard Reference Water Sample Project were also included for analyses.

Spoil Cores

A total of 136 spoil core subsamples were dried and sieved through a 10 mesh (2mm) sieve. Saturated paste extracts (SPE) were prepared and the following analyses were made on the SPE solutions: pH, redox potential (Eh), specific conductance, total selenium, sulfate, and dissolved organic carbon (DOC). Three subsamples were selected from each core for total elemental and mineralogical analysis.

The pH values for core subsamples were typically between 6.0 and 8.0. This is probably due to the buffering effect of carbonates, which were present in all samples. The pH and Eh measurements for SPE for core subsamples taken near the ground-water table were very similar to those obtained for the ground-water samples. The SPE specific conductance (0.21 to 0.84 S m^{-1}) indicate a large salt content in the core subsample solutions. Total selenium concentrations in the SPE ranged from 1 to 156 µg/kg.

Total elemental analyses of the 18 selected core subsamples were completed. Results indicate total selenium concentrations in core subsamples ranged from 0.1 to 15 mg/kg.

X-ray diffraction analyses indicated that the spoil core samples have similar types of mineralogy. Quartz, kaolinite, potassium feldspar, illite, and muscovite were identified in all samples. Additional minerals that were detected in some samples include: gypsum, calcite, dolomite, apatite, and geothite. Total elemental analyses indicated that all core samples were dominated by iron concentrations. X-ray diffraction analysis, however, did not show any peaks that are indicative of crystalline iron oxides. Visual inspection indicated the presence of a coating on selected clay particles in all spoil core samples that may have been an amorphous iron oxide.

Ground Water

Ground-water samples were analyzed for DOC and total selenium. DOC concentrations in ground-water samples collected in 1991 did not appear to be significantly different from those collected in 1992. Two of the ground-water samples (A-1 and B-1) contained adequate concentrations of DOC for isolation and fractionation studies. The DOC concentration of sample A-2 was not sufficient for isolation, but was used for DOC fractionation analyses. Isolation and fractionation of the DOC will be conducted according to the methods described below.

Total selenium concentrations in 1991 were found to parallel the DOC concentrations. Ground-water samples A-1 and B-1, which had high DOC concentrations, had selenium concentrations of 125 µg/L (A-1) and 88 µg/L (B-1). Ground-water sample A-2, which had a low DOC concentration, had a selenium concentration of 3 µg/L. Although sample A-2 had low DOC and selenium concentrations, the sample will be useful for studies of adsorption/desorption and precipitation/dissolution properties of the different backfill materials.

Adsorption/Desorption Studies

Adsorption/desorption experiments were conducted for six core subsamples. Results show that core subsamples have a very large selenium adsorption capacity. All samples adsorbed more than 90 percent of the added selenium (except one with a pH of 6.7 that adsorbed 75 percent). The pH of the samples examined ranged between 3.7 and 6.7. Although pH is a major factor in controlling adsorption, the adsorption capacity generally remained constant within the

observed pH range except at pH 6.7. The selenium desorbed by phosphate was about 50% of the adsorbed selenium; this decrease may be due to precipitation processes.

Precipitation/Dissolution Studies

Preliminary precipitation/dissolution experiments were conducted to determine the equilibrium conditions for core samples. Twenty-five grams of core subsample were reacted with 75 ml of distilled-deionized water on a mechanical shaker for 1 to 28 days. After reacting for 1, 3, 7, 14, 21, and 28 days, sample suspensions were filtered under an argon atmosphere using a 0.45 μm filter. Clear extracts were divided into two subsamples. Analysis of the extracts is in progress.

Controlled Redox Studies

To examine the effect of oxidation-reduction processes on selenium adsorption/dissolution and precipitation/dissolution reactions in mine backfill and associated ground water we have designed a redox controlling device (RCD) in which redox potential can be controlled. This unit consists of a sample chamber with platinum, pH, and reference electrodes connected to a pH/millivolt meter. The meter is connected to a relay, which controls redox potential (±10 milliVolts) and pH (±0.1 unit) in the reaction cell. The device was tested and calibrated for distilled-deionized water and soil samples. The device controlled redox potential from +500 to -500 milliVolts with an accuracy of ±15 milliVolts. Initial studies with pure selenium suggested that the RCD could be used to measure and quantify redox potential effects on selenium speciation.

Dissolved Organic Carbon

DOC was fractionated into 6 DOC fractions: hydrophobic acids, bases and neutrals, and hydrophilic acids, bases, and neutrals. The results of the DOC fractionation analysis indicate DOC in the ground-water samples was dominated by organic acids (61 to 82 percent), with organic neutrals ranging from 13 to 38 percent, and organic bases ranging from 4 to 10 percent. Initial studies indicated hydrophobic bases were a small percentage (0 to 2 percent) of the total DOC, therefore, this analysis will be omitted in future analyses.

SUMMARY

Three field sites were selected and sampled in reclaimed areas at two surface coal mines. Two spoil cores and two sets of ground-water samples have been collected from each field site. Analyses of ground-water samples indicate that total selenium concentrations ranged from 3 to 125 μg/L and DOC concentrations ranged from 11 to 88 mg/L. Results from adsorption/desorption experiments showed that core subsamples adsorbed 75 to more than 90 percent of the added selenium and approximately 50% of the adsorbed selenium was removed by a subsequent phosphate extraction. Precipitation/dissolution experiments were conducted, however, analysis of extracts are still in progress. A redox controlling device has been developed in which the effects of oxidation-reduction on selenium adsorption/desorption and precipitation/dissolution reactions will be studied. Fractionation of DOC in ground-water samples indicated predominance of organic acids (61 to 82 percent).

THE IMPORTANCE OF SOLID AND SOLUTION SELENIUM SPECIATION IN MOBILITY AND PLANT UPTAKE OF SELENIUM FROM WYOMING COAL MINE LAND RECLAMATION

G.F. VANCE, K.J. REDDY, L.K. SPACKMAN, S. SHARMASARKAR

Abandoned Coal Mine Land Research Program

Semi-Annual Report

for

THE IMPORTANCE OF SOLID AND SOLUTION SELENIUM SPECIATION IN MOBILITY AND PLANT UPTAKE OF SELENIUM FROM WYOMING COAL MINE LAND RECLAMATION

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The Importance of Solid and Solution Selenium Speciation in Mobility and Plant Uptake of Selenium from Wyoming Coal Mine Land Reclamation

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Introduction

Selenium (Se) is an element of environmental concern due to its ability of becoming increasingly mobile with time. During surface mining activities, materials previously in reducing environments become exposed to atmospheric oxidation, which may result in elevated levels of mobile Se and plant Se contents which subsequently can enhance the possibility of Se toxicity to animals. The post mining fate of a majority of the abandoned and reclaimed coal mine lands is grazing land, pastureland and/or wildlife habitat. Increased solubility and mobility of Se in disturbed areas may result in higher levels of Se in surface waters, groundwaters and in resaturated backfill. If Se mobilization is not attenuated, affected abandoned and reclaimed areas may not be suitable for post-mining land use or may require special resource management considerations. Therefore, appropriate research on soil and backfill material is necessary to characterize Se solubility, mobility and speciation in relation to plant uptake.

Objectives

The main objective of this research project is to examine the geochemistry of Se in abandoned and reclaimed coal mine sites and native rangelands. The project has been divided into four research tasks:

- development of a rapid and cost effective method for determining Se species in backfill and soil materials of abandoned and active coal mine sites,
- examination of solid-phase and solution speciation of Se in the rooting-zone of mine soils for correlation to plant uptake,
- characterization of Se adsorption/desorption and precipitation/dissolution processes controlling Se mobility in backfill and soil environments,
- determination of plant uptake of Se at coal mine lands and other affected sites that can be correlated to Se solid-phase and solution-phase speciation.

Selenium occurs naturally in several chemical forms. We propose that the analysis of the factors that control Se speciation and the direct analysis of Se species can be used to characterize and predict the processes that control Se solubility, mobility, availability, and plant uptake. This information will assist in designing preventative and/or remediation schemes for abandoned, reclaimed and active coal mine lands.

Survey of Abandoned Coal Mine Lands in Wyoming

Several sources of information, which were described in the third semi-annual ACML report, were used for locating research sites on abandoned and active coal mine lands. A comprehensive description of our survey of potential abandoned coal mine sites is available in an interim report submitted to the Office of Research, University of Wyoming on October 18, 1991.

Site Selection

Five surface coal mines located in north, central and southern Powder River Basin were selected and sampled during summer, 1991. In 1992, two additional mines were sampled; a reclaimed abandoned coal mine located near Rock Springs and a reclaimed uranium mine located in the southern part of the Powder River Basin. One transect sampled in 1991 was partially destroyed due to mining activities.

Field Work

In both 1991 and 1992, plant, soil, and backfill samples were collected from abandoned, reclaimed and native sites located in the Powder River Basin and near Rock Springs. Forty three sites have been established within thirteen transects located on seven different mines. In both 1991 and 1992, the five dominant plant species at each site were sampled.

Laboratory Analyses

All the soil, backfill, and plant samples were logged in and prepared for chemical analysis. The plant samples were oven-dried at 50-60°C for 24 hours and then ground to 60 mesh using a Wiley Mill. The soil and backfill samples were divided in two, using a Riffle Splitter, and one part was crushed with a hammer covered with cheese cloth and sieved to 10 mesh and the other air dried, sealed, and stored. The samples collected from the abandoned mine research sites were given the highest priority.

The aqueous chemical forms of an element often govern its solubility, mobility, availability and subsequent environmental impact. Thus, the analytical determination of the concentrations of aqueous Se species in soil and backfill solutions is required to adequately predict its fate and behavior. Soil and backfill samples have been analyzed for pH, EC, soluble SO_4^{2-}, extractable and total Se. Additional analyses currently being performed include: texture, mineralogy, carbon, cation exchange capacity, and base cations. Selected backfill samples from the abandoned mine research sites are also being examined by sequential extraction, adsorption-desorption and precipitation-dissolution methods to determine Se solid-phase speciation and potential mobilization. Plant samples have been analyzed for total Se by digesting in a nitric/perchloric acid mixture followed by Se analysis using an Atomic Absorption Spectroscopy-Hydride Generation (AAS-HG) technique.

