A REPORT ON

RECLAMATION RESEARCH IN NORTH DAKOTA: AN INVENTORY OF PROJECTS, PUBLICATIONS, AND FUTURE RESEARCH NEEDS

Prepared by

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Revised Edition, 1996

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PREFACE

This report was first published in 1984 under the title "Reclamation Research In North Dakota: Inventory of Past and Ongoing Research, and Identification of Future Research Needs," for submission to the North Dakota Legislative Council, in compliance with the requirements of NDCC 38-14.1-04.2. Since then, each year, additional scientific material on reclamation research conducted in North Dakota was regularly reviewed, summarized, and inventoried by the Reclamation Research Advisory Committee with the assistance of the Public Service Commission staff. A revised edition of the report was prepared in 1986, followed by an addendum to the report in 1989. Now, after twelve years of initial compilation, the 1996 revised edition has been prepared to provide a broader, up-to-date perspective of the mined land reclamation questions and concerns that have been researched in North Dakota and those that remain to be addressed. The subtitle of the present edition has been slightly modified from the original, as there are no reclamation research projects ongoing or being funded at this time.

The 1996 revised edition consists of two parts. Part A contains an inventory, with brief descriptions, of research projects that have been conducted on coal mining and reclamation related problems in North Dakota, and two listings of the 'current and future' reclamation research needs. The first list identifies the research needs as perceived in 1996. The second list is included for the purpose of assessing the progress of research over the past 12 years, as it identifies the research needs envisioned in 1984. Part B contains an annotated bibliography of research reports, papers, presentations, etc. related to coal mining and reclamation in North Dakota. A brief description and analysis of conclusions was developed for each of these published or unpublished reports and papers. The resulting 'publication briefs' have been classified into various subject categories and arranged chronologically within each category. The report also includes an executive summary and introduction in the front, and author and subject indexes at the end, which are based exclusively on the contents of Part B.

In preparing this report immeasurable help was provided by the past and present staff of the Public Service Commission's Reclamation Division, Abandoned Mine Lands Division, and the Data Processing Section. The Reclamation Research Advisory Committee gratefully acknowledges their help and thanks each one of them for their valuable input. The assistance rendered by Paul Klebe in reformatting this report and in redeveloping the subject and author indexes is greatly appreciated. Thanks are also due to a number of state and out-of-state research organizations, North Dakota Universities, state and federal government agencies, and the North Dakota Lignite Energy Council for providing information on the reclamation research projects and future needs. A close interaction with and timely information provided by North Dakota State University's Land Reclamation Research Center, Mandan, and the University of North Dakota's Energy and Environmental Research Center, Grand Forks, made the task of compiling this report easier. Finally, the 1996 revised edition would not have been possible without the active support and interest of the North Dakota Public Service Commissioners.

December 1996

Nirander M. Safaya, Chairman
Reclamation Research Advisory Committee,
& Environmental Sciences Administrator
Reclamation Division, NDPSC

EXECUTIVE SUMMARY

1. This is a revised, updated edition of a report that was prepared in 1984 pursuant to the amendments, NDCC 38-14.1-04.1, NDCC 38-14.1-04.2, and NDCC 38-14.1-04.3, made in the North Dakota surface mining and reclamation law in 1983.

2. As required by NDCC 38-14.1-04.1, a three-member Reclamation Research Advisory Committee (RRAC) was appointed by the North Dakota State Governor. The RRAC, with the administrative and staff assistance from the North Dakota Public Service Commission (NDPSC) was required (NDCC 38-14.1-04.2) to: 1) develop an inventory, with brief description and analysis of conclusions, of all past and ongoing reclamation research projects conducted in North Dakota; 2) identify all existing or future reclamation research needs, 3) establish priorities based on the criteria laid down in Section 38-14.1-04.3 of NDCC; 4) prevent duplication in reclamation research; and 5) prepare future reclamation research budgets administered by the Commission. It was in fulfillment of these requirements that the original report was prepared. This edition, however, does not include a research budget because the Commission is not currently administering any research projects.

3. The information presented in this report on reclamation research projects and current and future research needs in North Dakota was obtained from various research groups, state and federal agencies, and the lignite industry. Additionally, a comprehensive literature search was conducted, and all the available reports, papers, and other published and unpublished research material related to reclamation of North Dakota coal mine lands was reviewed and abstracted. These abstracts or "publication briefs" were developed to augment information on the reclamation research projects and to provide a consolidated reference source for all areas of reclamation research conducted in North Dakota.

4. Although there is a long history of reclamation research in North Dakota, a serious consideration to this end was given only after the enactment of the State's first reclamation law in 1969. The research efforts increased and diversified considerably during the 1970's and 80's, with much emphasis on geologic and hydrologic aspects of mining and reclamation, mine spoil characterization, restoration of agricultural productivity, and ecological rehabilitation of disturbed ecosystems. However, this trend has now reversed, as almost all active centers where reclamation research was vigorously pursued have either disengaged from this area of research or have been closed down.

5. Since the early 1970's, over 130 reclamation research projects have been conducted. Out of these, 50 projects have been devoted to geologic and hydrologic aspects, 50 projects to soil/spoil characterization and agricultural productivity of mined lands, and 30 projects to ecological aspects of mining and reclamation.

6. It was estimated that approximately $23,600,000 have been spent for conducting mining and reclamation related research in North Dakota during the period of 1970 to 1996. Out of this amount, about $10,000,000 were spent on geologic and hydrologic aspects, about $11,000,000 on agricultural aspects, and about $2,600,000 on ecological aspects of mine land reclamation. Ecological aspects of reclamation research received the least amount of funding, especially after 1984; the available information indicated that less than half a million was spent between 1984 to 1996.

7. There was not much redundancy detected in the research projects *per se*. However, some overlapping of goals and program objectives was evident in some cases. Also, some of the basic themes or questions seemed to have been researched over and over again, with no final answers. Limited interaction and collaboration, competition, inadequate or scattered funding, and short-term planning were, perhaps, some of the main reasons for overlapping of research objectives and repetitive field or laboratory studies. A marked tendency to publish the same results, findings, or ideas simultaneously in several reports and journals was quite evident. The redundancy in publication of results was due to the over-reporting requirements imposed by the funding agencies and, perhaps, also because of the 'publish or perish' ideology or the inflationary attitude prevalent in the scientific community.

8. Some of the research studies seemed to have had a significant influence on the surface mining and reclamation laws, rules, and practices in North Dakota. This includes the research on soil respreading requirements which led to the adoption of an alternative rule in 1985 that allows the soil respread thicknesses to be based on the characteristics of the underlying graded spoil. Also, enough data has been generated in many other subject areas (i.e., prime farmland restoration, soil productivity, management of reclaimed lands, erosion potential, water recharge, evaluation of revegetation success, etc.) that may be effectively used to bring about further changes in the mining and reclamation laws, rules and practices. Obviously, some of the research conducted thus far in North Dakota has and will continue to provide dividends in terms of reducing the cost of mining and reclamation, improving the quality of reclamation, and ensuring greater environmental safety. However, as several recently initiated studies remain incomplete, with no final conclusion drawn, their usefulness to the lignite industry will be slight.

9. The number of research needs perceived today are fewer and more well defined than those perceived in 1984. Some of the top priority research needs include: assessment and mitigation of mining effects on groundwater quality and quantity; suitability of mined areas for waste disposal; effectiveness of reclaimed wetlands for groundwater recharge; effects and alleviation of soil compaction in reclaimed mine lands; prime farmland restoration; stability of reclaimed grasslands; simple and reliable methods for evaluation of reclamation success, establishment, management and evaluation of tree and shrub communities; and use of microorganisms in reclamation. These and other research needs merit funding commitment.

10. A great deal of progress in reclamation research has been made in North Dakota since the enactment of its first reclamation law in 1969. This was possible mainly because several private and public entities in the state made a commitment to allow coal mining to occur at full scale while preserving the quality of environment and ensuring that the mined lands would be returned to their original or better use and productivity. This commitment was backed with proper funding and the interest of several dedicated scientists working at various universities and research organizations in the state. Since a large amount of money has already been spent in reclamation research, to reap its full benefit it is necessary that the outstanding questions and concerns are researched to their completion. The Lignite Energy Council is the most appropriate channel through which the lignite industry could seek funds from the Lignite Research Council for completing the remaining research.

11. This report will help the lignite industry, academia, and various public and private agencies to identify the tasks ahead, as it clearly defines what has been achieved and what remains to be addressed.

RECLAMATION RESEARCH IN NORTH DAKOTA

PART A

RESEARCH PROJECTS AND NEEDS

I. INTRODUCTION

Research on surface coal mining and reclamation in North Dakota received much emphasis during the 1970's and 80's, after the enactment of the state's first reclamation law in 1969. Federal and state grants enabled the creation of a few reclamation research laboratories/centers in the state, where many scientists and technicians dedicated their time and talent in developing the knowledge and techniques deemed necessary to minimize the environmental effects of and economic constraints to surface coal mining. Numerous research projects covering a wide range of mining and reclamation disciplines were conducted at these centers, which focused on both active and abandoned mine land problems. The results of these studies have been, and continue to be, published in various forms including reports, papers in refereed journals and symposia proceedings, popular scientific articles, etc. Most of this material is available for review and has been summarized in this report.

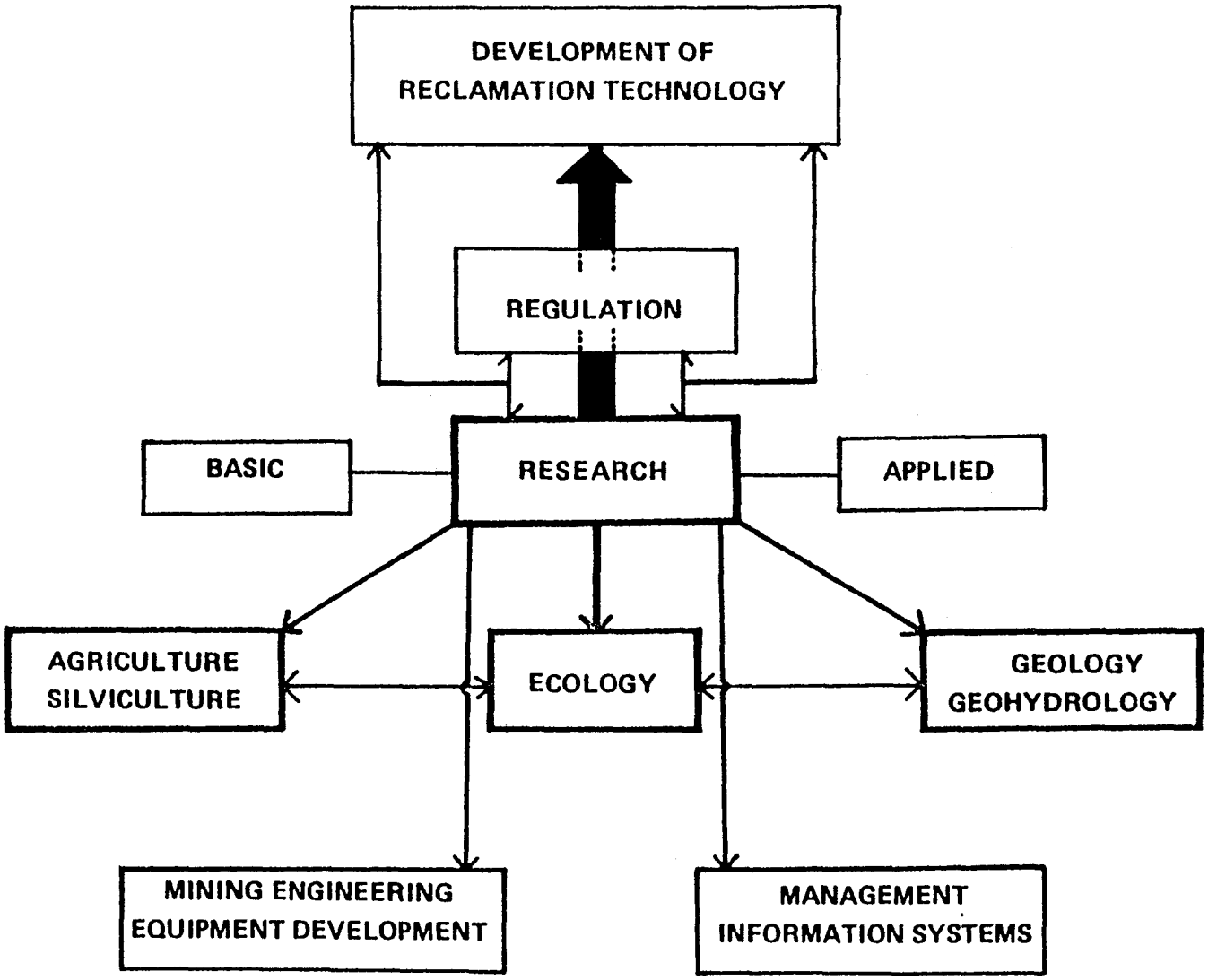
In 1983 the North Dakota state legislature mandated (NDCC 38-14.1-04.1) the creation of a three-member Reclamation Research Advisory Committee, which was required (NDCC 38-14.1-04.2), among other responsibilities, to: 1) develop an inventory with brief descriptions and analysis of conclusions of all past and ongoing reclamation research projects conducted in the state; 2) identify all existing or future research needs; 3) establish priorities and prevent duplication in research; and 4) prepare future reclamation research budgets to be administered by the Commission. It was in compliance with these requirements that the 1984 edition of this report was prepared. That report contained information on reclamation projects, publications, research needs, and a projected cost estimate of conducting research deemed necessary at that time. In the 1996 revised edition much of this information has been updated to provide a more recent assessment of the status of reclamation research and technology in North Dakota. The section on estimated funding requirements has been deleted, however, because reclamation research was largely funded by the Lignite Research Council (created by Executive Order 1987-4) and funneled through the Industrial Commission. Nevertheless, before approving funding for any reclamation research proposal, the Lignite Research Council sought and received comments and recommendations from the Reclamation Research Advisory Committee.

Since the initial publication of this report a dozen years back, the reclamation research climate in North Dakota has changed significantly. The USDA-ARS Northern Great Plains Research Laboratory, where the agricultural aspects of reclamation were first seriously considered and incorporated in its research program, officially ended its active field involvement in reclamation research in 1985. Around the same time the University of North Dakota's 'Project Reclamation', which had been initiated in 1975 with federal funds and later on supported by some contract funding from the Public Service Commission, came to an end in 1984 after years of concentrated work on ecological aspects of mining and reclamation. North Dakota State University's Land Reclamation Research Center, which developed a very good program in the soils and agronomic aspects of reclamation research, was closed in September 1996, for want of continued financial support from the state. Support and enthusiasm for reclamation research is also fading at other university departments/laboratories and in many government agencies which were earlier engaged in one or another aspect of reclamation research. Recently, a recommendation to repeal the law that created the Reclamation Research Advisory Committee has also been made. Apparently, for good reasons, the emphasis has now shifted more in support of those research and development activities that can make mining and reclamation practices less costly and help enhance the quality, value, and marketability of North Dakota coal.

Nevertheless, the fact remains that a substantial amount of money has been spent thus far in conducting mining and reclamation research in North Dakota, and additional funds may yet be needed for addressing some of the outstanding research needs. It is therefore essential to review and assess the overall impact that all this research has had in actually advancing the state-of-the-art of reclamation, and how it has affected the development and refining of reclamation laws and rules in the state. Research and regulation are interconnected in that the research provides a sound basis for making good rules, and rules and regulations challenge research to develop appropriate technology. A good example of this interaction is provided by the alternative rule for soil respreading thicknesses based on the properties of the underlying spoil, that was adopted in North Dakota in 1985. This rule was based squarely on the research conducted by the NDSU-Land Reclamation Research Center.

The interdependance of research, regulation, and technology relevant to mining and reclamation can not be overemphasized (see Figure 1). Reclamation research draws upon a number of basic and applied disciplines of science. For the reclamation research to be meaningful, expedient, and cost-effective, a clear understanding of the research needs and priorities is a must. Also, to avoid repetition of effort and redundancy in research spending, it is crucial to know what research has been already conducted and which problems have found their partial or complete solution. This report is meant to serve such a purpose, as it provides a concise and consolidated picture of the numerous research projects and publications on various aspects of coal mining and reclamation in North Dakota. Also, in preparing this report an attempt to present the material in a non-technical, easy-to-understand format has been made. The Reclamation Research Advisory Committee is aware that this report does not include information on all the projects, publications, or reports pertaining to reclamation research conducted in North Dakota, but hopes that the information presented in this report is useful to the coal industry, regulators, the scientific community, and the interested public.

Figure 1. Interrelationship between reclamation research, regulation, and technology.



II. RECLAMATION RESEARCH PROJECTS

This section provides an annotated inventory of the research projects conducted on surface coal mining and reclamation related problems in North Dakota. It is based on the information obtained from various research organizations, universities and government agencies that were directly or indirectly involved in these research projects. It covers the period 1970 to present.

Although large in number, and varied in their objectives and scope of work, the reclamation research projects fall into three major subject areas or disciplines, namely: 1. geology and hydrology, 2. mine land soils and agricultural production, and 3. ecology and ecosystem rehabilitation. This classification has been followed in the present inventory.

The information provided for each of the research projects generally includes: project title, name(s) of the principal investigator(s), name(s) of the organization(s) where the research was conducted, name(s) of the funding agency(ies), duration of the project and funding level, and a brief description of the objectives(s) and major finding(s). However, exact information on the duration and funding levels on individual projects under the subject area of "Mine Land Soils and Agricultural Production" was not available. For this reason, information on these items has not been included in the description of individual projects under this category; instead a general account of funding received during the entire duration of involvement in reclamation research by the research organizations in question has been given in the introductory part of that subsection.

Based on the information provided by various research groups, it was estimated that approximately $23,600,000 have been appropriated/spent for conducting research on mining and reclamation related problems in North Dakota during the period of 1970 to 1996. Out of this amount, approximately $10,000,000 have been spent on geologic and hydrologic aspects, approximately $11,000,000 on agricultural aspects, and approximately $2,600,000 on ecological aspects of mining and reclamation research.

A. GEOLOGY AND HYDROLOGY

Research on geologic and hydrologic (surface water and groundwater) aspects of coal mining and reclamation in North Dakota has been vigorously pursued since the early 1970's. The institutions and agencies which have been actively involved in this research include the University of North Dakota (Geology Department, Engineering Experiment Station, and Mining and Mineral Resources Research Institute, Energy and Environmental Research Center), North Dakota State University (Chemistry Department), North Dakota Geological Survey, and US Geological Survey. Funding for conducting this research was mostly provided by sources such as the US Bureau of Mines, US Environmental Protection Agency, US Department of Energy, US Bureau of Land Management, US Geological Survey, Old West regional Commission, Water Resources Research Institute, North Dakota Geological Survey, North Dakota State Water Commission, Lignite Research Council, and North Dakota Public Service Commission. Based on the information provided by various researchers involved in geologic and hydrologic research related to coal mining and reclamation in North Dakota, the total amount of funding received for conducting the following projects has been approximately ten million dollars ($10,000,000).

1. Geologic, Hydrologic, and Geochemical Concepts and Techniques in Overburden Characterization for Mined land Reclamation. - S.R. Moran, G.H. Groenewold (NDGS); funded by Old West Regional Commission, July 1974-June 1976, $102,000.

The objective of this project was to determine the distribution of geological materials and some of their properties, groundwater flow patterns, and the chemistry of groundwater at five existing and proposed mining sites (Falkirk, Indian Head, Beulah-Hazen, Center and Dunn Center) in west central North Dakota. The factors controlling the chemistry of overburden and groundwater in the study area were identified, and a semi-quantitative interpretative framework that relates potential pore-fluid chemistry to the type of materials and setting in the subsurface flow system were developed.

2. Investigations of the Subsidence and Surface Collapse Features in Reclaimed Coal Mines. - G.H. Groenewold (NDGS & MMRRI); funded by US Bureau of Mines, April 1977-March 1983, $315,000.

The objectives of this study were to: 1) relate the various practices of spoil emplacement in the study area to the specific degree of stability or instability associated with each, 2) determine whether the time of year during which emplacement occurs has an effect upon the stability characteristics of spoils, 3) determine the techniques of spoil emplacement necessary to assure optimum stability, 4) determine if relationships exist between groundwater conditions within spoils and method of emplacement of spoils, and 5) determine the relationship, if present, between instability phenomena and the geological characteristics of the spoils. This study was conducted at the Center and Indian Head mines. Area-wide settling, localized subsidence or collapse, and piping are the types of instability observed in reclaimed post-mining landscapes in western North Dakota. Area-wide settling is most pronounced during the first year after contouring but appears to cause only minimal disruption. Large-scale collapse develops only in the pre-contouring valley areas where frozen materials are contoured with a dozer. Although severe in some settings, development typically ends within one year. Piping appears to be a severe and long-term problem in some settings. Piping usually begins soon after contouring ceases and may

continue for several years. Piping is controlled by a combination of physical and chemical conditions in the spoil. A key factor is the presence of highly dispersive materials in the near surface.

3. **Cooperative Program to Evaluate Surface and Groundwater Problems Associated with Potential Strip Mine Sites. - G.H. Groenewold (NDGS & UND-Engineering Experiment Station); funded by US Environmental Protection Agency, July 1977-March 1983, $315,000.**

   This study was a part of a cooperative project involving geology, chemistry and soils research groups in North Dakota, Montana, and Wyoming, with one study site in each of these states. The total funding for the three state project was $2,850,000, out of which $315,000 were provided for geology/groundwater research in North Dakota. The latter included monitoring of the initial effects of surface mining on groundwater quantity and quality at the Falkirk mine. The local concerns of the City of Underwood, North Dakota, with respect to the effects of surface mining on the city's water supply were evaluated.

4. **Mechanisms, Distribution, and Frequency of Groundwater Recharge in Upland Areas of North Dakota. - G.H. Groenewold (NDGS & UND-Engineering Experiment Station); funded by Water Resources Research Institute, July 1978-June 1979, $25,000.**

   The premining groundwater recharge characteristics of Falkirk area were evaluated, and it was concluded that recharge is both aerially and temporally variable. Most of the recharge was found to occur in the spring season with prairie pothole sloughs acting as the major source of recharge in the study area. This project emphasized on the critical need for proper reclamation design with respect to sloughs.

5. **Geologic and Geochemical Controls on the Chemical Evolution of Subsurface Water in Surface Coal Mine Spoils. - G.H. Groenewold (NDGS & MMRRI); funded by US Bureau of Mines, October 1979-June 1982, $106,000.**

   The major objective of this project was to define the key minerals and chemical reactions in undisturbed settings and spoils that control the chemical evolution of groundwater. The ultimate goal was to gain the capability of predicting postmining groundwater quality and intelligently designing postmining landscapes such that deterioration of groundwater quality can be avoided or diminished. This project has demonstrated the need for detailed geologic and geochemical data as basic input not only with respect to the evaluation of postmining groundwater concerns, but also with respect to concerns associated with postmining plant growth success and surface water quality. This research has demonstrated that selective handling of certain types of overburden materials is needed in some settings if long-term reclamation success is to be achieved.

6. **Development of a Hydrogeological and Hydrogeochemical Data Base for Abandoned Lands - Phase I. - G.H. Groenewold (MMRRI), E.C. Murphy (NDGS), R.D. Koob (NDSU); funded by ND Public Service Commission, May 1982-August 1983, $77,000.**

   The objectives of this project were to characterize and classify significant abandoned surface mined lands in North Dakota with respect to some key geologic variables, select study sites which are typical of each generic type, and determine the geologic and groundwater characteristics of the

selected sites. Initially, a total of 51 abandoned mine sites were field evaluated and grouped into four generic categories. Four mine sites namely Noonan, Indian Head, Davenport and Velva, each representing a generic type, were selected for evaluation of local geology and geohydrology parameters. The results from this phase of the project indicated that the quality of the underground water at these four abandoned mine sites was generally similar to that found in the adjacent unmined areas, and the expected premine water tables had also become reestablished.

