PREDICTING REGRADED SPOIL QUALITY FOLLOWING RECLAMATION AT A SURFACE COAL MINE[1]

by

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Abstract. The quality of regraded spoil determines the thickness of soil replaced on reclaimed lands following surface mining in North Dakota. The required volume of soil to be salvaged prior to mining can be projected based on predicted soil replacement depth requirements. This paper evaluates a formula specified by the North Dakota Public Service Commission Reclamation Division to predict replacement depth requirements. The formula is based on the poorest quality overburden representing 20% of pre-mine overburden samples. Quality characteristics include sodium adsorption ratio (SAR), texture, and saturation percentage. Actual replacement depths were based on analyses of samples from 1,886 acres of regraded spoils at The Coteau Properties Company Freedom Mine. The weighted average projected replacement and actual replacement depths were 44.6 inches and 40.0 inches, respectively. Over 50% of areas with 24 inches of soil replaced had an original projection of 48 inches. Only 6% of areas with 48 inches of soil replaced had a 24 inch projection. Significant factors determining actual replacement depth include: 1) regrading with glacial till, 2) reclamation of facilities such as roads and ponds, and 3) prime farmlands. Areas reclaimed as prime farmland had a weighted average actual replacement depth of 47.8 inches. An annual soils handling plan is developed to assure required amounts of soil are salvaged and kept in inventory for mine reclamation.

Introduction

Earth moving is the major cost of surface mining. Predicting amounts and types of material to be moved is extremely important in controlling costs. Topsoil and subsoil, stripped ahead of mining and replaced on regraded lands, are more expensive to move than overburden.

This paper analyzes a formula developed by the State regulatory authority, the North Dakota Public Service Commission Reclamation Division, to predict regraded spoil quality. Regraded spoil quality dictates soil replacement depths, and ultimately soil volumes required to be salvaged for reclamation.

Previous Research

A tremendous amount of research has been conducted to determine required soil replacement depths over regraded spoil of known quality. Much less research has been conducted to develop a predictive model determining chemical and physical characteristics of regraded spoils.

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Soil Replacement Research. North Dakota surface mining regulations in the early 1980s required that five feet of soil be stripped and replaced on reclaimed lands. This depth was chosen because soil surveys in North Dakota generally extend to five feet, and the prevailing opinion was that all soil material available should be salvaged. Early work by Power et al. (1975, 1976, 1978, 1979) indicated lesser soil replacement may be sufficient to restore pre-mine productivity to reclaimed lands under certain conditions in the Northern Great Plains. Schuman and Power (1980) and Schuman et al. (1985) reported similar results. Barth and Martin conducted studies at the Center Mine in North Dakota to determine proper replacement depths for perennial grasses seeded on reclaimed lands. Their findings are similar to those of other researchers in North Dakota, and supported later regulatory changes reducing required soil replacement depths under certain conditions.

Power et al. (1974) and Halvorson et al. (1980) noted the existence of high sodium adsorption ratio (SAR) levels in overburden west of the Missouri River in North Dakota, and expressed concern regarding problems associated with reclamation of these sodic spoils. Ries et al. (1977), Sandoval and Gould (1978), Dollhopf et al. (1980), Merrill et al. (1980), and Power et al. (1981) studied required replacement depths as they relate to SAR values of regraded spoils. Most of this research was concentrated in North Dakota's coal fields.

Doll et al. (1984) summarized previously published papers, as well as research conducted by the USDA Northern Great Plains Research Center and the North Dakota State University Land Reclamation Research Center. This summary provided recommendations for required soil replacement depths over regraded spoils of various quality. Known as "Bulletin 514," this served as a cornerstone to revise North Dakota surface mining regulations in late 1986 (Pole 1988). These revisions eliminated a strict five foot depth lift-and-replace procedure with a table describing required soil replacement amounts dependent on regraded spoil quality (North Dakota 1987). Most reclamation at the Freedom Mine has taken place since these regulations were promulgated, and soil replacement depths were based on specific table requirements (Table 1).

Table 1. Table in North Dakota Public Service Commission regulations, used to determine soil respread depths over regraded spoils.

Spoil Properties			Total Redistribution Thickness (Topsoil Plus Subsoil) Average in	
Texture	Sodium Adsorption Ratio (meq/l)	Saturation Percentage	Inches	(Centimeters)
Medium*	< 12	***	24	(61)
Coarse**	< 12	***	36	(91)
***	12 - 20	< 95	36	(91)
***	12 - 20	> 95	42	(107)
***	> 20	***	48	(122)

* Loam or finer ** Sandy loam or coarser *** Not applicable

Predicting Regraded Spoils. Most geostatistical modeling and prediction has been conducted by geologists and geological engineers to determine characteristics associated with ore reserves prior to mining. Limited coring and sampling must be used as a data base to determine the extent of economically mineable reserves. Matheron (1963) pioneered this predictive work. "Classical" geostatistics is characterized by analyses using means, variances, degrees of freedom, etc. This has recently been supplemented by the use of kriging, which ostensibly provides a more precise model of spatial variability with fewer data points.

Merks (1992) compared kriging with classic geostatistical methodologies, and questioned the validity of kriging as a predictive tool. Nonetheless, kriging, and advances such as cokriging and disjunctive kriging, are commonly used to provide spatial characterization in geological studies.

These techniques have also been used for characterization of near surface soil materials. Vauclin et al. (1983) compared kriging, cokriging, and classic geostatistics to determine spatial characteristics of soil water availability with limited sampling. Webster (1991) mapped concentrations of copper and cobalt in agricultural soils, and Byers and Stephens (1983) correlated hydraulic conductivity and particle size on sandy soils in New Mexico using these techniques. In North Dakota, Cassel and Bauer (1975) used classic geostatistical methods to evaluate spatial variability for soil bulk density and 15 bar soil water content on three soils. They developed a formula to determine the number of samples required for a desired precision.