Selenium Extraction Methods: The extraction of Se by different techniques for all the 242 soil and backfill samples collected in 1991 and 1992 has been completed. Results from the extractable Se analysis indicate the following trend in the amount of Se extracted: Phosphate > AB-DTPA > Hot Water > Saturated Paste. Saturated paste extractable Se level was very low. In a number of sites, AB-DTPA extractable Se was found to be greater than the WDEQ-LQD Guideline No. 1 (1984) suitability limit of 0.1 mg/kg. Results of this work will be used to correlate soil-plant Se levels.

Plant Se Characterization: Total plant Se has been analyzed in all the 1991 (189 samples of 59 different species) and 1992 (202 samples of 66 different species) samples. A large number of samples contained Se levels >5 mg/kg . Statistical analyses are currently being run to evaluate any possible soil-plant Se correlations.

Se Speciation: Both Ion Chromatography (IC) and AAS-HG techniques can be used to speciate Se. IC provides speciation of SeO_3^{2-} and SeO_4^{2-} in solution without the need for sample pretreatment or HCl reduction. Although detection limits are only in the range of 10 to 20 µg/L and limits of quantification are approximately 50 µg/L, IC is very useful for applications where monitoring SeO_3^{2-} and SeO_4^{2-} transformations are essential. Interferences from SO_4^{2-} concentrations above 1000 mg/L can limit the effectiveness of ion chromatography for Se applications in some soils and groundwater. Speciation studies are currently being performed using both techniques, results of which have indicated both methods correspond well with one another. However, a number of soil and backfill materials have very high levels of sulfate and for them AAS-HG is more useful for Se speciation. Certain abandoned mine sites have been found to have very high Se and low sulfate, in such cases IC is more useful.

Solid Selenium Speciation: Sequential extractions are currently being conducted on certain abandoned mine samples ranging from low to high levels of extractable Se (AB-DTPA extractable Se: 0.017-1.412 mg/kg, 0.1 M KH_2PO_4 extractable Se: 0.045-3.010 mg/kg). Mobility and plant uptake of Se are dependent on the rate and degree of soil and overburden solubilization, as well as the nature of the chemical species formed. Se fractions from sequential extractions of these materials may provide very important information on soil-plant relationships with time. Water soluble fraction (0.25 M KCl) represent the soil solution, exchangeable (0.1 M KH_2PO_4) fraction refers to the Se concentrations related to mobility and plant uptake, acid soluble (4 M HCl) fraction indicates the amount of Se that may be accessible over time and which may be solubilized readily by plant root interactions.

Adsorption and Desorption Studies: Adsorption-desorption studies have been done on certain reclaimed mine samples from different depth and varying pH range (4.77-8.17) using a batch technique. Selenite has been found to be the potential adsorbent and the degree of sorption increases with decreasing pH. The sorption behavior follows both Freundlich and Initial Mass Isotherms. There is a large difference between adsorption and desorption, which indicates Se immobilization possibly through precipitation processes. These studies are important in that they are useful for: a) determining Se adsorption capacity of Coal Mine Land soils and backfill materials, b) identifying how solubility, mobility, and availability of Se is governed by adsorption, and c) correlating Se adsorption with chemical and pedological properties. Presently more sorption studies are being done on abandoned mine samples in relation to mechanistic immobilization and influence of other ions on Se sorption. In addition, iron extractions are also being carried out to correlate Se adsorptivity with extractable iron levels.

Precipitation and Dissolution studies: Precipitation studies are now going on from both undersaturation and supersaturation approaches. These studies are being performed from a kinetic standpoint where time is the major variable. Soil and backfill, as well as pure minerals, are being used in these studies; results will determine the potential solid phases controlling the solution Se chemistry. The results of the precipitation studies will be analyzed using the speciation model MINTEQA2 or GEOCHEM. Data from the solubility studies with the precipitates will also be compared to the existing thermodynamic predictions found in the literature. These studies are useful for: 1) characterizing solubilities and mobilities of different Se species and 2) determining Se levels with solid phase speciation. One of the solid phases that is believed to control soluble Se concentrations is $CaSeO_4 \cdot 2H_2O$. The following figure shows the X-Ray diffractogram of the $CaSeO_4 \cdot 2H_2O$ mineral phase that has been prepared in our laboratory.

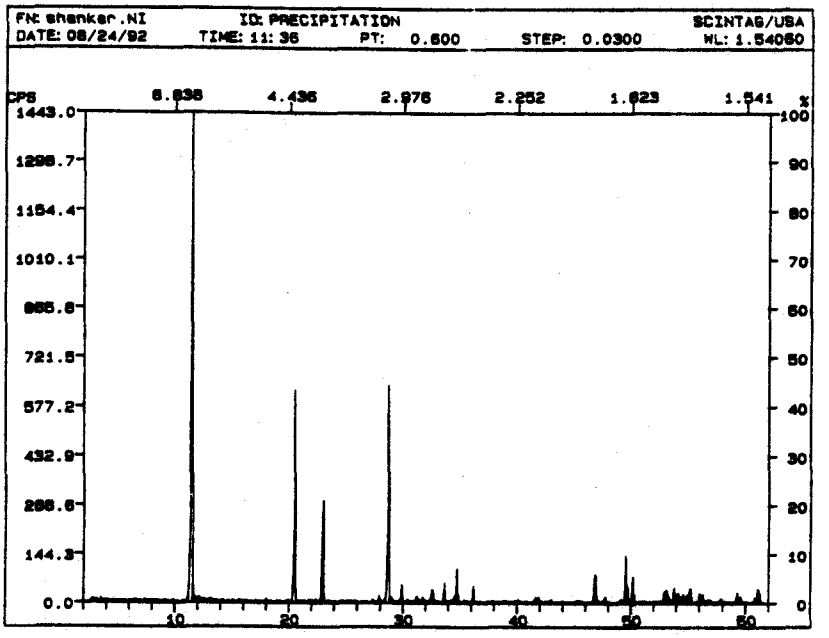

Figure 1. XRD characterization of $CaSeO_4 \cdot 2H_2O$ mineral.

Project Outcome

We anticipate the results of this research will provide the information necessary to predict the availability of Se to plants and the migration of Se to sensitive aqueous environments. This information can be used to aid in the development of suitability limits for regraded zone materials. The information may also be useful in designing remediation schemes by identifying materials which are locally available and which can fix mobile Se species. The identification of solid and solution phase Se species that correlate with plant Se accumulates can result in the development of methodologies to fix Se in plant unavailable forms. The results of this study should also provide information on where elevated Se overburden materials can be placed in the backfill environment (i.e. reduced, oxidized, or degree of saturation).

Personnel Involved with Project

Doug Bonett, Associate Professor of Statistics, is supervising all project statistics. Shankar Sharmasarkar, Soil and Environmental Chemistry Ph.D. student, has been working on the project since May 1992. Additional personnel contributing to this project include a Post-Doctoral Scientist, Dr. Micheal Blaylock, Research Associate, Tim Brewer, and undergraduate laboratory assistants.

Presentations:

Blaylock, M.J. and G.F. Vance. 1993. Relationships Between Chemical Properties of Selenium in Soil Materials to Potential Plant Uptake and Mobility. Workshop: Fundamentals of Selenium Biogeochemistry and Importance to Ecosystem Integrity. Sixth Billings Reclamation Symposium. Billings, Montana. **(invited)**

Blaylock, M.J. and G.F. Vance. 1993. Plant Uptake and Metabolism of Selenium. Workshop: Fundamentals of Selenium Biogeochemistry and Importance to Ecosystem Integrity. Sixth Billings Reclamation Symposium, Billings, Montana. **(invited)**

Vance, G.F and M.J. Blaylock. 1993. Analytical Advances for Selenium Determination in Soil and Overburden. Selenium Forum. Sixth Billings Reclamation Symposium. Billings, Montana. **(invited)**

Submitted Abstracts:

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Orso, W., M.J. Blaylock, and G.F. Vance. 1993. Predicting Selenium Bioavailability with Phosphate Extractions of Soils and Mine Backfill Materials. American Society of Agronomy Annual Meeting. Cincinnati, OH.

Sharmasarkar, S. and G.F. Vance. 1993. Environmental Implications of Soil and Plant Selenium Chemistry in Range and Reclaimed Coal Mine Lands within the Powder River Basin, Wyoming. American Society of Agronomy Annual Meeting. Cincinnati, OH.

Brewer, T., M.J. Blaylock, T.A. Tawfic, and G.F. Vance. 1993. Selenite Adsorption in Reclaimed and Abandoned Coal Mine Soil Materials. Soil Science Society of America Annual Meeting. Cincinnati, OH.

Sharmasarkar, S., G.F. Vance, K.J. Reddy, and M.J. Blaylock. 1993. Geochemical Immobilization of Selenium in Surface Coal Mine Land Environments. Soil Science Society of America Annual Meeting. Cincinnati, OH.

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RELATIONSHIP BETWEEN SOIL SELENIUM CONCENTRATIONS AND SELENIUM UPTAKE BY VEGETATION ON SURFACE COAL MINE LANDS IN WYOMING

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Semi-Annual Project Report

for the

Abandoned Coal Mine Land Research Program

RELATIONSHIP BETWEEN SOIL SELENIUM CONCENTRATIONS AND SELENIUM UPTAKE BY VEGETATION ON SURFACE COAL MINE LANDS IN WYOMING

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May 26, 1993

Relationship Between Soil Selenium Concentrations and Selenium Uptake by Vegetation on Surface Coal Mine Lands in Wyoming

Introduction

Selenium is an important issue to abandoned as well as active surface coal mine land reclamation. Overburden material that is brought to the surface during mining may have extractable selenium levels of 0.1 mg/kg or more, a level that has previously been identified as "unsuitable" for reclamation purposes in Wyoming. Surface mining may also affect soil/backfill selenium chemistry, which may influence soil-plant selenium relationships as well. This project will determine the relationship between soil and plant selenium concentrations in two surface coal mines in Wyoming.

