ABANDONED COAL MINE LANDS RESEARCH PROGRAM

THIRD-SEMI ANNUAL PROJECT REVIEW SEMINAR

SHERIDAN, WYOMING

NOVEMBER 17, 1992

The seminar series is sponsored jointly by the University of Wyoming, Office of Research and the Abandoned Mine Lands Program of the Wyoming Department of Environmental Quality.

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

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

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

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

Introduction

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

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

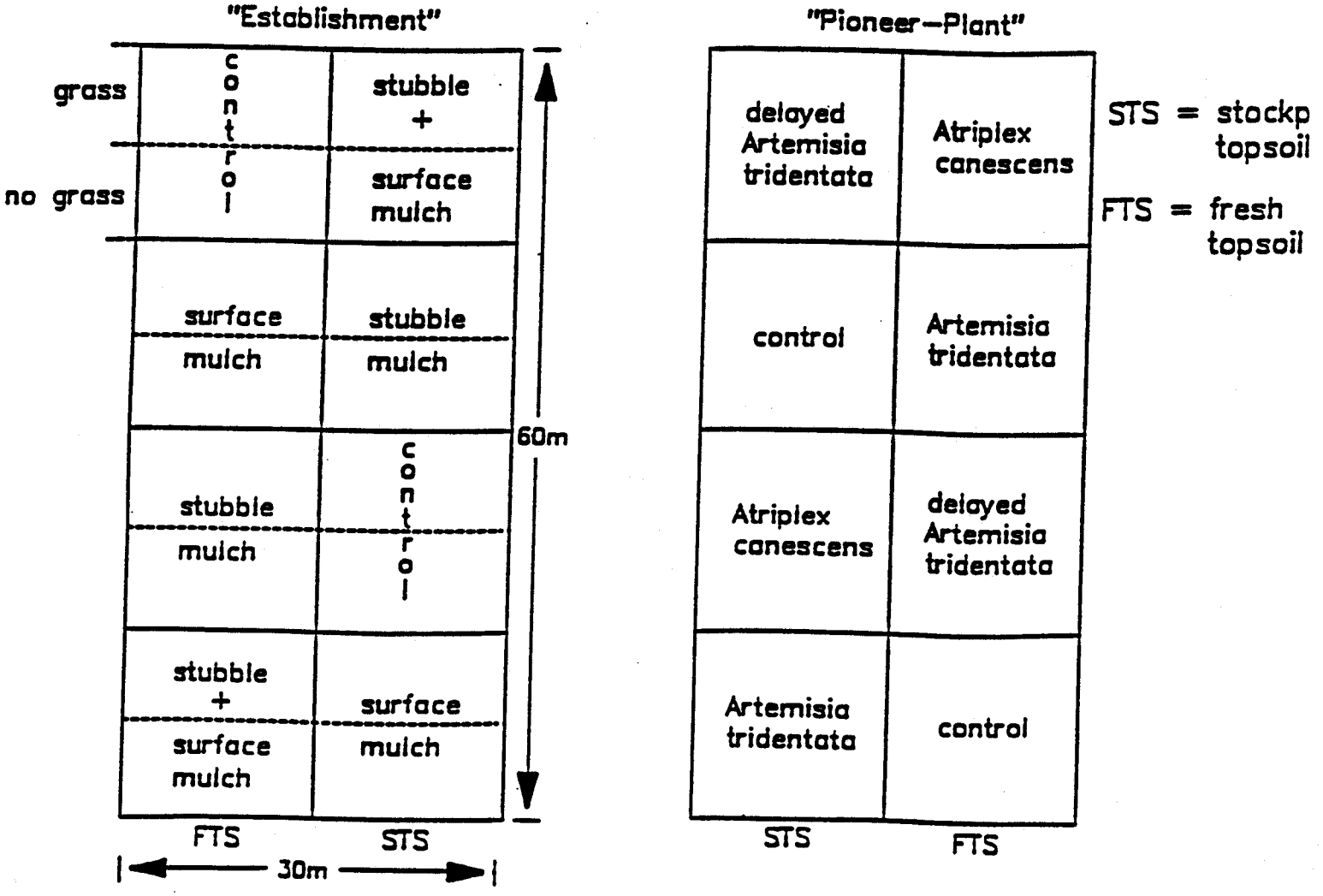
1. Efficacy of direct-applied topsoil for enhanced sagebrush stand establishment through effects of VAM and the topsoil as a seed source.
2. The value of a stubble mulch crop of annual grain for sagebrush establishment through effects on snow catchment and microsite modification.
3. The usefulness of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

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

Project Description

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

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



Establishment Study

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

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

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

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

Pioneer Plant Study

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

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

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

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

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

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

Progress Report

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

Establishment Study

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

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

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

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

Pioneer Study

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

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

Future Plans

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

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

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

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

R.B. SEE, K.J. REDDY, G.F. VANCE, A.A. FADLEMAWLA

SEMI-ANNUAL REPORT #3
THE ROLE OF NATURAL ORGANIC SOLUTES IN THE MOBILITY OF SELENIUM IN COAL MINE BACKFILL-GROUND-WATER SYSTEMS

Randolph B. See, U.S. Geological Survey
Katta J. Reddy, Wyoming Water Resource Center
George F. Vance, University of Wyoming
Amr A. Fadlemawla, University of Wyoming

SUBMITTED TO
THE ABANDONED COAL MINE LAND RESEARCH PROGRAM
November, 1992

Office of Research
University of Wyoming
P.O. Box 3355
Room 201, Old Main
Laramie, WY 82071-3355

INTRODUCTION

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

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

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

SITE SELECTION

Field sites were selected after consultation with hydrologists and other scientists from the Wyoming Department of Environmental Quality, U.S. Geological Survey, and mining industry in Wyoming. All available data records were searched including annual mining reports, Gillette Area Groundwater Monitoring Organization annual reports, Wyoming Department of Environmental Quality data files, Wyoming Geological Survey data files, and the U.S. Geological Survey National Water Information System.

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

FIELD SAMPLE COLLECTION

Spoil Cores

Six spoil cores were obtained during September 1992. Two spoil cores were collected from within approximately a 15-foot radius of the well at each of the three sites. Core holes ranged from 22.5 to 27.5 feet deep and were at least as deep as the associated well. Drilling logs recorded sampling procedures and sample descriptions.

