SELENIUM AND MINING IN THE POWDER RIVER BASIN, WYOMING: PHASE I - VEGETATION ANALYSIS[1]

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Abstract: Selenium in soils, waters, and plants is an important environmental issue to many western United State's areas. Because of concerns such as those associated with areas like Kesterson Wildlife Refuge in California, surface mining activities in the Powder River Basin of Wyoming have been characterized as being potentially harmful due to the relocation of seleniferous geological materials to rooting zone environments. As a result of regulatory actions initiated in the mid 1980's, Wyoming Department of Environmental Quality-Land Quality Division, Wyoming Mining Association, and University of Wyoming personnel formed an interactive research committee to address the issue of selenium and mining in the Powder River Basin. The objectives of the committee were: 1) to develop detailed sampling and selenium analytical procedures for soil, overburden, backfill, and vegetation; 2) to identify selenium levels in premining and postmining environments within the Powder River Basin; 3) to develop predictive relationships between selenium in the environment and organisms; and 4) to identify appropriate suitability levels for selenium in post-mining backfill. In order to address the objectives listed above, a three-phase research project for soil, overburden, vegetation, and wildlife was developed. Phase I consisted of analyzing vegetation selenium levels on both premined and reclaimed lands in 1991 and 1992. Phase II involved the analysis of selenium in overburden, backfill, and soils. Phase III attempted to identify the effect of selenium on target organisms.

This paper will discuss Phase I results only; Phase II and III studies are discussed in separate papers. Data for Phase I were collected from most of the active mine sites in the Powder River Basin of Wyoming, and included: environmental variables at each site, a vegetation survey, sampling the vegetation by life-forms, and analyzing the selenium in the sampled vegetation. The results of this study suggest that: 1) there is a slight, but distinct, tendency for selenium to be greater in reclaimed than premined vegetation; 2) reclaimed vegetation selenium concentrations decrease with time; 3) sites can be selected with elevated levels of selenium in vegetation based on non-vegetative site characteristics; 4) selenium levels in grasses were consistently lower than those in forbs and shrubs, and warm season grasses are lower than cool season grasses; 5) moisture availability may play an meaningful role in modifying selenium uptake, and 6) geographic location may be more important than any other factor in the elevation of selenium levels in vegetation.

Additional Key Words: Site Characteristics, Standard Operating Procedures, Lifeforms, Premined and Reclaimed Environments

Introduction

Selenium, an element widely distributed through the earth's crust, tends to be found in sedimentary geologic material and formations (Case and Cannia, 1988). Selenium is commonly found in varying degrees throughout sedimentary formations of Wyoming, including those of the Powder River Basin, a site of large scale surface coal mining activity. Selenium is an essential micronutrient when consumed in trace amounts, yet can be toxic when consumed in quantities exceeding particular threshold limits. Fisher et al. (1987) identified two areas of toxicological concern regarding selenium and surface coal mine reclamation: 1) the exposure of seleniferous materials by mining such that selenium uptake by plants could result in selenium toxicity to foraging animals; and 2) the quality of both surface and ground water that would come in contact with "exposed" seleniferous materials.

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[1]Paper presented at the 1995 National Meeting of the American Society for Surface Mining and Reclamation, Gillette, Wyoming, June 5-8, 1995.

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Proceedings America Society of Mining and Reclamation, 1995 pp 317-332
DOI: 10.21000/JASMR95010317

https://doi.org/10.21000/JASMR95010317

The concerns of Fisher et al. (1987) are also shared by the Wyoming mining industry and Wyoming regulatory agencies. However, the challenge has been to quantitatively assess selenium in the mining environment. Compounding the mining/selenium issue has been the national interest generated when selenium was found in the Kesterson Wildlife Refuge of California (Bainbridge et al., 1988) and more regionally in the Kendrick Irrigation Project of Wyoming (Edwards and Fallat, 1989). Selenium in the mining environment became a primary concern to the Wyoming coal industry in November 1984, when the Wyoming Department of Environmental Quality - Land Quality Division revised the definition of backfill suitability. (Guideline No. 1 "Topsoil and Overburden" 1984). One of the major revisions that was included in the new guideline was the reduction in the selenium suitability limit from 2.0 mg/kg to a "marginal" suitability of 0.1 mg/kg extractable selenium. (Wyoming Department of Environmental Quality-Land Quality Division, 1984). Extractable selenium represented the amount of selenium extracted by either hot water or AB-DTPA (ammonium bicarbonate - diethyltetraaminepentaacetic acid).

After the new guideline was established, the mining industry has been forced to seriously consider the effects of this revision because significant amounts of overburden material exceed the revised suitability criteria of 0.1 mg/kg extractable selenium. Some of the issues and concerns that apply to the mining environments include: 1) selenium extraction and analytical techniques are still undergoing development and change - the inability to duplicate and repeat analytical results between and within laboratories points to the need for standard operating procedures; 2) the 1984 suitability limit of 0.1 mg/kg extractable selenium was based, in part, on greenhouse experiments that focused on the development of multiple element extractants (Soltanpour and Workman, 1980; Vance, 1990); 3) little baseline information is yet available on pre-mining levels of selenium in vegetation, soil, or waters of the Powder River Basin in Wyoming; and 4) little information is available on the uptake of selenium by vegetation species being used in reclamation. Due in part to these concerns, and the substantial costs associated with special handling large quantities of overburden, the Wyoming Mining Industry and Wyoming Department of Environmental Quality entered into a joint agreement to address the selenium issue. On December 5, 1990, a meeting between the Wyoming Department of Environmental Quality-Land Quality Division and the Wyoming Mining Association was held. From that meeting a joint project was proposed and three subcommittees were formed to address selenium in the mining environment. The three subcommittees formed have focused on regulatory affairs, hydrology, and the combined issues of soil, overburden, vegetation, and wildlife. Each subcommittee is composed of members from the coal industry, Wyoming Department of Environmental Quality-Land Quality Division, and the University of Wyoming or comparable research-oriented entity.