Less work has been conducted to predict regraded spoil quality. Bos et al. (1984) determined optimum sampling density to characterize reclaimed soils following phosphate mining in Florida. No correlation with pre-mine overburden or soil characteristics was found, however. Halvorson (1989a, 1989b) tested several different sampling densities to map regraded spoil quality at North Dakota surface mines, including the Freedom Mine. Only poor correlations could be found between pre-mine overburden and regraded surface spoil characteristics. This was attributable to highly variable pre-mine overburden characteristics, and extensive shallow finish grading with tractor-scrapers, following spoil placement and rough grading.

Early opinion held that normal dragline operations would simply invert spoil, so that material which was at the base of the overburden would be at the top of spoil piles and, consequently, at the surface of regraded land. Winczewski (1978) sampled regraded spoils and found this to be untrue. Although a certain amount of inversion takes place, the amount of mixing and blending is much greater than previously believed.

Dollhopf (1986) studied overburden handling and placement at a surface coal mine near Colstrip, Montana. He related the presence of inhibitory materials, mostly overburden with high electrical conductivity (EC) and SAR, on the regraded spoil surface to its presence in undisturbed overburden. He found a linear relationship between spoil mixing and certain physical and chemical characteristics and drew conclusions about expected presence or absence of these materials in a post-mining setting, based on concentrations prior to mining. Different dragline digging and spoiling operations to bury inhibitory materials were evaluated. He found these operations add 10% to 50% to the cost of overburden removal, and may not be economically justified.

Dollhopf also developed a regression model to determine the pre-mine extent of inhibitory materials. Using classic geostatistical theory, this model showed that sampling on approximately a 90 foot square grid is required to make characterization estimates with 90% precision. He recognized that with industry-wide use under such a scenario, "the cost associated with overburden characterization would skyrocket into the millions of dollars," and "represent a financial burden to the mining industry."

Freedom Mine Setting and Operations

The Freedom Mine is owned and operated by The Coteau Properties Company, a wholly owned subsidiary of The North American Coal Corporation. The mine is located about 90 miles northwest of Bismarck, North Dakota.

Coal mining began in 1983. Current annual production is 14-15 million tons. The entire permitted mine area is about 16,500 acres. Annual land disturbance is 5-600 acres. Final reclamation commenced in 1986. To date over 2,000 acres have been completely reclaimed, and are now producing wheat, hay, and native rangeland forage for livestock grazing.

Vegetation and Land Use

Almost all land mined in North Dakota is privately owned. About 60% of the land at the Freedom Mine is used for small grain production, primarily hard red spring wheat. Durum wheat, barley, oats, flax, sunflowers, and corn for silage are also grown. A fallow rotation system is used, where crops are grown for two out of three years; land is fallowed the third year to conserve moisture.

Most remaining land is mixed grass prairie, used for cattle grazing. This is comprised primarily of western wheatgrass *(Agropyron smithii)*, needlegrass *(Stipa viridula)*, needle-and-thread *(Stipa comata)*, blue grama *(Bouteloua gracilis)*, and several different forbs. Grazing is normally season long (from May to September), with little or no pasture rotation.

Geology and Soils

The Freedom Mine is located within the glaciated subsection of the Missouri Plateau, part of the Great Plains Province. Formations of sedimentary origin were deposited in the Williston Basin, the dominant structural feature of western North Dakota. From 60 to 600 million years ago, numerous inland seas advanced and retreated across the area, depositing a wide range of marine and lagoonal sediments, mainly shales, limestones, and evaporates. Later deposition was interrupted by episodes of regional uplift, faulting, warping, and erosion.

During the Pleistocene Epoch (10,000 to one million years ago), continental glaciers advanced and retreated, modifying the existing topography by depositing varying thicknesses of glacial materials in upland areas and eroding and filling diversion trenches. Southwest of the Missouri River, glacial deposits are thin or absent. A mantle of glacial till exists over sedimentary clays and shales in much of the permit area. Its existence is marked on the surface by glacial erratics or boulders. These are not as common on steeply sloping sites where glacial materials have eroded to expose a residual soil parent material of clays and shales (Figure 1).

Soils formed in material weathered from glacial till are generally used as croplands, although steeper, rockier sites may be unsuitable for cropping. These Mollisol soils generally have a topsoil layer (mollic epipedon) that is 10-20 inches thick, underlain by calcareous clay loam till. Suitable subsoil generally exists to five feet, but may extend as deeply as twelve feet.

Soils formed from weathered bedrock are more commonly covered with native prairie and used for livestock grazing. These are steeper sites, have much shallower topsoil, normally 6-10 inches thick, with soft clay loam bedrock below. Suitable subsoil is only 10-40 inches in thickness, below the topsoil.

Overburden quality at the Freedom Mine is similar to that described by Schroer (1978). Quality is highly variable (Table 2) and largely dependent on the thickness of glacial till over clay and shale sediments of the Fort Union Group. Fort Union clays are characterized by high clay content and elevated SAR values. Electrical conductivity is generally low in soils derived either from glacial till or residual clay and shale parent materials.

Glacial till is generally clay loam, and has much lower SAR values than Fort Union clays. Electrical conductivity increases with depth in glacial till until it peaks at 10-20 feet below the surface, then normally starts declining.

Chemical and physical analyses of glacial till indicate it often has high quality characteristics (suitable texture, low EC, low SAR), allowing it to be substituted for subsoil. In other situations, elevated EC values may allow it to be used only to compensate for any subsoil shortages for replacement over sodic spoils.

Mining and Reclamation Operations

Mining methods used at the Freedom Mine are typical of large surface coal mining operations in the Northern Great Plains (Figure 2). Topsoil and subsoil are stripped with tractor-scrapers ahead of mining. Coteau also conducts a truck-shovel operation to assist with subsoil haulage and replacement.

When all topsoil and subsoil has been removed and required approval is received from the Public Service Commission, coal is uncovered. A single seam of lignite coal, averaging 16-20 feet in thickness, is mined. Overburden depth averages about 100 feet, but ranges from 20-200 feet. Two Bucyrus-Erie 110 cubic yard class electric walking draglines uncover coal in pits up to two miles long.

