ABANDONED COAL MINE LAND RESEARCH PROGRAM

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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, and J. GORES

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

G.E. Schuman, D.T. Booth, J.R. Cockrell, and J. Gores

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 reestablishment during mined land reclamation, the fact remains that reclamationists are required to restore sagebrush to mined lands when wildlife habitat is a critical postmine land use. 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, the seedlings inability to compete with herbaceous species, poor seed quality and/or ecotypic adaptation, inability of agronomic seeding methods to meet seed microsite requirements; and the effects of altered edaphic conditions on establishment of the vesicular-arbuscular mycorrhizal (VAM) associations that are believed important to sagebrush seedling survival.

A research study initiated in January 1991 set out to test several cultural approaches in an attempt 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 topsoil as a seed source,
2. The value of a stubble mulch crop of annual grain for sagebrush establishment through effects of 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 allows for the 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

areas reclaimed 10-13 years earlier was negligible and plays an insignificant role in enhancing this shrub species role in the reclaimed mined land ecosystem. When sagebrush was included in the seed mix, sagebrush densities averaged 0.419 seedlings/m^2; however when sagebrush was not seeded it only averaged 0.003 seedlings/m^2. One must remember that the seeding technology 10 years ago for most shrubs involved drill seeding which is now seldom used because of improved understanding of seedbed ecology for these species. The survey data also showed a significant relationship between sagebrush stem diameter and plant height except at the Shirley Basin site where wildlife browse is extremely heavy. Shrub densities were greater on those sites where sagebrush and fourwing saltbush had been seeded compared to where only fourwing saltbush was included in the seed mixture.

In general, the data show that shrub densities were greater when big sagebrush was included in the seed mixture and there was a strong correlation between shrub densities and shrub seeding rates (i.e. the greatest shrub densities occurred on those sites where increased shrub seeding rates were used). The reseeded plant communities were also evaluated for suitability for wildlife habitat for several species important to Wyoming. Further detail of the survey study will be available within the next couple of months in the thesis of Mr. James Gore.

Future Plans

A greenhouse study is being initiated to further evaluate the effects of VAM infection of the sagebrush seedling survival and establishment. This research will evaluate the effects of VAM infection on water stress tolerance of sagebrush seedlings. The research should be completed in mid-1996 and final report prepared.

Publications from Research

Cockrell, J.R., G.E. Schuman, and D.T. Booth. 1995. Evaluation of Cultural Methods for Establishing Wyoming Big Sagebrush on Mined Lands. p. 784-795. *In*: G.E. Schuman and G.F. Vance (ed). Decades Later: A Time for Reassessment. 12th Annual Meeting, June 3-8, 1995, Gillette, WY. American Society for Surface Mining and Reclamation, Princeton, WV

TOXICOLOGIC EVALUATION OF CHRONIC SELENOSIS IN WYOMING HERBIVORES

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TOXICOLOGIC EVALUATION OF SELENOSIS IN WYOMING HERBIVORES

Annual Report - November, 1995

M. F. Raisbeck, J. W. Waggoner, D. O'Toole

In our original proposal, the final year was to be devoted to correlation of toxicologic data obtained from controlled experimental feeding experiments during the first and second years of the study with similar parameters derived from natural exposure. Experimental feeding studies drastically limit environmental variables such as weather, dietary selectivity and antagonistic/synergistic nutrients. These factors probably account for some of the discrepancies in the older selenosis literature. Our previous studies suggest that 5 ppm total Se in vegetation on reclaimed minelands do not pose a significant toxicologic hazard to grazing herbivores under Wyoming conditions. This experiment tests the extension of this conclusion to the real world.

Due to a variety of complications, we were unable to conduct this study during the summer of 1994 and requested an extension to include the 1995 grazing season. As outlined in our presentation last Fall, there are two possible general methods to develop natural exposure data: 1) feeding diets derived from naturally seleniferous hay to animals at the UW facilities where the rest of the experiments were done; and 2) pasturing animals on reclaimed mine sites with varying forage selenium concentrations. We opted for the latter as it seemed more representative of the real world situation in the Powder River basin.

Five potential grazing sites were selected to represent the spectrum of Se exposure likely in the Powder River basin. Four were reclaimed pastures at active mines (A-D), the fifth (E) was a ranch with a history of alkali disease. The latter was necessitated by our inability to find a cooperating mine with toxic vegetation. Twelve steers at the High Plains Grasslands Research Station (HPGRS) in Cheyenne served as a control. Site E was 3000 acres. The owner of two of the sites (C&D) dropped out of the study prior to getting underway. Sites A, B & HPGRS varied between 100 and 200 acres.

After baseline blood samples were taken, yearling cattle were released on each of the sites. Dietary botanical composition was determined by visual observation at monthly intervals. Fecal samples were collected for microscopic botanical analysis as a secondary check on visual observations. Representative samples of grazed vegetation were collected onto dry ice for transport to the laboratory. Forage samples were frozen at -70 C, then lyophilized, ground and homogenized before analysis. Blood and serum were analyzed as previously.

Blood and serum will be fit to estimated intake to model the toxicokinetic relationship between exposure and tissue concentrations. Primary antibody response to OVA will be similarly modelled. While tissue Se concentrations do not, in themselves, prove toxicity, this model will permit comparison between experimental studies such as we conducted in previous years and real-world exposure with grazing selectivity.

As of this writing, we're still analyzing samples and data. We plan to have the completed analysis in our final report next Spring.

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

K.D. BASHAM, T.R. CARTER, and 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 December 31, 1995

Project Summary:

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 buildings damage, the author has reviewed and updated the ***Specifications and Recommendations for Residential Construction Subjected to Ground Movements Related to Mine Subsidence***. Also, a document entitled ***Specifications and Recommendations for Repair of Residential Structures Damaged by Ground Movements Related to Mine Subsidence*** is being developed.

The primary purpose of the first document, developed by the University of Wyoming in 1988 and funded by the Wyoming DEQ/LQD, is to provide construction specifications and recommendations for new structures built in areas with a potential for mine subsidence. This document provides guidelines and recommendations for residential construction that will reduce subsidence related building damage. Revisions include the new subsidence risk categories, construction updates and additional guidelines developed from mine subsidence insurance claims since 1988. This 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. This 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 reduce future and repeat subsidence damage and insurance claims.

To help introduce both documents, the investigator plans to develop information pamphlets addressing mine subsidence in Wyoming, related building damage, new construction guidelines and repair schemes. Information pamphlets will give initial guidance about mine subsidence and related concerns to homeowners and building professionals. In summary, 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) 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) Develop and publish a document entitled ***Specifications and Recommendations for Repair of Residential Structures Damaged by Ground Movements Related to Mine Subsidence***.

3) Develop information pamphlets to introduce mine subsidence, related concerns, and both documents to homeowners and building professionals of Wyoming.

Progress:

Phase I — Develop and publish 2nd edition of ***Specifications and Recommendations for Residential Construction Subjected to Ground Movements related to Mine Subsidence***

Document is 100% complete and currently under final review. Publishing is scheduled for mid-December 1995.

Phase II — Develop and publish ***Specifications and Recommendations for Repair of Residential Structures Damaged by Ground Movements Related to Mine Subsidence***

60% complete

Funding:

25% remaining

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

D.T. BOOTH, E.E. ROOS, and Y. BAI

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

D.T. Booth, E.E. Roos, and Y. Bai

INTRODUCTION

Returning native shrubs to the post-mining plant community in a cost-efficient manner has remained a challenge for western reclamationists. Since Wyoming big sagebrush is commonly recommended for revegetation of mined lands, and since there is a need to improve seeding success, this project was initiated in the fall of 1993 to measure the effect of post-harvest seed handling on seed quality and the effectiveness of pre-sowing seed moisture manipulation to improve seedling vigor.

Project Description

The research is a cooperative effort by scientists of the High Plains Grasslands Research Station, Cheyenne, WY (ARS), the National Seed Storage Laboratory, Fort Collins, CO (ARS), the University of Wyoming, Laramie, WY, and Wind River Seed Co. (Manderson, WY). The following studies have been completed, or are ongoing:

1. Pre-dispersal seed moisture. Seeds from several locations were collected in late winter. The initial seed moisture content was determined and seed germination and seedling vigor were tested.

2. Post-harvest seed handling. A 48" commercial debearder was used for seed processing to determine the effect of debearder processing on seed quality.

3. Seed humidification. Seed humidification refers to holding seed over free water in a high humidity environment. The effect of this treatment was tested at 4 temperatures (2, 5, 10 and 15°C) over 10 time periods (through 15 days) and for 2 seed collections. Seed moisture curves were developed to describe the influences of seed collections, initial seed moisture, and humidification temperature and duration on seed germination and seedling vigor.

4. Effect of humidification and pericarp on germination under water stress. Having found no benefit to seedling vigor from humidification treatments when seeds were germinated under optimum conditions, we then tested for an effect under moisture stress. This was evaluated in

combination with the effect of pericarp removal. Seeds with and without pericarp were hand separated from processed seed and used to measure the rate of moisture uptake, effect of humidification, germination and germination rate under water stress. The water stress was applied using the matric potential control system of Hardegree and Emmerich. This system consists of a membrane-bottom germination cup in contact with an osmotic solution. Seven water potentials ranging from 0 to -1.5 MPa were used in the test.

5. Management of sagebrush seed production. After evaluating our earlier findings we concluded that management of sagebrush seed production to increase seed dry weight might have greater potential for economic benefit to Wyoming's mining industry than a field test of humidified seed. We proposed a redirection of the field portion of the planned research that would allow us to answer the questions: (1) How does sagebrush seed production (quantity and quality) from reclaimed coal mined lands compare with production from adjacent undisturbed land? This addresses the general question of whether re-established stands of sagebrush are self-sustaining. (2) Can weedbarrier fabric and snowfence windbreaks be used to increase the quantity and quality of sagebrush seed? Our proposal for a change was accepted and the field study was installed at the Dave Johnson Coal Mine in July of 1995.

Progress Report

This report will cover only results not covered in previous progress reports.

Effect of humidification and pericarp on germination under water stress.

We have found seed humidification to have no effect on seedling vigor, even under water stress. We also found that the pericarp of sagebrush seeds did influence the rate of seed moisture uptake. This translated into a negative effect on germination under water stresses of -0.50 to -0.75 MPa in one seed collection, but no effect on a second collection. Water stress of -0.50 MPa reduced germination in both collections by about 50% of the germination recorded at 0 MPa. Pericarp removal during debearding may actually

promote rapid germination of some seeds. This may be beneficial due to the transient nature of soil moisture in the spring. We suggest that the current product, a mixture of seeds with and without pericarp is a desirable situation.

Management of sagebrush seed production.

The first seed harvest is planned for the third week of October. Given the unusually high spring precipitation received in Wyoming in 1995, we are not expecting differences due to treatments this harvest.

Other Significant Information

The monies we receive from this grant provide the greatest portion of support for Dr. Y. Bai's position. That position has contributed to our obtaining additional funds from the Saskatchewan Agricultural Development Fund and Ducks Unlimited of Canada to conduct cooperative work with the University of Saskatchewan on winterfat seedbed ecology. Since winterfat is a shrub commonly used in revegetation of Wyoming coal mined lands we are providing a brief synopsis of our progress on that project. We believe this information will certainly be of interest to readers of this report. New results:

Freezing tolerance of winterfat seeds not related to low temperature exotherm. Survival of fully hydrated seeds to -30°C at a cooling rate of 2.5°C h^{-1} was similar to that of seeds not subjected to freezing, even though low temperature exotherms (LTEs) were observed. LTEs have generally been regarded as an indication of lethal freezing. The winterfat LTEs were correlated with slower germination and reduced seedling vigor. This was particularly true for seed collections with the lightest weights. We conclude that imbibed winterfat seeds are capable of tolerating -30°C and that winterfat is different from other imbibed seeds that have been studied in their ability to survive an LTE.

Discussion and Future Plans

We believe the 6 most important findings to date, arising from our sagebrush work are:

1. Processing sagebrush seed with a debearder did not have a negative influence on seed quality and can be recommended as the method of choice in preparing seed for commerce.

2. The germination of processed sagebrush seed increased during 6 months of storage, indicating the presence of some seed dormancy or of an afterripening requirement.

3. The moisture level of sagebrush seed on the mother plants during February ranged from 2 to 9%. With time, the range in seed moisture narrowed to 5 to 6% and gemination and vigor increased.

4. Heavier sagebrush seeds germinated more quickly and had greater total germination than lighter seeds.

5. We found no evidence that management of seed moisture could be used to increase sagebrush seedling vigor under either optimal or water stress conditions. This contrasts with findings for seeds of crop species. The small size of the sagebrush seed, and the limited amount of stored food inside the seed may account for the difference.

6. The pericarp of sagebrush seeds can reduce the rate of seed moisture uptake and the amount of seed germinating during water stress. We suggest seeds with pericarp have some protection against germination during very transient periods of acceptable soil moisture. However, seeds without pericarp may have a greater probability for seedling establishment during suboptimal conditions.

We have completed the proposed work on post-harvest processing, seed humidification, imbibition and its interaction with time and temperature. What remains is the field work, as amended. However, if time and funds allow, we may also undertake further work to test the effect of wet/dry cycles on seed quality and seedling vigor.

<u>Presentations and Publications related to this project</u>

Published:

Booth, D.T., Y. Bai, and E.E. Roos. 1995. Wyoming big sagebrush seed quality as influenced by processing with an industrial debearder. Abstracts 1995 Meeting, American Society for Surface Mining and Reclamation.

Booth, D.T., Y. Bai, and E.E. Roos. 1995. Wyoming big

sagebrush seed quality related to debearder operation during seed cleaning and storage. pp. 8. IN: Fifth International Rangeland Congress Abstracts. Dept. of Rangeland Resources, Utah State Univ., Logan.

Bai, Y., D.T. Booth, E.E. Roos. 1995. Influences of initial seed moisture and humidification on seed germination of Wyoming big sagebrush. pp 4. IN: Fifth International Rangeland Congress Abstracts. Dept. of Rangeland Resources, Utah State Univ., Logan.

Submitted:

Booth, D.T., Y. Bai, and E.E. Roos. Preparing sagebrush seed for market: effects of debearder processing. J. Range Manage.

In Review:

Bai, Y., D.T. Booth, E.E. Roos. Seed moisture and seed humidification related to seedling vigor of Wyoming big sagebrush. J. Range Manage.

Bai, Y., D.T. Booth, and J.T. Romo. Freezing tolerance in winterfat (*Eurotia lanata* (Pursh) Moq.) seeds: Part I - seed hydration related to temperature.

Bai, Y., D.T. Booth, and J.T. Romo. Freezing tolerance in winterfat (*Eurotia lanata* (Pursh) Moq.) seeds: Part II - survival not related to low temperature exotherm.

In Preparation:

Hardegree, S.P., Y. Bai, D.T. Booth, and E.E. Roos. The function of pericarp in seed germination of Wyoming big sagebrush under water stress.

Bai, Y. and D.T. Booth. Determining moisture content of small sized seed by using capsules and microbalance.

Bai, Y., D.T. Booth and J.T. Romo. Freezing tolerance in winterfat (*Eurotia lanata* (Pursh) Moq.) Seeds: developmental stage and imbibition temperature related to survival of germinants.

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

Final Report

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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October 30, 1995

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), an element of interest and concern, has the potential of becoming increasingly mobile with time in oxidizing environments. During surface mining activities, materials previously in reducing environments become exposed to atmospheric conditions, thus increasing the potential of elevated levels of mobile and plant-available Se. Furthermore, solubility and mobility of Se in areas disturbed by mining may result in higher levels of Se in surface waters, ground waters, and in resaturated backfill environments. The post-mining land use of a majority of the abandoned and reclaimed coal mine lands is grazing land, pastureland and/or wildlife habitats. 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.

Objectives

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

1. **development of a rapid and cost effective method for determining Se species in backfill and soil materials of abandoned and active coal mine sites,**
2. **examination of solid-phase and solution speciation of Se in the rooting-zone of mine soils for correlation to plant uptake,**
3. **characterization of Se adsorption/desorption and precipitation/dissolution processes controlling Se mobility in backfill and soil environments,**
4. **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.**

The following sections describe results from research conducted in this AML project that relate to the above objectives.

Methods of Se Quantification (Objective 1)

Ion chromatography (IC) was effective in directly speciating selenite-selenate in aqueous phases at concentrations as low as 20 ppb. However, there were two limiting factors that affected Se quantification: type of Se extractant and nature of the soil-solution anionic composition. Higher concentrations of chloride, phosphate, sulfate and organic anions were found to interfere with selenite and selenate speciation. Thus, we were unable to analyze Se in chloride, phosphate, and AB-DTPA extracts by IC. Additionally, soils containing high soluble sulfates (i.e., > 1000 mg/L) were not amenable to Se determination by IC. However, for aqueous extracts of low sulfate soils, IC worked well.

Atomic absorption spectrophotometry with hydride generation (AAS-HG) was useful in detecting very low Se concentrations (1 ppb) and was especially useful for samples that could not be analyzed by IC. However, this method also had limitations: AAS-HG was capable of measuring total Se in the form of selenite, and could not be used to speciate selenite and selenate directly. Therefore, an indirect approach was used for Se speciation with AAS-HG. Each sample solution was analyzed for total Se

after digestion with 30% H_2O_2 + 12 *M* HCl. In addition, solution selenite was measured before the pre-treatment step. Selenate was calculated from the difference between total Se and selenite. The organic Se fraction was also determined by skipping the peroxide step in the digestion procedure in the procedures described above.

Studies involving both instruments have shown comparative results; however, with certain samples analytical discrepancies were noted, which were due to the fact that IC is capable of detecting Se as species, whereas, AAS-HG quantifies Se as components. A good correlation between chromatographic and spectroscopic findings, indicated negligible amounts of various Se species other than selenite and selenate.

To better understand the potential toxicity of Se, it is necessary to know the concentration of different Se ionic species (e.g., SeO_3^{2-} and SeO_4^{2-}). The hydride generation atomic absorption spectrophotometry (HGAAS) method of Se analysis cannot separate Se into individual ionic species. Ion chromatography (IC) can determine SeO_3^{2-} and SeO_4^{2-} concentrations simultaneously; however, common anions, such as sulfate (SO_4^{2-}), in solutions interfere with SeO_3^{2-} and SeO_4^{2-} speciation. We developed a method to measure the concentration of ionic SeO_3^{2-} and SeO_4^{2-} species in solution, thereby determine the chemical speciation of dissolved Se. Three solution samples with high concentrations of Mg^{2+} and SO_4^{2-} were used in this study. The ionic SeO_3^{2-} and SeO_4^{2-} species in the samples were selectively adsorbed onto copper oxide (CuO) particles by lowering the pH to 5.5. These ionic species were desorbed from the surface of CuO particles by increasing the pH to 12.5. Subsequently, the concentrations of SeO_3^{2-} and SeO_4^{2-} ionic species in solutions were determined with HGAAS and IC. An important aspect of the proposed method is that CuO could be used in the field to extract both SeO_3^{2-} and SeO_4^{2-} ionic species from natural water samples and these species could be desorbed from the CuO and measured using HGAAS or IC methods, depending upon the concentrations of these species.