Ground-Water Samples

Ground-water samples were collected at each well in September, 1991 and July or August 1992. Wells were pumped at approximately 1.2 gallons per minute with a submersible, positive displacement pump until pH, specific conductance, and temperature were stable ($\pm$ 10 percent). Usually this was about 3 to 5 casing volumes of water. Because of difficulty filtering samples onsite in September 1991, a second set of ground-water samples was collected at each site during July or August 1992. After pH, specific conductance, and temperature stabilized, the submersible pump was replaced with a slower positive displacement pump and filter assembly to collect ground-water samples. Field and laboratory analyses of ground-water samples are presented in Table 1.

LABORATORY ANALYSES

Quality Assurance

Laboratory quality assurance includes the use of blanks, standard reference samples and duplicate analyses. A total of 10 to 15 percent of the total analyses will be dedicated to quality assurance. A spoil reference sample was developed from excess spoil material collected during the sample collection. An additional soil standard reference material has been developed by the U.S. Geological Survey using soils from the San Joaquin Valley, California. Water standard reference samples prepared by the U.S. Geological Survey Standard Reference Water Sample Project were also included for analyses.

Spoil Cores

A total of 136 spoil core subsamples were dried and sieved through a 10 mesh (2mm) sieve. Saturated paste extracts (SPE) were prepared and the following determinations were made for the SPE: pH, redox potential (Eh), specific conductance, total selenium, sulfate, and dissolved organic carbon (DOC). Three subsamples were selected from each core for total elemental and mineralogical analysis. Mineral composition of core subsamples was determined with a Scintag PAD V power diffractometer using Ni-filtered CuKα radiation (Jackson, 1969).

The pH values for core subsamples were typically between 6 and 8. This is probably due to the buffering effect of carbonates, which were present in all samples. The pH and Eh measurements for SPE for core subsamples taken near the ground-water table were very similar to those obtained for the ground-water samples. The SPE specific conductance (0.21 to 0.84 S m^{-1}) indicate a large salt content in the core subsample solutions. Total selenium concentrations in the SPE ranged from 1 to 156 µg/kg.

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

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

Ground Water

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

Total selenium concentrations in 1991 were found to parallel the DOC concentrations (selenium results are not yet available for 1992). Ground-water samples A-1 and B-1, which had high DOC concentrations, had selenium concentrations of 165 µg/L (A-1) and 63 µg/L (B-1). Ground-water sample A-2, which had a low DOC concentration, had a selenium concentration of

3 µg/L. Although sample A-2 had low DOC and selenium concentrations, the sample will be useful for studies of adsorption/desorption and precipitation/dissolution properties of the different backfill materials.

Adsorption/Desorption Studies

Preliminary adsorption/desorption experiments were conducted for six core subsamples. Results show that core subsamples have a very large selenium adsorption capacity. All samples adsorbed more than 90 percent of the added selenium (except one with a pH of 6.7 that adsorbed 75 percent). The pH of the samples examined ranged between 3.7 and 6.7. Although pH is a major factor in controlling adsorption, the adsorption capacity generally remained constant within the observed pH range except at pH 6.7. The selenium desorbed by phosphate were about 50% of the adsorbed selenium; this decrease may be due to precipitation processes.

Precipitation/Dissolution Studies

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

Controlled Redox Studies

To examine the effect of oxidation-reduction processes on selenium adsorption/ dissolution and precipitation/dissolution reactions in mine backfill and associated ground water we have designed a reaction cell in which pH and redox potential can be controlled. This unit consists of a sample chamber with platinum, pH, and reference electrodes connected to a pH/ millivolt meter. The meter is connected to a relay, which controls redox potential (±10 milliVolts) and pH (±0.1 unit) in the reaction cell. After the cell is purged with argon, samples will be placed in the reaction cell with a specified solid to solution ratio. Samples will be mixed at regular, timed intervals. The field pH and redox potential of the solutions will be used as initial control points. After reaction periods of 1, 3, 7, 14, 21, and 28 days, suspensions will be collected from the unit using a syringe assembly containing a 0.45 µm filter.

Dissolved Organic Carbon

DOC was fractionated according to the method developed by Leenheer and Huffman (1979) that separates 6 DOC fractions: hydrophobic acids, bases and neutrals, and hydrophilic acids, bases, and neutrals. The results of the DOC fractionation analysis (Table 2) indicate DOC in the ground-water samples was dominated by organic acids (61 to 82 percent), with organic neutrals ranging from 13 to 38 percent, and organic bases ranging from 4 to 10 percent. Because hydrophobic bases were a small percentage (0 to 2 percent), this analysis will be omitted in future analyses.

SUMMARY

Three field sites were selected and sampled in reclaimed areas at two surface coal mines. Two spoil cores and two sets of ground-water samples have been collected from each field site. Analyses of ground-water samples indicate that total selenium concentrations ranged from 3 to 165 µg/L and DOC concentrations ranged from 11 to 88 mg/L. Results from adsorption/ desorption experiments indicated that core subsamples adsorbed 75 to more than 90 percent of the added selenium. Precipitation/dissolution experiments were conducted, however, analysis of

extracts are still in progress. A reaction cell has been developed in which the effects of oxidation-reduction on selenium adsorption/desorption and precipitation/dissolution reactions will be studied. Fractionation of DOC in ground-water samples indicated predominance of organic acids (61 to 82 percent).

REFERENCES

Jackson, N.L. 1969, Soil chemical analysis-advanced course, 2nd edition, Madison, Wisconsin.

Leenheer, J.A. and Huffman, E.W.D., 1979, Analytical method for dissolved organic carbon fractionation: U.S. Geological Survey Water-Resources Investigation 79-4.

Table 1. --Analytical results of ground-water samples

Well number	Date of collection	Field analyses				Laboratory analyses	
		pH	Specific conductance (micro-Siemens/ centimeter)	Electrical potential (milliVolts)	Temper-ature (degrees Celsius)	Dissolved organic carbon (milli-grams/ liter)	Total selenium (micro-grams/ liter)
A-1	9/17/91	7.1	10,000	350	11	88	165
A-1	7/7/92	7.3	10,000	370	11	84	--
A-2	9/17/91	5.5	5,000	450	10	11	3
A-2	7/7/92	5.6	4,200	450	11	14	--
B-1	9/18/91	6.3	3,650	400	10	87	63
B-1	8/19/92	6.4	3,800	370	14	79	--