Two main objectives of the Selenium in Soil, Overburden, Vegetation, and Wildlife committee were to establish current and detailed selenium sampling and analytical procedures for soils and vegetation, which was completed and published in 1994 (Spackman et al., 1994; Steward et al., 1994). Other committee objectives were to identify: 1) selenium levels in the premined and postmined environments of the Powder River Basin; 2) predictive relationships between selenium in the environment and organisms; and 3) appropriate suitability levels for selenium in postmining backfill. These objectives are being met by a multi-phase research project. This paper focuses on the accomplishments of Phase I of the "Joint Subcommittee on Soil, Overburden, Vegetation, and Wildlife".

Materials and Methods

The research proposed to evaluate selenium in soil, overburden, vegetation, and wildlife was divided into three phases to assure identification of all variables and develop proper field and laboratory techniques for consistency and reliability. Phase I consisted of identifying vegetative selenium levels for both premined and reclaimed lands. Phase II evaluated the relationship of plant selenium concentrations and selenium in overburden, soil, and backfill materials (see Spackman et al., 1995). Phase III attempted to identify the effect of selenium on target organisms (see Steward et al., 1995). Each of the coal mining operations in the Powder River Basin of Wyoming was asked to participate in this research project.

Phase I

A survey of vegetative selenium levels on premining and postmining lands was conducted in 1991 and 1992. Sample sites were both randomly and selectively chosen. Random sampling was designed to describe the average or typical levels of selenium in plants within coal mine related disturbances of the Powder River Basin of Wyoming, whereas selective sampling focused on locations where selenium levels were expected to be high. Vegetation was collected from both premined and reclaimed areas.

Vegetation was selected in Phase I to provide a basis for a more detailed study of potential environmental variables that may influence selenium changes resulting from the mining process. Samples of the collected vegetation were analyzed for total selenium levels after digestion of the plant materials (Steward et al., 1994). Analysis for selenium in vegetation is not complicated by the need to select from a variety of extraction methods prior to analysis, as is analysis for selenium in rooting zone material (Spackman et al., 1994).

Premined and Reclaimed Site Selection

All premined areas from which overburden was to be removed, or areas that have been reclaimed, were identified and mapped for each mine, excluding any existing disturbed areas. A 100-foot grid was overlaid on the overburden removal and reclaimed area maps with each grid center numbered. For premined sites, one sample location was selected using a random numbers table for every five hundred acres of overburden removal. For reclaimed sites, one sample location was selected for each fifty acres of reclaimed land. All sites used in this study were located and marked in the field.

Standard vegetation field site selection techniques were used to randomly locate each sample location within the plot (Steward et al., 1994). If a sample location was devoid of vegetation, an alternative site was located. Additional vegetation samples were collected from areas where existing overburden, backfill or plant data indicated the soils and/or parent material were above the selenium suitability limit (> 0.1 mg/kg). Each sample location was permanently marked in the field, labelled, and photographed. Preselected characteristics of each site were documented on a standardized data sheet (Steward et al., 1994).

Sample Time

Vegetation samples were collected between bolting and flowering of western wheatgrass to insure that all vegetation was sampled during a common growth period. The sampling period varied depending on Climatic factors such as precipitation, temperature, and wind.

Sampling Procedure

Plots of one square meter were delineated at each field site location. Vegetation cover, bare ground, litter, and other cover characteristics of the site were estimated as outlined in Guideline No. 2 (Wyoming Department of Environmental Quality-Land Quality Division, 1986). Lifeforms, including warm season grasses, cool season grasses, forbs, and shrubs, were harvested following vegetation cover estimation. Only non-woody portions of the plants were collected. When all four lifeforms were not present, the dominant individual species, identified by cover estimation, were collected so that up to four samples were taken. Approximately ten grams of the individual plants in each lifeform, or of the dominant species closest to the center of the plot, were collected. Plants were immediately chilled in the field, frozen within eight hours, and transported to the lab within 60 hours of collection. Samples were kept frozen until analysis, which occurred within two weeks of receipt by the analytical laboratory. Standard operating procedures, developed by the subcommittee, were followed throughout this research project, wherever possible (Steward et al., 1994).

Laboratory Preparation and Analytical Procedures

A modified perchloric acid/hydrofluoric acid/nitric acid method (Lim and Jackson, 1982) was used for plant digestion. Inductively coupled argon plasma atomic emission spectrometry (ICAP-AES) was used for selenium analysis on the digested samples (Steward et al., 1994).

Results and Discussion

Vegetation was sampled at 242 sites during the early summers of 1991 and 1992. Samples were either randomly or deliberately selected from premined or reclaimed areas. While the original data set contained only samples from sites where the vegetation had been established for two or more growing seasons, additional analyses were performed on data from sites where the vegetation had been established for only one growing season at the time of sampling. The augmented data set is referred to the "1991" data set. This 1991 data set was used for analysis only when specifically referenced. SAS statistical programs were used to describe the data set and to perform correlation analysis and analysis of variance.

Descriptive Statistics

Descriptive statistics for the data set as a whole are presented in Table 1. Information is presented for the combined data set, the data set separated by samtype (premined or reclaimed), by method (randomly or deliberately selected), and by time (sampled during year one (1991) or year two (1992) of the program).

Table 1. Descriptive statistics for combined site and sample variables evaluated in Phase I. See Appendix for abbreviation definitions.