Another method of Se quantification used in our study was high performance liquid chromatography (HPLC). Using fluorescence detection we were able to measure selenomethionine and several other amino acids in aqueous extracts of soils and plants. The results indicated the presence of greater amounts of amino acids derived from plants than soils, suggesting the logical conclusion that plants are a major source of organo-selenium, whereas soils act as a sink for organo-selenium compounds.

Solution and Solid Phase Se Speciation (Objective 2)

In aqueous phases, selenate (Se^{+6}) was found to be the potential species, while in the exchange phase, selenite (Se^{+4}) predominated, thereby indicating both Se species were available for leaching and/or plant uptake. The effect of divalent cations (e.g., Mg^{2+}) on the concentration of SeO_4^{2-} in aqueous solutions was also evaluated. The dissolved Se concentration in three water samples ranged from 22 to 151 μg/L. The CuO particles extracted 97% of SeO_3^{2-} from these samples, suggesting that Se (IV) concentrations were dominated by SeO_3^{2-} ion. However, CuO particles extracted 80% of SeO_4^{2-} from water samples. These results suggest that Se (VI) concentrations consisted of SeO_4^{2-} and other solution species. The dissolved Mg^{2+} in natural water samples formed a strong neutral ion pair with SeO_4^{2-} ($MgSeO_4^0$), which was not adsorbed by the CuO particles. Overall chemical speciation of dissolved Se, extracted with CuO particles, suggests that the natural water samples consisted of SeO_3^{2-} (6 to 36%), SeO_4^{2-} (32 to 65%), organic Se species (14 to 23%), and neutral ion pairs (9 to 16%).

The order of Se (total, inorganic and organic) extraction efficiency for different reagents was DI water < hot water < AB-DTPA << NaOH << KH_2PO_4. The inorganic:organic Se ratios in DI water, hot water, AB-DTPA, NaOH and KH_2PO_4 extracts were 60:40, 26:74, 61:39, 87:13 and 52:48, respectively, indicating predominance of inorganic Se in all but the hot water extract. Selenite was the dominant inorganic species in AB-DTPA and KH_2PO_4 extracts, while SeO_4^{2-} was the major Se species in the DI water, hot water and NaOH extracts. Significant correlations ($P < 0.01$) were observed among

extractable inorganic Se [NaOH and KH_2PO_4 (r = 0.95); hot water and AB-DTPA (r = 0.89)], total soluble Se [DI water with hot water (r = 0.98) and AB-DTPA (r = 0.95)], Se species [SeO_3^{2-} in AB-DTPA with SeO_4^{2-} in NaOH (r = 0.94) and SeO_3^{2-} in KH_2PO_4 (r = 0.88)]. These correlations are indicative of Se extraction efficiency, thermodynamically predicted chemical transformations (such as oxidation of SeO_3^{2-} to SeO_4^{2-}), and probable interconversions between the organic and inorganic Se fractions (r = 0.70 in KH_2PO_4 extracts); as a whole the correlations can be used as statistical validations of possible geochemical processes.

Solid-phase Se was partitioned sequentially into aqueous, exchangeable, acid extractable, sulfide and humic bound, and siliceous fractions. Selenate was found to be the potential aqueous specie, while in the exchange phase Se^{+4} predominated. These results support the findings of our solution-phase speciation studies. Both Se^{+4} and Se^{+6} were found to be distributed almost evenly in acid extractable fraction. Speciation data for the last two fractions, however, was not conclusive.

With increasing exchangeable Se there was a corresponding increase in Se in the aqueous fraction. A similar increasing trend was found between exchangeable Se fraction and acid extractable Se fraction. This relationship suggested a probable interconvertibility between these three fractions. The results also indicated that soils with more resistant Se would have less Se in available forms; however, weathering of the resistant fractions would result in a gradual increase in Se availability. During pedochemical changes, the weatherable fraction would be first transformed to the conditionally available fraction, which, subsequently would be transformed to the available fractions; however, there could also be some interconversion between the available and conditionally available forms of Se.

Total soil Se increased with increasing clay content, with a reverse trend observed for sand content, thus suggesting Se was associated with the clay sized soil fraction. Siliceous Se was linearly related to total soil Se suggesting the presence of Se in silicate minerals. This fraction was again found to increase with increasing soil clay content, thereby supporting the above findings. Thus, we recommend further mineralogical studies for identifying siliceous Se.

Sorption and Precipitation Processes (Objective 3)

Both column and batch techniques were used to study sorption and precipitation processes. For different soils, sorption isotherms were found to follow either linear or curvilinear models, which indicated sorption could be either a continuous or discontinuous function of solution Se, depending on soil parameters, i.e., pH, clay content, mineralogy. Selenite sorption was greater than 90 percent within the suitability limit of 0.1 mg/kg; however, the amount adsorbed decreased with increasing Se treatment levels. A kinetic study indicated selenite had a faster rate of immobilization as well as solubilization, in comparison to selenate. Moreover, selenate had a shorter breakthrough time and lower K_d than selenite. Thus, selenite was found to be the potential species that would be rendered immobile in comparison to selenate. Both Se species were desorbed over time by phosphate, although the desorption kinetics of selenite were very slow. The adsorption and desorption processes were found to be path-functions, which suggested the occurrence of hysteresis.

The data followed Langmuir, Freundlich, Temkin and Initial Mass isotherms. Langmuir model results fit SeIV in most of the samples, whereas SeVI sorption in only one sample was explained by this model. The number of SeIV molecules present in the monolayer coverage varied between 30 to 637 ($x10^{14}$). Percent sorption varied from 48-99% for SeIV, and 44-94% for SeVI; for all the soil samples the percent SeIV sorbed was always greater than that for SeVI, which indicated SeIV as a stronger adsorbent. This was reconfirmed by the greater K_f values for SeIV obtained from Freundlich model, which was a better fit in comparison to Langmuir model for both SeIV and SeVI species. Both Se species fit the Temkin model, with a few exceptions for SeVI. The best fitting of SeIV and SeVI adsorption was noted for the Initial Mass isotherm. The B_i and RSP_i values indicated there was

indigenous soil Se, mainly SeVI, in most of the samples. Higher K_i values for SeIV were due to greater sorptivity in comparison to SeVI.

Different adsorption parameters were found to be linearly related to various soil properties. Phosphate extractable Se was positively ,correlated to adsorption parameters for both SeIV (K_lB_l and K_i) and SeVI (K_f, K_{tl}, RSP_i). Similarly total Se was also related to these parameters. Extractable cations in both crystalline and amorphous forms were related to different sorption parameters including B_l, n_f, K_f, and K_t indicating the presence of these cations in soils will enhance Se retention. Positive correlations between n_f, conductivity, clay content and specific surface area also suggested dependence of Se adsorption on other soil properties. The information obtained from this adsorption study can be applied for developing Se attenuation strategies in coal mine land reclamation.

Selenite, selenate and sulfate were distributed into solid, solution and complexed phases. In the solid phase, a greater proportion of SeO_3^{-2} was adsorbed with Fe, Cu, Zn, CuO, La_2O_3 and WO_3 as compared to SeO_4^{-2}; greater retention of SeO_4^{-2} was found with C, Sb, CaO and MgO. An adsorption order of $SeO_3^{-2} > SO_4^{-2} > SeO_4^{-2}$ was observed with Fe, Cu, Zn, CuO, La_2O_3 and WO_3. Both SeO_3^{-2} and SeO_4^{-2} retention was lower than SO_4^{-2} for Sb, CaO, MgO, MnO_2. Activated C adsorbed the maximum SeO_4^{-2} followed by SO_4^{-2} and SeO_3^{-2}. Greater percent distributions of these anions were observed mainly in the solution phase as compared to solid or complexed phases. In the solution phase, the percentage of SeO_4^{-2} was either greater than or equal to SeO_3^{-2} percentage in the case of most of the treatments, and percentages of either SeO_3^{-2} or SeO_4^{-2} or both were higher than that of SO_4^{-2}. The percentages of SeO_3^{-2} and SeO_4^{-2} in complexed phases were highest (89 and 33 %, respectively) for the MgO treatment, indicating $MgSeO_3^0$ and $MgSeO_4^0$ are the strongest Se ion pairs amongst the different solids studied. The $CaSO_4^0$ and $MgSO_4^0$ were the most abundant S ion pairs amongst the different solids studied. For MgO, the tendency of ion pair formation would be $MgSeO_3^0 > MgSeO_4^0 > MgSO_4^0$. A greater or equal SeO_3^{-2} distribution in complexed phases, as compared to SeO_4^{-2}, was observed for the treatments of Fe, Cu, Sb, MgO, MnO_2, CuO, La_2O_3 and WO_3. For the remaining solids, SeO_4^{-2} percent was higher than SeO_3^{-2} in complexed phase. Except for the CaO treatment, percentages of either SeO_3^{-2} or SeO_4^{-2} or both were higher than that of SO_4^{-2}.

The experimental pk^0 values for $CaSeO_4.2H_2O$ and $ZnSeO_3.H_2O$ were higher than theoretical values (obtained from literature), whereas for $MgSeO_3$ the determined pk^0 was lower; theoretical and experimental data for both $CaSeO_3.H_2O$ and $MnSeO_3$ were comparable. Results indicated that $CaSeO_4.2H_2O$ had the maximum solubility ($pk^0 = 4.20$). The order of ΔG^o_f was $CaSeO_4.2H_2O < CaSeO_3.H_2O < MgSeO_3 < ZnSeO_3.H_2O < MnSeO_3$. At low pH (< 6), $CaSeO_4.2H_2O$ was highly unstable and at pH < 4 the stability-order of the selenite solid phases was $ZnSeO_3.H_2O > MnSeO_3 > CaSeO_3.H_2O > MgSeO_3$. At pH 7, $CaSeO_3.H_2O$ was the most stable Se solid phase examined. Under high pH conditions (> 8), the stability-order was $MgSeO_3 > CaSeO_3.H_2O > MnSeO_3 > CaSeO_4.2H_2O > ZnSeO_3.H_2O$. Results suggest that in acidic soils $ZnSeO_3.H_2O$ and $MnSeO_3$ may be the most stable solid Se phases, whereas in alkaline and neutral environments $MgSeO_3$ and $CaSeO_3.H_2O$ may govern selenite dissolution chemistry. At lower redox and pH conditions, selenite would be the major Se species in equilibrium with the solid phases. Under oxidizing soil conditions, the stability-order for SeO_4^{-2} formation from SeO_3^{-2} solids was $MgSeO_3 > CaSeO_3.H_2O > MnSeO_3 > ZnSeO_3.H_2O$.

Values for pe+pH (>15) indicated the mine soils were from alkaline and oxidized environments; high soil electrical conductivities also suggested high ionic mobility. Both anionic and complex species of Se, including SeO_4^{2-}, SeO_3^{2-}, $HSeO_4^-$, $HSeO_3^-$, $H_2SeO_4^0$, $CaSeO_4^0$, $MgSeO_4^0$, $MnSeO_4^0$, $ZnSeO_4^0$, $H_2SeO_3^0$, $CaSeO_3^0$ and $MgSeO_3^0$, were identified in the mine soil solutions; SeO_4^{2-}, SeO_3^{2-}, $CaSeO_4^0$, $MgSeO_4^0$, $MgSeO_3^0$ and $CaSeO_3^0$ were the predominant species. The soil solutions were found to be undersaturated with respect to various Se solid phases; however, $MgSeO_3$, $CaSeO_3$, $CaSeO_3.H_2O$ and $CaSeO_4.2H_2O$ had the lowest saturation indices. There was a decrease in solution metal content and an increase in SeO_3^{2-} and SeO_4^{2-} concentrations when DOC data were included in the GEOCHEM

calculations. Percentages of both Se ions as "free" components were higher when DOC was considered, whereas, calculations without considering DOC resulted in greater ionic distributions in "bound" components. These observations suggested a probable metal-DOC complexation which might have resulted in higher SeO_3^{2-} and SeO_4^{2-} levels in solutions. MINTEQA2, however, did not consider DOC complexation and the percent of "bound" SeO_3^{2-} was much higher than the "free" component. A reverse trend was observed for SeO_4^{2-}, which indicated there was a greater binding capacity of SeO_3^{2-} as compared to SeO_4^{2-} in mine soil solutions.

The studies with selenomethionine, a toxic Se-containing amino acid released by plants, indicated there are various fates of this compound. Selenomethionine was retained by soils in a nonlinear fashion, with clayey soils having greater retentivity. SeM disappearance from mine soil solutions followed 1st order kinetics. Results also suggested mineralization of the organic compound to simple inorganic selenite, a possible transformation to other organo derivatives, and microbial degradation to volatile Se products.

From a management stand point, the findings of our studies suggest application of inorganic amendments (having more electropositive cations), organic manures and biosolids during reclamation would reduce Se release into soil solution; however, before adding these materials they should be tested for potential contaminants.

Soil-Plant Se Correlations (Objective 4)

The order of extractable soil Se from range and mine lands was: phosphate > AB-DTPA > hot water > saturated paste. In general there was a significant correlation between phosphate and AB-DTPA extractable Se irrespective of land type. In the abandoned soils, correlations between phosphate and AB-DTPA extractable Se with water extractable Se were noted, which was not observed in native and reclaimed sites. Saturated paste extractable Se levels were typically very low, and were not correlated with other extracts. In a number of sites, AB-DTPA as well as phosphate extractable Se was found to be greater than the WDEQ-LQD Guideline No. 1 (1984) suitability limit of 0.1 mg/kg.

The general plant Se distribution in various range and mine soils was: shrub>forb>grass. In native and abandoned lands the distribution pattern was: shrub>forb>grass, whereas in reclaimed land the trend changed to: forb>shrub>grass.

Soil-plant Se correlations were found to be specific to the sampling sites as well as vegetation types. In native range lands, Se in shrub vegetation was found to be related to both AB-DTPA and phosphate extracts, whereas forb Se corresponded to only AB-DTPA extractable Se; grass however, was not correlated with any of the extracts. In reclaimed mine sites, both shrub and grass Se contents were correlated to AB-DTPA extractable Se, whereas phosphate extractable Se and forb Se contents were not correlated. In abandoned sites, forb Se was related to AB-DTPA, water and phosphate extractable Se, whereas, grass was dependent on AB-DTPA and phosphate extractable Se only; shrub, however, did not show any correlations. In general, under comparable circumstances, AB-DTPA Se had stronger correlations with plant Se followed by phosphate Se.

In native range samples, 0.1 mg/kg AB-DTPA extractable Se corresponded to 2 mg/kg Se in both shrub and forb vegetation, whereas 0.1 mg/kg phosphate extractable Se corresponded to 0.8 mg/kg plant Se. In reclaimed environments, 0.1 mg/kg AB-DTPA extractable Se corresponded to 0.9 and 1.3 mg/kg shrub and grass vegetation, respectively. On abandoned mine lands, calculated forb Se concentrations at the 0.1 mg/kg AB-DTPA, hot water and phosphate extractable Se level would corresponded to 0.6, 1.2 and 0.4 mg/kg plant Se, respectively, whereas for grass vegetation 0.1 mg/kg AB-DTPA and phosphate extractable Se corresponded to 0.8 and 0.6 mg/kg plant Se levels, respectively. In our soil-plant Se statistics we used a boundary condition of plant Se levels that were less than 5 mg/kg. This concentration limitation was done in order to avoid skewing or statistical bias in the analysis. From this

correlation study, we recommend site and vegetation specific characterization, rather than a general approach, and we also suggest the use of different class-intervals (i.e., low, medium, high) for the plant data.

Recommendations for Future Research

From our analytical studies, we recommend the use of both chromatographic and spectroscopic techniques for Se quantification. However, further research is needed to develop more precise methodologies for Se analysis in order to correct the problems we encountered in some of the soil and water systems, and also to minimize quantification errors. From the management stand point, we recommend application of inorganic amendments (having more electropositive cations) and organic manures or biosolids during reclamation, which would potentially reduce Se released. However, research should be done to test for toxicity effects of other contaminants before adding the amendments, and to determine their interaction with respect to Se mobility. We also suggest a combined investigation that deals with the mobility of Se from soils to surface waters and aquifers. From the soil-plant correlation study we recommend site and vegetation specific characterization, rather than following a general "one-size-fits-all" approach. We also suggest the use of different class-intervals (i.e., low, medium, high) for the plant data. Our sequential fractionation study also indicates the necessity of further mineralogical investigations for identifying siliceous Se.

1994 and 1995 Publications:

Vance, G.F. and M.J. Blaylock. 1994. *Adsorption of selenite and selenate by gypsum, kaolinite, montmorillonite, and coal mine spoil materials.* Agronomy Abstracts. p. 407.

Sharmasarkar, S., G.F. Vance, R. Zhang, K.J. Reddy, and L.K. Spackman. 1994. *Selenite-selenate mobility in range and mine soils.* Agronomy Abstracts, p. 259.

Vance, G.F. and S. Sharmasarkar. 1994. *Amino acid release from soil/plant mixtures and Selenomethionine removal in coal mine soils.* Agronomy Abstracts, p. 278.

Sharmasarkar, S. and G.F. Vance. 1994. *Application of partial fractionation and speciation techniques for predicting groundwater contamination by soil selenium movement.* *In* R.A. Marston and V.R. Hasfurther (eds.) Effects of Human-Induced Changes on Hydrologic Systems. American Water Resources Association, Bethesda, MD. TPS-94-3:1055-1063.

Sharmasarkar, S. and G.F. Vance. 1994. *Characterization of amino acid release and mobility of selenomethionine in surface coal mine environments* American Water Resources Association, Wyoming State Section, Laramie, Wyoming. Mining Hydrology section. Vol 94. 3 pp.

Drever, J.I. and G.F. Vance. 1994. Chapter 6 - *Role of Soil Organic Acids in Mineral Weathering Processes.* **In** E.D. Pittman and M.D. Lewan (eds.) Organic Acids in Geological Processes. Springer-Verlag, Berlin, Germany. pp. 138-161.

Sharmasarkar, S. and G.F. Vance. 1994. *Sequential fractionation and speciation of selenium in soils and mine spoils.* American Association for the Advancement of Science/Western Society of Soil Science Abstracts, p. 95.

Sharmasarkar, S., and G.F. Vance. 1994. *Characterization of amino acid release and mobility of selenomethionine in surface coal mine environments.* Proceedings, Mining Hydrology Division, American Water Resources Association, Wyoming State Section, Laramie, WY. 1 pp.