Objectives

The main objective of this project is to evaluate plant and soil/backfill selenium relationships. The specific objectives of this study are to determine:

1) **What analytical procedures should be used to determine "soluble" (plant available) soil selenium;**

2) **What forms of selenium are present in seleniferous soil and backfill materials and how these are related to plant uptake of selenium;**

3) **What impact chemical, physical and biological soil characteristics have on plant uptake of selenium;**

4) **How selenium content of native and revegetation species may vary across a growing season;**

5) **What effect soil depth has on plant uptake of selenium;**

6) **What suitability limits should be recommended for selenium concentrations in backfill materials to be topsoiled and revegetated.**

Project sites are located on an abandoned coal mine and two active coal mines located in the Powder River Basin. The abandoned coal mine site is located north of Sheridan and the two active coal mines are located south of Gillette. The advantage of involving active coal mines is that extensive soil and backfill selenium data already exists.

The relationship between soil/backfill selenium levels (determined from four different extraction methods and total selenium), and plant selenium levels (three different life forms, i.e., grass, forb, and shrub) is being examined. Information from active coal mine sampling sites located in both native and reclaimed areas will be extrapolated to abandoned coal mine lands. The information obtained from this study will in part be used to better understand those conditions that influence selenium uptake in plants. This is an important issue to both abandoned and active coal mine lands because it may indicate how overburden materials should be handled in the backfilling and reclamation process.

Methods of Analysis

Four methods of soil selenium extraction (AB-DTPA, hot water, phosphate extraction, and saturated paste) and total soil selenium are being evaluated to determine which is the most reproducible and accurate for determining the effects of selenium uptake by plants. Plant selenium is being determined after plant digestion using nitric acid. A quality control/quality assurance program (see original proposal for details) was developed by the two laboratories, Inter-Mountain Laboratory, Sheridan, Wyoming and the Soil and Environmental Chemistry Laboratory at the University of Wyoming, that are conducting the soil and plant selenium analyses.

Vegetation and Soil/Backfill Sampling

All 1992 sampling for both vegetation and soil/backfill materials have been collected and analyzed, and are currently being statistically analyzed. Site selection, plant and soil/backfill collection and analysis for the first year (1991) of this project were reported in the 2nd semi-annual report and at the meeting held in Gillette (May 20, 1992). The following describes some additional accomplishments since the last semi-annual report:

- Additional soil and backfill analysis included:

  - Phosphate extractable selenium: Approximately 250 samples were analyzed to complete the analysis run in Summer 1992. Ten percent of the 1992 samples were rerun for quality control/quality assurance.

  - Saturated paste selenium: Approximately 275 samples were analyzed to complete the analysis run in Fall 1991 and Summer 1992. Ten percent of the Fall 1991 and Spring 1992 samples were rerun for quality control/quality assurance.

  - Hot water extractable selenium: Approximately 40 samples were analyzed to complete the analysis run in Summer 1992. No percentage of the 1992 samples were rerun.

  - Total soil selenium: Approximately 40 samples were analyzed to complete the analysis run in Summer 1992. No percentage of the 1992 samples were rerun.

- Statistical correlation analyses were run on all dependent and independent parameters to determine possible significant relationships; R values exceeding 0.50 at the appropriate p levels, i.e., 0.05 or 0.001, were used to identify possible variables to be used in regression models for plant lifeform uptake of selenium.

- Significant variables identified in the correlation analysis were incorporated into initial regression models. Although variables are significant at the appropriate p levels mentioned above, resulting R^2 values were in the range of 0.70 or less.

- Initial statistical modeling results for "extractable soil/backfill Se versus plant Se levels" were presented at the Billings Reclamation Symposium in Billings, Montana, on March 25, 1993.

- Initial statistical results of plant uptake by lifeform, as well as seasonal variability of uptake, will be presented at the 10th annual meeting for the American Society of Surface Mining Reclamation in Spokane, Washington on May 19, 1993.

Preliminary Findings

Correlation and regression analyses were performed using the five soil/backfill Se concentrations (i.e, total Se (TSe), hot water Se (HWSe), AB-DTPA Se (ABCSe), saturated paste Se (SPESe), and KH_2PO_4 Se (HPSe)) and four of the plant Se concentrations (composite grass (CG), and average grass (G), forb (F) and shrub(S)) at native (5 depths) and reclaimed (3 depths) sites. Several significant correlations were determined between the soil/backfill Se and plant Se concentrations. A significant correlation existed for soil/backfill Se and plant Se in 17 out of the 32 (i.e., 8 depths (5 native and 3 reclaimed) x 4 plants) relationships tested using TSe; 18 out of 32 for HWSe; 15 out of 32 for ABCSe; 14 out of 32 for SPESe; and 4 out of 9 for HPSe.

Regression analyses were performed using soil/backfill extractable Se and plant Se as variables. For this analysis the two mines were aggregated. Only meaningful correlations ($p < 0.1$) were considered. From the regression data, the soil/backfill Se level that corresponded to a given plant Se concentration was estimated. The level of soil/backfill Se that would result in 5 ppm plant Se was generally lowest for shrubs followed by forbs and then grasses. Due to the lack of consistent results, further statistical analysis (i.e., multiple regression or cluster analysis) is suggested, as well as collection of additional data, before reliable conclusions or trends can be drawn from this study. The additional data collection will occur during 1993.

The coefficient of variation (CV) was calculated for the five Se variables (i.e., total Se and the four extractable Se levels) at each site and depth. A large range in CV's was noted (0 to 153%); however, the larger CV's tended to be grouped at specific sites and depths. Of the 823 CV's calculated, only 26 (or 3%) were greater than 100%. Average CV's for mine type and ecological system (i.e., native versus reclaimed) were approximately 25%. Overall, total Se varied the least among the five Se variables followed by KH_2PO_4 < AB-DTPA < hot water = SPE Se.

The quality control/quality assurance program for this project revealed excellent agreement between results from Inter-Mountain Laboratories and the Soil and Environmental Chemistry Laboratory at University of Wyoming. For AB-DTPA, hot water, and phosphate extractable selenium, linear regression analyses had correlation coefficients greater than 0.95.

Research Plan for 1993-1994

Vegetation and soil/backfill material will be sampled from native and reclaimed research sites that were established in 1991. Vegetation will be collected during two sampling periods, one at the time soil/backfill materials are sampled in early June and another during late July. Plant cover and percent plant species at each site will be recorded to determine if there were major changes in vegetation composition as compared to 1991

and 1992. The 1993 soil sampling protocol will be revised according to statistical results obtained from 1991 and 1992 samplings.

Both 1991 and 1992 data are currently being statistically analyzed to determine what relationships exist between soil/backfill and plant Se. Plant species, cumulative depth, and their relationship to the various extractants and resulting plant selenium are a few of the evaluations being done. In addition, the significance of sampling soil/backfill at three holes at each site location will be determined.

Items to be completed within the next reporting period include

1) Final statistical models based on the 1991 information will be derived; formal cross validation with the 1992 data will be conducted.

2) The 1993 field sampling program will be conducted based on recommendations from the 1991 and 1992 programs.

3) Laboratory analysis of 1993 soil and vegetation samples will be cross validated with 1991 models. In addition, separate models based on 1993 information will be derived and cross validated with 1992 data to determine differences with 1991 model validation.

Presentations:

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TOXICOLOGIC EVALUATION OF CHRONIC SELENOSIS IN WYOMING HERBIVORES

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Toxicologic Evaluation of Chronic Selenosis in Wyoming Herbivores

M. F. Raisbeck, E. L. Belden, D. T. O'Toole, J. W. Waggoner and E. T. Thorne

The overall objective of this project is improved understanding of chronic selenosis in economically important Wyoming herbivores. Together with other AML-funded studies relating soil/spoil and plant Se concentrations, these results will permit better predictive assessment of the toxic potential of abandoned mine sites before and after reclamation.

The principle tasks outlined for the second year of the project are experimentally establishing dose-responses for selenomethionine and selenite in calves. Most of our efforts for the last 6 months have focused upon getting this experiment underway.

Animal studies

One of the obstacles discovered during last summer's preliminary experiments was the induction of conditioned aversion in cattle by dietary sodium selenite. We have redesigned this summer's animal experiments to: 1) distribute each day's experimental Se dose throughout the total day's ration; and 2) feed each high or mid-range dosage animal immediately adjacent to a control or low-dose animal.

This restructuring required considerable modification of our physical facilities, but we anticipate it will eliminate or minimize development of a conditioned aversion. Spreading the daily dose of Se out over a 24 hour period not only better mimics the natural situation in a grazing herbivore, but lessens the chance that a given animal will develop gastrointestinal irritation as the result of eating a 24 hour dose in a few minutes. Conditioned aversion breaks down under peer pressure. The physical layout of the feeders permits each steer to observe pen mates eating the same basal ration; published experiments with conditioned aversion indicate that such will obviate the aversive response.

Ruminal metabolism of ^{75}Se compounds

Last Fall we reported that much of ^{75}Se labelled $NaSeO_3$ added to an artificial rumen remained with the water insoluble (ash) fraction, and that only approximately 10% was incorporated into microbial protein. At the time we speculated what, if any, the effect of long term ruminal adaptation to Se might be.

Artificial rumens were cultured with inocula from a steer on a "normal" (0.2 ppm Se) diet and a relatively high diet (25 ppm Se hay). ^{75}Se-selenite was added at 0, 1.0, 10 or 50 ppm to four of each; two were incubated for 24 hours and two were incubated for 48 hours at 39° C. After incubation, the cultures were killed by freezing and separated into water insoluble, protein and sub-protein fractions. The protein fraction was derivatized with iodoacetate and

hydrolyzed with HCl. The water insoluble fraction was further incubated with acid-pepsin to model abomasal digestion, then derivatized with iodoacetate. The sub-protein fraction was also derivatized with iodoacetate. All fractions were chromatographed on silica gel TLC plates and the added Se identified by radioautography.