7. **Investigation of the Environmental Effects of Disposal of Fly Ash and Flue Gas Desulfurization Waste in Surface Lignite Mines. - O.E. Manz (UND), G.H. Groenewold (MMRRI), D.J. Hasselt (SEM); funded by US Department of Energy, 1977-1985, $372,000.**

The objectives of this project were to: 1) determine the concentrations and chronological history of chemical pollutants released from fly ash and FGD waste disposal sites at the Center mine, 2) characterize the chemical and physical properties of the fly ash and FGD waste and soils at the disposal sites and to relate these properties to pollutant concentration changes in groundwater as a function of time and monitoring well position, 3) evaluate the suitability and practicality for disposal of FGD waste in the vees between strip mine overburden waste piles, and in the strip mine decoaled seam (pit bottom), 4) determine the alkaline buffering capacity and mechanisms of alkaline leachate attenuation by disposal site soils, and 5) generate a manual of procedures for the disposal of fly ash and FGD waste in western surface coal mines. Monitoring of the disposal sites for the last five years has indicated that underground water in the vicinity of buried fly ash has high pH and high concentrations of As, Se, and Mo, and that in the vicinity of FGD waste are high in SO_4 and cation concentrations with no significant trace metal contamination. Groundwater influenced by FGD waste was found to be similar to groundwater in some areas of spoil without FGD waste but where SO_4 and total dissolved solid concentrations are high. Presently, the areal extent of groundwater contaminated by fly ash or FGD waste at the Center mine is small.

8. **Detection of Underground Lignite Mine Voids by Surface Resistivity and Microgravity Surveys. - S.S. Saluja, S.D. Gosnold (UND-Geology Department); funded by ND Public Service Commission, 1982-1983, $30,000.**

This project was conducted under two separate contracts, one dealing with resistivity method and the other with microgravity method of surveying and detecting underground voids in abandoned mine lands. The studies were conducted at the New Leipzig, Beulah, Buechler, and Urlacher mines. An additional objective was to test the feasibility of using microgravity method to determine the extent to which underground cavities have been filled with slurry or other materials. Both methods were found to be useful in delineating underground voids and, thus, in evaluating the hazard potential of abandoned underground mines.

9. **Determination of $0^{18}/0^{16}$ and D/H in Surface and Groundwater. - R.D. Koob (NDSU); funded by US Environmental Protection Agency, 1975-1982, $315,000.**

The objective of this project was to obtain evidence on the origin and history of the groundwater in some locations of interest, using stable isotopes. The EPA funding, which continued for seven years, was over before some additional studies could be completed.

10. Determination of S^{34}/S^{32} in Lignites and Overburden Materials in Water Bourne Sulfates, and in H_2S from Soil Sampling Drillings. - R.D. Koob (NDSU); funded by Office of Water Research and Technology, USGS, 1982-1984, $67,000.

This project was undertaken in cooperation with the US Geological Survey to aid in understanding the degree to which surface mining of coal affects salinity of soils and groundwater.

11. Determination of the Buffering Capacity of North Dakota Soil Materials. - R.D. Koob (NDSU); funded by US Department of Energy, 1983-1984, $25,000.

Studies conducted under this project were aimed to evaluate the acid and alkali neutralization capacity of some soil and overburden materials. The reasons for conducting these studies included both the existence of acid forming materials in the overburden and the disposal of fly ash and other alkaline waste products of power plants in the spoil materials. Since some trace elements can assume toxic concentrations under acid and some under alkaline conditions, the buffering capacity of overburden materials offers an important attenuating mechanism.

12. Hydrological Changes Due to Lignite Mining in North Dakota, Part I - Reconnaissance of Strippable Lignite Deposits. - W.F. Horak Jr., (USGS); funded by Bureau of Land Management, July 1974-June 1977, $50,000 per year.

The objectives of this project were to define for each strippable lignite deposit (as identified in publications of the US Bureau of Mines and the US Geological Survey) the following information: 1) a summary of local geologic conditions, 2) description of the local groundwater flow system, 3) flow characteristics of the streams, 4) chemical quality of water from streams, lakes, and aquifers, 5) stream sediment loads, and 6) recommendations for more intensive hydrologic studies in probable problem areas. The project envisioned the development of conceptual models, their testing, and the determination of probable hydrological changes resulting from mining in each coal deposit area. The groundwater aspects of the lignite were also addressed.

13. Availability of Groundwater from Aquifers in the Cretaceous and Tertiary Systems in the Fort Union Coal Region. - M.G. Croft (USGS); funded by US Geological Survey, July 1974-June 1977.

The major objectives of this regional study were 1) to determine the location, extent, and nature of the major aquifers and confining beds in the Cretaceous and Tertiary systems in the Fort Union coal region, 2) to evaluate the occurrence, movement and availability of groundwater, including sources of recharge and discharge, and 3) to determine the chemical quality of the groundwater. The investigation was concerned mainly with the compilation, analysis, and interpretation of existing pertinent data from available sources in the states of North Dakota, South Dakota, Wyoming, and Montana. Major aquifers in the Cretaceous and Tertiary systems were identified, described, and correlated mainly through the use of geophysical and lithologic logs.

14. Hydrological Effects of Strip Mining in the Gascoyne Area, Bowman County, North Dakota. - M.G. Croft (USGS); funded by Bureau of Land Management, July 1975-June 1978, $50,000 per year.

The purpose of this investigation was to determine and evaluate the effects on the hydrologic system created by the expansion of the Gascoyne lignite mine. Specifically, the objectives are 1) to measure and predict the changes in the runoff characteristics, sediment load, and water quality of streams draining the mine area, and 2) to determine the location and extent of the major aquifers and predict the changes in chemical quality of water within them. The existing hydrologic system was simulated with a digital conceptual model involving finite element and difference approximations of the groundwater and surface-water flow equation. Data for the models was obtained from new and existing test wells and gauging stations.

15. Hydrologic Evaluation of Mining and Reclamation, Beulah Trench Area, Mercer County, West-Central North Dakota. - O.A. Crosby (USGS); funded by Bureau of Land Management, April 1976-September 1979, $80,000 per year.

The objectives of this project were to 1) define premining hydrological and geochemical conditions in a 28 square mile area to provide historical data for the measurement of the magnitude of change during and after mining 2) to provide, on basis of observations from this study site, guidelines for mining and reclamation that will minimize adverse effects of these operations on the hydrologic system 3) to determine the hydrologic and chemical effects of mining operations on the Antelope Creek aquifer. Existing hydrologic and geochemical data from prior studies in the area were collated and evaluated. Conceptual models of the hydrological and geochemical systems were developed and sites selected for the collection of needed geologic, hydrologic, and chemical data.

16. Surfacewater Resources, Fort Union Coal Region of Western North Dakota. - N.D. Haffield (USGS); funded by US Geological Survey, October 1977- September 1982, $107,000 per year.

The purpose of this study was to describe the surfacewater resources of the Fort Union coal region of western North Dakota in a readily usable format. The specific objectives were 1) to determine the streamflow and water quality characteristics for the streams located in the region and 2) to describe seasonal and areal variations that occur within the various stream systems. Existing data were condensed and analyzed to define the characteristics of the various components of the streamflow systems located within the study area; data from surfacewater gaging stations located within the study area were assembled by basin.

17. Evaluation of Probable Hydrologic Effects of Future Lignite Mining and Reclamation Activities in the Rattlesnake Butte Area, North Dakota. - W.F. Horak, Jr., (USGS); funded by Bureau of Land Management, October 1978-September 1982, $60,000 per year.

The objectives of this project were to 1) determine the geographical extent of the minable lignite beds and identify aquifers to a depth of about 400 feet beneath the lower minable lignite in the Rattlesnake Butte area, 2) assess the groundwater flow regime in all aquifers encountered, 3) evaluate the flow characteristics of the two streams draining the study area, 4) evaluate the after quality of the aquifers and streams in the study area, and 5) qualitatively assess the impacts on the hydrologic system that mining might impart. Data from 65 test holes and 40 observation wells were used to determine dominant lithologies and bed associations in the study area. The major aquifers were identified, mapped, and the groundwater flow regime of each aquifer was described.

The mode and degree of interaction between the aquifers was also hypothesized. Sampling of most of the observation wells for chemical analysis enabled the water quality characterization of the aquifers. Streamflow magnitudes and water quality were monitored at gauging stations on the two streams that drain the mineable area. Qualitative considerations of the hydrologic and hydrochemical impacts of mining was addressed.

18. **Evaluation Through Modeling of Probable Surfacewater Hydrologic Effects of Future Lignite Mining and Reclamation Activities in the Antelope Creek Area, Mercer County, North Dakota, and the Wibaux-Beach Deposit Area, Wibaux County, Montana, and Golden Valley County, North Dakota. - D.E. Emerson (NDGS); funded by Bureau of Land Management, October 1979-September 1982, $120,000 first year and $100,000 per year for 4 years.**

The objectives of this investigation were 1) to determine premining hydrologic conditions in a small representative drainage basin, 2) to provide historical data with which to compare the magnitude of change with mining, and 3) to develop the capability of making reasonably accurate projections of hydrologic effects resulting from the various land treatments imposed by surface mining. A comprehensive study of two small representative watersheds was conducted and a surfacewater model developed through coupling of snowmelt/rainfall/runoff models. A modular design program was used with each element of the hydrologic system being defined by a subroutine. This program has the capability of combining subroutines to best fit a particular problem. A distribution - parameter approach was used by having the basin partitioned into subunits based on slope, aspect, vegetation type, soil type, and snow distribution. Work on this project continued in 1983, and the US Geological Survey's Precipitation Runoff Modeling System was calibrated for both watersheds for snowmelt runoff. For the snowmelt period, maximum available water-holding capacity of soil profile (SMAX), emissivity of dry air (EAIR), and correction for daily precipitation (DSCOR) were parameters which were most sensitive. Several basic delineations were tested and it was found that for well defined snow distribution about 36 subunits adequately showed the variability in the basin.

19. **Geochemistry of the Fort Union Group as Related to Impacts of Strip Mining of Lignite in the Gascoyne Area, North Dakota. - R.L. Houghton (USGS); funded by Bureau of Land Management, US Environmental Protection Agency, US Geological Survey, ND Geological Survey, October 1979-September 1984, $120,000.**

The purpose of this investigation was to quantitatively describe major controls on the movement of critical solutes in local and regional groundwater systems within the Fort Union Group affected by surface mining of lignite in western North Dakota. Specific objectives are to define the hydrogeologic and hydrogeochemical character of the shallow groundwater system in the Gascoyne mine area and to ascertain the source of observed anomalous sulfate concentrations. The effects of discharge of mine-impacted groundwater on the surfacewater system in the area are also being studied. After obtaining a clear and complete understanding of the hydrologic regime, the mineralogy and mineral chemistry of the Fort Union Group was determined. Cation exchange rates and constants were determined and oxidation reduction reactions were defined for important species pairs. The solute flux from mine to locations of water was also studied.

20. Evaluation of the Hydrologic Systems in the New Leipzig Coal Area, Grant and Hettinger Counties, North Dakota. - C.A. Armstrong (USGS); funded by Bureau of Land Management, October 1980-September 1981, $50,000.

The primary objective of this project was to define the hydrologic regime in the study area which would include assessment of the groundwater flow system and chemical characteristics and determination of surfacewater flow magnitudes, chemical quality, sediment concentration, and sediment load. This would also provide a historical data base which would be used to monitor changes in the system as mining proceeds.

21. Pumping Techniques Bias in Chemistry of Groundwater Samples. - R.L. Houghton (USGS); funded by US Geological Survey and ND State Water Commission, October 1980-September 1982, $40,000.

The objective of this investigation was to determine the nature and magnitude of chemical biases introduced during the sampling of groundwater by several different common pumping methods. Pumps being investigated included airlift, air squeeze, gas driven reciprocating, peristaltic, and submersible centrifugal. Analyses of groundwater sampled by these techniques, including Kemmerer-type and conventional bailers, provided a basis for evaluating historical groundwater data and determining preferred methods for future sampling. First, only wells of similar construction were studied, thus minimizing water alteration due to well conditions. Next, randomly selected wells were sampled without regard to construction design, but only water from wells of similar construction and composition were considered in each statistical group. To fully assess the affected parameters, deep, intermediate, and shallow wells were included. To assure applicability of the results to all water types, wells yielding sulfate, bicarbonate, and chloride waters were studied. Additionally, adjacent wells to the same aquifer depth but cased in different materials were sampled to evaluate the effect of well construction on apparent groundwater quality.

22. Evaluation of Probable Hydrologic Effects of Future Lignite Mining and Subsequent Reclamation Activities in the M&M Deposit, Williams County, North Dakota. - W.F. Horak, Jr., (USGS); funded by Bureau of Land Management, October 1980-September 1983, $70,000 for 2 years.

The objective of this project was to define the hydrologic regime of the study area in the greatest possible detail. This included assessment of the groundwater flow system and its chemical characteristics, determination of flow frequencies and magnitude, chemical quality, and sediment concentration and load of the larger streams. A historical data base was established, and the capability for projecting the hydrologic effect of physical treatments imposed by surface mining developed. The assembled data was used in conjunctions with digital models to define the groundwater flow system. The surfacewater system was defined through available records, data collection, and regionalized equations. Quality of water was defined through an intensive sampling program. Methods for estimating the hydrologic effects for various land treatments imposed by mining were developed.

23. Hydrology of Area 47, Northern Great Plains Coal Province, North Dakota. - O.A. Crosby (USGS); funded by US Geological Survey, March 1981- September 1982, $60,000.

The purpose of this project was to described the hydrology of Area 47 in a format readily usable by the coal mining industry, the regulatory agencies, interest groups and the general public. The specific objectives of the study were to present 1) a description of the area in a hydrologic framework, 2) a quantitative assessment of the occurrence and availability of water, 3) an assessment of the present quality of available water, and 4) and identification of current and planned utilization of water. Only the existing data based on previous reports was utilized to establish an information framework for the study area.

24. Hydrology of Area 46, Northern Great Plains Coal Province, North Dakota. - M.G. Croft (USGS); funded by US Geological Survey, October 1982-September 1983, $60,000.

The purpose of this project was to describe the hydrology of Area 46 in a format readily usable by the coal mining industry, the regulatory agencies, interest groups, and the general public. The specific objectives of the study were to present 1) a description of the area in a hydrologic framework, 2) a quantitative assessment of the occurrence and availability of water, 3) an assessment of the present quality of available water, and 4) an identification of current and planned utilization of water. Only the existing data based on previous reports were utilized to establish an information framework for the study are.

25. Evaluation of Hydrologic System in New England - Mott Coal Area, Adams and Hettinger Counties, North Dakota. - M.G. Croft (USGS); funded by Bureau of Land Management, October 1982-December 1983, $50,000.

The primary objective of this project was to define the hydrogeologic regime in the study areas including assessment of the groundwater flow system and chemical characteristics and determination of surface water flow magnitudes, chemical quality, sediment concentration, and sediment load. A historical data base was established which will be used to monitor changes in the system as mining in this area proceeds.

26. Evaluation of the Hydrologic System in the Dickinson Coal Area, Stark County, North Dakota. - C.A. Armstrong (USGS); funded by Bureau of Land Management, October 1982-September 1983, $70,000.

The primary objective of this report was to define the hydrogeologic regime in the study area, including assessment of the ground water flow system and characteristics and determination of surface water flow magnitudes, chemical quality, sediment concentration, and sediment load. A historical data base was established which could be used to monitor changes in the system as mining proceeds.

27. Evaluation of the Hydrologic System in the Sand Creek - Hanks Coal Area, Williams County, North Dakota. - funded by Bureau of Land Management, October 1982-September 1983, $40,000 for 2 years.

The primary objectives of this report was to define the hydrologic regime in the study area including assessment of the groundwater flow system and chemical characteristics and determination of surface water flow magnitudes, chemical quality, sediment concentration, and

sediment load. A historical data base was established which could be used to monitor changes in the system as mining in the area proceeds.

28. Evaluation of Effects of Ongoing and Future Mining and Reclamation Activities in Western North Dakota. - D.G. Emerson (USGS); funded by Bureau of Land Management and US Geological Survey, October 1982-September 1985, $50,000 per year.

The purpose of this project was to provide the capability to assess and predict the effects of mining and energy development on the hydrologic system. The specific objectives were to :1) monitor the variations in the quantity and quality of surface water below active energy development sites, 2) use the data collected to augment and refine predictive models presently available, and 3) verify the transferability of a calibrated watershed model. The study included the operation of five river stream-gauging and water quality sites, one complete weather station, and three precipitation sites. The US Geological Survey's Precipitation Runoff Modeling System was selected as the predictive model. The model was calibrated for the site where the model was developed.

29. Hydrochemical Impacts of Surface Mining of Lignite - the Sulfur Cycle. - R.L. Houghton (USGS); funded by US Geological Survey and ND Geological Survey, October 1983-September 1984, $85,000 per year.

The objective of this project was to quantitatively describe the sulfur sources which contribute to groundwater sulfate in strip mines situated in recharge zones and to determine the hydrogeochemical processes which control the sulfur path to the groundwater. Isotopic studies were to be employed to: 1) trace sulfur transformations among solid and aqueous species present throughout the sulfur cycle, 2) quantify the relative magnitude of each transportation as a contributor to groundwater sulfate concentrations, and 3) determine which transformations are affected by biological activity. The study was conducted at two active mine sites (Center and Gascoyne). Sulfur species present at various depths were to be identified and the sulfur isotopic ratios used to determine transformation paths. The presence and activity of sulfur-metabolizing microorganisms were also to be determined. Comparison of organism distribution and isotopic ratios would be used to determine the stages at which biological activity affects the sulfur cycle.

30. Hydraulic Characteristics of Aquifers and Confining Units into the Fort Union Formation. - T.B. Reed (USGS); funded by US Geological Survey, October 1983-September 1985, $30,000.

The objectives of this project were to: 1) evaluate the available methodologies appropriate for the *in situ* determination of hydraulic conductivity (or transmissivity), specific storage, and specific yield of fractured rock aquifers and for the determination of vertical hydraulic conductivity and specific storage of confining beds; 2) establish and execute a systematic procedure for the collection and analysis of data required for the determination of the hydraulic properties of the lignite and sandstone aquifers and confining beds; 3) examine the data for correlative relationships between lignite hydraulic conductivity and various physical or geologic parameters such as depth of burial or lignite bulk density; and 4) with those derived from pumping tests, to evaluate the validity of the slug test method for fracture rock and granular aquifers.

31. Application of Unsaturated Zone Monitoring and Modeling Techniques to the Determination of Groundwater Recharge. - W.F. Horak, Jr., (USGS); funded by US Geological Survey and ND State Water Commission, October1983-September 1986, $120,000; canceled after completing literature review.

The objectives of this project were to: 1) measure the hydraulic properties, including the functional relations of hydraulic conductivity and of matric potential to moisture content, for the major soil groups in the study area; 2) evaluate the areal variability of those data; 3) or variably saturated flow; 4) use the model to test the sensitivity of the flow system to variations in soil hydraulic properties and assumed boundary conditions; 5) collect the data required for use of the Penman combination method of estimating potential evapotranspiration (PET); and 6) make recommendations as to the optimum manner in which to interface the information output by the recharge and ET process model(s) with the groundwater flow model.

32. Hydrogeochemical Controls on the Mobility of Radiogenic Constituents in Uraniferous Lignite and Ash in North Dakota. - R.L. Houghton (USGS); funded by ND Public Service Commission and US Geological Survey, June 1983-September 1987, $110,000.

This project was to be conducted at eight abandoned mine and kiln processing sites in Billings, Stark, and Slope counties in North Dakota. The objectives were: 1) determination of the physicochemical conditions which promote the mobility of radiogenic, select trace metal, and other potentially hazardous chemical constituents from uraniferous lignite and its ash throughout the hydrologic system; 2) prediction of the mobility of these constituents at each of the abandoned mine sites in western North Dakota; 3) comparison of predicted and observed groundwater, pore-water, and surfacewater compositions affected by mine derived solutes; 4) development of reclamation methods which might limit hazardous waste mobility from the sites; and 5) evaluation of reclamation practices adopted by the North Dakota Public Service Commission to restore the sites to maximum safe usefulness. The study consisted of three phases. Phase 1 was designed to provide the geohydrologic and geohydrochemical data at all eight sites necessary to develop initial reclamation plans. Phase 2 was designed to determine the geochemical processes controlling radiochemical mobility in the hydrologic system. Three sites were selected for this purpose. In Phase 3 the transference value of information gathered in Phase 2 to the remaining phase 1 sites was to be assessed.

33. Development of a Hydrogeological and Hydrogeochemical Data Base for Abandoned Lands - Phase II - G.H. Groenewold (UND), E.C. Murphy, (NDGS), and R.D. Koob (NDSU); funded by the ND Public Service Commission, August, 1984 - February , 1986, $27,000.

The objective of this project was to ascertain why heavily salinized water in old mine spoils is not observed. This objective was to be achieved by distinguishing between two possible explanations for this phenomenon: 1) either there is minimal flushing, except in low topographic settings in the spoils or 2) there is extensive flushing and leaching of soluble constituents in all topographic settings in the spoils. The test site was an abandoned strip mine near Noonan, ND. Results from this study confirm the first explanation, namely that increased mineralization known to be associated with surface-mine spoils in North Dakota still resides within the ridge areas of the Noonan site, because of minimal flushing.

34. **Fundamental Studies of Coal-Bearing Strata. - D.J. Daly, H.J. Hartman, C.R. Schmit, N. Hunke (MMRRI); funded by MMRRI Allotment Grant and Philip McKenna Foundation, $100,000 per year.**

The objective of this project is to collect information on the characteristics and distribution of materials in the Paleocene coal-bearing sequences in western North Dakota and elsewhere, and study the nature of the depositional systems responsible for these sequences. The Hagel and Kinneman Creek coal seams at the Center Mine are being currently studied with respect to palynologic, petrogrpahic, chemical and combustion characteristics.

35. **Stratigraphic Evaluation and Entry of North Dakota Lignite Resource Data System. - C.R. Schmit, G.H. Groenewold, C. Bleth, A. Kuchera; funded by U.S. Geological Survey, $25,000 per year.**

The purpose of this project is to collect, evaluate and submit coal-related data for entry into the National Coal Resources Data System (NCRDS) which is developed and managed by USGS-Branch of Coal Resources. Data from Slope, Golden Valley, Billings, McKenzie, Hettinger, Adams, Stark, Morton and Grant counties has been collected.

36. **Ash Utilization in the State of North Dakota.- O.E. Manz, F.W. Beaver, D.J. Hassett, T. Johnson; funded by Electric Power Research Institute, United Power Association and Cooperative Power, June 1988 - December 1990, $185,327 per year.**

This project was designed to determine the structural and environmental suitability of using flyash as a replacement in Portland cement for use in highway construction. Possible impacts on groundwater were assessed by field monitoring as well as by conducting leaching studies in the laboratory. This project was used as a basis for the M.S. thesis in groundwater by Terry Johnson.

37. **The Effects of Flyash and Flue-Gas - Desulfurization Wastes on Groundwater Quality in a Reclaimed Lignite Strip Mine Disposal Site. - F.W. Beaver, G.H. Groenewold, O.E. Manz, D.J. Hassett (MMRRI); funded by U.S. Department of Energy and Baukol-Noonan Coal Mining Company, June 1980 - December 1990, $369,307 per year.**

The objectives of this study were to: 1) determine the concentrations and chronological history of chemical pollutants released from a flyash disposal site and flyash/alkali-FGD waste disposal site, 2) characterize the chemical and physical properties of the flyash, FGD waste, and soils at the disposal sites, and to relate these properties to pollutant concentration changes in groundwater as a function of time and monitoring well position, 3) evaluate the suitability of flyash and FGD waste disposal in the spoil V's, and 4) determine the alkaline-buffering capacity of disposal site spoil materials and identify the mechanisms of alkaline-leachate attenuation. The results indicated that groundwater at flyash disposal sites was high in pH, As, Se and Mo. FGW waste disposal sites showed increases only in SO_4 and some major cations in the groundwater.

38. **Western Flyash Research Development, and Data Center. - F.W. Beaver, D.J. Hassett, F.J. Stevenson and O.E. Manz, P. Kumarathasan, R. Steinke, and S. Steinwand, (MMRRI) and G.J. McCarthy (NDSU-Departments of Chemistry and Geology), funded by Cooperative**

Power Associaiton, Northern States Power, Otter Tail Power, Nebraska Ash, National Minerals Corporation, and Electric Power Research Institute, 1985, $90,000.