Steward, D.G., J.G. Luther, P.K. Carroll, L.E. Vicklund, G.F. Vance, and L.K. Spackman. 1994. *Standard operating procedures for the sampling selenium in Vegetation.* Research Publication MP-77. College of Agriculture, University of Wyoming, Laramie, WY. 6 pp.

Spackman, L.K., G.F. Vance, L.E. Vicklund, P.K. Carroll, D.G. Steward, and J.G. Luther. 1994. *Standard operating procedures for the sampling and analysis of selenium in soil and overburden/spoil material.* Research Publication MP-82. College of Agriculture, University of Wyoming, Laramie, WY. 13 pp.

Pierzynski, G.M., J.T. Sims, and G.F. Vance. 1994. Soils and Environmental Quality. Lewis Publishers Inc., Chelsea, MI. 313 pp.

Sharmasarkar, S., K.J. Reddy, and G.F. Vance. 1995. *Metal selenite solubility in aqueous phases.* Geochemistry Newsletter, GEOC-088.

Sharmasarkar, S. and G.F. Vance. 1995. *Dissolved selenium speciation in soils and mine spoil extracts.* American Association for the Advancement of Science/Western Society of Soil Science Abstracts, p. 58.

Vance, G.F., S. Sharmasarkar, K.J. Reddy, and L.K. Spackman. 1995. *The importance of solid and solution selenium speciation in mobility and plant uptake of selenium from Wyoming coal mine reclamation.* National American Society for Surface Mining and Reclamation Meetings Abstracts, p. 859.

Sharmasarkar, S., G.F. Vance, K.J. Reddy, R. Zhang, and L.K. Spackman. 1995. *Understanding selenium mobility by sorption and extraction processes in surface coal mine spoil.* **In** G.E. Schuman and G.F. Vance Decades Later: A Time for Reassessment. American Society for Surface Mining and Reclamation, Princeton, WV. Vol I:284-289.

Sharmasarkar, S. and G.F. Vance. 1995. *Release, retention and amino acid interaction of selenomethionine in reclaimed coal mine environments.* **In** G.E. Schuman and G.F. Vance Decades Later: A Time for Reassessment. American Society for Surface Mining and Reclamation, Princeton, WV. Vol I:290-299.

Vance, G.F., A.A. Fadlelmawla, R.B. See, and K.J. Reddy. 1995. *Role of natural organic solutes on the sorption of selenium by coal mine backfill-core samples from the Powder River Basin, Wyoming.* **In** G.E. Schuman and G.F. Vance Decades Later: A Time for Reassessment. American Society for Surface Mining and Reclamation, Princeton, WV. Vol I:246-257.

Reddy, K.J., Z. Zhang, and G.F. Vance. 1995. *Selenite and selenate determination in surface coal mine backfill ground water.* **In** G.E. Schuman and G.F. Vance Decades Later: A Time for Reassessment. American Society for Surface Mining and Reclamation, Princeton, WV. Vol I:237-245.

Sharmasarkar, S. and G.F. Vance. 1995. *Characterization and correlation of soil and plant selenium in some range and coal mine environments of Wyoming.* Communications in Soil Science and Plant Analysis 26:2577-2591.

Sharmasarkar, S. and G.F. Vance. 1995. *Fractional partitioning for assessing solid-phase speciation and geochemical transformations of soil selenium.* Soil Science 160:43-55.

Reddy, K.J., Z. Zhang, M.J. Blaylock, and G.F. Vance. 1995. *A method for detecting selenium speciation in ground water.* Environmental Science and Technology 29:1754-1759.

Schuman, G.E. and G.F. Vance (eds.). 1995. Decades Later: A Time for Reassesment. Proceedings of the 12th Annual Meeting of the American Society for Surface Mining and Reclamation. ASSMR, Princeton, WV. 867 pp.

Sharmasarkar, S., K.J. Reddy, and G.F. Vance. 1995. *Preliminary quantification of metal selenite solubility in aqueous solutions.* Chemical Geology (In press)

Sharmasarkar, S., and G.F. Vance. 1995. *Extraction and distribution of soil organic and inorganic selenium in coal mine environments of Wyoming, USA.* Environmental Geology (In press)

Vance, G.F. 1995. *Collaborative efforts to evaluate the importance of selenium in the Powder River Basin, Wyoming.* American Association for the Advancement of Science/Western Society of Soil Science Abstracts, p. 60.

Sharmasarkar, S., K.J. Reddy, and G.F. Vance. 1995. *Solubility and free e nergy of some selenate and seleinite minerals.* American Association for the Advancement of Science/Western Society of Soil Science Abstracts, p. 58.

Blaylock, M.J., T.A. Tawfic, and G.F. Vance. 1995. *Modeling selenite sorption in reclaimed coal mine soil materials.* Soil Science 159:43-48.

Sharmasarkar, S. and G.F. Vance. 1995. *Dissolution thermodynamics of some selenium solid phases.* Soil Science Society of America Journal (in review)

Sharmasarkar, S., and G.F. Vance. 1995. *Kinetics of selenomethionine disappearance from reclaimed coal mine soils of Wyoming, U.S.A.* Environmental Geology (In review)

Sharmasarkar, S., and G.F. Vance. 1995. *Selenite-Selenate Adsorption Modeling in Reclaimed Coal Mine Soils of Wyoming.* Journal of Environmental Quality. (In review)

Tawfic, T.A., M.J. Blaylock, G.F. Vance, and K.J. Reddy. 1995. *Selenite sorption and solution complexes in reclaimed mine soils.* Environmental Geology and Water Science (In review)

Sharmasarkar, S., and G.F. Vance. 1995. *Geochemical modeling to predict selenium dissolution and speciation in mine soils.* Soil Science. (In review)

Sharmasarkar, S., G.F. Vance and K.J. Reddy. 1995. *Geochemical Modeling for Assessing Aqueous Selenium Speciation.* The 1995 Rocky Mountain Groundwater Conference - Science and Policy: Who's Driving Groundwater Management, p. 51.

Vance, G.F. and S. Sharmasarkar. 1995. *Selenium sorption characteristics of surface coal mine soils of Wyoming.* Agronomy Abstracts, p. 354.

Sharmasarkar, S. and G.F. Vance. 1995. *A comparison of computer models used for assessing soil selenium speciation.* Agronomy Abstracts, p. 226.

Sharmasarkar, S., G.F. Vance, and F. Cassel-Sharmasarkar. 1995. *Spectroscopic and chromatographic analysis of selenium: a comparison and phase distribution study.* Communications in Soil Science and Plant Analysis. (In review)

Vance, G.F. (ed.). 1995. Selenium: Mining, Reclamation, and Environmental Impacts. Office of Surface Mining, Denver, CO. (in progress)

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

G.F. VANCE, R.N. PASCH, P.K. CARROLL, M.S. PAGE,
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Abandoned Coal Mine Land Research Program

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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 surface coal mining operations often has extractable Se levels greater than 0.1 mg/kg, a level that has been identified as "unsuitable" for reclamation purposes in Wyoming. Surface mining may also affect soil/backfill Se chemistry, which may influence soil-plant Se relationships as well. This project examined the relationship between soil/backfill and plant Se concentrations at two surface coal mines in the Powder River Basin, Wyoming.

Objectives

The main objective of this project was to evaluate soil/backfill and plant Se relationships. The specific objectives of this study were to determine:

1) What extraction procedures might be a better indicator of "soluble" (plant available) soil Se?
2) What forms of Se are present in seleniferous soil and backfill materials, and how are these related to plant uptake of Se?
3) What impacts do chemical, physical and biological soil characteristics have on plant uptake of Se?
4) How does Se content of native and reclaimed plant species vary during a growing season?
5) What effect does soil depth have on plant uptake of Se?
6) What Se suitability limits should be recommended for backfill materials to be topsoiled and revegetated?

Site Selection

Sites selected for this project included two active coal mines (Black Thunder (BT) and Coal Creek (CC)) located south of Gillette. There were many advantages in involving active coal mines, one of which is the extensive soil and backfill Se data base that already exists.

The relationship between soil/backfill Se levels (determined by four different extraction methods and total Se) and plant Se levels (three different lifeforms - grass, forb, and shrub, as well as a composite grass sample, which was a random collection of a mixture of grasses) was examined. The information obtained from this study can be used to better understand conditions that influence Se uptake by plants. This is an important issue to 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 Se extraction methods (hot water Se (HWSe), AB-DTPA Se (ABCSe), KH_2PO_4 Se (HPSe), and saturated paste Se (SPSe)) and the analysis of total soil Se (TSe) were evaluated to determine which method(s) is the most reproducible and accurate for determining the effects of Se uptake by plants (grass (G), forb (F), shrub(S), and composite grass (CG)). Plant Se was 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 conducted the soil and plant Se analyses. Selenium analysis of 1991, 1992, and 1993 vegetation and soil/backfill samples has been completed and a database created that contains 1809 rows (soil/backfill samples) and 24 columns (site, soil/backfill, and vegetation parameters).

Vegetation and Soil/Backfill Sampling

During the summer of 1991, 1992, and 1993, both vegetation and soil/backfill materials were sampled. Plant species inventories and percent plant cover at each site were tabulated during the summer sampling periods.

Statistical Analysis

A document containing all site, soil/backfill, and vegetation characteristics for 1991 through 1993 is available from the Office of Research, University of Wyoming; in addition, the complete data base was also compiled in a SAS format for statistical analysis on the University of Wyoming mainframe computer.

A listing of simple descriptive statistics was obtained on both cuttings of the 1993 vegetation, as well as the 1993 soil information and was summarized by Year (1993), Mine (BT or CC), Type (N or R), and Depth depending on Type (1, 2, 3, 4, 5, and 6 foot for N; 1, 2, and 3 foot for R). Correlation by Type and Depth and simple regression analyses by Type and Depth were conducted. T tests comparing 1991 and 1993 Native data were also conducted, as well as evaluating seasonal vegetation differences for each sampling period.

Results

Selenium (Se) values produced by hot water extraction and AB-DTPA extraction produced similar results. The highest soil Se values were produced by phosphate extraction with the lowest values produced by saturated paste analysis. Shrubs provided the highest Se content with forbs coming in a distant second. Variability as indicated by the standard deviation was generally high for all lifeform categories. Maximum values for grass and composite grass did not exceed 5 ppm.

Higher soil Se means were found in CCN and CCR sites than in BTN and BTR sites. Higher overall Se values were found in BTR than BTN. A generally wide range of pH and SO4 values were found in BTN. EC values ranged the most at CCN sites. Soil Se means were also generally higher throughout 1993 than 1991, regardless of sampling period.

Within the 1993 sampling periods, no significant differences were noted between the early and late sampling means with the exception of shrubs on reclaimed areas ($p = 0.008$).

Based on correlation analyses and summarized by Type, resulting "r" values generally exceeded 0.70 with the exception of all TSe values regardless of depth and all extractable levels at Depth 6 in Native and Depth 1 in Reclaimed. When summarized by Mine and Type, the highest "r" values were produced by : HWSe at Depth 3, Native; and SPSe and HPSe at Depths 2 and 3, Reclaimed. All "r" values were generally significant at the $p = 0.001$ level.

Significant R squared values produced during regression analyses of the averaged plant values (over sampling period) vs. soil values NOT averaged over the three holes/location ranged from less than 0.10 to approximately 0.90, depending upon the categories of summarization. The highest values were produced by SPSe and shrubs when summarized by Type and Depth regardless of Mine. Significant R squared values for averaged plant Se values vs. soil Se values averaged over the three holes/location were fewer and not as great as within those R squared values generated by soil values averaged per location.

Objective #1 - *What extraction procedures might be a better indicator of "soluble" (plant available) soil Se?*

Although this project evaluated several Se extraction methods to determine the relationship between soil/backfill and plant Se concentrations, we did not analyze the various Se species present in the extracted solutions. We

took the approach that if a particular extractant correlated to plant Se concentrations, then we could hypothesize which extractant would be a better predictor of plant-available Se. One consistent pattern noted in this study was that native site vegetation is more highly correlated to extractable Se concentrations than was reclaimed site vegetation; correlations at reclaimed sites were somewhat inconsistent, which may be due to such variables as time of reclamation or specific site conditions. Because of the variation in native vs. reclaimed site correlations, the above approach was inadequate for determining which extractant best measures soluble or plant available Se.

Objective #2 - *What forms of Se are present in seleniferous soil and backfill materials, and how are these related to plant uptake of Se?*

For purposes of this study, it was assumed that the two plant available forms of Se are selenate and selenite, and that HW and SP would extract primarily water soluble Se, whereas ABC and HP would extract both water soluble and complexed forms of Se. Typically, the level of Se extracted from different soil/backfill materials was of the order HPSe>ABCSe>HWSe>SPSe. This was expected since phosphate is capable of displacing Se on exchange sites, DTPA in ABC can compete with Se complexes, hot water dissolves some Se complexes, and saturated paste is an inert form of extraction (e.g., only soluble Se forms are detected).

Using a significance level of $p=0.05$ and a correlation coefficient of 0.9 or greater, several trends were found when comparing soil/backfill extractable and total Se concentrations for the 1991 and 1993 data. When separating by mine and type, a consistent relationship was found, which indicated HWSe, ABCSe, and HPSe were all statistically correlated. Including depth as a variable in these examples resulted in several significant correlations; however, the only logical combinations are between type, and mine and type because mine, type, and depth combinations are meaningless since depths for native sites are by 30 cm increments and depths for reclaimed are by approximately 60 cm increments. With native sites, significant correlations were found for HWSe, ABCSe, and HPSe for all depths except depth 1 (top 30 cm of soil). Overall, depth 3 of native sites was the most consistent with respect to correlations among soil Se extract results; soil-plant Se correlations were also more significant in depth 3 of the native sites. All reclaimed depths 2 and 3 had HWSe, ABCSe, and HPSe that were significantly correlated.

Objective #3 - *What impacts do chemical, physical and biological soil characteristics have on plant uptake of Se?*

Initially, the 1991 data were used to develop simple linear regression models for soil/backfill Se versus plant Se relationships. A majority of these simple regression models were nonsignificant. Nine measured independent variables were also used for regression analysis and modeling. These nine variables were anticipated to be driving variables in the project, but, in actuality, age of the reclaimed areas, which was not considered initially, was determined to be a major factor. Multiple regression analysis including cofactors indicated pH was an important parameter for native sites only. Finally, polynomial models were developed that sufficiently described the relationship between soil Se and plant uptake on native areas; however, the polynomial models for reclaimed areas were still poorly correlated.

From our studies, it was evident that backfill Se alone was not sufficient to describe backfill-plant Se relationships. Because of the younger age of reclaimed sites, e.g., the earliest revegetation data was 1979, backfill Se concentrations were probably influenced by changing chemical and physical conditions that are accompanying backfill as it equilibrates in its new environment. Therefore, one might predict that age of reclamation may be an important variable that should be included in correlation and regression analyses. In fact, we found that separating the reclaimed sites into two groups (1979-1985 and 1986-1991) increased the correlations between backfill-plant Se. As expected, extractable Se levels in the older reclaimed sites were more highly correlated than were the relationships between younger aged reclaimed sites and the associated plants.

Objective #4 - *How does Se content of native and reclaimed plant species vary during a growing season?*

Based on the original data, it was difficult to pull out individual plant species and include them in the overall regression analysis and modeling effort; however, it was noted that reclaimed plant Se values were generally higher at both mines than the corresponding native plant Se values. With the exception of individual accumulator species, most plant values did not reach the anticipated toxic level of 5 ppm level. Within the modeling process, type (i.e., native vs. reclaimed) was significant, indicating data from the two vegetation types could not be combined.

Instead of evaluating Se concentrations in individual plant species, plants were grouped into composite grass, grass, forb and shrub lifeforms in order to maximize our statistical evaluations. Due to a postponement in the awarding of project funds, during 1991 only one vegetation cutting (five different plant clippings) was completed on approximately 100 sites. In 1992 and 1993, two cuttings were completed. Statistical evaluation of lifeform Se levels in cuttings one and two of 1992 and 1993 indicated there were no significant differences in time of plant collection. This suggests the vegetation Se levels can be averaged over cuttings for each year. However, it should be noted that actual means were generally higher for the second cutting in 1993. Note that this finding is specific to the conditions of this study and should not be used as a general statement for plant Se levels throughout the Powder River Basin.

Objective #5 - *What effect does soil depth have on plant uptake of Se?*

Depth was an important independent variable in both reclaimed and native areas. Depth was found to be significant in the modeling process, which indicates native site data could not be combined over depth. Data for depths 2 and 3 of reclaimed sites (i.e., backfill material) were nonsignificant, thus suggesting the data could be combined. As indicated above, depth 3 of native sites and depths 2 and 3 of reclaimed sites provided the most significant relationships, which were used to evaluate soil/backfill and plant Se correlations.

Objective #6 - *What Se suitability limits should be recommended for backfill materials to be topsoiled and revegetated?*

Both type and depth were found to be significant, which implies that data can only be combined by mines. Therefore, relationships between type, depth, soil/backfill extractable Se, lifeform Se, and in some cases cofactors (pH, SO_4, and EC) variables were considered in developing simple and complex models for soil/backfill-plant Se correlations. Based on 1991, 1992, and 1993 information, each mine permit area within the Powder River Basin likely contains a unique set of characteristics which must be considered in developing a specific suitability standard. An overall standard that would apply to the entire Powder River Basin is difficult to determine at this point.

Summary and Conclusion

Soil and vegetation samples were collected in 1991, 1992, and 1993 from two active mine sites located in the Powder River Basin, Wyoming. Soil/backfill Se levels were determined by five methods: total Se and hot water, AB-DTPA, saturated paste, and dihydrogen phosphate extractable Se. Selenium concentrations in four lifeforms were also examined in this study and included: composite grass, grass, forb, and shrub. Statistical analyses were conducted by regressing Se levels determined in the four dependent vegetation lifeforms against the five independent soil Se variables. These regression analyses were conducted with soil depth, vegetation type (native versus reclaimed), and mine (Black Thunder and Coal Creek) as important subcategories. Several significant correlations were detemined from the soil/backfill Se vs. vegetation lifeform correlation analysis.

Since Se oxidation and the resulting increase in plant available may be an ongoing process in mined areas within

the Powder River Basin, it would be important to maintain longterm records of the current project. It may be that there is an initial flush of Se into the soil environment with a substantial drop after a certain period of time. In conjunction with this idea, other independent variables may need to be included in overall regression analysis. One of these factors includes age of the reclaimed area. Any discussion of reclaimed areas should be based on the relative age of the area.

Considerable progress has been made towards standardizing Se laboratory analysis, which should be of immense interest to government agencies, mining companies, and other related individuals or organizations. Maintenance of this consistency in Se analysis is important if trends within a particular region are to be identified.