Obs	Variable	N	Minimum	Maximum	Average	Std Dev
242	VEG	222	5.00	112	36.0	17.7
	LITROCK	223	1.00	90.0	42.3	20.1
	BARESOIL	207	1.00	95.0	26.6	20.2
	CSPGC	213	0.01	90.0	17.8	12.2
	WSPGC	92	0.01	55.0	7.80	9.62
	SHRBC	93	0.10	45.0	9.91	10.3
	OTHERC	66	0.10	82.0	9.19	13.9
	FORBC	145	0.01	64.0	7.77	11.2
	PPTN	237	14.3	38.1	30.5	4.60
	CSPGSe	205	0.01	3.60	0.48	0.53
	WSPGSe	82	0.01	2.75	0.40	0.39
	FORBSe	143	0.01	75.0	1.88	6.89
	SHRBSe	89	0.01	12.3	0.73	1.38
	AGCRSe	18	0.10	1.95	0.49	0.46
	AGDASe	45	0.01	2.50	0.59	0.63
	AGSMSe	84	0.01	2.40	0.56	0.47
	ARTRSe	10	0.10	0.70	0.35	0.24
	ASBISe	3	47	575	233	297
	BOGRSe	5	0.15	0.40	0.29	0.11
	BRTESe	12	0.01	2.60	0.68	0.74
	CAFISe	9	0.01	0.25	0.14	0.09
	CALOSe	7	0.01	0.75	0.26	0.24
	CELASe	3	0.35	1.90	0.95	0.83
	KOCRSe	16	0.01	0.90	0.30	0.22
	MESASe	8	0.25	2.40	0.75	0.69
	SAKASe	5	0.50	13.2	3.60	5.44
	STCOSe	27	0.01	1.25	0.39	0.32
	STVISe	27	0.01	1.95	0.53	0.50
	TAOFSe	5	0.10	4.60	1.16	1.93

Combined

Overall, absolute vegetation cover in the study area averaged 36 percent and ranged from 5 to 112 percent. On the average, about one-quarter of the surface of the sample location was bare soil; approximately half of the surface was covered by litter or rock. In the worst case sample, bare soil was exposed over 95 percent of the surface. Vegetation cover was dominated by cool season grasses (18 percent); warm season grasses, shrubs, and forbs each averaged between 8 and 10 percent cover. Annual grasses also averaged about 9 percent cover overall. Average precipitation in the study area was 30.5 cm, with a large range from 14.3 to 38.1 cm.

Among lifeforms, the highest average level of selenium was found in forbs, whereas the lowest average selenium content was in warm season grasses (1.88 vs.0.40 mg/kg). Lifeform values ranged from below detectable to 75 mg/kg. Some data were available by species; the selenium level in two-grooved milkvetch (*Astragalus bisulcatus*) was the highest encountered at 575 mg/kg. Of interest were the relatively high levels of selenium in dandelion (*Taraxacum officinale*) (average of 1.16 mg/kg) and Russian thistle (*Salsola kali*) (average of 3.60 mg/kg). Warm season grasses such as prairie sandreed (*Calamovilfa longifolia*) and blue grama (*Bouteloua gracilis*) were low (averages of 0.25 and 0.29 mg/kg) in selenium; warm season species appeared to be about forty to fifty percent lower than the typical average values for the various cool season grasses of about 0.5 mg/kg. No large differences were observed between premined and reclaimed wheatgrasses, although crested wheatgrass (*Agropyron cristatum*) had a lower maximum and a lower average than the other wheatgrass species. Although the level of selenium in shrubs as a growth form was high (average of 0.73 mg/kg) relative to the other lifeforms, some individual species values, notably big sage (*Artemisia tridentata*) at 0.35 mg/kg, were lower. Winterfat (*Ceratoides lanata*), which in this study was found only on premined lands, had an average selenium level of 0.95 mg/kg. Four-wing saltbush (*Atriplex canescens*), the species most likely to be encountered on reclaimed lands, was not sampled individually for selenium content in this study. Average selenium levels in thread-leaf sedge (*Carex filifolia*), a graminoid, were lower than selenium in any other species encountered (0.14 mg/kg). Junegrass (*Koeleria cristata*), a grass similar in phenology to thread-leaf sedge, was also low in selenium (0.30 mg/kg). Selenium in alfalfa (*Medicago sativa*), which might be expected to be high because of its extensive root system, averaged far below the other forbs at 0.14 mg/kg. None of the average values for selenium in either the lifeform or species category, exceeded the level often cited as hazardous, 5 mg/kg. In fact, levels over 5 mg/kg were found only in the <u>maximum</u> values for forbs (as a group), shrubs (as a group), and two-grooved milkvetch, and Russian thistle as individual species.

Premined versus Reclaimed

Descriptive statistics comparing premined and reclaimed lands are given in Table 2. The age of reclaimed lands, based on date of permanent revegetation (DPERMVEG), ranged from 1975 through 1990. Topsoil depths averaged 21.4 inches on reclaimed land; topsoil includes premined A, B, and C horizon material mixed together and laid on backfill. Average depth of combined A and B horizon material on premined lands was 27.2 cm. Slope steepness was higher on native than reclaimed lands, likely due to the regulatory restrictions placed on landscape reconstruction.

While reclaimed lands had the highest maximum absolute vegetation cover, premined lands had higher average vegetation cover. Litter and rock cover was higher (maximum and average) on reclaimed lands than premined lands. Cool season grass cover and forb cover were higher on reclaimed lands, while warm season grass cover and shrub cover were higher on premined lands. Annual grass cover, on average, was higher on reclaimed lands than premined lands, although the maximum value encountered for annual grasses was on premined lands. The trend observed in the data was for selenium to be slightly higher on reclaimed lands than premined lands. This was true of maximum values for shrubs (the group), crested wheat grass, thickspike wheatgrass (*Agropyron dasystachyum*), cheatgrass (*Bromus tectorum*), prairie sandreed, alfalfa, Russian thistle, needle and thread (*Stipa comata*), green needlegrass (*Stipa viridula*), and dandelion as individual species.

Table 2. Descriptive statistics for premined and reclaimed sites evaluated in Phase I.