Table 2. Range of important characteristics for overburden at the Freedom Mine.

Material	Electrical Conductivity mmhos/cm	Sodium Adsorption Ratio meq/l	Texture
Glacial till overburden	0.5 - 7	0.5 - 8	Clay loam-clay
Fort Union clay overburden	0.5 - 4	5 - 30 +	Clay-silty clay

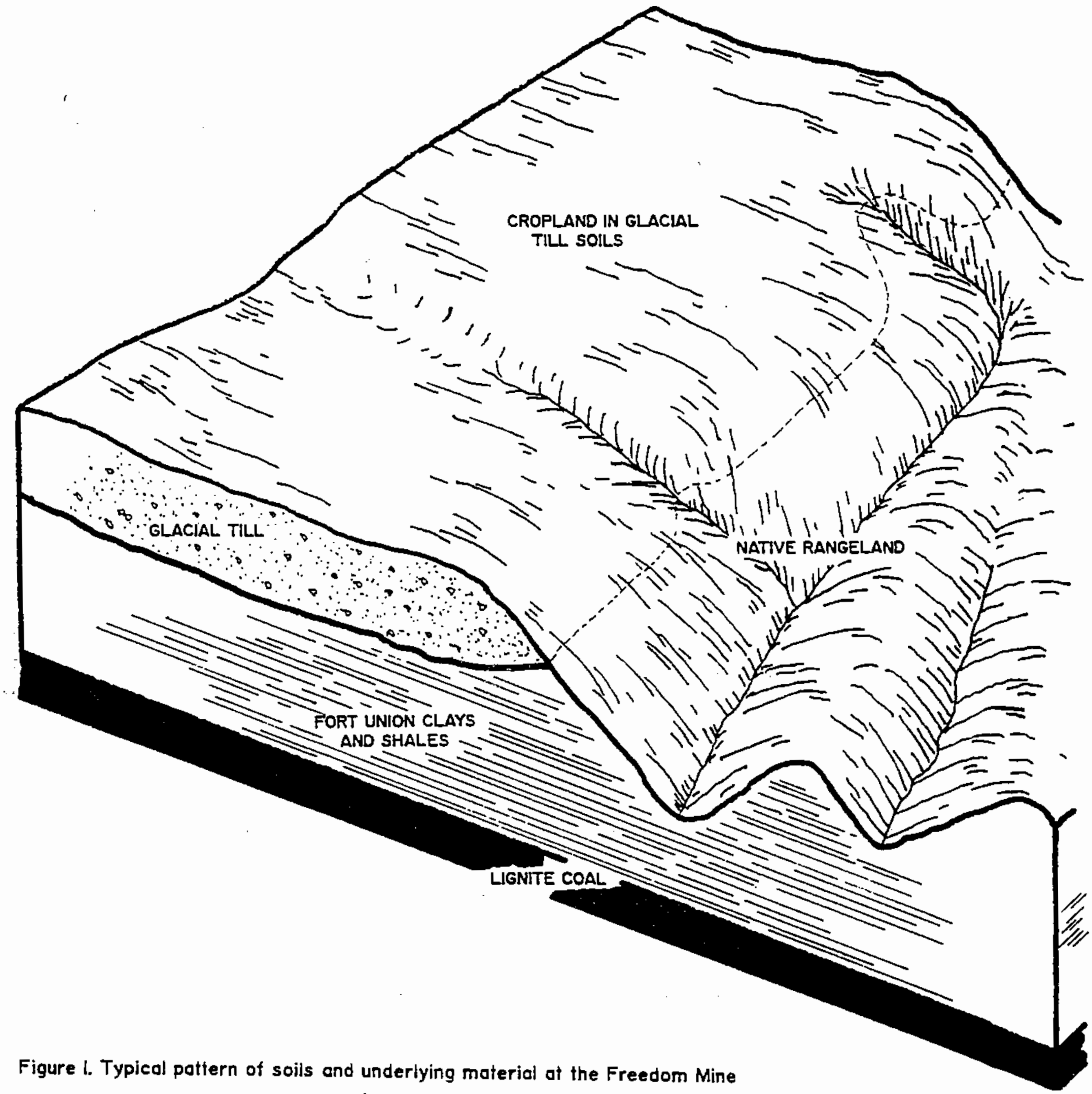

Figure l. Typical pattern of soils and underlying material at the Freedom Mine

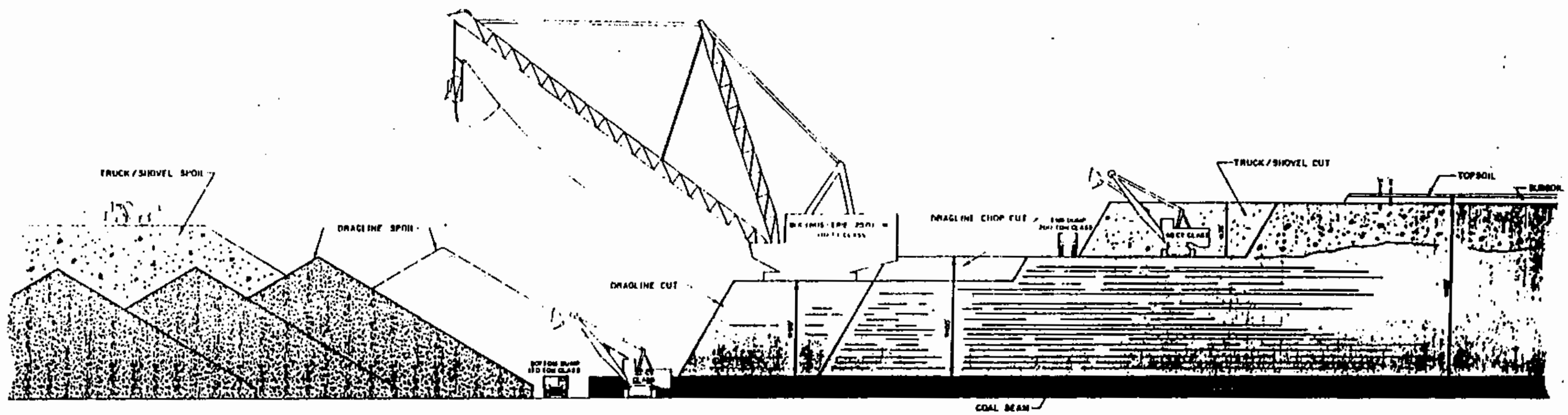

Figure 2. Typical mining operation at the Freedom Mine

In deeper cover, draglines are assisted by Coteau's truck-shovel fleet, primarily using a P & H 2800 electric loading shovel and end dump trucks to prebench and chopcut ahead of the draglines. Coal is uncovered exclusively with tractor-scrapers, bulldozers, and trucks and shovels in low cover areas.

