Evaluation of land reclamation practices on the Fort Peck Dam
by Mark Joseph Gruener

A professional paper submitted in partial fulfillment of the requirements for the degree of Master of Science in Land Rehabilitation
Montana State University
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Abstract:
The construction of large earth filled dams, such as that at Fort Peck in northeastern Montana, often results in land disturbances that require reclamation. The U.S. Army Corps of Engineers has completed several reclamation projects at Fort Peck and is interested in using state of the art technology in future land rehabilitation efforts.

The most recent reclamation project involved the regrading, topsoil salvage and respreading and revegetation of approximately 50 acres of land on the powerhouse slope. Although this project produced a vigorous stand of crested wheatgrass (Agropyron cristatum), the native species contained in the seed mixture were not successfully established. Upward migration of sodium, which may hinder the long term success of this reclamation project, was measured.

Lessons learned from evaluation of the powerhouse slope rehabilitation project and technologies developed through reclamation research on mined lands are applicable to future reclamation of disturbed areas around the Fort Peck Dam.

One such disturbed area, the spillway slope, has been scheduled for rehabilitation in the future. The most promising technologies involve the use of chemical amendments which may prevent topsoil sodication and reduce the amount of topsoil required for plant root zones.

It is recommended that the U.S. Army Corps of Engineers initiate a pilot study designed to evaluate the use of chemical amendments for rehabilitation of the spillway slope.

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MONTANA STATE UNIVERSITY
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APPROVAL

of a professional paper submitted by

Mark Joseph Gruener

This professional paper has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

The construction of large earth filled dams, such as that at Fort Peck in northeastern Montana, often results in land disturbances that require reclamation. The U.S. Army Corps of Engineers has completed several reclamation projects at Fort Peck and is interested in using state of the art technology in future land rehabilitation efforts.

The most recent reclamation project involved the regrading, topsoil salvage and respreading and revegetation of approximately 50 acres of land on the powerhouse slope. Although this project produced a vigorous stand of crested wheatgrass (Agropyron cristatum), the native species contained in the seed mixture were not successfully established. Upward migration of sodium, which may hinder the long term success of this reclamation project, was measured.

Lessons learned from evaluation of the powerhouse slope rehabilitation project and technologies developed through reclamation research on mined lands are applicable to future reclamation of disturbed areas around the Fort Peck Dam. One such disturbed area, the spillway slope, has been scheduled for rehabilitation in the future. The most promising technologies involve the use of chemical amendments which may prevent topsoil sodication and reduce the amount of topsoil required for plant root zones.

It is recommended that the U.S. Army Corps of Engineers initiate a pilot study designed to evaluate the use of chemical amendments for rehabilitation of the spillway slope.

INTRODUCTION

Reclamation research has produced technology that is applicable to a wide range of reclamation challenges. The Fort Peck Dam, built and operated by the U.S. Army Corps of Engineers in northeast Montana, has completed two reclamation projects and is currently awaiting funding for another. These projects are intended to stabilize and revegetate areas that have been disturbed during the construction of the dam and power generation facilities. The technology used on these projects employs reclamation techniques that are similar to those used on many mining reclamation projects.

At Fort Peck, slope stability is a critical concern. Three areas have been the focus of attention: the face of the dam, the powerhouse slope and the spillway slopes. Following construction, the dam and powerhouse slopes were recontoured to a maximum grade of 4:1. The spillway slopes were not recontoured. The spillway slope contour is variable but badly eroded slopes on grades of 3:1 are common. The downstream face of the dam, extending through approximately 5 km (3 mile) sections, was successfully revegetated following the completion of construction in the

early 1940's. The powerhouse slope was recontoured and revegetated in the fall of 1978. The success of this project has not been evaluated. A design memorandum outlining specifications for the stabilization of slopes in the vicinity of the spillway is presently being reviewed by the Omaha District, Corps of Engineers. The specifications require that an area of approximately 120 hectares in the vicinity of the spillway be stabilized and seeded with native grasses. Since the Corps of Engineers desires to enhance the probability of reclamation success, recent advances in reclamation technology may be applicable to this project.

The Corps of Engineers is particularly interested in using state of the art technology to complete construction projects in an economical and timely manner. This study will review past reclamation efforts in the Fort Peck area and make recommendations for future Corps of Engineers reclamation projects. The objectives of the study are:

1) To evaluate the success of the 1978 powerhouse slope stabilization project.

2) To investigate potential reclamation problems that may be encountered during the spillway slope stabilization project.

3) To make rehabilitation recommendations to the U.S. Army Corps of Engineers for possible inclusion in reclamation contract specifications.

The work was conducted on land owned by the U.S. Army Corps of Engineers in Valley and McCone counties in Montana.

LITERATURE REVIEW

Rehabilitation research in the western United States has included a wide range of subjects. Techniques that have been the focus of extensive research include: soil properties, topsoiling, vegetation establishment, fertilization, irrigation and surface manipulation. The importance of using techniques that are compatible with the specific reclamation objective and the limitations and capabilities of the land has been repeatedly emphasized (Coenenberg 1982, Williams et al. 1983).

The U.S. Army Corps of Engineers has long recognized the importance of applying research findings to water development projects. In 1939, following a mass soil movement that resulted in the partial failure of the dam and claimed the lives of eight workers, the Corps of Engineers concluded that the success of the project would require extensive monitoring and periodic stabilization. The primary objective of stabilization efforts at Fort Peck has been erosion control. Secondary objectives include forage for wildlife, livestock and aesthetic considerations (Wallem 1987).

Soil Characteristics and Reclamation

The primary resource that governs the success or failure of a reclamation project is the soil. The sodium dominated montmorillonite clays found in the Fort Peck area are particularly suitable for the construction of earth filled dams (Wallem 1987), but research studies have shown that this type of soil may inhibit or, in some cases, be toxic to the growth of plants (Goodin 1977, Veseth and Montagne 1980). Studies conducted by Byron (1984) found that the soils on the powerhouse slope are characterized by adverse physical and chemical plant growth parameters and may require special reclamation techniques.

Clay mineralogy and the chemical and physical properties of soils are important considerations in the development of a reclamation plan. Byron (1984) classified the soils near the powerhouse as a Ustic Torriorthent, fine loamy mixed. These soils are derived from Bear Paw Shale parent material described by Veseth and Montagne (1980). They are high in clay and are dominated by smectite mineralogy (Klages and Montagne 1985). Byron found that although the soil pH (7.6) was not inhibitory, the sodium adsorption ratio (SAR) of 27 and the electrical conductivity (EC) measured at 7.9 ds/m were indicative of a saline-sodic soil (Richards 1954). The soil contained approximately 10% sand, 28% silt and 62% clay.

Smectite clays, dominated by an excess of exchangeable and soluble sodium, can severely limit the establishment of vegetation. Goodin (1977) found that some plants may experience a sodium induced nutrient imbalance and noted that in some cases high levels of sodium may be directly toxic to sensitive plants. Dollhopf et al. (1985) stated that an excess of sodium tends to disperse the clay system causing a general loss of soil structure. This results in decreased water infiltration-permeability rates thereby increasing overland flow and surface erosion. Byron (1984) concluded that this type of soil was an unacceptable plant growth medium.

A commonly employed reclamation practice designed to overcome the limitations of sodic soils involves the reconstruction of the root zone by placing good quality topsoil over the sodic material. Barth (1984) found that 71 cm of good quality material was the minimal depth for establishing a suitable root zone over sodic spoil. Shallow depths of material may deteriorate because of an upward migration of salts. Merrill et al. (1983), working in soils similar to those encountered in the Fort Peck area, found that when 15 to 30 cm of good quality material was placed over sodic spoils (SAR = 27), the topsoil became sodic in three years. Other research has shown that this contamination is the result of upward migration of salts

caused by diffusion (Sandoval and Gould 1978), but the rate of contamination may be slower than that reported by Merrill (Dollhopf et al. 1985). Working with 70 cm of sandy loam topsoil placed over sandy loam sodic spoil, Dollhopf et al. (1985) found no detectable increase in SAR during the first two years of a seven year study. After seven years, a trend toward upward migration was observed, but the study estimated that it would take 18 to 36 years for the soil profile to become sodic. The study concluded that the rapid upward movement of salts reported by Merrill et al. (1980 and 1983) was not a problem in soils dominated by non-swelling illite or kaolinite clays. These results confirmed the findings of earlier research (Dollhopf et al. 1980) that concluded that a loamy cover soil placed over a saline and/or sodic loam-clay-loam spoil can support highly productive vegetation and the probability is low that sodium salts will migrate upwards and contaminate the topsoil (Dollhopf 1983).