The Western Flyash Research Development, and Data Center (WFA RDDC) was established under the aegis of MMRRI in 1985. Its objective is to develop a comprehensive understanding of the efficient methods of disposal and utilization of coal-conversion residues such as flyash, bottom ash, and FGD waste.

39. **Solid Waste Codisposal Study. - G.H. Groenewold, D.J. Hassett, and D.E. Mauz (MMRRI), G.J. McCarthy (NDSU-Departments of Chemistry and Geology), funded by Gas Research Institute and Radian Corporation, June 1986 - December 1989, $177,431 per year.**

The objective of this project was to evaluate the advantages of codisposal of the combined waste streams of the coal gasification and electricity generating plants at Beulah, ND. By combining wastes with solid water, the overall leachability of the bulk material is reduced. The final report on this project has been completed, but the long-term leaching test still continues. A follow-up study "Hydration and Consolidation Reactions and Long-term Leaching in Codisposal Mixtures", has been undertaken to evaluate whether some trace and major constituents in solution will be affected by secondary-phase formation or other phenomena. Bulk ash samples have been analyzed for As, Be, Cd, Co, Cr, Cu, Mn, Mo, In, Pb, Sb, Se, V, An, Ti, Sr, and P. Selected minerological phases of ash samples were analyzed for So, P, Mo, As, Se, Ba, and Ti.

40. **Investigation of the Immobilization of Leachable Materials in Flyash. - D.J. Hassett, F.W. Beaver, funded by Northern States Power Company, September 1987 - April 1989, $60,000 per year.**

A previous study had shown that Se from flyash leached into groundwater. This project was designed to study how Se and other harmful trace elements could be immobilized from reaching the groundwater from disposal sites. The role of Fe and cement in reducing leachability of trace elements was also be studied.

41. **Ion Exchange and Soil Attenuation of Gulf Coast and Great Plains Disposal Site Sediments. - D.J. Hassett, G.H. Groenewold (MMRRI), funded by U.S. Department of Energy, September 1984 - September 1988, $189,567 per year.**

This project focused on trace-element attenuation and pH buffering properties of near-surface sediments from coal-conversion and solid waste disposal sites in the western coal-bearing areas of the U.S. Sampling sites were selected on the basis of key geological and climatic variables. Sediments were characterized with respect to their chemical, physical and minerological properties, including their alkaline-neutralizing and pH-buffering properties. Attenuation of selected trace-elements was studies in relation to concentration, ionic strength and pH. The concentrations of Cd, Pb and Hg were controlled by precipation mechanisms and occurred in the order Cd>Pb>Hg. The attenuation of these elements decreased as the pH decreased. But the attenuation of As, Se and Mo decreased with increases in pH. The equilibrium concentration of these elements were in the order Mo>Se>As.

42. **Ash Disposal Site Selection. - G.H. Groenewold, F.W. Beaver, D. Ronnei (MMRRI); funded by Montana-Dakota Utilities, November 1985 - August 1987, $75,246.**

This project was conducted to evaluate several potential ash disposal sites for the MDU's Heskett plant in Mandan, ND, which utilizes coal from the Beulah Mine. Geological and hydrological characterization of the sites was made, and these investigations formed the basis of the M. S. thesis by Dave Ronnei.

43. **Ash-Disposal Site Selection at Montana-Dakota Utilities' Coyote Station. - F.W. Beaver and G.H. Groenewold, N. Hunke (MMRRI), funded by Montana-Dakota Utilities, September 1987 - December 1988, $44,789.**

The objective of this project was to define the occurrence and flow of goundwater at a proposed disposal site and, using this and other information, to assess its suitability as an ash-disposal site. This study was used as the basis for an M.S. thesis by Nate Hunke. The study concluded that the proposed site was acceptable for disposal because the waste could be positioned above the saturation zone, thus reducing leachate generation, and the minerological characteristics of the site material were such that would attenuate the problematic trace elements.

44. **Groundwater Movement and Chemical Evolution from the Root Zone to the Water Table. - G.H. Groenewold, F.W. Beaver, R.D. Butler, D.J. Hassett; funded by U.S. Bureau of Mines, North American Coal Corporation, and Cooperative Power Association, 1989-1992, $1,404,862.**

The main objectives of this project were to: 1) evaluate the suitability of various types of abandoned surface mine sites for reclamation, 2) determine the optimum design of reclamation procedures, and 3) evaluate long-term impacts of current reclamation procedure on subsurface water quality and availability. This project was undertaken as a continuation of a previous study, "Development of a Hydrogeological and Hydrogeochemical Data Base for Abandoned Lands", and in combination with a complementary NDSU-LRRC project entitled "Surface and Root Zone Hydrology of Mined Lands". These studies were conducted at the Indian Head Mine, a location where the abandoned spoil area lies adjacent to both unmined and currently mined areas. The study was expanded to include the Velva Mine.

45. **Horseshoe Pit Hydrogeological Investigation. - F.W. Beaver, T. Johnson, E. Graney (MMRRI); funded by Minkota Power Cooperative, July 1988 - June 1989, $13,286.**

The objective of this investigation was to determine hydrogeologic conditions in the vicinity of "Horseshoe Pit" at the Center Mine which is being used for disposal of bottom ash, flyash and FGD sludge generated by the Milton R. Young Power Station. The information gathered indicated that the disposal pit has had little effect on the local hydrogeologic regime.

46. **BNI Lignite Test Program. - G.G. Mayer, D.J. Stepan, D.J. Hassett (MMRRI); funded by Minnesota Power, February 1989 - November 1989, $62,908.**

This project was conducted to examine the chemical characteristics of hot water-dried Baukol-Noonan lignite process water to determine options for removing chemical contaminants from the

waste water to satisfy effluent discharge criteria. The treatment options identified included the use of biological oxidation for the removal of biodegradable organics, granular-activated carbon for the removal of organics and color, and clinotilolite ion-exchange for the removal of ammonia.

47. **The Impacts of Agricultural Chemicals on Groundwater Quality in North Dakota. - F.W. Beaver, G.H. Groenewold, R.D. Butler (MMRRI); funded by U.S. Department of Agriculture, 1989 - 1991, $1,000,000.**

The objective of this project is to study the occurrence, transport and fate of selected agricultural chemicals in representative regions of North Dakota which include, Red River Valley, glaciated uplands, prairie pot-hole region and western rangelands. The NDSU-LRRC was subcontracted to carry out investigations dealing with the impacts on root zone hydrology.

48. **Regional Energy Policy Program for the Northern Great Plains. - D. Daly (MMRRI); funded by Department of Energy, August 1989 - July 1990, $50,000.**

The objective of this project was to facilitate the collection, development, and dissemination of information related to energy resources in the Northern Great Plains, that is consistent with, and supplemental to, developing federal energy policy. This program is intended to assist government and industry planners at the State level and will be developed with their input and cooperation.

49. **Fritz Mine Reclamation Project. - R.D. Butler, F.W. Beaver (EERC/MMRRI); funded by North Dakota Public Service Commission, April 1990 - February 1991, $ 8982.**

The objective of this project was to conduct drilling and sampling at the Fritz Mine (an abandoned mine south of Belfield, ND, containing uraniferous lignite waste and spoils) to identify the base of the spoils, and to determine the pH, conductivity, and radiation levels in the material. The data was used to prepare a map of the mine showing areas of high radiation levels (high risk spots for reclamation work). This study helped to develop and execute appropriate reclamation plans for the site.

50. **National Mine Land Reclamation Center: Research Program for the Western Region. - R.D. Butler, F.W Beaver, G.H. Groenewold D.J. Hassett (EERC/MMRRI, 1988-1993); J.A. Harju, H.J. Foster, D.J. Hassett, Jaroslav Solc (EERC/MMRRI, 1993-95); funded by U.S. Bureau of Mines under subcontract to West Virginia University, 1988-1995.**

As one of the three regional centers of the National Mine Land Reclamation Center (NMLRC), the University of North Dakota's Energy and Environmental Research Center (EERC) has also been involved in the following projects, either directly or by subcontracting with the NDSU- Land Reclamation Research Center:

ND01: Surface and root zone hydrology of mined lands; at the Indian Head and Velva Mines; subcontracted to NDSU-LLRC.

ND02: Groundwater movement and chemical evolution from root zone to the water table; at the Indian Head, Velva, and Fritz mines.

ND03. Stabilization of underground mine voids by filling with coal conversion residual materials; at the Wilton Mine.

ND04. Modeling soil water status of mine land profiles; at the Indian Head and Velva mines.

ND05. Wetland hydrology of mine lands; at several North Dakota mines; with NDSU-LRRC.

ND06 Diagenesis and leaching characteristics of aged coal conversion residues from mine disposal settings; at several North Dakota mines.

B. MINE LAND SOILS AND AGRICULTURAL PRODUCTION

Research on the agricultural aspects of reclamation of surface mined lands in North Dakota was first seriously initiated in 1970 by the USDA-ARS, Northern Great Plains Research Center at Mandan, ND, with some collaboration provided by the USDA-Soil Conservation Service. In 1974 the Soils Science Department of the North Dakota State University (NDSU) started a reclamation research program of its own, which was conducted in close cooperation with the USDA-ARS group. On July 1, 1981, NDSU established the Land Reclamation Research Center (LRRC) as a separate administrative unit of the North Dakota Agricultural Experiment station with laboratories and offices at Mandan, ND. With this development, and due to some policy changes, the actual field involvement of USDA-ARS in reclamation research ceased in 1985. Now, after several years of vigorous involvement in the soils and agronomic aspects of reclamation research, the NDSU-LRRC facility completely closed down in September 1996.

From 1970 to 1982 the USDA-ARS annual budget for conducting reclamation research was approximately $250,000. The NDSU reclamation research program for 1974-1976 was funded by a grant of $300,000 from the Old West Regional Commission, and for 1976-1977 by the North Dakota Agricultural Experiment station. From 1977 to 1985 the reclamation research program of NDSU was funded by the Energy Development Impact Office, with moneys from the Coal Severance tax, at a rate of $250,000 to $300,000 or more per year. Additionally, a grant of about $40,000 per year for a period of six years (1974-1981) was received by NDSU through a tri-state EPA project, and another grant of slightly less than $40,000 per year for a period of about four years (1978-1982) from the Falkirk Mining Company. Based on this information, approximately six million dollars ($6,000,000) were spent by the USDA-ARS (1970-1982) and NDSU-Soils Department/LRRC (1974-1985) on reclamation research during the time frames shown. From 1985 to 1995 the NDSU-LRRC received research grants from the state, the lignite industry, and the federal government, totaling a sum of about five million dollars ($5,000,000). Thus, the total amount of money spent in North Dakota on agricultural aspects of reclamation research is estimated to be about eleven million dollars ($11,000,000).

Information on the reclamation research projects conducted by USDA-ARS and NDSU-Soils Department/LRRC, either jointly or independently, has been summarized in the following pages. The USDA-ARS scientists involved in some of these projects included: R.E. Barker, A. Bauer, A.D. Berdahl, A.L. Black, J.J. Bond, E.J. Doering, A.B. Frank, L. Hofmann, R.J. Lorenz, S.D. Merrill, J.F. Power, G.A. Reichman, R.E. Ries, F.M. Sandoval, W.D. Willis, and A.C. Wilton. The NDSU staff, working at the LRRC, Mandan, or in the various departments of the university at Fargo, who were actively involved in the agricultural aspects of reclamation research included: T.H. Brown, F.S. Carter, H. Carvallo, E.C. Doll, G. Gee, J. Gilley, G. Halvorson, D.R. Kirby, K.J. Lang, S. Melsted, M.P. Miller, M. Nathan, P. Nyren, H.W. Omodt, D.D. Patterson, M. Pole, J.L. Richardson, F. Schroer, S. Schroeder, P.P. Sharma, C.M. Smith, K.C. Vining, W. Whitman, N. Wollenhaupt, and L. Zimmerman.

In the first three years of its existence, the NDSU-LRRC research program included the following four major projects :

4523. Chemical and physical characteristics of shaped mined lands and their effects on plants.

4524. Surface and root zone hydrology of shaped surface mined spoil bank and rehabilitated land.

4525. Plant establishment and culture on surface mined lands.

4529. Evaluate surface and groundwater problems associated with potential stripmine sites.

These projects were replaced by new projects (Projects 6101, 6102, and 6103 - supported by state appropriated moneys; and Projects 5801, 5802, and 5805 - supported by different grants). Some of these projects were initiated as of July 1, 1983 and others much later. In 1989, Senate bill 2005 of the Fifty First Legislative Assembly specified that funds appropriated to the NDSU-LRRC for reclamation research be used for the following purpose:

- development of criteria for evaluating reclamation success for bond release based on vegetative reestablishment and soil parameters,
- effect of postmine topography on soil moisture levels and crop yield,
- effect of reclamation techniques on soil compaction and soil productivity,
- methods of evaluating and controlling runoff and erosion from reclaimed lands.

A brief description of each project or study related to the agricultural aspects of reclamation research is given below.

1. **Soil, Overburden, and Spoil Characterization. - USDA-ARS and NDSU-Soils Department Staff.**

This research involved several studies which were conducted to evaluate the physical and chemical characteristics of soils, overburden, and spoil materials for development of better understanding of the problems encountered in reclaiming the surface mined lands in North Dakota. Various soil and overburden related factors restricting revegetation of mined areas were identified. Together with the profile characteristics of important agricultural soils, this research led to the development of criteria for the suitability/unsuitability of topsoil, subsoil, and overburden materials. Several improved methods for the analysis of spoil and overburden materials were developed. The effects of various drilling mud and water qualities on the chemical analysis of overburden samples were also determined. This research established that basically most spoil materials in the coal mining areas of North Dakota are fine textured with moderate to high levels of sodicity and salinity.

2. **Initial Evaluation of Nutrient Characteristics of Reclaimed Land. - USDA-ARS and NDSU-Soils Department Staff.**

Spoils within the Fort Union group of North Dakota and the Northern Great Plains were found to be extremely low in phosphorus. Available nitrogen in spoils varied considerably, depending on age of the exposed spoils. Later work showed that ammonium-nitrogen contained in Fort Union shale became nitrified when exposed to the atmosphere after mining. This resulted in increased available nitrogen in spoils of 1-5 years of age, after which available nitrogen content became less, and positive responses to nitrogen fertilization were observed. The problems of nutrient deficiencies and toxicities in strip mined lands in semiarid and arid areas were also addressed.

3. **Comparison of Topsoil Spreading and Application of Gypsum for the Reclamation of Mine Spoils with Wide Variation in Sodicity. - USDA-ARS Staff.**

In this study, conducted at four western North Dakota mine sites, the effects of 12 inches of respread topsoil, with or without gypsum (10 tons per acre), on the growth of crested wheatgrass were evaluated. The spoil materials varied in sodicity (SAR 1,11,12, & 27). The effect of summer fallowing was also studied. Forage yields, averaged over four years, were increased by topsoiling especially where sodic conditions were greatest. Yield increases from gypsum application occurred in non-topsoiled treatments on moderately sodic spoil and in topsoiled treatments on the most sodic spoil site. The 12-inch thickness of topsoil was definitely not enough for maximum yields at the highly sodic site, and was probably suboptimal at the 2 moderately sodic sites. Topsoil placement was considerably more effective for increasing crop productivity than was gypsum application. Summer fallowing was generally not effective for lowering sodium levels in spoil, or in topsoil in contact with sodic spoil. Considerable sodium migrated into the lower 6 inches of respread topsoil at the sodic spoil sites.

4. **Chemical Reclamation Procedures for High-Sodicity Mine Spoil. - USDA-ARS Staff.**

The theoretical and the practical aspects of chemical reclamation of highly sodic mine spoil with calcium chloride solutions were studied. Laboratory permeability measurements demonstrated that solution concentrations approaching at least 0.2 N would be required to restore a level of hydraulic conductivity to impermeable spoil of western North Dakota to permit reasonably rapid chemical reclamation. Laboratory tests also demonstrated that incorporation of gypsum into such mine spoils, or use of saturated gypsum solution, was inadequate because of the limited solubility of this amendment. A field demonstration using calcium chloride to reclaim five feet of high-sodicity mine spoil was carried out. Based on the need for displacement of a zone of high salt concentration (generated by this type of chemical reclamation) away from the soil surface, it was calculated that the cost of reclamation with calcium chloride would be as great as saving and respreading 5 feet of soil materials over mine spoils. However, the high salt technique may be useful for situations where surface soil is not available.

5. **Cation Exchange Equilibria of Mine Spoil Material Over an Extended Range of Total Soluble Salt Concentrations. - USDA-ARS Staff.**

Studies of sodium-calcium exchange with a fine textured, montmorillonite-dominated spoil, typical of western North Dakota were conducted with the following conclusions: 1) this spoil

material exhibited approximately the same cation exchange coefficient at lower salt concentrations as the average value of a set of agricultural soils described in the literature. Thus, ESP of spoil can be inferred from SAR for SAR values up to at least 20. 2) As total salt concentration increased from 0.04 to 1.06 N, the exchange coefficient decreased from 0.0163 to 0.0085 $(mmol/liter)^{1/2}$. 3) The reduction in the magnitude of the exchange coefficient as salt concentration increases causes the exchange efficiency to increase, i.e. a greater percentage of the applied calcium amendment will displace sodium than would be predicted if USDA Handbook 60 value were applied for high salt concentration.

6. Initial Restoration of Productivity by Soil Material Replacement. - USDA-ARS Staff.

In this study the effects of topsoil and subsoil respreading on the yield of several crops were evaluated. Yields of crested wheatgrass, wheat, alfalfa, and warm season grass were found to increase as the total soil thickness (topsoil plus subsoil) was increased to 3 - to 5 - feet depth. The highest yields obtained in this study equaled or exceeded yields which would be expected on similar undisturbed soil types under good management in the same county and with similar precipitation. In most instances, over 90% of the maximum yields observed were obtained when 28 inches of subsoil plus 8 inches of topsoil covered sodic spoils (SAR, 25; clay, 38%). Yields from 24 inches of topsoil were similar to those from 8 inches of topsoil. Without topsoil, the only crop to produce over 75% of maximum expected yield for similar soil types was native grama grass. All species tested produced 90% of the maximum expected when at least 3 feet of the mixed subsoil/topsoil were replaced over spoil except for wheat which yielded only 80% of the maximum expected. Water was extracted by the crops from the upper 1 to 3 feet of spoil when the soil - spoil interface was within 3 feet of the soil surface. Thickness of topsoil had no influence on depth of water extraction. There was no evidence of any accumulation of soil water just above the soil - spoil interface under any situation.

7. Runoff and Erosion Characteristics of a Revegetated Surface Mined Site in Western North Dakota. - NDSU-Soils Department staff.

The objective of this study was to evaluate erosion and runoff potential and their control on mined lands. Bare soil lost 200 percent more sediment than conventional grain harvested systems. One-half ton straw mulch reduced sediment losses by 66 percent. Runoff was smallest from the mulch and conventionally harvested plots.

8. Establishment of Forage Species on Reclaimed Lands. - USDA-ARS and NDSU-Soils Department Staff.

A study to evaluate the ability of 36 forage species or varieties to establish on mine spoil and mine spoil covered by 6 inches of topsoil was initiated in the spring of 1974. In general, plant establishment was better where spoils were dressed with topsoil. Species usually recommended for dryland seedings (wheatgrasses and wildryes) provided the best stands and had the highest forage yields. Warm-season species were very difficult to establish.

9. Species Response to Salt Levels and Spoil Textures. - USDA-ARS Staff.

Plant species responded differently to similar salt levels and ionic concentrations. Stage of plant development also was important in how plant species responded, with the greatest effects apparent during the period of emergence and stand establishment. Responses during the period of vegetation growth were complex, with some plant species affected by both salt level and kind of salt, and other plant species being tolerant to both these variables. Differences in plant species response to medium and fine textured spoil materials were also observed.

10. Use of Point Frame Quadrat to Estimate Cover on Reseeded Grazing Land. - USDA-ARS Staff.

Canopy and ground cover under four grazing intensities of reclaimed land were measured with point frame quadrats located by line transects and oriented diagonally, parallel, or perpendicular to seeded rows, or randomly located and placed parallel with the rows. There were no differences (P=.05) due to quadrat orientation. The point frame quadrat technique was an easy, reliable method for determining vegetation canopy and basal cover.

11. Effect of Thickness and Quality of Returned Subsoil upon Crop Yield and Soil Water Content. - S.D. Merrill, R.E. Ries, J.F. Power (USDA-ARS).

Field studies were conducted at the Indian Head mine to determine the effects of quality and thickness of subsoil (with uniform layer of topsoil over subsoils) respread on sodic spoils on the production of spring wheat, Russian wildrye and crested wheatgrass. The effects of subsoil quality were found to depend on the crop type, topographic position, and precipitation. Grain yield of spring wheat was highest on plots with saline (EC 7 mmhos/cm) subsoil having high water holding capacity, while forage yields of Russian wildrye and crested wheatgrass were higher on plots with nonsaline subsoil of lower water holding capacity. Topographic position affected wheat yields considerably less than the forage yields of the grasses. Forage yields were less affected by subsoil quality in the year of abundant precipitation. Crested wheatgrass gave highest yields at total soil thicknesses of 20 to 32 inches, and spring wheat at soil thicknesses of 35 to 43 inches.

12. Effects of Topsoil Depth on Crop Production. - G.A. Halvorson, S.W. Melsted (NDSU-LRRC).

The objectives of this study, conducted at the South Beulah and Falkirk mines, were to: 1) determine optimum depth of topsoil required for reclamation of salt and nonsalt affected spoils, and 2) determine whether the second lift is required for reclamation of nonsalt affected spoils. On moderately sodic spoils (South Beulah), crop yields were found to improve considerably when 12 inches of topsoil was replaced as compared to only 2 inches of topsoil. Increasing topsoil thickness to 24 inches increased crop yields only slightly over that obtained with 12 inches of topsoil. On medium to fine textured nonsodic overburden (Falkirk), poor responses to topsoil thicknesses greater than nine inches were obtained. On sandy spoils (Falkirk) addition of 27 inches of topsoil improved yields over that of 9 inch topsoil only. Addition of subsoil to 27 inches of topsoil did not significantly improve yields.

13. Effect of Thickness of Soil Over Sodic Mine Spoils on Water and Nitrogen Movement and Use. - S.D. Merrill, J.F. Power, S.J. Smith (USDA-ARS).

The objectives of this study were to: 1) monitor water, nitrate, and bromide movement through reconstructed soil-spoil profiles as affected by time after fertilizer application and the thickness of respread soil, and 2) determine the fate of surface-applied fertilizer nitrogen as a function of soil thickness and time. Results showed that nitrogen usage by crested wheatgrass growing poorly in plots with 10 inch layer of topsoil was similar to that observed for plants growing adequately in plots with 40 inch layer of topsoil. However, the poorly growing, water-stressed plants absorbed greater proportion of applied nitrogen from close-to-the-surface layers of soil. A link between water stress and nitrogen uptake was inferred.

14. Physicochemical Mechanisms Involved in Sodium Migration in Topsoiled Mine Spoils. - S.D. Merrill, E.J. Doering, J.F. Power, F.M. Sandoval, (USDA-ARS).

The objectives of this project were to: 1) assess the relative importance of various mechanisms involved in the migration of sodium from mine spoil into overlying topsoils, 2) simulate processes occurring in the field in laboratory column experiments, and 3) evolve appropriate mathematical models of salt and water flow and apply these models to column experiments and selected field results. Column experiments using a sodic mine spoil with two texturally different types of topsoils demonstrated that sodium movement from spoil with the overlying soil material was driven by a concentration gradient and followed the slow kinetics of diffusion process.

