OVERBURDEN CHEMISTRY

A REVIEW AND UPDATE[1]

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Abstract: Surface mining in the western United States involves the identification and handling of unsuitable overburden. The methodologies involved in overburden characterization vary greatly among western states and are the subject of debate. Once unsuitable materials are identified they are usually special handled (selective placement) to insure that vegetation, surface and groundwater systems are not impacted. The selective placement of unsuitable materials varies between states and even varies within states.

There are major uncertainties concerned with drill hole spacing, sampling procedures, analytical methodologies, parameters of interest, suitability criteria and placement of unsuitable materials in the backfill. These uncertainties must be understood prior to accurately determine whether unsuitable materials are present in sufficient quantities to impact surface revegetation, or surface and groundwater quality. The occurrence of spoil wells with elevated concentrations of chromium, nitrates and selenium awakens us to the realization that we have only scratched the surface in our knowledge of mine land reclamation.

INTRODUCTION

All western states require the identification of potentially acid, alkaline and toxic-forming materials in overburden prior to mining. However, the suitability criteria, methods for chemical characterization, and methods for handling unsuitable materials differ between states even within the same basin (Powder River Basin of Wyoming and Montana). Requirements for baseline studies from appropriate state regulations and guidelines has been recently outlined (Walsh, 1985) and are included in Table 1.

The objectives for overburden evaluations are to determine the chemical and physical characteristics of the materials, to estimate the vertical and lateral extent of unsuitable materials, and to develop appropriate mining and reclamation plans which will insure reclaimability of the post-mining root zone and reclaimed aquifers. Impacts to the quality of surface and groundwater resources, and to the quality of the materials within the post-mining root zone are two major areas of concern because they are critical to the post-mining ecology. A number of reports have been published which discuss approaches to overburden sampling, analysis, and interpretation for surface reclamation (Barth et al., 1981; Sutton et al., 1981; Dollhopf, 1983; Berg, 1983; Dollhopf et al., 1981; Munshower, 1983; Severson, 1984).

OVERBURDEN CHEMISTRY

Elements of Environmental Concern

The National Research Council (1980) identified the elements of greatest concern in coal and coal resource development as C, N, S, and the trace elements As, B, Cd, Hg, Mo, Pb and

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Table 1. Selected Requirements for Baseline Overburden

Item	Federal (30 CFR 700.1 1984)	Colorado (MLRD 1981 & MLRD 1983)	Montana (DSL 1980 & DSL 1983)	New Mexico (MMD 1980 & MMD 1984)	North Dakota (NDPSC 1983 & NDPSC 1984)	Wyoming (WDEQ 1980 & WDEQ 1984)
Geologic map coal crop lines, strike-dip	yes	yes	not specified	not specified	yes	yes
Overburden isopach map	not specified	not specified	not specified	not specified	yes	yes
Cross-sections; mined seams, rider seams, underburden	yes	yes	not specified	yes	yes	yes
Drill hole intensity	not specified	1 hole/640 ac 3 holes min.	1 hole/40 ac more for suspect areas	1 hole/150 ac minimum of 3 holes	1 hole/40 ac	up to 1 hole/ 80 ac; up to 1 hole/40 ac for special handling (at least 2 cores per second)
Sampling interval	not specified	4 - 10 ft	not specified	2 - 10 ft	5 ft	5 - 10 ft
Quality assurance split sampling	not addressed	not addressed	not addressed	not addressed	not addressed	recently omitted
Lithologic logs	yes	yes	yes	yes	yes	yes
Geophysical logs	not specified	not specified	not specified	not specified	yes	1 geophysical log/1000 ft
Identify acid & toxic forming strata	yes	yes	yes	yes	yes	yes
ESP, SAR	not addressed	SAR	ESP, SAR	SAR	SAR	SAR
Se, B	not addressed	Se, B	Se, B	Se, B	not addressed	Se, B
ABP, sulfur forms	not addressed	pyritic, sulfate, organic, total	ABP may be requested	ABP (for some samples)	not addressed	ABP organic carbon
Trace elements	not addressed	Mo, Pb, As, Cd, Fe, Mn, Cu, Hg, Zn	Mo	Al, As, Ba, Cd, Cr, Co, Cu, Cn, Fe, Pb, Hg, No, Ni, Ag, So-4, U, V, Zn, Ra-226, Ra-228, Mo, Cu	not addressed	As, Mo

Source: James P. Walsh & Associates, "Soil and Overburden Management in Western Surface Coal Mine Reclamation, contractor report to OTA, August 1985.

Se. Pelham et al. (1980) determined that the following elements may present potential adverse environmental impacts during and after the western surface mining operations; major elements - Al, Fe, Mg; essential trace elements - Cr, Cu, Mo, Se, and Zn; non-essential trace elements - An, Ar, Be, B, Cd, Pb, Li, Hg, Ni, Th, U, F. Most of these elements with the addition of Co, U, and V are the elements of concern in uranium mining and milling (Yamamoto, 1982; Nuclear Regulatory Commission, 1980).

Munshower (1983) discussed in detail trace element concentrations in soils and overburden from the western United States and pointed out that many of the present characterization programs are inadequate for predicting elemental toxicities on reclaimed lands.

Most western states have recommended overburden chemical suitability criteria which are summarized in Table 2. Certain elements appear more often than other on regulatory agency lists of suspected toxic trace elements. In the semi-arid west, selenium, boron and molybdenum form soluble anions at higher pH and are found on most state lists of potentially toxic elements (Table 2).

Table 2. Overburden unsuitability criteria by state.

Parameter	Montana (DSL 1983)	New Mexico (MMD 1984)	Wyoming (DEQ 1984)
pH acid	<5.5	<6.0	<5.0
pH alkaline	>8.5	>9.0	>9.0
EC (mmhos/cm)	>4.0-8.0	>16.0	>12.0
Texture	excessively clayey, silty or sandy	none given	none given
Sat %	<25% >85%	none given	none given
SAR	none given	>12.0 >15.0 >20.0 depending on texture	>12.0 >15.0 depending on texture
ESP	>15.0 >18.0 depending on texture	none given	none given
B	>5.0 ppm	>5.0 ppm	>5.0 ppm
Se	>0.1 ppm	>0.5 ppm	none given
ABP	none given	0 tons $CaCO_3$, equivalent/ 1000 tons	<-5 tons $CaCO_3$, equivalent 1000 tons
Mo	>0.5-1.0 ppm	none given	none given
Organic Carbon	none given	none given	>10%

Source: James P. Walsh & Associates, "Soil and Overburden Management in Western Surface Coal Mine Reclamation," contractor report to OTA, August 1985.

Oxidized and Reduced Zones

Oxidized zones in the western United States surface mining operations are typically confined to approximately the surface 50 feet. The depth of the oxidized zone is dependent on lithologic textures and the current and paleoclimatic conditions. Oxidized zones are typically high chroma with iron oxide staining, gypsum and jarosite precipitates. The reduce zones are typically comprised of low chroma materials. The depth of oxidation for Texas lignite overburden has been reported to 60 feet (Ahlrichs et al., 1984). Bentonite overburden from Montana exhibited oxidation to approximately 15 feet (Fisher and Munshower, 1984).

Within these oxidized zones the effects of overburden material oxidation are apparent both visually and upon chemical analysis. Typically, lower pH and SAR, elevated nitrate concentrations, and increased soluble selenium are found within this oxidized zone. Deeper zones in the overburden often have higher pH values, lower nitrate but higher ammonium values, and lower water soluble selanium than the upper oxidized zones.

The overburden chemistry can change abruptly at the oxidized/reduce interface. Most notably is a rapid change in overburden pH values from acidic to neutral or alkaline pH. Although the reduced zone may have pH values near neutrality these zones can still exhibit significant potentials to create acidic conditions if exposed to oxidized environments. The trend of increasing pH with depth is demonstrated in Tables 3-5.

Ahlrichs et al. (1984) reported a decrease in pH in all cores nearer the surface for Texas lignite overburden. The pH of near surface materials was often low due to natural weathering. In addition, total amounts of selected trace alements were very low throughout the oxidized zones. There was an abrupt increase in the contents of all trace elements from the oxidized to the reduced zone. They attribute this distribution of trace elements in the overburden to natural weathering processes. Overburden chemical data from a coal mine in Washington demonstrates many of these same trends of increasing pH and SAR, and decreasing DTPA extractable manganese with depth (Table 4). Fisher and Munshower (1984) presented data for bentonite overburden from Montana which also showed decreased pH and SR within the upper oxidized zones. The OTPA extractable metals (Fe, Mn and Zn) decreased with depth while DTPA extractable Pb increased with depth.

Several reports have suggested that sulfur in western overburden is primarily in organic or sulfate form and therefore pyrite oxidation would be minimal due to low pyritic sulfure percentages. These data presented in Table 5 demonstrate that pyritic sulfure can represent a significant percentage of the total sulfur. The percentage of pyritic sulfur to the total sulfur

Table 3. Acidic and potentially acidic overburden, Powder River Basin, Wyoming.