	Premined (N=147)					Reclaimed (N=95)				
Variable	N	Minimum	Maximum	Average	Std Dev	N	Minimum	Maximum	Average	Std Dev
TVEG	134	6	96	38.4	16.7	88	5	112	32.3	18.6
LITROCK	134	1	80	41.6	17.3	89	1	90	43.3	23.8
BARESOIL	126	2	95	25.2	18.6	81	1	86	28.7	22.4
CSPGC	127	1	80	16.4	10.6	86	0.01	90	20.0	13.9
WSPGC	88	0.01	55	7.92	9.8	4	2	10	5.0	3.5
FORBC	94	0.01	40	5.19	6.56	51	0.01	64	12.5	15.8
SHRBC	86	0.1	45	10.5	10.4	7	1	5.0	2.57	1.7
OTHERC	44	0.1	82	7.22	13.2	22	0.1	46	13.1	14.7
ABDEPTH	135	1.30	122	27.2	20.8	-	-	-	-	-
DPERMVEG	-	-	-	-	-	91	1975	1990	1985	4.1
TSDEPTH	-	-	-	-	-	87	5.3	152	54.4	23.4
SLOPEPOS	147	1	7	3.31	1.47	94	1	7	2.91	1.71
SLOPESTP	147	1	4	2.12	0.93	95	1	4	2.00	0.97
CSPGSe	134	0.01	3.6	0.43	0.50	71	0.01	3.25	0.56	0.57
WSPGSe	79	0.01	2.80	0.39	0.39	3	0.30	1.25	0.65	0.52
FORESe	98	0.01	75	2.30	8.30	45	0.07	5.05	0.91	1.05
SHRBSe	84	0.01	3.0	0.58	0.59	5	0.20	12.3	3.26	5.12
AGCRSe	5	0.20	1.0	0.44	0.35	13	0.01	1.95	0.50	0.51
AGDASe	9	0.01	0.90	0.31	0.29	36	0.01	2.50	0.66	0.68
AGSMSe	36	0.01	1.80	0.54	0.42	48	0.10	2.40	0.58	0.50
ARTRSe	8	0.10	0.70	0.39	0.24	2	0.10	0.30	0.20	0.14
ASBISe	2	47	575	311	373	1	76	76	76	-
BOGRSe	5	0.15	0.40	0.29	0.11	0	-	-	-	-
BRTESe	2	0.01	0.40	0.21	0.28	10	0.15	2.60	0.78	0.78
CAFISe	9	0.01	0.25	0.14	0.09	0	-	-	-	-
CALOSe	3	0.01	0.30	0.15	0.15	4	0.15	0.75	0.32	0.29
CELASe	3	0.35	1.90	0.95	0.83	0	-	-	-	-
KOCRSe	13	0.01	0.90	0.31	0.24	3	0.15	0.35	0.23	0.10
MESASe	0	-	-	-	-	8	0.25	2.40	0.75	0.69
SAKASe	0	-	-	-	-	5	0.50	13.2	3.60	5.44
STCOSe	23	0.01	1.00	0.35	0.28	4	0.07	1.25	0.59	0.49
STVISe	8	0.01	1.30	0.47	0.42	19	0.10	1.95	0.55	0.54
TAOFSe	3	0.10	0.30	0.23	0.11	2	0.50	4.60	2.55	2.90

Maximum selenium values were higher on premined lands for cool season grasses (as a group), warm season grasses (as a group), and forbs (as a group). They were also higher for big sage, two-grooved milkvetch, and junegrass. However, big sage and junegrass occurred more frequently on premined than mined lands, so their apparently higher values on premined land may be due primarily to lack of samples from reclaimed lands. With respect to average selenium levels, cool season perennial grasses, warm season perennial grasses, shrubs, crested wheatgrass, thickspike wheatgrass, western wheatgrass (*Agropyron smithii*), cheatgrass, prairie sandreed, needle and thread, green needlegrass, and dandelion were all higher on reclaimed than premined land. Only forbs, big sage, two-grooved milk vetch, and junegrass were higher on the average on premined lands. Blue grama, thread-leaf sedge, winterfat, alfalfa, and Russian thistle could not be compared as they were not found in both groups. Interestingly, when a few sites from areas revegetated in 1991, and thus not part of the originally designed data set, were included in the analysis, average selenium levels increased in cool season perennial grasses, western wheatgrass, two-grooved milkvetch, cheatgrass, and Russian thistle. Average selenium levels decreased with the addition of data for forbs and thickspike wheatgrass. No other lifeforms or species were affected by the addition of the 1991 data. These changes suggest that selenium in reclaimed vegetation may change as the site ages.

Random versus Select

Certain sites thought to be high in selenium were selected for sampling based on the hypothesis that they might be high in selenium. Based on pre-existing soil information or the presence of selenium indicator plant species. Both random and select sites could be either premined or reclaimed. Descriptive statistics for random and select sites are given in Table 3. So-called select sites had far less absolute total vegetation cover than did random sites (averages 24.6 percent versus 34.9 percent), and greater forb cover (10.7 percent versus 7.2 percent). Samples in select sites generally contained higher average selenium levels in vegetation for cool season perennial grasses, shrubs, thickspike wheatgrass, western wheatgrass, needle and thread, and green needle grass. Levels were lower on select sites only for crested wheatgrass and cheatgrass. Blue grama, prairie sandreed, thread-leaf sedge, winterfat, junegrass, alfalfa, and Russian thistle could not be compared as they were not found in both groups.