Table 2. --Dissolved organic carbon fractionation of ground-water samples

Well number	Date of collection	Hydrophobic solutes (percent)				Hydrophilic solutes (percent)			
		Total	Bases	Acids	Neutrals	Total	Bases	Acids	Neutrals
A-1	9/17/91	58	2	42	15	42	2	32	8
A-1	7/7/92	46	0	38	8	54	5	44	5
A-2	9/17/91	49	0	43	6	51	10	26	15
A-2	7/7/92	47	0	45	3	53	2	16	35
B-1	9/18/91	70	0	53	17	30	6	15	8
B-1	8/19/92	71	0	50	21	29	6	23	0

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

Semi-Annual Project Report

for the

Abandoned Coal Mine Land Research Project

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

GEORGE F. VANCE

University of Wyoming
Department of Plant, Soil and Insect Sciences

KATTA J. REDDY

Wyoming Water Resources Center
University of Wyoming

LOWELL K. SPACKMAN

State of Wyoming
Department of Environmental Quality

SHANKAR SHARMASARKAR

University of Wyoming
Department of Plant, Soil and Insect Sciences

November 17, 1992

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

George F. Vance, Katta J. Reddy, Lowell K. Spackman, and Shankar Sharmasarkar

INTRODUCTION

During surface mining activities, materials previously in reducing environments are exposed to oxidizing conditions. The oxidation of Se can result in elevated levels of Se becoming available to plants, which might induce greater plant Se uptake and enhance the possibility of Se toxicity to animals. Increased solubility and mobility of Se in disturbed areas may result in higher levels of Se in surface waters, groundwaters and in resaturated backfill. A majority of the abandoned and reclaimed coal mine lands will ultimately be used for grazing, pastureland and wildlife habitat. Because Se bioaccumulation has been associated with certain aquatic environments, surface and ground waters with elevated Se concentrations are of concern. If the elevated concentration of Se does not attenuate, these abandoned and reclaimed areas may not be suitable for post-mining land use or may require special resource management considerations. Therefore, without appropriate Se research to ascertain the relationship between soil, backfill and overburden characteristics to Se uptake by plants and enhanced mobility, these questions cannot be reliably answered.

OBJECTIVES

Selenium has been detected in plant, soil, overburden, and backfill materials collected throughout Wyoming. Therefore, the main objective of this research project is to examine the biogeochemistry of Se in abandoned and reclaimed coal mine sites and native lands. The project is divided into four research tasks:

1) **development of a rapid and cost effective method for determining Se species in overburden, 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 overburden, 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.**

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

Survey of Abandoned Coal Mine Lands in Wyoming

Several sources of information, which were described in the 2nd semi-annual ACML report, were used for locating research sites on abandoned and active coal mine lands. A comprehensive description of our survey of potential abandoned coal mine sites is available in an interim report submitted to the Office of Research, University of Wyoming. Additional information has been obtained (AML Site Investigation Report, Site 6C-8) which suggests a reclaimed abandoned mine site outside of Rock Springs may contain evaluated levels of extractable Se. There is also sufficient evidence (AML Site Investigation Report 15-2-34) that indicates Se is associated with uranium mining as well.

Site Selection

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

Field Work

In 1992, plant, soil, and backfill samples were collected from abandoned, reclaimed and native sites located in the Powder River Basin and near Rock Springs. Forty (40) soil/backfill samples were collected from nine research plots located in three transects on three different mine sites. Sufficient volume of soil/backfill material was sampled so enough material would be available for all analyses.

As was done in 1991, the non-woody portion of the plants sampled were clipped to obtain approximately 5-10 g of sample. Approximately five plant samples were collected from each of the research plots. A total of 202 plant samples of 66 different species were clipped, placed in ziplock plastic bags and immediately put on ice. All sites sampled in 1991, except for two lost due to mining activity, plus the nine plots established in 1992, were sampled again by clipping the five dominant plant species.

Photographs were taken at each research plot and site, location, topography, transect characteristics, and unique features were recorded. The project document was updated to include this years sites and samples. A general description of each transect, along with a listing of associated soil and plant samples and their respective Se contents summarizes the project results to date. Plants were identified with the assistance of personnel from the Rocky Mountain Herbarium, Plant, Soil and Insect Sciences department, and Range Management department at the University of Wyoming.

Laboratory Analyses

All the soil/backfill and plant samples have been logged in and prepared for complete chemical analysis. The plant samples were oven-dried at 50-60°C for 24 hours and then ground to 60 mesh using a Wiley Mill. The soil/backfill samples were divided in two, using a Riffle Splitter, and one part was crushed with a hammer covered with cheese cloth and sieved

to 10 mesh and the other sealed and stored. The samples collected from the abandoned mine research sites were given the highest priority.

The chemical form of an element in an aqueous environment is important in determining its solubility, mobility, availability and environmental impact. Thus, the analytical determination of the concentrations of aqueous Se species in soil and backfill solutions is required to adequately predict its fate and behavior. Soil/backfill samples have been analyzed for total Se. Additional analyses currently being performed are: pH, texture, mineralogy, carbon, cation exchange capacity, base cations, and extractable Se. Soil and backfill samples from the abandoned mine research sites are being used for selective sequential extractions to determine the Se solid-phase speciation. Plant samples have been analyzed for total Se by digesting in nitric/perchloric acid mixture followed by Se analysis using an atomic adsorption/hydride generator technique.

Se Speciation Using Ion Chromatography: Ion chromatography provides speciation of SeO_3^{2-} and SeO_4^{2-} in solution without the need for sample pretreatment or HCl reduction. Although detection limits are only in the range of 10 to 20 µg/L and limits of quantification are approximately 50 µg/L, ion chromatography is very useful for applications where monitoring SeO_3^{2-} and SeO_4^{2-} transformations are essential. Interferences from SO_4^{2-} concentrations above 1000 mg/L can limit the effectiveness of ion chromatography for Se applications in some soils and groundwater. The figure shows Se speciation in a solution containing 1 m*M* NO_3^-, PO_4^{3-}, and SO_4^{2-}.