Drill Hole	Depth	pH	ABP	Lithology
A117DD	4.7 - 6.9	4.1	-17.1	Clay, sandy, brown, carb
	9.0 - 11.2	3.5	-61.8	Clay, sandy, brown, carb
	39.0 - 44.0	4.5	-2.9	Sandy, light brown, carb, pyrite
	44.0 - 49.0	3.7	-13.9	Sandy, light brown, carb, pyrite
	49.0 - 54.0	3.7	-7.4	Sandy, light brown, carb, pyrite
	54.0 - 58.4	3.8	-2.4	Sandy, light brown, carb, pyrite
	59.0 - 62.8	4.5	-4.7	Sandy, light brown, carb, pyrite
	62.8 - 63.0	5.7	-332.0	Black SS, carb, pyrite
	69.0 - 74.0	7.3	+45.3	Dark grey shale
	74.0 - 78.6	7.7	+38.7	Dark grey shale
	79.0 - 84.0	7.7	+62.8	Dark grey shale
	125.4 - 128.1	7.7	-162.0	Dark grey shale

Table 4. Overburden chemical data, Washington State.

Depth	pH	SAR	Mn†
0 - 5.0	5.3	3.9	73
5.0 - 9.1	4.9	0.3	46
9.1 - 14.2	5.6	0.8	47
14.2 - 23.2	4.3	0.9	18
23.2 - 31.0	6.9	1.6	6
31.0 - 37.0	7.0	5.3	12
37.0 - 46.0	7.3	3.6	6
46.0 - 56.0	7.4	4.0	5
56.0 - 61.0	7.5	5.4	4
61.0 - 71.0	7.5	6.7	2

† DTPA extractable Mn (mg kg^{-1})

Table 5. Potentially acidic overburden, Powder River Basin, Wyoming.

Depth	2-35	25-30	30-35	60-65	65-70	70-75
pH	4.3	4.9	6.3	6.4	7.4	7.8
ABP	-12.0	-12.0	-16.0	-71.0	-12.0	-5.0
Total S %	0.40	0.48	0.68	3.16	0.61	0.34
SO4-S %	0.07	0.01	0.01	0.01	0.01	0.01
Org-S %	0.07	0.02	0.01	0.75	0.03	0.00
Pyr-S %	0.26	0.46	0.67	2.41	0.58	0.34

ranges from 9 (data not shown) to 100%. Again the trend of acidic materials (not potentially acidic) is confined to the surface oxidized zones of this overburden profile.

The results of oxidation can change the chemical speciation of numerous elements and increase the solubility of others as demonstrated above. Elevated concentrations of nitrates are typically confined to the surface 50 feet, while exchangeable ammonium concentrations would be nominal within the oxidized zone but increase in the reduced zones. As shown in Table 6 nitrate values drop rapidly at the 27 foot depth. At this same depth interval the exchangeable ammonium values increase indicating an oxidized/reduced interface zone. The pre-mining water table was at approximately 27 feet.

Selenium concentration in the same overburden profile also exhibits increased solubility within the oxidized zone (Table 6).

Specific Lithologies

The distribution of potentially acidic and toxic forming materials is not isolated to the upper oxidized zones. Very high concentrations of deleterious materials can be found throughout the overburden, including the deeper, reduced zones. In some instances specific lithologic materials may represent deleterious materials and require special handling for prevention of environmental impacts. Lithologic units which most often exhibit unsuitable chemical qualities include: pyritic sandstones and carbonaceous units. Other lithologic units can contain deleterious chemistry and should not be considered suitable until sampled and analyzed.

Sandstones

In general, sandstone units usually contain low levels of toxic or acid forming materials. Ebens and McNeal (1977) demonstrated that sandstones from the Northern Great Plains have lower concentrations of Al, B, Cr, Cu, F, Mo and Ni than shales. Hinkley et al. (1978) demonstrated that sandstones generally have lower concentrations of trace elements than carbonaceous shales and siltstone-shale samples. Sandstone materials from southwestern Wyoming were reported to contain lower electrical conductivities, ESP and SAR as compared to strata containing greater than 60 percent combined silt and clay (Gray et al., 1982).

However, extremely high concentrations of toxic materials and/or acid forming materials have been recorded in sandstones throughout the

Table 6. Overburden nitrogen and selenium speciation, Powder River Basin, Wyoming.

Depth (ft)	Total N%	.... mg kg^{-1} .... Leachable NO_3	Exch-NH_4	.... mg kg^{-1} .... Total Se	Leachable Se	% Leachable Se
10.4 - 14-5	0.08	66.0	5.0	0.5	0.12	24
14.5 - 19.0	0.08	62.0	4.2	0.8	0.16	20
19.0 - 23.0	0.07	50.0	5.1	0.4	0.13	32
23.0 - 27.5	0.10	36.0	8.0	1.0	0.15	15
27.5 - 31.5	0.06	14.0	10.0	0.5	0.11	22
31.5 - 36.4	0.09	0.2	13.0	0.5	0.06	12
36.4 - 43.0	0.06	0.2	14.9	0.7	0.05	7
43.0 - 46.5	0.16	0.5	10.9	0.5	0.03	6
46.5 - 51.0	0.31	1.2	13.5	0.8	0.05	6
51.0 - 55.0	0.76	0.4	13.0	1.9	0.09	5

Source: Dreher and Finkelman (1986).

western United States. Table 3 demonstrates the extreme concentration of pyrite (62.8 - 63.0 interval) in a sandstone unit from the Powder River Basin, Wyoming. These sandstone units are often too small and discontinuous for mapping and would not result in environmental degradation if not special handled. However, large zones of acid-producing sandstone materials may be encountered during the mining operation.

Nearly 4600 uranium deposits in sandstone units are known in the United States. Most of these deposits are in four regions. About 95% of these are located in the west-central portion of the United States extending over an L-shaped region which includes portions of Montana, North Dakota, South Dakota, Wyoming, Colorado, Utah, Arizona, New Mexico, Texas, and Oklahoma (Finch, 1967). Extreme pyritic sandstone units are associated with most uranium deposits of the western United States.

Many of the uranium deposits in sandstones of the western United States are roll-front type deposits. These highly mineralized sandstone units contain large concentrations of reactive sulfides. The distribution of pyrite, marcasite and arsenopyrite in various sandstone roll-front deposits throughout the western United States and Canada has been extensively described (Goldhaber and Reynolds, 1979; Reynolds and Goldhaber, 1983). Pyrite concentrations greater than 20% (200,000 mg kg^{-1}) have been reported for the Gas Hills uranium district of Wyoming (Harshman, 1974). A large portion of reactive sulfides in these deposits has resulted in extreme surface acidification (Table 7).

Roll-front uranium deposits exemplify the ability of groundwater to transport elements and subsequently precipitate them in the form of a mineral deposit. In addition to containing high pyrite concentrations, extremely high trace element concentrations have been reported in and around uranium enriched areas in Utah, Colorado, Wyoming, New Mexico, Arizona, North and South Dakota. Several trace elements, including arsenic, copper, molybdenum, lead and selenium are often associated with these deposits. Arsenic concentrations in sandstone overburden materials from the Gas Hills uranium district are reported to exceed 10,000 mg kg^{-1} (Harshman, 1974).

Table 7. Reclaimed uranium spoils, Gas Hills, Wyoming.

Sample depth (ft)		pH	ABP
CW	0-1	2.0	-69.3
	1-2	NA	NA
	2-3	6.1	-38.1
	3+	7.2	-67.8
CB	0-1	2.2	-16.5
	1-2	NA	NA
	2-3	7.3	-150.7

NA = not analyzed

Selenium can be highly enriched in areas of sulfide ore deposits or sedimentary sulfide enrichment. The highest selenium contents of sulfides are associated with uranium ore in sandstone-type deposits in the western United States. Selenium concentrations of over 40% have been reported in pyrite-ferroselite zones from Emery County, Utah. Concentrations as high as 4500 mg kg^{-1} have been reported for uranium overburden from the Southern Powder River Basin, Wyoming (Table 8).

Very high concentrations of both selenium and molybdenum have been reported at the inactive Baggs uranium district. Mineralization in this

Table 8. Total selenium concentrations, Uranium Deposits, Wyoming.

Location	Maximum Se (mg kg^{-1})†
Gas Hills	500
Shirley Basin	1200
Powder River Basin (Campbell Co.)	3000
Powder River Basin (Converse Co.)	4500
Baggs (Carbon Co.)	3000
Black Hills (Crook Co.)	900

†Values taken from Finch (1967), Davidson (1963), Troyer et al. (1954), Vine and Prichard (1954), Love (1954), and Harshman (1966), (1974).

uranium district occurs not in fluvial units (roll-front deposits) but in eolian sandstones of the Browns Park Formation. Water soluble selenium values as high as 76 mg kg^{-1} have been reported for spoil and overburden associated with abandoned uranium mines of this district (Wyoming, 1985). In addition, extractable molybdenum concentrations have been reported to exceed 25 mg kg^{-1}.

Carbonaceous Materials

Extensive research has shown that acid production predominantly results from the oxidation of sulfides such as pyrite and marcasite. In the eastern US oxidation of sulfides is the major source of acidity on mined lands and is caused by carbonaceous rider seams and bone coal (May and Berg, 1966). Highly carbonaceous materials (rider coal, partings, leonardite and carbonaceous shales) have been attributed with producing acidity upon oxidation. Acid production from carbonaceous materials has been identified in overburden and abandoned coal spoils in Wyoming, New Mexico, Montana, Utah, Colorado and Texas (Holm and Elmore, 1986; Boon, 1986; Hagener, 1985; Boon and Smith, 1985; Fisher and Munshower, 1984; Miller et al., 1976; Arora et al., 1980).