^{75}Se was more readily incorporated into soluble proteins and bacterial proteins of the unadapted rumen at low Se concentrations. In contrast, the adapted rumen bacteria incorporated ^{75}Se into protein at higher dietary Se concentrations. Likewise, the acid pepsin fraction accumulated more ^{75}Se at higher dietary concentrations. These results indicate that acclimation of rumen microflora probably do play a significant role in chronic selenosis and support our contention that it is neither accurate nor sufficient to directly extrapolate from small rodent studies to grazing herbivores.

Effect of Se on ruminal metabolism

In an related experiment, we compared the effect of added selenomethionine or selenite on volatile fatty acid (VFA) production and dry matter digestibility of adapted and non-adapted rumen microflora. While there were no clear cut trends with regard to VFA production, the adapted microflora demonstrated consistently better dry matter digestion at all Se concentrations.

***In vitro* immunology**

Preliminary field studies during the summers of 1991 and 1992 indicated that cattle grazing moderately seleniferous abandoned mine sites had slightly compromised immune competence. As one method of confirming that this was truly a Se-related effect we exposed peripheral blood lymphocytes (PBL's) from an animal on a high Se hay diet and from a control animal to various selenium compounds *in vitro*. Selenomethionine, selenite or selenocystine were added to culture media at varying concentrations ranging from 0.007 ug/ml to 1.0 ug/ml. Blastogenesis assays were performed on these PBL's to determine their proliferative response to the mitogens Con A and PHA. Elispot assays were also done to determine the effects of Se on immunoglobulin secretion at the cellular level. Preliminary results indicate inhibition of several immune functions at high concentrations of all 3 forms of Se; however, selenite and selenocystine appear to be more potent inhibitors than selenomethionine. Interestingly, cells from the high Se diet animal seem to be more sensitive to these inhibitory effects.

METHODOLOGY FOR THE GEOMORPHIC CLASSIFICATION AND DESIGN OF DRAINAGE BASINS AND STREAM CHANNELS IN THE POWDER RIVER COAL FIELD OF WYOMING

T.A. WESCHE, H.W. LOWHAM, R.L. DADDOW, M.E. SMITH

SEMI-ANNUAL REPORT # 4 FOR THE ABANDON COAL MINE LAND RECLAMATION PROGRAM

METHODOLOGY FOR THE GEOMORPHIC CLASSIFICATION AND DESIGN OF DRAINAGE BASINS AND STREAM CHANNELS IN THE POWDER RIVER COAL FIELD OF WYOMING

PRINCIPAL INVESTIGATORS

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Hugh W. Lowham - U.S. Geological Survey

Richard L. Daddow - U.S. Geological Survey

Mark E. Smith - U.S. Geological Survey

GRADUATE RESEARCH

A CLASSIFICATION OF DRAINAGE BASINS IN THE EASTERN POWDER RIVER BASIN COAL FIELD OF WYOMING

Anthony J. Anderson - University of Wyoming

CHARACTERIZATION OF DRAINAGE NETWORKS FOR MINE LAND RECLAMATION IN THE EASTERN POWDER RIVER BASIN, WYOMING

Lee E. Jensen - University of Wyoming

PROGRESS REPORT PERIOD: 10/31/92 - 5/26/93

Introduction

The University of Wyoming and U.S. Geological Survey project team members have finalized detailed research plans to accomplish the overall project objectives. These objectives are to: 1) inventory, review, and summarize design procedures being used for reconstruction and reclamation of drainage basins and stream channels in the Powder River coal field of Wyoming, emphasizing the extent that the geomorphic approach is used for reconstruction design; 2) develop a classification system for drainage basins and stream channels in the Powder River coal field of Wyoming based on the natural, physical characteristics of selected groups of small drainage basins; and 3) analyze and summarize the geomorphic characteristics of different classes or types of drainage basins and stream channels, thereby developing geomorphic methodology and criteria for the design of reconstructed drainage basins and stream channels.

Portions of the overall project have been allocated to two Master of Science theses at the University of Wyoming. The first thesis research project is titled "A Classification of Drainage Basins in the Eastern Powder River Basin Coal Field of Wyoming". This project is being investigated by Anthony J. Anderson and focuses primarily on objective 2 of the overall project. Specific objectives of this project are to: 1) delineate a study area representative of the Eastern Powder River Basin coal field; 2) select and measure a set of watershed characteristics including: soils, vegetation, climate, and topographic features for small drainage basins using available maps and digital databases; and 3) based upon the physical characteristics outlined above, develop a classification system of drainage basins using the multivariate statistical techniques of principal components analysis, cluster analysis, and discriminant function analysis.

The second research project is titled "Characterization of Drainage Networks for Mine Land Reclamation in the Eastern Powder River Basin, Wyoming". This project is being investigated by Lee E. Jensen and focuses primarily on objective 3 of the overall project. Specific objectives of this project are to: 1) characterize geomorphic features of natural (relatively undisturbed) drainage networks in the Eastern Powder River Basin, including: channel and network geometry, channel and network morphology, and the overall hydrologic regime; 2) formalize recognizable geomorphic relationships; 3) classify stream channels based on morphometric characteristics; 4) establish procedures to utilize the geomorphic approach for design purposes; and 5) outline areas for future research which can be incorporated into the overall project infrastructure.

The overall project objective of conducting an intensive literature review of current design techniques has and will continue to be incorporated into the two theses research projects.

Progress During the Report Period

Several data sources have been evaluated to determine which might fit the study design. There is an abundance of data available for a wide range of drainage basins

and their specific physical characteristics; however, upon review of data collection procedures and analyses, it was determined that these data should not be included in the present project. Selected information from some of these data sources (U.S.G.S, coal mines, and others) will be used for comparative purposes to evaluate data collected for the overall project.

The theses study plans have been approved by project and committee members, and both projects are well underway. Upon approval of the study plans it was possible to refine the project scope and direction, as outlined in the following. The study area boundaries were defined and finalized (Figure 1.). The study is incorporating a systems approach to characterize third order drainage basins and drainage networks. Utilizing this approach, two second order, and three first order drainage basins were selected for analysis within each third order basin at the 1:24,000 scale. Non-random criteria were used to determine the suitability of drainage basins for analysis. There were over 90 third order drainage basins considered for analysis, of which 50 to 65 will be included in the final analysis, dependent upon field investigations (Figure 1.). Approximately 100 second order, and 150 first order basins have been selected for analysis within the third order basins, bringing the total number of study basins to 300.

The specific variables which will be used to characterize the drainage basins and drainage networks has been completed (Table 1.). All variables in the drainage basin and drainage network analysis are being measured from U.S.G.S. 1:24,000 quadrangles using a digitizing tablet and Autocad software. Two digital databases are being used for delineation of soil types (STATSGO, 1992) and vegetaton community type (GAP, 1992). Additionally, an isohyet map for precipitation is being developed and will be included in the classification procedures. Upon finalizing measurment of drainage basin and drainage network variables, the classification analysis will proceed.

Field analysis of stream channel characteristics began May 10, 1993 and will continue through August 1993. Thirty three third order channels have been selected for study. There are 66 second order, and 99 first order channels within the 33 third order channels which have also been selected for analysis. The total number of channels selected for analysis is 198. The actual number of channels that are investigated in the field is dependent upon available time and any unforeseen complications such as channel disturbances. Variables being used to characterize stream channels are shown in Table 1.

Future Work

The drainage basin and drainage network analysis will continue through late spring. It is anticipated that initial classification results will be completed by late July or early August 1993. The stream channel investigation will continue through August 1993. Upon completion of the drainage basin classification and the stream channel investigation, final analysis procedures will be initiated.

FIGURE 1.

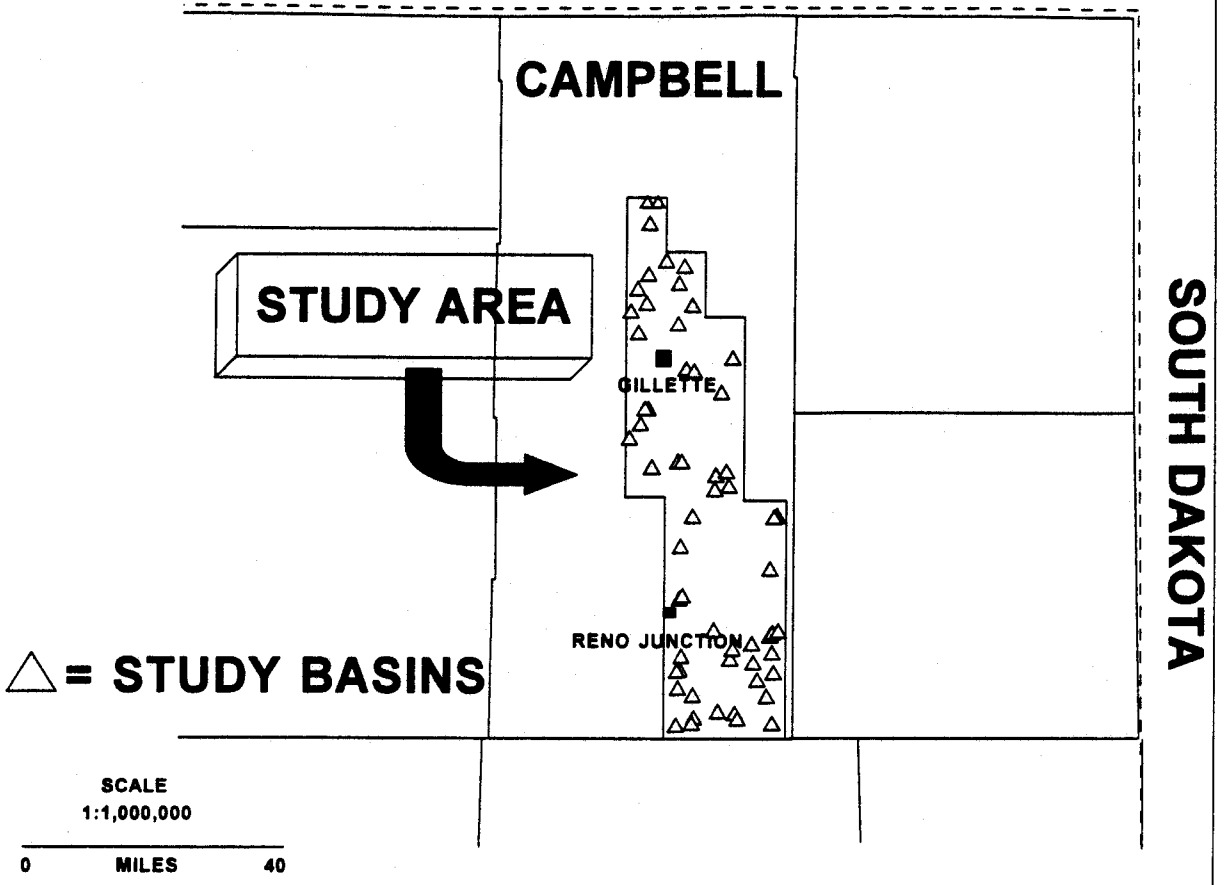

TABLE 1.