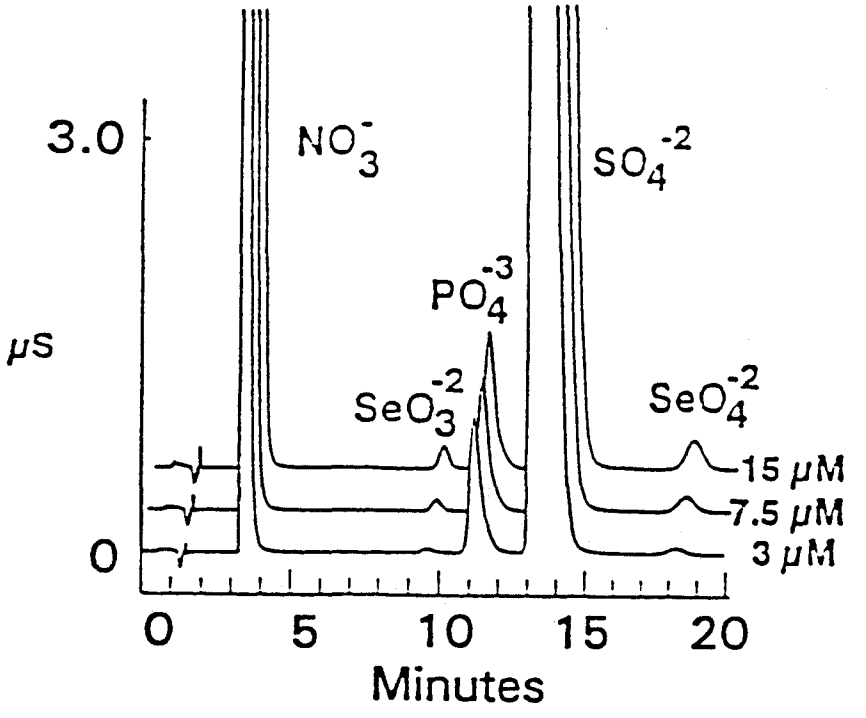


Figure 1. Example of an Ion Chromatography analysis of µM levels of selenite (SeO_4^{2-}) and selenate (SeO_4^{2-}) in solutions containing 1 mM NO_3^-, PO_4^{3-}, and SO_4^{2-}.

Selenium Extraction Methods: Results obtained through the application of a chemical extraction techniques will be used to test the relationship of Se in soil/backfills and plant contents. The extraction techniques applied in this study include hot-water, AB-DTPA, saturated paste and

phosphate methods. The saturation paste extracts will be analyzed for Se species to determine which species correlates with Plant Se content.

Precipitation and Dissolution studies: Attempts are being made to precipitate metal selenite and selenate from aqueous soil extracts. These will be compared with the pure compounds through their characterization by XRD and SEM. Currently some XRD studies have been done. Solubility studies with the precipitate will be performed and compared to the existing thermodynamic predictions in literature. Finally the results of the precipitation studies will be analyzed using the speciation model MINTEQA2. These studies are useful for: 1) characterizing solubilities and mobilities of different Se species and 2) determining its correlation with solid phase speciation.

Adsorption and Desorption Studies: Currently adsorption/desorption studies are being conducted using batch technique. These studies are important for a) determining Se adsorption capacity of the Abandoned Coal Mine Land soils, b) identifying how solubility, mobility, and availability of Se is governed by adsorption, and c) correlating Se adsorption with chemical and pedological properties.

Solid Selenium Speciation: Mobility and plant uptake of Se are dependent on the rate and degree of soil and overburden solubilization, and the nature of the chemical species formed. Se fractions from sequential extractions of these materials provide very important information on soil-plant relationships. Water soluble fraction (0.25 M KCl) represent the soil solution, exchangeable (0.1 M KH_2PO_4) fraction refers to the Se concentrations related to mobility and plant uptake, acid soluble (4 M HCl) fraction indicates the amount of Se that may be accessible over time and may be solubilized readily by plant root interactions.

Project Outcome

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

Personnel Involved with Project Doug Bonett, Associate Professor of Statistics, is supervising all project statistics. Shankar Sharmasarkar, Soil Chemistry Ph.D. candidate, joined the project in May 1992. Additional personnel contributing to this project include a Post-Doctoral Scientist, Research Associate and an undergraduate laboratory assistant.

Presentation Sharmasarkar et al., 1992. Selenium Adsorption and Precipitation Processes in Controlling Groundwater Contamination. Presented at the 5th Annual Wyoming State Section Meeting of the American Water Resources Association.

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

R.N. PASCH, G.F. VANCE, S.E. WILLIAMS, B.K. SCHLADWEILER, P. WANEK, M.S. PAGE, P.K. CARROLL

Semi-Annual Project Report

for the

Abandoned Coal Mine Land Research Program

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

Roger N. Pasch
Inter-Mountain Laboratories, Inc.
Sheridan, Wyoming

George F. Vance, Stephen E. Williams, Brenda K. Schladweiler, and Patsy Wanek
Department of Plant, Soil, and Insect Sciences
University of Wyoming

Margaret Stacy Page
Department of Environmental Quality
State of Wyoming

Peter K. Carroll
Thunder Basin Coal Company
Wright, Wyoming

November 17, 1992

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

Introduction

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

Objectives

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

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

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

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

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

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

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

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

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

indicate how overburden materials should be handled in the backfilling and reclamation process.

Methods of Analysis

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

Vegetation and Soil/Overburden/Backfill Sampling

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

On June 23, 1992, soil and plant samples were collected from four reclaimed sites at the AML Project 8, Hidden Water location outside of Sheridan. Twelve soil and 14 plant samples were collected.

Vegetation samples were collected twice from the active coal mine sites during the 1992 growing season.

During May 29 to June 6, 1992, plant samples were collected from the same sites sampled in 1991 at both Coal Creek Mine and Black Thunder Mine. Ten native sites from Coal Creek Mine were sampled, from which 58 plant samples were collected. Twenty-seven plant samples were collected from six reclaimed Coal Creek Mine sites. From the Black Thunder Mine, 67 plant samples from 13 native sites and 211 plant samples from 46 reclaimed sites were collected. Plant cover data was also estimated at each site location.

The second set of vegetation samples was collected from July 7-11, 1992. For this collection, 58 plant samples from the 10 native sites and 30 plant samples from the six reclaimed sites at the Coal Creek Mine were collected. From the Black Thunder Mine, 61 plant samples from 13 native sites and 188 plant samples from 46 reclaimed sites were collected. The same sites were sampled as in the previous month, and the collected plant species were similar, wherever possible.

Plants were cut, oven-dried and ground at the Soil and Environmental Chemistry Laboratory, University of Wyoming, and then sent to Inter-Mountain Laboratories, Inc., for analysis of total plant selenium.

Although this project was not funded to analyze soil/overburden/backfill samples in the second year, the project investigators felt there was a need for this data. On July 14, 1992, 15 soil samples from three native sites (4-6 depths per site) and eight soil samples from three reclaimed sites (2-3 depths per site) were collected from the Coal Creek Mine area. At the Black Thunder Mine, soils were collected from two native sites (4-7 depths per site) and from 10 reclaimed sites (two depths per site); no topsoil samples were collected from these reclaimed sites.