Sulfide minerals occur in significantly higher concentrations in the finer grained sedimentary rocks associated with coals: roof shales, floor material and partings (Arora et al., 1980; Valkovic, 1983). Carbonaceous materials typically contain greater quantities of sulfur and often contain greater quantities of pyrite sulfur than associated overburden or coal (Hinkley et al., 1978; Merritt, 1983). Although pyrite is the dominant sulfide mineral in coal and carbonaceous materials other chalcophilic minerals have been identified including: marcasite, sphalerite, galena, lead selanide, chalcopyrite and arsenopyrite (Finkelman, 1981; Valkovic, 1983; Dreher et al., 1985). Elevated selenium concentrations in backfill wells in the Powder River Basin of Wyoming has been attributed to being derived from the oxidation of Se-bearing pyrite (Dreher and Finkelman, 1986).

Pettijohn (1957) found unusually high trace element concentrations in carbonaceous shales. Hinkley et al. (1978) reported that carbonaceous shales have higher trace element concentrations than non-carbonaceous shales and sandstones. Materials that contain appreciable biologically inert organic carbon, such as carbonaceous shales, leonardite, or coal slack, may contain toxic levels of boron (Power et al., 1978).

Ebens and McNeal (1977) suggest that any reclamation efforts in the Northern Great Plains should treat shale material as chemically suspect due to increased trace element concentrations. Trace elements which are elevated in Fort Union formation shales include: Al, B, Cr, Cu, F, Mo, and Ni.

Trace elements which are enriched in coal and carbonaceous materials include: As, B, Cd, Cl, Cr, Cu, F, Hg, Mo, Ni, Pb, Se and Zn. The mechanisms for trace element and pyrite accumulation in coals and carbonacoeous materials have been summarized (Finkelman, 1981; Valkovic, 1983). Trace element enrichment in coal and carbonaceous materials from Wyoming also demonstrated enrichment of As, B, Cd, Cr, Cu, F, Hg, Se and Zn (Boon and Smith, 1985).

Carbonaceous shales from the Manning Canyon formation in Utah are reported to contain 96.3 mg kg^{-1} total selanium and 16 mg kg^{-1} selenium in a water soluble form (Beath et al., 1946). Carbonaceous shales collected from Albany County, Wyoming contained 150 mg kg^{-1} total selenium (Beath and Gilbert, 1936). Davidson and Gulbrandsen (1957) reported selenium contents up to 1500 mg kg^{-1} for carbonaceous mudstones. Dreher and Finkalman (1986) reported significantly higher total selenium and water soluble selenium in top-of-coal cleanings as opposed to overburden from the Powder River Basin of Wyoming (Table 9).

Table 9. Average total and leacheble selenium overburden and top-of-coal cleaning, Powder River Basin, Wyoming.

Material	.... mg kg^{-1} .... Total Se	Water Soluble Se
Overburden	0.8 ± 0.4	0.12 ± 0.06
TCC*	2.4 ± 0.6	0.23 ± 0.04

*Top-of-coal cleanings.

IDENTIFICATION OF UNSUITABLE MATERIALS

The adequate identification of alkaline, acid and/or toxic materials in overburden has been a subject of serious debate for some time. There are major uncertainties concerned with drill hole intensity, sampling procedures, parameters of interest, suitability criteria, and analytical procedures. These uncertainties must be understood prior to accurately determine whether deleterious materials are present in sufficient quantities to impact surface revegetation, or surface and groundwater quality.

Overburden Drilling Intensity

Overburden drilling is the method most often utilized for obtaining samples for the characterization of overburden chemical and physical properties for identification of zones of deleterious materials. Required or recommended drilling intensities for overburden drill holes ranges from 1 hole per 40 acres in Montana, North Dakota, Wyoming, and Utah; 1 hole per 150 acres in New Mexico; to 1 hole per 640 acres in Colorado (OTA, 1986). There are no specified drill hole intensity listed in the Federal requirements.

The criteria use on basing drill hole densities for most states is the work conducted by Dollhopf et al. (1981) and a subsequent report by Abbott et al. (1982). The ability of characterizing unsuitable overburden with drill holes 600 to 1500 meters apart has an accuracy of only 45-60% (Dollhopf et al., 1981). It is likely that incorrect interpretations are being made resulting in inhibitory materials being unknowingly deposited either in the future aquifer zone or root zone (Dollhopf et al., 1981). These same researchers demonstrated that a drilling intensity of approximately 195 feet would be required to predict the occurrance of unsuitable materials with 80-90% accuracy.

Sampling the overburden in a "phased" approach provides a compromise between accuracy and increased costs. If materials are identified as unsuitable as a result of initial overburden characterization then those areas may require additional sampling and evaluations to determine the full extent of the unsuitable zones.

Samples are typically collected from rotary drill cuttings or from continuous core samples. Rotary drilling method results in mixing of cuttings as they rise up the hole. Continuous coring results in intact cores but is significantly more expensive. Therefore, continuous core drilling is rarely utilized outside of requirements for baseline information. Wyoming recommends at least two holes per 640 acres be cored for baseline investigations. For additional overburden investigations, chip samples can be utilized although the compositing intervals for similar materials is decreased for chip sampling due to mixing and should not exceed five foot intervals as opposed to ten foot compositing of similar lithologic materials from cores.

Developmental drilling is utilized after mining has begun for areas of unsuitable materials that need to be more accurately defined. The use of coal quality drilling for overburden characterization can greatly reduce costs for additional overburden drilling. Developmental drilling is normally conducted to a recommended intensity of 660 foot centers for baseline plus developmental drilling. This often brings the combined drilling intensity up to 1 hole per 40 acres.

Operational drilling is usually performed at the discretion of mine personnel. This drilling or sampling program is designed to further define the limits of unsuitable materials so costly special handling can be avoided. This would bring the combined drilling intensities to more than 1 hole per 40 acres.

The goal of the increased overburden sampling program for deleniating unsuitable materials is to reduce the variability of the data to a level acceptable to both regulators and operators. However even with a more intense sampling program the reduction in variability may not be adequate for the cost incurred for additional drilling. Sampling the overburden to delineate all unsuitable materials would mean overburden characterization costs would drastically increase. Changes in lithology and geochemistry over short distances has raised concerns about whether high intensity drilling will increase the probability of accurately predicting areas of unsuitable materials (OTA, 1986).

Sampling and Analytical Methodologies

Walsh (1985) reported that, of the States studied in the OTA report, all except North Dakota have guidelines for chemical analyses of selenium, boron and acid-base potential. The requirements for the prediction of potential acidity differs among states. The Wyoming Department of Environmental Quality (WDEQ, 1984) and the Utah Division of Oil, Gas and Mining (UDOGM, 1986) recommend acid-base potential measurements on all overburden samples. The North Dakota regulatory authority considers the possibility for acid formation to be extremely limited in the state. For this reason they do not routinely require acid-base potential measurements. The New Mexico regulatory authorities recommend an acid-base potential measurement only on non-calcareous strata (MMD, 1984). The Montana regulatory authority may require acid-base accounting depending on the nature of the overburden. Colorado guidelines specify a determination of pyritic and sulfate sulfur for overburden samples (MLRD, 1982).

Many States utilize different extraction procedures for determination of trace elements in western overburden. This has led to a problem in interpretation of data and also presents problems to operators conduction mining in several western States. Many of these different analytical techniques were reported by Berg (1983). The unreliability of some laboratory analysis techniques for generating chemical data about overburden is a serious limitation in delineating overburden strata that may be detrimental to revegetation or post-mining water quality. Berg (1978) discussed the limitations of soil testing on drastically disturbed lands and stressed that calibrations need to be conducted on reclamation species under field conditions.

Many of the problems associated with overburden sampling, analysis and interpretation have been addressed (Klusman, 1980; Severson, 1984). The results of round robin soil and overburden sampling programs demonstrates the variability of analytical data from laboratories throughout the western United States (Severson and Fisher, 1985). Unfortunately, no states currently utilize a quality assurance procedure for sampling and analysis for overburden chemical characterization (OTA, 1986). The lack of reliable methods for interpreting the results of laboratory techniques for overburden characterization pose potential risks related to predicting post-mining water quality and revegetation success.

Statistical Evaluations

A number of geostatistical methods have been developed which can be applied to identification of unsuitable zones in overburden and spoil. Some statistical methods are relatively simple and well accepted. Some of these include: mean, confidence intervals, frequency distribution, regression analysis, weighted averaging, polygon area of influence, and scatter diagrams. It is important to define the distance of influence beyond which the similarities between sample values becomes negligible. These distances may vary significantly between deposits, between different lithologies within the same deposits, and within the same lithology, and with direction. Severson (1984) discussed severel approaches to evaluate sampling intensities for overburden in the western energy regions. These methods eveluate the relationship between sample variance and distance.

A geostatistical tool which can be utilized to quantify similarity (dissimilarity) between drill holes is called the semi-variogram. Once a semi-variogram has been calculated, it must be interpreted by fitting to it a mathematicel formula which helps to identify the materials continuity. The main components of the semi-variogram are:

Sill - which shows the highest level of variability measured by the semi-variogram.

Range - is the distance at which the semi-variogram plateaus or reaches the sill value and represents a measure of the maximum distance of influence of a drill hole in the direction concerned. Beyond this distance, sample values are independent of one another.

Nugget effect - is tha value of the semi-variogram at zero distance. It represents the sample variability at small distances. It elso gives an important indication of the presence and magnitude of sampling, analytical and reporting errors.