Although the clay mineralogical properties of the soils on the powerhouse slope have not been extensively studied, tests conducted by Byron (1984) found high levels of clay and speculated that montmorillonite dominated the soil system. Research on abandoned bentonite lands near Belle Fourche, South Dakota has shown that chemical and physical amendments may be useful in reclaiming such sodic

soils (Dollhopf and Bauman 1981, Dollhopf et al. 1988). This research is supported by the findings of Van Schack (1967) and Pair and Lewis (1959). Van Schack (1967) found that permeability of a montmorillonite dominated soil was nearly zero when the exchangeable sodium percentage (ESP) exceeded 15 to 20. Pair and Lewis (1959) found that gypsum applied at 22 and 44 mt/ha (10 to 20 t/a), on slick spots, increased water intake from .02 cm to .2 and .55 cm per hour. Salt removal with gypsum was directly related to intake rates and both treatments decreased the ESP. Dollhopf (1971) found that gypsum not only increased the ability of saline-alkali soils to transmit water but a greater quantity of water was measured moving through a 15 cm soil mass. He concluded that although application rates may vary depending on site conditions, the application of 22 mt/ha (10 t/a) of gypsum reduced the swelling and shrinking tendencies and improved the infiltration properties of sodium dominated montmorillonitic soils. In cases where topsoil is limited or unavailable, the use of chemical amendments may be the most promising alternative for the reclamation of sodium dominated soils.

Use of Topsoil

The salvage and redistribution of topsoil is a topic of considerable interest in reclamation research. Williams

et al. (1983) noted that because the final goal of a reclamation project will usually be a plant-soil system which will be stable and capable of withstanding a range of environmental perturbations, the role of topsoil is a critical reclamation consideration. However, they also found that because of the high costs incurred in topsoil salvage operations, the question of optimum and minimum depths of material is a sensitive reclamation issue. These concerns are applicable to past and future reclamation programs at the Fort Peck Project (Wallem 1987).

Two key questions have arisen in recent years regarding topsoil salvage and redistribution: (1) what are the effects of topsoil horizon segregation on vegetation production? and (2) how does a topsoil depth influence plant response? Considerable research has been carried out on these issues (Crofts et al. 1987, Barth 1984, Power et al. 1976, 1979, 1981 and DePuit and Coenenberg 1979) but the results have been variable.

Crofts et al. (1987) addressed the question of segregation of topsoil during salvage and redistribution. He noted that topsoil is defined by the Office of Surface Mining (OSM 1983) as "The A and E soil horizon layers of the four master soil horizons. Subsoil is defined as the "B" horizon, the layer typically is immediately beneath the E horizon". Because OSM regulations require the segregation

of topsoil from subsoil, it is common practice to salvage and respread topsoil and subsoil in two separate lifts (Walsh 1985). This practice is justified by the belief stated by OSM (1979) that "to mix the various soil horizons, during removal could be counterproductive to restoration of the disturbed area to a level at least equal to the premining capability".

Research has produced conflicting findings concerning the validity of this premise. Allen (1984) studied the effects of disturbance on mycorrhizae and concluded that any practice which sustained the plant mycorrhizae relationship enhanced vegetation establishment. However, Biondini et al. (1984) found that the recovery of dehydrogenase activity and mycorrhizae infection potential after six years was not different between slight and severe levels of soil disturbance. These results were substantiated by Power et al. (1979 and 1981), who found, that over a four year period, yields from native vegetation on mixed horizon soils were within 90% of yields obtained with segregated horizons treatments. Because Power's studies were conducted on sodic soils similar to those found in the Fort Peck area, these findings are particularly noteworthy.

The results of research involving various depths of topsoil are more consistent. When topsoil is placed over good quality spoil, Crofts et al. (1987) found that thicker

layers of topsoil were more productive especially during the early stages of succession. Barth (1984) found that shallow soils will support vegetation, but concluded that deeper profiles are required when the underlying spoil is of poor quality.

In addition to providing a growth medium, the use of topsoil has other benefits. DePuit et al. (1980a) reviewed the literature on seed reserves and concluded that most seeds were confined to the upper 5 to 7 cm of the profile. Allen (1984) studied the inoculation of mycorrhizae and suggested that spreading 2 to 3 cm of fresh topsoil might be more advantageous than a thicker application of biologically inert topsoil. These studies have shown that direct hauling topsoil, even in thin layers, can be very beneficial in reclamation.

Research has shown a wide variety of plant responses following topsoil spreading and there is little question that the use of topsoil is a valuable reclamation tool. However, the availability of topsoil may be limited. If topsoil is stripped from native range, the borrow area must be reclaimed. Dollhopf and LoPiccolo (1987) studied the process of natural revegetation of a topsoil borrow area and found that if pH, EC, texture and saturation percentage are not inhibitory, the B horizon material can support productive vegetation. Because reclamation at Fort Peck is not

subject to OSM regulatory restrictions concerning the use of borrow pits, these findings may be relevant to any revegetation program at the site. Although stripping topsoil from native range does offer an alternative for reclamation, there are adverse impacts. By excavating topsoil from native range, the area of disturbance is increased. The Corps of Engineers was able to alleviate this problem in the 1978 revegetation project by removing topsoil from fish rearing ponds they were constructing adjacent to the Fort Peck Reservoir. The excavated soil was moved to the powerhouse slope and the resulting borrow pits flood during high water and are used by the Montana Department of Fish Wildlife and Parks to rear warm water game fish. Because no additional fish ponds are required, future reclamation projects may be forced to consider the impact of increasing the size of the disturbed area by excavating topsoil from native range.

Selection of Vegetation

The ultimate success of a reclamation project is reflected by the establishment of the vegetation. Valentine (1971) noted that certain ecological principles, especially competition and succession, must be considered when selecting plant species for rangeland seeding. In addition, the selection of plant materials should be based on climate,

soils and post disturbance land use (Thornburg and Fuchs 1978). Because the primary purpose of reclamation at Fort Peck is erosion control, the species used must establish quickly and firmly anchor the soil on the slope.

Considerable research has been conducted to evaluate those species adapted for reclamation use. Hafenrichter et al. (1968) emphasized the importance of developing cultivars that are capable of performing specific reclamation functions. DePuit (1984) commented that some early reclamation research results may not accurately evaluate the full potential of some cultivars which were released in the early 1970's. Four cultivars are particularly important for this study: Rosana western wheatgrass (Agropyron smithii), Critana thickspike wheatgrass (Agropyron dastachyum), Lodorm green needlegrass (Stipa viridula) and Wytana fourwing saltbush (Atriplex canescens). These species have been used for reclamation in the Fort Peck area and have been included in several mineland reclamation studies (Meyn et al. 1976, DePuit et al. 1980b, Coenenberg 1982, and Rennick et al. 1984). Each grass has specific characteristics and must be analyzed both individually and collectively in a mixture.

Rosana western wheatgrass was developed specifically as a reclamation species for use on dry, clayey sites (Stroh 1973). Thornberg (1982) noted that it is a strongly

rhizomatous grass, salt tolerant and attains optimum performance when annual precipitation exceeds 30 cm. Nichols (1969) found that western wheatgrass can be established successfully in dense, deteriorated clays. DePuit et al. (1980a) found that when adequate moisture is available, western wheatgrass establishes quickly and competes well with annual species, but noted that in a dry year (1978-79) at Colstrip, Montana, canopy cover of this species declined. They attributed the decline to increased competition from more drought tolerant species such as thickspike wheatgrass.

The release of Critana thickspike wheatgrass has had a substantial impact on reclamation. Developed from a strain originally collected near Havre, Montana, Critana is particularly well adapted for use in the northern Great Plains (Stroh 1972). Thornburg (1982) noted that thickspike performs well on silty or clayey textured soils. It is salt tolerant and can survive on less than 20 cm of rain per year. The drought tolerance of thickspike wheatgrass has been confirmed by DePuit et al. (1980b) who found that even in a dry year (1978-79) thickspike can compete effectively with other native species such as green needlegrass and western wheatgrass.

Lodorn green needlegrass is a cool season bunch grass that is commonly used in native species mixtures. Green

needlegrass required more moisture than thickspike or western wheatgrass (35 to 50 cm/yr), but is well adapted to clayey sites (Hafenrichter et al. 1968 and Thornburg 1982). DePuit and Coenenberg (1979) found that if problems with seed dormancy such as those noted by Dollhopf and Majerus (1975) can be overcome, green needlegrass may persist as a dominant species. Although the production of green needlegrass may be lower than some wheatgrasses, it establishes a dense ground cover at low seeding rates and is well adapted for use in a mixture with western and thickspike wheatgrass.

Wytana fourwing saltbush is a long lived shrub well adapted to xeric sites (Thornburg 1982). Although fourwing saltbush may decline in vigor during cold winters or when faced with competition from perennial grasses, DePuit et al. (1980a) found that it was compatible with a wide range of native grass mixtures. Rennick et al. (1984) noted that this species traditionally performs well on revegetated areas and is an important part of many plant communities on reclaimed land.