Draglines dig a parallel pit uncovering the next coal, while filling the previous pit where coal has just been removed. Reclamation is contemporaneous, i.e. spoil peaks are constantly being knocked down and rough graded with bulldozers behind the active pit. No more than four spoil peaks exist at any one time. Following rough grading, finish grading is conducted. Regraded lands must be approved by the Public Service Commission prior to soil replacement.

Samples of regraded spoil are taken to a two-foot depth, on 400-foot centers. These are analyzed for texture, pH, sodium adsorption ratio, electrical conductivity, and saturation percentage. Results of these analyses are compared to regulatory guidelines and a soil replacement depth is determined. A tract may have one or several different replacement depths, depending on regraded spoil quality variability. All available topsoil is uniformly replaced on regraded lands, so differences in replacement depth are accomplished by differential subsoil replacement thickness.

About 90% of the soil at the Freedom Mine is directly replaced on regraded lands behind the active pit. North Dakota regulations require soil segregation by landowner, so direct soil replacement is possible only where Coteau owns land being mined and reclaimed, or where soil mixing agreements exist between landowners.

Following subsoil and topsoil replacement, the surface is tilled, rocks are picked, and the area is seeded to the appropriate land use seed mixture. Reclaimed lands are managed by Coteau and contracted to local farmers for hay cutting, grazing, or crop production.

<u>Determining Regraded Spoil Quality</u>

Utilizing a method developed by the Public Service Commission, regraded spoil quality was projected and mapped for each permit area. This was translated into a map showing projected soil replacement depths. This information was used to project volumes of subsoil to be stripped ahead of the dragline. The accuracy of the predictive method was tested by overlaying a map of actual soil replacement depths on projected replacement depths, and making comparisons (Figure 3).

<u>PSC Method to Project Soil Replacement Depth</u>

Following regulatory revision in late 1986, the Public Service Commission developed a predictive tool for operators to determine future soil replacement depths.

With no previous model in place, Public Service Commission staff looked at available data and designed a method that would be used until more data became available. No complex mathematical or statistical analysis or modeling techniques were used to develop this method (Deutsch 1992).

To provide guidance and rule interpretation, PSC Policy Memorandum No. 17 states:

> "Since the total SPGM [suitable plant growth material, or soil] respread thicknesses are tied to the regraded spoil properties, the amount of SPGM