VARIABLES FOR CHARACTERIZATION

DRAINAGE BASIN	NETWORK	STREAM CHANNEL
-BASIN ORDER	-STREAM ORDER	-CHANNEL WIDTH
-BASIN AREA	-STREAM LENGTH BY ORDER	-CHANNEL DEPTH
-BASIN LENGTH	-MAIN CHANNEL LENGTH	-LOCAL SLOPE
-BASIN PERIMETER	-TOTAL CHANNEL LENGTH	-CHANNEL PATTERN
-BASIN RELIEF	-LOCAL SLOPE	-LENGTH OF OVERLAND FLOW
-BASIN SHAPE	-NUMBER OF EACH ORDER	-D50 BED MATERIAL
-RELIEF RATIO	-SINUOSITY	-D50 BANK MATERIAL
-RUGGEDNESS NUMBER	-DRAINAGE	
-DRAINAGE DENSITY		
-VEGETATION		

LONG-TERM STABILITY OF DESIGNED CHANNELS AT RECLAIMED COAL MINES IN WYOMING

S.L. RATHBURN, P.A. RECHARD, T. HANLIN, D.R. JENSEN

LONG-TERM STABILITY OF DESIGNED EPHEMERAL CHANNELS AT RECLAIMED COAL MINES, WYOMING

May 26, 1993

Final Executive Summary
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Long-term Stability of Designed Ephemeral Channels at Reclaimed Coal Mines, Wyoming

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INTRODUCTION

Evaluating the long-term performance of designed ephemeral channels at reclaimed coal mines in Wyoming is difficult because major channel adjustments that test channel stability typically occur during infrequent, very large floods. Complete certification and bond release issues are management and regulatory decisions that involve evaluating long-term performance of reclaimed channels, but the rarity of channel-changing discharges and the short time since reclamation construction completion poses a great challenge to Abandoned Mine Land (AML) and Department of Environmental Quality/Land Quality Divisions (DEQ/LQD) personnel. At present, many of these decisions are based on short-term observations provided by post-construction monitoring or annual permit application information. There is a need to derive a means of evaluating long-term channel stability that is not limited by short-term monitoring. The specific objectives of this research are:

- To understand previous channel design practices at reclaimed abandoned coal mine sites in Wyoming through an inventory of engineering design reports and plans;
- To determine characteristics that contribute to ephemeral channel stability by conducting field investigations of natural, unmined channels and drainage basins, and;
- To derive a risk-based stability evaluation for reclaimed channels using statistical comparisons of channel design criteria from reclaimed AML coal sites with adjacent, natural surface drainage systems.

A major premise of this research is that natural alluvial channels represent long-term stability because their deformable boundaries allow channel geometry adjustments to accommodate water and sediment discharges. In addition, natural channels have evolved over long periods of time with channel cross section parameters of width, depth, and slope reflecting prevailing climatic and hydrologic conditions. By our definition natural channels are stable, whether depositing or eroding sediment, a definition that evaluates reclaimed channel stability solely on how closely reclaimed channels resemble unmined, natural drainages. Reclaimed channels that are properly integrated into the surrounding landscape, specifically the drainage basin, will respond to large flows in a manner that is similar to up and downstream areas. Incipient erosion and/or deposition that occurs on a basin-wide scale and migrates upstream or downstream into the reclaimed reach is considered within the natural evolution of drainage

basins and stream channels. Initiation of headcuts, knickzones, or deposition within the reclaimed channel reach, however, would be indicative of an instability, or a design failure.

Undisturbed areas adjacent to mined lands provide natural analogs of pre-disturbance conditions, or stable channels. Given the absence of premining baseline information at AML sites, and the limited time of exposure of reclaimed channels at active mines, it is generally accepted that stable, natural channels be used as analogs for designing reclaimed channels.

INVENTORY

A review of consultant's reports, engineering design plans, construction-as-builts, and AML site files was conducted for 14 reclaimed coal sites with earthen channel reclamation. Information collected during the inventory included channel design criteria, runoff assumptions, and channel and basin characteristics. Information was readily available in the AML library, Herschler Building, Cheyenne, and AML archives.

Results of the inventory indicated that AML projects 6C-2 and 6C-8, the Rainbow and Colony Coal mine sites, south of Rock Springs, are the only reclamation sites with complete reclamation design information. Our research into channel stability has thus focused on this area near Rock Springs, encompassing the Rainbow and Colony mines. In addition, an area northeast of Hanna was chosen as a test site to apply the stability analysis developed using the Rock Springs unmined and reclaimed data.

Reclaimed Channel Characteristics

The twenty reclaimed channels at the Rainbow and Colony Coal mines south of Rock Springs form broad, shallow swales. Flow depths associated with the 10-year, 1-hour design event range from 0.1-0.3 feet deep, and top widths range from 5-7 feet. Minor incision of 1-4 inches was observed during field work in channel bottoms at the two abandoned mines. Tables 1 and 2 list reclaimed channel characteristics.

FIELD INVESTIGATIONS

Data from natural, unmined channels and basins within the Rock Springs and Hanna areas were collected to match the inventory information. Initially, topographic maps and aerial photographs were used to select natural channels based on similarity in geology and size to reclaimed basins, where possible.

Rock Springs

Seventeen natural basins were studied within the Rock Springs area. In the field, a channel cross section was surveyed at the mouth of each unmined basin along with a local

channel slope at the cross section. The general condition of each channel was described, noting the presence of bedrock influence, headcuts or knickzones, and bank sloughing or undercutting.

A visit was made to the reclaimed Rainbow and Colony Coal mine sites to document site-wide conditions 3 years after construction. No measurements were made at the reclamation site, but photographs were taken, and design plans visually compared to constructed topography.

Results of the field investigations show that natural channels in the vicinity of Rainbow and Colony Coal mines south of Rock Springs are largely alluvial, and have narrow, deep, v-shaped cross sections, a sharp contrast to the shallow swales at reclaimed sites. Natural channel slopes are relatively steep, ranging from 0.03 to 0.13 feet/feet, with a mean of 0.0747. Velocities associated with the 10-year event range between 3.7 and 7.6 feet/second. Depths and top widths for 10-year, 1-hour discharges within the natural channels studied vary from 0.1-1.3 feet and 1.3-6.5 feet, respectively. Tables 1 and 2 list natural channel characteristics for the Rock Springs study site.

Hanna

Ten unmined channels were studied in the vicinity of Hanna, a site of continued active mining and one abandoned mine site, AML 7-26. The channels are largely alluvial, and are less entrenched than at Rock Springs, with larger cross sectional areas. Many of the unmined channels near Hanna had headcuts within channel bottoms. Channel slopes are steeper than Rock Springs, ranging between 0.02 and 0.198 feet/feet, and 10-year flow velocities vary from 3.1 to 6.8 feet/second.

RISK-BASED STABILITY ANALYSIS

A stability evaluation of reclaimed channels at the Rainbow and Colony mines was developed using three channel parameters judged most useful in engineering channel design; channel slope, flow velocity, and flow area. The stability analysis quantifies how closely channel design at reclaimed sites resembles natural analog channels within the same geographic region.

Regression Analysis

Initially a regression analysis was performed to identify relationships between hydraulic channel properties and drainage basin characteristics from the natural channel data set. Regression results indicate strong correlation between flow depth, flow area, hydraulic depth, hydraulic radius, and Area Gradient Index (AGI) for unmined channels at Rock Springs. In this study, AGI is the product of mean basin slope and drainage basin area. Strong correlation between 10 and 100-year discharge and AGI indicates AGI is a surrogate measure of flow magnitude. As a result, AGI was selected as the primary independent variable for regression analysis because it correlates most strongly with hydraulic variables.