Other native species that appear to be well adapted for use at Fort Peck include streambank wheatgrass (Agropyron riparium), bluebunch wheatgrass (Agropyron spicatum) and slender wheatgrass (Agropyron trachycaulum). Each of these species is well adapted to clayey soils, but

precipitation requirements are variable. Streambank wheatgrass can survive under a wide range of precipitation conditions (30 to 50 cm/yr), but achieves optimum performance when annual precipitation is between 30 to 40 cm per year. Bluebunch wheatgrass required 30 cm of rain per year to sustain productivity, but is well adapted to shallow upland sites. Slender wheatgrass thrives under more mesic conditions (35 to 50 cm/yr), but can establish quickly with excellent early vigor if sufficient moisture is available.

Although other native species may be adapted to the soil and precipitation regime at Fort Peck, reclamation research has shown that satisfactory results can be achieved with the species previously discussed. A number of introduced species are well adapted for erosion control, but the Corps of Engineers has expressed a preference for the use of native species in reclamation at Fort Peck (Wallem 1987).

Seeding Techniques and Surface Manipulation

One of the most widely studied areas of reclamation involves the influence of seeding techniques and seed mixtures. Research has shown that seeding rates have a direct influence on canopy cover and production (Packer and Aldon 1978). DePuit (1984) found that heavy seed rates 22.4 Kg/ha (20 lbs PLS per acre) produce high plant densities in

the first year following seeding, but production was greater when a lighter rate 11.2 Kg/ha (10 lbs PLS/a) was used. These trends are generally applicable for both drill and broadcast seedings, but each technique has certain advantages and limitations.

Some studies have shown that drill seeding is preferable to broadcast seeding (Cook et al. 1970, 1974). Drill seeding uniformly distributes the seed and physically places it into the soil. This minimizes seed loss from wildlife depredations and has produced higher germination rates than those achieved by broadcast seeding (Valentine 1971). Other advantages of drill seeding include: improved infiltration and moisture storage, wind protection, easy application to mulched surfaces and usually more rapid production of seeded plants (Valentine 1971, DePuit et al. 1980a). However, Hodder and Atkinson (1974) noted limitations associated with drill seeding. These included: 1) access problems on steep and uneven terrain, 2) higher cost for seeding large areas and 3) incomplete compatibility with the range of variation of seed characteristics of diverse seed mixtures.

Broadcast seeding has achieved variable degrees of success in reclamation. DePuit et al. (1980a) stated that some bias against broadcast seeding may have been caused by seeding failures on adverse sites. He suggested that a

combination of factors were involved in these failures, and noted that previous mined land revegetation studies in Montana (Meyn et al. 1976) established no clear superiority of one method over the other. In studies at Colstrip, Montana, DePuit et al. (1980b) noted that although drill seeding appeared to favor larger seeded species of Agropyron (thickspike wheatgrass, streambank wheatgrass and western wheatgrass), fourwing saltbush and green needlegrass established better cover when broadcast seeded. This study also found that optimum stand densities were achieved by drill seeding at a rate of 25.8 Kg/ha (23 lb PLS/ac) and broadcast seeding at 50.5 Kg/ha (45 PLS/ac). The study concluded that the final decision concerning seeding technique must be based on an evaluation of area accessibility, location, slope, seedbed preparation, topsoil characteristics seasonal timing of seeding and individual seed characteristics.

STUDY SITE DESCRIPTION

Location

The study site was located on the U.S. Army Corps of Engineers' Fort Peck Project, approximately 32 km (20 m) south of Glasgow, Montana. Figures 1 and 2 show the specific study areas.

The Fort Peck Dam Study Area

The downstream face of the dam is approximately 300 m long and 1500 m wide (Figure 1). On the aerial photograph, the dark strip at the bottom of the picture is Fort Peck Lake. The face of the dam slopes gently to the north and is distinctly divided by access roads which traverse the face of the dam in an east-west direction. The slope extending downhill to the north from the crest of the dam to the first east-west access road is approximately 4:1, but gradually flattens out to a 6:1 slope near the downstream toe of the dam. The change in elevation from the crest of the dam to the downstream toe is approximately 77 m. Except during periods of high water, the entire flow of the Missouri River is diverted through the intake structures located in the lower right corner of the picture.

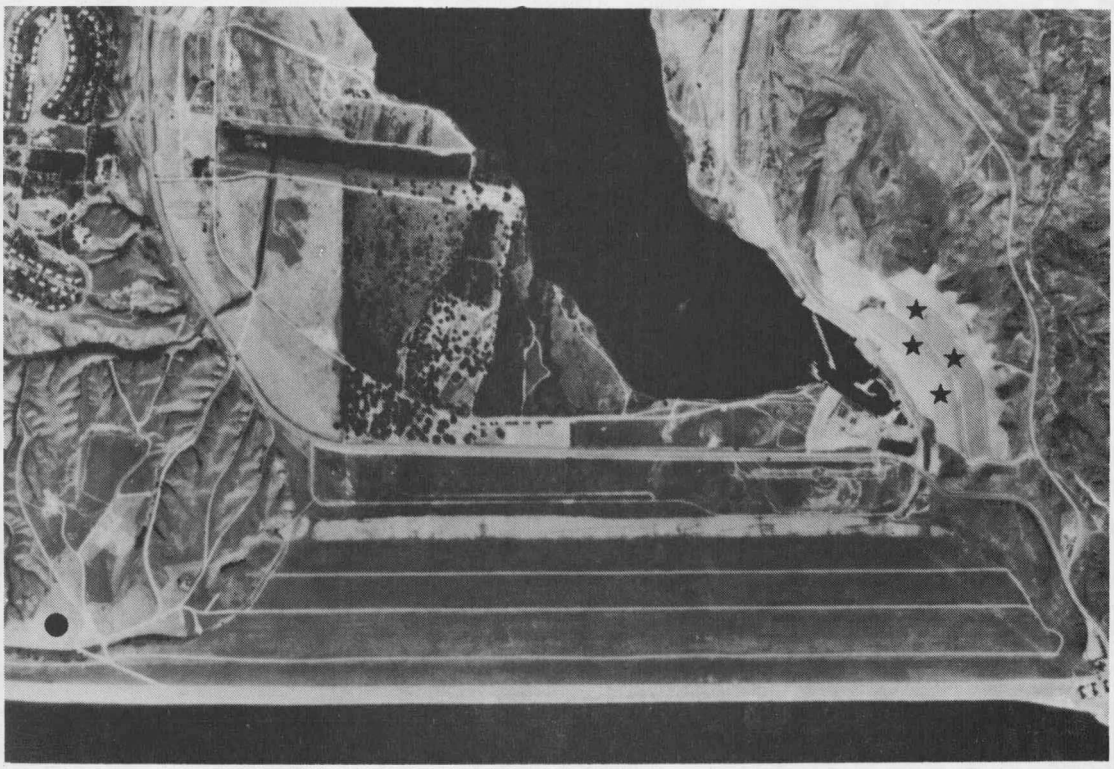


Figure 1. The Fort Peck Dam and powerhouse slope study areas. Sec 15 T26N R41E. Scale: 1 cm = 200 meters.