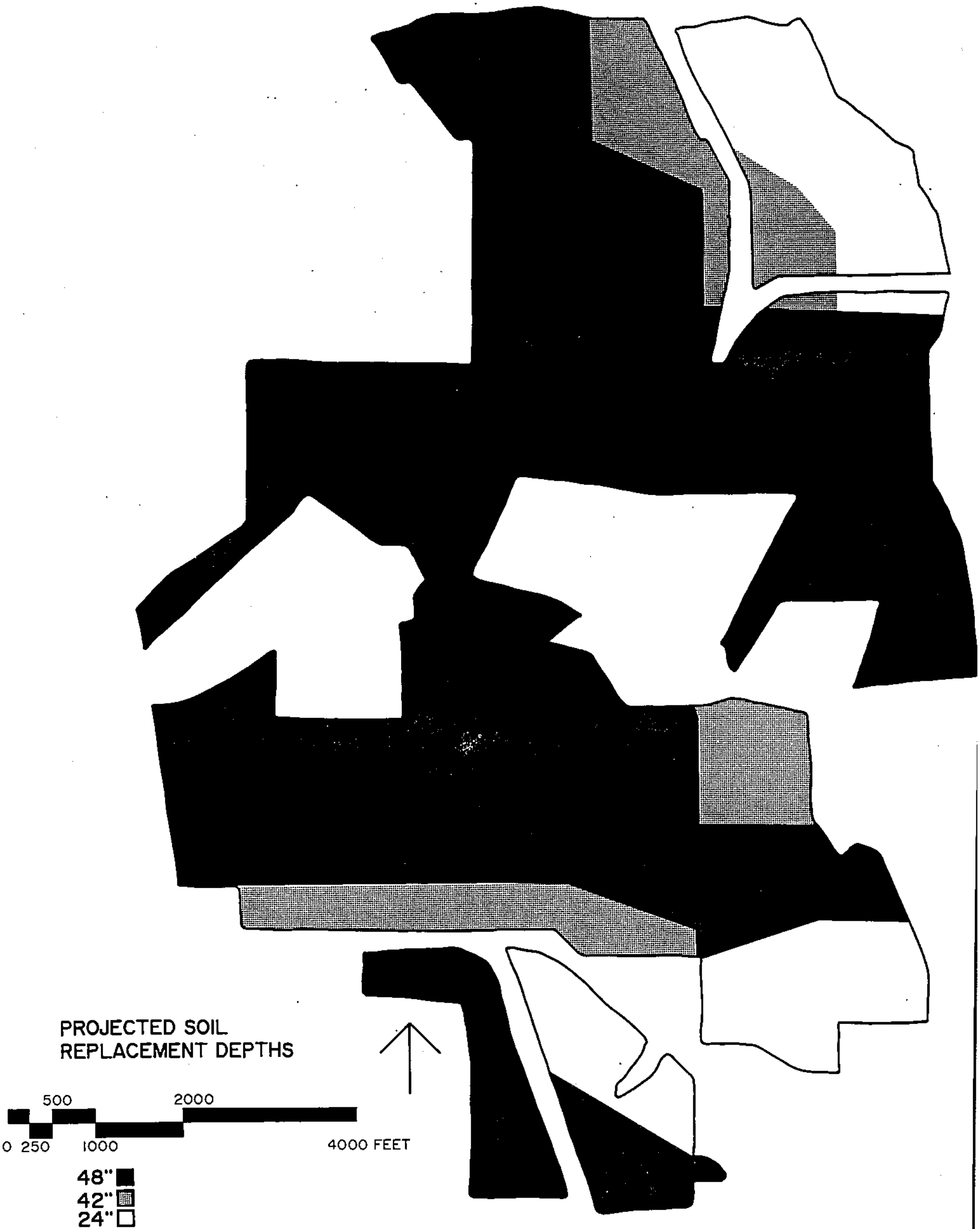

FIGURE 3 (I OF 2)

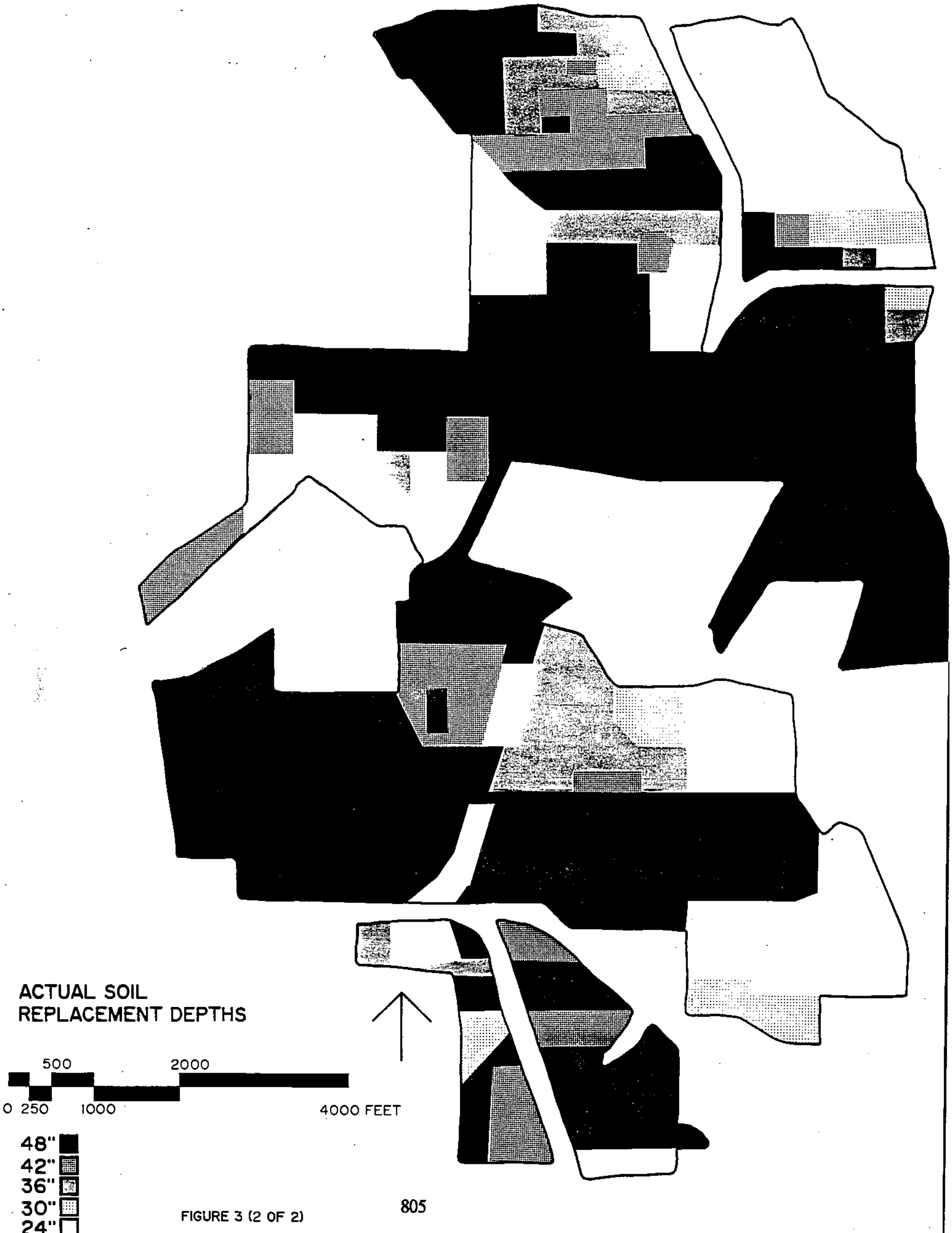

FIGURE 3 (2 OF 2)

to be removed prior to mining will be based on the pre-mine overburden analyses. However, at the present time, there is no model for accurately predicting regraded spoil properties from the pre-mine overburden data. Until a suitable model is developed, the proposed SPGM respread thicknesses for the permit area will be determined by the Commission prior to permit approval according to the following procedures using available overburden sample results:

a). If one coal seam will be mined and the overburden will be removed with a dragline, the respread thickness for the area represented by each drill hole will be specified based on the most undesirable material (i.e., that requiring the greatest thickness of replaced SPGM) occurring in twenty percent or more of the overburden above the coal seam to be mined. Example - if the overburden thickness down to the coal seam is eighty feet and four of the sixteen five-foot overburden segments have SAR's greater than twenty, the respread thickness will be 48". However, depending on the distribution of the least desirable material and site specific SAR values, variations from this procedure may be considered on a case by case basis."

The policy memo also lists procedures for multiple seam mining and allows operators to use an alternative method, based on site specific characteristics, when overburden is handled exclusively by tractor-scrapers or trucks and shovels. Coteau follows the detailed procedure described for normal dragline operations for all areas, realizing this is a conservative approach.