Publications:

Vance, G.F., R.N. Pasch, D.L. Bonett, B.K. Schladweiler, P.K. Carroll and M.S. Page. 1992. Evaluation of various selenium extraction methods for correlating soil/backfill levels to plant concentrations. Agronomy Abstracts, p.246.

Schladweiler, B.K., G.F. Vance, R.N. Pasch, P.K. Carroll, M.S. Page, P. Wanek, D.L. Bonett, and S.E. Williams. 1993. Comparison of selenium uptake by vegetation on surface coal mine lands in Wyoming and seasonal variability of uptake. American Society of Surface Mining and Reclamation Vol. II:828-838.

Carroll, P.K., J.G. Luther, M.F. Raisbeck, L.K. Spackman, D.G. Steward, G.F. Vance and L.E. Vicklund. 1993. Selenium and Mining in the Powder River Basin, Wyoming. Billings Reclamation Symposium Proceedings Vol I:160-175.

Pasch, R.N. 1993. Producing an extractable selenium standard from spoil material for use as a control sample. Billings Reclamation Symposium Proceedings Vol I:131-138.

Schladweiler, B.K., R.N. Pasch, G.F. Vance, P.K. Carroll, M.S. Page, D.L. Bonett and S.E. Williams. 1993. Relationship between soil selenium concentrations and selenium uptake by vegetation on surface coal mine lands in Wyoming. Billings Reclamation Symposium Proceedings Vol. I:119-130.

Steward, D.G., J.G. Luther, P.K. Carroll, L.E. Vicklund, G.F. Vance, and L.K. Spackman. 1993. Standard operating procedures for sampling selenium in vegetation. College of Agriculture Miscellaneous Bulletin. MP77, University of Wyoming, Laramie, WY. 6 pp.

Spackman, L.K., L.E. Vicklund, G.F. Vance, P.K. Carroll, D.G. Steward, and J.G. Luther. 1994. Standard operating procedures for the sampling and analysis of selenium in soil and overburden/spoil material. College of Agriculture Miscellaneous Bulletin MP82, University of Wyoming, Laramie, WY. 13 pp.

Carroll, P.K., D.G. Steward, G.F. Vance, L.K. Spackman, L.E. Vicklund, and J.G. Luther. 1994. Selenium and mining in the Powder River Basin of Wyoming: Phase I vegetation results. Journal of Environmental Quality (in review)

Schladweiler, B.K., G.F. Vance, D.E. Legg, and C. Bilen. 1995. Regression analysis to predict selenium levels at two surface coal mines in the Powder River Basin, Wyoming. In: G.E. Schuman and G.F. Vance, Decades Later: A time for Reassessment. American Society for Surface Mining and Reclamation, Princeton, WV Vol I:246-257.

Presentations

Vance, G.F., R.N. Pasch, D.L. Bonett, B.K. Schladweiler, P.K. Carroll and M.S. Page. 1992. Evaluation of various selenium extraction methods for correlating soil/backfill levels to plant concentrations. Agronomy Abstracts, p.246.

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/Soil Science Society of American National Meeting, Cincinnati, Ohio.

Schladweiler, B.K., G.F. Vance, D.E. Legg, and C. Bilen. 1995. Regression analysis to predict selenium levels at two surface coal mines in the Powder River Basin, Wyoming. In: G.E. Schuman and G.F. Vance, Decades Later: A time for Reassessment. American Society for Surface Mining and Reclamation Meetings, Gillette, Wyoming.

HANDBOOK OF RECLAMATION TECHNIQUES FOR THE WESTERN UNITED STATES WITH FIELD GUIDE

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HANDBOOK OF WESTERN RECLAMATION TECHNIQUES
with Field Guide

PROGRESS REPORT
24 October 1995

The handbook will be presented as a compilation of techniques written by various experts in the mining industry. These techniques are separated into the following categories of reclamation: Topsoil, Hydrology, Topography, Wildlife Mitigation and Protection, Vegetation, Postmining Land Use, and Drilling.

Progress has continued in each of these areas. However, recent reorganization within many of the area mines in the last year has resulted in heavier workloads of mine personnel. As a result, progress has been slower than originally anticipated.

The section on Drilling is essentially finished, with only final editing remaining. The small Topography section is almost complete. Good progress has been made on the Vegetation section, with only a few techniques remaining before it will be complete. Work is proceeding at this time on the techniques for both the Postmining Land Use and Wildlife sections. Both the Topsoil and the Hydrology sections have several completed techniques and several yet to be done.

ESSENTIAL HYDROLOGIC FUNCTIONS OF PLAYAS IN THE POWDER RIVER BASIN OF NORTHEASTERN WYOMING

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Abandoned Coal Mine Land Research Program
Semi-Annual Report

Essential Hydrologic Functions of Playas in the Powder River Basin of Northeastern Wyoming

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INTRODUCTION

This research has as its primary purpose to characterize the unique hydrologic functions of playas within the Powder River Basin of northeastern Wyoming by defining the interrelationships which exist between soils, vegetation and water and how these interrelationships will be important in the restoration of playa areas once they are drastically disturbed by mining activities.

PROGRESS DURING THE REPORT PERIOD OF APRIL 15, 1994 - OCTOBER 31, 1995

The members of the playa project conducted an informational meeting for mining industry personnel on June 2, 1994, at the Campbell County Public Library. The mining company representatives participating in this meeting agreed to allow members of the playa project access to playas located within mine permit boundaries on an as-needed basis with prior notification.

At the present time, four mining companies are participating (physically and monetarily) in the project and allowing the project team access to playas on their properties for intensive study. They are: AMAX Coal West, Inc. (Belle Ayr Mine); Kerr McGee Corporation (Jacobs Ranch Mine); Atlantic Richfield Company (Black Thunder Mine) and Powder River Coal Company (North Antelope and Rochelle Mines).

Field investigations began in June 1994 and have continued to the present time. The field investigations were separated into two investigations. The first investigation consists of a reconnaissance level survey of over 60 playas within the Eastern Powder River Basin. The field investigations and sampling for these 60 plus playas were completed in early August 1995. The second investigation involves an intensive study of seven individual playas on the five different mine sites indicated above. The Belle Ayr site has three different playas that are being intensively studied. Installation of necessary wells, lysimeters and climatic equipment occurred on the Belle Ayr playas from October 1994 through May of 1995 and have been monitored since that time. Installation of wells, lysimeters and climatic equipment for the four other mine sites occurred in July and August of 1995 and are in the monitoring stage at the present time.

Soils

Reconnaissance level soils work for the 60 plus reconnaissance level playas began by conducting literature reviews during 1994. Soil sampling at depths from 0-6 and 6-12 inches in each of the vegetation zones identified for each of the 60 plus playas was completed in June 1995. These soil samples have been undergoing analysis for color,

organic content, texture, electrical conductivity, particle size distribution, some Atterberg limits and pH. Over 500 soil samples were collected. The analysis on these soil samples should be completed by the end of November 1995. The intensively studied playas were sampled during August and early September 1995. Soil samples were collected from each soil horizon identified in the field during trench excavations within each of the vegetation zones of the playas and at other points where it was determined necessary. Trench depths were generally between 5 and 8 feet for a length of 5 to 10 feet. These soil samples are presently being analyzed for the same things as indicated for the reconnaissance level playas plus soluble salts, reduced iron and some other metals. Analysis of the over 100 samples will be completed by Spring 1995. From the trench excavations, horizons that are present and their corresponding thicknesses were obtained, as well as, information on surface horizon textural class and dominate subsoil textural class.

The field investigations indicate that playa formation is most probably due to settlement as a result of physical changes in the coal beds (burning, etc) followed by surface runoff and weathering of parent material to form the fine sediment deposits in the low areas of the playas. The soil material available for deposition seems to vary within the entire study area from the analysis of the reconnaissance level playas giving rise to different groupings of the playas within the study area. The groupings are presently being statistically analyzed to see if differences really exist.

Vegetation

During the summer of 1994, field work and data collection for the reconnaissance level playas was initiated. Over 60 playas located in the Powder River Basin were surveyed for the reconnaissance level study. The playas surveyed were selected randomly from an initial population of approximately 450 playas and screened to determine geologic and hydrogeologic setting, accessibility, the existence of modifications, and the overall condition of the playas. Playas selected for the study were functioning in an unmodified hydrogeologic setting and appeared to be as close to a natural condition as possible.

The reconnaissance level playas were mapped by identifying the transition zones between different vegetation communities that occurred on each playa and identifying the boundary between upland areas and the playa basin. The transition zones and playa/upland boundaries were staked, and the vegetation communities defined by the three (or four in some instances) most dominant vegetation species that occurred within that zone. A topographic survey of the playas was done making sure to define the boundaries of each

of the vegetation zones.

Vegetation zone classification of the reconnaissance level playas was accomplished on the basis of major groups during July and August of 1995. The major vegetation groups were artemesia, bromus, agropyron, opuntia, rumex, thistle-like plants, taraxacanum, lupinus, plantago, mustards, legumes, poa, carex, bouteloua, miscellaneous forbs, bare ground and other. An estimate of the percentage of each group present in the zone was made along with the approximate total cover by grasses. No conclusions have been drawn at this point.

Vegetation zones were identified for each of the intensively studied playas in a manner similar to the reconnaissance level playas. Then detailed vegetation sampling was performed on each of the seven playas during the summer of 1995. The sampling pattern (radial lines from the center of the playa) used determines the types and amounts of vegetation present in each visibly distinct upland and playa vegetation zone on each of the seven playas. Data that was collected includes (but is not limited to) count and identification of species present, estimates of percent cover, production and community composition, and determination of slope and exposure of each of the lines used. Classification of some species is still ongoing from samples taken in the field. The field sampling generally indicated that the same vegetation types existed within the same vegetation zones identified for each of the playas studied.

Water

From survey data collected on each playa, the playa's length, width, and depth were evaluated and the shape plotted. From this data, the development of geomorphic properties of the playas was completed. A relationship between the playa size and configuration and the water quantity which could potentially be stored within the playa throughout the year was then produced.

A review of sample collection methods (e.g., sample volume required, bottle types, preservation methods, etc.) for use with the soil water samplers was done. We contacted the Wyoming Department of Environmental Quality/Land Quality Division (WDEQ/LQD) for guidance on the critical constituents for which to sample. It is very likely that the individual soil moisture samplers will not collect a volume sufficient to analyze for all the parameters listed in WDEQ/LQD's Guideline 8 - Hydrology, Appendix 1 - Water Quality Sampling. Lowell Spackman, Soil Scientist with WDEQ/LQD in Cheyenne, recommended that we sample for the major anions and cations (bicarbonate, carbonate, chloride, sulfide, iron, magnesium, potassium and sodium). If enough sample is available, testing for selenium and boron should also be conducted. This was done for the lysimeters on the

Belle Ayr mine site playas. The lysimeters were sampled at two different times during the wet spring of 1995. The volume of sample obtained from individual lysimeters indicated that only a small amount of water is moving downward toward the groundwater table even in times of high precipitation.

The data to be used for the water balance analysis is presently being reduced so that estimates of water movement within the playa areas can be made.

PRELIMINARY DATA INTERPRETATION

Preliminary data analyses and field observations indicate that playas are a result of settlement and depositional activity in the Powder River Basin. The soil types which exist within the playa seem to be directly related to the vegetation existing within each zone depending on the water available as a result of the size and shape of the playa. The correlations and issues associated with the interaction of water, soil and vegetation within a playa should come to light with the extensive data collected and now available for analysis. The analysis will start during this winter and will continue to the end of the project (September 1996).

STABILITY EVALUATION FOR DESIGNED EPHEMERAL CHANNELS IN WYOMING

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STABILITY EVALUATION FOR DESIGNED EPHEMERAL CHANNELS IN WYOMING

July 31, 1995

Final Executive Summary
For
Abandoned Coal Mine Lands
Research Program

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Western Water Consultants, Inc. has conducted its work and presents these findings in a manner consistent with the level of care and skill ordinarily exercised by members of the profession currently practicing in the same locality under similar conditions. No other representation and no warranty or guarantee is made or intended.

1.0 INTRODUCTION

Surface coal mining disrupts vast tracts of land. The mining process causes surface drainage networks to become blocked by spoils, rerouted, or unearthed; vegetation is destroyed, and soil properties are altered, leaving entire drainage basins vulnerable to erosion. An increasingly important aspect of mined land reclamation is the restoration of surface drainage systems disrupted by mining. Reclamation seeks to control erosion and reestablish channel stability through channel designs that efficiently route surface water and sediment.

One of the greatest challenges facing mine operators and regulators is the evaluation of channel designs. Design engineers and regulatory personnel involved in channel reclamation are challenged in their efforts for two main reasons: 1) large flows in semiarid environments capable of significant channel modification are infrequent, and 2) completed channel construction at many reclamation sites has occurred only within the recent past; most reclaimed channels at active and abandoned mines in Wyoming have been constructed within the last 4 to 10 years, a limited time of exposure to channel modifying events. Subsequently, field observations of reclaimed channel responses to large flows are difficult to obtain, yet channel designs must incorporate discharge information to ensure stability during high magnitude floods.

In Wyoming, decisions regarding long-term channel stability that continually confront those involved in mined land reclamation are usually based on short-term monitoring. Complete certification at Abandoned Mine Land (AML) sites is evaluated by 3 years of post-construction monitoring (time required to reestablish vegetation), which means the probability of a large magnitude flow occurring within the monitoring period is very small (i.e. the probability of a 50-year event occurring in a 3-year period is a approximately 6%).

In an effort to assess channel stability independently of short-term monitoring and annual reporting, Western Water Consultants, Inc. (WWC) developed a risk-based statistical technique to evaluate stability of ephemeral channel designs at reclaimed coal mines in southern Wyoming (WWC, 1993). The research described herein extends the application of the stability evaluation to areas of active mining in Wyoming, and expands the scope of investigation into the controls on ephemeral channel stability. Specific objectives for this Abandoned Coal Mined Land Research Program (ACMLRP) grant period are to:

1. collect and compile existing sources of data on premined channel and drainage basin characteristics;
2. test the applicability of regression relationships developed for southern Wyoming (WWC, 1993) to other geographic areas in Wyoming;
3. further investigate controls on channel slope using available channel sediment data; and
4. develop a regional analysis of channel design criteria and apply the developed stability evaluation to assess reclaimed channel designs (WWC, 1993).

1.1 Previous Findings

WWC (1993) presented a risk-based statistical technique to evaluate channel stability for ephemeral channels in semiarid environments. The premise of the original work (WWC, 1993), and adhered to again, is that reclaimed channel designs should be modeled after natural premined channels representative of the geographic area of interest. Natural alluvial channels have

evolved over long periods of time with channel cross section characteristics of width, depth, and slope reflecting prevailing climatic and hydrologic conditions. Information about the premined state of surrounding natural channels provides a crucial starting point for the restoration of drainage basins.

The stability evaluation presented by WWC (1993) uses three of the most important parameters in channel design (cross sectional flow area, flow velocity for the design event, and channel slope), and statistically measures how closely designed channels resemble adjacent natural, undisturbed channel conditions when subjected to the same design analyses. First, regression relations were developed for natural channels between drainage basin parameters (difficult and cost prohibitive to modify during reclamation) and the three channel hydraulic properties mentioned previously. The regression relations between drainage basin and hydraulic parameters were then used to develop a risk-based channel stability test based on the natural variation about mean predicted values exhibited by natural channels. One-tailed confidence intervals were computed to allow the determination of conservative channel design parameters.

While reclamation seeks to replace existing gradients and channel planforms, it is impossible to recreate the premined soil structure within channel bottoms once mining has ceased. Additionally, the newly created channels must be protected from excessive erosion during the first several years, until vegetation is established. The stability assessment derived by WWC (1993) reflects this need for conservatism in the design of reclaimed channels. One-tailed confidence intervals are used to quantify discrepancies between natural and reclaimed channel and allow designs to err on the side of caution. Thus designers and reviewers can determine, with a selected level of probability, whether a given channel has flow velocity and channel slope values less than or equal to the mean exhibited values of undisturbed channels with similar drainage basin parameters. Likewise, flow area values can be compared to determine if they are greater than or equal to expected flow area values of similar natural channels. The method is a risk-based approach because it allows user flexibility in choosing an acceptable level of error, or alpha (α). Alpha, typically selected at either 0.1 or 0.01, indicates the probability or percentage of times (90% or 99% for $\alpha=0.1$ and 0.01, respectively) a reclaimed channel would have hydraulic characteristics conservatively designed compared with natural channels.

WWC concluded that stability tests, if incorporated into regulatory decisions, can quantify differences between reclaimed channel characteristics and natural premined areas. A standardized, quantitative approach to channel design will help maintain consistency within a process that has historically been subjective and reviewer-specific.

1.2 Study Sites

The main coal-bearing regions of Wyoming were selected for study to include areas of Wyoming where there is active mining of coal and channel restoration, and areas that receive a majority of the regulatory attention and interest. Our expanded data set includes 82 drainage basins and stream channel cross sections from the main coal-bearing regions of Wyoming, including: 1) Rock Springs; 2) Hanna; 3) Kemmerer; 4) Powder River Basin; and 5) Glenrock (Figure 1-1). Information on premined channel characteristics was collected from existing sources.