[1]Location of soil sample sites on powerhouse slope are shown by ★

[2]Location of soil sample site in topsoil borrow area is shown by ●

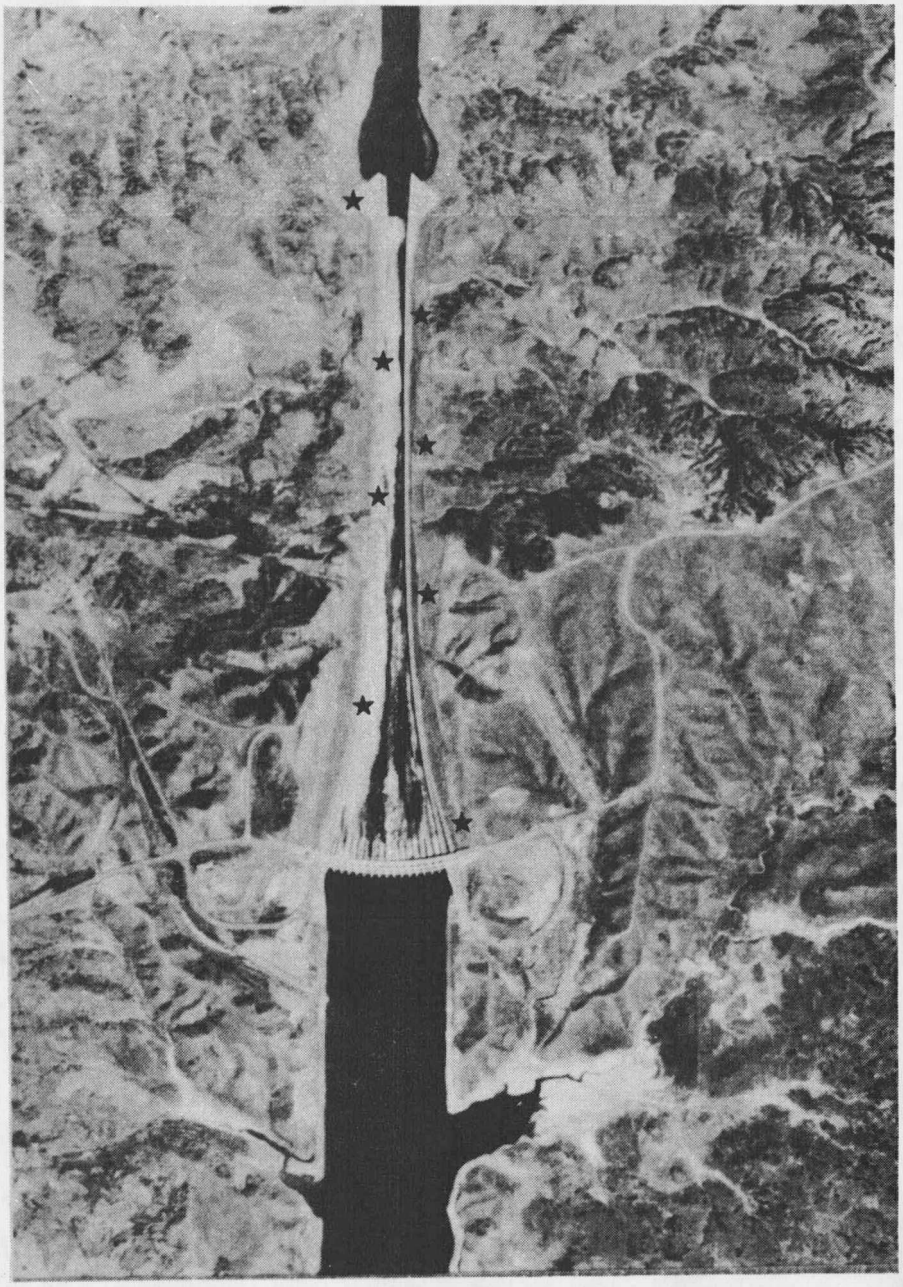


Figure 2. The Fort Peck Dam spillway slope study area. Sec. 6 and 7 T26N R42E. Scale: 1 cm = 200 meters.

[1]Location of soil samples sites are indicated by★

The water flows approximately 1500 m underground and is discharged through the two powerhouse structures located in the right center portion of the aerial photograph. The Missouri River downstream from the Fort Peck Dam flows directly north for a distance of approximately 5000 m and is shown in the photo as a large dark colored body of water in the upper center of the photo. The town of Fort Peck is located in the upper left portion of the picture. To facilitate vegetative sampling, the face of the dam was divided into three sections. The first section included the area from the crest of the dam downhill to the first east-west access road. The second section extended downhill to the second east-west access road. The third section extended from the second to the third access road.

The Powerhouse Slope Study Area

The powerhouse slope is the light colored area located in the right center of Figure 1. The powerhouse slope is approximately 20 ha (50 ac) and has been recontoured to a 4:1 slope.

The Spillway Slopes Study Area

The spillway is approximately 6000 m south of the Fort Peck Dam on U.S. Highway 24, and is approximately 1500 m long (Figure 2). The study area includes the slopes

on either side of the spillway. The total area included in this study area is approximately 120 ha (300 ac).

Topography

The topographies of the study areas are variable and in the case of the dam and powerhouse slope were determined by the design criteria of construction memorandums. The downstream face of the dam has a north facing aspect with convex slopes ranging from 4:1 to 6:1. The powerhouse slope faces southwest and has a 4:1 slope. The powerhouse slope is uniformly steep, but is punctuated approximately every 100 m by 5 m wide terraces that provide for drainage. The spillway slopes have variable aspects and topography, but the most severe gradients are 2:1. The spillway drains to the north into the Missouri River and is bordered on either side by west and east facing slopes.

Climate

Continental climatic conditions exist in the Fort Peck area with cold winters and warm summers. July is usually the warmest month; January is the coldest. The climate is semiarid with an average of 37.2 cm of precipitation annually (N.O.A.A. 1986). The majority of the precipitation comes in the form of rain during the months of April, May and June. Prevailing winds from the west

average 16 k/hr (10 mph), but gusts in excess of 90 k/hr (55 mph) are common. Table 1 shows the average monthly temperature, precipitation and wind velocities. During the 17 year period from 1960-1977, average precipitation was above the thirty year norm (Branson and Miller 1981), but drought conditions prevailed in 1979, 1980 and 1982. Monthly precipitation and temperature data for the 1979 growing season were obtained directly from the U.S. Army Corps of Engineers at Fort Peck. Table 1 compares the monthly averages and deviations from the long term averages for temperature and precipitation at Fort Peck, Montana.

Table 1. Mean monthly temperature and precipitation for 1979-80 at Fort Peck and deviations from 1960-77 average.

Month	Mean temperature °C	Deviation °C	Mean precipitation cm	Deviation cm
October	7.5	-2.7	2.1	0.2
November	4.3	-5.7	1.1	-0.5
December	-8.7	-5.4	1.8	-0.8
January	-13.5	-6.2	2.3	-1.2
February	-5.8	-1.6	0.5	-0.9
March	1.2	2.1	5.1	3.5
April	4.8	-2.3	2.7	-1.4
May	10.6	-1.4	4.0	-2.1
June	16.2	0.3	5.2	-3.5
July	22.6	1.7	2.7	-0.4
August	23.3	3.4	2.9	-0.6
September	13.5	-1.5	2.4	1.3

Soils

The soils in the badlands south of Fort Peck were derived from Bear Paw Shale material described by Veseth and Montagne (1980). Alluvial materials predominate in the flood plain. Using the criteria specified in Soil Taxonomy (Soil Survey Staff 1975), the soils excavated from the Missouri river flood plain, during the construction of the dam, were classified as Typic Ustifluvents. Upland soils, north of Fort Peck, were classified as Typic Ustorthents Series. The soils in the vicinity of the powerhouse slope and the spillway slopes were classified as Typic Paleargids and are dominated by high amounts of sodium in montmorillonitic clays (Byron 1984).

Vegetation

Vegetation on rangeland in eastern Montana is generally classified as mixed grass prairie. Dominant species in badlands south of the Missouri River include Agropyron smithii, A. spicatum and Artemisia tridentata (Payne 1973).

History of Reclamation

The construction of the Fort Peck dam, spillway and power generation facilities resulted in a sequence of reclamation problems. These problems included the removal

of several shanty towns established during the 1930's, establishing vegetation on the downstream face of the dam and stabilizing slopes in the vicinity of the power generation facilities and the spillway.

The approach to the reclamation of the shanty towns and the dam were similar. During the initial phase of construction, the Corps of Engineers excavated topsoil and stockpilled it for used on the dam face once construction was completed. While the reservoir was filling in 1937-38, topsoil was excavated from the flood plain and surrounding hills and hauled directly to the shanty town sites. The shanty towns were burned and topsoil was spread. Although the exact amount of the respread topsoil is not known, the amount was sufficient to establish a thriving plant community dominated by crested wheatgrass. Both areas were liberally seeded exclusively with crested wheatgrass and by 1945 well established stands of crested wheatgrass were present on both the dam and the old shanty town sites (Wallem 1987).

The construction of the power generation facilities was completed in 1963. During the construction of the powerlines and switchyards, a slope consisting of sodium dominated montmorillonitic soils was disturbed. This disturbed area became subject to periodic mass soil movement and repeatedly deposited soil in the switchyards. In 1974,

the U.S. Army Corps of Engineers attempted to ameliorate the problem by regrading and terracing the slopes. Although this reclamation effort was partially successful, unusually heavy spring rains in 1975 resulted in the development of erosion rills and renewed the problem of sedimentation in the electrical switchyards. Some of the erosion rills were more than one meter deep. The failure of this particular rehabilitation effort was attributed to the lack of vegetation on the slope (Wallem 1987).

In 1978, the Corps of Engineers designed and executed a more detailed and expensive reclamation project on the powerhouse slope. Approximately 380,000 m^3 (500,000 yd^3) of topsoil was excavated from the previously reclaimed shanty town area. An additional 76,000 m^3 (100,000 yd^3) of material was excavated from the shoreline of Fort Peck Lake in a project that was designed to build fish rearing ponds. The topsoil was moved approximately 6000 meters, by truck, to the powerhouse slope. The prepared seedbed consisted of approximately 25 cm of topsoil placed on a regraded 4:1 slope. The slope was broadcast seeded with native species seed in October 1978. Although the contract specified that an asphalt emulsion mulch would be applied over the seed, cost overruns incurred in the movement of the topsoil necessitated the elimination of this provision.