The semi-variogram measures the decrease in correlation or similarity over distance. It is this way that the semi-variogram provides a statistical tool for evaluation of the site. The semi-variogram in Figure 1 graphically shows the relationships between observations in terms of the distance from each sample to each of the other samples. The x-axis represents the distence between sample points and the y-axis represents the "variance" of the difference in concentrations between pairs of samples which are equal distances apart.

A horizontal semi-variogram implies that the variable is random and can be represented simply by a mean and a variance. If the correlation is strong, then the differences between samples taken close together are smaller than differences between samples taken further apart, and the semi-variogram is a rising curve. It is important to understand that the variogram for each site is unique and unknown until sufficient samples are analyzed and interpreted.

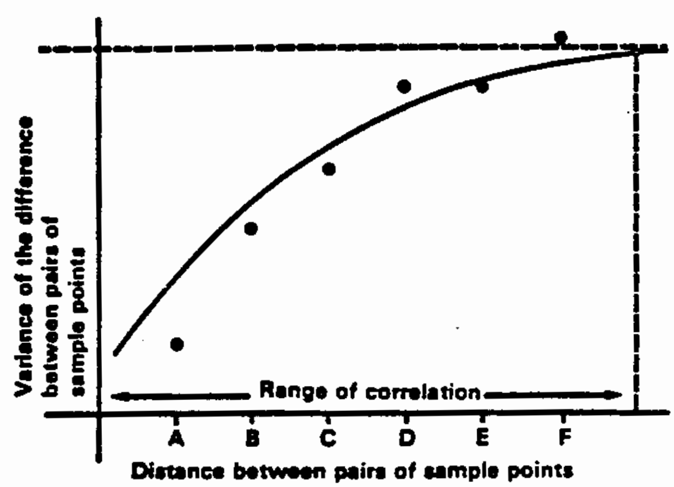

Figure 1. Generalized Semi-variogram.

Mapping Unsuitable Zones

Once the semi-variogram has been developed then the data can be evaluated by a number of techniques. One technique which has been utilized extensively for coal thickness and quality evaluations is called kriging (Render, 1982; Ley and Welborn, 1982). Kriging interpolates concentration levels at points between the sampling sites so that "isopleths" of concentrations can be drawn. The result is an isomap with lines of equal values. These types of maps can be generated for each mining bench for identifying unsuitable or suitable overburden materials. By using these types of geostatistical outputs, the operator and regulator can identify areas requiring special handling, more sampling or no further investigations.

Several other methods for mapping and tracking unsuitable materials are currently utilized by mining operations in the Powder River Basin of Wyoming. One mine in the Powder River Basin of Wyoming has developed a system of maps which facilitate proper identification and handling of unsuitable overburden. Toe and crest maps, essentially topographic maps of the pit and pit advance areas, are overlaid onto suitability maps of identical areas. These maps are utilized by the mining engineers for reference. The toe and crest maps are updated monthly thus providing a reasonably current assessment of overburden quality for the pit engineers. Overburden monitoring cross sections maps are developed for transects basically perpendicular to the direction of pit advancement. They are lithologic cross sections based on overburden monitoring drilling operations conducted on 500 foot centers. Each grid point is cored to 45 feet, corresponding to the typical maximum depth that unsuitable material is anticipated per the overburden baseline data for the mine. The maps are legended according to particle size and rock type. The overburden potentiometric surface is also illustrated. Further, for each 500 foot grip point, any depth interval which tests unsuitable per Guideline No. 1 criteria is illustrated and labelled according to the unsuitable parameter. The cross section maps consequently provide a detailed and accurate depiction of the overburden ahead of mining and provide direction for placement of unsuitable meterial in the backfill.

Another mine in Wyoming's Powder River Basin has developed two dementional overburden quality maps of each overburden bench mined. The overburden quality maps, projecting about 1 1/2 years ahead of mining, are essentially color illustrations of tha baseline overburden quality program besed on drilling at 660 foot centers. Unsuitable zones are color coded. The actual percentage of bench height which is unsuitable and limiting chemical parameters are listed for every mapping unit present on the bench maps.

A second set of maps is utilized to convey the baseline information to the mining shift foreman. This second map system is the actual pit map illustrating pit topography, including overburden benches and backfill benches. Areas in the overburden which are currently being mined and are unsuitable are color coded. The appropriate target zones are surveyed in the pit and their boundaries staked and flagged with lathe and colored ribbons. The mining shift foreman then completes the tracking process by accounting for the quantity of unsuitable materials placed in the pit backfill. The tracking pit maps illustrate the unsuitable overburden and backfill zones and are updated bi-weekly. The quantity of unsuitable material moved is updated by shift. The combined effect of surveying the unsuitable backfill areas and accounting for the quantities of unsuitable materials moved allows for accurate placement of unsuitable material.

Spoil Water Quality

Post-mining groundwater quality impacts are highly variable and depend on water quality entering the spoils, the amount and type of recharge, distribution, and leachability of spoils materials through which groundwater or precipitation percolates. Unfortunately, there is little agreement as to the best method for producing consistent and valid predictions for overburden impacts on post-mining groundwater quality (Jackson et al., 1984; McWhorter and Landers, 1985; OTA,1986).

The most common methods for identifying unsuitable materials which may impact water quality from surface mining include: batch tests, column leach tests, correlation of overburden chemistry to actual spoil water quality, and computer modeling.

Batch extraction methods involve the mechanical mixing of a unit volume of water with a unit mass of overburden material. This method has been noted for its ease of operation and low experimental variation (Lowenbach, 1978; Western Water Consultants, 1986). The most common form of batch extraction tests are saturation extract analysis. The saturation extract method may only estimate tha short-term spoils water quality and ignores the long term salt generation capacity (Moran et al., 1978). However, saturation extract analysis is rapid and less expensive than other predictive methods. Batch extraction tests were used by the USGS to simulate changes in groundwater quality that may occur as a result of mining operations in the West Decker area of Montana (Davis, 1983). One of the problems with batch extraction is the apparent large pore volumes which often result in many parameters being below analytical detection limits. Davis (1983) estimated that the amount of water in a 2:1 mixture of water and spoils material represents almost 900 effective pore volumes based on the assumptions listed in the report.

Column leach experiments are currently the recommended procedure for assessing the potential impacts to spoil water quality. A column extraction method involves the continuous flow of liquid through a fixed bed of overburden material. Leachate generated by the column method is thought to be more representative of spoil water quality than batch extraction tests.

The use of geochemical modeling in the interpretation of water quality analysis has been discussed (Davis, 1983; Johnson, 1985). The most common geochemical computer models utilized include: PHREEQE, WATEQF, BALANCE, and MINTEQ. These models identify the chemical reactions and speciations likely to occur as groundwater moves through backfill materials. These models can simulate groundwater quality changes along a selected flow path according to user-specified reaction constraints.

One of tha problems often encountered with predicting post-mining water quality impacts is the use of "worst case" materials for leaching experiments. This gives the regulator and operator no information concerning the "actual" water quality of the overall backfill materials. Additional problems are encountered if "generic" overburden is used in leach experiments. If tha chemical quality of the leachate is poor no information regarding the source material can be obtained from the experiment.

A better alternative is to conduct leaching tests (batch or columns) on specific lithologic materials present over the mine site and to utilize computer modeling to mix the water quality from each lithologic material in various ratios expected in the backfill. This gives the operator and regulator a more realistic alternative than utilizing "worst case."

Large volumes of data are available regarding the water quality of resaturated spoils. Praliminary investigations show that a number of parameters including pH, EC, TDS, Se, Cr, and nitrates are elevated above appropriate suitability criteria (Naftz, 1987). The correlation of overburden chemistry, column leach and batch tests, and actual spoil water quality needs to he conducted.

HANDLING UNSUITABLE MATERIALS

Special Handling Considerations

Special handling programs should allow for a number of options in placement, handling and treatment of unsuitable materials. Mining sequences, equipment and other factors need to be evaluated prior to any special handling commitment. The primary constraints for special handling of unsuitable overburden are operational, equipment, and economics.

Dragline

Although draglines are expensive, they move materials more cheaply than any other method. However, their ability to special handle unsuitable material is somewhat limited since they can only deposit materials across the pit at a distance of approximately 280 feet. Draglines can remove approximately 150 feet of overburden in a single pass.

Dollhopf et al. (1981) demonstrated that a dragline could special handle saline material and place this material in backfill area below future root zones and above the post-mining water table. Without clay encapsulation, the selective handling costs approximately 50% more than normal mining. If the saline material was clay encapsulated the increased cost over normal spoiling was 300%. A dragline has the ability to scatter spoil material over a large area. This scatter spoiling technique is a method of blending or diluting unsuitable materials (Dollhopf, 1983).

Truck-shovel

Truck-shovel operations typically use shovels with a 30-cubic yard capacity which removes approximately a 50 feet overburden bench. Large haul trucks (100 - 350 ton) are used to transport the overburden materials to the backfill area. This type of operation allows flexibility in the placement of unsuitable overburden in tha backfill. Most of the special handling currently being conducted in the Powder River Basin of Wyoming occurs at truck-shovel operations. Truck-shovel operations in Wyoming are more likely to be required to special handle unsuitable material than dragline operations because the flexibility of their equipment makes it more operationally feasible (Walsh, 1985).

Combination Truck-Shovel, Dragline

Operations which utilize a truck-shovel assist dragline type operation can operationally special handle the upper bench material which is typically mined by the truck-shovel fleet. This is a good system for special handling the upper bench material to insure that this material is placed in the same relative position in the backfill as pre-mining. This method of mining works well for insuring a suitable four foot cover on the reclaimed surface since the truck-shovel operation can selectively remove and place suitable cover materials over less suitable spoils.