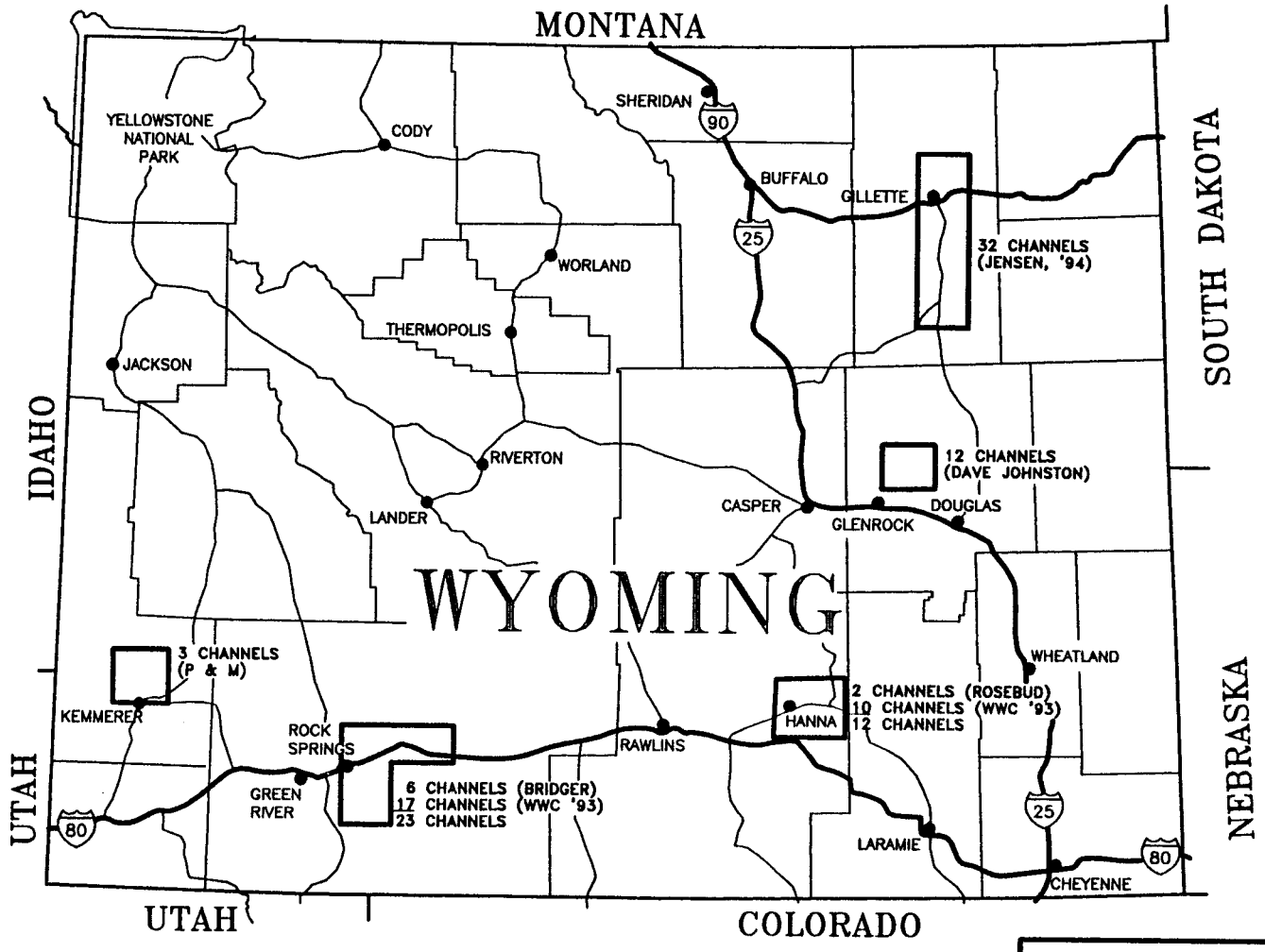

FIGURE 1–1

LOCATION OF STUDY AREAS

ACMLRP

Western Water Consultants, Inc.

K:\94-037L\CADD\WY-MAP 07/31/95 08:40

2.0 METHODS

Data were collected on natural drainage basins and stream channels from four sources: 1) WWC (1993), 2) Jensen (1994) and Anderson (1994), unpublished Master's theses, 3) mine permit applications, especially Appendix D-6 on mine hydrology and geomorphology at theWyoming Department of Environmental Quality/Land Quality Division (WDEQ/LQD), and 4) bed sediment data for Powder River Basin streams.

The WWC (1993) information consists of a report submitted to the University of Wyoming, Office of Research under an earlier ACMLRP project entitled 'Long-term Stability of Designed Ephemeral Channels at Reclaimed Coal Mines, Wyoming.' WWC surveyed 27 unmined channels in the area of Rock Springs and Hanna areas. The Jensen (1994) and Anderson (1994) data consist of 31 surveyed undisturbed channels studied in the Powder River coal field. Mine permit application information consists of premined channel and basin data supplied to WDEQ/LQD by mine operators. Finally, the bed sediment data were collected by Jensen (1994) as part of his Master's thesis, and sieved by WWC for grain size distribution.

Once the initial channel information was obtained from the various sources, additional work was completed to derive the suite of required parameters to generate a consistent database. Topographic maps (1:24,000 scale) were obtained and basins were outlined to digitize basin area, stream length, and elevation difference from divide to basin mouth.

2.1 Flood Discharge Estimates

A computerized version of the National Oceanic and Atmospheric Administration's (NOAA) Precipitation Atlas called PREFRE was used to determine precipitation quantities for each basin. Next, rainfall-runoff simulation based on the Soil Conservation Service's (SCS) Triangular Hydrograph Method of calculating flow discharge was used to estimate flood discharges for various return intervals (10-, and 100-year events). Based on basin parameters and following a review of available soil, hydrologic soil group, curve number (CN), and minimum infiltration rate data, flood discharges using rainfall-runoff simulation were derived for each basin based on 1, 6, and 24 hour precipitation events. Only the maximum of these discharges for each return period were used for each basin.

While SCS rainfall-runoff simulation techniques are commonly used among mine reclamation specialists, hydrologists, and design engineers, a second technique of deriving channel flow magnitudes from basin characteristics is available in the literature and is also frequently used. Lowham (1988) conducted a regional analysis of streamflows in Wyoming using basin parameters and gage records to estimate discharge on ungaged streams. Flood discharge estimates obtained from Lowham's Regional Analysis are frequently higher than those obtained through rainfall-runoff simulation methods. Discharge estimates using Regional Analysis were also computed for each basin, so that reclaimed channel designs based on floods discharge estimates derived by this method might also be evaluated,

2.2 Hydraulic Parameter Computation

Channel hydraulic parameters were computed for each basin using the HEC-2 model. This open channel hydraulic model is commonly used in reclamation design and was employed to determine cross sectional flow area, topwidth, depth, and flow velocity for each flood

discharge assuming normal flow conditions. Manning's 'n' values characteristic of small ephemeral streams in Wyoming were determined (0.035 and 0.065 for the channel and overbank areas, respectively). At Glenrock, Manning's 'n' values were calibrated based on gaging information provided in the Dave Johnston mine permit application.

2.3 Channel Bed Sediment Analysis

A data set on channel bed sediments was developed by sieving 21 samples of channel bed sediment collected for Jensen's (1994) Master's thesis on Powder River Basin drainages. The samples were dried, split, and run through a nest of sieves to determine the distribution of sediment particles by size and general classification of percent sand and silt/clay by weight.

2.4 Statistical Analysis

During reclaimed channel design, hydraulic properties of the channel (cross sectional flow area, channel slope, depth, topwidth) are manipulated by reclamation planners until an acceptable reclaimed design is achieved. Drainage basin area and mean basin slope, characteristics of the drainage basin, are difficult and cost prohibitive to freely modify during engineering design and construction. However, these rather fixed basin parameters are relatively easy to measure from topographic maps, and provide useful information on geomorphic properties of drainage basins. A major emphasis of this research project was to develop relationships from natural, undisturbed streams between basin parameters and channel hydraulic parameters that are most important to designing channels and influencing ephemeral channel stability. In this way, the relationship between drainage basin and channel hydraulic parameters used in reclaimed channels mirrors those found in natural premined channels, and deviations are statistically quantifiable.

2.4.1 Regression Analysis

Regression analysis identifies the relationship between two (or more) variables such that information about one variable allows knowledge or prediction of the other. Regression analysis was conducted by regressing the independent basin variables of drainage basin area (DA), mean drainage basin slope (BS), and Area Gradient Index (AGI, defined as the product of drainage area and mean basin slope (WWC, 1993)) against dependent channel variables; cross sectional flow area, velocity, topwidth, depth, and channel slope.

Once the initial regression analyses were completed, bed sediment information, where available, was included to strengthen relations by adding additional information relating to channel stability.

Differences between the regression equations for each area were also investigated. Statistical tests described in Ott (1984) and based on the probability that derived regression coefficients for variables representing geographical differences between study areas differ from zero were conducted to test the significance of differences among study sites. F-tests based on the drop in mean square error between "full" (including independent parameters related to geography) and "reduced" (not including geographical variables) regression models were also used to confirm findings in certain situations (Johnson, 1984; Devore, 1982; Ott, 1984).

2.4.2 Confidence Intervals

A method for evaluating the uncertainty in the regression relations for premined channels, or the variance about a mean predicted value, involves the development of confidence intervals. A confidence interval is typically defined by an upper and lower limit having a known probability (or confidence level) of containing the true parameter value of an estimated parameter. For example, to say that the 95% confidence interval for the natural channel slope of basins with a drainage area of 1.0 square miles is between 0.018 and 0.025 feet per feet means that the assertion "natural basins with a 1.0 square mile drainage area have a mean channel slope between 0.018 and 0.025" will be true 95% of the time. Confidence bands were computed for the regression relations derived between drainage basin and channel hydraulic parameters to develop a risk-based channel stability test.

To account for the need for conservative reclaimed channel designs, due to uncertainties concerning the reclamation of pre-existing soil structures, one-tailed confidence intervals are used to define regions of acceptable channel hydraulic values. This allows designers and reviewers to make assertions like "the reclaimed channel slope is equal to, or shallower than, the mean slope which would be exhibited from natural basins of the same size" with a known degree of certainty. One-tailed confidence intervals at 90% and 99% probability levels were calculated for the more critical hydraulic parameters of channel slope, flow area, and flow velocity. For the less significant parameters of flow depth and flow topwidth, only the 90% confidence intervals about the mean prediction line were calculated. These results can be taken as guides to derive suitable channel dimensions once the more important parameters of channel slope, flow velocity and flow area have been determined. The method is a risk-based approach to evaluating channel stability because it allows user flexibility in choosing an acceptable level of error, or alpha (α) which can be adjusted according to the seriousness of the effects of a reclamation failure.

3.0 RESULTS

Table 3-1 presents natural basin data, computed flood discharge and computed hydraulic data for the Rock Springs study area. Similar computations and data summaries were completed for each of the study areas and are presented in the Final Technical Report.

3.4 Regression Analysis and Confidence Intervals

Regression analysis was performed on the study area data to assess the use of basin parameters (drainage area and AGI) to predict measured channel slope and computed 10 and 100-year hydraulic parameters (flow area, velocity, depth, and topwidth).

The results of the regression analysis for the Rock Springs and Hanna study areas are presented in Table 3-2. Table 3-3 presents the regression results for the Powder River Basin and Glenrock areas. As only three basins were available for study in existing permits in the Kemmerer area, insufficient data were available to develop regression relationships. Figures presenting these results graphically, including one- and two-tailed confidence bands as described in the Methods section, are included in Appendix A through D of the Final Technical Report.

In general, results show that both the rainfall-runoff and regional analyses show very good correlation. Of the more important design parameters, (channel slope, flow area, and flow velocity) flow area consistently shows the highest degree of correlation with drainage basin

TABLE 3-1. ROCK SPRINGS AREA DATA

BASIN PARAMETERS

DRAINAGE		Drainage Area (mi2)	Mean Basin Slope SB (ft/mi)	AGI (1) (Acres)	Rainfall Runoff Analysis: Curve Number	Rainfall Runoff Analysis: Minimum Infiltration Rate (in/hr)	Regional Analysis (2): Avg. Ann. Precip. Pr (in)	Regional Analysis (2): Geographical Factor Gf
RAINBOW/	3	0.010	733.33	0.89	93	0.15	9	0.8
COLONY	4	0.073	571.43	5.08			9	0.8
	5	0.033	700.00	2.80			9	0.8
	6	0.122	441.18	8.52			9	0.8
	7	0.083	575.88	7.62			9	0.8
	7a	0.008	578.95	0.56			9	0.8
	7'	0.026	769.23	2.42			9	0.8
	12a	0.005	692.31	0.42			9	0.8
	12b	0.001	777.78	0.09			9	0.8
	13	0.022	676.47	1.90			9	0.8
	15	0.073	417.91	3.70			9	0.8
	16	0.089	448.28	4.78			9	0.8
	16a	0.013	1411.76	2.22			9	0.8
	24	0.031	982.96	3.62			9	0.8
	25	0.014	500.00	0.85			9	0.8
	28	0.020	479.26	1.16			9	0.8
	31	0.005	763.16	0.46			9	0.8
BRIDGER	9-5MW	3.100	199.63	75.01			9	0.8
	LTD	37.300	84.04	269.56			9	0.8
	MDW	29.300	54.73	194.39			9	0.8
	NW	17.400	94.09	177.35			9	0.8
	TDT	8.100	100.78	98.94			9	0.8
	UDT	12.100	88.05	129.14			9	0.8

(1) AGI is the product of Drainage Area and mean Basin Slope
(2) Parameters Pr and Gf after Lowham (1988)

FLOOD DISCHARGES

DRAINAGE		Rainfall Runoff Analysis: Max 10-Year Discharge (cfs)	Rainfall Runoff Analysis: Max 100-Year Discharge (cfs)	Regional Analysis: 10-Year Discharge (cfs)	Regional Analysis: 100-Year Discharge (cfs)	Ratio of Computed Discharges: 10-Year Regional/ Rainfall-Runoff	Ratio of Computed Discharges: 100-Year Regional/ Rainfall-Runoff
RAINBOW/	3	1.20	4.90	4.4	16.3	3.63	3.33
COLONY	4	6.20	30.50	16.8	57.1	2.71	1.87
	5	3.20	14.90	10.0	36.2	3.12	2.36
	6	8.00	43.30	23.3	77.1	2.91	1.78
	7	8.50	40.40	19.6	65.9	2.31	1.63
	7a	0.90	3.80	3.7	14.0	4.12	3.70
	7'	2.70	12.10	8.5	30.3	3.15	2.51
	12a	0.60	2.50	2.6	10.2	4.37	4.07
	12b	0.10	0.50	0.7	3.2	7.44	6.34
	13	2.10	9.70	7.6	27.3	3.61	2.81
	15	4.80	25.90	16.8	57.1	3.50	2.20
	16	6.20	33.00	18.9	63.8	3.05	1.93
	16a	1.50	6.50	5.2	19.4	3.50	2.99
	24	3.30	14.50	9.6	33.9	2.90	2.34
	25	1.50	6.50	5.5	20.4	3.69	3.13
	28	2.00	9.10	7.1	25.7	3.56	2.82
	31	0.80	2.40	2.6	10.2	4.37	4.24
BRIDGER	9-5MW	173.80	474.20	146.6	422.5	0.84	0.89
	LTD	913.10	2640.20	475.7	1266.8	0.52	0.48
	MDW	545.30	1630.10	427.4	1147.2	0.78	0.70
	NW	523.40	1520.80	337.3	921.2	0.64	0.61
	TDT	300.70	880.70	235.0	658.8	0.78	0.77
	UDT	388.30	1104.20	284.7	787.1	0.73	0.71

HYDRAULIC DATA

DRAINAGE		Channel Slope	Rainfall Runoff Analysis: Max 10-Year Event FLOW AREA	VEL	DEPTH	TOPWID	Max 100-Year Event FLOW AREA	VEL	DEPTH	TOPWID	Regional Analysis: 10-Year Event FLOW AREA	VEL	DEPTH	TOPWID	100-Year Event FLOW AREA	VEL	DEPTH	TOPWID
RAINBOW/	3	0.072	0.61	2.37	0.30	2.90	2.06	2.39	0.62	11.66	1.82	2.42	0.60	10.06	5.21	3.13	0.82	18.20
COLONY	4	0.077	1.72	3.60	0.63	4.30	5.79	5.27	1.35	6.82	3.69	4.55	1.02	5.87	9.63	5.93	1.95	8.90
	5	0.134	0.92	3.49	0.63	2.43	2.92	5.10	1.28	3.67	2.16	4.64	1.06	3.26	5.70	6.18	1.93	4.87
	6	0.038	2.03	3.94	0.63	4.22	7.23	5.99	1.58	6.57	4.51	5.17	1.14	5.47	11.37	6.78	2.16	8.08
	7	0.051	2.21	3.85	0.66	4.76	6.53	6.19	1.49	5.56	3.92	5.00	1.00	5.16	9.29	7.09	1.97	5.97
	7a	0.070	0.39	2.28	0.27	2.40	1.10	3.45	0.53	2.99	1.06	3.42	0.52	2.97	2.86	4.89	1.03	4.02
	7'	0.046	0.83	3.24	0.63	2.63	2.69	4.50	1.15	4.38	2.04	4.16	1.00	3.90	5.21	5.81	1.68	5.16
	12a	0.128	0.26	2.29	0.21	1.88	0.77	3.24	0.46	2.40	0.80	3.26	0.47	2.44	2.25	4.54	0.96	3.49
	12b	0.131	0.07	1.47	0.11	0.98	0.23	2.17	0.24	1.59	0.30	2.34	0.28	1.79	1.30	2.46	0.61	7.01
	13	0.087	0.68	3.09	0.47	2.33	2.14	4.53	0.98	3.40	1.77	4.29	0.87	3.16	4.67	5.86	1.61	4.49
	15	0.049	1.36	3.52	0.53	3.64	4.88	5.31	1.26	5.71	3.66	4.74	1.03	5.09	10.15	5.63	2.00	10.41
	16	0.026	1.91	3.24	0.94	5.04	6.75	4.89	1.73	9.18	3.99	4.73	1.32	5.76	11.72	5.43	2.15	13.74
	16a	0.058	0.57	2.61	0.36	2.83	1.81	3.59	0.69	4.55	1.53	3.40	0.63	4.31	4.25	4.56	1.14	6.74
	24	0.049	1.08	3.05	0.51	3.88	3.18	4.56	0.98	4.92	2.36	4.09	0.80	4.58	5.90	5.74	1.48	5.89
	25	0.100	0.53	2.84	0.33	2.15	1.54	4.21	0.74	2.84	1.37	4.01	0.67	2.73	3.67	5.58	1.37	3.89
	28	0.078	0.93	2.16	0.20	6.29	2.52	3.62	0.46	6.58	2.16	3.28	0.39	6.52	5.20	4.94	0.84	7.03
	31	0.075	0.27	2.24	0.30	1.77	0.78	3.09	0.53	2.61	0.81	3.20	0.55	2.65	2.34	4.36	1.01	4.02
BRIDGER	9-5MW	0.017	22.94	7.81	2.93	13.57	53.02	10.48	4.78	19.36	20.44	7.28	2.75	12.97	47.96	10.14	4.49	19.52
	LTD	0.004	179.91	5.12	3.35	73.84	467.00	7.37	5.55	221.99	118.33	4.02	2.42	63.43	226.79	5.79	3.94	85.51
	MDW	0.010	59.14	9.85	4.64	17.78	189.21	12.53	8.60	64.84	60.47	8.75	4.15	17.20	100.73	12.82	6.68	27.34
	NW	0.009	60.27	9.51	4.65	20.42	276.29	11.08	7.89	124.16	44.54	8.00	3.74	15.91	126.75	10.51	6.44	66.83
	TDT	0.010	46.23	6.51	3.57	22.89	100.34	8.58	5.52	32.62	38.46	6.11	3.22	21.14	82.38	7.97	4.95	28.74
	UDT	0.010	67.93	5.72	2.80	42.92	134.55	8.21	4.06	48.22	56.80	5.10	2.31	41.88	107.23	7.34	3.48	46.12