The requirement to conduct overburden sampling every 40 acres and analyze every five foot increment was unchanged from previous regulations. Where two adjacent holes dictated different replacement depths, a boundary is placed halfway between them.

Testing the Public Service Commission Method

About 200 acres were regraded at the Freedom Mine before these new regulations and methodology became effective. The Public Service Commission method was used to project soil replacement depth on 1,886 acres regraded since that time. The weighted average projected soil replacement depth is 44.6 inches. This compares with the actual replacement depth over regraded spoils of 40.0 inches. Considering the lack of previous modeling data or experience, this is quite a favorable comparison, and indicates the Public Service Commission method may be suitable as a predictive tool. If one considers the basic predictive model, while not grounded in statistical theory or based on exhaustive analysis, to be fairly accurate, there are several other reasons for discrepancies between projected and actual soil replacement depths.

Factors Affecting Soil Replacement Depths

There was no projection for any 36 inch replacement depth on regraded lands, although there were 125 acres where 36 inches was actually replaced following regraded spoil sampling (Table 3). Regulations have a provision for a 36 inch replacement depth under two conditions. When regraded spoil is chemically suitable

Table 3. Actual vs. projected soil replacement depths, by acreage, at the Freedom Mine.

	Projected Replacement Depths			
Actual replacement depths	24"	42"	48"	Total Acres
24"	83.4	89.0	194.9	367.3
30"	16.4	24.0	20.5	60.9
36"	2.5	62.8	59.8	125.1
42"	8.1	39.7	129.5	177.3
48"	50.9	204.7	900.1	1,155.7
	161.3	420.2	1,304.8	1,886.3

for a 24 inch replacement, but has a sandy loam or coarser texture, 36 inches must be replaced. This is to avoid construction of a soil profile susceptible to drought (Halvorson et al. 1986). Overburden at the Freedom Mine contains very little sandy material.

Second, if the SAR of a regraded spoil is 12 to 20, but the saturation percentage is <95, required replacement depth decreases to a 36 inch requirement from a 42 inch requirement. This was added during rule making negotiations, and there remains some question to this day whether this requirement is supported by research. A requirement to sample for saturation percentage in pre-mining overburden, if the SAR is 12 to 20, was enacted concurrently with other rule changes affecting soil replacement depths. Most overburden data had already been collected and approved in existing permits. Without data on saturation percentage, Coteau had to assume all pre-mine overburden with an SAR of 12 to 20 would require a 42 inch replacement depth. During later regraded spoil sampling and analysis, it was found this was not the case, and that much of the area could be reduced from a 42 inch to a 36 inch requirement, based on favorable saturation percentage.

There is no projected 30 inch replacement depth. However, about 60 acres actually had 30 inches replaced. There are two reasons for this. Although no soil replacement depths are based on electrical conductivity values of regraded spoils, some regraded areas determined to require a 24 inch replacement depth had EC values of four to seven mmhos/cm. Coteau and the Public Service Commission agreed that something more than 24 inches should be replaced on these sites to assure vegetation was not affected by higher salt levels. Second, rules require that soil replacement be ±6" of staked amounts. Under wet or snowy conditions, this can prove very difficult when replacing shallow depths. To assure a required 24 inches of soil replacement was achieved in these situations, Coteau staked the area for an actual 30 inch soil replacement depth.

A review of actual replacement versus projections indicates there was a tendency for actual depths to be much lower than projected, rather than higher (Figure 4). For example, over half the areas with an actual 24 inch replacement had an original projected replacement of 48 inches, whereas only 6% of areas with an actual 48 inch replacement had an original projection of just 24 inches. One reason for this reduction, from projected to actual replacement depths, is the evaluation of saturation percentage following regrading, but not before mining, at