Year One versus Year Two

Separate data in this data set were collected in 1992, and 1991. Descriptive statistics are given in Table 4. Average precipitation for 1991 was 33.3 cm; in 1992 average precipitation was 27.9 cm. This difference in precipitation was generally reflected in the vegetation cover. Of note were the higher litter cover and the higher cover of warm season grasses during the drier year. The higher warm season perennial grass cover probably reflects the arrival of rain too late to affect the cover of cool season perennial grasses, shrubs, and forbs, but in time to help out the warm season perennial grasses. Selenium levels were higher, on the average, in the drier year than the wetter year for cool season perennial grasses, warm season perennial grasses, some forbs, thickspike wheatgrass, western wheatgrass, thread-leaf sedge, junegrass, needle and thread, green needlegrass, and dandelion. This may indicate that selenium levels decline when plant growth is copious. Selenium levels were, in contrast, lower during the dry year than the wet year for some forbs, crested wheatgrass, blue grama, cheatgrass, winterfat, and alfalfa. The difference between these two groups could possibly be attributed to phenology or growth strategy -- the second group was more likely to have active growth during the times of that dry year when slightly more moisture was available (very early in the spring or later in the summer). This would make the mechanics of selenium uptake with respect to moisture availability similar in all kinds of plants. The relationship between selenium uptake and moisture availability is speculative at this time.

Correlation Analysis

Simple correlations for select variables are presented in Table 5 and will be discussed below as being significant at the $p \leq 0.05$ level. Selenium in warm season grasses was positively correlated with selenium in cool season grasses ($r = 0.84$, $p < 0.001$). Selenium in warm season grasses was also highly correlated with selenium in shrubs and forbs ($p < 0.001$). Forb and cool season perennial grass selenium levels were also highly correlated ($r = 0.31$, $p < 0.001$), although forb and shrub levels were not. Because of these correlations, it might be reasonable to select one lifeform or one common species to represent vegetation selenium levels from a site.

Table 3. Descriptive statistics for random and select sites evaluated in Phase I.

	Random (N=198)					Select (N=44)				
Variable	N	Minimum	Maximum	Average	Std Dev	N	Minimum	Maximum	Average	Std Dev
TVEG	178	8	112	37.9	17.7	44	5	80	28.0	15.1
LITROCK	179	1	90	42.3	19.1	44	1	85	42.4	24.1
BARESOIL	167	1	80	24.6	17.8	40	2	95	34.8	26.9
TCOV	179	23	136	85.4	19.9	44	7	110	70.3	29.0
CSPGC	172	1	90	18.4	19.9	41	0.01	35	15.7	10.7
WSPGC	82	0.1	55	7.73	9.84	10	0.01	25	8.4	8.0
FORBC	122	0.01	64	7.21	11.0	23	0.01	45	10.7	12.4
SHRBC	84	0.1	45	10.6	10.5	9	1	16	3.78	16.6
OTHERC	60	0.1	82	8.32	13.5	6	2	38	17.8	16.6
CSPGSe	174	0.01	3.25	0.44	0.48	31	0.10	3.60	0.72	0.71
WSPGSe	75	0.01	2.75	0.40	0.40	7	0.15	1.10	0.39	0.35
FORESe	128	0.01	75	1.87	7.18	15	0.07	14.4	1.95	3.60
SHRBSe	81	0.01	12.3	0.71	1.42	8	0.15	2.65	0.94	0.96
AGCRSe	17	0.10	1.95	0.49	0.48	1	0.45	0.45	0.45	-
AGDASe	32	0.01	2.10	0.45	0.51	13	0.15	2.50	0.93	0.78
AGSMSe	65	0.01	2.40	0.54	0.45	19	0.10	1.80	0.66	0.51
ARTRSe	10	0.10	0.70	0.35	0.23	0	-	-	-	-
ASBISe	0	-	-	-	-	3	47	575	232	297
BOGRSe	5	0.15	0.40	0.29	0.11	0	-	-	-	-
BRTESe	6	0.01	2.60	0.70	0.95	6	0.15	1.35	0.67	0.55
CAFISe	9	0.01	0.25	0.14	0.09	0	-	-	-	-
CALOSe	7	0.01	0.75	0.25	0.24	0	-	-	-	-
CELASe	3	0.35	1.90	0.95	0.83	0	-	-	-	-
KOCRSe	16	0.01	0.90	0.30	0.22	0	-	-	-	-
MESASe	8	0.25	2.40	0.75	0.69	0	-	-	-	-
SAKASe	0	-	-	-	-	5	0.50	13.2	3.60	5.44
STCOSe	22	0.01	1.00	0.35	0.27	5	0.07	1.25	0.55	0.50
STVISe	17	0.01	1.95	0.40	0.45	10	0.15	1.70	0.75	0.53
TAOFSe	5	0.10	4.60	1.16	1.93	0	-	-	-	-

Table 4. Descriptive statistics for 1991 versus 1992 data comparisons evaluated in Phase I.