TABLE 3-2. REGRESSION RESULTS FOR ROCK SPRINGS AND HANNA AREAS

where, DA = Drainage Area (mi.^{2})
AGI = Area Gradient Index (acres)

and $Y = Bo * (X)^{B1}$

ROCK SPRINGS AREA

Dependent Parameter, Y	Independent Parameter, X	B0	B1	Correlation Coefficient, r
Channel Slope	DA	0.021	-0.302	0.95
	AGI	0.474	0.943	0.90
RAINFALL-RUNOFF ANALYSIS				
10-Year Flow Area	DA	10.138	0.665	0.996
	AGI	0.478	0.936	0.99
10-Year Flow Velocity	DA	4.957	0.147	0.94
	AGI	2.557	0.205	0.95
10-Year Flow Depth	DA	1.483	0.339	0.97
	AGI	0.323	0.471	0.98
10-Year Flow Topwidth	DA	10.875	0.340	0.96
	AGI	2.396	0.463	0.94
100-Year Flow Area	DA	29.725	0.668	0.996
	AGI	1.507	0.916	0.99
100-Year Flow Velocity	DA	6.895	0.139	0.92
	AGI	3.669	0.194	0.94
100-Year Flow Depth	DA	2.742	0.312	0.97
	AGI	0.676	0.433	0.98
100-Year Flow Topwidth	DA	21.197	0.400	0.94
	AGI	3.603	0.541	0.92
REGIONAL ANALYSIS				
10-Year Flow Area	DA	13.082	0.510	0.99
	AGI	1.341	0.700	0.99
10-Year Flow Velocity	DA	5.257	0.085	0.80
	AGI	3.568	0.121	0.82
10-Year Flow Depth	DA	1.731	0.227	0.95
	AGI	0.624	0.316	0.96
10-Year Flow Topwidth	DA	11.706	0.270	0.91
	AGI	3.524	0.367	0.90
100-Year Flow Area	DA	30.946	0.469	0.99
	AGI	3.805	0.643	0.98
100-Year Flow Velocity	DA	7.186	0.093	0.81
	AGI	4.702	0.132	0.83
100-Year Flow Depth	DA	2.954	0.205	0.95
	AGI	1.177	0.285	0.95
100-Year Flow Topwidth	DA	18.523	0.266	0.88
	AGI	5.723	0.356	0.85

HANNA AREA

Dependent Parameter, Y	Independent Parameter, X	B0	B1	Correlation Coefficient, r
Channel Slope	DA	0.019	-0.355	0.78
	AGI	1.032	1.186	0.73
RAINFALL-RUNOFF ANALYSIS				
10-Year Flow Area	DA	13.981	0.598	0.98
	AGI	1.137	0.739	0.99
10-Year Flow Velocity	DA	3.907	0.056	0.65
	AGI	3.066	0.076	0.72
10-Year Flow Depth	DA	1.608	0.287	0.95
	AGI	0.487	0.348	0.94
10-Year Flow Topwidth	DA	19.113	0.379	0.92
	AGI	3.899	0.470	0.93
100-Year Flow Area	DA	44.071	0.647	0.98
	AGI	2.946	0.793	0.99
100-Year Flow Velocity	DA	6.276	0.010	0.69
	AGI	4.139	0.122	0.89
100-Year Flow Depth	DA	2.774	0.279	0.95
	AGI	0.867	0.338	0.94
100-Year Flow Topwidth	DA	31.615	0.414	0.93
	AGI	5.576	0.511	0.94
REGIONAL ANALYSIS				
10-Year Flow Area	DA	29.201	0.573	0.99
	AGI	2.696	0.689	0.98
10-Year Flow Velocity	DA	5.304	0.067	0.81
	AGI	4.025	0.079	0.78
10-Year Flow Depth	DA	2.233	0.212	0.94
	AGI	0.825	0.282	0.90
10-Year Flow Topwidth	DA	27.023	0.367	0.93
	AGI	5.377	0.472	0.93
100-Year Flow Area	DA	66.646	0.534	0.99
	AGI	1.309	0.641	0.97
100-Year Flow Velocity	DA	7.513	0.075	0.87
	AGI	5.510	0.087	0.82
100-Year Flow Depth	DA	3.393	0.195	0.92
	AGI	1.519	0.227	0.87
100-Year Flow Topwidth	DA	37.617	0.376	0.92
	AGI	7.768	0.459	0.91

TABLE 3-3. REGRESSION RESULTS FOR POWDER RIVER BASIN AND GLENROCK AREAS

where, DA = Drainage Area (mi.^{2})
AGI = Area Gradient Index (acres)

and $Y = Bo * (X)^{B1}$

POWDER RIVER BASIN AREA

Dependent Parameter, Y	Independent Parameter, X	B0	B1	Correlation Coefficient, r
Channel Slope	DA	0.011	-0.382	0.61
	AGI	0.036	-0.415	0.55
RAINFALL-RUNOFF ANALYSIS				
10-Year Flow Area	DA	24.437	0.556	0.91
	AGI	3.124	0.718	0.91
10-Year Flow Velocity	DA	4.138	0.148	0.49
	AGI	2.484	0.173	0.45
10-Year Flow Depth	DA	1.741	0.448	0.79
	AGI	0.385	0.508	0.69
10-Year Flow Topwidth	DA	24.683	0.084	0.16
	AGI	15.535	0.181	0.27
100-Year Flow Area	DA	65.958	0.550	0.94
	AGI	8.722	0.705	0.94
100-Year Flow Velocity	DA	5.902	0.138	0.58
	AGI	3.605	0.170	0.56
100-Year Flow Depth	DA	3.105	0.449	0.82
	AGI	0.683	0.510	0.72
100-Year Flow Topwidth	DA	37.057	0.099	0.23
	AGI	22.848	0.184	0.34
REGIONAL ANALYSIS				
10-Year Flow Area	DA	44.291	0.491	0.92
	AGI	7.326	0.626	0.91
10-Year Flow Velocity	DA	5.216	0.127	0.54
	AGI	3.366	0.149	0.49
10-Year Flow Depth	DA	2.466	0.415	0.79
	AGI	0.620	0.462	0.68
10-Year Flow Topwidth	DA	30.733	0.061	0.14
	AGI	21.510	0.142	0.25
100-Year Flow Area	DA	110.800	0.487	0.94
	AGI	18.516	0.623	0.93
100-Year Flow Velocity	DA	6.952	0.106	0.56
	AGI	4.820	0.124	0.51
100-Year Flow Depth	DA	4.195	0.405	0.81
	AGI	1.082	0.454	0.71
100-Year Flow Topwidth	DA	47.329	0.099	0.23
	AGI	26.698	0.192	0.35

GLENROCK AREA

Dependent Parameter, Y	Independent Parameter, X	B0	B1	Correlation Coefficient, r
Channel Slope	DA	0.017	-0.318	0.91
	AGI	0.065	-0.426	0.90
RAINFALL-RUNOFF ANALYSIS				
10-Year Flow Area	DA	51.172	0.564	0.84
	AGI	4.778	0.763	0.85
10-Year Flow Velocity	DA	4.345	0.158	0.46
	AGI	2.326	0.201	0.43
10-Year Flow Depth	DA	2.482	0.219	0.68
	AGI	1.069	0.272	0.62
10-Year Flow Topwidth	DA	40.078	0.305	0.67
	AGI	10.759	0.423	0.66
100-Year Flow Area	DA	112.344	0.611	0.67
	AGI	8.834	0.819	0.66
100-Year Flow Velocity	DA	5.710	0.141	0.45
	AGI	3.229	0.184	0.43
100-Year Flow Depth	DA	3.681	0.246	0.79
	AGI	1.410	0.309	0.73
100-Year Flow Topwidth	DA	67.174	0.427	0.75
	AGI	11.509	0.566	0.74
REGIONAL ANALYSIS				
10-Year Flow Area	DA	48.124	0.467	0.79
	AGI	6.818	0.629	0.79
10-Year Flow Velocity	DA	4.240	0.117	0.35
	AGI	2.707	0.145	0.32
10-Year Flow Depth	DA	2.389	0.167	0.57
	AGI	1.288	0.199	0.50
10-Year Flow Topwidth	DA	39.148	0.273	0.62
	AGI	12.105	0.378	0.63
100-Year Flow Area	DA	122.276	0.485	0.79
	AGI	16.574	0.644	0.77
100-Year Flow Velocity	DA	5.864	0.089	0.31
	AGI	4.121	0.114	0.29
100-Year Flow Depth	DA	3.823	0.174	0.68
	AGI	1.975	0.213	0.61
100-Year Flow Topwidth	DA	69.690	0.383	0.69
	AGI	14.467	0.506	0.66

parameters. Nevertheless, good results were also obtained for channel slope and flow velocity as well as the channel shape variables of flow depth and topwidth.

In addition to the standard regression analyses performed to assess the use of basin parameters to predict measured channel slope and computed hydraulic parameters, channel bed sediment data were available for 19 of the 31 basins within the Powder River Basin area. Returning to Table 3-2, regressions for the Powder River Basin show good results for the determination of flow area and flow depth. In contrast with results from the other study areas, regression coefficients are less strong for channel slope and flow velocity. Very poor regressions were found for the determination of flow topwidth. A portion of the poor relationships encountered may be explained by the fact that this data set encompasses, by far, the largest geographical area of the data sets studied.

The inherent assumption in the regression relationships thus far derived is that the unaccounted for sources of variation within each data set are minimized by selecting basins within a relatively close geographical area. This assumption breaks down when large geographical areas are used.

To this end, methods of dividing the Powder River Basin data set into distinct areas were investigated. The most recent work related to this effect is provided in Jensen (1994) and Anderson (1994). In these related studies, the morphology of drainage basins (shape and size) were found to be influenced primarily by the lithologic unit into which the channels are cut. To discuss differences in near surface geology of Powder River Basin channels, a classification of A, B, and C was developed (termed "stratum" by Jensen (1994) and Anderson (1994)). "Stratum A" was applied to channels dominantly within the Fort Union formation with a broad range of basin sizes (0.48-7.43 square miles), "Stratum B" indicates Wasatch and Fort Union formation combined, with smaller basin areas (less than 2.6 square miles), and "Stratum C" was assigned to large basins solely in the Wasatch formation (2.58 to 8.65 square miles).

The "stratum" classification system was tested to see if stronger regression relationships could be derived on the basis of drainage basin lithology. The data set contains nine Strata A basins, nine Strata B basins, and 13 Strata C basins. Only the Strata C basins were significantly different from the rest of the Powder River Basin data. Regression results obtained by splitting the data set along Strata A/B and Strata C division lines show improved correlation coefficients for the Strata A/B data set, but reduced correlation coefficients for the Strata C.

An analysis of the bed sediment results according to basin strata are summarized below.

	n	Mean D_{50} (mm)	Std. Dev.	Mean % passing #200 sieve	Std. Dev.
Strata A	7	2.60	2.59	17%	25%
Strata B	5	0.19	0.13	31%	22%
Strata C	7	0.08	0.03	55%	14%

These results show the differences between strata found by Anderson (1995) and Jensen (1995), are apparent in the bed sediment data. The Strata A basins have predominantly larger sized bed sediment material, the Strata B consists of a fairly consistent band of mid-sized bed sediments and the Strata C basins contain, quite uniformly, the smallest bed sediment materials.

This may help to explain the previous findings, that regression correlation coefficients significantly improved with the removal of the Strata C basins and that poorer relationships

existed amongst the remaining Strata C basins when considered alone. As the amount of silt and clay material increases in soils, cohesive forces which are difficult to characterize, become more significant.

To test this theory, the 19 basins with bed sediment data were divided according to those with 20% of material passing the #200 sieve. Correlation coefficients above 0.97 were found for channel slope, flow area and flow depth. Correlation coefficients for flow velocity and topwidth, however, showed marked declines.

Another approach to include bed sediment in the predictive process is to include a bed sediment parameter as an independent variable in a multiple regression. The resulting correlation coefficient values show the strength of the derived relationships improved with the addition of D_{50} data and statistical test confirmed the significance of this parameter in predicting channel slope, flow area and flow depth. However, good relationships ($R^2 < 0.50$) were not found for flow velocity or flow topwidth.

These results, taken together, seem to support channel sediment as an important parameter in the formation of channels in the Powder River Basin; this probably holds true of all of the study areas. However, differences in channel sediments in smaller geographical areas, typical of the other study areas examined, were insufficient to detract from the strength of the resulting correlation coefficients.

3.5 Geographic Transferability of Regression Results

In WWC's 1993 work it was found that there were no significant differences between natural channel data for the Rock Springs and Hanna areas and, therefore, the two sites could be considered one population. Analyses were performed to test whether or not regression equations are applicable to larger areas.

Checks of the significance of geographical factors for the remaining hydraulic parameters revealed a variety of results which, in general, showed the existence of differences between study sites, especially where very strong local regression relationships were found.

In general, these results indicate that when available, data from nearby channels is preferred. This result was not completely unexpected. Differences between study sites probably are manifested in a continuous manner. The inherent assumption in the relatively simple relationships thus far derived is that unaccounted for sources of variation within each data set are minimized by selecting basins within a relatively close geographical area. As basins from further distances are grouped together, more opportunities exist for variation.

3.6 Channel Design Example and Stability Evaluation

To illustrate the use of our stability assessment of a channel design based on regression results, a hypothetical example is provided. Suppose a mine in the Powder River Basin is faced with reclaiming an ephemeral channel. The basin to be reclaimed is situated within the range of premined ephemeral channel information presented in this report, has a drainage basin area of 0.5 mi^2, and no bed sediment data are available. Using the graphs presented in the Final Technical Report, Appendix C (Figures C-1 through C-5), the following characteristics are determined based on varying levels of confidence for the 100-year event determined by rainfall-runoff analysis. Figure 3-1 presents the graphs used in this example for channel slope, flow area, and flow velocity.

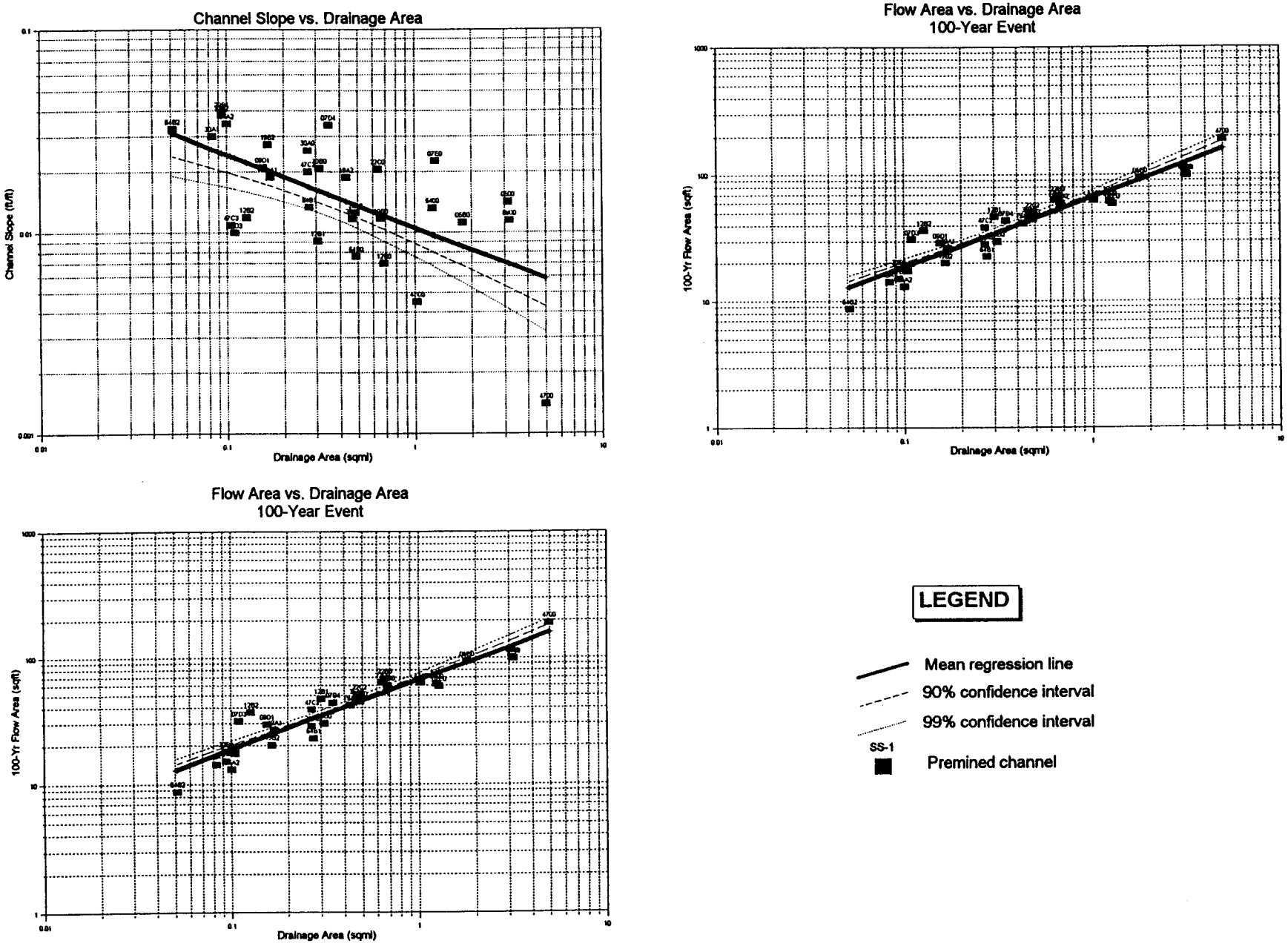

Figure 3-1. Channel slope and 100-year rainfall-runoff flow area and velocity graphs for Powder River area.

Parameter	Confidence Level 99%	90%	50%
channel slope, (ft/ft)	.011	.013	.014
flow area, (ft^2)	52	49	45
flow velocity, (fps)	4.8	5.1	5.4
flow depth, (ft)	--	--	2.3
flow topwidth, (ft)	--	--	35

Depending on the level of confidence determined suitable for the channel to be reclaimed, then the above parameters represent the criteria to which the complete reclaimed channel design should conform. To complete the design, the designer should also examine hydraulic performance during the 10-year event and consider the suitability of a low-flow guide channel.

4.0 CONCLUSIONS

Design and evaluation of stable, reclaimed channels at active and abandoned coal mines in Wyoming and throughout the western U.S. will continue to be a challenging endeavor. While field-based methods of evaluating channel stability are most desirable, the infrequency of channel-modifying events, the remoteness of many reclaimed channel projects, and the cost of field monitoring equipment renders a real-time assessment infeasible.

Channel reclamation design and regulatory evaluation of designs can be improved, in spite of a lack of field data, with knowledge of the premined physical characteristics of the landscape to be mined or slated for reclamation. We have shown that accurate information on drainage basin area allows prediction of channel design parameters of cross-sectional flow area, channel topwidth, depth, and slope. Prediction of channel properties is strengthened by including bed sediment grain-size.