15. Sodium and Salt Movement in Reclaimed Soils. - G. Halvorson, E.C. Doll, K.J. Lang, N.C. Wolleuhaupt (NDSU-LRRC.

Old tests plots, established at the Indian Head and Glenharold mines several years back, were sampled to evaluate the movement of salts that had occurred in their profiles. Intact cores were removed and cut into sections. Saturation extracts of these samples were analyzed for Ca, Mg, Na, Cl, CO_3, HCO_3, pH, and EC. SAR values were also calculated. Some leaching of salts below the surface was noted to have occurred at some topsoiled as well as nontopsoiled sites. In some cases, Na had moved into the replaced topsoil. With greater depths of topsoil, the quantity of Na moving into the topsoil had also increased. Where no topsoil was replaced, some leaching of Na, Ca, and Mg had occurred.

16. Moisture Levels and Changes in Reshaped Mine Land Soils. - S.A. Schroeder (NDSU-LRRC).

Studies were conducted at the Center, Glenharold, Indian Head and South Beulah mines to: 1) measure variations in total soil water over time for determining total soil water changes within the profiles of reshaped spoils, vegetated spoils, and native grassland sites, 2) determine if water percolated deeper than 244 cm, and 3) correlate characteristics of the spoil/soil sites and nongrowing season precipitation effects on soil water recharge. Monitoring over a 7 year period (1974-1981) indicated that little, if any, water percolated beyond the rooting zone (0-122 cm) at either the spoil or undisturbed grassland sites. Total soil water below the rooting zone decreased over time, presumably due to evapotranspiration. The spoil sites contained more total soil water in 1974 than the undisturbed sites but greater evapotranspiration losses at the spoil sites decreased soil water to a level nearly equal to that of undisturbed sites by 1981.

17. Factors Affecting Efficient Water Use by Crops. - S.A. Schroeder (NDSU-LRRC).

Field experiments were conducted at Center, Glenharold, Indian Head and South Beulah mines to determine the effects of topsoil depth and fertility on water use efficiency. The water use efficiency of corn silage was significantly greater for topsoil depths of 12 inches or more, and of wheat at topsoil depths of 6 inches or more as compared to shallower than 23 and 6 inches, respectively. A beneficial effect of nitrogen fertilizer on water use efficiency was observed for corn silage in two out of five years, and none for wheat.

18. Tillage Effects on the Physical Properties on Prime, Nonprime, and Reclaimed Soils. - S.A. Schroeder, G.A. Halvorson (NDSU-LRRC).

This study was conducted at the Center and South Beulah mines to: 1) determine effects on physical properties such as bulk density, water-stable aggregates, and water infiltration, 2) determine best management practices for reclaimed soils to promote better water infiltration and soil water recharge, and root penetration.

19. Productivity of Prime, Nonprime and Reclaimed Soils in Western North Dakota. - S.A. Schroeder, G.A. Halvorson F.S. Carter, E.C. Doll (NDSU-LRRC).

Greenhouse and field studies were conducted to determine the productivity of prime, nonprime, soil mixtures, and reclaimed soils. The greenhouse experiment was conducted with soil materials collected from the Freedom mine near Beulah, ND and the field experiments were conducted at the Center and South Beulah mines. The results of these experiments suggest that separate removal and segregation of soil materials from prime and nonprime lands may not be necessary for optimum reclamation. Instead, such factors as 1) chemical and physical characteristics of soil materials, and 2) restoration of a post-mine topography which includes "primeland areas" in which soil moisture levels similar to those in prime soils can develop are more critical for post-mining development of prime farmlands.

20. Amelioration of Overburden Compaction With Time. - G.A. Halvorson, S.A. Schroeder, F.S. Carter, (NDSU-LRRC).

In this study, bulk density changes over time in overburden materials from the Falkirk mine were determined. By compacting overburden materials, bulk density value initially increased but with time the bulk density of these samples decreased to a level comparable to the samples which had not been compacted. In situations where overburden was disturbed and replaced without compaction, the bulk density values were initially less than the adjacent undisturbed site, but the values increased over time to approximately the same level as found in the undisturbed site.

21. Nitrogen, Phosphorus, and Zinc Fertilization of Reclaimed Land. - G.A. Halvorson, (NDSU-LRRC).

Field experiments were conducted at several mine sites in western North Dakota to evaluate the effects of nitrogen, phosphorus, and zinc fertilizers on the yields of crops grown on reclaimed land. Responses to nitrogen and phosphorus were generally variable and small. Lack of adequate moisture, and nitrification of native ammonium in stockpiled soils were given as possible reasons for low crop responses to nitrogen. Phosphorus fertilization was found to influence the species composition of reclaimed pastures. No significant responses to zinc were observed.

22. Moisture Relationships Under Continuous Cropping and Fallow. - G.A. Halvorson (NDSU-LRRC).

This study was conducted on undisturbed land at Falkirk Mine to determine the effects of continuous cropping and fallowing on the yields of wheat, oats, barley, sunflower, and corn. Wheat yields were about 50% higher on fallowed soil than on continuously cropped soil. Yields of corn silage, sunflower, barley, and oats were about 20% higher on follow soil.

23. Establishment of Range Plant Species on Disturbed Land Using Supplemental Irrigation. - R.E. Ries, R.F. Follett, F.M. Sandoval, J.F. Power (USDA-ARS).

This study was conducted at the Gascoyne mine to: 1) evaluate amounts and frequencies of irrigation most beneficial in establishing range plant species, 2) monitor successional trends of stands established with supplemental irrigation, and 3) evaluate seeding date effect on range plant establishment. The results indicated that the use of irrigation to supplement natural precipitation can help rapid and successful establishment of perennial plants, permit late planting, and provide some means of controlling final species composition in newly established stands.

24. Supplemental Irrigation with Different Water Qualities and Quantities to Insure Vegetation Establishment After Mining. - R.E. Ries, J.F. Power, F.M. Sandoval, (USDA-ARS).

This study was conducted at the Gascoyne mine to: 1) evaluate the effects of different qualities and quantities of irrigation water on vegetation establishment, 2) evaluate initial soil salinity levels and changes caused by different qualities and quantities of irrigation water, and 3) explore the possibility of irrigation as a waste water disposal technique. The results indicated that irrigation with waters of 3-4 mmhos/cm EC to vegetation growing on rapidly permeable soil-spoil profiles caused no adverse effect and was rather beneficial. Salt accumulation was observed at a depth of 14-20 inches in the soil-spoil profile from both natural leaching and the addition of poor quality water.

25. Water Requirements for Range Plant Species Establishment in Monocultures. - R.E. Reis, A.B. Frank, A.L. Black, A. Bauer, (USDA-ARS).

This study was conducted at Mandan, ND to study the water requirements of blue grama, crested wheatgrass, sideoats grama and Russian wildrye. A rainout shelter which provided for automatic closure and control or elimination of natural precipitation was constructed for the purpose of this study. The objectives were to: 1) determine the quantity of water needed by each species, 2) determine when water is needed, and 3) investigate the reasons for differential requirements of water for the establishment of different species.

26. Prairie Hay as a Seed Source for Revegetation. - R.E. Ries, L. Hofmann, (USDA-ARS).

This project was conducted to: 1) provide an evaluation of the value of prairie hay as a seed source for revegetation, 2) evaluate the effects of harvest date range condition, and yearly climatic variations on the kind and number of seeds present in prairie hay, 3) evaluate effects of storage time of prairie hay on the number of establishing seedlings, and 4) evaluate techniques for rapid and workable method of estimating kind and number of potential seedlings in various lots of

prairie hay. The results indicated that prairie hay has potential to increase community diversity, provide a supplemental seed source when mulched along with seeded desired species, supply seed not commercially available, and to establish plant communities readily able to undergo ecological succession. Storage of prairie hay for one year did not reduce the number of possible seedlings that could be obtained from the same hay lot without storage.

27. Runoff and Erosion Studies. - S.A. Schroeder, K.J. Lang (NDSU-LRRC), L. Prunty (NDSU-Soils Department), L.A. Disrud (NDSU-Agricultural Engineering Department).

Laboratory and field studies were conducted to evaluate erosion and runoff potential of stockpiled topsoils and reshaped spoils. The study with stockpiled topsoils was conducted in laboratory using simulated rain fall technique, and evaluated the effects of slope steepness, mulch rate, and antecedent soil moisture on runoff, splash, soil loss in runoff, and the primary particle composition of soil in splash and sediment from interrill areas on topsoils collected from stockpiles at the Falkirk and Indian Head mines. Erodibility ratio index for these soils was developed. Field studies are being conducted on reshaped spoil plots established at the Center mine. Effects of simulated rainfall (dry and wet runs) on run off, and erosion from chiseled and fallow plots are being studied.

28. Evaluation of Cover Factor on Mined and Nonmined Grassland as Related to Runoff and Soil Erosion. - L. Hofmann, R.E. Ries (USDA-ARS), J.E. Gilley (NDSU-Soils Department).

A simulated rainfall study was conducted on nonmined and reclaimed mined land near the Center mine to determine the relationship of ground cover factors to runoff and soil loss. Both foliage cover and ground cover were found to be related to runoff and soil loss. In both cases total cover (live plants plus litter) or, alternatively, bare soil were better related to runoff and soil loss than either live plant cover or litter cover alone. Reclaimed areas and native range areas had similar runoff and erosion characteristics. It was found that adequacy of soil protection can be best estimated by percentage of bare soil.

29. Grazing Reclaimed Mine Land. - L. Hofmann, R.E. Ries, R.J. Lorenz (USDA-ARS).

This study was conducted on nonmined and reclaimed mine land near the Center mine. The objectives were to: 1) determine the effects of grazing intensity of reclaimed mined land on grass survival and productivity, soil stability, and animal performance, and 2) develop methodology to perform the above measurements. Under light, moderate, and heavy grazing intensity, both the reclaimed land and the reestablished vegetation were found to be stable. Vegetation and beef production on the reclaimed pastures responded similar to the vegetation and beef production on nonmined land in the same general area.

30. Comparison of Season Long Grazing of Cool-Season Introduced Grasses with Native Pasture. - L. Hofmann, R.E. Ries (USDA-ARS).

This study was initiated in 1980 at Mandan, ND to: 1) compare the seasonality of grazing for cool-season introduced grass pastures versus native grass pastures, and 2) document the beef gain or loss of steers grazing these pastures season long. Steers on smooth brome pastures and native pastures gained 110 pounds per head. Steers grazing native pasture at 1/3 the stocking rate gained

100 pounds per head. Steers on Russian wildrye gained 60 pounds per head. Vegetation production and utilization were also studied.

31. Effects of Phosphorus Placement on Crop Growth and Phosphorus Availability on Coal Mine Spoil Material and Effects of Soil and Mine Spoil Characteristics on Phosphorus Availability. - G.A. Reichman, A. Bauer, (USDA-ARS).

The objectives of this study were to: 1) evaluate the effects of chemical properties, moisture levels, and physical characteristics of mine spoils on phosphorus availability during the equivalence of a cropping season, and 2) to evaluate the effects of placement depth of phosphorus and soil characteristics on the growth and quality of crops. Laboratory incubation studies and field experiments were also conducted.

32. Effect of Salt Concentration on Sodium Exchange. - E.J. Doering (USDA-ARS).

The objective of this project was to determine the relationship between ESR and SAR as affected by a wide range of salt concentrations. A number of spoil and soil samples collected from North Dakota, Montana, and Wyoming were studied.

33. Water Transmission Properties of Reconstructed Mine Soils. - S.D. Merrill, E.J. Doering (USDA-ARS).

This project concentrated on laboratory measurements of unsaturated and saturated hydraulic conductivities of undisturbed core samples of soils and spoils. The objectives were to evaluate water transmission, storage, and release characteristics of topsoil-spoil profiles as affected by quality of topsoil and spoil.

34. Collection and Evaluation of Western Wheatgrass and Blue Grama for Reclaimed Lands. - R.E. Barker, J.D. Berdahl (USDA-ARS), E.T. Jacobson (USDA-SCS).

The objectives of this project were: 1) to collect local ecotypes of western wheatgrass and blue grama, and 2) to conduct initial evaluations for their potential for reclamation use. Five vegetative samples were made at over 1040 sites for each grass species in 1977. Plants were established at Mandan in 1978 and 10% of the most desirable western wheatgrass plants were selected for breeding populations in 1979. Criteria included spread and density of stand, plant color, disease resistance, and general appearance.

35. Long Term Productivity and Water Use Efficiency of Perennial Forage Grasses on Mine Soils. - S.D. Merrill, R.E. Ries (USDA-ARS).

This study was conducted at the Center, Glenharold, Indian Head and South Beulah mines. The objectives are: 1) to compare long term productivity of perennial grass stands on regraded mine spoils with or without topsoil, 2) to study the interaction of nitrogen fertilization and water use efficiency, and 3) to examine the components of water use efficiency. Measurements of biomass, leaf area index, density, forage quality, nutrient uptake, and soil nitrogen will be made periodically.

36. Seasonality of Use of Reclaimed Grazing Land. - L. Hofmann, R.E. Ries, J.F. Karn (USDA-ARS).

The objective of this project was to evaluate the seasonality of grazing use on mined lands reclaimed with cool-season grass species and compare it with that on unmined native grazing land. Animal performance on the two types of lands will also be evaluated. Species preference and the effects of season-long grazing on the cool-season introduced grass species will be determined.

37. Soil Development and Stability on Reclaimed Mine Lands. - N. Wollenhaupt, S. Schroeder, G. Halverson, E.C. Doll, (NDSU-LRRC), J.L. Richardson (NDSU-Soils Department).

The objectives of this project were: 1) to characterize soil forming processes in reclaimed mine soils in relation to soil and spoil materials, topography, and disruptive effects of reclamation, and 2) to measure and predict topographic stability of reshaped mine spoils.

38. Management and Water Relations of Reshaped Mine Lands. - S. Schroeder, G. Halverson, N. Wollenhaupt, F.S. Carter, E.C. Doll (NDSU-LRRC, Project 6102), L.D. Prunty, L.J. Brun (NDSU-Soils Department).

The objectives of this project were to: 1) measure runoff and erosion from reshaped mine soils by use of a rainfall simulator, 2) study moisture recharge and use by crops on reshaped mine spoils as related to soil factors, tillage methods, and cropping systems, and 3) determine the effects of supplemental irrigation on crop yields and root zone hydrology in reclaimed soils. The study was initiated in 1986 at the Center and Falkirk mines. Topographic position was found to have a significant effect on available water and wheat yield, both being higher at the down slope positions. Soil loss and basal cover (inversely bare surface) showed good linear relationship, allowing a simple first estimate of cover needed to meet regulatory requirements for soil erosion by water.

39. Vegetation Reestablishment on Reclaimed Lands. - G. Halvorson, S. Schroeder, N. Wollenhaupt, F.S. Carter, K. Long, E.C. Doll (NDSU-LRRC), E.J. Deibert, R.J. Goos (NDSU-Soils Department).

The objectives of this project were to: 1) relate the depth of first and second lift materials (topsoil and subsoil) needed for optimum plant production and revegetation to the chemical and physical properties of the underlying spoil, 2) relate plant growth to movement of soluble salts and diffusion of sodium in replaced soil and underlying spoil materials on strip mined areas and to soil contaminated by salt spills during oil development, and 3) survey the chemical and mineralogical composition of overburden materials to determine their suitability as plant growth materials.

40. Site - Specific Land Reclamation Systems. - E.C. Doll, G. Halvorson, S. Schroeder, N. Wollenhaupt, S.C. Carter (NDSU-LRRC), J.L. Richardson, D.D. Patterson (NDSU-Soils Department), W.C. Nelson, J.A. Leitch (NDSU-Agricultural Economics Department), W.T. Barker, G. Clambey (NDSU-Botany Department).

The objectives of this project were to: 1) develop models to relate crop yields and vegetative reestablishment to precipitation, soil moisture, pertinent soil chemical and physical measurements,

and topographic location, 2) develop site - specific recommendations for least-cost reclamation procedures to attain desired crop yield and revegetation levels, and 3) utilize the information obtained from objectives 1 and 2 above to formulate site - specific postmining land use alternatives.

41. Relation of Compaction and Soil Physical Parameters to Productivity of Reclaimed Soils. - S.A. Schroeder, K.C.Vining, (NDSU-LRRC Project 5801).

This study was conducted at the Center and Coteau Mines (initiated in 1987) and the Beulah and Glenharold Mines (initiated in 1989) to study 1) the effects of deep tillage on bulk density, root development, and forage/small grain yields, and 2) the effects of root growth and climatic factors on compaction and soil physical parameters by analyzing soil reclaimed over a period of years. Tillage treatments, consisting of chiseling, ripping with a grader, and deep ripping, were applied to subsoil and topsoil at the first two mines, and to the topsoil only at the two other mines. Wheat yields were affected significantly by topsoil tillage treatments in three out of eight plot years. Forage yields remained unaffected. Bulk density of topsoil decreased with time but that of subsoil increased because of settling.

42. Surface and Root Zone Hydrology of Mine Lands. - P.P. Sharma, F.S. Carter, K.C. Vining, G.A. Halvorson, (NDSU-LRRC Project 5802).

This project, funded by Bureau of Mines through the National Mine Land Reclamation Research Center, aimed to quantify surface and root zone factors that affect infiltration, movement, and retention of water in soil profiles of similar landscape location on undisturbed, reclaimed, and AML settings. Soil water distribution, precipitation and micrometeorological data collection began in 1989 at the Indian Head Mine and in 1991 at the Velva Mine. Water infiltration capacity of the undisturbed soils with permanent vegetation was highest and that of the reclaimed soils least. A lack of macropores and low permeability of the micropores in the reclaimed soils accounted for this difference. In the abandoned minelands some recharge of water to deeper soil depths occurred at depressions underlain with non-sodic spoil.

43. Wetland Hydrology of Minelands. - P.P. Sharma, F.S. Carter, J.L Richardson, (NDSU-LRRC Project 5805).

This project, funded by Bureau of Mines through the National Mine Land Reclamation Research Center, was initiated in 1992 to study the hydrology and groundwater recharge potential of natural wetlands, wetlands created under SMCRA, and wetlands formed in AML settings. The study sites were located at the Velva and Indian Head mines.

44. Soil Development on Reclaimed Minelands. - G.A. Halvorson, M.V. Nathan, F.S. Carter, (NDSU-LRRC, Project 6101, a continuation of the project listed above at No. 37).

The objectives of this project were to 1) determine the relationship between the reestablishment of soil properties disrupted by mining and restoration of productivity, and 2) characterize soil forming processes in reclaimed soils. The essential focus was to make a comparative evaluation of productivity of prime and non-prime soils, and to determine the physical properties of reclaimed prime and non-prime soils. Monitoring of physical properties of prime and non-prime soils was

started in 1986 and followed through 1992. Additional field test plots were established at the Freedom and Falkirk mines in 1992. Some significant changes in bulk density and infiltration of reclaimed soils were noted after six years of reclamation. From the field plot experiment at the Freedom mine, it was noted that Zahl soil produced less plant dry matter and grain compared to Bowbells and Williams soils. However, significant interactions were observed between soil and land type (crop and range) and between soils and sites (prime and non-prime locations).

45. Vegetative Reestablishment of Mined Lands. - G.A. Halvorson, F.S. Carter, M.V. Nathan, (NDSU-LRRC, Project 6103; a continuation of the project listed above at No.39).

This project covered a variety of studies with different objectives. One of the most important objectives was to determine the depth of topsoil and subsoil needed for revegetation based on the chemical and physical properties of the underlying spoil. This objective was accomplished by a thorough review of past studies, new experiments, and a sound theoretical reasoning, and culminated in the publication of NDSU-Agricultural Experiment Station Bulletin 514, titled "Soil Replacement for Reclamation of strip-mined lands in North Dakota." The recommendations made in this bulletin became the basis for adopting in 1985 an alternative rule for SPGM respreading. The new rule required the soil respread thickness to be based on the characteristics of the underlying spoil. Thus, for reaping the full economic benefit of this rule (cost savings in soil removal), it was deemed that predicting the characteristics of the regraded spoil from the undisturbed overburden would be highly useful. Therefore, studies were conducted to compare premine bore hole data with regraded spoil characteristics. This line of investigation proved inconclusive. In a separate investigation conducted at the Indian Head and Glenharold mines' abandoned areas, it was noted that respreading these areas with 5 to 15 cm of soil material increased plant yields significantly. In yet another study, grain yield and water use in a small watershed were found dependent on the topofactor in that higher yields were obtained at lower field elevations.

46. Reclamation of Abandoned Mine Lands Using Gypsym, Calcium Chloride, Fly Ash, and Higher Quality Spoil. - G. Halvorson, M. Miller, (NDSU-LRRC); funded by Bureau of Mines, June 1988 - September 1990, $70,000 for entire period.

The objectives of this project were to: 1) determine whether good quality spoil available at the abandoned mine land sites can be used as a topsoil substitute for their reclamation, 2) determine whether incorporation of chemical amendments such as $CaCl_2$, $CaSO_4$ will improve vegetative cover and production at the abandoned mined lands, and 3) determine if flyash can be used as a chemical amendment to help promote plant growth at these sites. Data on spoil, vegetation and climatic variables was collected from two field experimental sites established at the Glenharold and Indian Head Mines.

48. Relation of Compaction and Soil Physical Parameters to Productivity of Reclaimed Soils. - E.C. Doll, S. A. Schroeder, K. Vining (NDSU-LLRC); funded by Office of Surface Mining, August 1988 - July 1991, $160,000 for 3 years.

The objectives of this project were to: 1) evaluate the effect of deep tillage practices on root development, and 2) study the effects of root growth and climatic factors on compaction and pertinent soil physical parameters by analyzing soil reclaimed over a period of years. Field

experiments have been initiated at the Freedom, Center, Beulah and Glenharold Mines. The parameters being measured include bulk density, penetrometer resistance by depth, profile soil water, biomass, and root length density.

47. **Surface and Root Zone Hydrology of Mined Lands. - E.C. Doll, G.A. Halvorson, S.A. Schroeder, P.P. Sharma (NDSU-LRRC); funded by the National Mine Land Reclamation Center, August 1988 - July 1993, $90,000 per year.**

This project was a part of a twin-study conducted in collaboration with the UND's Mining and Mineral Resources Research Institute (MMRRI). The objectives of this project were to: 1) measure water infiltration, movement and retention in soil and spoil materials as related to topographic position on abandoned mine lands, reclaimed lands and undisturbed lands to evaluate effects of mining on these parameters, 2) determine profile distribution of vaporite minerals in relation to soil and spoil moisture distribution and movement, and 3) estimate the probability of summer storms with respect to frequency, duration, and intensity of rainfall, and to estimate probable runoff, runon and discharge at specific topographic locations. The other part of this study, conducted by UND-MMRRI involved investigation of groundwater movement and chemical evolution from the root zone to the water table. The study sites were at the Indian Head and Velva mines.

49. **Comparative Evaluation of Productivity of Prime and Nonprime Soils. - G. Halvorson (NDSU-LLRC); funded by the North Dakota Industrial Commission, Lignite Industry, and NDSU (Projects LRC-VIII-31, LRC-XII-44, SFY-94-XI-49, FY-95-XVIII-58), January 1992 - January 1996, $328,573.**

The main objective of these studies was to compare the productivity of prime and nonprime topsoils in different topographic positions and to determine whether separate handling of the prime and nonprime soils is necessary. Field experiments were carried out at the Falkirk and Freedom mines over a period of 1992-95. At each of these mine, experimental plots were constructed out of Bowbells, Williams and Zahl topsoil materials that were placed at topographically prime and nonprime locations in the field. Each soil type was respread to two different soil depths. In, 1995, wheat yield was unaffected by soil depth at both sites and affected by topographic position at the Freedom Mine only. Bowbells and Williams gave similar yields but Zahl responded inconsistently. These studies showed that some nonprime topsoils can be mixed with the prime topsoils without significantly affecting the productivity potential of the latter.

50. **The Success of Current Soil Depth Requirements on Mineland in North Dakota: An Assessment. - G.A. Halvorson (NDSU-LLRC); funded by the North Dakota Industrial Commission, Lignite Industry, and NDSU (Project SFY94-XV-50), January 1994 - December 1995, $67,900.**

This project was initiated to re-evaluate, as required by the sunset clause in the rule regarding soil respread depths adopted in 1986, productivity of mined areas reclaimed under different soil respreading requirements. Wheat yields from areas reclaimed under the two alternative soil respreading options, and from undisturbed areas were measured and appropriate comparisons made.