Table 1. Channel Slope and Flow Velocity Test Statistics for 10-yr, 1-hr Design Event, Rock Springs Study Site

Unmined Basin	AGI	Channel Slope (ft/ft)	10-yr Flow Velocity (ft/sec)	100-yr Flow Velocity (ft/sec)
3	1.06	0.072	4.03	3.7
4	4.51	0.077	6.97	9.85
5	2.78	0.134	7.60	10.9
6	6.30	0.038	6.16	8.53
7	6.82	0.051	6.64	9.64
7a	0.33	0.070	3.86	5.87
7'	2.42	0.048	4.83	6.95
12a	0.43	0.128	4.56	6.72
12b	0.07	0.131	2.99	4.42
13	1.70	0.087	5.86	8.36
15	3.16	0.049	5.84	8.21
16	4.92	0.026	4.68	5.36
16a	2.16	0.058	4.05	5.92
24	2.39	0.049	4.84	7.27
25	0.99	0.100	5.47	8.04
28	1.41	0.078	3.98	6.38
31	0.52	0.075	3.66	5.37
Mean	2.47	0.0747	5.06	7.15
Stand. Dev	2.07	0.0325	1.29	1.98
n	17			
(Sx) ^ 2	1762.12			
S(x ^ 2)	172.27			
Sum of Squares for Error				
SSE=		0.0170	26.6506	
Se=		0.0326	1.2906	

						Case 1:		Case 2:	
					Upper Limiting Value:	0.0642	4.64	0.0543	4.25
Reclaimed Basin		AGI	Channel Slope (ft/ft)	Flow Velocity (ft/sec)	Is Channel Slope< Upper Limiting Slope	Is Velocity <Upper Limiting Velocity	Is Channel Slope< Upper Limiting Slope	Is Velocity <Upper Limiting Velocity
6C-2	1	0.19	0.02	2.35	Yes	Yes	Yes	Yes
Rainbow	2	0.16	0.02	2.18	Yes	Yes	Yes	Yes
Mine	3	0.09	0.02	1.94	Yes	Yes	Yes	Yes
	4	0.20	0.03	2.49	Yes	Yes	Yes	Yes
	5	0.11	0.02	1.83	Yes	Yes	Yes	Yes
	6	0.09	0.03	1.97	Yes	Yes	Yes	Yes
	7	0.25	0.03	2.61	Yes	Yes	Yes	Yes
	8	0.08	0.06	1.97	Yes	Yes	No	Yes
	9	0.21	0.03	2.31	Yes	Yes	Yes	Yes
	10	0.16	0.04	2.23	Yes	Yes	Yes	Yes
	11	0.20	0.05	2.45	Yes	Yes	Yes	Yes
	12	0.21	0.08	2.57	No	Yes	No	Yes
	13	0.17	0.07	2.27	No	Yes	No	Yes
	14	0.08	0.02	1.83	Yes	Yes	Yes	Yes
	15	0.05	0.02	1.67	Yes	Yes	Yes	Yes
	16	0.30	0.04	2.75	Yes	Yes	Yes	Yes
6C-8	I	0.39	0.075	2.75	No	Yes	No	Yes
Colony	II	0.82	0.048	2.92	Yes	Yes	Yes	Yes
Mine	III	0.38	0.04	2.52	Yes	Yes	Yes	Yes
	IV	0.09	0.01	1.50	Yes	Yes	Yes	Yes

Stability Analysis for Channel Slope and Flow Velocity:

Confidence Interval:

$$\textit{Upper Limit} = \bar{x} - t_{\alpha,n-1} s \sqrt{\frac{1}{n}}$$

case 1: $t = 1.337$ *for* $\alpha = 0.10$

case 2: $t = 2.585$ *for* $\alpha = 0.01$

Table 2. Flow Area Test Statistics for 10-yr, 1-hr Design Event, Rock Springs Study Site

Unmined Basin	AGI	Flow Area (sqft)	Reclaimed Basin		AGI	Actual Flow Area (sqft)	Pred. Flow Area (sqft)	Case 1: Lower Limit Flow Area 1.341	Case 1: Is Flow Area > Lower Limiting Area	Case 2: Lower Limit Flow Area 2.602	Case 2: Is Flow Area > Lower Limiting Area
3	1.06	0.70	6C-2	1	0.19	1.23	0.26	0.44	Yes	0.62	Yes
4	4.51	2.41	Rainbow	2	0.16	1.05	0.24	0.43	Yes	0.60	Yes
5	2.78	1.10	Mine	3	0.09	0.78	0.20	0.39	Yes	0.57	Yes
6	6.30	3.73		4	0.20	0.92	0.26	0.45	Yes	0.62	Yes
7	6.82	3.39		5	0.11	0.71	0.21	0.40	Yes	0.58	Yes
7a	0.33	0.56		6	0.09	0.56	0.20	0.39	Yes	0.57	No
7'	2.42	1.41		7	0.25	0.96	0.29	0.47	Yes	0.65	Yes
12a	0.43	0.31		8	0.08	0.30	0.20	0.39	No	0.57	No
12b	0.07	0.10		9	0.21	0.78	0.27	0.45	Yes	0.63	Yes
13	1.70	0.92		10	0.16	0.53	0.24	0.43	Yes	0.61	No
15	3.16	2.34		11	0.20	0.53	0.26	0.45	Yes	0.62	No
16	4.92	3.76		12	0.21	0.35	0.27	0.45	No	0.63	No
16a	2.16	0.92		13	0.17	0.35	0.24	0.43	No	0.61	No
24	2.39	1.70		14	0.08	0.71	0.20	0.39	Yes	0.57	Yes
25	0.99	0.68		15	0.05	0.60	0.18	0.37	Yes	0.56	Yes
28	1.41	1.29		16	0.30	0.84	0.32	0.50	Yes	0.67	Yes
31	0.52	0.37	6C-8	I	0.39	0.62	0.37	0.54	Yes	0.71	No
			Colony	II	0.82	1.06	0.60	0.76	Yes	0.91	Yes
			Mine	III	0.38	0.95	0.36	0.54	Yes	0.71	Yes
				IV	0.09	1.33	0.20	0.39	Yes	0.57	Yes

Population Statistics:

Mean	2.47	1.51
n	17	
(Sx)^2	1762.1	
S(x^2)	172.3	
S(X-Xavg)	68.62	

Sum of Squares for Error (SSE)	2.1541
Mean Square Error (MSE)	0.3790

Flow Area vs. AGI

Regression Output:

Constant	0.1515
Std Err of Y Est	0.3790
R Squared	0.9062
No. of Observations	17
Degrees of Freedom	15
X Coefficient(s)	0.5506
Std Err of Coef.	0.0457

Stability Analysis for Flow Area:

Confidence Interval:

$$\text{Lower Limit} = \hat{y} + [t_{\alpha,n-2}(S\sqrt{\frac{1}{n} + \frac{n(x_o-\bar{x})^2}{n\sum x_i^2 - (\sum x_i)^2}})]$$

case 1: $t = 1.341$ *for* $\alpha = 0.10$

case 2: $t = 2.602$ *for* $\alpha = 0.01$

By definition, flow area is related to flow depth, hydraulic depth, and hydraulic radius. Flow area was, therefore, used singularly in the statistical analysis with AGI because it is a standard variable in engineering design.

Confidence Intervals

The risk-based channel stability test is comprised of confidence intervals developed around the mean predicted values for natural channels, against which, the reclaimed data is evaluated. Confidence intervals were calculated using Student's t distribution. The Student's t distribution is a variation of the normal distribution adjusted to account for small sample sizes. Confidence intervals were developed for three channel parameters judged most useful in engineering channel design; channel slope, flow velocity for the design event, and cross sectional flow area.

An important component in statistical testing is specifying an acceptance level to control the probability of an erroneous result. Typically, the user chooses an alpha level to denote the amount of acceptable risk associated with approving a given channel design; herein lies the risk-based approach to this channel stability evaluation. Alpha typically is selected at either 0.1 and 0.01, and indicates the probability or percentage of times an error in design acceptance will occur. For example, an alpha=0.1 means that the probability of accepting a channel design that does not meet the stability criteria is 1 in 10. Two cases were tested for each of the three design parameters of channel slope, flow velocity, and flow area; Case 1 at alpha=0.1 and Case 2 at alpha=0.01. The smaller alpha provides a more stringent stability test, favoring conservative channel designs.

Channel Slope

Channel slope is poorly correlated with basin parameters (AGI), and a test for normality indicates channel slope can be considered random. Channel slope for all but reclaimed Basins 12 and 13 at the Rainbow Mine, and Basin I at Colony Coal Mine are less than the upper confidence limit of 0.0642 feet/feet for alpha=0.1 (Case 1; Table 1). At alpha=0.01, 4 of the 20 reclaimed channel slopes are steeper than the mean of natural analog areas. Channel slopes steeper than the mean of natural analog sites will generate higher-than-normal flow velocities and undesirable erosion will likely result.

Flow Velocity

Similar to channel slope, flow velocity is poorly correlated with drainage basin parameters (AGI) and is, therefore, assumed random. All of the 10-year channel flow velocities for the reclaimed channels at Rainbow and Colony Coal mines are acceptable below the limit of 4.64 feet/second for Case 1. Designed flow velocities for the reclaimed channels are consistently below 3 feet/second, satisfying both Cases 1 and 2 test criteria.

Flow Area

Strong correlation between flow area and AGI means there is no single limiting stability value as with channel slope and flow velocity, but it varies depending on AGI (Table 2). All but three of the 10-year, 1-hour channel flow areas for reclaimed drainages at the Rainbow and Colony mines are acceptable at alpha=0.1 (Case 1; Table 2). Basins 8, 12, and 13 at the Rainbow Mine have flow areas smaller than the mean of natural analog areas (Figure 1). Smaller flow areas increase flow depth and velocities, resulting in a greater potential for erosion. At alpha=0.01, 7 of the 20 reclaimed flow areas are rejected. A smaller alpha (0.01 vs. 0.1) corresponds with wider confidence bands that encompass more points between the mean and limiting line, or the rejection region.

APPLICATION OF RISK-BASED APPROACH

The data set developed for unmined channels in the Hanna area provides an example application for the risk-based stability evaluation. Designed flow areas submitted to DEQ/LQD or AML for approval that are greater than the lower limit depicted on Figure 2 would be determined stable, provided AGI falls within 0 and 9 acres, the constraints of the data set. Likewise, channel slopes and flow velocities less than 0.0638 feet/feet and 4.86 feet/second, respectively (Table 3), are determined as limiting values at alpha=0.1. It is recommended that 2 out of the 3 stability tests (channel slope, flow velocity, flow area) are satisfied prior to design acceptance.

CONCLUSIONS

- There is a general lack of information on channel and basin characteristics for reclaimed channels at reclaimed coal mines in AML library reports and plans.

- Projects 6C-2 and 6C-8, the Rainbow and Colony mines, are the only sites with complete design information. At a minimum, drainage basin area, runoff information (precipitation, storm distribution, curve number, etc.), design flow recurrence interval, and channel geometry are necessary to evaluate reclamation design performance.

- The product of drainage basin area and mean basin slope (AGI) correlates strongly with natural channel characteristics of flow depth, channel flow area, hydraulic radius, and hydraulic depth for the Rock Springs and Hanna areas. Natural drainage data show AGI correlates well with flood magnitude.