Scrapers and Bucket Wheel Excavators

Other types of special handling equipment would include both scrapers and bucket-wheel excavators. Both of these pieces of equipment have the ability to special handle and selectively place unsuitable overburden. Rubber-tired scrapers are used in the western United States and have the flexibility to remove small layers of unsuitable materials. However, scrapers are the most costly form of overburden removal and are not used to a great extent for special handling. Bucket wheel excavators have not been utilized to any extent in the western United States. However, mines in Germany and the U.S.S.R. use bucket wheel excavators and conveyor systems successfully to segregate suitable and unsuitable overburden materials (Dollhopf, 1983).

Special Handling Options

Mixing

Many people contend that the normal mining method adequately mixes the unsuitable zones to an acceptable level. The efficiency with which overburden can be mixed by mining equipment is a topic of heated discussion in the Northern Great Plains. Most operators have been challenged and requested to conduct a mixing study to quantify the amount of mixing by that specific method. There is a general consensus that truck-shovel mining results in more mixing than a dragline operation.

In Wyoming, the suitablity criteria for special handling is based on a percentage of bench. If the unsuitable material is more than 15% of a dragline bench (Dollhopf et al., 1981) or 20% of a truck-shovel bench then special handling of the entire bench may be required. Several studies have been initiated in Wyoming for evaluation of the 20% criteria for mixing at truck-shovel operations. These suitability criteria (% of bench) can have profound operational and economic impacts on a mining operation in regards to the quantities of unsuitable materials requiring special handling since many mining operations are being required to special handle large volumes of unsuitable materials.

Staggered Truck Backfilling

In this situation, depending on relative overburden qualities, for every truck of unsuitable material that dumps at a site, a number of trucks of suitable material (taken from a different section of overburden) will dump at the same site. Hence, the block of backfill will bland to a suitable quality.

Veneering

With veneering a specified layer of unsuitable material is spread as a thin line of backfill along the length of the entire backfill area. Thus, a block of unsuitable material will be transformed into a thin wedge of material covering a line of backfill. The advantage of this configuration is that a block of unsuitable material becomes a wedge surrounded by suitable material, and such phenomena as buffering, ion exchange and dilution can occur more evenly and quickly.

Selective Placement

With selective placement the unsuitable material is placed on a specific backfill location typically above the post-mining water table and/or below the surface four feet. This type of placement is typical for fly ash disposal within the backfill or for large volumes of materials that are unsuitable for groundwater placement or surface reclamation.

A real controversy exists concerned with the appropriate placement of unsuitable materials in reference to the post-mining water table levels. Many contend that deep burial on the pit floor will result in rapid flooding and subsequent reduction, thus limiting any additional oxidation which reduces the potential for water solubility and acid production. The controversy to this issue is that short term impacts to water quality may be significant. Data from column leach experiments demonstrates a large purge of poor quality water for the first several pore volumes. Still others recommend that the acidic and/or toxic material should be buried below the surface four feet and above the post-mining group water table. The arguments here are usually numerous and include: cost, equipment limitations, volume limitations, scientific uncertainty, and inconsistencies with other operations.

A mine in New Mexico buries fly ash, bottom ash, and scrubber sludge in low permeability mine spoils below the post-mining water table, while a mine in northwestern Colorado is required to dispose of utility wastes in dry mine spoils above the post-mining water table (OTA, 1986). Due to thin overburden conditions at the Wyodak Mine in Wyoming, fly ash is disposed of below the water table but it is required to be encapsulated in compacted clay cells. At some mines in Wyoming, unsuitable potentially acidic or toxic materials are disposed of above the post-mining water table at some mines, below the water table at others and anywhere in the backfill at others.

Encapsulation

Encapsulation is not often practiced due to the time and economic constraints associated with this type of disposal. Dollhopf et al. (1981) demonstrated the potential for draglines to encapsulate highly saline materials in Montana. This type of disposal is also used in Wyoming at the Wyodak Mine for fly ash disposal. The fly ash is disposed of in clay encapsulated areas of the backfill below the post-mining water table due to the occurrence of a thin overburden situation.

Environmental Impacts

Surface Reclamation

Impacts on surface reclamation from inadequate identification or handling of unsuitable materials include phytotoxicities or the production of toxic vegetation. Phytotoxic conditions are most often associated with low pH which results in increased solubility of toxic metals (Al, Cu and Mn). At higher pH values boron becomes the element most likely to produce phytotoxic conditions. Prevantion of trace element toxicities to livestock involves adequate chemical characterization of overburden, regraded spoil and topsoil (Munshower, 1983). Vegetation containing elevated concentrations of selenium or molybdenum is capable of producing toxicities to livestock and wildlife.

Erdman et al. (1978) reported unusually high concentrations of uranium in crested wheatgrass (Agropyron cristatum) and sweetclover (Melilotus sp.) grown on spoils at a coal mine in the southern Powder River Basin. This mine occurs on the edge of the southern Powder River Basin uranium district so uraniferous overburden could be expected. Severson and Gough (1983) reported high concentrations of boron in plants from a coal mine in southwestern Wyoming. These authors suspected that boron toxicity may be a problem because of high water soluble boron in cover soil and spoil materials.

Studies by Moffett and Tellier (1977), Vavilox et al. (1977), Cataldo et al. (1977), Dreesen et al. (1978) and others have established that plant penetration into uranium spoils and tailings and uptake of toxic elements (As, Mo, and Se) and radionuclides may constitute a significant food chain transport mechanism. The possible hazards posed by toxic trace elements associated with uranium mining and milling has been addressed (Merritt, 1971; Dreesen et al., 1978; Nuclear Regulatory Commission, 1980; Yamamoto, 1982; Smith and Boon, 1985).

Molybdenum toxicity has been reported in cattle grazing near uranium mines in Texas (Dollahite et al., 1972), near uranium mills in North Dakota (State of North Dakota, 1978) and in Colorado (Chappel, 1975). Mortality of sheep grazing in a uranium ore outcrop area in New Mexico was reported as selenium toxicity (Rapaport, 1963). Molybdenosis has been reported in areas of North and South Dakota which are underlain by uranium bearing lignites (Stone et al., 1983). These authors suggest that disruption of rock and soil during mining can mobilize enough molybdenum to cause pronounced molybdenosis in cattle.

Water Quality

Overburden materials mined from a reduced zone and placed in an oxidized environment may result in impacts to surface weter systems. Trouart and Knight (1984) reported significantly higher nitrate and nitrite concentrations in surface runoff from overburden plots as opposed to topsoiled plots in Texas. Skogerboe et al. (1979) conducted a study on the effects of western strip coal mining on surface water quality for northwestern Colorado. Significant increases in stream concentrations of manganese and selenium were reported. Increases in cadmium, copper, lead and selenium occurred in surface waters following lignite mining in North Dakota (Houghton, 1985).

Overburden materials mined from an oxidized non-saturated zone and placed in a saturated zone can produce significant impacts to groundwater systems. Groundwater impacts are generally evaluated in terms of conductivity or total dissolved solids. However, several occurrences of elevated concentrations of selenium, chromium, arsenic, zinc, and nitrate-nitrogen have occurred in spoil wells at several locations in the western United States.

Skogerboe et al. (1979) reported elevated concentrations of iron, manganese and zinc in groundwater associated with older spoils, while alevated levels of arsenic, mercury, and selenium were associated with groundwater in equilibrium with less weathered spoil. Significant increases in the concentrations of cadmium, copper, lead, and selenium occurred in the groundwaters following lignite mining in southwestern North Dakota (Houghton, 1982).

The potential for nitrate groundwater contamination can be inferred from several reports. The likely source of nitrate in backfill wells results from the oxidation of exchangeable ammonium in shales. Significant quantities of exchangeable ammonium have been reported in Paleocene and Paleozoic shales (Stevenson, 1962; Power et al., 1974). High levels of nitrate have been reported in groundwater in weathered Canadian glacial tills (Hendry et al., 1984), in various marine sediments in Utah, Colorado, Wyoming and California (Stewart and Peterson, 1917) and in overburden at surface coal mines in the western United States. Geological nitrates at levels of 1012 mg kg^{-1} have been reported in shales and mudstones from the western United States (Sullivan et al., 1979).

Power et al. (1974) reported rapid nitrification of ammonium in Paleocene shales when exposed to atmospheric conditions. Hendry et al. (1984) also reported rapid nitrification of ammonium in glacial tills containing shale fragments during column lasch experiments.

Other studies have suggested that becterial nitrification of naturally occurring ammonium in geological materials has occurred after exposure of the geological materials by surface mining (Dreher et al., 1985; Draher and Finkelman, 1986). Nitrate concentrations have exceeded livastock suitability in several areas in the Powder River Basin of Wyoming (Fig. 2). Nitrate in these beckfill wells is attributed to oxidation of ammonium bearing minerals (clays) present in the oxidized overburden prior to mining. Placement of these oxidized materials into a post-mining saturated zone resulted in leaching of the water soluble nitrates.