The erosion of the slopes in the vicinity of the spillway created drainage and soil movement problems that threatened the safe operation of the structure. Large slabs of concrete that formed the drainage basin of the spillway had displaced as a result of pressure created by swelling soils. Under the provisions of a Corps of Engineers design memorandum, the slopes adjacent to the spillway were to be excavated and terraced. Because the spillway was projected for use only in periods of extreme high water and had been used only once since 1938, the excavated soil was to be placed in the basin of the spillway. The weight of the earth was expected to alleviate the heaving of the concrete. The design memorandum also specified that the excavated and terraced slopes should be topsoiled and planted using techniques similar to those used on the powerhouse slope. The excavation and placement of earth in the spillway basin was partially completed in 1974. Unfortunately, record high water levels in 1975 crested over the top of the spillway and washed away the soil from the spillway basin. Because of increased fuel costs resulting from the oil crisis of 1973, the topsoil and seeding were never completed. Soil eroding from the spillway slopes continues to clog the storm drainage structures. Concrete displacement caused by mass soil movement is also a cause for concern.

In the fall of 1986, the Corps of Engineers executed a reclamation plan designed to alleviate the problems caused by sedimentation of the storm drain structures. Under the provisions of contract DACW 45-85-C-0182, the drain structures were cleaned and the terraces regraded. In an attempt to establish vegetation on the terraces, a seed mixture identical to the one used in the 1978 power-house reclamation project was broadcast seeded on the terraces. Seeding was completed on September 15, 1986.

METHODS AND MATERIALS

Experimental Design

The intent of this study was to evaluate the success of previous reclamation projects in the Fort Peck area and make recommendations for future land rehabilitation efforts. To complete this task, soil and vegetation information collected from completed and proposed reclamation project areas was required. An experimental design was constructed to compare the soils on the powerhouse slope with the soils found on the spillway slope. The establishment of vegetation on the face of the dam was compared with the vegetation on the powerhouse slope. The growth of vegetation on the face of the dam was defined as the success standard. Therefore, plant canopy cover on this site was compared with the cover on the powerhouse slope.

Soil Sampling and Analysis

The purpose of soil sampling and analysis was to evaluate and compare the physical and chemical properties of soils on the powerhouse and spillway slopes. Because of funding limitations, only 12 samples were analyzed. Four

samples were taken from the powerhouse slope and eight samples were collected from the spillway slope. The approximate locations of the sample sites are shown in Figures 1 and 2.

On both the powerhouse and spillway slopes, soil pits were dug to a depth of 50 cm. The gradient at the sample locations was 4:1. Five hundred gram samples of A horizon material were taken from a depth of 5 to 8 cm below the surface. This depth was selected because it is the lower part of the topsoil applied to the site in the 1978 rehabilitation effort. It should show signs of salt diffusion from materials lower in the profile if salt movement has occurred. At each pit, visual observations of soil depth, color, texture, structure, consistence and coarse fragment content were recorded.

Two additional topsoil samples were collected. One sample was collected from an undisturbed area with a 4:1 gradient immediately north of the powerhouse slope. The other topsoil sample was collected from a flat area adjacent to the borrow pit that provided topsoil for the powerhouse reclamation project. The soil was collected from the 1-5 cm depth. These samples tell us what the soil salt load was on the powerhouse slope prior to rehabilitation efforts and what the salt concentration was in topsoil applied to the powerhouse slope. These two samples were needed to

provide a comparison for analyzing possible upward salt and sodium migration into the topsoil on the powerhouse slope since rehabilitation in 1978.

In addition to collecting soil samples for laboratory analyses, infiltration tests on the reclaimed powerhouse slope and the unreclaimed spillway slope were conducted in the field. An infiltrometer similar to the unit developed by Chow and Harbaugh (1965), and built from construction plans presented by Meeuwig (1971) was used to simulate rainfall. A runoff collection frame of 48 x 48 cm was used to collect and funnel runoff into a container. Simulated rainfall was applied at a constant rate of 12.5 cm/hr for 30 minutes (Meeuwig 1971). The runoff was measured in milliliters at 5 minute intervals. A canvas tarp was used to shield the infiltration device from the wind. Two infiltration trials were performed at each sample site. Infiltration rates were recorded and mean values were calculated from the two trials. Total runoff volumes were converted to percent infiltration.

Laboratory analyses were performed at the Montana State University Soil Testing Laboratory. Specific testing included analysis for pH; EC; SAR; soluble Ca, Mg, and Na; saturation percentage and particle analysis. An aliquot obtained from a saturated soil paste was used to measure EC and pH (Richards 1969). Soluble Ca, Mg, and Na were

determined and SAR was calculated using the techniques described by Sandoval and Power (1977). Particle size analysis was conducted using the hydrometer method described by Black (1965). Saturation percentage was estimated using the technique described by Richards (1969). Clay mineral analysis was performed on three samples using the x-ray diffraction technique of Whittig (1965) and semiquantitative analysis (Klages and Hopper 1982) was used to estimate relative proportions of the clay minerals.

Vegetation Sampling

The U.S. Army Corps of Engineers considers total canopy cover to be the most valid measure of vegetation establishment and uses ocular estimates during periodic dam safety inspections. Therefore, total cover of vegetation on the face of the dam and the powerhouse slope was sampled using techniques described by Daubenmire (1959).

Canopy cover was recorded for all plots between May 20 and May 23, 1987. Fifty 20 x 50 cm sampling frames were used on the powerhouse slope and an additional one hundred fifty frames were read on the face of the dam. Daubenmire's cover classes were modified for this study as listed in Table 2 (Hertzog 1983).

Statistical Analysis

An unpaired t-test was used to analyze the canopy cover data. The null hypothesis tested in the study stated that the cover sampled on the face of the dam was not significantly different from the canopy cover observed on the reclaimed powerhouse slope. Significance was defined as the rejection of the null hypothesis with a probability greater than 95 percent ($p = 0.05$).

Table 2. Cover classes used for canopy cover sampling.

Cover class	Range of percent canopy cover	Midpoint of cover class
1	0	0
2	0 - 5	2.5
3	5 - 10	7.5
4	10 - 20	15
5	20 - 30	25
6	30 - 40	35
7	40 - 50	45
8	50 - 60	55
9	60 - 70	65
10	70 - 80	75
11	80 - 90	85
12	90 - 95	92.5
13	95 - 100	97.5
14	100	100

RESULTS AND DISCUSSION

Criteria Used for Interpretation

The goal of reclamation projects in the Fort Peck area is to create a soil system that will support plant growth and prevent erosion. Although the Corps of Engineers is not legally bound to comply with the reclamation guidelines set by the Montana Department of State Lands (MDSL 1983), these guidelines provide an excellent basis for reviewing the success and potential problems of reclamation in the Fort Peck area. Table 3 contains the suspect levels for soil parameters outlined by the Montana Department of State Lands. Plant production is assumed to be restricted at levels exceeding these parameters.

Vegetation sampling using the point quadrant technique described by Daubenmire (1959) was used to evaluate the success of the 1978 Powerhouse Slope reclamation project. Plant cover on the powerhouse slope was compared with the plant cover on the face of the dam. The face of the dam was successfully revegetated in 1950 and has passed periodic safety inspections since that time. The powerhouse slope is not subject to dam safety inspection criteria. However,

Table 3. Selected Montana Department of State Lands guidelines used to evaluate physical and chemical properties of topsoil on the powerhouse and spillway slopes (MDSL 1983).

Parameter	Suspect Level
Electrical Conductivity (EC)	4-6 mmhos/cm
Sodium Adsorption Ratio (SAR)	12
Mechanical Analysis	clay >40% sand >70%
Saturation %	< 20% or > 80%
pH	8.8 to 9.0

since the Corps of Engineers uses an ocular estimate of plant cover on earth filled dams to evaluate erosion control and slope stability, total canopy cover is an appropriate criteria for evaluating the success of revegetation efforts on the powerhouse slope.

Physical and Chemical Soil Analysis

The soils on the powerhouse and spillway slopes were evaluated for the parameters listed in Table 3. The results are summarized in Tables 4 and 5. Complete test data are included in Appendix A.

Table 4. Powerhouse slope soil test results for samples collected at a profile depth of 5-8 cm (Sample size n=4).

Parameter	Mean x	Range	STD deviation ±
EC (mmhos/cm)	2.1	0.5 to 4.3	.8
SAR	12.4	9.9 to 13.0	1.3
Mechanical Analysis			
% Sand	22	21 to 23	.8
% Silt	35	34 to 36	.8
% Clay	43	42 to 44	.8
pH	7.5	7.5 to 7.6	.05
Saturation %	68.5	67 to 70	.4

Table 5. Spillway slope soil test results for samples collected at a profile depth of 5-8 cm (Sample size n=8).