C. ECOLOGY AND ECOSYSTEM REHABILITATION

Research on the ecology and rehabilitation of mined land ecosystems in North Dakota dates back to the mid-1940's, when the North Dakota State Game and Fish Department was actively engaged in developing wildlife areas on some abandoned mine lands. Later, some revegetation studies were also conducted by the USDA-Soil Conservation Service. However, maximum emphasis on ecological aspects of reclamation research began in the early 1970's, mainly by the scientists working at the University of North Dakota (Project Reclamation), North Dakota State University (Botany Department) and USDA Forest Service (Rocky Mountain Forest and Range Experiment Station, Rapid City, SD). Some field demonstration work on the rehabilitation of several abandoned mine sites has also been conducted by the Dickinson State University (School of Applied Science and Technology), as a part of North Dakota State's Abandoned Mine Land's (AML) construction program. These AML projects are not included in the following inventory because they are considered as construction rather than research projects.

Support and funding for conducting ecologically oriented reclamation research on North Dakota mined lands has been mostly provided by the US Bureau of Mines, US Environmental Protection Agency, US Office of Surface Mining, USDA Forest Service, and North Dakota Public Service Commission. The total amount of funding received for the following projects conducted during 1975-1996 was approximately of 2.6 million dollars ($2,600,000).

The first thirteen projects listed below were conducted by the UND-Project Reclamation scientists during the period 1975-82, under the direction of M.K. Wali (Principal Investigator), in a comprehensive program entitled: **A Systems Approach to the Reclamation of Strip Mined Areas in North Dakota,** funded by the US Bureau of Mines at a total cost of $1,400,000. The main objective of this program was to make a thorough evaluation of the ecological variables operating in mined land ecosystems in North Dakota, and to develop an understanding of the factors that affect the rehabilitation and revegetation potential of the mined lands. The results of each of these projects when finally integrated would, it was hoped, yield a holistic picture of the problems involved in and the possible solutions for the establishment of sustained biological productivity on the mined lands. The ecological studies conducted at the UND-Project Reclamation and other research centers are briefly summarized below.

1. Physical and Chemical Properties of Overburden and Topsoils as Affected by Time and Amendments. - N.M. Safaya, R.H. Bares, N. Malakondaiah, S.A. Nicholson (UND-Project Reclamation).

Spoil and soil samples were collected from field experiment plots at six coal mine sites in Oliver and Mercer counties over a five year period to monitor their physical and chemical properties as affected by various amendments applied once at each site. The analyses included monitoring of trace elements along with other soil/spoil parameters.

2. Plant Production on Spoils and Topsoils as Affected by Time and Amendments. - R.H. Bares (UND-Project Reclamation).

Six field study sites were established on regraded mined areas during the early 1970's for evaluating the effects of several amendments on spoil/soil properties and on the establishment and

growth of plants. A number of grass and legume species combinations were tested. Application of leonardite or slack (100mT/ha) to the spoils and topsoils decreased grass growth but increased the growth of legumes. On topsoiled plots treated with leonardite the production of weedy species was lower than without leonardite. NPK fertilizers applied once prior to seeding increased plant production during the first two to three years, after which the effect disappeared. This effect was much more pronounced on the spoils. Weedy species accounted for most of the biomass during the first growing season.

3. **Mineral Analysis of Plants Grown on Spoils and Topsoils. - N. Malakondaiah, N.M. Safaya. (UND-Project Reclamation).**

Plant samples collected from several test and non-test sites at the Center, Beulah, and Indian Head mines were analyzed for their nutrient concentrations. The vegetation from the mined areas generally showed lower concentrations of N, P, and Cu and failed to meet the nutritional requirements for beef cattle as defined by National Research Council. Plants from Beulah showed generally higher concentrations than those from the Center or Indian Head mines. Lower concentrations of P were also reported in most of the plants on the unmined site at Indian Head. The concentrations of Ca, Mg, Na, Fe, Cu, and N in grasses were significantly higher on topsoil than on slack amended spoil at the Center test site. None of the nutrients analyzed were found to be in the toxic range.

4. **Soil and Vegetation Development on Abandoned Mines. - M.K. Wali, R.H. Pembel (UND-Project Reclamation).**

Soil and vegetation development were studied on abandoned mine sites near Velva in Ward county, North Dakota. The sites studied were 1, 7, 17, 30, and 45 years old since abandonment; unmined sites were also studied to provide measures of comparison. Stand ordination revealed that site ages were the most important in influencing species diversity and composition. Stand-environmental complex ordinations encompassing 53 variables showed topographic variables to be the most important followed by site ages. Rates of nutrient accumulations were also determined. Species distributional diagrams were developed to show their habitat preferences which may be helpful in formulating species prescriptions for revegetation..

5. **Soil and Vegetation Development on Topsoiled Areas. - L.R. Iverson, M.K. Wali (UND-ProjectReclamation).**

Four reclaimed mined sites, one to four years in age, were studied for patterns of species colonization, biochemical interaction among species, competitive phenomena, and management applications. *Kochia scoparia*, a colonizer, was the dominant species for the first two years, but was completely eliminated by the fourth year; the planted *Agropyron* grasses concomitantly increased during this four year period. Chemical analysis of the soils over the same period showed decreases in several soluble elements due to leaching, and a slight buildup of nitrogen and organic matter. Competition experiments between *kochia* and *Agropyron* revealed that *kochia* initially acted as a 'nurse' crop for *Agropyron* establishment, but later in the first season began to shade excessively which reduced *Agropyron* tillering. Field and growth chamber experiments revealed that decaying *kochia* leaves and roots were toxic to *kochia* growth, and were partially responsible for the rapid disappearance of the species. Bioassay experiment implicated allelochemics to be

important in several other colonizing species also. Mowing of the first year colonizing species (especially *kochia*) just prior to seed set proved to be very effective at reducing weed populations and improving planted *Agropyron* populations in the second year.

6. **Studies on Soil-plant Nutrient Relations on Mine Spoils and Soils. - N.M. Safaya, N. Malakondaiah, M. Saeed, (UND-Project Reclamation), J.W. Harrell, Jr (UND-Physics Department).**

This project involved several growth chamber and laboratory experiments which were conducted to 1) determine the germination behavior of several plant species on spoil materials as affected by different inorganic and organic amendments, 2) evaluate fertility status and productivity potential of spoil and stockpiled topsoil materials from different mines in North Dakota, 3) study growth and mineral composition of some grass and legume species as affected by applications of major- and micronutrients and amendments to spoil and soil materials, 4) evaluate the effects of nutrient and amendment applications on the physicochemical properties of spoils and soils, 5) study phosphorus diffusion and availability in spoils as affected by leonardite and moisture, 6) study the potassium release characteristics of various spoil materials, and 7) evaluate the feasibility of foliar fertilization.

7. **Screening Plants for Phosphorus Requirements. - N.M. Safaya, N. Malakondaiah (UND-Project Reclamation).**

In this study several plant species were screened with respect to their phosphorus uptake efficiency using continuous flow culture and spoil culture techniques. The experiments were conducted in environment-controlled growth chambers. Screening of plants by the two methods yielded almost identical results, indicating that continuous flow culture technique could be used as a quick method for identifying phosphorus efficient plant species for use on phosphorus deficient spoils. Legumes were found to require relatively higher levels of phosphorus than the grasses. Weedy species such as *Kochia scoparia* and *Salsola collins* were found to be most efficient with respect to phosphorus uptake and therefore least sensitive to its deficiency. This explained the reason why these weedy species thrive so well on the mine spoils in North Dakota which are highly deficient in plant available phosphorus.

8. **Chemistry of Leonardite. - A. Kollman (UND-Project Reclamation).**

Laboratory studies were conducted to investigate the chemical properties of leonardite, a low BTU, naturally oxidized lignitic material. This material is rich in humic and fulvic acid and has been used as a soil/spoil amendment. The studies included analysis of leonardite materials from different sources for their organic and inorganic constituents and study of their sorption and desorption characteristics with respect to Al, Cu, Fe, Mn, P, and Zn.

9. **Relationship Between Cover and Aboveground Biomass. - D.K. Schimmelpfennig (UND-Project Reclamation).**

The objective of this study was to evaluate the predictability of aboveground biomass production on revegetated mined sites and adjacent native prairies using plant cover estimates made with the point frame method. The field work was conducted at 16 reclaimed and 4 undisturbed prairie sites

located at the Center, Beulah, and Indian Head mines. A positive correlation was demonstrated between plant cover and aboveground biomass regardless of community type (mined or native), species composition, diversity or level of biomass production.

10. Viability and Diversity of the Seed Bank. - L.R. Iverson, L. Brophy (UND-Project Reclamation).

The objective of this study was to determine viable seed populations in soils of unmined prairie and post-mined revegetated coal mined lands in western North Dakota. Soil samples collected from grazed and ungrazed areas, topsoil stockpiles, and six mined sites aged 2-6 years were studied for their viable seed populations. Analysis of seed numbers present in topsoil indicated that seeds of the most prevalent colonizers (e.g. *Kochia scoparia*, *Setaria virdis*, and *Salsola collins*) were not present in the topsoil prior to respreading but rather appeared by immigration from the surrounding areas. The grazed sites had greater seed density than the ungrazed, but the percentage of seeds of the weedy species was higher in the former. The stockpiled topsoils had very low seed densities. Seed densities and diversity decreased with depth. Several species were found in the seed bank which were also found on the 3 and 4 year old mined sites in the above ground vegetation. However, there was a poor correlation between the aboveground flora and the belowground seed.

11. Studies on Algal Colonization and Succession on Surface Mined Lands. - T.L. Starks, L.E. Shubert (UND-Project Reclamation & Biology Department).

The main objective of this study was to investigate the ecological role of soil algae in the establishment of favorable soil conditions on surface mined lands. Soil/spoil samples from 0-10 cm depth were collected during 1975-1977 from the experimental test sites established at several mines in western North Dakota as well as from 1-45 year old, abandoned spoil piles at Velva, ND, and analyzed in the laboratory for algal biomass and species diversity. These parameters were then statistically correlated with the soil/spoil physical and chemical properties. All test sites revealed distinct soil algal communities and demonstrated a successional trend as evidenced by significant increases in species variety and biomass over time.

12. Aquatic Invertebrates and Water Chemistry of Strip Mine Impoundments in Western North Dakota. - D.L. Batema (UND-Biology Department).

This project (Master's thesis) was conducted to study the chemical and biological properties of mine impoundments in Mercer County, ND. Water, bottom sediments, and spoil materials surrounding the ponds were analyzed for 27 chemical variables. Invertebrate species were identified and their biomass and diversity measured.

13. Influence of Macro- and Microclimate on Plant Production on Spoils and Topsoils. - R.H.Bares (UND-Project Reclamation).

In this study macro- and microclimate data were obtained from several climatic stations installed at South Beulah and North Beulah test sites and from the National Oceanic and Atmospheric Administration meteorological stations at Beulah, Center, and Velva, North Dakota. The climatic elements of precipitation, incoming solar radiation, standard air temperature, and soil temperatures

at 2.5 and 20 cm were recorded. The climatic effects on the revegetation of mined lands, as assessed from test plot studies, were evaluated.

14. **Vegetation - Environment Relationships of Woodland and Shrub Communities, and Soil Algae in Western North Dakota. - M.K. Wali, K.T. Killingback, R.H. Bares, and L.E. Schubert (UND-Project Reclamation), funded by ND Legislative Council, $79,700.**

This project was not directly related to reclamation research but provided a data base regarding woodland and shrub communities and their relationships with habitat parameters in the western North Dakota. Field studies were conducted during the growing seasons of 1976 and 1977 at 807 sampling sites located in Dunn, Mc Kenzie, Golden Valley, Billings, and Stark counties. Based on importance value of species, the woodland vegetation was classified into six major community types: 1) cottonwood, 2) aspen-birch, 3) green ash-American elm, 4) bur oak, 5) juniper, and 6) ponderosa pine. Three major shrub communities were recognized: 1) silver sage, 2) buck brush, and 3) buffalo berry. Fifty-two species of algae were found in the soils of these communities. Based on the frequency of occurrence and abundance of trees and shrubs, their ecological modalities along several environmental gradients were demonstrated. These represented the influences of topography, particle size distribution of soils, available soil water, and major and trace elements in soils. The information provided by this study should be of use in the management of woody vegetation in the coal mining areas.

15. **Evaluation of Available Vegetation Data and Sampling Procedures for the Development of Guidelines for Pre- and Post-mining Vegetation Assessments in North Dakota. - G.M. Van Dyne (CSU), funded by OSM through ND Public Service Commission, 1978-1981, $194,012; S.A. Nicholson (UND- Project Reclamation), funded by OSM 1982-1984, $34,488; M.K. Wali (SUNY), funded by OSM, 1982-1984, $13,060; total funding received $241,560.**

The main objective of this project was to develop adequate sampling methodologies for pre- and post-mining vegetation inventories, and to provide a comprehensive data base and rationale for the use of "standards" and "reference areas" in the evaluation of revegetation success on mined lands. This involved 1) an exhaustive review of all available ecological and agronomic information on the vegetation of northern Great Plains in general and that of western North Dakota in particular, and 2) field experimentation at four locations in western North Dakota to determine the cost and time-efficiency of different vegetation sampling and analysis techniques.

16. **Vegetation - Environment Relationships of Abandoned Mines: Toward their Successful Revegetation, Stability, and Long-term Production. - S.A. Nicholson, R.H. Bares, L.R. Iverson, W.S. Dancer, D.R. Jordan, J.E. Jordan (UND-Project Reclamation), funded by ND Public Service Commission, 1982-1984, $223,527.**

The main objectives of this project were to: 1) determine site, soil/spoil, and vegetation characteristics of a number of abandoned surface mine sites in western North Dakota, 2) classify the abandoned mine sites with respect to their major edaphic stresses and revegetation potential, 3) develop lists of plant species (from literature search and field observations) adapted to the prevailing edaphic stresses, and 4) determine from literature review the physical and biological techniques which could be effective in establishing adequate vegetation on the sites studied.

17. **Ecological Analysis of Aquatic and Terrestrial Plant Communities Associated with Selected Strip Mine and Stock Ponds in the Northern Great Plains. - A.J. Bjugstad (USDA-Forest Service), W.T. Barker (NDSU-Botany Department); funded by USDA-Forest Service, Rocky Mountain Forest and Range Experiment Station, 1980-1983, $30,000.**

This project was contracted to the North Dakota State University by the Rocky Mountain Station. Studies on the vegetation of stockponds and mine impoundments in western North Dakota indicated that mine impoundments often exhibited a number of established zones of vegetation but these were generally very narrow compared to the stockponds.

18. **Invertebrate Species, Abundance and Standing Crop Biomass in Strip Mine Ponds in the Northern Great Plains. - C.L. Hawkes (USDA-Forest Service); funded by Environmental Protection Agency, 1980-84, $40,000.**

A study of invertebrates and plant species in stockponds and mine impoundments in the Northern Great Plains including coal mining areas of western North Dakota was conducted. Stockponds were found to be rich in organismal diversity and abundance compared to mine impoundments. The substrate in mine impoundments was limiting in several cases for proper establishment of species. However, organismal diversity was found to increase with the age of impoundments and stockponds.

19. **Selection and Increase of Perennial Forbs for Mine Spoil Reclamation in the Northern Great Plains. - A.J. Bjugstad (USDA-Forest Service), W.C. Whitman (NDSU - Botany Department); funded by USDA-Forest Service, 1981-83, $15,000.**

This project was contracted to the North Dakota State University by the Rocky Mountain Station. Studies were conducted to evaluate the potential use of perennial forbs on mine spoils. Overwintering of the seeds of some species in spoil was found necessary for their germination. Some perennial forbs were easy to establish on the spoil materials.

20. **Rooted Aquatic Plant Revegetation of Strip Mine Impoundments in the Northern Great Plains. - A.J. Bjugstad (USDA-Forest Service), W.T. Barker (NDSU-Botany Department); funded by USDA-Forest Service, 1981-83, $40,000.**

This project was contracted to the North Dakota State University by the Rocky Mountain Station. Containerized seedlings were found to have excellent success in reestablishment on mine impoundments. Some plant species rapidly dominated their particular zone after transplanting.

21. **Basin Morphometry of Strip Mine Ponds Compared to Stockponds in the Northern Great Plains. - M.A. Rumble (USDA-Forest Service); funded by USDA-Forest Service, 1981-83, $25,000.**

Studies of aquatic vegetation in Northern Great Plains indicated that the plant communities on mine impoundments form relatively narrow concentric bands compared to more complex, mosaic patterns on livestock ponds. The importance of pond morphometry to enhance the potential for reestablishment of vegetation on reclaimed wetlands has been emphasized.

22. **Water Quality in Strip Mine Ponds Compared to Stockponds in the Northern Great Plains. - C.L. Hawkes (USDA-Forest Service); funded by Environmental Protection Agency, 1981-84, $80,000.**

Water samples were collected from stockponds and mine impoundments in coal mining areas of the Northern Great Plains, including western North Dakota. Several water samples were found to be higher in some of the EPA established standards (particularly As and Pb) for livestock use. Contamination due to overland flow was inferred.

23. **Waterfowl Use of Water Impoundments Left by Strip Mining in the Northern Great Plains. - D.W. Uresk (USDA-Forest Service); funded by Environmental Protection Agency, 1981-84, $20,000.**

This study showed that the diversity of waterfowl species on strip mine ponds was lower compared to stockponds in the western North Dakota.

24. **Analyses of Aquatic and Wetland Flora of the Northern Great Plains. - M.A. Rumble, G.E. Larson (USDA-Forest Service); funded by USDA-Forest Service, 1981-84, $50,000.**

The objectives of this project were to identify and describe the aquatic plant species occupying stockponds and other wetlands in the Northern Great Plains, including the coal mining areas in western North Dakota. The information obtained will be used to determine the habitat requirements of the aquatic plants for eventual development of vegetation on the sedimentation ponds at the coal mines. The studies completed so far have shown that there are numerous species inhabiting stockponds and wetlands, and several of these are quite adapted to various habitat conditions.

25. **Development of Wildlife Habitat and Areas of Public Benefit on Abandoned Mine Lands - Phase I - H. Goetz (NDSU) and J. Thompson (RPM, Inc.), funded by the ND Public Service Commission, July, 1984 - January, 1985, $46,500.00.**

The objective of this project was to collect fall data on wetland parameters (water, soil, vegetation) at a number of abandoned mine land sites with water bodies, and to develop a computer model for wildlife enhancement program. The sites studied included: Bowbells, Custer, Noonan, Scranton, Velva and Wilton. Water and substrate (soil) samples were collected from several locations at each of these abandoned mine sites, and analyzed for a number of parameters. Investigation of wetland plant communities included measurements of density, frequency, cover and importance value by species. All data from these abandoned mine wetland areas were computerized, and a software program was developed for use as a management and design tool for reclamation of AML sites to produce wildlife habitat.

26. **Development of Wildlife Habitat and Areas of Public Benefit on Abandoned Mine Lands - Phase II - H. Goetz (NDSU) and J. Thompson (RPM, Inc.), funded by ND Public Service Commission, June-August, 1985, $30,750.**

The objective of this project was to collect summer data on wetland parameters at six abandoned mine land sites, and complete the database for the aquatic wildlife habitat study on abandoned

mines. These data were collected and computerized for use in the computer model developed in Phase I of this project in 1984. Seasonal changes were noted in several water chemistry parameters as well as species importance. This information will be useful when wetlands are the final reclamation objective in future abandoned mine land projects.

27. **Development of Wildlife Habitat and Areas of Public Benefit on Abandoned Mine Lands - Phase III - J. Thompson (RPM, Inc.) and W.T. Barker (NDSU) funded by ND Public Service Commission, February - June, 1986, $5,700.**

The objective of this project was to enhance a computer simulation model, previously developed under Phase I, for interactive assessment of abandoned surface mines. Wetland field data collected under Phase I and Phase II was analyzed to ascertain water-plant relationships. These relationships were programmed into the computer model together with similar relationships for rangeland, woodland and cropland. The model is equipped to analyze user-supplied site data for a variety of post-reclamation land uses and generate a list of plant species which should tolerate the site conditions. Seed sources, seeding rates and seeding techniques are also computer generated. The computer program and data generated in the various phases of this entire study should be useful to other government agencies, current mining operators, and any owner of an AML site who may be interested in improving the wildlife habitat at an abandoned mine land site.

28. **Soil Depth and Quality Requirements for Reclamation of Rangelands. - D. R. Kirby (NDSU-Department of Animal and Range Science), G. Halvorson (NDSU-LRRC); funded by the North Dakota Industrial Commission, Lignite Council, and NDSU (Projects LRC-I-7, LRC-III-14, LRC-V-22, LRC-VII-28), July 1988 - June 1993, $212,426.**

The purpose of this study was to determine the optimum soil depths and quality necessary to meet productivity and species diversity requirements for reclaimed grasslands as compared to reference areas within similar topoedaphic units. The study attempted to quantify how the various parameters - soil quality, soil and spoil texture, and topography - interact in a given rangeland site and affect productivity and diversity. These investigations were conducted at the Glenharold, Indian Head and Center Mines.

29. **Evaluating the Success of Reclaimed Grasslands. - D.R. Kirby (NDSU-Department of Animal and Range Science); funded by the North Dakota Industrial Commission, Lignite Council, and NDSU (Projects LRC-X-37), September 1992 - August 1995, $51,000.**

The purpose of this study was to develop a database for evaluation of grassland reclamation success, and to review regulatory requirements determining that success. Topoedaphic data was collected from many sites at the Freedom and Beulah mines and subject to multi-variant analysis to determine a minimum soil depth that would be sufficient to meet productivity, cover, and diversity requirements of reestablished grasslands. The data and conclusions could then be used to improve the regulations or guidelines.

30. **Improving the Public Service Commission Guidelines for Evaluating the Success of Reclaimed Grasslands. - D.R. Kirby (NDSU-Department of Animal and Range Science); funded by the North Dakota Industrial Commission, Lignite Council, and NDSU (Projects LRC-XI-40), July 1993 - June 1994, $20,000.**

The objective of this project was to determine the relationship between precipitation, temperature and growing degree days, and herbage yield, seasonality and species diversity for various range sites. Vegetation data was collected from the Glenharold and Center mines, and weather data from Dickinson Research Center, and USDA-ARS Northern Great plains Research Center at Mandan, ND. Vegetation data included yield and species composition. Weather data included precipitation, temperature, number of days having greater than 95 F temperature, and growing degree days per month. All data were statistically analyzed and used for developing weather-plant growth models.

III. CURRENT AND FUTURE RECLAMATION RESEARCH NEEDS

The information contained in this section is based on the responses obtained from various research groups, government agencies, and the lignite industry. These entities were periodically (1983, 1986, 1995) surveyed to obtain their opinions regarding reclamation research needs. The results of these surveys have been summarized into two lists, presented in Subsection I and Subsection II, respectively.

Subsection I includes information based on the most recent survey and, therefore, provides a glimpse of some of the outstanding research needs as perceived today. The agency or entity that identified the research need is shown by acronym in parenthesis at the end of the stated need. The entities surveyed include North Dakota Public Service Commission (PSC), State Water Commission (SWC) State Department of Health (SDH), Bureau of Reclamation (BOR), UND-Energy and Environmental Research Center (EERC), Lignite Energy Council (LEC), Natural Resources Conservation Service (NRCS), and Fish and Wildlife Service (FWS). Suggestions and opinions of the NDSU-Land Reclamation Research Center and USDA-ARS Northern Great Plains Research Center Scientists are also included in this list.

Subsection II summarizes information on research needs that were identified about 12 years back and presented in the 1984 edition of this report. This information is included to provide, by comparison with the recent list, some general idea of the progress that has been made in the last decade, and the old or new concerns that still remain to be addressed. The list of research needs presented in Subsection B does not include the name of the agency/entity that identified the need, but identifies the priority a specific research need was assigned at that time. The high (H), Medium (M) and Low (L) priorities are shown at the end of each stated need.