	1991 Analysis (N=116)					1992 Analysis (N=126)				
Variable	N	Minimum	Maximum	Average	Std Dev	N	Minimum	Maximum	Average	Std Dev
TVEG	96	12	112	44.2	18.6	126	5	80	29.7	14.0
LITROCK	97	1	75	35.8	16.0	126	1	90	47.3	21.5
BARESOIL	95	1	80	23.9	17.0	112	1	95	28.9	22.4
TCOV	97	48	136	89.8	18.4	126	7	115	76.8	24.2
CSPGC	91	1	90	20.6	14.7	122	0.01	52	15.8	9.5
WSPGC	49	0.1	30	5.30	5.42	43	0.01	55	10.6	12.3
FORBC	82	0.4	64	8.61	12.8	63	0.01	45	6.7	8.8
SHRBC	56	0.1	43	10.3	10.8	37	1	45	9.4	9.5
OTHERC	52	0.1	82	8.97	14.3	14	1	38	10.0	12.7
PPTN	111	29.0	38.1	33.3	3.53	126	14.2	31.8	28.2	4.1
CSPGSe	92	0.01	3.25	0.43	0.54	113	0.01	3.6	0.51	0.52
WSPGSe	43	0.01	2.75	0.36	0.44	39	0.01	1.25	0.44	0.33
FORESe	94	0.01	75	2.05	8.3	49	0.07	14.4	1.60	2.50
SHRBSe	57	0.01	3.00	0.50	0.52	32	0.01	12.3	1.14	2.20
AGCRSe	11	0.10	1.95	0.49	0.54	7	0.10	1.00	0.48	0.35
AGDASe	10	0.01	1.70	0.51	0.63	35	0.01	2.50	0.61	0.64
AGSMSe	42	0.01	1.80	0.54	0.42	42	0.10	2.40	0.59	0.51
ARTRSe	10	0.10	0.70	0.35	0.23	0	-	-	-	-
ASBISe	0	-	-	-	-	3	47	575	233	297
ATCASe	2	0.75	1.35	1.05	0.42	0	-	-	-	-
BOGRSe	4	0.20	0.40	0.32	0.09	1	0.15	0.15	0.15	-
BRTESe	6	0.01	2.60	0.70	0.95	6	0.15	1.35	0.67	0.55
CAFISe	5	0.01	0.15	0.10	0.07	4	0.01	0.25	0.18	0.11
CALOSe	7	0.01	0.75	0.25	0.24	0	-	-	-	-
CELASe	2	0.60	1.90	1.25	0.92	1	0.35	0.35	0.35	-
KOCRSe	8	0.10	0.55	0.29	0.16	8	0.01	0.90	0.30	0.28
MESASe	6	0.25	2.40	0.84	0.79	2	0.40	0.55	0.47	0.11
SAKASe	0	-	-	-	-	5	0.50	13.2	3.6	5.4
STCOSe	9	0.01	1.0	0.36	0.33	18	0.07	1.25	0.41	0.32
STVISe	13	0.01	0.9	0.31	0.23	14	0.15	1.95	0.73	0.60
TAOFSe	1	0.30	0.30	0.30	-	4	0.10	4.60	1.37	2.16

Table 5. Correlation analysis (r) for 13 plant selenium, site and time variables evaluated in Phase I.

	CSPG Se	WSPG Se	SHRB Se	FORB Se	SLOPE POS	CSPG COVER	TOPSOIL DEPTH	A+B DEPTH	ASBI Se	METH	SAMPLE TYPE	TIME	DBKFL GRD
CSPGSe	-												
	-												
	205												
WSPGSe	0.84	-											
	<0.001	-											
	78	82											
SHRUBSe	0.16	0.48	-										
	0.13	<0.001	-										
	88	44	89										
FORBSe	0.31	0.55	0.12	-									
	<0.001	<0.001	0.31	-									
	128	56	70	143									
SLOPE POS	0.10	0.24	0.10	0.03	-								
	0.14	0.03	0.36	0.72	-								
	204	82	89	143	241								
CSPG COVER	-0.07	-0.16	-0.08	-0.07	-0.01	-							
	0.33	0.16	0.48	0.40	0.95	-							
	189	82	77	123	212	213							
TOPSOIL	0.04	-0.77	-0.33	-0.02	0.03	0.33	-						
DEPTH	0.73	0.44	0.58	0.89	0.82	0.002	-						
	64	3	5	40	86	80	87						
A+B DEPTH	0.03	-0.03	-0.20	-0.06	0.16	0.24	-	-					
	0.72	0.79	0.07	0.59	0.07	0.01	-	-					
	122	75	79	91	135	115	0	135					
ASBISe	-	-	-	-	-0.54	-0.05	-	-	-				
	-	-	-	-	0.64	0.97	-	-	-				
	1	0	0	1	3	3	1	2	3				
METHOD	0.19	-0.01	0.05	0.003	-0.06	-0.09	0.08	0.01	-	-			
	0.006	0.94	0.66	0.97	0.34	0.20	0.45	0.93	-	-			
	205	82	89	143	241	213	87	135	3	242			
SAMPLE	0.12	0.13	0.45	-0.10	-0.12	0.14	-	-	-0.46	0.32	-		
TYPE	0.09	0.25	<0.001	0.26	0.05	0.04	-	-	0.70	<0.001	-		
	205	82	89	143	241	213	87	135	3	242	242		
TIME	0.08	0.11	0.22	-0.03	-0.03	-0.19	0.05	-0.10	-	0.45	0.23	-	
	0.25	0.35	0.03	0.68	0.70	0.005	0.65	0.26	-	<0.001	<0.001	-	
	205	82	89	143	241	213	87	135	3	242	242	242	
DBKFLGRD	-0.18	-0.10	0.38	0.13	-0.14	-0.27	0.25	-	-	0.41	-	0.76	-
	0.18	0.94	0.52	0.42	0.21	0.02	0.03	-	-	<0.001	-	<0.001	-
	57	3	5	40	80	73	72	0	1	80	80	80	80

First # = correlation coefficient
Second # = P value
Third # = Number of Samples

Table 6. Sample type

Dependent Variable	Mean Square (Dep Variable)	Error Mean Square	Error DF	F	P
CSPGSe	0.812	0.277	203	2.93	0.09
WSPGSe	0.201	0.153	80	1.32	0.25
FORBSe	61.8	47.3	141	1.31	0.26
SHRUBSe	34.0	1.54	87	22.1	<0.001

Table 7. Random versus Select

Dependent Variable	Mean Square (Dep Variable)	Error Mean Square	Error DF	F	P
CSPGSe	2.07	0.271	203	7.64	0.006
WSPGSe	0.001	0.155	80	0.01	0.95
FORBSe	0.077	47.8	141	<0.001	0.97
SHRUBSe	0.386	1.93	87	0.20	0.66

Table 8. Year one versus Year Two

Dependent Variable	Mean Square (Dep Variable)	Error Mean Square	Error DF	F	P
CSPGSe	0.367	0.280	203	1.31	0.25
WSPGSe	0.138	0.153	80	0.90	0.35
FORBSe	8.00	47.7	141	0.17	0.68
SHRUBSe	8.46	1.83	87	4.61	0.03