The 54 soil samples that were collected from Black Thunder and Coal Creek mines were analyzed for pH, EC, and SO_4 in saturated paste extracts (SPE). Selenium was also measured in these samples after SPE, hot water, AB-DTPA, and KH_2PO_4 extraction. In addition, Inter-Mountain Laboratories analyzed pH, total Se, and hotwater and AB-DTPA extractable Se in the AML Hidden Water soil samples.

Finally, data from all analyses of the 54 soil samples and more than 700 plant samples were assembled into a format for statistical analysis.

Preliminary Findings

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

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

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

Overall, total Se varied the least among the five Se variables followed by KH_2PO_4 < AB-DTPA < hot water = SPE Se.

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

Research Plan for 1992-1993

Vegetation and soil/overburden/backfill material will be sampled from native and reclaimed sites that were established in 1991. Vegetation will be collected at the same time soil/overburden/backfill materials are sampled. Plant cover and percent plant species at each site will be recorded to determine if there were major changes in vegetation composition as compared to 1991 and 1992. 1993 soil sampling techniques will be revised according to statistical results obtained from 1991 and 1992 samplings.

Both 1991 and 1992 data are currently being statistically analyzed to determine what relationships exist between soil/overburden/backfill and plant Se. Plant species, cumulative depth, and their relationship to the various extractants and resulting plant selenium are a few of the evaluations being done. In addition, the significance of sampling soil/overburden/backfill at three holes at each sampling location. This information will be used to further refine the 1993 soil/overburden/backfill sampling procedure.

Presentations:

Vance et al., 1992. Evaluation of Various Selenium Extraction Methods for Correlating Soil/Backfill Levels to Plant Concentrations. Presented at the national Soil Science Society of America Annual Meeting in Minneapolis, MN.

Two abstracts have been approved for presentation (initial project results only).

1) Relationship Between Soil Selenium Concentrations and Selenium Uptake by Vegetation on Surface Coal Mine Lands in Wyoming. 1993. Billings Reclamation Conference, Billings MT.

2) Comparison of Selenium Uptake by Vegetation on Surface Coal Mine Lands in Wyoming. 1993. American Society of Surface Mining and Reclamation 10th Annual Meeting, Spokane WA.

TOXICOLOGIC EVALUATION OF CHRONIC SELENOSIS IN WYOMING HERBIVORES

M.F. RAISBECK, E.L. BELDEN, D. O'TOOLE, J.W. WAGGONER
E.T. THORNE AND K.ZINN

Toxicologic Evaluation of Chronic Selenosis in Wyoming Herbivores

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

The overall objective of this project is improved understanding of chronic selenosis in economically important herbivores in Wyoming. Such basic understanding is one prerequisite to more accurately predict conditions under which Selenium (Se) in reclaimed mine sites is likely to pose a hazard to livestock and wildlife. The alternative is to continue accepting uncritically the "worst case" scenarios taken from the older scientific literature.

The principle tasks outlined for the first year of the project were to: 1) synthesize [^{75}Se]-Na_2SeO^3, [^{75}Se]-selenomethionine and cold selenomethionine; 2) Investigate the effects of Na_2SeO^3 and selenomethionine on rumen microbial digestive processes and 3) determine the metabolic fate of Na_2SeO^3 and selenomethionine in the rumen environment. Although not specifically noted in the proposal, we also initiated range finding studies preliminary to the animal experiments proposed for Spring '93.

Synthesis of selenium compounds at the UMC Research Reactor

[^{75}Se]-Na_2SeO^3 has been synthesized and is being used in the artificial rumen (see below). Unfortunately, because approval of the proposed research wasn't received until May, the facilities at the UMC reactor needed for selenomethionine synthesis were turned over to another project, and have only recently become available. At the time the proposal was written, selenomethionine was not commercially available in the quantities needed for the project; however, since that time *relatively* pure (80%) selenomethionine from natural sources has become commercially available. Dr. Zinn is currently investigating the relative merit (time vs. cost) of purifying selenomethionine from these sources rather than synthesizing them *de novo* as originally planned.

Identify ruminal metabolites of selenite and selenomethionine

[^{75}Se]-Na_2SeO^3 was added to artificial rumen cultures to provide 0, 0.1, 1.0, 10 and 50 ppm supplemental Se. After incubation for 24 hours at 39° C, the culture was killed by freezing and separated into water insoluble, protein and subprotein fractions. The protein was derivatized with iodoacetate and hydrolyzed with HCl. The water insoluble fraction was further incubated with acid-pepsin to model abomasal digestion, then, together with the subprotein fraction derivatized with iodoacetate. All

fractions were chromatographed on silica gel TLC and radioactivity identified with radioautography.

Surprisingly, the bulk (60%-70%) of the added ^{75}Se remained with the water insoluble fraction. Approximately 25% remained insoluble after acid pepsin digestion. Only 10% of ^{75}Se added to the *in vitro* system was incorporated into protein. At present we have identified selenomethionine, selenocysteine and what we believe is the ^{75}Se analogue of glutathione in output from the artificial rumen. Very little (less than background radioactivity), if any of the added activity was trapped on the activated charcoal filter, indicating that few volatile metabolites were formed. There do not appear to be any other major ^{75}Se metabolites. The experiment will be repeated various time intervals and with [^{75}Se]-selenomethionine as soon as the latter is available.

Determine effect(s) of naturally occurring forms of Se on rumen function *in vitro*.

Cold Na_2SeO_3 and selenomethionine were added at 0, 0.1, 1.0, 10 and 50 ppm Se to artificial rumen cultures. After a 24 hour incubation, the cultures were killed with dilute acid, and incubated with acid pepsin. Dry matter disappearance (digestibility), acetate, propionate and butyrate production (fiber digestion) and residual nitrogen were measured. Addition of 10 ppm Na_2SeO_3 and both 10 and 50 ppm selenomethionine slightly decreased digestibility at 24 hours. Added Se had relatively little effect on volatile fatty acid production at 24 hours, but dramatically decreased VFA production at 48 hours, regardless of form or dose. Conversely, residual nitrogen was less in the 0.1, 1 and 10 ppm Se cultures.

Range-finding study in cattle

Three yearling calves were utilized in a series of preliminary experiments to work out several details of the animal studies proposed for this Spring. One animal was given high (approximately 25 ppm) Se hay, one was given Na_2SeO_3-spiked feed and one was kept as a control from early June until October. Both the Se hay steer and the Na_2SeO_3 fed heifer had rough hair coats and failed to gain weight normally. After 90 days on Na_2SeO_3, the heifer showed a pale discoloration below the coronary band of the hooves and increased fragility of mane and tail. At this time the animal began to loose weight, and after approximately 120 days on trial, she died acutely overnight. There was never any sign of neurological disease, nor was any lameness observed in either animal.