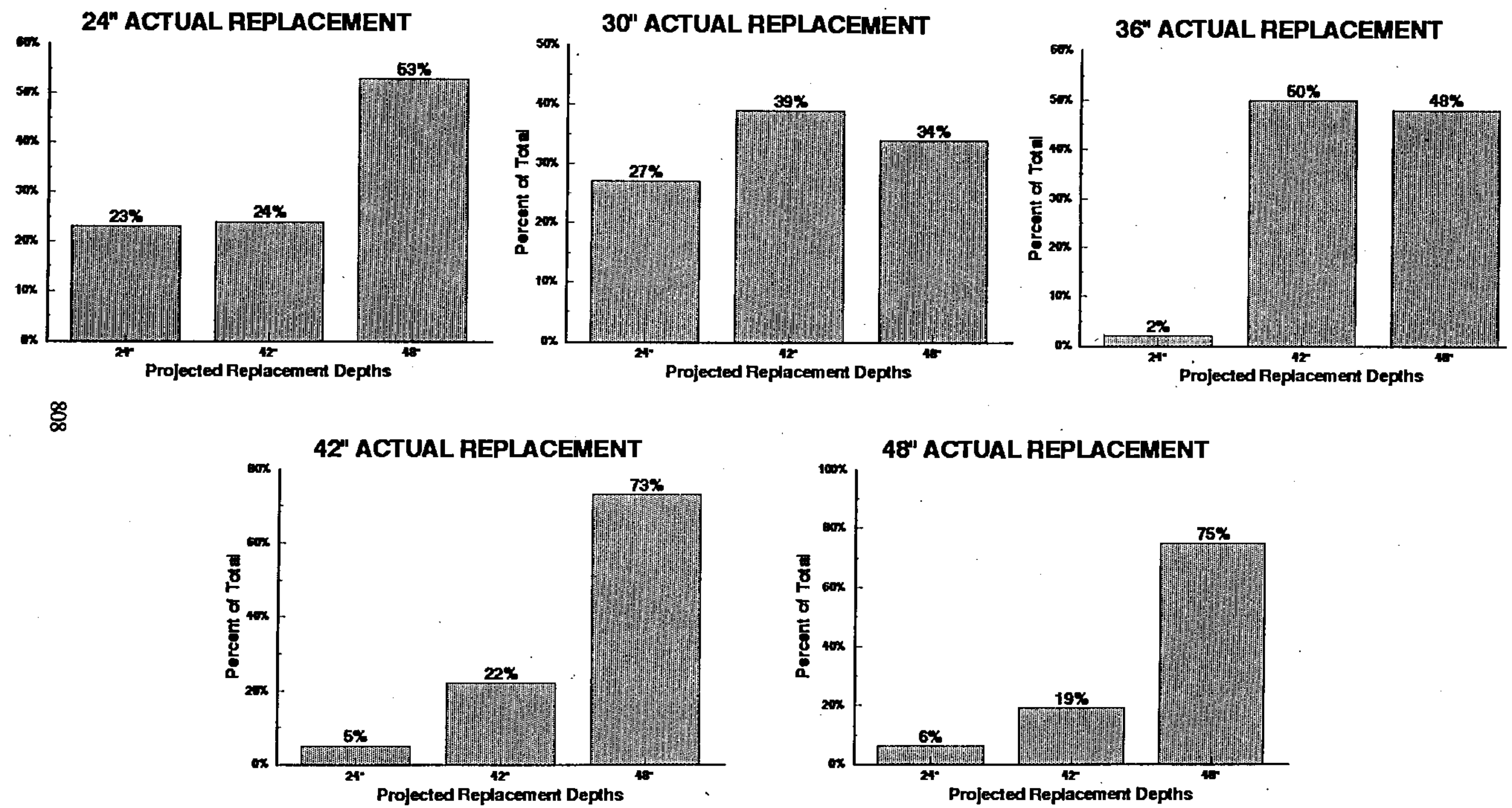

Figure 4. Percent of projected replacement depths by actual replacement depth category

least in actual replacement depths of 36 inches versus projections of 42 inches. Another reason is a conscious attempt to place a layer of glacial till on spoil areas during final regrading. This is evidenced by the increased difference between projected and actual soil replacement depths from 1987 to 1990 (Figure 5). During this time overburden depths were increasing, and Coteau implemented a truck-shovel operation to supplement dragline operations in high cover areas. More effort was placed on hauling prebench and chopcut materials, which is generally higher quality glacial till, to areas being regraded. Since that time, actual replacement depths remain about 90% of projections.

Hauling glacial till during reclamation enhances the quality of regraded spoil, reducing required soil replacement depths, thereby reducing expensive subsoil haulage. While the same total volume of material must be moved to uncover coal, a greater percentage of this material can be moved less expensively by the dragline. However, regraded spoil areas with a high SAR, normally requiring a 48 inch soil replacement, may be so far from the source of glacial till that the lower cost of hauling additional subsoil a shorter distance may actually outweigh the cost of trying to reduce replacement depths by hauling glacial till from much further away. This is underscored by the fact that required replacement depths can be reduced by only two feet, from a 48 inch replacement to a 24 inch replacement, but require the placement of two feet of suitable glacial till anyway. Achievement of a desired post-mining topography may not require that additional material be hauled to a regraded site. Glacial till may actually be used more beneficially in another area which requires additional fill anyway, even if it means spreading the till 10 to 20 feet thick or more. The costs of reducing required soil replacement depths can often outweigh the benefits. Achieving an acceptable post-mining topography, haulage distances, equipment used, and ultimately overall earthmoving costs must be carefully considered and balanced against any benefits from attempts to reduce required soil replacement depths.

Another factor complicating determination of soil replacement depths is reclamation of other facilities, such as haulroads or ponds in mined out areas. Construction using select fill, such as specified clays for roads and pond embankments, will have a significant local effect on actual replacement depths. Generally these areas showed an increase in replacement depth over that projected, as most construction materials were poor quality in terms of plant rooting media. These normally comprise only a small part of the overall area, and may not have a significant effect on the overall weighted average.

Reclamation of prime farmlands has a significant effect on soil replacement depth. The Freedom Mine has reclaimed about 350 acres of prime farmlands since 1986. Special regulatory requirements state that 48 inches of soil be replaced in any prime farmland areas, regardless of regraded spoil quality. The only exception is that prime farmlands may have a lower replacement depth, if such lesser depth existed prior to mining. Over 90% of prime farmlands reclaimed have had at least 48 inches of soil replaced, although much less than that was actually required based on regraded spoil characteristics. By excluding prime farmlands, the average replacement depth for all other lands was 38.6 inches. The average replacement depth for prime farmlands was 47.8 inches. Through careful planning, however, many prime