Parameter	Mean x	Range	STD deviation ±
EC (mmhos/cm)	2.5	0.5 to 4.3	1.1
SAR	23.1	19.9 to 27.1	2.2
Mechanical Analysis			
% Sand	13	11 to 15	1.4
% Silt	24	22 to 25	1.0
% Clay	63	60 to 66	2.1
pH	8.0	7.8 to 8.1	.09
Saturation %	83	80 to 87	2.0

The soil test results showed that the soil samples exceeded the MDSL suspect levels for several parameters. The topsoil samples collected from the spillway slope exceeded suspect levels for SAR, clay content and saturation percentage. The topsoil samples collected from the reclaimed powerhouse slope exceeded the suspect level for SAR and clay. The textural class of all samples was classified as clay (Soil Survey Staff 1975). Although these tests alone are not sufficient to conclude that reclamation problems will occur, they indicate that decreased infiltration, increased runoff and erosion and soil crusting could be potential problems.

The x-ray diffraction test results, shown in Table 6, confirmed that the soil system on the spillway slope is dominated by smectite clay mineralogy. These test findings are important because they indicate that the soil system may be subject to low infiltration rates which could result in increased runoff and erosion, crusting, shrinking and swelling of the soil surface. The upward migration of salts through the soil profile is also enhanced by smectite clay mineralogy.

The infiltration rate study confirmed that the infiltration rates on both the powerhouse and spillway slopes were moderately slow (SCS 1951). These results, summarized in Table 7, indicate that the soil system would

support the upward movement of salts through the soil profile.

Table 6. Results from x-ray diffraction and analysis of spillway slope topsoil.*

Mineral	Sample No. 1	2	3	Avg.
Smectites	69	70	65	68.0
Mica	20	18	21	19.7
Kaolinite	11	12	14	12.3

* 0-5 cm expressed as percent of the clay fraction.

Table 7. Mean infiltration rate measured over time on the powerhouse and spillway slopes (n=2).

Time (min.)	Infiltration Rate (cm/hr) on 20% Slope Powerhouse Slope	Spillway Slope
0 - 5	11.2	10.6
5 - 10	5.8	3.6
10 - 15	2.5	1.2
15 - 20	1.8	0.9
20 - 25	1.6	0.6
25 - 30	1.4	0.5

Analysis of Potential Reclamation Problems

An analysis of the soil chemical and physical data indicates that several problems may hinder reclamation. One serious problem which may occur in smectite dominate soil systems is poor water infiltration. Although the infiltration rate during the initial 5 minute wet up period was moderately rapid, the rates quickly declined. During the 10 to 15 minute period, the rate of infiltration had declined to 1.2 cm/hr on the spillway slope and 2.5 cm/hr on the powerhouse slope. These values are representative of moderately slow infiltration classification (SCS 1951).

The low infiltration rate explains the apparent upward movement of salts into the respread topsoil on the powerhouse slope and suggests that a loss of soil structure has occurred. Although no soil tests were conducted prior to the 1978 powerhouse reclamation project, it appears that some topsoil sodication had occurred on the respread topsoil. A soil sample collected from a profile depth of 0 to 5 cm in the borrow pit area (Figure 1) revealed an SAR of 3. However, topsoil that had been excavated in 1978 and respread on the powerhouse slope had an SAR of 12. This topsoil sodication process may be best explained by Merrill (1983), who found that in clayey soils with poor hydraulic conductivities, water movement across the topsoil-spoil interface approached zero. This is particularly significant

in soils which have a high water holding capacity. Under these conditions, salts can use water retained in the soil profile as the conducting medium to move up into the respread topsoil. The high saturation percentage observed in the Fort Peck soils suggests that these conditions exist on both the powerhouse and spillway slopes.

Although the soil sampling intensity was not sufficient to accurately characterize the magnitude of the topsoil sodication problem, it is clear that substantial upward movement of sodium salts has occurred on the powerhouse slope during the 9 year period following reclamation. This trend is similar to the results reported by Dollhopf et al. (1985), who found that the degree of sodication in respread topsoil was low near the surface, but increased with depth. Therefore, the degree of topsoil sodication that has occurred on the powerhouse slope is not unusual and a similar phenomena could be expected to occur if topsoil is spread over the high SAR material that is present on the spillway slopes.

Another serious reclamation problem was reflected in the measurements observed for SAR and clay content. These levels, which were particularly high on the unreclaimed spillway slope soils, are indicative of a soil which will exhibit crusting problems as well as shrinking and swelling phenomena. Because of the small size of the clay particles

and the lack of a strong oxygen-hydroxyl linkage in a 2:1 lattice clay, the soil swells freely when wet and shrinks and cracks when dry. Shultz (1978) noted that soil material weathered from Bear Paw Shale parent material, forms wide cracks and dries to a hard crust because of the sodium-rich montmorillonitic clay mineralogy. Dollhopf (1971) cited research by Chepil (1955) and Staufer (1927) and concluded from his own study that clay soils dominated by smectite form a hard crust that impedes seedling establishment. Byron (1984) conducted a greenhouse study using soil collected from the unreclaimed area north of the powerhouse slope and concluded that the severe cracking and crusting problems encountered in some Fort Peck area soils severely inhibited plant growth.

Spillway Slope Reclamation Options

Reclamation of the spillway slope must address the potential problems of topsoil sodication, high rates of runoff and erosion and the physical limitations of soil crusting, shrinking and swelling. Although the problems posed by adverse soil conditions are substantial, recent studies in reclamation technology provide some promising reclamation alternatives.

Barth (1984) found that on less severe sites the topsoil sodication problem could be overcome by increasing

the depth of the topsoil. He suggested that 71 cm of topsoil was necessary to ensure reclamation success on sodic spoils. However, Barth's study was conducted only two years after the treatment and the findings may not be applicable for longer periods of time. Barth's recommendations could be implemented on a small scale in the spillway area, but the limited availability of topsoil and the high cost of moving large volumes of material may make this option impractical. A more economical option is needed.

One possible alternative for ensuring the long term success of reclamation in the spillway area involves the use of chemical amendments. Recent research conducted on abandoned bentonite mined land (Smith 1988), found that the use of chemical amendments can be effective in overcoming the adverse physical characteristics that are encountered in sodium dominated montmorillonitic soils. These amendments included: calcium chloride, magnesium chloride, gypsum, sulfuric acid, manure and wood chips. Dollhopf and Bauman (1981) reported that the use of wood chips could promote the initial development of vegetation, but later concluded that calcium chloride and gypsum were more effective in altering soil structure.

For purposes of discussion, sample calculations using calcium chloride, magnesium chloride and phosphogypsum were performed. Detailed calculations are included in Appendix

C. The critical decision involves the determination of an appropriate level of exchangeable sodium (ESP). Dollhopf (1987) recommended that an ESP of 4 would be required to overcome the adverse physical characteristics encountered in montmorillonitic clays. Ferguson (1987) suggested that an ESP of 7 might be adequate. Representative soil on the spillway slope had an SAR of 23.1 (See Table 5). Exchangeable sodium percentage and SAR are nearly identical in this range (Richards 1969). Therefore, SAR and ESP were considered equal for the purpose of amendment calculations. Average soil CEC at the site was 34.9 meq/100g. Given a conservative reclamation goal (ESP = 4), Table 8 summarizes the cost of reclaiming the spillway slope with chemical amendments.

Table 8. Cost analysis for chemical amendment required to reduce ESP from 23 to 4 on the spillway slope (Area = 120 ha).

Chemical Amendment	Quantity Required (mt/hectare)	Cost/ Hectare*	Total Cost
$CaCl_2$	18.56	$5568	$668,160
$MgCl_2$	44.11	$3308	$396,990
Phosphogypsum	34.05	$2043	$245,160

* Cost projections based on 1987 prices including approximate transportation costs to Fort Peck.

Although the use of chemical amendments may seem expensive, the cost of topsoil excavation, transportation and respreading is also substantial. As shown in Table 9, topsoiling operations accounted for approximately 75% of the cost estimates submitted by contractors bidding for the 1978 powerhouse slope reclamation project. The environmental costs of excavating topsoil from native range must also be considered. Although it is possible to establish vegetation on excavated areas, the Fort Peck area is presently enduring a drought and the exposed soil is subject to wind erosion. Stripping large acreages of native range to provide topsoil does not appear to be cost effective and is not recommended.

Table 9. Contractors' bids for 1978 powerhouse slope reclamation project*.

	Description of Work			
Bid #	Drainage Structures	Topsoil Operations**	Seeding	Other Costs
1	$45,000	$395,000	$57,000	$25,400
2	$53,000	$445,000	$20,000	$26,600
3	$62,000	$457,000	$38,000	$56,000
Govt Est.	$27,416	$257,865	$21,996	$21,996

* Invitation for bids Number DACW45-78-B-0104, U.S. Army Corps of Engineers, Omaha District.