The most pronounced clinical effect of Na_2SeO_3 was a conditioned feed aversion. After a few days to a week, the heifer refused to eat the spiked

feedstuff, whether or not additional Se was added. The effect was reversible by exposing the heifer to another animal eating similar feedstuffs for a period of days. This effect has not been noted in the steer fed high Se hay.

The most striking *post mortem* lesion in the heifer was focal myocardial (heart) necrosis. Tissues from this animal have been used to perfect the Danscher stain, a technique for demonstrating the presence of Se in individual cells. There were initially several problems encountered with nonspecific precipitates interfering with the stain, but these seem to be solvable by modified tissue preparation techniques.

Surprisingly, there were no obvious indications of organ damage in any of the clinical pathologic tests run during the experiment. Given the fact that the predominate pathologic findings were seen in myocardium, we are evaluating changes in the panel of tests we intend to use in the experiment this Spring. The conditioned aversion response seen in this animal indicates that administering the experimental toxicants in normal feedstuffs may pose a bigger obstacle than previously anticipated. While it remains possible to administer a daily dose of selenomethionine directly via a rumen cannula, we prefer that the toxicant be ingested normally. We are investigating several possible social methods of preventing the development of conditioned aversion response.

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

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

Progress Report

to

Abandoned Coal Mine Land Research Program

Office of Research

University of Wyoming P.O Box 3355

Room 202, Old Main

Laramie, Wyoming 82071-3355

Project Title: Methodology for the Geomorphic Classification and Design of Drainage Basins and Stream Channels in the Powder River Coal Field of Wyoming

Principal Investigators:

Thomas A. Wesche
University of Wyoming

Hugh W. Lowham
U.S. Geological Survey

Richard L. Daddow
U.S. Geological Survey

Mark E. Smith
U.S. Geological Survey

Graduate Research Assistants:

Lee E. Jensen
University of Wyoming

Anthony J. Anderson
University of Wyoming

Progress Report Period: 6/1/92 - 10/31/92

Introduction

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

Progress During the Report Period

Project team meetings have been held at regular intervals since project initiation. These meetings were a cooperative effort by University of Wyoming and U.S.G.S. project members and serve as a means of pooling resources, reviewing available data, and conducting detailed planning to achieve project objectives.

Interviews were conducted with coal mine personnel in the Powder River coal field to establish contacts, discuss project objectives, assess current mine operations, and gain an understanding of problems encountered in drainage basin and stream channel design. All surface coal mines in the eastern Powder River Basin area were included in the interviews. The interviews were conducted by both University of Wyoming and U.S.G.S. project team members.

The literature review has been ongoing with participation by both the University of Wyoming and the U.S.G.S.. The focus of this review is primarily drainage basin and stream channel classification and design, and methodologies for geomorphic analysis. More than 50 articles have been reviewed to date.

The major impetus for this report period has been a intensive search of available data sources for drainage basin and stream channel characteristics, streamflows, climate, geology, soils, and vegetation of the Powder River coal field. Due to the availability of data sources investigated to date, we have defined our study area to include lands within or around active surface coal mine permit areas in the eastern Powder River Basin. There are numerous data sources for this area and those applicable to our project objectives will be used. Two major data sources are being intensively reviewed by project members at this time. One source is the data contained in the coal mine permit applications at the Department of Environmental Quality in Cheyenne, Wyoming.

University of Wyoming project members have investigated and compiled a large portion of these data; however, these data contain variations in accuracy, methods of measurement, and type of data collected. Suitability of these data for project use has not yet been determined. U.S.G.S. project members are evaluating data from streamflow-gaging stations operated by the Bureau of Land Management, coal companies, and the U.S.G.S. in the study area to determine suitability for project use. Project members have agreed that existing databases for soils, vegetation, climate, and geology will be used to the extent possible. Databases from the Soil Conservation Service, Bureau of Land Management, Department of Zoology at the University of Wyoming, and the Department of Environmental Quality are being evaluated. The use of Geographic Information Systems (G.I.S) is also being considered.

Drainage basins and channel networks will be characterized and classified at a 1:24,000 scale using U.S.G.S. topographic maps. A published U.S.G.S. database containing 102 delineated drainage basins in the study area at the 1:24,000 scale and other possible data sources exist at this scale. Channel morphology and hydraulic geometry will be characterized by onsite investigations and the use of large scale (1:500) aerial photographs and topographic maps.

A base map at the 1:250,000 scale will be used for selection of sampling sites. Sample sites will be selected by random sampling and stratified random sampling procedures. The properties of the 102 drainage basins measured and analyzed previously by the U.S.G.S. will be used as "core" data for preliminary testing of properties' statistical significance. An expanded sample of natural basins, with insignificant human disturbances, then will be selected that: 1) include small drainage basins, entirely within the study area, for which streamflow data of acceptable quality are available; 2) cover the study area geographically; and 3) incorporate basins measured previously by coal mine companies or consultants, assuming that acceptable quality of data can be assured. A subsample of the drainage basins selected for analysis will be used for onsite investigation of channel morphology and hydraulic geometry.

A list of potential variables used to characterize drainage basins and channel networks has been compiled for preliminary consideration. Project members have selected several variables for characterization of the drainage basins and channel networks. These variables will be used to describe the linear, aerial, and relief characteristics of the drainage basins, drainage networks, and stream channels. Final variable selection will be presented in the graduate research study plans indicated below.

Portions of the research project will be developed in two Master of Science theses at the University of Wyoming. The two theses are titled: 1) "A Geomorphic Classification of Drainage Basins in the Eastern Powder River Basin, Wyoming"; and 2) "Characterization of Drainage Networks for Mine Land Reclamation in the Eastern Powder

River Basin, Wyoming". These graduate research projects are being pursued by Lee E. Jensen and Anthony J. Anderson, graduate research assistants in Range Management / Water Resources at the University of Wyoming. The impetus of the two thesis projects centers around the project objectives. Detailed study plans for each thesis project are scheduled to be completed by December, 1992.