Channel slope and flow velocity were previously uncorrelated with independent basin parameters (WWC, 1993). It was not until the data sets were expanded, incorporating basins varying by several log factors in size, that relationships for these parameters became evident. Further work along these lines should include a continuous, wide span of drainage basin sizes.

Channel sediment is an important parameter in the formation of channels. If small geographical areas are used, differences in channel sediments are probably insufficient to detract from the strength of the resulting correlations. However, we suspect that information on **both** bed and bank sediments (bank sediment composition influences meander migration, bank undercutting and sloughing), will add additional strength to the predictive equations and allow the determination of more widely applicable design equations. Further work examining the role of channel sediment in ephemeral channel formation would be a fruitful endeavor.

The relationships derived for the computed hydraulic parameters of flow area, velocity, depth and topwidth assumes the existence of a certain level of consistency in the engineering methods used in reclamation design. In this regard, caution must be exercised. Possible variation in the determination of runoff curve numbers and Manning's 'n' values could be significant. Floods derived by regional analysis should show very little variation as there are fewer parameters requiring estimation. However, the selection of Manning's 'n' values remains an important parameter.

It is important to ensure that, prior to applying the regression equations and stability evaluations presented herein, the channel to be reclaimed is within the range of data presented.

Application of predictive equations to areas outside the geographical areas studied introduces uncertainty.

The one-tailed statistical test accepts 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. The risk-based approach of selecting acceptable error adds an additional level of flexibility for regulatory design review and channel stability evaluations.

Stability tests, if incorporated into regulatory decisions, can quantify differences between reclaimed channel characteristics and natural, premined areas. A standardized, quantitative approach will help maintain consistency in the design and review process at all levels.

The information presented herein is the largest data set of Wyoming ephemeral channels and allows users to select site specific equations. In the end, sound judgement and appropriate use of existing data will ensure a successful channel design at reclaimed lands in the state of Wyoming.

5.0 RECOMMENDATIONS

Specific recommendations that became evident during this project include:

1. Standardize WDEQ/LQD reporting methods. There is an abundance of useful premined channel information dispersed among several sources at WDEQ, which presently is difficult to extract. Mine permit applications, in particular, provide an enormous resource (above and beyond premined channel data) if rigid guidelines for acceptable contents are established and enforced.

2. When incorporating this stability evaluation into channel design, use the most site specific data available for the area to be reclaimed. Channel data from distant areas aids channel design only when more specific information is not available. Channel bed sediment data may improve channel parameter predictions.

3. If a statistical evaluation for evaluating channel designs is a desirable approach for regulators to assess channel designs, and mine operators want premined information for designing reclaimed channels, then additional data are necessary to fill in gaps in drainage basin sizes studied in the main coal bearing areas of Wyoming. Regression analyses are only as complete as the initial data set. While 81 channels provides reasonable coverage, further premined data from important coal-rich regions of Wyoming would further test and verify these findings.

4. Reclamation practices have generally proven quite successful in reestablishing vegetation cover on disturbed lands. However, the technology does not presently exist to restore physical properties of soil or geologic bedrock with the same success. Much can be gained in reclamation science if a concerted effort is launched to address and rectify the influence of a disturbed substrate on channel stability.

5. Making the data available on the newly developed TIPS database (especially the Cumulative Hydrologic Impact Assessment (CHIA) data) is consistent with our goals of making the data set available to a wide array of users. Arrangements for data transfer are currently in progress.

REFERENCES CITED

Anderson, A., 1994, A Classification of Drainage Basins in the Eastern Powder River Basin Coal Fields of Wyoming, unpublished Master's Thesis, University of Wyoming, Laramie, WY, 182 p.

Devore, J.L., 1982, Probability and Statistics for Engineering and the Sciences, Wadsworth, Inc., Monteray, CA, 640 p.

Jensen, L., 1994, Characterization of Drainage Networks for Mine Land Reclamation in the Eastern Powder River Basin, Wyoming, unpublished Master's Thesis, University of Wyoming, Laramie, WY, 155 p.

Johnston, J., 1984, Econometric Methods, McGraw-Hill Inc., New York, New York.

Lowham, H.W., 1988, Streamflows in Wyoming: U.S. Geological Survey Water-Resources Investigations Report 88-4045, 76 p.

Ott, L., 1984, "Introduction to Statistical methods and Data Analysis", Dunsbury Press, Boston, MA, 775 p.

Western Water Consultants, Inc., 1993, Long-term stability of designed ephemeral channels at reclaimed coal mines, Wyoming: Final Technical Report submitted to Abandoned Coal Mine Land Research Program May 25, 1993, 37 p.

Wyoming Department of Environmental Quality, Land Quality Division, various years, mine permit applications, various mines.

GEOPHYSICAL DETECTION OF ABANDONED MINE TUNNELS

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Abandoned Coal Mine Research Program
Geophysical Detection of Abandoned Mine Tunnels
Final Report

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INTRODUCTION: In 1990, the University of Wyoming seismic field crew conducted high-resolution seismic (HRS) testing in Rock Springs, Wyoming, to determine the utility of the shallow seismic reflection method in locating faults and abandoned underground coal mines. A total of five seismic lines were recorded at four different sites with depths of interest ranging from 60 to 120 feet below the surface. In December, 1991, groundwater penetrating radar (GPR) was also used because of its potential resolution and speed. In 1993 and 1994, six seismic lines and 7 GPR profiles were recorded. The results are variable for both techniques.

MODELING SEISMIC RESPONSE. As expected, logs of a borehole through coal seams show a large difference in density and velocity between coal seams and surrounding rocks. The velocity difference is about 3,000 feet per second. This results in very large reflection coefficients and indicates that strong reflections should be associated with voids in coal seams. When mined out, the density and velocity differences become even larger, so that reflections should be associated with coal seams. If the mined void is filled with rubble, reflections probably become diffuse, and this case needs to be investigated in more detail.

Results of Study in 1990-1991

At Thompson Street, faulting and subsidence was mapped with high-resolution seismics and processed into a normal CDP stacked section and a true amplitude section (Fig. 1). The seismic section (Fig. 1) shows good reflections associated with coal zones, and these reflections are offset, indicating positions of faults including one with an offset of about 60 feet at the north side of the section. Smaller faults are associated with a cracked garage. True-amplitude plots distinguish between unmined coal, mined voids, and rubble. Synthetic seismics generated on a computer, based on logged boreholes, and superposed on the seismic section, show that the seismic interpretation is confirmed by drilling.

At Maple Street, the seismic section (Fig. 2) shows a fairly distinct reflection dipping to the south from a depth of about 80 feet to 160 feet. This reflection correlates with a partially mined coal bed. The irregular nature of the reflection indicates that this is cut by a number of faults with displacements of five to fifteen feet. GPR data suffers from heavy interference from sources of electromagnetic radiation such as power lines. After strong processing, using seismic processing routines, interference is attenuated (Fig. 2B), faulting is recognized. Ringing may be caused by voids, both grouted and ungrouted.

Along the Belt, GPR provided a striking example for mapping shallow features over a landfill. Here a low spot had been filled in by fly ash. The base of the landfill was well-mapped by the GPR and an underlying coal seam was also imaged. Convex upward events (diffractions) at the base of the coal may indicate strong discontinuities. GPR imaged possible voids and grouted voids along the Maple Street traverse and water table and bedrock surfaces on a Channel Street traverse.

Results of Study in 1993-1994

<u>High Resolution Seismics</u>. Optimum source-receiver offset varied from 60 to 160 feet, depending on the target depth, and low-cut filter settings of 128 Hz worked best. Sources tested included a weight drop, a .308 caliber rifle, a .22 caliber rifle, and a sledgehammer. A sledgehammer was selected as the best source because it gave comparable results to the .308 rifle with minimal environmental disturbance; for example, it was cheap and effective. The .22 rifle was too weak and the .308 rifle (cheap surplus ammunition was used) was good but noisy, and made people nervous in built-up areas. The weight drop produced too much seismic noise.

In terms of surface conditions, HRS gave useful results where soil, clay, or sandstone were at the surface. Working along sidewalks has proved difficult because the sidewalk propagates high-velocity seismic noise that interferes with seismic reflections.

HRS profiles are presented for McKinley Street, Lincoln Street, Cody Street, and the water tank. Ground truth is provided by drilling at Lincoln and McKinley streets. Note that color scales representing amplitudes are not calibrated from one profile to the next so that a given color does not have the same interpretation. Mined areas are at depths around 100 to 120 feet on these profiles. This depth is found in the upper part of the color sections presented. An HRS profile over shallow (50-60 feet) mined areas at Alder Street is not presented because the data was degraded by high-velocity noise along sidewalks. Here useful information was, however, obtained from GPR and follows in this report.

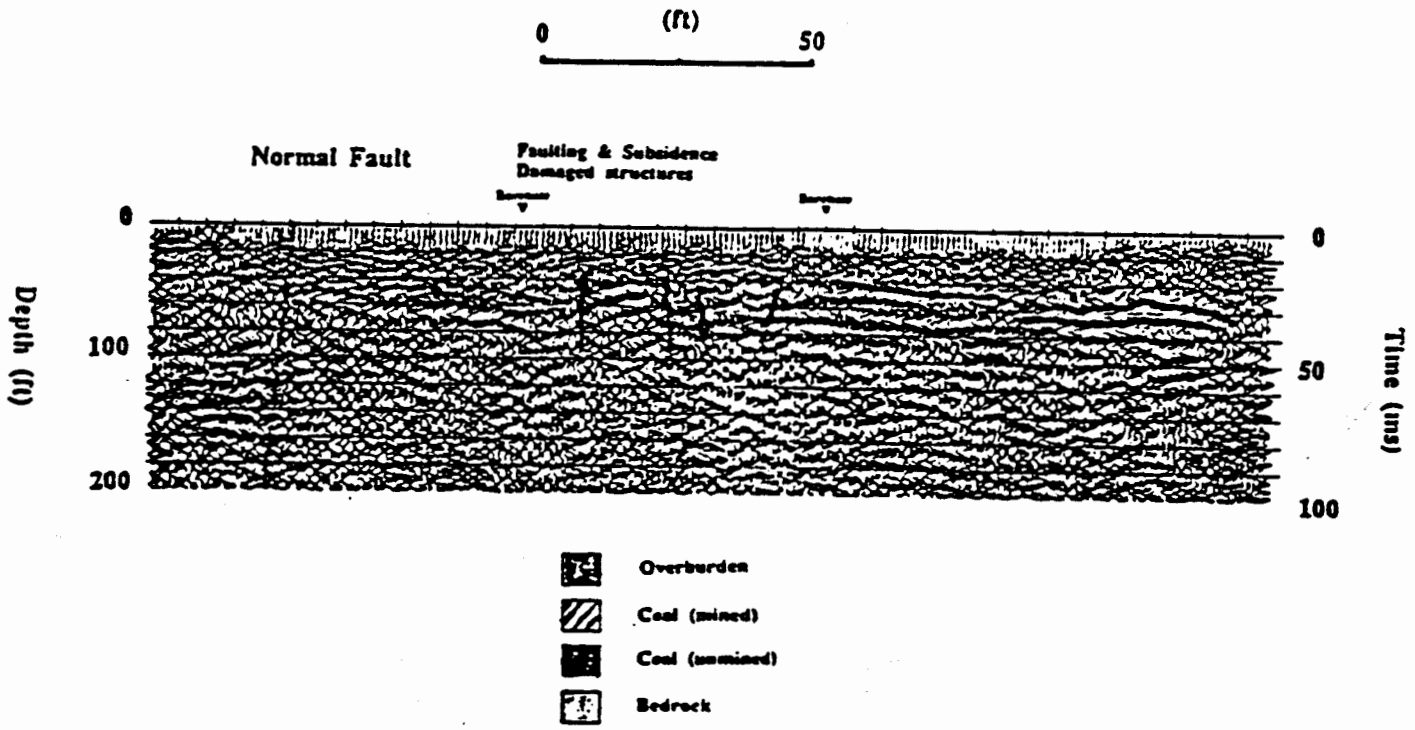
The Lincoln Street HRS profile runs along the alley next to the cemetery and was drilled after we recorded the profile. Coal was found along most of the profile. A void was shown by drilling appears in the seismic section as a color change. The HRS profile along McKinley Street is calibrated by projecting from drilling about 50 feet off the profile. A coal horizon, at 120 feet, is indicated by the red line on the right side of the section. A void with roof collapse encountered at 97 feet is marked by two shallower heavy red lines at the left center of the section. Possibly a grouted void appears to the left. The shallow roof-collapse zone indicates the kind of complication in seismic signature that must be further calibrated by drilling.

The Cody HRS profile is located in a vacant lot southeast of Cody Street but has not been drilled. Based on amplitudes, we interpreted a mined zone (blue line in upper part of the section at about 110 feet depth. We will use further processing analysis and comparison with known voids to provide more support for the interpretation. An HRS profile was run at the new water tank located off the Southwest Beltway. The mined coal horizon is imaged and two voids are interpreted. No drilling information is available. An HRS profile at Blairtown provided a good image of shallow (~60 ft) coal. Several voids are interpreted in the profile but have not been drilled.

Ground Penetrating Radar. Ground penetrating radar (GPR) has been tested with a number of problem areas at Rock Springs including a sink hole, faulted coal beds, grouted cavities, air shaft, and a tunnel. The application of GPR is affected by nearby metal objects and the nature of the soil zone so that, in several cases, results were degraded by reflections from metal at the surface, and apparently by some conductive soil zones. The GPR system, however, works well on bedrock and provides depth coverage from the surface down to about 60 feet, the depth range where HRS is slower and less satisfactory.

The GPR is extremely fast, simple, and environmentally compatible providing a real-time image of the subsurface. Faulted coal beds were imaged from down to a depth of about 20 feet and the faults themselves were directly imaged by the GPR. Along the Beltway, we were directed to a sinkhole that had been backfilled. The GPR image of this area shows the sinkhole, a buried topographic ridge, and interference from three overhead wires. The sinkhole and buried ridge are imaged nicely; the cavity underlying the sinkhole may be revealed by the thick green area in the plot, but its presence is complicated by the arcuate interference, caused by overhead wires. Such interference effects were noted by the operator in the field. At Alder Street, we profiled over voids that had already been grouted at depths of about 50 feet Here two grouted areas were detected at slightly different depths together with a water-filled cavity. The arcuate bands are reflections and diffractions at the top of both grout-filled and water-filled cavities. The grouted cavities were interpreted in the GPR image based on their occurrence at grout-filled drill holes and likewise with the water-filled cavity. GPR survey over known adits (Fig. 4) at depths of 30 to 50 ft have shown that they are readily located and that a rubble zone may be distinguished from a void. Faulting in a subdivision at Pioneer Street was also imaged by GPR. Because the GPR signatures may appear similar, more work (like looking at true amplitude) needs to be done to improve interpretation. In summary, the GPR method has produced useful subsurface images in four cases and unsatisfactory results in two cases. Future study involves developing a better understanding of subsurface signatures and solving the problem of surface interference and attenuation. For both HRS and GPR, surface conditions are a major factor determining success and resolution of subsurface imaging.

High Resolution Seismic (HRS)



True Amplitude Display

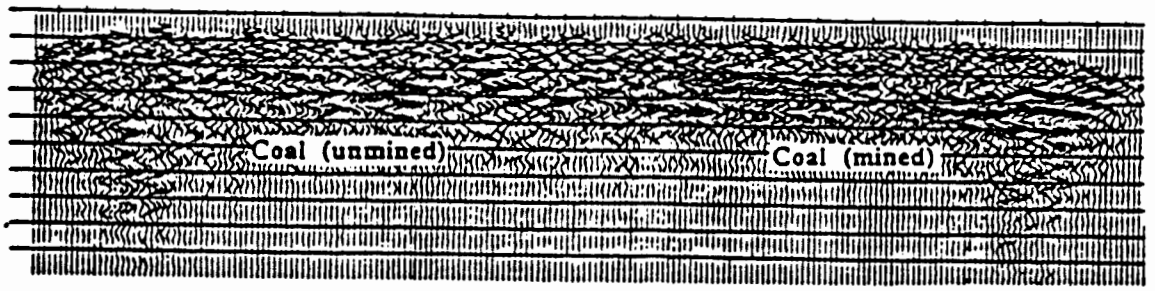


Figure 1 Thompson St. seismic profile showing faults and voids. Top is interpretation and bottom is true-amplitude plot showing how amplitude changes with mining.

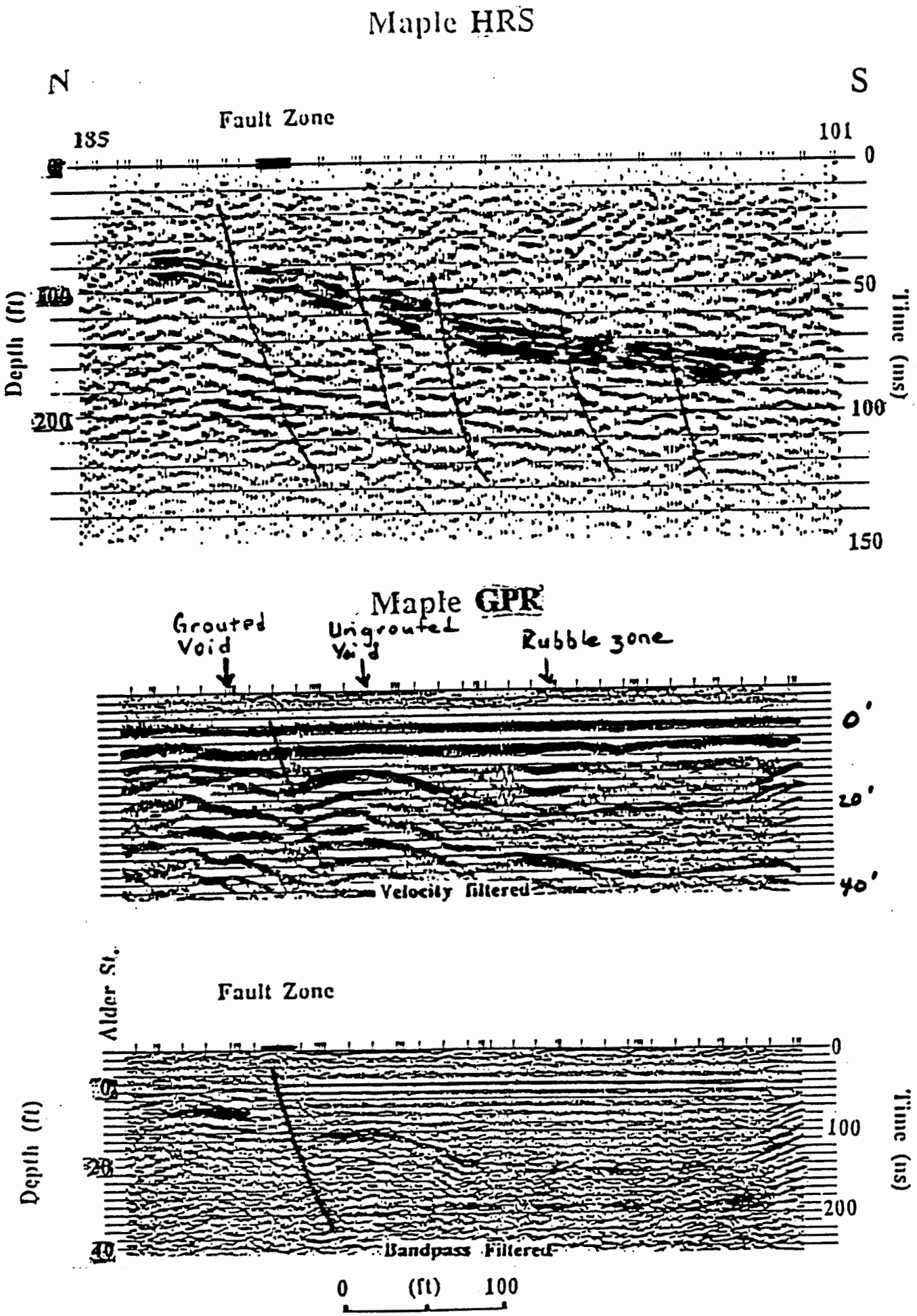


Figure 2. Seismic profile (top) and GPR (bottom) of Maple St. profile showing faulting.