The nitrate eppears to be rapidly removed presumably through reduction mechanisms. Nitrate is the second chemical species to be reduced when a soil or spoil material becomes saturated (Ponnamperuma, 1972). Microbial population analyses indicate that backfill materials have a large and active microbial population (Klein, 1986). Nitrifier populations are found in the

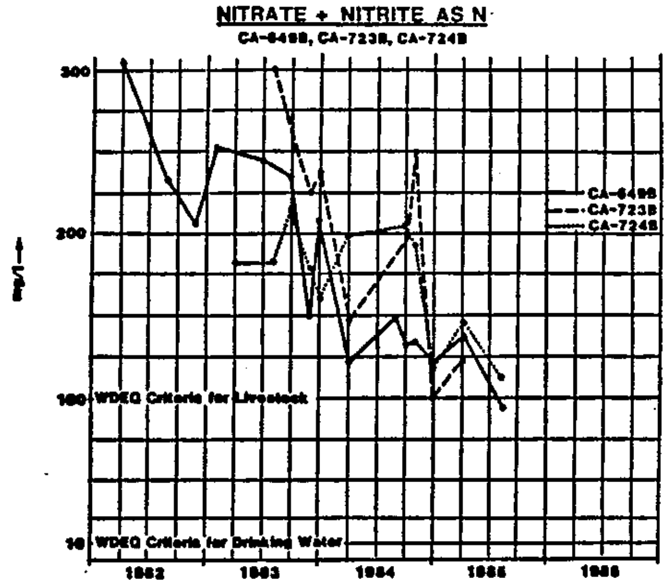

Figure 2. Nitrate + Nitrite Concentration in Spoil Wells, Powder River Basin, Wyoming.

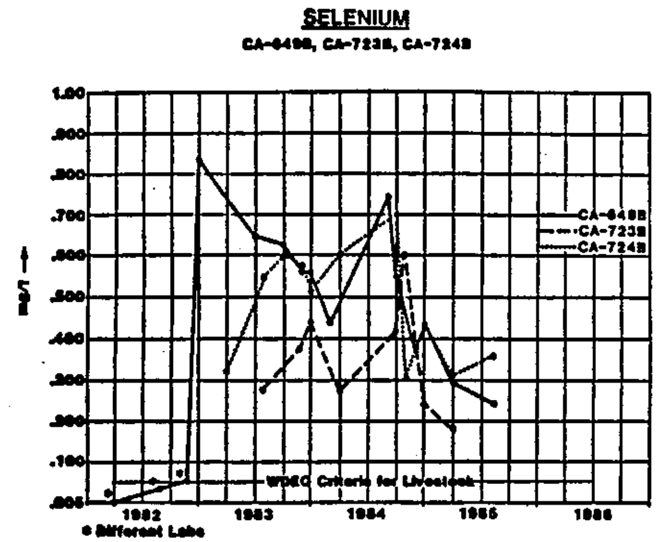

Figure 3. Selenium Concentration in Spoil Wells, Powder River Basin, Wyoming.

middle and upper portions of the backfill column while the highest denitrification activities occur just above the water saturated zone.

Numerous column leach and batch experiments conducted on overburden from throughout the western United States has demonstrated that selenium can be readily solublized from the overburden materiels. Many of the leach experiments report selenium concentrations in column leachate thet exceed selenium values reported for the overburden. This increased water soluble selenium within the oxidized surface zones hes been suggested as the source of elevated selenium in beckfill spoil water from a mine in the Powder River Basin of Wyoming (Fig. 3). During the beckfilling operations, materials from the surface oxidized zone containing increasd concentrations of soluble selenium were placed in a beckfill position below the post-mining groundwater table. Groundwater recharging tha beckfill dissolved the soluble selenium resulting in increased spoil water selenium. These figures demonstrate that the impact from nitrates and reclaiming are apperently short-term.

Monitoring

Regraded Spoil

Sampling of regraded spoils is necessary to determine if overburden handling procedures have been adequate in keeping unsuitable materials out of the potential root zone. In addition, sampling of regreded spoils will determine if pre-mining overburden information has adequately predicted the nature of tha regreded material. Several researchers and organizations have indicated a need for spoil monitoring (Doll et al., 1984; RRAC and NDPSC, 1984; Hargis and Redente, 1984; National Research Council, 1981; OTA, 1986).

Recommended regraded spoil sampling intensities range from 300 foot centers (Montana, 1983) to 500 foot centers (Merritt, 1983). If problems are reported for the regraded spoil then additional sampling may be required to further delineate the extent of unsuitable materials. Spoil sampling is the norm in Montana and Wyoming. The North Dakota regulatory authority rarely requires spoil sampling because they require so much soil cover that unsuitable overburden will not be a problem. In Colorado, spoil sampling is used to evaluate reclamation only if it is required in a permit stipulation. In New Mexico spoil sampling is not the norm (OTA, 1986). Reclaimed soil and recontoured spoils are not being monitored on a routine, long-term quantitative basis on typical reclaimed landscapes; revegetation success is being used as the indicator of the soil/spoil reconstruction success (OTA, 1986). Additional information can be obtained by collecting spoil samples during installation of spoil monitoring wells.

An analysis of regraded spoil data from a mine in Wyoming concluded that to distingush adequately between 6-acre parcels with 95% confidence, approximately three to five samples were needed for an adequate description of differences in pH, EC, and saturation percentage. Six-acre parcels could not be distinguished from one another when analyzing for ABP. Statistical analysis of the sampling densities necessary to characterize the regraded spoil for the specific parameters of concern should be conducted at all mines with regrading spoil sampling programs and the programs modified accordingly or discontinued.

Vegetation

Sampling of vegetation to determine chemical quality is not currently practiced in the western United States unless reclamation failures occur. Plant analysis to assess vegetative quality prior to bond release of reclaimed lands has been suggested (Munshower, 1983; Boon, 1984; Smith and Boon, 1985). Neuman and Munshower (1983) suggested that monitoring plant quality on the reclaimed surface may be more effective than baseline studies of overburden trace metal content.

Groundwater

One of the most accurate ways to determine the water quality of saturated spoils is to monitor over time. The recent findings of elevated concentrations of trace elements (Cr and Se) and nitrates in spoil well raise concern over the adequacies of current overburden characterization and special handling procedures for the protection of post-mining groundwater quality.

A large number of mines have been collecting backfill (spoil) water quality data for a number of years. This large volume of data needs to be evaluated and compared to the overburden chemical characteristics, and the predictive methodologies utilized for prediction of the PHC (probable hydrological consequences).

Backfill water quality data should be correlated to the specific overburden characteristics and mining methods utilized for movement of unsuitable materials. From these types of correlations we can begin to understand the predictability of quantifying spoil water quality.

SUMMARY

The elements of environmental concern to mining in the western United States include: N, S, B, Cr, and Se. Although other elements mey be of concern, these elements have continued to impact both surface and subsurface reclamation efforts in the western United States.

The general chemistry of oxidized and reduced zones have been discussed. In general, the oxidized zones contain lower pH and SAR values but increased concentrations of water soluble constituents such as nitrates and selenium. Preliminary data suggests that placement of these oxidized zones into a saturated position in the backfill may cause short term spoil water quality impacts.

All western states require the identification of potentially acid, alkaline and toxic forming materials in overburden prior to mining. However, the methods utilized for determination of these types of unsuitable materials has been a subject of debate for some time. There are major uncertainties concerned with drill hole intensity, sampling procedures, parameters of interest, analytical procedures, suitability criteria, mixing of unsuitable zones during mining, and appropriate placement of unsuitable materials in relation to the post-mining groundwater table. These uncertainties must be understood prior to accurately detemine whether unsuitable materials are present in sufficient quantities to impact surface reclamation and surface and groundwater quality. Changes in lithology and geochemistry over short distances have raised concern about whether high intensity drilling will increase the probability of accurately predicting areas of unsuitable overburden (OTA, 1986).

Several lithologic units appear to exhibit the potential for producing toxic and/or acid conditions. These units include, but are not limited to, pyrite sandstones and carbonaceous materials. Pyritic sandstones are most commonly associated with uranium roll-front deposits in the western United States. These sandstone units can be extremely acid producing and contain elevated concentrations of toxic trace elements. Carbonaceous materials are generally associated with coal mining and include such units as rider seams, roof shales and partings. Some of these units have been shown to produce acid conditions upon oxidation. In addition many of these carbonaceous units have the ability to contribute water soluble toxic elements to the reclaimed ecosystem.

The special handling of unsuitable materials and the appropriate placement of these materials in the backfill has been the subject of debate in the western United States for some time. Special handling programs need to be evaluated in light of new data regarding spoil water quality. Spoil water quality needs to be correlated to overburden chemistry, the predictive methodologies utilized for spoil water quality, the mining methods employed and placement of unsuitable materials in the backfill. Once this information has been gathered and evaluated, then and only then can we determine the "proper" placement and mining methods necessary to minimizing impacts from surface mining in the western United States.

Although we have discussed "state-of-the-art" in reference to overburden characterization and mine land reclamation for several years we, as reclamation scientists, are still in the infancy stage in many areas of our scientific knowledge. A new marriage of disciplines is necessary to answer many of the remaining uncertainties. Many of these uncertainties were identified by Williams et al. (1983). Most, if not all, are still uncertainties. An interdisciplinary effort similar to the WSOTG Parameter Papers' group is needed to further define: the chemistry of overburden, the methodologies necessary for identifying and mapping unsuitable overburden, amount of spoil mixing during normal mining operations, regraded spoil sampling intensities, methodologies for predicting spoil water quality, and the most appropriate placement of unsuitable materials in relation to the post-mining groundwater level.

REFERENCES

Abbott, R.D., D.J. Dollhopf, and A.M. Janney. 1982. Evaluation of overburden sampling intensity in mined land reclamation. Reclamation and Revegetation Research 1:255-269.