- Reclamation designs for 18 out of 20 constructed earthen channels at the Rainbow and Colony mines satisfy the recommended 2 out of 3 stability tests at alpha=0.1. At alpha=0.01, 16 out of 20 reclaimed channels are stable over the long-term.

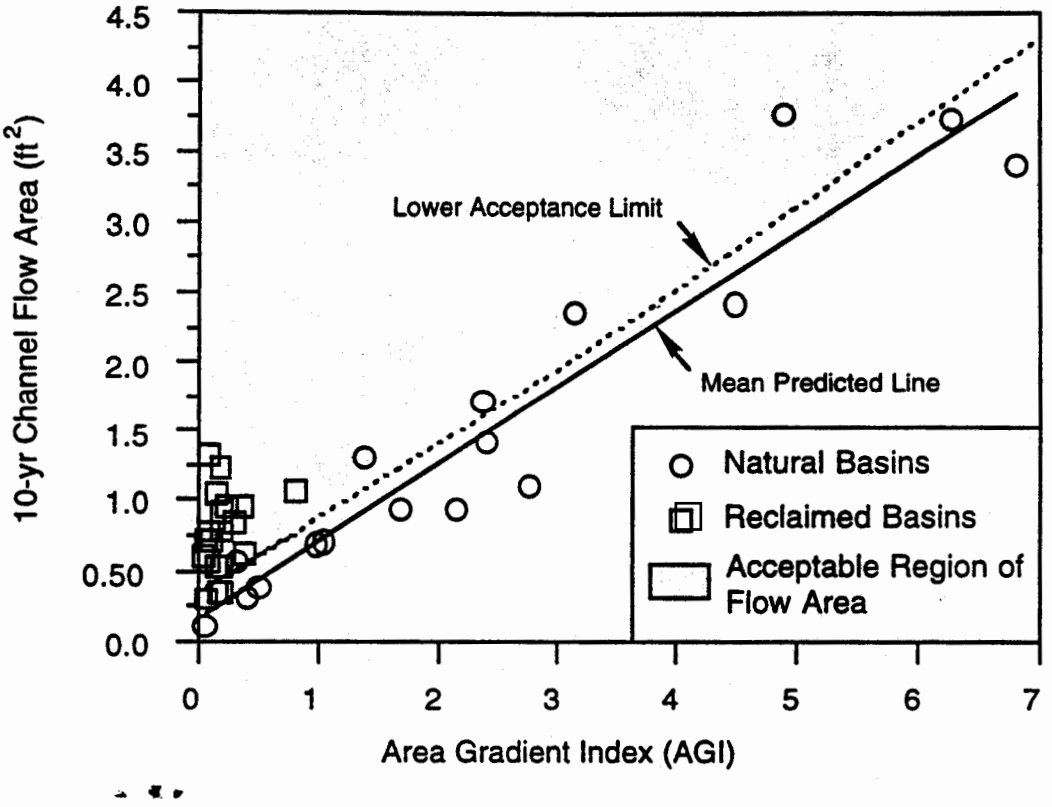

Figure 1. Limiting Flow Area for $\alpha = 0.10$, Rock Springs Study Site.

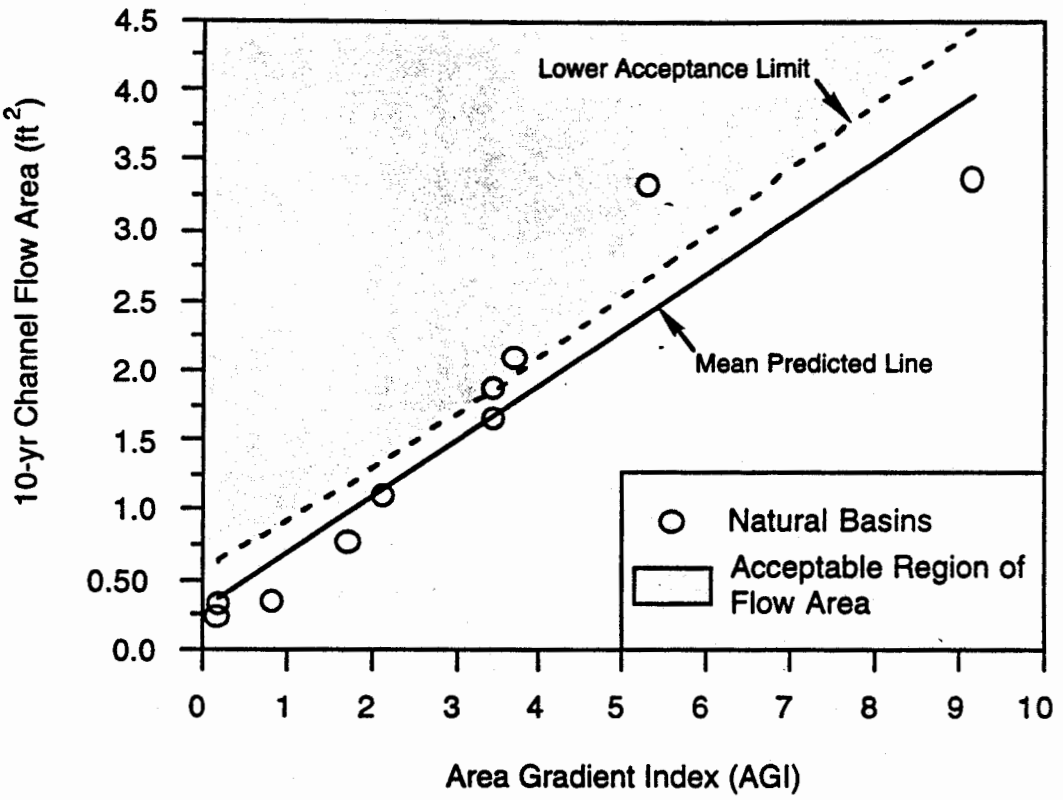

Figure 2. Limiting Flow Area for $\alpha = 0.10$, Hanna Study Site.

Table 3. Flow Area, Channel Slope, and Flow Velocity, Unmined Basins, Hanna Study Site

Unmined Basin	AGI	10-Year Flow Area (ft2)	Channel Slope (ft/ft)	10-Year Flow Velocity (ft/sec)	100-Year Flow Velocity (ft/sec)
1	5.30	3.31	0.016	3.91	5.11
1a	0.84	0.34	0.106	5.26	7.20
2	9.18	3.36	0.047	6.80	9.56
3	3.46	1.64	0.082	6.24	9.31
4	2.14	1.09	0.109	6.17	7.29
5	3.71	2.09	0.057	6.30	9.60
6	1.73	0.77	0.198	6.40	9.75
7	3.45	1.86	0.090	5.28	7.58
8	0.19	0.32	0.053	3.11	4.40
9	0.18	0.23	0.097	4.46	6.20
Population Statistics:					
Mean	3.02	1.50	0.0854	5.39	7.60
Standard Dev.	2.73	1.17	0.0494	1.22	1.94
n	10				
(Sx) ^ 2	910.89				
S(x ^ 2)	158.29				
Sxx	67.20				
Sum of Squares for Error (SSE)		1.45			
Mean Square Error (MSE)		0.43			

Area Gradient Index vs. Flow Area - Regression Output:

Constant		
Std Err of Y Est		0.289
R Squared		0.426
No. of Observations		0.882
Degrees of Freedom		10
X Coefficient(s)	0.401	
Std Err of Coef.	0.052	

Limiting Values:

	Acceptable Alpha Error Levels	
	0.10	0.01
Flow Area	See Figure 2.	
Channel Slope (ft/ft)	0.0638	0.0413
10-Year Velocity (ft/sec)	4.86	4.30
100-Year Velocity (ft/sec)	6.75	5.86

- o Statistical limits developed from natural channel data near Hanna are useful for evaluating channel designs in the area. Limiting channel slope and 10-year, 1-hour flow velocity in the vicinity of Hanna are 0.0638 feet/feet and 4.86 feet/second, respectively.

- o One-tailed statistical tests accept shallower channel slopes or larger flow areas than natural channel systems, desirable conditions that minimize flow velocity within a channel and favor more conservative designs. This risk-based approach of selecting acceptable errors provides an additional level of flexibility for regulatory design review and channel stability evaluations.

- o Channel slope and flow velocity data from natural basins near Rock Springs and Hanna are not statistically different. Stability analyses for channel slope and flow velocity can thus be applied to the southwestern and south central portions of Wyoming.

- o Stability tests, if incorporated into regulatory decisions, can quantify differences between reclaimed channel characteristics and natural, adjacent unmined areas. A standardized approach will help maintain consistency in decisions regarding complete certification and bond release. A minimum of work is necessary to develop the requisite data set and to conduct a relatively basic statistical analysis.

RECOMMENDATIONS

1. Establish permanent survey locations to monitor changes in channel cross section and longitudinal profiles of reclaimed channels. The cross sections could be resurveyed annually during the 3 year post-construction monitoring.

2. Investigate the geographic variability of relations that show strong correlation within the Rock Springs and Hanna areas. Additional work could verify application of AGI and channel hydraulic parameters to other regions of the state with active or abandoned coal mining.

3. Determine optimal sample size associated with defining relationships that influence ephemeral channel stability. This study shows 10-17 data points are acceptable but the lower limit has not been defined.

4. Investigate the role of pilot channels on designed stability. Pilot channels have formed in the bottoms of reclaimed channels at the Rainbow and Colony mines. If pilot channels are shown to develop naturally, then including them in channel designs may be unnecessary. Conversely, constructing pilot channels will ensure they occur in desirable locations (not up against a bank), and of an adequate size determined by hydraulic calculations.