Future Work

The suitability of the various databases will be presented in the graduate research study plans. After the study plans are finalized and accepted by project and graduate committee members, the plans will be initiated. During the first four to six months of 1993 the drainage basins and drainage networks to be studied will be selected and delineated. Field measurements of channel morphology and hydraulic geometry will be scheduled at the earliest time field conditions allow in the spring of 1993. Variables to be measured for the drainage basins, drainage networks, and channel morphology and hydraulic geometry will be decided upon finalization of the theses study plans. U.S.G.S. project members will be compiling streamflow information and will assist with drainage basin and drainage network characterization and classification as well as participate in the onsite investigations of channel morphology and hydraulic geometry.

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

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

Long-Term Stability of Designed Channels at Reclaimed Coal Mines in Wyoming

Sara L. Rathburn
Paul A. Rechard
Todd Hanlin
Daryl R. Jensen

Western Water Consultants, Inc.

Abandoned Coal Mine Land Research Program
Semi-Annual Project Review Seminar
Sheridan, Wyoming
November 17, 1992

Introduction

The long-term performance of designed channels at reclaimed coal mines in Wyoming is largely unknown due to the lack of large magnitude events and the short time since construction completion. Management and regulatory decisions, however, confront Abandoned Mine Land (AML) and Department of Environmental Quality/Land Quality Division (DEQ/LQD) personnel in the form of complete certification and bond release issues. The overall objective of this research is to understand the controls on channel stability for ephemeral channels in Wyoming to derive a means of evaluating long-term designed channel performance in the absence of a long-term data sets. Specific objectives of the research include:

1. Inventory geomorphic and channel design criteria at reclaimed abandoned coal mines with channel restoration work to understand previous reclamation practices.

2. Conduct field investigations at unmined drainage basins and channel systems to define criteria that provide for a dynamic equilibrium or stable condition.

3. Quantitatively evaluate reclaimed channel performance by statistically comparing design criteria employed at reclaimed AML coal sites with data from similar, unmined surface drainage systems.

The basic premise of our research is that natural channels serve as proxies for premining or baseline conditions. Natural alluvial channels develop over long, continuous exposure to prevailing climatic conditions. The channel geometry that develops reflects the sediment and water discharges delivered to and conveyed by streams, and indicates a stable yet dynamic channel configuration.

Inventory

A review of consultant's reports, engineering design plans, construction-as-builts, and AML site files was conducted for 14 reclaimed coal sites. During the inventory, it was noted that 4 of the 18 sites initially identified as channel reclamation projects were not oriented to channel design, and therefore were dropped from the inventory.

Information collected during the inventory included channel design criteria, runoff assumptions, and channel and basin characteristics. While the success of locating project reports and plans for review was high, the success of finding information necessary for data evaluation within the literature was low. The most commonly lacking data were subbasin area draining reclaimed channels, despite the fact that channel design necessitates a rainfall-runoff analysis and delineation of subbasin areas. While the work was obviously completed for all reclamation projects, it was not included in the submitted reports. Efforts to contact consultants responsible for the design work were unfruitful due to changes in personnel, and difficulty in locating working papers from older projects.

Field Work

Data from natural channels were initially collected from topographic maps and aerial photographs. The natural channels were selected based on similarity of geology, basin size, basin shape, and aspect if possible. It was difficult to match reclaimed basin size at the undisturbed basins because of the small size (<10 acres) of the reclaimed sites. The scale of topographic maps (1:24,000) and aerial photos (1:22,000) limited accurate small basin delineation. We surveyed the perimeter of a few small basins to expand the data set to better correspond to the <10 acre drainage area of the reclaimed channels.

Twenty four unmined basins were studied within the Rock Springs study site. The field work entailed surveying channel cross section and a local slope at the mouth of each unmined basin, and generally assessing the overall character of the stream (i.e., presence of gullies, headcuts, bank instabilities). A concerted effort was made to study only those channels/basins that appeared unaffected by anthropogenic activity such as roads, structures, and obvious grazing. Photographs were taken at each unmined basin measured.

Data Evaluation

Data evaluation to date has included comparing various channel and basin morphometric parameters (such as channel slope vs. drainage basin area) that are documented as influential to channel stability (Patton and Schumm, 1975; Elliott, 1990), and developing regression relations. A parameter called the Area Gradient Index (Schumm et. al., 1984) has also been used which improved correlations by including a quasi-measurement of total stream power. Total stream power represents the ability of drainages to transport sediment, an important component of channel equilibrium and stability. The Area Gradient Index is useful in regions where hard data on sediment transport is unavailable.

Results

Projects 6C-2 and 6C-8, the Colony and Rainbow sites south of Rock Springs, WY, were the only sites where a complete suite of design information was readily available (Table 1). Particularly useful were the hydraulic tables and separate geomorphic report submitted to AML. Our research into stability has thus focused on the Rock Springs study site, the area encompassing the Rainbow and Colony mines.

It was observed during field work that natural, unmined channels adjacent to the Rainbow and Colony mines are narrow and deep. Dense sagebrush frequently anchors the top bank of channels, and coarse sediment of the Rock Springs Formation armors channel bottoms to varying degrees. Typical channel cross sections for the unmined channels are V-shaped, with a narrow, flat bottom. Reclaimed channel cross sections are significantly different, forming broad, shallow swales. Flow depths associated with the 10-year, 1-hour design event range from 0.1-0.3 feet, and top widths from 5-7 feet at the reclaimed drainages. In contrast, depths and top widths for 10-year, 1-hour discharges within the natural channels studied vary from 0.1-1.3 feet and 1-9 feet, respectively.

Natural channel slopes for basins within the Rock Springs study site form a limiting

threshold, and the reclaimed Rainbow and Colony channels plot well within the envelope. Poor correlations by linear regression were obtained for plots accounting for only hydraulic capacity of channels, and apparently morphometric information alone does not fully account for channel stability. Including Area Gradient Index on plots improves the correlation (R^2=0.77), and indicates that reclaimed channels at the Colony and Rainbow mines have channel top widths that are larger, and channel depths for the design event that are less than those of adjacent reclaimed drainages. Within the constraints of the data, the response of the reclaimed channels to significant flow events may be to incise, to effectively decrease top width and increase depth.

Preliminary Findings

- There is a general lack of data on designed channels at reclaimed coal mines in consultant's reports and engineering plans submitted to AML.

- At a minimum, drainage basin area, runoff information, design flow recurrence interval, and channel geometry are necessary to evaluate reclamation design performance.

- A threshold channel slope of <0.22 ft/ft develops for undisturbed basins 0-80 acres in size adjacent to the Rainbow and Colony mines. Reclaimed channel slopes plot well within the limiting curve.

- Poor correlation between channel and basin morphometric parameters indicates that hydraulic capacity alone is an insufficient means of defining channel stability within the Rock Springs study site.