Ahlrichs, J.S., L.R. Hossner, J.B. Dixon, and A.L. Senkayi. 1984. Chemical and physical properties of lignite overburden as related to environments of deposition. pp. 431-461. Proc. Am. Soc. Surface Mining and Reclamation.
http://dx.doi.org/10.21000/JASMR84010431

Arora, H.S., C.E. Pugh, L.R. Hossner, and J.B. Dixon. 1980. Forms of sulfur in east Texas lignite coal. J. Environ. Qual. 9:383-386.
http://dx.doi.org/10.2134/jeq1980.00472425000900030011x

Barth, R.C., L.G. Cox, A. Giardinelli, S.M. Sutton, and L.C. Tisdel. 1981. State of the art and guidelines for surface coal mine overburden sampling and analysis - Phase I report - survey of current methods and procedures. Colorado School of Mines Research Institute. Golden, Colorado. 256 pp.

Beath, O. A., and C. S. Gilbert. 1936. Selenium-bearing vegetation during late Cretaceous time. Science 84:484-485.
http://dx.doi.org/10.1126/science.84.2187.484

Beath, O.A., A.F. Hagner, and G.S. Gilbert. 1946. Some rocks and soils of high selenium content. Wy. Geol. Sur. Bull. 36:1-23.

Berg, M. 1983. State requirements for soil and overburden. In: M. Berg (ed), Soil and overburden requirements for successful revegetation. Denver, CO. February.

Berg, W.A. 1978. Limitations in the use of soil test on drastically disturbed lands. pp. 653-664. In: F.W. Schalle and P. Sutton (eds), Reclamation of drastically disturbed lands. SSSA Publication, Madison, WI.

Boon, D.Y. 1984. The ammonium bicarbonate-DTPA soil test (AB-DTPA) for determination of plant available Pb, Cd, Ni, and Mo in mine tailings and contaminated soils. Information Series No. 53. Colorado Water Resources Research Institute, Colorado State University, Fort Collins, CO.

Boon, D.Y. 1986. Identification and handling of acid materials. pp. 49-65. In: Proc. High Altitude Revegetation Workshop No. 7, Coloredo Water Resources Research Institute Information Series No. 58, Colorado State University, Fort Collins, CO.

Boon, D.Y., and P.J. Smith. 1985. Carbonaceous materials: Problems associated with reclamation. Am. Soc. Surface Mining and Recl. 2:248-256.
http://dx.doi.org/10.21000/JASMR85010248

Cataldo, D.A., D. Paine, C.E. Cushing, R.M. Emery, and B.E. Vaughan. 1977. Radionuclide transport, Chapter V. pp. 5.1-6.13. In Ecology of the 200 area plateau waste management environs: A status report. L.E. Rogers and W.H. Rickard, editors. 118 p. Battelle Pacific Northwest Laboratories. Richland, Wash. [Accession Number PNL-2253, UC-11, National Technical Information Service, Springfield, Va.]

Chappell, W.R. 1975. Transport and biological effects of molybdenum in the environment. p. 167-188. In: P.A. Krenkel (ed.), Heavy metals in the aquatic environment. Proceedings of the International Symposium. Nashville, Tenn., December 1973. Pergamon Press, Oxford, England.

Davidson, D.F. 1963. Selenium in some oxidized sandstone-type uranium deposits. U.S. Geol. Sur. Bull. 1162-C.

Davidson, D.F., and R.A. Gulbrandsen. 1957. Selenium in the Phosphoria formation in Idaho, Wyoming, Utah and Montana. Geol. Soc. Am. Bull. 68:1714.

Davis, R.E. 1983. Geochemistry and geohydrology of the West Decker and Big Sky coal-mining areas, southeastern Montana. USGS Water-Resource Investigations Report 83-4225.

Doll, E.C., S.D. Merrill and G.A. Halvorsen. 1984. Soil replacement for reclamation of strip mined lands in North Dakota. N. Dak. Agr. Exp. Sta., Fargo.

Dollahite, J.W., L.D. Rowe, L.M. Cook, D. Hightower, E.M. Mailey, and J.R. Kyzar. 1972. Copper deficiency and molybdenosis intoxication associated with grazing near a uranium mine. The Southwestern Vet. 26:47-50.

Dollhopf, D.J. 1983. Overburden reclamation at coal surface mines in the northern Great Plains. pp. 589-626. In: Coal development : Collected Papers. Bureau of Land Management. July.

Dollhopf, D.J., et al. 1981. Selective placement of strip mine overburden in Montana, V summary report. U.S. Bureau of Mines Contract H0262032.

Dreesen, D.R., M.L. Marple, and N.E. Kelley. 1978. Contaminant transport, revegetation, and trace element studies at inactive uranium mill tailings piles. p. 111-140. In Uranium mill tailings management, Volume I:

Proceedings of a symposium. [Fort Collins, CO: November 20-21] 172 p. Geotechnical Engineering Program, Civil Engineering Dept., Colorado State University, Fort Collins.

Dreher, G.B. and R.B. Finkelman. 1986. Factors affecting ground water quality in the Caballo Mine backfill: Final Report. Prepared for the Carter Mining Company, Gillette, WY.

Dreher, G.B., R.B. Finkelman and E.I. Sandvik. 1985. Factors affecting groundwater quality in the Caballo mine backfill: status report. Exxon Production and Research Company, Houston, TX. 66 pp.

Ebens, R.J. and J.M. McNeal. 1977. Geochemistry of Fort Union shale and sandstone in outcrops in the Northern Great Plains Coal Province. pp. 185-197. U.S. Geological Survey. Open-file report. 77-872.

Erdman, J.A., R.J. Ebens and A.A. Case. 1978. Molybdenosis: A potential problem in ruminents grazing on coal mine spoils. J. Range Manage. 31:34-36.
http://dx.doi.org/10.2307/3897628

Finch, W.I. 1967. Geology of epigenetic uranium deposits in sandstone in the United States. U.S. Geol. Surv. Prof. Paper 538.

Finkelman, R.B. 1981. Mode of occurrence of trace elements in coal. U.S. Geological Survey. Open-file report. 81-99.

Fisher, S.E. and F.F. Munshower. 1984. Extremely acid soils, overburden and mineral in the Great Plains. Symposium on Surface Coal Mining and Reclamation in the Northern Great Plains. Billings, MT. March, 1984.

Goldhaber, M.B. and R.L. Reynolds. 1979. Origin of marcasite and its implications regarding the genesis of roll-front uranium deposits. U.S. Geol. Survey Open-File Report. 79-1696, 38 pp.

Gray, T.D., C.E. Bowen, and J.E. Trummel. 1982. Depositional studies of the early paleocene Jim Bridger coal deposits and its application to surface mine problems. Utah Geological and Mineral Bulletin 118: 102-114.

Hargis, Norman E. and Edward F. Redente. 1984. Soil handling for surface mine reclamation. J. Soil and Water Cons. 39:300-305.

Harshman, E.N. 1966. Genetic implications of some elements associated with uranium deposits, Shirley Basin, Wyoming. U.S. Geol. Surv. Prof. Paper 550-C, C167-C173.

Harshman, E.N. 1974. Distribution of elements in some roll-type uranium deposits. IAEA Proc. IAEA-SM-183/4, Vienna, Austria.

Hendry, M.J., R.G.L. McCready, and W.D. Gould. 1984. Distribution, source and evolution of nitrate in a glacial till of southern Alberta, Canada. Canada J. Hydrol., 70:177-198.
https://doi.org/10.1016/0022-1694(84)90121-5

Hinkley, T.K., R.J. Evens, and J.G. Boerngen. 1978. Overburden chemistry and mineralogy at Hanging Woman Creek, Big Horn County, Montana, and recommendations for sampling at similar sites. U.S. Geological Survey. Open-file report 78-11-5, pp. 150-168.

Holm, D. and T. Elmore. Passive mine drainage treatment using artificial and natural wetlands. pp. 41-48. In: Proc. High Altitude Revegetation Workshop No. 7, Colorado Water Resources Research Institute Information Series No. 58, Colorado State University, Fort Collins, CO.

Houghton, R.L. 1982. Trace-element enrichments in water associated with strip mining of lignite in the Fort Union Group of southwestern North Dakota. p. 46. In: Gough and Severson (eds.) Trace Element Mobilization in Western Energy Regions.

Jackson, D.R., B.C. Garrett, and T.A. Bishop. 1984. Comparison of column and batch methods of predicting composition of hazardous waste leachate. pp. 145-153. EPA-600/9-84-007.

Johnson, K. 1985. Use of geochemical modeling in the interpretation of water quality and overburden chemical analysis. pp. 404-412. In: Proc. of the Am. Soc. of Surface Mining and Reclamation, Denver, CO, October.
http://dx.doi.org/10.21000/JASMR85010404

Klein, D. 1986. Subsurface nitrogen and selenium mobilization study. Prepared for The Carter Mining Company, Gillette, WY.

Klusman, R.W. 1980. Sampling designs for geochemical baseline studies in the Colorado oil shale region: A manual for practical applications. US Dept. of Energy Publication DOE/EV/10298-2, Washington, DC.

Ley, P.A. and L.E. Welborn. 1982. Encore - A computer program for drill-hole data management, coal orebody modeling, and coal reserve estimation. Utah Geol. and Mineral Surv. Bull. 118: 149-157.

Lowenbach, W. Compilation and evaluation of leaching test methods. EPA-600/2-78-095.