** Includes topsoil excavation, transportation and respreading costs.

It is important to emphasize that the use of chemical amendments does not eliminate the requirement for topsoil but, if used, the topsoil volume can be substantially reduced. In addition, the benefits derived from improving the physical properties of the "in place" soils could be expected to reduce the upward movement of salts. By incorporating chemical amendments to a depth of 30 cm, the severe problems associated with soil crusting, shrinking and swelling would be alleviated. The soil structure would be improved, infiltration rates could be expected to increase, and the soil that was previously not capable of supporting vegetation would become a viable part of the plant root zone. The use of chemical amendments is an economical alternative that will greatly enhance the probability of reclamation success.

Vegetation Analysis

Following the completion of dam construction in the 1940's, the face of the dam was successfully seeded with crested wheatgrass. Although the vigor of the vegetation appears to have declined in recent years (Wallem 1987), the slope on the face of the dam has been stable for over 40 years. Erosion is not a problem and the reclamation of the face of the dam is assumed to be successful. The vegetative canopy cover of the 1978 powerhouse slope reclamation was

compared with the face of the dam using the techniques described by Daubenmire (1959). An unpaired t-test was used to make statistical comparisons. The results are summarized in Tables 10 and 11.

The analysis showed that both the face of the dam and the powerhouse slope had established approximately 70% vegetative cover. The dominant species in both areas was crested wheatgrass (Agropyron cristatum). Vegetation appears to be uniformly established on both the powerhouse slope and the face of the dam. Statistical computations, shown in Appendix B, revealed that there was no significant difference in canopy cover between the vegetation on the powerhouse slope and the face of the dam.

Table 10. Total plant cover on powerhouse slope and face of Fort Peck Dam (May 1987) n=50.

Location	Mean (%)	Range (%)	STD Dev (%)
Powerhouse Slope	67	20 - 95	15.4
Dam - Upperslope	69	20 - 95	15.8
Dam - Midslope	71	30 - 100	17.3
Dam - Lowerslope	70	40 - 95	14.4

Table 11. Comparison of vegetative cover using unpaired t-test, May 1987.

Comparison	df	S	t Value[1]	Table Value	Conclusion
Powerhouse slope vs. upper dam slope	98	2.60	.0018	1.987	*[2]
Powerhouse slope vs. middle dam slope	98	2.75	.0540	1.987	*
Powerhouse slope vs. lower dam slope	98	1.02	.0408	1.987	*
Powerhouse slope vs. entire face of dam	198	3.55	.0946	1.960	*

* accept null hypothesis.

[1] T values taken from Table III of Fisher and Yates' Statistical Tables for Biological, agricultural medical Research, Oliver and Boyd Ltd., Edinburgh.

[2] The null hypothesis states that there is no significant difference in vegetative cover between the powerhouse slope and the dam.

Although the face of the dam has sustained vegetation for approximately 40 years and shows no evidence of instability or erosion, it is not appropriate to use the favorable statistical comparison as the sole success indicator. The seed mixture used to revegetate the powerhouse slope contained thick spike wheatgrass, western wheatgrass, green needlegrass and four wing saltbush. Despite the use of cultivars, that appeared to be well adapted to climate and soil conditions, none of the seeded species were widely established. Seeded species made up less than 10% of the species composition of the cover on the powerhouse slope. Crested wheatgrass plant propagules transported with the topsoil appeared to be responsible for establishing the wheatgrass community on this slope. The existing stand of vegetation is vigorous and has substantially reduced soil erosion. Although the goal of slope stabilization has been achieved, the failure of the seeded native grasses is disappointing.

One solution that could promote the establishment of native species on the spillway slope involves the source of topsoil. The borrow area previously utilized by the Corps of Engineers is dominated by stands of crested wheatgrass. Excavating topsoil from these areas for use in the reclamation of the spillway slope would likely result in the establishment of a stand of crested wheatgrass similar to

the stand that was established on the powerhouse slope. Because crested wheatgrass is an extremely competitive species, it is unlikely that native species could be successfully established under these conditions. Excavation of topsoil from a borrow area where crested wheatgrass is present is not recommended. Although this alternative may require excavation from native range, using soil which presently supports native vegetation should enhance the ability of seeded species to successfully establish on the spillway slope.

The elimination of the mulching provisions from the powerhouse slope revegetation contract likely had an adverse effect on the establishment of seeded vegetation. Wallem (1987) noted that high winds, reported to be in excess of 80 kph, occurred one week after reseeding was completed. Substantial seed loss appears to have resulted. Sampling showed that the seeded species were more commonly observed on the lower reaches of the slope in those areas that were partially shielded from the wind by the powerhouse structures. Although it is possible that a combination of other environmental factors contributed to this plant distribution pattern, there is little question that the effects of wind must be considered in future reclamation projects. The use of a native haymulch, crimped into the respread topsoil, would improve moisture retention in the soil, mitigate the

effects of high winds, and promote more efficient nutrient cycling.

The value of irrigation to establish native vegetation on the spillway slope at Fort Peck is questionable. Although Fort Peck Lake provides a source of high quality water that could enhance vegetation growth during the first growing season, research (DePuit et al. 1980) has shown that long term impacts on vegetation establishments are negligible. It could be argued that the dry conditions encountered in the spring of 1979 were responsible for the poor establishment of native species on the powerhouse slope, but it is unclear whether irrigation would have allowed the native species to compete effectively against the crested wheatgrass. Because of the high costs incurred in the set-up and operation of an irrigation system, the practice is generally not utilized in large reclamation projects and does not appear to be a cost effective alternative for the reclamation of the spillway slope.

SUMMARY AND RECOMMENDATIONS

Field research at Fort Peck indicated that several factors must be overcome to ensure the success of future reclamation projects. The use of reclamation research technologies developed in the past decade may help overcome these inhibitory factors.

The topsoil sodication that has occurred on the powerhouse slope during the past ten years is cause for concern, but has not hindered the establishment of vegetation. Although no further reclamation in this area is recommended at this time, the adverse soil physical properties resulting in a shrinking, swelling and crusting phenomena may cause a decline in plant vigor in future years. If future reclamation efforts are required in this area, the topsoil sodication problem must be resolved using methods similar to those recommended for the spillway slope.

The reclamation of the spillway slope could be enhanced by the use of several reclamation technologies. The following techniques are recommended:

1. The application of phosphogypsum at the rate of 22 mt/ha (10 t/a). The addition of calcium to the soil will

indirectly alleviate the crusting problem that presently exists. The use of phosphogypsum is the most economical amendment that will provide a solution to the adverse soil physical problems at the spillway site.

2. Apply 15 cm of topsoil. After treatment with phosphogypsum, 15 cm of topsoil should be applied to the recontoured slope. Although 15 cm of topsoil is less than the optimum depth for plant growth, it is sufficient to establish a stand of vegetation. The topsoil should be excavated from an area devoid of crested wheatgrass. The plant propagules and mycorrhizae that are present in topsoil are important in establishing a stand of vegetation. If a crested wheatgrass seed source is introduced with topsoil, the establishment of native species will be hindered.

3. Crimp a native hay mulch into the soil at a rate of 1 to 2 metric tons per acre. In areas where this is not possible, the use of a tackifier is recommended. The mulch will reduce seed loss caused by high winds and will conserve soil moisture. Although the use of native hay mulch may be somewhat more expensive than other options, it provides an additional seed source and will increase organic matter and retain moisture in the soil.

4. Continue the use of the seed mixture and application rate used in the 1978 powerhouse slope reclamation project. This particular seed mixture includes species that

have been shown to be well adapted to the environmental conditions that exist in the Fort Peck area. The seeding rate of 21.3 Kg/ha (19 lb/a) of pure live seed is adequate to establish a stand of native vegetation and control erosion.

5. Use drill seeding methods. Drill seeding is better suited for use on windswept slopes than hydroseeding. The use of a hydroseeder is justified on steep slopes (3:1 or greater), but should not be the principle means of seed application.

6. Use fall seeding. Soil moisture is the critical factor in seeding operations in the Fort Peck area. Because of the unpredictable spring weather, which may preclude the use of equipment on wet slopes, seeding during the period 15 October to 15 November is recommended.

7. Refrain from irrigation. Although Fort Peck lake provides a readily available source of good quality water, the expense incurred during irrigation cannot be justified. The long term success of the project is not dependent upon plant performance during the first growing season. Any short term benefits obtained by using irrigation would be offset by the high cost of the system.

8. Conduct soil fertility tests. Soil fertility was not included in this study. Critical nutrients which may be in short supply in the Fort Peck area are nitrogen and

phosphorous. Soil testing based on the specific reclamation objective and the species desired will be useful in preparing contract specifications for fertilization. It should be pointed out, however, that agricultural fertilization recommendations should not be used. Only low to very low levels of N and P are necessary to support stands of native vegetation.

9. Conduct a pilot study. Considering the large amount of money that is involved in reclaiming the spillway slope, the lessons learned from a preliminary research project could result in substantial overall savings. The Reclamation Research Unit, located at Montana State University, has the expertise to conduct this research. The cost would probably not exceed $25,000.