Most of the significant correlations illustrated in Table 5 are explicable. For example, the cover of cool season grasses increases as topsoil depth (a measure made only on reclaimed surfaces) increases ($p < 0.002$). Cool season grass cover was also significantly correlated ($r = 0.24$, $p < 0.01$) with ABdepth (a measure of topsoil depth on premined surfaces). ABdepth was somewhat correlated ($p \leq 0.07$) with slope position, represented numerically as: 1 = summit; 2 = shoulder; 3 = backslope; 4 = footslope; 5 = toeslope; 6 = drainage. This correlation reflects the tendency of soils to be deeper at footslopes and in minor drainage ways. Shrub selenium was negatively correlated ($r = -0.20$, $p = 0.07$) with ABdepth, suggesting that typically barren sites with shallow soil cover such as carbonaceous outcrops were likely to produce higher selenium levels in deep rooted shrubs that could survive in such an environment.

Method (1=random, 2=select), samtype (1=premined, 2=reclaimed), and time (1=year one, 2=year 2) are variables with only two possible values. Cool season perennial grass selenium levels were positively correlated with method and samtype, indicating that both reclaimed and non randomly selected sites had levels of selenium elevated in comparison to premined or randomly selected sites. Shrub selenium was also correlated to samtype and time (1=sampled in 1991, 2=sampled in 1992).

While the correlation between sample type and shrub selenium is consistent with other observations, the correlation between time and shrub selenium is more difficult to explain. Possibly the dry condition of the second year affected selenium uptake in shrubs, or possibly more reclaimed shrub samples were taken in the second year, and this confounded the time relationship. The latter supposition is supported by the significant correlation between samtype and time. Unexpected results were the significant correlations between samtype and method ($r = 0.32$, $p < 0.001$), and method and time ($r = 0.45$, $p < 0.001$), indicating that reclaimed sites were preferentially selected, in comparison to premined sites, prior to sampling as possibly having high levels of selenium in vegetation. In addition, more non-random sites were apparently chosen during the second year of study than the first. Both these situations are explainable: more information is typically available about soil selenium on reclaimed areas, making it easier to select potentially high selenium sites, and, as the study progressed, more interest was generated in non-randomly selected sites than random sites.

As might be expected, time and date of backfill grading (dbkflgrd) were significantly correlated. With an additional year, more young reclaimed sites were able to meet the study conditions of two growing seasons. More difficult to explain was the high correlation between method and date of backfill grading. Once again, more information is typically available from reclaimed sites, particularly young reclaimed sites, due to increased regulatory requirements. Although cool season grass cover was significantly correlated ($r = 0.14$, $p = 0.04$) with samtype, reflecting the dominance of cool season grasses in the reclaimed environment, cool season grass cover was significantly negatively correlated with time ($r = -0.19$, $p = 0.005$) and DBKFLGRD ($r = -0.27$, $p = 0.02$). These negative relationships reflect the increase of grass cover as the sites age. Two significant correlations that could not be plausibly explained were the correlation of warm season grass selenium and slope position ($r = 0.24$, $p = 0.03$), and the correlation between samtype and slope position ($r = -0.12$, $p = 0.05$). These may be spurious correlations, or they may reflect an underlying relationship yet to be identified.

Similar to the descriptive statistics, the correlation analysis was re-run with 1991 data included. The differences of interest include greater significance with the 1991 data than without for: topsoil depth vs. cool season perennial grass cover; time vs. cool season perennial grass cover; date of backfill grading vs. cool season perennial grass cover; date of backfill grading vs. method; and samtype vs. time. Some of these increased correlations are probably due to the increase of cool season grasses on reclaimed surfaces with time, and some are due to the increased selection of non-random sampling sites.

Analysis of Variance

Analysis of variance was conducted for all plant growth form categories for the following conditions: samtype (premined vs. mined samples), results in Table 6; method (randomly selected vs. non randomly selected sites), results in Table 7; and time (year one vs. year two samples) results in Table 8. In addition, an analysis of variance between mines was conducted with the 1991 data included.

Cool Season Perennial Grass

A significant f-ratio at the 5% level was found for cool season perennial grasses when "samtype" was the treatment. However, mean separation tests failed to segregate the two treatments. Thus, this treatment effect was marginal. When the 1991 data were included in this analysis of variance, the f-ratio was significant, and the average separation tests identified a significant difference between the two treatments. The difference between the 1991 and non-1991 analyses perhaps indicates a rapidly changing environment through time with respect to selenium.

For cool season perennial grasses, when 1991 data were included, there was a significant f-ratio for "sites" as a treatment. Sites were either premined or reclaimed sites from each mine. Average separation using Duncan's test revealed three significant groups, but with significant overlap between the groups: three mines were grouped in a "high" group with averages of 1.99, 1.55, and 0.95 mg/kg; one of those three was re-grouped with 22 other mines in a "low" group, with averages ranging from 0.95 to 0.08 mg/kg; and 14 of those same 23 "low" mines (including the one mine that was also in the "high" and the "low" group) made up a "medium" group, with averages ranging from 0.95 to 0.28 mg/kg. It is worthy of note that none of these values is close to the 5 mg/kg "level of concern".

Pairwise comparisons revealed that only one mine (including both native and reclaimed sites) was different from all the other mines. Interestingly, this was the same mine that had a number of 1991 sample sites. The analysis of variance by site was not re-run with the 1991 sites removed to see if this mine remained significantly different from the others.