- By incorporating sediment transport considerations, a reasonable correlation is developed for unmined basins in the Rock Springs area.

- Plots of top width and depth versus Area Gradient Index indicate that incision may be a likely response of reclaimed channels to significant flow events. This is consistent with field observations of approximately 1-4 inches of incision within the Rainbow and Colony reclaimed channels.

Information Transfer

One abstract has been published and a presentation given at the Fifth Annual American Water Resources Association Meeting:

Rathburn, S.L., Rechard, P.A., Hanlin, T., Jensen, D.J., Long-term Stability of Designed Channels at Reclaimed Coal Mines, Rock Springs, Wyoming, AWRA Wyoming State Section Fifth Annual Meeting, October 28-30, 1992.

References Cited

Elliott, J.G., 1990, Geomorphic evaluation of erosional stability at reclaimed surface mines in northwestern Colorado: U.S. Geological Survey Water-Resources Investigations Report 90-4132, 67 p.

Patton, P.C., and Schumm, S.A., 1975, Gulley erosion, northwestern Colorado: A threshold phenomena: Geology, 3, p. 88-90.

Schumm, S.A., Harvey, M.D., and Watson, C.C., 1984, Incised Channels - Morphology, Dynamics and Control: Water Resources Publications, Little, Colorado, 200 p.

TABLE 1. DESIGNED CHANNEL CHARACTERISTICS, RECLAIMED AML COAL SITES, WYOMING

Site	Basin	Drainage Area (acres)	Design Event	Design Discharge (cfs)	Velocity (fps)	Bottom Width* (ft)	Top Width* (ft)	Depth (ft)	Channel Slope	Width Depth Ratio	Shear Stress (lb/ft2)	Hydraulic Length (ft)	Side Slopes	X-Sec Shape	Long Profile Shape	Pilot Channel	Comment
6C-2	1	9.6	10-yr,	2.9	2.35	3.04	4.90	0.31	0.02	15.81	0.39	1420	3:1	trap		2-4' wide	
Rainbow	2	7.8	1-hr	2.3	2.18	3.09	4.71	0.27	0.02	17.44	0.34	1330		(on grading			
Mine	3	4.3		1.5	1.94	2.87	4.19	0.22	0.02	19.05	0.27	730		plans)			
	4	6.7		2.3	2.49	3.11	4.55	0.24	0.03	18.96	0.45	860					
	5	5.3		1.3	1.83	2.95	4.15	0.20	0.02	20.75	0.25	1100					
	6	3.1		1.1	1.97	3.01	3.97	0.16	0.03	24.81	0.30	560					
	7	8.4		2.5	2.61	2.91	4.47	0.26	0.03	17.19	0.49	1580					
	8	1.4		0.6	1.97	3.11	3.65	0.09	0.06	40.56	0.34	440					
	9	7.1		1.8	2.31	3.07	4.33	0.21	0.03	20.62	0.39	1800					
	10	4.1		1.2	2.28	2.83	3.79	0.16	0.04	23.69	0.40	1150					
	11	3.9		1.3	2.45	3.08	3.98	0.15	0.05	26.53	0.42	870					
	12	2.6		0.9	2.57	2.86	3.52	0.11	0.08	32.00	0.55	950					
	13	2.4		0.8	2.27	3.21	3.81	0.10	0.07	38.10	0.44	860					
	14	4.0		1.3	1.83	2.95	4.15	0.20	0.02	20.75	0.25	1010					
	15	2.7		1.0	1.67	3.02	4.04	0.17	0.02	23.76	0.21	650					
	16	7.5		2.3	2.67	3.14	4.46	0.22	0.04	20.27	0.55	1100					
6C-4	0 to 2		10-yr,		4.7	10		1.8	0.01				1:1	trap	stepped	no	bedrock control
College	2 to 2.75		24-hr		7.4			1.2	0.04								
Hill	2.75 to 4				5.5			1.6	0.016								
	4 to 4.6				5.6			1.5	0.017								
	4.6 to 7				4.3			1.9	0.0075								
6C-8	I	5.2	10-yr,	1.7	2.8	4.17	5.34	0.13	0.075	41.08	0.55	700	4.5:1	trap	convex-	to form	
Colony	II	17.0	1-hr	3.1	2.9	4.12	6.01	0.21	0.048	28.62	0.53	1000			concave	naturally,	
Mine	III	9.6		2.4	2.5	4.17	5.88	0.19	0.04	30.95	0.41	1000				assumed 4'	
	IV	8.7		2.0	1.5	3.96	6.30	0.26	0.01	24.23	0.13	900				wide w/	
																4.5:1 side	
																slopes	
7-26		154	100-yr,	200		8		2	0.049			3925	4:1	trap		no	
			24-hr														
7-28									0.005				3:1				rock gallery
Toilet																	
Bowl																	
7B-1	SE Site					12			0.05				4:1	V in V	concave-	3' deep	meandering planform
Elk Mtn.															convex		
area																	

TABLE 1. DESIGNED CHANNEL CHARACTERISTICS, RECLAIMED AML COAL SITES, WYOMING (cont.)

Site	Basin	Drainage Area (acres)	Design Event	Design Discharge (cfs)	Velocity (fps)	Bottom Width* (ft)	Top Width* (ft)	Depth (ft)	Channel Slope	Width Depth Ratio	Shear Stress (lb/ft2)	Hydraulic Length (ft)	Side Slopes	X-Sec Shape	Long Profile Shape	Pilot Channel	Comment
8-8						40		~7.5					5:1	V			
8-13 Mine Fire Site			100-yr, 24-hr	350					0.005						concave & convex portions		
8-19 Hidden Waters	Channel 1 Channel 2					72 40			 0.0267				20:1 15:1	V in V V in V		12' wide 4:1 10' wide 5:1	
8-23 Hidden Waters	Type A Type B					30 15		2.5 1.25	0.02 0.005				10:1 6:1	V in V V		10' wide, 1.5' deep no	
8-24						40			0.03				20:1	V in V		8' wide, 4:1	
9B-15						8		2	0.13				2:1	V ditch			
15A-22 Welch Mine/ Kaycee Site	Type I Type II		10-yr, 24-hr		5	12	28	2 2 min	0.004				4:1 3:1	V in trap V		1' deep, 2:1	
15A-24 Pugsley Mine	Type I	5.3	10-yr, 24-hr		5	12	28	2 min	0.022				4:1	V in trap		1' deep, 2:1	

* Calculated using FlowMaster and available design information