SPECIFICATION AND RECOMMENDATIONS FOR REPAIR OF RESIDENTIAL STRUCTURES DAMAGED BY GROUND MOVEMENTS RELATED TO MINE SUBSIDENCE

K.D. BASHAM, B.A. SUPRENANT, W.L. JOHNSON

SPECIFICATIONS AND RECOMMENDATIONS FOR REPAIR OF RESIDENTIAL STRUCTURES DAMAGED BY GROUND MOVEMENTS RELATED TO MINE SUBSIDENCE

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Amount: $59,000

Project Duration: April 10, 1993 to March 31, 1994

Abstract:

Abandoned mines underlay many areas of Wyoming. As mine cavities collapse they can cause settlement (subsidence) and ground distortions on the surface which may damage or even destroy buildings and affixed utilities. To increase the ability of building officials, contractors, architects, engineers, and homeowners of Wyoming to mitigate subsidence related building

damage, the authors are reviewing and updating the *Specifications and Recommendations For Residential Construction Subjected To Ground Movements Related To Mine Subsidence* and developing a document entitled *Specifications and Recommendations For Repair Of Residential Structures Damaged By Ground Movements Related To Mine Subsidence*. The purpose of the first document, developed by the University of Wyoming in 1988 and funded by the WY DEQ/LQD, is to provide construction specifications and recommendations for new structures built in areas with a potential for mine subsidence. The intend of the construction specifications and recommendations document is to provide guidelines for residential construction that minimize subsidence related building damage. The document also serves as an essential part of the qualifying process to insure new structures through the Wyoming Mine Subsidence Insurance Program. The second document or repair manual will consist of guidelines, recommendations, and repair schemes for repair of residential structures damaged by mine subsidence type ground movements. The repair manual will help architects, engineers, construction professionals, and homeowners of Wyoming to efficiently devise and execute suitable repair schemes. The repair manual will also set a standard for optimizing subsidence related building repair which will help minimize future repeat subsidence damage and insurance reclaims. To help introduce both documents, the investigators plan to develop information pamphlets on mine subsidence, related building damage and repair schemes. Information pamphlets will provide initial guidance with regards to subsidence to homeowners and the building community. In summary, the results of this project will enhance the ability of Wyoming communities to minimize the potential residential building damage caused by mine subsidence and to optimize subsidence repair schemes.

Project Goals:

1) To review and update the DEQ - Land Quality Division's document entitled *Specifications and Recommendations For Residential Construction Subjected To Ground Movements Related To Mine Subsidence*.

2) To develop and publish a document entitled *Specifications and Recommendations For Repair Of Residential Structures Damaged By Ground Movements Related To Mine Subsidence*.

3) To develop information pamphlets to introduce both documents as well as an overview of subsidence related problems in Wyoming to homeowners and the building community.

Impact of Research:

The results of this project will enhance the ability of Wyoming communities to minimize potential residential building damage caused by mine subsidence. The guidelines for construction of new buildings and the repair manual will also set minimum standards for new construction and repairs. More specifically, the results of this project will have the following impact:

- Increase the ability of architects, engineers, contractors, building inspectors, city officials, and homeowners of Wyoming to construct residential buildings to tolerate mine subsidence related ground movements.

- Ensure new homes covered by the Wyoming Mine Insurance Program satisfy minimum construction standards which will mitigate subsidence related damage.

- Minimize settling losses to the Wyoming Mine Insurance Program by minimizing subsidence damage repair claims.

- Enhance the quality of subsidence related building repairs by providing engineers, contractors, and homeowners detailed repair schemes and cost comparisons.

- Increase the ability of building communities to repair subsidence related building damage in such a manner so the potential for repeat subsidence damage and resulting insurance reclaims are minimized.

THE INFLUENCE OF POST-HARVEST AND PREPLANTING SEED TREATMENT ON SAGEBRUSH SEEDLING VIGOR

D.T. BOOTH, E.E. ROOS

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14 May 1993

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University of Wyoming
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From: D.T. Booth
USDA, Agricultural Research Service
High Plains Grasslands Research Station
8408 Hildreth Road
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RE: Brief outline of research plans for newly funded project "The influence of post-harvest and preplanting seed treatment on sagebrush seedling vigor," ACMLRP.

This project will be conducted by scientists of the High Plains Grasslands Research Station, Cheyenne, WY (ARS) and the National Seed Storage Laboratory, Fort Collins, CO (ARS), with the cooperation of Wind River Seed Co. (Manderson, WY). Wind River Seed will locate and collect seed from appropriate locations so seedlots tested will represent a range of ecotypes likely to be used by mining companies in this region. Because of the need to identify, collect, and do seed quality analysis, initiation of funded support for the project will begin 1 January 1994.

We will be testing post-harvest handling, humidification, imbibition, and germination / early growth for three ecotypes of big sagebrush. Specific research questions and the interaction of factors likely to influence seedling vigor are:

I. POST-HARVEST HANDLING

A. Questions:
1. Does drying sagebrush seed have a negative influence on germination or seedling vigor? If so, is this due to an increase in seed dormancy, or does drying damage the seedcoat?
2. Does exposure to heat (>50°C) during seed processing affect germination or seedling vigor?
3. Should the pericarp be retained during seed processing to protect the seed from desiccation - does it influence seed moisture?

B. Tests: These questions will be addressed in replicated laboratory germination and growth studies and will follow

studies monitoring temperature and humidity during seed processing.

II. HUMIDIFICATION

A. Questions:
   1. How does initial seed moisture influence seed humidification?
   2. What will be the pattern of weight gain over time?
   3. How do time and temperature influence total gain? Rate of gain?

B. Test: Humidification curves will be developed by weighing seed samples held over distilled water after the initial seed moisture has been determined. Tests will be conducted at 2 or more temperatures and 3 or more time periods.

III. IMBIBITION

A. Question: How do humidification treatments influence imbibition?

B. Tests: Imbibition curves showing water uptake over time will be developed at 3 imbibition temperatures for likely humidification conditions. These curves will be used to determine the average time needed for seed to reach Phase II imbibition.

IV. GERMINATION AND GROWTH

A. Questions: Are germination and post-germination seedling vigor (heterotrophic growth) influenced by the interaction of seed moisture and temperature during humidification, imbibition, and germination?

B. Test: Humidified seed will be imbibed until Phase II imbibition is reached, then transferred to the germination temperature. Germination will be counted daily. Seedling growth will be measured after 5, 7, and 10 days of incubation at the germination temperature. The growth measurements will be taken at these intervals to assure that all treatments are measured when they reach their maximum length and before seedlings begin to atrophy. It is not expected that the growth measurements will be indicative of growth in the field; rather, that they will serve as an index to relative seedling vigor among the seed treatments. Laboratory results will subsequently be retested in greenhouse and field studies.

V. FIELD TEST

A. Question: Will optimum seed handling make a real difference to mine reclamation?

B. Test: If laboratory and greenhouse tests indicate that improvements to post-harvest handling and/or using seed humidification will increase seedling vigor, then these

treatments will be tested in the field at Glenrock Coal Company's Dave Johnson Mine to determine if the treatments result in a greater number of seedlings at the end of the first growing season. Treated and non-treated sagebrush will be sown using the most current information and technology.

INVENTORY OF KEMMERER COAL COLLECTION

P. MALMBERG

Fossil Country Futures, Inc.

Progress Report: Kemmerer Coal Company Papers

Work on the Kemmerer Coal Company papers began on Saturday May 15th with the transportation of the collection from the Pittsburg-Midway storage facility to the Fossil Country Future Museum. The project will be divided into several stages, including the initial inventory, conservation and storage of materials, and archival arrangement of the entire collection.

Proper conservation of the collection is essential. A large percentage of the artifacts are acidic papers which have been stored in highly acidic folders. Many of these artifacts need alkalization treatments and all of them need to be transferred to acid-free folders and storage boxes. The collection will then be moved to an environmentally controlled vault at the Lincoln County Library.

Photocopies of the original collection will be arranged for researchers and members of the general public. An archival listing will be made available to the public. Copies of the compiled listing will be sent to research facilities across the state.

The success of the entire project will be determined by the usefulness of the collection to researchers who who access the collection.

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GEOPHYSICAL DETECTION OF ABANDONED MINE TUNNELS

S.B. SMITHSON, M.C. HUMPHREYS

GEOPHYSICAL DETECTION OF ABANDONED MINE TUNNELS

By Scott B. Smithson and M. C. Humphreys

I. The project is based on combined use of high-resolution seismics (HRS) and ground-penetrating radar (GPR) to image shallow, subsurface features such as coal beds, voids, grout-filled voids and faults.

   A. These two methods complement each other because GPR provides best penetration above the water table and HRS below the water table.

   B. Changes in physical properties (velocity) of the subsurface produce reflections in both techniques.

      a. These reflections can be used to map the subsurface and lateral changes in reflection amplitude can be used to determine changes in material.

II. These methods were previously applied in Rock Springs as a feasibility study.

   A. In some locations, tunnels, faults and water tables were located.

      a. Interpretations were confirmed by drilling.

   B. In other locations, no useful results were obtained.

      a. This was primarily a function of surface conditions such as asphalt and fill or heavy weathering and source noise.

      b. GPR was strongly degraded by power lines and other cables.

      c. Improved data acquisition techniques can lead to usable data as demonstrated in the feasibility study.

      d. Field techniques must be constantly adjusted for varying local conditions.

III. New research will combine HRS and GPR in Rock Springs.

IV. Goals

   A. Adjust recording techniques for surface conditions.

      a. Recording parameters. Noise test. GPR walkaway.

b. Test seismic sources, i.e. sledgehammer, weight drop, caps, shotgun, rifle. Some seismic sources work better in certain conditions.

B. Continuously monitor data acquisition with field computer to aid in adjusting parameters.

C. Determine best filter setting. Determine best GPP geometry.

D. Modify GPR system for more rapid use.

E. Improve GPR antennas.

F. Calibrate HRS and GPR with drilling results.

a. Geophysical imaging provides better lateral coverage but needs calibration from drilling.

b. Calibrate in different areas and subsurface problems.

G. Integrated HRS and GPR interpretations.

H. Interpretation of amplitude variation to determine presence of grout.

I. Develop catalog of optimum recording parameters for different surface conditions.

a. Relate to shallow velocity profiles determined by seismic refraction and to depth of water table.

J. Optimize field and processing techniques for speed and economy.

V. Technology Transfer.

A. Prepare report after each year.

B. At completion, hold workshop with "hands-on" use of recording equipment.

a. Critique techniques and results.