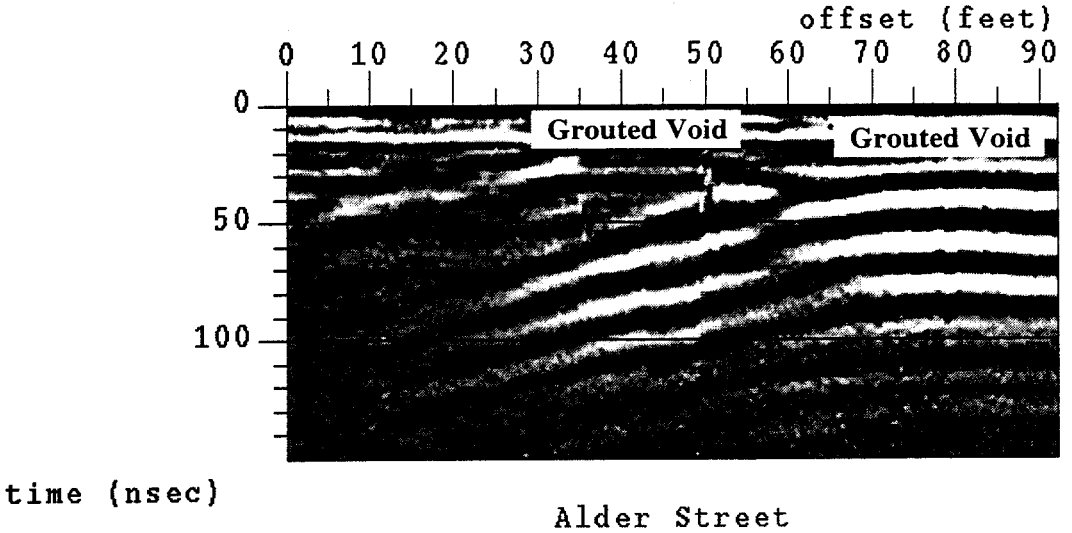
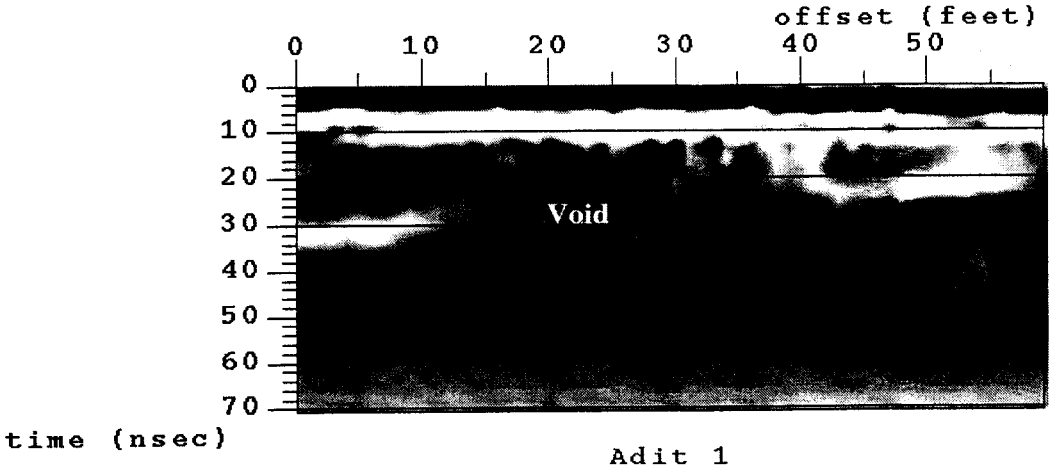


Figure 3. GPR image of grout filled voids at slightly different depths at Alder Street.



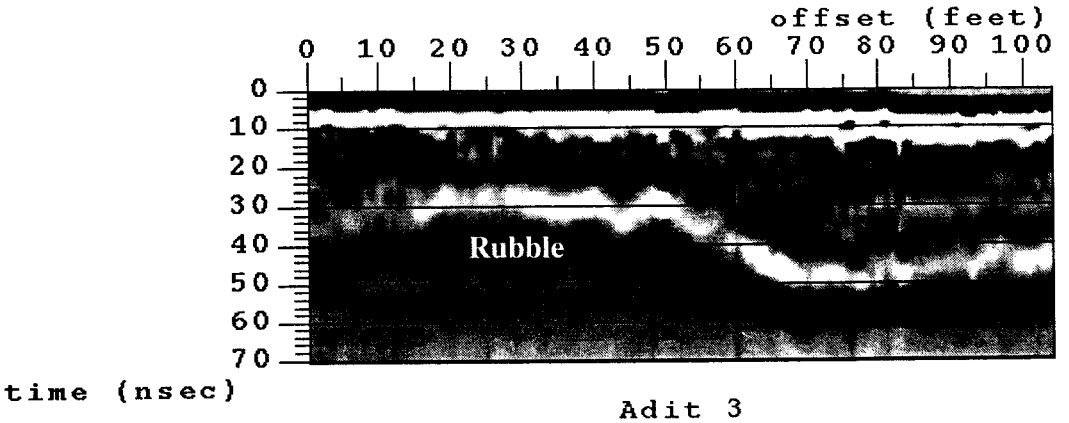


Figure 4. GPR over known adits in coal area, Rock Springs, WY

DETERMINATION OF CONTRIBUTION TO CUMULATIVE GROUNDWATER IMPACTS FROM COALBED METHANE DEVELOPMENT AND SURFACE COAL MINING

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ABANDONED COAL MINE LANDS RESEARCH PROGRAM

Semi-annual Progress Report
October 31, 1995

Determination of Contribution to Cumulative Groundwater Impacts From Coalbed Methane Development and Surface Coal Mining

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The primary energy development in the Powder River Structural Basin has been coal mining and conventional oil and natural gas development. These types of energy development coexist well in that regulatory conflicts are not often encountered. Recently, there has been increased interest in coalbed methane resources in the basin. It is anticipated that development of this resource may impact water levels in the coal aquifer. In particular, this may affect the ability of coal mine operators to remain in compliance with the Surface Mining Control and Reclamation Act (SMCRA). Determination of individual contributions to aquifer impacts will likely be a critical issue in coming years. This project was funded to investigate this issue.

Three primary objectives were identified for investigation during a 2 year project.

- ***Investigate the existence of anisotropy of hydraulic conductivity in the coal aquifer for the purpose of evaluating modeling methods used by Peacock and Kern (1995), and to verify the presence or absence of inter-aquifer communication at these test sites.***

- ***Develop methods to differentiate groundwater changes due to surface coal mining activities from those associated with non-mining related aquifer stresses.***

- ***Acquire and assess all available data from Permit to Mine Applications using all available means for the four active mines nearest the Marquiss CBM development.***

Current Progress:

Work on the project began on June 1, 1995 and focused on the first and third objectives. It is anticipated that groundwater flow models will be used to differentiate between sources of impact. Therefore, improvement of the information available to support the modeling effort was a high priority early on in the project. Significant progress has been made on both of these objectives.

Little is known about the degree of anisotropy in the Wyodak coal, although most investigators speculate that some form of anisotropy exists, probably related to cleats in the coal. In August, a multiwell test was conducted by the investigators in the vicinity of highway 59 south of Gillette. Further, 2 multiwell pump tests were conducted in the southern part of the basin in cooperation with John Nedalski of Powder River Coal Company. A fourth test is currently planned for the month of November which will be adjacent to the Belle Ayr Mine. That test is being organized in cooperation with Bob Stowe of Belle Ayr mine. Preliminary analyses indicate that major axes of anisotropy may be oriented approximately North-West. Work related to the multiwell pump tests also includes development of analysis methods for a set of n observation wells from which k tests are conducted. The method includes application of least squares to fit the "best" transmissivity ellipse to the observed data. Computer software was developed in MATLAB and is currently available. In addition, methods to construct confidence intervals for the axis orientation are also being investigated.

Four mines were identified for data entry and quality control analyses, and to date aquifer test data for 9 mines has been acquired, entered into electronic form and submitted to a quality assurance procedures. These data are currently being entered into the CPR data base. This is a table which has not previously been populated in the CPR. For quality assurance, each test was analyzed to insure that appropriate assumptions were satisfied, and that data were properly recorded and analyzed. In many cases data were reanalyzed from field data sheets obtained from the permit to mine applications. Each test was given a quality rating for incorporation into future analyses. In an ideal world, only the highest quality data would be used in modeling efforts. The most recent work includes statistical analyses investigating the spatial characteristics of the aquifer test data. Some questions of interest include investigation of spatial trends in the basin, spatial autocorrelation of hydraulic conductivity and the univariate statistical distribution of the data.

The project has been greatly enhanced by the level of enthusiasm and cooperation received from John Nedalski and Bob Stowe. Prior to inception of the project, it was not anticipated that more than 2 to 3 pump tests would be affordable. However, through the use of existing wells and with the cooperation of these individuals, four tests will likely be completed by the end of the first year of funding for the project. We thank John and Bob for their participation.

CHRONIC SELENOSIS IN WATERFOWL: DEVELOPMENT OF DIAGNOSTIC HISTOLOGICAL AND TOXICOLOGICAL CRITERIA AS AN AID FOR RECOGNITION AND CONTROL

D. O'TOOLE AND M. RAISBECK

CHRONIC SELENOSIS IN WATERFOWL: DEVELOPMENT OF DIAGNOSTIC HISTOLOGICAL AND TOXICOLOGICAL CRITERIA AS AN AID FOR RECOGNITION AND CONTROL - INTERIM REPORT

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INTRODUCTION:

Bioaccumulation of selenium from natural geologic sources occurs in some wetland areas of the western United States following disposal of seleniferous agricultural wastewater, and ecological impacts may include die-offs and terata in wild aquatic birds. The best known episode involved Kesterson National Wildlife Refuge in the southern part of the San Joaquin Valley in California in the 1980s. Since then, reconnaissance studies by US Department of the Interior (USDOI) personnel indicate that the "Kesterson effect" was seen in 11 of 16 sites including the Kendrick project in Wyoming, and that there were associated declines or die-offs of fish and/or birds in 6 of these areas. Indeed, it is argued by some (Presser et al (1994): Environmental Management 18(3):423-436) that there is a fundamental problem when irrigation districts in seleniferous areas discharge agricultural wastewater into wetlands. A similar process may occur in seleniferous former mine sites where wetlands are constructed in mitigation for lost natural wetlands. Currently there is no way to bioremediate contaminated sites short of draining and filling natural or man-made wetlands - as happened at Kesterson - or by withdrawing selected irrigated lands from production. These issues will likely be resolved in the courts, where both owners of wetlands and environmental interests have substantial legal support.

USDOI personnel currently rely on chemical analysis of tissues from birds and fish in contaminated sites as the primary technique for establishing whether deformities and losses in waterfowl are linked to selenium poisoning. Although these are the best estimates available (Skorupa and Ohlendorf (1991) pp 345-368 *In* The Economics and Management of Water and Drainage in Agriculture, eds. Dinar and Zilberman, Kluwer Academic Publishers), we question whether chemical analysis *alone* can be used as the diagnostic shibboleth. This is because:

1. the margin between "normal" and "toxic" concentrations of selenium in tissues is narrow.
2. predictions based on the Kesterson paradigm have failed in some sites, such as the Grasslands district in Ca (Hothem and Welsh (1994) Arch Environ Contam Toxicol 27:180-185).
3. avian species differ in their tolerance for selenium, and in their capacity to accumulate it in tissues. Unfortunately, most of the predictions for toxicity are based on experimental work using one species of waterfowl, the mallard duck. These excellent studies, done at the US Fish and Wildlife Service's Patuxent laboratory, generated much information about Se concentrations in response to various dosing regimens and chemical forms of Se, but little data about the pathobiology of selenosis.

In short, USDOI criteria for selenosis come perilously close to Justice Brennan's definition of obscenity ("I can't define it - but I know it when I see it"). There is a need to complement toxicological analyses with other diagnostic techniques in order to establish significance of finding increased selenium residues in dead waterfowl.

MATERIALS AND METHODS:

Sixty adult male ducks were obtained from a commercial source on 6 June 1995, housed individually, acclimated to a proprietary waterfowl ration, and fed selenium (Se) in the form of selenomethionine (Se-met) as 10, 25, and 60 ppm Se for up to 150 days. The 10-60 ppm Se range was selected as a preliminary trial (data not shown) found that some ducks fed 80-100 ppm Se died of acute hepatic necrosis within a week of dietary exposure. The original protocol had both an ad libitum-fed control group (n=12), and a pair-fed control group (n=12) to match the dietary intake of the high-dose (60 ppm) group, in anticipation of high feed refusal in the 60 ppm group. Because feed refusal approached 60-100% in the 60 ppm group, the pair-fed control group birds are being used for a separate Se dietary study that will be completed in early 1996 and will therefore not be reported here. Birds were scheduled to be killed and examined at 50, 100 and 150 days of dietary exposure (15 August, 4 October, and 20-24 November 1995, respectively). A comprehensive, standardized set of tissues are collected

from each of the 60 ducks for toxicological and histological examination. Particular attention is paid to analysis of keratinized structures like skin, feathers, beak, nails, esophagus and gizzard, since it is likely that selenium accumulates at these sites, from previous studies on selenium-intoxicated cattle and people.

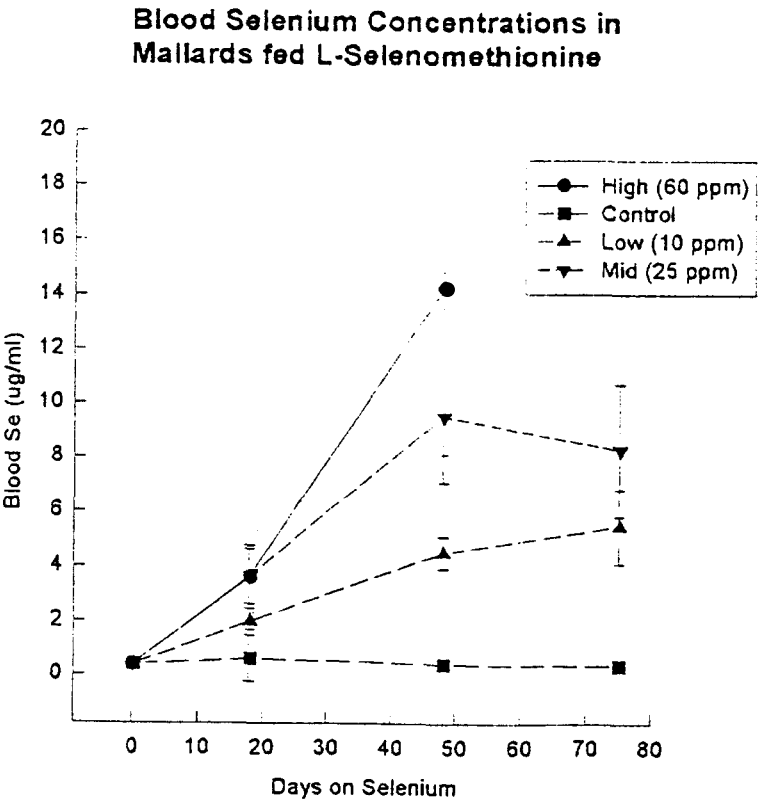
PRELIMINARY RESULTS AND DISCUSSION:

1. Dietary concentration of 60 ppm selenium (high dose group), fed as Se-met, results in considerable weight loss (20-50% body weight) within 50 days of exposure. It was necessary to kill all 11 of 12 mallards fed 60 ppm Se between 22-50 days of exposure, due to emaciation and loss of condition; the remaining 60 ppm Se-fed bird died at 48 days of dietary exposure. At least some birds have distinctive microscopic lesions in two sites: in liver, and in the growth zone of the proximal shaft of contour feathers. Hepatic lesions include biliary hyperplasia, intracellular iron deposition, karyomegaly, and micronodular hyperplasia. Pterylopathic lesions include degeneration and necrosis in the germinal epithelium of the barb and rachidial ridges, parakeratosis of the rachis, and inflammation in the feather pulp.

2. Similar lesions, resulting in loss of contour feathers from the dorsal midline of the neck and from the face, occur in some birds fed 25 ppm selenium (medium dose group) in the diet for an extended period (> 80 days). Some of these 25 ppm birds have developed thick, deformed nails that detach readily, and there is some depression of body weights relative to the control group.

3. No clinical signs have yet developed in the 10 ppm Se group (low dose group), suggesting that 25-60 ppm Se is the dietary range in which subchronic-chronic effects are seen.

4. Blood selenium concentrations quickly rose from normal (0.3 - 0.5 ppm) to moderately elevated concentrations (3.0-4.0 ppm) in the high dose birds within 30 days exposure, and subsequently rose to markedly elevated concentrations within 50 days (11-23 ppm), shortly before the birds' condition necessitated euthanasia (Fig 1).



5. Contour feathers, collected from live birds with excessive blood Se concentrations, have a characteristic break in the feather shaft, between the rachis and calamus, that is probably responsible for feather loss. We are currently attempting to develop a histological technique for feathers sampled from live birds to establish the basis for this, and to define its possible diagnostic application.

These results will be discussed in the context of the likelihood of selenosis being a significant problem in man-made wetlands at post-reclamation mineland sites.