A perusal of both lists will readily reveal that although the number of research needs has significantly decreased over the past 12 years, there are many reclamation questions and concerns for which no complete answers have been found as yet. Also, the reader will note that some new research needs have surfaced that need to be addressed. Concerns regarding supply and quality of groundwater following reclamation, waste disposal in mined areas, soil handling and evaluation of productivity in prime farmland areas, and alleviation of compaction in reclaimed lands, require immediate attention. Compaction in reclaimed lands is a serious problem. Engineering and/or agronomic solutions for alleviation of compaction need to be invented; otherwise realizing the required productivity goals from reclaimed lands may be in serious jeopardy. Development of scientifically appropriate and practical methods of evaluating the success of tree and shrub communities, and use of microbial techniques for establishing these and other plant communities on reclaimed lands, are also some of the outstanding research needs that need to be addressed as soon as possible.

SUBSECTION A

RECLAMATION RESEARCH NEEDS PERCEIVED IN 1996

GEOLOGY AND HYDROLOGY

- Develop appropriate methods for assessment and mitigation of mining effects on groundwater quality and supply. (PSC)
- Determine aquifer properties of spoils, and reassess the role of spoils saturated zone in groundwater movement and quality. (SWC)
- Determine suitability of surface mined lands as solid waste disposal facilities. (SDH)
- Compare the hydrologic functions and effectiveness of reclaimed wetlands to natural, undisturbed basins in relation to groundwater recharge. (BOR, EERC)
- Evaluate the hydrologic impacts of sedimentation ponds retained as permanent impoundments in the post-mining environment. (SDH)

SOIL MANAGEMENT

- Determine if the rule regarding soil respread thicknesses based on graded spoil properties should be continued. (PSC)
- Determine if prime farmland soils warrant separate handling. (PSC)
- Assess long term effects of soil compaction on hydrology and productivity of reclaimed lands and develop effective methods of alleviating soil compaction. (PSC, LEC)
- Are reclaimed croplands more susceptible to erosion than unmined croplands? (PSC)
- Study the profile characteristics of reclaimed soils for assessment of soil development process and classification of the reclaimed soils. (NRCS, LEC, PSC)

AGRICULTURAL PRODUCTION / MANAGEMENT

- Determine long term stability and sustainability of reclaimed grasslands and their best management requirements. (LEC, NRCS, PSC)
- What is the minimum density of warm and cool season grasses needed for reclaimed native grasslands to ensure adequate cover under different grazing pressures? (PSC)
- Develop appropriate methods for determining crop yields of reclaimed lands. Compare hand sampling, strip harvest, and whole field harvest methods of determining crop yields. (PSC)

- Establish scientifically valid methods for meeting sample adequacy requirements under different conditions of population distributions. (PSC)

ECOLOGY AND ECOSYSTEMS

- Develop management and evaluation techniques for tree and shrub communities on reclaimed lands. (PSC, LEC, FWS)

- Determine grading and soil replacement for the construction and establishment of wetlands. How long can wetland soils be stockpiled without losing seed viability. (PSC)

- What are the ecological implications in making a large wetland to replace several small ones. How is wetland recovery affected after functioning as a sediment pond. (PSC)

- Data on mining impacts on wildlife need publishing. (PSC)

- Continued development and selection of plant cultivars and ecotypes suitable for revegetation of mined lands. (LEC, PSC)

- Determine the role of mycorrhizae and other microorganisms in the development of reclaimed soils and in the establishment of self sustaining plant communities on mined lands. (PSC)

SUBSECTION B

RECLAMATION RESEARCH AND DEVELOPMENT NEEDS PERCEIVED IN 1984

GEOLOGY AND HYDROLOGY

- Develop methods of assessing, predicting, and achieving post-mining landscape stability. **(M)**

- Evaluate the effects of disposing fly ash and FGD wastes in mine spoils on surface stability and groundwater quality. **(H)**

- Create a composite computer data base of overburden chemical properties for the eventual development of hydrogeochemical model(s) for predicting the impacts of mining and reclamation on groundwater quality. **(H)**

- Determine and quantify the mechanisms and rates of water and salt movement through vadose zone in reclaimed and abandoned mine lands for eventual modeling of factors affecting groundwater recharge and aquifer reestablishment. **(H)**

- Refine the existing methodologies and develop appropriate model(s) for determining cumulative hydrological impacts of mining and reclamation. **(H)**

- Determine the hydraulic properties of lignite. **(M)**

- Determine the effects of organic compounds present in lignite on the quality of ground water. **(M)**

- Determine the effects of buried water impoundments on final reclamation. **(M)**

MINE SOILS AND AGRICULTURAL PRODUCTION

Soil Requirements

- Determine the optimum topsoil and subsoil thickness requirements as related to soil and spoil characteristics, topography, and post-mining land use. **(H)**

- Reevaluate soil handling requirements for the reclamation of prime farmlands. Determine if the differences in productivity between prime and nonprime soils are essentially moisture and topography related. **(H)**

- Determine the effect of compaction of respread soil on productivity. Devise methods to reduce compaction. **(M)**

- Evaluate the effects of removal, stockpiling and direct respreading processes on the volume changes in topsoil and subsoil. **(H)**

- Quantify the effects of soil type and soil horizon mixing on productivity. **(H)**

- Long term monitoring of erosion, productivity, and cover of reclaimed landscapes as an aid in evaluating adequate soil respread thickness requirements and erosion control methods. **(H)**

- Develop effective techniques for preventing recurrent sodification and salinization in the root zone of respread soils. **(M)**

Mine Soil Properties

- Reassess the adequacy of current regulatory program parameters and critical limits for soil and spoils. **(H)**

- Determine the extent of spatial variability in the physical and chemical properties of graded spoils and respread soils, and its influence on productivity and cover. **(H)**

- Develop and standardize methods for assessing the fertility status and fertilizer requirements of reclaimed lands; determine appropriate methods of fertilizer application. **(M)**

- Quantify moisture retention and release characteristics of reclaimed mine soils and identify best method of moisture conservation. **(H)**

- Quantify and develop predictive models for assessing the vertical and lateral flow of water and salts in reclaimed landscapes. **(H)**

- Determine runoff and erosion potential for variously reclaimed mined lands (spoils and mine soils). **(M)**

- Monitor soil development processes on reclaimed landscapes and determine the types of soils being formed. Also, determine the practices which may aid in hastening the soil development process. **(H)**

Agricultural Production

- Determine the effects of different levels of management on the long term productivity of mined lands. **(H)**

- Determine appropriate methods for assessing revegetation success on reclaimed mined lands. Develop guidelines for assessing the productivity and cover of mined lands. **(H)**

- Verify the USDA published crop yield data in the coal producing counties of the State. **(M)**

- Review, evaluate, and analyze experiment station yield data for use in deriving cropland revegetation success standards. **(M)**

- Obtain baseline data on vegetation in coal mining areas. Investigate the feasibility and utility of implementing ongoing programs for documenting crop and rangeland vegetation data in active and potential surface coal mining areas in the State. **(M)**

- Determine simple and reliable techniques of predicting time of occurrence of peak yield in various rangeland communities. **(M)**

- Investigate alternatives to plant biomass as indicators of success of reclamation on mined lands, such as use of soil development parameters. **(H)**

- Evaluate the effectiveness of reclamation measures employed several years ago on various mine sites. **(L)**

- Determine the amount of total surface ground cover needed to provide adequate soil protection on grasslands. **(H)**

- Develop indexes of potential productivity on disturbed and reclaimed lands. **(M)**

- Develop techniques of water harvesting and conservation; continue research on use of supplemental irrigation. **(M)**

- Continue research on the effects of grazing management on reclaimed lands. **(M)**

ECOLOGY AND ECOSYSTEM DEVELOPMENT

Wildlife and Wetland Habitats

- Determine ecological and management requirements and effective techniques for the reestablishment of woody draw ecosystems on mined lands. **(H)**

- Determine ecological and management requirements and effective techniques for the reestablishment of wetlands on mined lands. **(H)**

- Develop lists of plants suitable for woody draws and wetlands, and determine their cultural requirements. **(H)**

- Study avian and small mammal community responses to reclaimed sites; and evaluate wildlife productivity and population dynamics. **(M)**

- Devise methods to reestablish or entice the animal component to artificially developed association of plants on mined lands. **(H)**

- Evaluate the feasibility and utility of using high resolution remote sensing techniques for pre- and post-mining vegetation and land use inventories. **(M)**

Physiological Ecology

- Identify and develop plant materials adapted to and capable of growing successfully on mined sites. **(H)**

- Determine the tolerance limits of adapted species to sodicity, salinity, acidity, water stress, and nutrient deficiencies/toxicities, and identify physiological or other mechanisms imparting tolerance for specific stresses. **(H)**

- Determine the role of mycorrhizae and other soil microorganisms on the development of mine soils, and in the establishment of self sustaining plant communities on mined lands. **(H)**

- Determine the role of weedy species in the reestablishment and succession of desirable plant communities. **(M)**

- Determine the techniques for enhancing the germination and establishment of seeds and propagules of native plant species on mined lands. Develop methods of propagating and storing large quantities of seeds of important native species which are currently in short supply. **(M)**

- Determine the extent to which plant species and community composition on abandoned mine lands can reflect the site and spoil characteristics of the area in question. **(L)**

- Determine appropriate methods for the reclamation of uraniferous abandoned mine lands. **(H)**

- For use at uraniferous sites, identify and develop listing of plant species which will not translocate radionuclides. **(M)**

DEVELOPMENT NEEDS

- Develop a reclamation research administrative group that includes representatives from industry, government agencies, the public, and the academic research community, and is charged with the responsibility of promoting, monitoring, and coordinating reclamation research, and transmitting important findings and policy recommendations to the legislative branch. **(M)**

- Develop a mechanism for stable, predictable, and secure funding for various reclamation research groups in North Dakota. **(H)**

- Implement policies that end destructive competitive tactics and provide safeguards against duplication in research. **(H)**

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RECLAMATION RESEARCH IN NORTH DAKOTA

PART B

RESEARCH PUBLICATION BRIEFS

GEOLOGY AND HYDROLOGY (GH)

Title: **A GEOLOGIST'S VIEW OF STRIP MINING**

Author: E.A. Noble

Organization: University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Some Environmental Aspects of Strip Mining in North Dakota (M.K. Wali, ed.), pp. 53-60. North Dakota Geological Survey Educational Series 5, 1973

Key Index Words: Geology, Geohydrology, Hydrogeochemistry, Mining Impacts,

Brief Description

This paper presents the geologist's view of surface mining as a unique but relatively minor disturbance of a small portion of the earth's surface with minor changes in topography and regional ground water flow. The author believes that the geochemical and other effects of mining would eventually be mitigated. The needs and problems of surface mining in western North Dakota and the adequacy of the reclamation efforts are discussed.

Analysis of Conclusions

Research conducted subsequent to the publication of this paper has revealed that surface mining can cause several hydrogeochemical and hydrological problems which can be prevented only by careful planning and implementation of mining and reclamation techniques.

Title: **POTENTIAL IMPACT OF LARGE - SCALE STRIP MINING ON GROUNDWATER SUPPLIES IN WESTERN NORTH DAKOTA**

Authors: G.H. Groenewold, S.R. Moran, and C.A. Anderson

Organization: North Dakota Geological Survey and University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Proceedings of North Dakota Academy of Science 29(1):11, 1975

Key Index Words: Geology, Geohydrology

Brief Description

In this presentation, four potential modifications of groundwater supplies, which may result from large-scale lignite development in western North Dakota, were discussed. An overview of the problems was presented and studies underway in areas of proposed development were explained.

Analysis of Conclusions

These research findings have been greatly elaborated in subsequent work of similar nature.

Title: **GEOLOGY OF THE NORTH BEULAH, CENTER, AND GLENHAROLD LIGNITE MINES IN MERCER AND OLIVER COUNTIES, SOUTHWESTERN NORTH DAKOTA**

Author: R.E. Kulland

Organization: University of North Dakota, Grand Forks, ND

Format: Thesis

Reference: M.S. Thesis, University of North Dakota, Grand Forks, ND, 1975

Key Index Words:

Brief Description

Document was not available for review.

Analysis of Conclusions

Analysis of conclusions was not possible.

Title: **PROBABLE CAUSES OF SURFACE INSTABILITY IN CONTOURED STRIP MINE SPOILS**

Authors: G.H. Groenewold and L.M. Winczewski

Organization: North Dakota Geological Survey and University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Proceedings of North Dakota Academy of Science 31(1):10, 1976

Key Index Words: Geology, Subsidence, Surface Instability

Brief Description

This presentation dealt with a preliminary reconnaissance of existing graded strip mine spoils in western North Dakota. This was done to identify the various geological and engineering problems which exist within these materials. The problems include differential subsidence of the surface of the spoil, slope instability, and piping features.

Analysis of Conclusions

Research along these lines has been greatly advanced by the subsequent work by the senior author.

Title: **DEVELOPMENT OF A PRE-MINING GEOLOGICAL FRAMEWORK FOR LANDSCAPE DESIGN RECLAMATION IN NORTH DAKOTA**

Authors: S.R. Moran, G.H. Groenewold, L.A. Hemish, and C.A. Anderson

Organization: North Dakota Geological Survey and University of North Dakota, Grand Forks, ND.

Format: Report

Reference: North Dakota Geological Survey Miscellaneous Series No. 55, 1976

Key Index Words: Geology, Geohydrology, Mining Impact

Brief Description

This report discusses the conceptual framework for reclamation in light of the possible impacts of mining on groundwater quality and agricultural productivity. Preliminary data are presented to highlight the implications of mining and reclamation on the hydrologic and hydrogeochemical properties of the reclaimed land and their features of instability.

Analysis of Conclusions

This and subsequent studies along similar lines have advanced our understanding of the geological factors considerably. Continued research in this area is essential.

Title: **CHEMICAL AND BACTERIOLOGICAL ANALYSES OF STREAM SEDIMENTS IN THE KNIFE RIVER BASIN OF NORTH DAKOTA**

Authors: M.C. Bromel and K. Johnson

Organization: NDSU-Department of Microbiology

Format: Report

Reference: Report prepared for Office of Research and Development, US Environmental Protection Agency, Washington, DC 66 p.

Key Index Words: Surface Hydrology, Water Quality, Microbiology

Brief Description

A base line study was conducted of the chemical and bacteriological quality of the stream and mine impoundment waters and sediments in the Knife River Basin of North Dakota. This study, including the impact analyses of present strip mining of coal deposits on water quality, will provide a comparison for future assessments of stream quality under expanded coal production and coal conversion activities.

Analysis of Conclusions

The baseline data obtained on the chemical and bacteriological quality of the stream, mine impoundments, and sediments will be useful for future comparisons.

Title: **WESTERN NORTH DAKOTA LIGNITE STRIP MINING PROCESSES AND RESULTING SUBSURFACE CHARACTERISTICS**

Author: L.M. Winczewski

Organization: Department of Geology, University of North Dakota, Grand Forks, ND

Format: Thesis

Reference: M.S. Thesis, University of North Dakota, 432 p., 1977

Key Index Words: Geology, Geohydrology

Brief Description

The research reported in this thesis was undertaken to study the subsurface geologic characteristics both before and after strip mining using current techniques. The groundwater recharge and flow through mined areas was also studied.

Analysis of Conclusions

This thesis is very useful for understanding some geologic and hydrogeologic impacts of surface mining in North Dakota.

Title: **GEOLOGY, GROUNDWATER HYDROLOGY ANDHYDROGEO-CHEMISTRY OF A PROPOSED SURFACE MINE AND LIGNITE GASIFICATION PLANT SITE NEAR DUNN CENTER, NORTH DAKOTA**

Authors: S.R. Moran, J.A. Cherry, P. Fritz, W.M. Peterson, M.H. Sommerville, S.A. Stancel, and J.H. Ulmer

Organization: North Dakota Geological Survey; Department of Earth Sciences, University of Waterloo, Waterloo, Ontario; and Engineering Experiment Station, University of North Dakota, Grand Forks, ND

Format: Report

Reference: North Dakota Geological Survey Report of Investigation No. 61, 1978

Key Index Words: Geohydrology, Hydrogeochemistry, Coal Gasification

Brief Description

The objective of this study was to describe the subsurface hydrological and hydrochemical regime in the area of a proposed coal mining area near Dunn Center, North Dakota. Several geologic test holes were drilled and logged, and core samples were taken from selected holes. Nests of observation wells were installed for water level monitoring, water sampling and permeability testing. Laboratory analyses were conducted on the core samples. This study resulted in a detailed description of geological and hydrogeochemical properties of the study area.

Analysis of Conclusions

Should mining be proposed for the area included in this study, this report contains ample information to allow a detailed analysis of possible effects on the groundwater supplies of the area.

Title: **GEOLOGIC, HYDROLOGIC, AND GEOCHEMICAL CONCEPTS AND TECHNIQUES IN OVERBURDEN CHARACTERIZATION FOR MINED LAND RECLAMATION**

Authors: S.R. Moran, G.H. Groenewold, and J.A. Cherry

Organization: Alberta Research Council, Edmonton, Alberta, Canada; North Dakota Geological Survey, Grand Forks, ND; Department of Earth Sciences, University of Waterloo, Waterloo, Ontario, Canada

Format: Report

Reference: North Dakota Geological Survey Report of Investigation, No. 63, 1978

Key Index Words: Geology, Geohydrology, Hydrogeochemistry, Mining Impacts

Brief Description

The objective of this study was to evolve techniques for the identification of materials which would be beneficial or deleterious to revegetation if replaced near the post-mining land surface during reclamation. In addition, an attempt was made to identify the physical and chemical interactions which control subsurface water chemistry. Field studies consisting of drill hole sampling and analyses were conducted at five (5) sites in western North Dakota. The results of this study include the development of an interpretative framework which relates pore fluid chemistry to a number of hydrogeochemical factors. In addition, the authors conclude that saturation extract tests do not provide an adequate assessment of overburden chemistry for reclamation purposes.

Analysis of Conclusions

This study was the first to propose an interpretive hydrogeochemical explanation (conceptual model) for the chemistry of post-mining groundwater which develops in surface mined landscapes. A precise quantitative relationship between overburden chemical parameters and post-mining groundwater quality remains to be developed.

Title: **HYDROLOGY OF A WATERSHED WITH SUBIRRIGATED ALLUVIAL MATERIALS IN CROP PRODUCTION**

Authors: D.J. Dollhopf, G.W. Wende, J.D. Doering, and D.W. Hadberg

Organization: Montana Agricultural Experimental Station, Montana State University, Bozeman, MT

Format: Report

Reference: Peabody Coal Contract No. 055 (1975-1979), 1979

Key Index Words: Alluvial Valley Floors, Subirrigation, Groundwater

Brief Description

This report documents the investigation of a subirrigated alluvial valley floor that is located downstream from a surface coal mining operation near Coal Strip, Montana. The major source of recharge to the alluvium was located below the coal but mining did intercept secondary sources of recharge to the alluvium. The baseline water quality in the alluvium is hard and high in TDS, but suitable for irrigation water.

Analysis of Conclusions

Since the major source of recharge is stratigraphically below the coal most of the cropland is expected to stay subirrigated during mining. But a drop in the water table level could occur which would cause a temporary decrease in crop production. In general, no definite trends or major changes were observed for either surface runoff or groundwater chemistry within the study area.

Title: **GEOLOGY AND GEOHYDROLOGY OF THE KNIFE RIVER BASIN AND ADJACENT AREAS OF WEST CENTRAL NORTH DAKOTA**

Authors: G.H. Groenewold, L.A. Hemish, J.A. Cherry, B.W. Rehm, G.N. Meyer, and L.M. Winczewski

Organization: North Dakota Geological Survey, Grand Forks, ND; Oklahoma Geological Survey, Norman, OK; Department of Earth Sciences, University of Waterloo, Waterloo, Ontario, Canada; Minnesota Geological Survey, St. Paul, MN; and Engineering Experiment Station and Department of Geology, University of North Dakota, Grand Forks, ND

Format: Report

Reference: North Dakota Geological Survey Report of Investigation No. 64, 1979

Key Index Words: Geohydrology, Hydrogeochemistry, Stratigraphy

Brief Description

This study discusses the surface and subsurface geology, regional groundwater flow systems, chemistry and chemical evolution of groundwater in the near surface units of the Knife River Basin in west central North Dakota. Two sites outside of the Knife River Basin, the Center and Falkirk sites, are also discussed. The regional stratigraphic framework of the units overlying the Pierce Formation has been worked out based on extensive test drilling. In addition a geochemical model which attempts to account for the groundwater chemistry of the various units is proposed.

Analysis of Conclusions

The geochemical model first presented in NDGS Report of Investigation No. 63 is further refined and expanded in this study. The information presented here on the regional and local hydrogeology of the study sites provides the background information necessary to evaluate the possible hydrologic consequences of mining.

Title: **HYDROLOGIC MODELING OF COAL LANDS**

Authors: B.P. Van Haveren and G.H. Leavesley

Organization: Bureau of Land Management and USGS-Water Resources Division

Format: Report

Reference: BLM and USGS-Water Resources Division (Central Region) Report, May 1979

Key Index Words: Hydrologic Modeling, Mining Impacts

Brief Description

This report discusses development of a digital model for determining hydrologic consequences of surface mining. It describes various inputs including climate, physical characteristics, overburden, vegetation, etc. This model can apply to watersheds with limited data to assess hydrological impacts.

Analysis of Conclusions

It is our understanding that funding for this program has been discontinued. Continued funding is necessary to complete calibration of the model. This program would be extremely useful to the PSC if it were available. This is the only sophisticated technique that can be used to anticipate surface water hydrologic impacts from surface coal mining operations.

Title: **INSTABILITY OF CONTOURED SURFACE MINED LANDSCAPES IN THE NORTHERN GREAT PLAINS: CAUSES AND IMPLICATIONS**

Authors: G.H. Groenewold and B.W. Rehm

Organization: North Dakota Geological Survey and UND-Engineering Experiment Station, Grand Forks, ND

Format: Paper

Reference: Adequate Reclamation of Mined Lands? - A Symposium, pp. 2-1 to 2-15, Soil Conservation Society of America and WRCC-21, Billings, MT, March 1980

Key Index Words: Subsidence, Piping

Brief Description

The design of a stable post-mining landscape requires the knowledge of the distribution of overburden materials, proper equipment selection, and a consideration of climatic factors. There are three common forms of instability encountered in mined lands: area wide settling, localized collapse, and piping.

Analysis of Conclusions

Area wide settling is less in scraper contoured areas than in bulldozer contoured areas, particularly if contouring occurred in mid-winter. Area wide settling generally occurs during the first year after completion of contouring. Dozer contouring of frozen spoils concentrates large blocky fragments in valley areas. Settlement and thawing in areas where the frozen blocky materials have been concentrated is the cause of localized collapse. This type of instability may be avoided if dozer contouring is restricted during the winter months. Piping is controlled by a combination of physical and chemical conditions in the spoils. Piping begins as a crack that is located in areas of near surface highly dispersive sodic materials. Piping then will develop if an avenue for water is available in the subsurface such as a fracture zone. Fracturing in the subsurface is related to differential settling between areas of stable scraper contouring and unstable dozer contouring.

Title: **POTENTIAL EFFECTS ON GROUNDWATER OF FLY ASH AND FGD WASTE DISPOSAL IN LIGNITE SURFACE MINE PITS IN NORTH DAKOTA**

Authors: G.H. Groenewold, J.A. Cherry, O.E. Manz, H.A. Gullicks, D.J. Hassett, and B.W. Rehm

Organization: North Dakota Geological Survey, Grand Forks, ND; University of Waterloo, Waterloo, Ontario; University of North Dakota, Grand Forks, ND; Soil Testing Service of Minnesota, Minneapolis, MN

Format: **Report**

Reference: Symposium on Flue Gas Desulfurization, Houston, TX, October 1980

Key Index Words: Waste Disposal, Fly Ash, FGD, Groundwater

Brief Description

This paper presents a summary of the results from an investigation of the effects of fly ash and FGD waste disposal on groundwater quality at the Center Mine

Analysis of Conclusions

North Dakota lignite fly ash produces leach waters that have high pH and high concentrations of arsenic, molybdenum, and selenium. FGD waste from North Dakota lignite produces a leach water that has pH values from 7.0 to 8.5 and is high in concentrations of sulfate, magnesium, and sodium. Piezometers installed near the fly ash disposal area as well as piezometers installed in buried fly ash yield contaminated waters with high pH and high concentrations of arsenic, selenium, and molybdenum. Water from piezometers in spoil with FGD waste contained high sulfate concentrations and showed no significant concentrations of arsenic, selenium, or molybdenum. The areal extent of groundwater contaminated by FGD waste or fly ash is small but is expected to increase gradually as a result of groundwater flow and continued waste disposal.