Love, J.D. 1954. Preliminary report on uranium in the Gas Hills area, Fremont and Natrona Counties, Wyoming. U.S. Geol. Surv. Circ. 352.

May, R.F. and W.A. Berg. 1966. Overburden and bank solidity. Coal Age 71:74-75.

McWhorter, D.B. and R.A. Landers. 1985. Prediction of post-mining water quality with column tests and overburden chemistry. I: Proc.

Am. Soc. Surface Mining and Reclamation. Denver, CO. October.

Merritt, R.C. 1971. The extractive metallurgy of uranium. Colorado School of Mines Research Institute. Johnson Publishing Company, Boulder, CO.

Merritt, R.D. 1983. Coal overburden. Noyes Data Corporation, Park Ridge, NJ. p. 343.

Miller, W.L., C.L. Godfrey, W.G. McCully and G.W. Thomas. 1976. Formation of soil solidity in carbonaceous soil materials exposed by highway excavations in East Texas. Soil Science 121:163-168.
http://dx.doi.org/10.1097/00010694-197603000-00004

MLRD (Mined Land Reclamation Division). 1982. Guidelines for the collection of baseline water quality and overburden geochemistry data. Colorado Department of Natural Resources, Denver, Colorado.

MMD (Mining and Mineral Division). 1984. Overburden and soils inventory and handling guidelines. Draft, Energy and Minerals Department, Santa Fe, New Mexico.

Moffett, D. and M. Tellier. 1977. Uptake of radioisotopes by vegetation growing on uranium tailings. Canadian Journal of Soil Science 57(4):412-424.
http://dx.doi.org/10.4141/ciss77-047

Moffett, D. and M. Tellier. 1978. Radiological investigations of an abandoned uranium tailings area. Journal of Enviroment Quality 7(3):310-314.
http://dx.doi.org/10.2134/jeq1978.00472425000700030003x

Montana. 1983. Soils and overburden guidelines - draft. Montana Dept. State Lands - Reclamation Division, Helena, MT.

Moran, S.R., et al. 1978. Geologic, hydrologic, and geochemical concepts and techniques in overburden characterization for mined-land reclamation. North Dakota Geological Survey, report of investigation No. 63.

Munshower, F.F. 1983. Soil and overburden trace element concentrations. In Proceedings: Conference on soil and overburden requirements for successful revegetation. M. Berg. (ed.). Denver, CO.

Naftz, D. 1987. Statistical summary of groundwater-quality data from selected mined areas in the Powder River Basin, Wyoming. In: Proc. Am. Soc. Surface Mining and Reclamation. Billings, MT. March.

National Research Council. 1980. Trace element geochemistry of coal resource development related to environmental quality and health. Washington, D.C.: National Academy Press.

NDPSC (Public Service Commission of North Dakota) and RRAC (Reclamation Research Advisory Committee). A report on reclamation research in North Dakota: inventory of past and ongoing research and identification of future research needs. Prepared for the North Dakota Legislative Council, Bismarck, North Dakota.

Neuman, D.R. and F.F. Munshower. 1983. Copper molybdenum uptake by legumes growing on topsoiled mine spoils, final report. Reclamation Research Unit, Mont. Agr. Exp. Sta., Bozeman.

Nuclear Regulatory Commission. 1980. Final Generic Environmental Impact Statement on Uranium Milling. Office of Nuclear Material Safety and Safeguards, U.S. Nuclear Regulatory Commission (Project M-25). NUREG-0706, Volume I, pp. 6-16.

OTA. 1986. Western surface mine permitting and reclamation. U.S. Congress, Office of Technology Assessment. OTA-E-279. U.S. Government Printing Office, Washington, DC.

Pettijohn, F.J. 1957. Sedimentary rocks. 2nd Edition. Harper and Row, pp. 361-363.

Ponnamperuma, F.N. 1972. The chemistry of submerged soils. Adv. Agron. 24:29-96.

Power, F.F., R.E. Ries, and F.M. Sandoval. 1978. Reclamation of coal mined land in the Northern Great Plains. J. Soil Water Conservation. March-April. pp. 69-74.

Rapaport, I. 1963. Uranium deposits of the Poison Canyon Ore Trend, Grants District. p. 122-. In: Geology and technology of the Grants Uranium District. Memoir 15, 277 p. New Mexico Bureau of Mines and Mineral Resources. Socorro, NM.

Rendu, J. 1982. Application of geostatistics to coal evaluation. Utah Geol. and Mineral Surv. Bull. 118: 251-261.

Reynolds, R.L. and M.B. Goldhaber. 1982. Iron disulfide minerals and the genesis of roll-type uranium deposits. Economic Geology 78:105-120.

Severson, R.C. 1984. Soil and overburden sampling needs and programs. pp. 211-222. In: Proc. Surface Coal Mining and Reclamation in the Northern Great Plains. Billings, MT. March.

Severson, R.C. and S.E. Fisher. 1985. Results of the first western task force round robin soil and overburden analysis program. USGS Open-file report 85-220.

Severson, R.C. and L.P. Gough. 1983. Boron in mine spoils and rehabilitation plant species at selected surface coal mines in Western United States. J. Environ. Qual. 12:142-146.
http://dx.doi.org/10.2134/jeq1983.00472425001200010026x

Skogerboe, R.K., C.S. Lavelle, M.M. Miller, and D.L. Dick. 1979. Environmental effects of western coal surface mining. Part III - The water quality of Trout Creek, Colorado. EPA-600/3-79-008, Envir. Res. Lab., Duluth, MN.

Smith, P.J., and D.Y. Boon. 1985. Plant analysis: A measure of successful reclamation. Am. Soc. Surface Mining and Recl. 2:95-101.
http://dx.doi.org/10.21000/JASMR85010101

State of North Dakota. 1978. Final west-central North Dakota regional environmental ipoact study on energy development. Bureau of Land Management, Bismarck, ND.

Stevenson, F.J. 1962. Chemical state of the nitrogen in rocks. Geochim. Cosmochim. Acta 26:797.
https://doi.org/10.1016/0016-7037(62)90040-6

Stewart, R. and W. Peterson. 1917. Further studies of the nitric nitrogen content of the country rocks. Utah Agric. College Exp. Stn. Bull. 152:20 pp.

Stone, L.R., J.A. Erdman, G.L. Feder, and H.D. Holland. 1983. Molybdenosis in an area underlain by uranium-bearing lignites in the Northern Great Plains. J. Range Manage. 36:280-285.
http://dx.doi.org/10.2307/3898469

Sullivan, Patrick J., Gerrison Sposito, S.M. Strathouse, and C.L. Hansen. 1979. Geologic nitrogen and the occurrence of high nitrate soils in the western San Joaquin Valley, California. Hilgardia 47(2):15-49.
https://doi.org/10.3733/hilg.v47n02p015

Sutton, S.M., R.C. Barth, and L.C. Tisdel. 1981. State of the art guidelines for surface coal mine overburden sampling and analysis. Prepared by Colorado School of Mines for the Office of Surface Mining, Washington, D.C. C/N J5161047.

Troyer, M.L., E.J. McKay, P.A. Soister, and S.R. Wallace. 1954. Summary of investigations of uranium deposits in the Pumpkin Buttes area, Johnson and Campbell Counties, Wyoming. U.S. Geol. Surv. Circ. 338:1-17.

Trouart, J.E. and R.W. Knight. 1984. Water quality of runoff from revegetated mine spoil. pp. 15-36. Proc. 1984 National Meeting of the Americen Society for Surface Mining and Reclamation. Owensboro, KY.
http://dx.doi.org/10.21000/JASMR84010015

UDOGM. 1986. Guidelines for management of topsoil and overburden. State of Utah, Division of Oil, Gas and Mining. Salt Lake City, UT.

Valkovic, V. 1983. Trace elements in coal. CRC Press Inc., Boca Raton, FL. p. 210.

Vavilov, P.O., B.I. Gruzder, V.I. Maslov, V.YA. Ovehentor, and A.I. Taskaer. 1977. Results of an experiment over many years in decontaminating radium-bearing and uranium radium-bearing pollutants in the central Taiga. The Soviet Journal of Ecology 8(6):496-500.

Vine, J.D., and G.E. Prichard. 1954. Uranium in the Poison Basin area, Carbon County, Wyoming. U.S. Geol. Surv. Circ. 344.

Walsh, James P. & Associates. 1985. Soil and overburden management in western surface coal mine reclamation. Contractor Report to OTA. August.

WDEQ. 1984. Wyoming Department of Environmental Quality - Land Quality Division. Guideline No. 1 - Topsoil and Overburden. Cheyenne, WY.

Western Water Consultants. 1985. Hydrologic evaluation and reclamation technologies for western surface coal mining. Contractor Report to OTA. August.

Williams, R.D., W.J. Ruzzo and J.P. Reganold. 1983. Soil and overburden research needs. pp. 165-178. Proc. Soil and Overburden Requirements for Successful Revegetation. Denver, CO, Feb. 22, 1983.

Wyoming. 1985. Soils analytical data. AML Project No. 7, Wyoming Department of Environmental Quality - Land Quality Division, Abandoned Mine Lands Program, Cheyenne, WY.

Wyoming. 1985. Department of Environmental Quality - Land Quality Division - Abandoned Mine Lands Project Number 7. Soils analytical data for AML project number 7. Baggs, WY. Progress report.

Yamamoto, T. 1982. A review of uranium spoil and mill tailings revegetation in the western United States. USDA Forest Service General Technical Report RM-92.