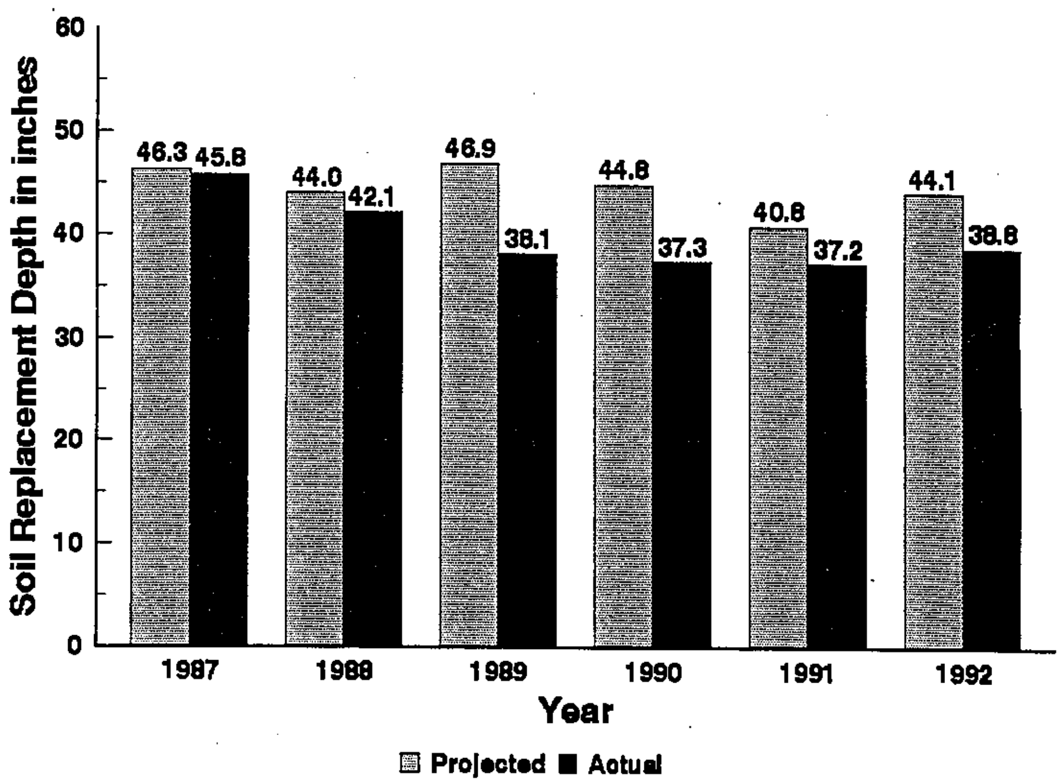

Figure 5. Actual and projected soil replacement depths, by year, at the Freedom Mine

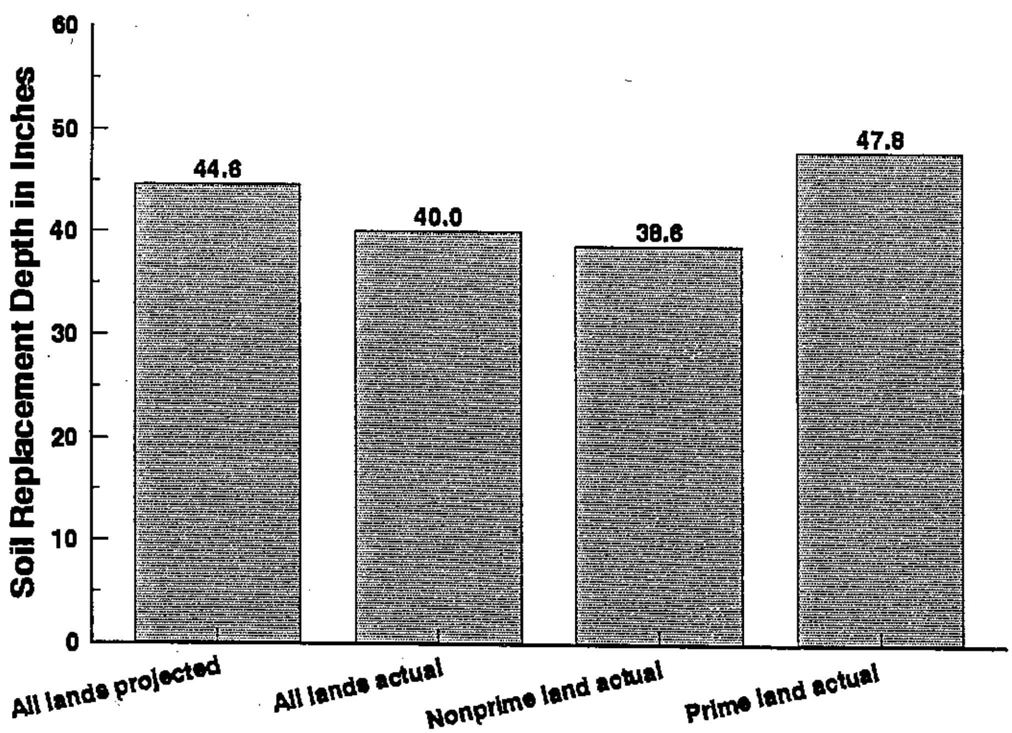

Figure 6. Weighted average projected replacement depth for all lands, and average actual replacement depths for all lands, nonprime lands, and prime farmland only.

farmlands are being reclaimed on areas that would have required a 48 inch replacement depth anyway, based on regraded spoil characteristics. Nonetheless, special soils handling requirements for prime farmlands impose an unnecessary additional cost on reclamation operations.

Annual Soils Handling Plan

The Coteau Properties Company develops an annual soils handling plan. This plan describes amounts of soil to be lifted, depths to be replaced, projected prime farmland locations, and amounts of soil in inventory. This planning tool is important to assure that sufficient soil is available at any time for final reclamation of the entire mine if operations should end abruptly. Currently, about 15 million cubic yards are being maintained as inventory. Annual adjustments are made up or down to this amount, which has a contingency of about 5%. The Public Service Commission reviews and approves this plan every spring. It helps them maintain awareness of Coteau's operation, and assures them that reclamation can be completed as described in approved permits.

Certain assumptions are made when developing this plan. One of them is the amount of subsoil required for final reclamation, based on pre-mining predictions. Based on the analysis conducted here, consideration may be given to reducing projected required soil replacement amounts up to 10%, to reflect actual amounts replaced since 1987.

Summary and Conclusions

A test of the North Dakota Public Service Commission method to project soil replacement depths was conducted at The Coteau Properties Company Freedom Mine. The following conclusions are based on analyses of projected versus actual replacement depths.

1. Actual replacement depths were about 10% less than projected, with greater deviations occurring under special circumstances.

2. There was a greater tendency to show a substantial decrease than increase in actual from projected replacement depths.

3. Greatest cost-saving opportunities should be exploited appropriately, i.e., shifting from a projected 48 inch to an actual 24 inch replacement. However, one must consider the cost of achieving this goal to determine if economics are truly favorable under all conditions.

4. Reclamation of prime farmlands under current regulations requires needless additional soils handling, increasing costs unnecessarily. Changes in prime farmland soils handling requirements in North Dakota should be explored.

5. Assumptions used to determine amounts of soil required for replacement, for annual soils handling plans, should be reevaluated. There is the possibility of reducing the amount of soil required, from that currently projected, by as much as 10%.

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