Title: **DEPOSITIONAL SETTING AND GROUNDWATER QUALITY IN COAL BEARING SEDIMENTS AND SPOILS IN WESTERN NORTH DAKOTA**

Authors: G.H. Groenewold, B. Rehm, and J.A. Cherry

Organization: North Dakota Geological Survey; UND-Engineering Experiment Station, Grand Forks, ND; University of Waterloo, Waterloo, Ontario, Canada

Format: Report

Reference: Recent and Ancient Nonmarine Depositional Environments: Models for Exploration (F.G. Ethridge and R.M. Flores, eds.), SEPM Special Publication No. 31, 1981

Key Index Words: Groundwater, Overburden Analysis, Hydrogeochemistry

Brief Description

This report includes hydrogeochemical studies conducted at five surface mines in North Dakota. Hydrogeochemical processes include pyrite oxidation, carbonate dissolution, gypsum precipitation and dissolution, cation exchange and sulfate reduction. The key components (mineralogical variables in the sediments) are largely dependent upon fluctuations in the fluvial depositional settings of the sediments. Degradation of groundwater quality in spoils settings is dependent on mineralogical variables and the degree of weathering, dissolution, and ion exchange that takes place in the post-mine settings.

Analysis of Conclusions

The potential for weathering and the generation of elevated salinities in post-mining landscapes can be decreased by the selective emplacement of overburden materials during mining and post-mining operations. Unweathered materials should be placed at the base of the spoils (below the post-mining water table) where sulfide oxidation will be minimum. The differences in mineralogy, which is related to the depositional environments, will dictate the direction of chemical evolution the groundwater will take after disturbance. For example, the overburden at the Indian Head Mine is primarily clayey sediments deposited in a flood basin environment. The overburden at the Center Mine is predominantly sandy sediments deposited in point bar and natural levee environments. Finely disseminated pyrite is common in the reduced (flood basin) setting. Pyrite is uncommon in the coarse textured sediments. TDS values at Indian Head range as high as 15,880 mg/l which is nearly three times as high as the maximum TDS value for spoils water at Center.

Title: **PROGRESS REPORT ON THE EFFECTS OF SURFACE MINING ON THE SURFACE WATER HYDROLOGY OF THE SELECTED BASINS IN THE FORT UNION COAL REGION, NORTH DAKOTA AND MONTANA.**

Author: D.G. Emerson

Organization: United States Geological Survey (In Cooperation with U.S. Bureau of Land Management), Bismarck, ND

Format: Report

Reference: USGS Open File Report 81-678, 1981

Key Index Words: Hydrologic Modeling, Mining Impacts, Surface Water

Brief Description

This report discusses the development of a means (model) to assess the impacts on surface water hydrology due to changes in land use resulting from surface mining in North Dakota and Montana. The data collected to date and the additional information needed to complete the study are given. Data were collected from West Branch Antelope Creek study area in North Dakota since October 1976, and from Hay Creek study area in Eastern Montana since March 1978.

Analysis of Conclusions

No conclusions are drawn. Report summarizes progress made thus far on model development and data collection efforts.

Title: **WATER RESOURCES INVESTIGATIONS IN NORTH DAKOTA, 1981**

Compiled by: C.R. Martin and L.L. Albright

Organization: USGS, Water Resources Division, Bismarck, ND

Format: Report

Reference: USGS Open File Report 81-923, 1981

Key Index Words: Water Resources, Surface Water, Groundwater

Brief Description

Describes surface and groundwater investigations being conducted by the USGS. Includes county groundwater studies, aquifer evaluations, snow surveys, hydrologic changes resulting from lignite mining, hydrologic effects of strip mining at Gascoyne, etc.

Analysis of Conclusions

No conclusions have been drawn; report summaries specify progress made to date.

Title: **HYDROLOGIC CHARACTERISTICS AND POSSIBLE EFFECTS OF SURFACE MINING IN THE NORTHWESTERN PART OF WEST BRANCH ANTELOPE CREEK BASIN MERCER COUNTY, NORTH DAKOTA**

Authors: M.E. Crawley and D.G. Emerson

Organization: U.S. Geological Survey, Bismarck, ND

Format: Report

Reference: Water Resources Investigations 79-81, 1981

Key Index Words: Groundwater, Surface Water, Hydrogeochemistry, Runoff, Mine Drainage

Brief Description

The study area is the northwestern part of the West Branch Antelope Creek basin located in north central Mercer County, North Dakota. The study area encompasses 28 sq. miles. The area was selected for study because of the near future development of the lignite deposits. This document established the pre-mining conditions as a standard to evaluate any future changes to the hydrologic regime as a result of surface mining.

Analysis of Conclusions

Data available indicate that small local plumes of water rich in sodium and sulfate could result from mining along the edge of the West Branch Antelope Creek tributary. In some locations there will be movement of this enriched water toward the Antelope Creek aquifer. The potential for contamination of ground waters by toxic concentrations of trace metals for people would be small. Transport would be greatly retarded by adsorption and cation exchange and the large bicarbonate concentration in the water would produce rapid precipitation of most trace metals. The impact of the mining on the quantity and timing of runoff will probably be minor and will be dependent on mining practices. There would be major changes on small areas for short periods of time but the overall flow regime would be altered only slightly. Sediment yields will change depending on mining practices. Runoff from spoils, reclaimed areas, or both, will have increased salinity.

Title: **HYDROGEOLOGICAL AND GEOTECHNICAL PROCEDURES MANUAL FOR THE DISPOSAL OF FLY ASH AND FGD WASTE FROM LOW RANK COALS IN WESTERN STRIP MINES**

Authors: D. Daly, G. Groenewold, O. Manz

Organization: Engineering Experiment Station and MMRRI, University of North Dakota, Grand Forks, ND

Format: Report

Reference: US DOE, Grand Forks Energy Technology Center, Bulletin No. 83-04-EES-03, 1982

Key Index Words: Fly Ash, FGD, Waste Disposal, Groundwater, Trace Elements

Brief Description

The purpose of this manual is to provide a summary of the current regulatory framework, FGD equipped power plant characteristics, and surface coal mine FGD waste disposal site operations within the western states. A set of guidelines based on geologic and hydrologic criteria is presented for use in establishing waste disposal sites within surface mines.

Analysis of Conclusions

In order to evaluate a future FGD waste disposal site, the geology and hydrogeology must be understood. Geologic characterization should consist of lithologic samples and logs accompanied by geophysical logs. This data will enable the geologist to characterize the stratigraphy, lithology, structure, and geochemical properties in the pre-mine setting. Hydrogeologic characterization should consist of gathering hydrogeologic and hydrogeochemical data for the saturated and unsaturated zones. Hydrogeological data synthesis should consist of determining groundwater flow directions, hydraulic characteristics of shallow aquifers and aquitards, position of the water table, and background water quality. Disposal site candidates are then chosen on the basis of projected post-closure water table, hydrogeologic and hydrogeochemical character of the materials below the elevation of the pit bottom, and projected character of the spoil material. The ideal natural setting would have the following characteristics: 1) semiarid to arid climate 2) low permeability spoil materials 3) significant acid/base buffering capacity in the surrounding materials

Title: **HYDROGEOCHEMICAL CONSEQUENCES OF STRIP MINING IN THE FORT UNION GROUP OF SOUTHWESTERN NORTH DAKOTA**

Author: R. Houghton

Organization: U.S. Geological Survey, Bismarck, ND

Format: Paper

Reference: Symposium on Surface Mining Hydrology Sedimentology and Reclamation, pp. 79-86; Lexington, KY, 1982

Key Index Words: Hydrogeochemistry, Water Quality, Mining Impacts

Brief Description

Since 1973 the USGS has been conducting hydrogeochemical investigations at the Gascoyne Mine in southwestern North Dakota. An increase in lignite production between 1974 and 1976 has caused degradation in quality and quantity of shallow groundwater systems. This increase in lignite production has prompted concern about the effects of mining on the quality and quantity of shallow groundwater in this semiarid part of the country.

Analysis of Conclusions

Mining increases the quantity of soluble salts available to infiltrating waters by exposing the overburden to sufficient air to oxidize all reactable forms of reduced sulfur. Also, overburden with large contents of soluble salts is placed below the water table where dissolution can occur. The water quality deterioration that is observed in saturated spoils is characterized by a 5 fold increase in dissolved solids. The deterioration in water quality may be reduced by retaining the salt rich horizons above the post-mining water table. Expanded mining along the lignite outcrop could result in a major decrease in recharge to the aquifer as a whole.

Title: **TRACE ELEMENT ENRICHMENTS IN WATERS ASSOCIATED WITH STRIP MINING OF LIGNITE IN THE FORT UNION GROUP OF SOUTHWESTERN NORTH DAKOTA**

Author: R.L. Houghton

Organization: USGS-Water Resources Division, Bismarck, ND

Format: Paper

Reference: Proceedings of Symposium on "Trace Element Mobilization in Western Energy Regions (L.P. Gough and R.C. Severson, eds.), p. 46, Colorado School of Mines Research Institute, Denver, CO, November 1982

Key Index Words: Trace Elements, Surface Water, Groundwater

Brief Description

Weathering of outcropping lignite and spoil near Gascoyne Mine have resulted in enrichment of several trace elements in local ground and surface waters. Cadmium, copper, lead, and selenium concentrations exceed recommended domestic water criteria in many parts of the lignite aquifer. Concentrations do not, however, exceed recommended levels for stockwatering.

Analysis of Conclusions

This report is the only one that indicates that concentrations of some heavy metals in ground water may be of concern in some surface mined areas in North Dakota. This report indicated the need for additional research.

Title: **THE MINERALOGY OF LOW RANK COAL FLY ASH**

Authors: G.J. McCarthy and S.J. Steinwand

Organization: Department of Chemistry, NDSU, Fargo, ND

Format: Paper

Reference: Materials Research Society, 1982

Key Index Words: Fly Ash, Mineralogy, X-ray Diffraction

Brief Description

X-ray diffraction analysis of seventy-seven specimens of fly ash have been performed at NDSU. Most of the specimen originated at low rank coal-fired power plants.

Analysis of Conclusions

The results of these analysis along with results obtained by workers at Iowa State, Penn State, Purdue and UND gives better understanding of low rank coal mineralogy.

Title: **MECHANISMS, DISTRIBUTION AND FREQUENCY OF GROUNDWATER RECHARGE IN AN UPLAND AREA OF WESTERN NORTH DAKOTA**

Authors: B.W. Rehm, G.H. Groenewold, and W.M. Peterson

Organization: North Dakota Geological Survey, Grand Forks, ND

Format: Report

Reference: North Dakota Geological Survey Report of Investigation No. 75, 1982

Key Index Words: Groundwater, Recharge, Mining Impacts

Brief Description

This study focuses on the area surrounding the Falkirk Mine near Underwood in McLean County, North Dakota. Estimates of groundwater recharge rates for 1979 were obtained using a network of piezometers and water table wells, these data were supplemented with observations on evapotranspiration rates, soil moisture changes, and stable isotope concentrations. The average rate of groundwater recharge for the year was determined along with its spatial and temporal distribution.

Analysis of Conclusions

The methods and conclusions presented herein are applicable to determining possible differences in recharge capacity between the pre- and post-mining settings.

Title: **EARTH RESISTIVITY INVESTIGATIONS IN RECLAIMED SURFACE LIGNITE MINE SPOILS**

Authors: A.E. Kehew and G.H. Groenewold

Organization: North Dakota Geological Survey, Grand Forks, ND

Format: Report

Reference: North Dakota Geological Survey Report of Investigation No. 77, 1983

Key Index Words: Resistivity, Hydrogeochemistry, Hydrology, Groundwater

Brief Description

This report describes the results of an investigation in which earth resistivity techniques were used to evaluate hydrochemical and hydrogeologic conditions on reclaimed and undisturbed sites at Falkirk, Center, and Indian Head mines in North Dakota. Resistivity can be used as a tool for evaluating groundwater degradation following mining and reclamation. Resistivity surveys show an inverse correlation between measured resistivity values and total dissolved solids content of groundwater. The higher the resistivity of the overburden materials, the better the quality of groundwater below reclaimed spoils that can be expected.

Analysis of Conclusions

This is the only study of its kind in North Dakota, which uses basic concepts to study fundamental aspects of post-reclamation groundwater quality. This study demonstrates usefulness of "remote-sensing" techniques to study groundwater.

Title: **GEOLOGICAL AND GEOCHEMICAL CONTROLS ON THE CHEMICAL EVOLUTION OF SUBSURFACE WATER IN UNDISTURBED AND SURFACE MINED LANDSCAPES IN WESTERN NORTH DAKOTA**

Authors: G.H. Groenewold, R.D. Koob, G.J. McCarthy, B.W. Rehm, and W.M. Peterson

Organization: North Dakota Geological Survey, Grand Forks, ND

Format: Report

Reference: North Dakota Geological Survey Report of Investigation No. 79, 1983

Key Index Words: Hydrogeochemistry, Groundwater, Overburden Analysis

Brief Description

The major purposes of this study were to refine the previously developed hydrogeochemical model and to determine its applicability to spoils settings. Field activities included detailed instrumentation of undisturbed and spoils settings at two mines, and laboratory work included overburden analyses, leaching, weathering, and acid-base neutralization studies. The researchers concluded that the mineralization of subsurface water in spoils settings is typically two to three times greater than in the undisturbed settings and that this highly mineralized water has the potential to impact local surface water bodies.

Analysis of Conclusions

The previously developed geochemical model to explain post-mining groundwater quality is further refined in this report. In addition several aspects of the relationship between hydrogeochemical processes and properties and various aspects of reclamation success are discussed.

Title: **DETECTION OF UNDERGROUND LIGNITE MINES BY GRAVITY SURVEYS - FINAL REPORT TO PUBLIC SERVICE COMMISSION**

Authors: W.D. Gosnold, Jr., C. Quinn, and M. Luther

Organization: North Dakota MMRRI, University of North Dakota, Grand Forks, ND

Format: Report

Reference: North Dakota MMRRI Bulletin No. 83-10-MMRRI-01, 1983

Key Index Words: Microgravity Surveys, AML, Underground Mines

Brief Description

This report describes the results of an investigation conducted at four abandoned mine land sites in western North Dakota to locate and map underground mine tunnels and voids using microgravity surveys

Analysis of Conclusions

Conclusions of this project indicate that gravity surveys are effective in locating underground mine tunnels. However, from a practical viewpoint, gravity surveys are best suited for areas with individual mine tunnels rather than closely-spaced mine rooms. The investigators recommended that gravity surveys be cross-checked with available drill hole data to validate interpretations of anomalies.

Title: **HYDROGEOLOGICAL AND HYDROGEOCHEMICAL DATA BASE FOR ABANDONED SURFACE MINED LANDS - PHASE I**

Authors: G.H. Groenewold, E.C. Murphy, R.D. Koob, and C.R. Schmidt

Organization: North Dakota MMRRI, University of North Dakota, Grand Forks, ND

Format: Report

Reference: North Dakota MMRRI Bulletin No. 83-10-MMRRI-02, October 1983

Key Index Words: Groundwater, Geohydrology, Hydrogeochemistry

Brief Description

This report describes the results of hydrogeological and hydrogeochemical investigations conducted at four abandoned lignite mined sites in western North Dakota. No significant differences in the groundwater levels and groundwater quality were observed between the disturbed and the adjoining undisturbed locations at each of the four sites.

Analysis of Conclusions

It was concluded that the lack of difference in the quality of groundwaters at disturbed and undisturbed sites was due to either attenuation caused by infiltrating waters or due to lack of leaching. It was purported that to determine the exact mechanism involved would help make proper decisions about regrading.

Title: **WATER RESOURCES DATA, NORTH DAKOTA, WATER YEARS 1982**

Authors: R.E. Harkness and N.D. Haffield

Organization: USGS Water Resources Division, Bismarck, ND

Format: Report

Reference: USGS-Water Data Report ND-82-1, 1983

Key Index Words: Water Resources, Water Quality

Brief Description

These reports provide water quality and quantity data for USGS gaging stations throughout North Dakota.

Analysis of Conclusions

Information provided is utilized by mining companies for determining hydrologic balance of streams within and adjacent to mining areas. Several monitoring stations are important to the mining companies' data collection effort.

Title: **WATER RESOURCES INVESTIGATIONS IN NORTH DAKOTA**

Compiled by: N.K. Laukford and L.L. Albright

Organization: USGS, Water Resources Division, Bismarck, ND

Format: Report

Reference: USGS Open File Report 83-220, 1983

Key Index Words: Water Resources, Surface Water, Groundwater

Brief Description

Describes surface and groundwater investigations being conducted by the Water Resources Division of USGS in North Dakota. Status reports are provided for each of the thirty-five (35) projects included in this report.

Analysis of Conclusions

No conclusions have been drawn; report summaries specify progress made to date.

Title: **DATA FROM THE SURFACE WATER HYDROLOGIC INVESTIGATIONS OF THE HAY CREEK STUDY AREA, MONTANA, AND THE WEST BRANCH ANTELOPE CREEK STUDY AREA, NORTH DAKOTA, OCTOBER 1976 THROUGH APRIL 1982**

Authors: D.G. Emerson, S.W. Norbeck, and K.L. Boespflug

Organization: US Geological Survey, Bismarck, ND (in cooperation with US Bureau of Land Management)

Format: Report

Reference: USGS Open File Report 83-136, 1983

Key Index Words: Surface Water, Hydrology

Brief Description

The report contains data on air temperature, relative humidity, wind direction, wind run, solar radiation, precipitation, soil temperature, snowpack density and water content, streamflow, water quality, soil moisture, land use, and basin characteristics of Haycreek Study Area in Montana and the west Branch Antelope Creek Study area in North Dakota.

Analysis of Conclusions

The purpose of this study was to collect and analyze hydrologic and other environmental data for selected coal deposit areas in Montana and North Dakota in response to the leasing nomination of federal coal. The study areas have high leasing potential; thus the watersheds were selected to determine the pre-mining hydrologic characteristics and provide the necessary baseline data to assess the effects of surface mining.

Title: **GROUND-WATER DATA FOR SELECTED COAL AREAS IN WESTERN NORTH DAKOTA**

Authors: J.D. Wold and S.W. Norbeck

Organization: U.S. Geological Survey in cooperation with Bureau of Land Management

Format: Report

Reference: USGS Open-file Report 83-219, 1983

Key Index Words: Ground-Water Data

Brief Description

Groundwater data is provided for the Sand Creek, Hanks, New England, Mott, Dickinson and Bowman-Gascoyne coal area, North Dakota. The report contains the following: 1) Maps showing the location of wells, springs and test holes; the location of wells and test holes where driller logs are available; the location of wells with chemical analysis; and 2) tables showing well, spring and test-hole records; logs; and chemical analysis of water. Descriptions of the location of data collection sites and methods used to collect data are included.

Analysis of Conclusions

The U.S. Geological Survey conducted a groundwater inventory in selected areas of the Fort Union coal region of Western North Dakota to provide information to the BLM as an aid in making leasing decisions. Knowledge of the pre-mining hydrologic conditions is necessary to evaluate probable impacts should mining occur in these areas of probable development.

Title: HYDROGEOCHEMICAL CHARACTERISTICS OF ABANDONED SURFACE MINES IN NORTH DAKOTA - IMPLICATIONS WITH RESPECT TO RECLAMATION

Authors: G.H. Groenewold, R.D. Koob, and E.C. Murphy

Organization North Dakota MMRRI, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Proceedings of the National Symposium and Workshops on Reclamation of Abandoned Mine Lands, Bismarck, North Dakota, 1984

Key Index Word: AML, Groundwater, Vegetation

Brief Description

Fifty one abandoned surface mine sites were field evaluated and grouped into four generic categories based upon geological and vegetative variables. One study site was chosen as representative of each of the four generic categories. This characterization was undertaken to determine whether reclamation is appropriate or not at each type of abandoned mine site.

Analysis of Conclusions

An objective evaluation of the suitability of each generic type of abandoned mine land for reclamation will require continued research focused on the distribution of salts in the spoils and infiltration/recharge characteristics of each setting.

Title: **WATER RESOURCES DATA - NORTH DAKOTA WATER YEAR 1984**

Authors: N.D. Haffield and G.L. Ryan

Organization: U.S. Geological Survey, Bismarck, ND

Format: Report

Reference: USGS Water-Data Report ND-84-1, 1984

Key Index Words: Surface Water, Groundwater, Water Quality, Water Data

Brief Description

Water-resources data for North Dakota consists of stage, discharge, and water quality of streams; stage, contents, and water quality of lakes and reservoirs; and water levels and water quality of ground-water wells. This report contains discharge records for 108 gaging stations; stage only records for 21 gaging stations; stage and contents for 13 lakes and reservoirs; water quality for 108 gaging stations, 8 lakes, 33 wells, 2 precipitation stations; and water levels for 31 observation wells. These data represent that part of the National Water Data System operated by the U.S. Geological Survey and cooperating State, Federal, and local agencies in North Dakota.

Analysis of Conclusions

No conclusions. This is a listing of data compiled by US Geological Survey.

Title: **NORTH DAKOTA MINING AND MINERAL RESOURCES RESEARCH INSTITUTE ANNUAL REPORT - 1984**

Authors: G.H. Groenewold

Organization: North Dakota MMRRI, University of North Dakota, Grand Forks, ND

Format: Report

Reference: North Dakota Mining and Mineral Resources Research Institute Bulletin No. 84-10-MMRRI-01, 1984

Key Index Words: AML, Hydrology, Waste Disposal, Fly Ash, FGD Waste, Lignite Resources

Brief Description

This report summarizes the objectives and results of eleven ongoing research projects conducted at the MMRRI during July 1, 1983 to June 30, 1984. The projects include: 1) evaluation of lignite and geothermal resources, 2) reclamation of abandoned mined lands, 3) characterization, use, and disposal of power industry generated wastes, 4) overburden characterization, etc. Educational and training activities of the Institute, and a list of reports, papers, and presentations made during the report period are also included.

Analysis of Conclusions

The information contained in this report covers a wide range of research topics of practical value to the mining and power industry. However, because of the ongoing nature of most of these investigations, no final conclusions of recommendations have been given. Continued research on these projects is necessary.

Title: **HYDROGEOCHEMISTRY OF THE UPPER PART OF THE FORT UNION GROUP IN THE GASCOYNE LIGNITE STRIP-MINING AREA, ND**

Authors: R.L. Houghton, D.C. Thorstenson, D.W. Fisher, G.H. Groenewold

Organization: U.S. Geological Survey, Bismarck, ND

Format: Report

Reference: USGS Open File Report 84-131, 1984

Key Index Words: Hydrogeochemistry, Water Quality, Fort Union Group

Brief Description

This report is a continuation of studies that have been conducted by the U.S. Geological Survey at the Gascoyne Lignite Mine since 1973. This report addresses the effects on groundwater quality that will be caused by exposing the reduced sediments from below the water table to oxidating conditions in the spoils.

Analysis of Conclusions

The undisturbed aquifers within the Gascoyne Mine area are a sodium sulfate/bicarbonate type with dissolved solid concentrations ranging from 575 mg/l to 8740 mg/l. The base of the spoils resaturate quite rapidly and the ground water is degraded as compared to the pre-mine setting. Dissolved solids in aquifers reestablished in spoils range from 4,400 to 11,000 mg/l. The researches estimate that one pore volume must leach the spoils in order to return the salt levels to their premine geochemical salt balance. They estimate that the time involved to complete such leaching would approximate 120 years based on the average hydraulic conductivity and water storage of the spoils.