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APPENDICES

APPENDIX A

SOIL PROPERTIES

Table 12. Summary of soil analysis-powerhouse slope, March 1987.

Parameter	Mean x	Range Min-Max	Variance (S^2)
pH	7.6	7.5-7.6	0.1
SAR	12	12-14	0.8
EC (mmhos/cm)	2.5	2.4-2.7	0.2
% Sand	22	21-23	0.5
% Silt	35	34-36	0.5
% Clay	43	42-44	0.5

Table 13. Soil chemical and physical properties - powerhouse slope, March 1987.

Sample #	pH	SAR	EC (mmhos/cm)	Saturation %	% Sand	% Silt	% Clay
1	7.6	12	2.7	68	22	36	42
2	7.69	14	2.5	70	22	35	43
3	7.5	12	2.4	67	23	34	43
4	7.6	12	2.4	68	21	35	44

Table 14. Summary of soil analysis-spillway slope, March, 1987.

Parameter	x	Range Min-Max	Variance (S^2)
pH	7.9	7.8-8.1	9.3
SAR	25	22-27	2.9
EC (mmhos/cm)	3.3	1.9-7.9	4.6
Saturation %	83	80-87	5.1
% Sand	13	12-15	4.0
% Silt	24	22-25	1.0
% Clay	63	60-66	20.9

Table 15. Soil chemical and physical properties - spillway slope, March 1987.

Sample #	pH	SAR	EC (mmhos/cm)	Saturation %	% Sand	% Silt	% Clay
1	7.9	27.1	2.1	80	14	24	62
2	7.8	23.4	2.3	82	13	25	62
3	7.9	24.5	1.9	84	13	24	63
4	8.0	25.6	2.2	85	11	24	65
5	8.0	23.9	2.3	82	15	25	60
6	8.1	26.7	5.4	83	14	24	62
7	7.9	22.9	2.8	81	15	25	60
8	8.0	27.7	7.9	87	12	22	66

APPENDIX B

VEGETATIVE COVER COMPARISON

Table 16. Vegetation measurements on powerhouse slope.

Plot No.	Cover Class	Plot No.	Cover Class
1	9	26	12
2	9	27	11
3	7	28	10
4	5	29	10
5	6	30	9
6	9	31	11
7	10	32	10
8	11	33	9
9	11	34	10
10	12	35	11
11	8	36	11
12	9	37	10
13	12	38	9
14	12	39	8
15	10	40	9
16	9	41	10
17	8	42	11
18	7	43	12
19	9	44	11
20	11	45	11
21	10	46	10
22	9	47	10
23	10	48	9
24	11	49	11
25	8	50	11

Table 17. Vegetation measurements on dam face - upper slope.

Plot No.	Cover Class	Plot No.	Cover Class
1	9	26	10
2	9	27	11
3	8	28	11
4	10	29	10
5	9	30	10
6	11	31	9
7	13	32	8
8	12	33	7
9	12	34	7
10	11	35	10
11	12	36	9
12	10	37	11
13	9	38	10
14	9	39	12
15	8	40	11
16	5	41	12
17	7	42	12
18	8	43	10
19	10	44	11
20	10	45	9
21	11	46	10
22	12	47	10
23	10	48	10
24	10	49	9
25	11	50	10

Table 18. Vegetation measurements on dam face - midslope.

Plot No.	Cover Class	Plot No.	Cover Class
1	8	26	6
2	7	27	7
3	7	28	10
4	6	29	10
5	7	30	11
6	10	31	12
7	9	32	10
8	10	33	9
9	11	34	9
10	11	35	8
11	10	36	10
12	10	37	11
13	12	38	12
14	13	39	12
15	14	40	11
16	10	41	10
17	11	42	9
18	11	43	9
19	9	44	10
20	11	45	11
21	10	46	12
22	10	47	11
23	12	48	11
24	12	49	12
25	11	50	10

Table 19. Vegetation measurement of dam face - lower slope.

Plot No.	Cover Class	Plot No.	Cover Class
1	11	26	10
2	12	27	9
3	8	28	9
4	7	29	8
5	7	30	8
6	10	31	10
7	10	32	11
8	11	33	11
9	12	34	7
10	10	35	9
11	8	36	11
12	5	37	10
13	10	38	12
14	9	39	10
15	11	40	10
16	9	41	11
17	8	42	12
18	10	43	13
19	10	44	9
20	7	45	9
21	10	46	10
22	12	47	11
23	11	48	9
24	10	49	10
25	9	50	12

APPENDIX C

CHEMICAL AMENDMENT CALCULATIONS

In calculating amendment application rates, amendment purity and quantitative displacement must be calculated. The quantitative replacement factor accounts for the incomplete exchange reactions between the amendment and the soil. Each of the following examples contain representative calculations which consider these variables.

Several constants are useful in performing chemical amendment calculations. The quantity of free sulfur (S) required to replace 1 meq of NA/100 g soil has been determined to be .32 tons/acre foot and one meq of exchangeable Na/100 g soil is replaced by 1.7 tons $CaSO_4$ $2H_2O$/acre-foot. The quantity of $CaSO_4 \cdot 2H_2O$ that is equivalent to 1 ton of free S has been determined to be 5.38 tons (Richards 1969). Calculations for $MgCl_2$, $CaCl_2$ and $CaSO_4 \cdot 2H_2O$ can be performed by using the equivalent weights of the amendments that is equivalent to 1 ton of free S and then multiplying this quantity by .32 tons to ascertain the quantity of amendment required to replace 1 meq of Na/100 g soil per acre foot. The metric conversion is 3.8 metric tons (mt) $CaSO_2 \cdot 2H_2O$/hectare/30 cm.

Example #1: Calcium Chloride Requirement ($CaCl_2$)

Calculations for calcium chloride pellets used a 1.05 purity factor (95% pure) and assumed a quantitative

displacement factor of 1.25. The cost is estimated to be $300 per ton delivered to Fort Peck.

$CaCl_2$ equivalent weight = 55.44 g
$CaSO_4 \cdot 2H_2O$ equivalent weight = 86.10 g

One ton of free S equals 5.28 tons $CaSO_4 \cdot 2H_2O$

Therefore: $\frac{86.10}{5.38} = \frac{55.44}{x}$ = 3.46 tons $CaCl_2$ is equiv. to 1 ton S

Relative to S: .32 x 3.46 = 1.11 tons $CaCl_2$/ac-ft

Metric conversion = 2.11 mt/ha/30cm

$CaCl_2$ requirement/ha =

6.7 (meq Na/100g) x 2.11 (mt/ha/30cm) = 14.14 mt/ha/30cm

14.14 (mt/ha/30cm) x 1.05 = 14.85 mt/ha/30cm

= .49 mt/ha/cm

14.85 (mt/ha/30cm) x 1.25 = 18.56 mt/ha/30cm

18.56 (mt/ha/30cm) c $300/mt = $5568/ha

$5568/ha x 120 ha = $668,160

Example # 2: Magnesium Chloride Requirement ($MgCl_2$):

Calcium for magnesium chloride brine used an amendment purity factor of 3.12 (32%), but did not use a displacement factor due to the liquid nature of the brine. The cost is estimated to be $75/ton delivered to Fort Peck, Montana.

$MgCl_2$ equivalent weight = 47.61 g
$CaSO_4 \cdot 2H_2O$ = 86.10 g

One ton of free S equals 5.38 tons $CaSO_4 \cdot 2H_2O$

Therefore: $\frac{86.10}{5.38} + \frac{47.61}{x}$ x = 2.97 tons $MgCl_2$ is equiv. to 1 ton S

Relative to S: .32 x 2.97 = .95 $MgCl_2$/ac-ft to to replace 1 meq Na/ 100 g soil.

Metric conversion: = 2.11 mt/ha/30cm

$MgCl_2$ brine plot requirement =

6.7 (meq Na/100g)	x	2.11 (mt/ha/30cm)	= 14.14 mt/ha 30cm
14.14 (mt/ha/30cm)	x	3.12	= 44.11 mt/ha/30cm (1.47 mt/ha/cm)
44.11 (mt/ha/30cm)	x	$75/mt	= $3308/ha
$3308/ha	x	120 ha	= $396,990

Example #3: Phosphogypsum Requirement:

Phosphogypsum has a purity factor of 93.5% and a quantitative displacement factor of 1.25. The cost is estimated to be $60/ton delivered to Fort Peck Montana.

6.7 (meq Na/100g)	x	3.8 (mt/ha/30cm)	= 25.46 mt/ha/30cm
25.46 (mt/ha/30cm)	x	1.07	= 27.24 mt/ha 30cm
27.24 (mt/ha/30cm)	x	1.25	= 34.05 mt/ha/30cm (1.14 mt/ha/cm)
34.05 (mt/ha/30cm)	x	$60	= $2043/ha
$2043/ha	x	120 ha	= $245,160

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