Warm Season Perennial Grasses

Significant f-ratios for samtype as a treatment were not found for the warm season grass lifeform. The treatment effect of the sample location was not found to be significant for warm season grasses either, although pairwise comparison identified at least two sample locations that were significantly different from others. It is not considered statistically valid to accept significant pairwise comparisons when no significant treatment effect exists in the analysis of variance. Nonetheless, it is interesting to speculate that the sample locations near the top of the range (average selenium around 0.80 mg/kg) might be in different selenium environment's than the mines near the bottom of the range (average selenium around 0.20 mg/kg), especially when one of the sample locations had significantly high selenium levels in cool season perennial grass.

Forbs

Significant f-ratios for samtype as a treatment were not found for the forb lifeform. Similar to warm season perennial grasses, site was not found to be a significant treatment for forbs, although some isolated pairwise comparisons were significant. Group averages in this case ranged from 7.15 mg/kg to 0.10 mg/kg. However, the significant comparisons were not as easy to interpret as were those for the warm season grasses.

Shrubs

An extremely significant treatment effect due to samtype was found for shrubs (table 6). Average separation tests revealed a significant difference between shrubs found on reclaimed land, with an average selenium level of 3.26 mg/kg, and shrubs found on premined land, with an average selenium level of 0.58 mg/kg. While shrubs were not separated by species, observation revealed that the shrub most likely to be found on reclaimed land was four-wing saltbush (*Atriplex canescens*). This species is commonly considered to be a secondary selenium indicator.

When sites were considered as the treatment variable, group averages ranged from 1.69 mg/kg to 2.06 mg/kg. One reclaimed site was in its own group at the high end, and the other 24 sites were in another lower group. The site in its own group was also found to be significantly different in pairwise comparisons for cool and warm season grasses.

Summary and Conclusion

A state subcommittee comprised of personnel from the Wyoming Department of Environmental Quality, the Wyoming Mining Association, and the University of Wyoming developed a three phase project to address the issue of selenium in geological materials (i.e., overburden, soil, and backfill) and the role of Se in affecting selenium in vegetation and wildlife. Phase I consisted of site selection and characterization, vegetative cover survey and sampling, and data compilation and evaluation. Frequency and descriptive statistics were reported for several environmental and vegetative variables determined from 242 sample sites.

Some interesting points arise from analysis of this data set. First, there is a slight but distinct tendency for selenium to be greater in reclaimed than premined vegetation. Second, that tendency appears to decrease with time on the reclaimed sites. Third, it appears possible to select sites with elevated levels of selenium in vegetation based on non-vegetative site characteristics. Fourth, selenium levels in grasses appear consistently lower than those in forbs and shrubs, and warm season grasses are lower than cool season grasses. Fifth, moisture availability may have a role in modifying selenium uptake. Finally, geographic location, that is, "site", may be more important than any other factor in the elevation of selenium levels in vegetation. These summary results appear to be consistent with other research regarding selenium in vegetation.

Additional information on vegetation selenium levels was accumulated throughout Phase II (Spackman et al., 1995). Phase II information was used to determine if selenium levels analyzed in overburden, backfill, or soil can be correlated to selenium concentrations in vegetation. Results of Phase II were also used to develop phase III (Steward et al., 1995).

Acknowledgements

Members of the Wyoming State Subcommittee on Selenium in Soils, Vegetation, Overburden, and Wildlife wish to express their appreciation to the many coal mines in the Powder River Basin of Wyoming that participated in this project. Without their cooperation and support, this project would not have been conducted.

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Appendix: Key to abbreviation used in tables.

TVEG	Total Vegetation
LITROCK	Percent absolute litter and rock cover
BARESOIL	Percent bare soil cover
CSPGC	Cool season perennial grass cover (%)
WSPGC	Warm season perennial grass cover (%)
FORBC	Forb cover (%)
SHRBC	Shrub cover (%)
OTHERC	Other vegetative cover (%)
DPERMVEG	Date of permanent revegetation seeding for reclaimed sites (year)
ABDEPTH	Depth of A&B horizons for unmined sites (cm)
TSDEPTH	Depth of replaced topsoil for reclaimed sites (cm)
SLOPEPOS	Site slope position (summit = 1 to closed drainage = 7, see description in text)
SLOPESTP	Site slope steepness (flat = 1 to steep = 4, see text)
CSPGSe	Cool season perennial grass selenium (mg/kg)
WSPGSe	Warm season perennial grass selenium (mg/kg)
FORBSe	Forb selenium (mg/kg)
SHRBSE	Shrub selenium (mg/kg)
AGCRSe	Crested wheatgrass (*Agropyron cristatum*) selenium (mg/kg)
AGDASe	Thickspike wheatgrass (*Agropyron dasystachyum*) selenium (mg/kg)
AGSMSe	Western wheatgrass (*Agropyron smithii*) selenium (mg/kg)
ARTRSe	Big sage (*Artemisia tridentata*) selenium (mg/kg)
ASBISe	Two-grooved milkvetch (*Astragalus bisulcatus*) selenium (mg/kg)
ATCASe	Four-wing saltbush (*Atriplex canescens*) selenium (mg/kg)
BOGRSe	Blue grama (*Bouteloua gracilis*) selenium (mg/kg)
BRTESe	Cheatgrass (*Bromus tectorum*) selenium (mg/kg)
CAFISe	Thread-leaf sedge (*Carex filifolia*) selenium (mg/kg)
CALOSe	Prairie sandreed (*Calamovilfa longifolia*) selenium (mg/kg)
CELASe	Winterfat (*Ceratoides lanata*) selenium (mg/kg)
KOCRSe	Junegrass (*Koeleria cristata*) selenium (mg/kg)
MESASe	Alfalfa (*Medicago sativa*) selenium (mg/kg)
SAKASe	Russian thistle (*Salsola kali*) selenium (mg/kg)
STCOSe	Needle and Thread (*Stipa comata*) selenium (mg/kg)
STVISe	Green needlegrass (*Stipa viridula*) selenium (mg/kg)
TAOFSe	Dandelion (*Taraxacum officinale*) selenium (mg/kg)