Title: **MINERALOGY AND LEACHING BEHAVIOR OF FIXED BED GASIFICATION ASH DERIVED FROM NORTH DAKOTA LIGNITE**

Authors: G.J. McCarthy, R.J. Stevenson and G.H. Groenewold, D.J. Hassett, R.R. Honke

Organization: Dept of Chemistry, NDSU, Fargo, ND, MMRRI, Engineering Experiment Station, Energy Research Center, University of North Dakota, Grand Forks, ND

Format: Report

Reference: Gas Research Institute Contract, 1984

Key Index Words: Ash Mineralogy, Coal Gasification, Lignite

Brief Description

The objective of this study was to provide a detailed understanding of the chemistry, mineralogy and leaching behavior of ash from coal gasification plants. Three gasifiers were used including Great Plains Gasificiation Associates commercial facility near Beulah, ND. The gasifier had similar maximum temperatures but incorporated several differences in operating and ash handling conditions. Lignite from the same seam was gasified in all tests.

Analysis of Conclusions

None of the gasification ashes would be classified as a "hazardous waste" according to EPA standards. Several elements are present in the leaching solutions at levels above drinking and irrigation water standards, but this is not a concern for ash placed in a properly engineered disposal area.

Title: **QUALITY OF WATER FOR LIVESTOCK IN MAN-MADE IMPOUNDMENTS IN THE NORTHERN HIGH PLAINS**

Authors: M.A. Rumble

Organization: USFS - Rocky Mountain Forest and Range Experiment Station, Rapid City, SD

Format: Paper

Reference: Journal of Range Management 38(1): 74-77, 1985

Key Index Words: Impoundments, Water Quality

Brief Description

This paper discusses water quality problems of surface mine impoundments for livestock watering based on a study of twenty-seven parameters. Age of the impoundments was included for interpretive purposes. Statistical analysis was used to determine where differences among impoundment types existed.

Analysis of Conclusions

An excellent study with very useful data, as well as a recommendation to use TDS as a primary indicator of water quality for livestock.

Title: **RECONNAISSANCE MAPS TO ASSIST IN IDENTIFYING ALLUVIAL VALLEY FLOORS, WEST-CENTRAL, NORTH DAKOTA, DRAFT**

Authors: D. Nimck, R. Rasmussen, B. Rusmore, and J. Schmidt

Organization: Earth Resource Associates, Helena, Montana

Format: Draft Report

Reference: Department of the Interior, Office of Surface Mining, OSM/TM - 3/85, 1985

Key Index Words: Alluvial Valley Floors

Brief Description

The objective of this study was to identify surface irrigated and subirrigated sites in west central North Dakota. In addition, sites which meet the geomorphic criteria and have the potential to be surface irrigable were identified on the basis of regional agricultural practices. The authors emphasize that these maps represent a reconnaissance-level efforts.

Analysis of Conclusions

All irrigated and subirrigated valleys underlain by unconsolidated deposits were identified as potential alluvial valley floors. More detailed site specific data collection may indicate the lack of an alluvial valley floor due to unsuitable soils, topography, or water supply. These maps as well as the "Alluvial Valley Floor Identification and Study Guidelines" should be used when determining the presence or absence of an alluvial valley floor.

Title: **SNOWMELT TRACT-ELEMENT ENRICHMENTS IN PRAIRIE POTHOLES AND SOILS OF CENTRAL NORTH DAKOTA**

Authors: R.L. Houghton and J.E. Foss

Organization: U.S. Geological Survey, Bismarck, ND, NDSU - Soils Department, Fargo, ND

Format: Paper

Reference: National Atmospheric Deposition Program Technical Committee Meeting, October 8-11, 1985

Key Index Word: Trace Elements, Buffering Capacity, Prairie Potholes, Soil Properties

Brief Description

A discussion of the chemical consequences of a snowmelt event under both field and laboratory conditions, evaluating pH and trace element concentrations.

Analysis of Conclusions

A technical paper providing some insight into the buffering capacity of ferromagnesian minerals, removal of volatile trace-elements via adsorption, and a discussion of acidity based on rate of snowmelt and soil conditions (frozen or unfrozen).

Title: **MINERALOGY OF FIXED-BED GASIFICATION ASH DERIVED FROM NORTH DAKOTA LIGNITE**

Authors: R.J. Stevenson and G.J. McCarthy

Organization: North Dakota MMRRI, University of North Dakota, Grand Forks, ND, and NDSU- Department of Chemistry and Geology, Fargo, ND

Format: Paper

Reference: Presented at Materials Research Society of Boston, Dec. 1-7, 1985

Key Index Words: Coal Gasification, Fly Ash, Ash Mineralogy

Brief Description

The mineralogy of ash samples derived from North Dakota lignite and gasified in three different fixed bed producers was determined by X-ray diffraction and scanning electron microscopy. The lignite that was gasified came from the same formation but from 2 different mines separated by about 20 km. This paper presents a summary of the mineralogy of the ash samples.

Analysis of Conclusions

This and other studies have advanced our understanding of the impacts of ash disposal. Continued research in this area is necessary to evaluate the design of future ash disposal sites.

Title: **PALEOENVIRONMENTS OF THE PALEOCENE-SENTINEL BUTTE FORMATION, KNIFE RIVER AREA, WEST CENTRAL NORTH DAKOTA**

Authors: D.J. Daly, G.H. Groenewold, C.R. Schmit

Organization: North Dakota MMRRI, Univeristy of North Dakota, Grand Forks, ND

Format: Paper

Reference: Rocky Mountain Section, S.E.P.M., Denver, CO., 1985

Key Index Words: Lignite, Depositional Model

Brief Description

This paper utilizes subsurface litholoic and geophysical information to identify and study four sedimentation intervals in the Paleocene Sentinel Butte Formation of the upper Fort Union Group in West Central North Dakota. The lower Sentinel Butte is interpreted as a record of swamp (lignite components) and Pluvio-lacustrine (clastic components) conditions that alternatively dominated a broad, flat alluvial plain with drainage to the East-South-East.

Analysis of Conclusions

This paper describes the four sedimentation intervals in the lower Sentinel Butte Formation and out lines areas where further investigation is needed to develop a comprehensive depositional model for the upper Fort Union Group in the Williston Basin.

Title: **SINKHOLE DEVELOPMENT IN RECLAIMED SMECTITIC SPOIL**

Authors: M.B. Dusseault, J.D. Scott and S.R. Moran

Organization: University of Alberta and Alberta Geological Survey, Edmonton, Alta.

Format: Paper

Reference: Proceedings of the Frist Multidisciplinary Conference on Sinkholes, Orlando, FL, 1985

Key Index Words: Sinkhole, Stopping Mechanism, Subsidence, Smectitic Spoil

Brief Description

Discussion of sinkhole development on reclaimed strip mine spoil several years after leveling. Differential subsidence is described as well as mechanisms for sinkhole development. Possible mitigating procedures are also addressed.

Analysis of Conclusions

Elimination of sinkholes by filling is not difficult but the general problem of differential subsidence is the root cause and has a deleterious effect on agriculture, not only for safety concerns, but also because of ponding water with the potential for soil salinization. It is desirable to eliminate the cause rather than correct the symptoms.

Title: **ATTENUATION CAPACITY OF WESTERN NORTH DAKOTA OVERBURDEN SEDIMENTS**

Authors: D.J. Hassett and G.H. Groenewold

Organization: UND - Mining and Minerals Resource Research Laboratory, Grand Forks, ND

Format: Report

Reference: DOE Contract DE-AB18-80FC10120, 105 p, 1985

Key Index Words: Fly Ash, Waste Disposal

Brief Description

The objective of this project was to determine the cation and anion attenuation capacity of typical overburden materials from these surface mines. The sediments were evaluated in both oxidized and reduced states. The experiments were performed in which these sediments were treated with solutions of selected cations and anions at known concentrations.

Analysis of Conclusions

This and ongoing studies have advanced our understanding of the impacts of ash disposal. Continued research in this area is necessary to evaluate the design of future ash disposal sites.

Title: **HYDROLOGY OF THE WIBAUX-BEACH LIGNITE DEPOSIT AREA, EASTERN MONTANA AND WESTERN NORTH DAKOTA**

Authors: W.F. Horak

Organization: U.S. Geolgical Survey, Bismarck, ND

Format: Report

Reference: USGS Water-Resources Investigators Report 83-4157, 1985

Key Index Words: Hydrology, Wibaux-Beach Lignite Deposit, Water Resources

Brief Description

The study area encompasses the entire mineable portion of the Wibaux-Beach deposit. This area includes the Beaver Creek water course that would receive runoff from the potential mine area. Concerns for the water resources in the area prompted the study. This document established the pre-mine conditions as a standard to evaluate any changes to the system as a result of surface mining.

Analysis of Conclusions

The researchers conclude that streamflow and stream water-quality impacts can be mitigated by applying appropriate mining and reclamation techniques. Post-mining water quality within the base of the spoils is expected to increase. Potentiometric declines in the lignite aquifer is projected to be several feet up to 2 or 3 miles from the mining activity. Mining impacts on aquifers beneath the lignite are expected to be minor.

Title: **TECHNICAL BASIS FOR CODISPOSAL OF GASIFICATION AND COMBUSTION AS FROM THE PLANTS AT BEULAH, NORTH DAKOTA**

Authors: G.J. McCarthy, D.J. Hassett, O.E. Manz, G.H. Groenewold, R.J. Stevenson, K.R. Henke, and P. Kumarathasan

Organization: NDSU - Department of Chemistry, Fargo, ND, Engineering Experiment Station, MMRRI, Energy Research Center, Grand Forks, ND

Format: Paper

Reference: Materials Research Society Symposium Volume GS, 1985

Key Index Words: Fly Ash, Coal Gasification

Brief Description

The technical basis for codisposal of gasification ash from the Great Plains Gasification Associates plan, combined with cementitious "scrubber ash" and bottom ash from the adjoining Antelope Valley generating station, both located in Beulah, North Dakota, has been explored. Nine blends containing only the ashes and tap water were fabricated into cylinders and tested for compressive strength and other physical properties. A blend having the ash proportions of the two plants was tested for leachability with respect to several regulated and minor elements. Mineralogical characterization by XRD and SEM was performed on the individual waste solids and the cured mixes. Most of the blends had compressive strengths greater than 400 psi after 7-day/38°C and 28-day/21°C curing. Leaching behavior, evaluated by the EPA-EP and ASTM tests, was determined for As, Se, B, V, Mo, Ba, Sr, and K.

Analysis of Conclusions

In addition to ash proportions, curing conditions (T, pH_2O, time) and water to solid ratio appear to be key parameters in obtaining well-consolidated and lower leachability products.

Title: **NORTH DAKOTA MINING AND MINERAL RESOURCES RESEARCH INSTITUTE ANNUAL REPORT - 1985**

Authors: North Dakota MMRRI staff

Organization: North Dakota MMRRI, University of North Dakota, Grand Forks, ND

Format: Report

Reference: North Dakota Mining and Mineral Resources Research Institute Annual Report, 1985

Key Index Words: AML, Hydrology, Waste Disposal, Fly Ash, FGD waste, Lignite Resources

Brief Description

This report summarizes the objectives and results of fifteen ongoing research projects conducted at the MMRRI during July 1, 1983 to June 30, 1984. The projects include: 1) evaluation of lignite and geothermal resources, 2) reclamation of abandoned mined lands, 3) characterization, use, and disposal of power industry generated wastes, 4) overburden characterization, etc. Educational and training activities of the Institute, and a list of reports, papers, and presentations made during the report period are also included.

Analysis of Conclusions

The information contained in this report covers a wide range of research topics of practical value to the mining and power industry. However, because of the ongoing nature of most of these investigations, no final conclusions of recommendations have been given. Continued research on these projects is necessary.

Title: **DATA USES AND FINDINGS OF STREAM FLOW-GAGING PROGRAM IN NORTH DAKOTA**

Authors: G.L. Ryan

Organization: USGS Water Resources Division, Bismarck, ND

Format: Report

Reference: USGS Open-File Report 85-349, 1985

Key Index Words: Stream Flow, Surface Water, Hydrology

Brief Description

This report documents the uses, funding and availability of the stream flow data currently collected in North Dakota. As of 1984, 94 stream flow gaging stations are operated in North Dakota. Station type, data uses, and funding sources are identified for each station.

Analysis of Conclusions

Data from all stations have multiple uses. All stations have sufficient justification for continuation, but five stations primarily were used for short term research studies and were scheduled to be discontinued at the end of 1985.

Title: **TYPES, CAUSES AND EFFECTS OF INSTABILITY PHENOMENA IN RECLAIMED SPOILS AT TWO SURFACE COAL MINES IN WESTERN NORTH DAKOTA - APPENDICES**

Authors: ND Geological Survey Staff

Organization: North Dakota Geological Survey, Grand Forks, ND

Format: Report - Appendices

Reference: Bureau of Mines Contract J0275010, 1985

Key Index Words: Groundwater, Lignite

Brief Description

These data are the result of studies done by the North Dakota Geological Survey under a U.S. Bureau of Mines contract. The data were collected at Baukol-Noonan's Center Mine and North American Coal Corporation's Indian Head Mine. It consists of elevation and histories which are a measurement of vertical and horizontal movement of groundwater in reclaimed spoils.

Analysis of Conclusions

The data presented in these appendices are useful for assessing ground water recharge and movement in reclaimed spoils.

Title: **DEVELOPMENT OF A HYDROGEOLOGICAL AND HYDROGEOCHEMICAL DATA BASE FOR ABANDONED MINE LANDS - PHASE II**

Authors: G.H. Groenewold, E.C. Murphy, and R.D. Koob

Organization: North Dakota MMRRI - University of North Dakota, Grand Forks, ND, North Dakota Geological Survey, Grand Forks, ND, North Dakota State University, Fargo, ND

Format: Report

Reference: MMRRI Bulletin No. 86-02, MMRRI - 01, 1986

Key Index Word: AML, Hydrology, Hydrogeochemistry

Brief Description

This report represents the results of hydrogeological and hydrogeochemical work done at the Noonan abandoned mine site that was one of the four sites investigated in the Phase I portion of this study.

Analysis of Conclusions

Unlike recently reclaimed surface mines, this site showed only a slight increase in mineralization of subsurface waters. The conclusion was that reclamation was inappropriate in this setting.

Title: **NORTH DAKOTA MINING AND MINERAL RESOURCES RESEARCH INSTITUTE ANNUAL REPORT - 1986**

Authors: North Dakota MMRRI staff

Organization: North Dakota MMRRI, University of North Dakota, Grand Forks, ND

Format: Report

Reference: North Dakota Mining and Mineral Resources Research Institute Annual Report, 1986

Key Index Words: Waste Disposal, Fly Ash, FGD Waste, Lignite Resources, Hydrology

Brief Description

This report contains information on thirteen ongoing research projects conducted by the MMRRI staff during July 1, 1985 to June 30, 1986. Most of the projects were the same as listed in the 1985 annual report. New projects include studies on ash disposal, soil liners for fly ash disposal sites, effects of fly ash and FGD wastes on groundwater quality and environmental impacts of underground coal gasification. Educational, training and other activities and accomplishments of the MMRRI are also included.

Analysis of Conclusions

This is a valuable source of information about the research activities of the MMRRI. It covers a wide range of research topics of practical value to the mining and power industry. Continuation of these studies is strongly recommended until each study is successfully concluded.

Title: **EVAPORITE MINERALOGY ASSOCIATED WITH SALINE SEEPS IN SOUTHWESTERN NORTH DAKOTA**

Authors: M.E. Timpson, J.L. Richardson, L.P. Keller, and G.J. McCarthy

Organization: NDSU-Soil Science Dept. and Dept of Chemistry and Geology, Fargo, ND

Format: Paper

Reference: Soil Science Society of America Journal 50(2),: 490-493, 1986

Key Index Words: Salinity, Evaporite Mineralogy, Lateral Transport, Efflorescence

Brief Description

This paper discusses the mineralogic changes occurring as saline waters migrate through the soil profile, and the mineralogic composition of the saline efflorescences present at the soil surface of saline seeps.

Analysis of Conclusions

An excellent paper on the mineral crystallization sequence from the water table to the soil surface observed in saline seeps.

Title: **THE EFFECTS OF GROUNDWATER HYDROLOGY ON SALINITY IN A RECHARGE-FLOW THROUGH-DISCHARGE WETLAND SYSTEM IN ND**

Authors: J.L. Arndt and J.L. Richardson

Organization: Soil Science Dept., Fargo, ND

Format: Draft

Reference: Unpublished

Key Index Words: Salinity, Pond Permanence, Geochemistry, Groundwater Recharge, Wetlands

Brief Description

A study conducted to evaluate soil salinization in a topographic series of wetlands within a catchment. Emphasis was placed on salt distribution in the soil profile as related to groundwater movement, recharge-discharge relationships, and number and duration of ponding events. The entire process was then directly related to evapotranspiration and progressive freezing of pondwater and shallow groundwater as mechanisms of concentration.

Analysis of Conclusions

Data presented are preliminary and the study is ongoing; however, research to date indicates both progressive freezing and evapotranspiration play an important role in the evolution and morphology of wetland soils as well as salt distribution within the wetland system.

Title: **HYDROLOGY OF NEW ENGLAND - MOTT COOL AREA, NORTH DAKOTA**

Authors: M.G. Croft

Organization: U.S. Geological Survey, Bismarck, ND

Format: Report

Reference: Unpublished

Key Index Words: Lignite, Groundwater

Brief Description

The need for this investigation came about as a response to the U.S. Department of Interior request for hydrologic information on federal coal lands leased and eligible for lease within the New England - Mott lignite deposit. Study will concentrate on defining the ground water flow system and chemical characteristics and determination of surface water flow magnitudes, chemical quality, sediment concentration, and sediment load.

Analysis of Conclusions

No technical analysis is possible at this time; however, a study of this magnitude will provide information to serve as a data base for possible future mining in this area.

Title: **COMPOSITION OF ATMOSPHERIC DEPOSITION IN WESTERN NORTH DAKOTA**

Authors: R.L. Houghton

Organization: U.S. Geological Survey, Bismarck, ND

Format: Professional-Communication

Reference: Unpublished

Key Index Words: Atmospheric deposition, Trace Elements, Detection Limits

Brief Description

Study of the composition of atmospheric deposition and its effect on the hydrologic system.

Analysis of Conclusions

Conclusions are that North Dakota is receiving acidic deposition with the major contributor being sulfates from gas-flaring and coal-fired power generation. Long term studies of pH indicate an overall lowering; however, the data base is currently too small to confidently define this trend or to relate it to increased sulfur and nitrogen oxides associated with energy development.

Title: **GEOCHEMISTRY AND MICROBIOLOGY OF SULFUR IN SHALLOW GROUND WATER SYSTEMS ASSOCIATED WITH LIGNITE DEPOSITS, NORTH DAKOTA**

Authors: R.L. Houghton, R.D. Koob, G.H. Groenewold, D. Brekke

Organization: U.S. Geological Survey, Bismarck, ND

Format: Report

Reference: Unpublished

Key Index Words: Geochemistry, Groundwater

Brief Description

A detailed geochemical investigation to quantitatively describe the sulfur sources that contribute to ground water sulfates in strip mines situated in recharge zones and to determine the hydrogeochemical processes that control the sulfur path to the ground water.

Analysis of Conclusions

No technical analysis is possible at this time; however, because sulfates are the principal cause of ground water deterioration in the vicinity of lignite mines in North Dakota, it is important to define and understand the sulfur cycle so that appropriate mitigation procedures can be implemented.

Title: **PROBABLE AND OBSERVED HYDROLOGIC CONSEQUENCES OF LIGNITE STRIP MINING IN THE FORT UNION GROUP NEAR GASCOYNE IN SOUTHWESTERN NORTH DAKOTA**

Authors: R.L. Houghton

Organization: U.S. Geological Survey, Bismarck, ND

Format: Report

Reference: Unpublished

Key Index Words: Geohydrology, Lignite

Brief Description

The purpose of this investigation is to define the effects of discharge of mine-impacted ground water on the surface water system.

Analysis of Conclusions

No technical analysis is possible at this time; however, based on observed anomalous sulfate concentrations in shallow ground water systems, there appears to be problems and questions that this study will focus in on.

Title: **COAL-BASED STRATIGRAPHY FOR THE UPPER FORT UNION GROUP (PALEOCENE) WEST CENTRAL NORTH DAKOTA**

Authors: G.H. Groenewold, D.J. Daly, C.R. Schmit, and L.A. Hemish

Organization: North Dakota MMRRI, University of North Dakota, Grand Forks, ND

Format: Paper submitted to SEPM

Reference: Unpublished

Key Index Words: Fort Union Group, Lignite

Brief Description

A detailed stratigraphic framework was constructed for the Paleocene strata of the Sentinel Butte and upper Bullion Creek formations in the Knife River area in West Central North Dakota. The study sequence found to be characterized by at least seven major coals continuous over the 8000 km^2 of the study area instead of locally persistent coals as interpreted by previous investigations. Each major lignite has been named and assigned both type and reference test holes.

Analysis of Conclusions

The resulting framework provides a basis in this portion of the study area for a more accurate evaluation of the magnitude and distribution of coal reserves.

Title: **NORTH DAKOTA MINING AND MINERAL RESOURCES RESEARCH INSTITUTE ANNUAL REPORT - 1987**

Authors: North Dakota MMRRI staff

Organization: North Dakota MMRRI, University of North Dakota, Grand Forks, ND

Format: Report

Reference: North Dakota Mining and Mineral Resources Research Institute Annual Report, 1987

Key Index Words: Waste Disposal, Fly Ash, FGD Waste, Lignite Resources, Hydrology

Brief Description

This report contains information on fifteen ongoing research projects conducted/initiated by the MMRRI staff during July 1986 to June 30, 1987. Most of the projects were the same as listed in 1985 and 1986 annual reports and concentrated on evaluation of lignite resources and coal-bearing strata in North Dakota, use and disposal of energy industry generated wastes, and groundwater quality. A demonstration project to study the economic feasibility of producing mineral wool fibers from molten slag generated by cyclone boiler at the MDU's power plant at Beulah is also included in this report.

Analysis of Conclusions

Like other annual reports of MMRRI, the information included in this report covers a wide range of energy and environment related research topics of much practical value to the mining and power industry. Some of these projects require continued investigation.

Title: **PREVENTION OF GROUND-WATER QUALITY DEGRADATION DURING RECLAMATION OF A URANIFEROUS LIGNITE MINE, NORTH DAKOTA**

Authors: R.L. Houghton, G.S. Anderson, S.R. Hill, J.L. Burgess, J.D. Wald, D.P. Patrick, R.L. Hall, and J.D. Unseth

Organization: U.S. Geological Survey, ND Public Service Commission, ND State Department of Health, Bismarck, ND

Format: Paper

Reference: Proceedings of Combined Fourth Biennial Billings Symposium on Mining and Reclamation in the West and the National Meeting of the American Society for Surface Mining and Reclamation, pp. G-4-1 to G-4-19, Billings, MO, March 17-19, 1987

Key Index Words: AML, Uranium, Groundwater, Salinity

Brief Description

A pilot AML reclamation project, conducted at the Palaniuk site, near Belfield, ND, to eliminate radiation hazards due to uranium in the spoil, is discussed. Reclamation plans were developed to control the principal geochemical processes that lead to mobility of uranium and associated constituents. The spoil was buried at a certain depth in the pit which effectively reduced surface radiation and radon gas to background levels. The saline spoil were selectively placed above the water table, and covered by mounded clay cap to prevent dissolution of salts and contamination of ground water. Uranium concentration in the local ground water was reported to have decreased, and the reclaimed site was considered suitable for grazing or haying use..

Analysis of Conclusions

An understanding of the local geochemical processes is crucial for developing and implementing reclamation plans for uraniferous coal mines. The success achieved in reclaiming this uraniferous abandoned mine site testifies to the above observation. However, post-reclamation monitoring of this site for a few more years would seem advisable.

Title: **NORTH DAKOTA MINING AND MINERAL RESOURCES RESEARCH INSTITUTE ANNUAL REPORT - 1988**

Authors: North Dakota MMRRI staff

Organization: North Dakota MMRRI, University of North Dakota, Grand Forks, ND

Format: Report

Reference: North Dakota Mining and Mineral Resources Research Institute Annual Report, 1988

Key Index Words: Waste Disposal, Fly Ash, FGD Waste, Lignite Resources, Hydrology, Trace Elements

Brief Description

This report contains information on sixteen ongoing research projects conducted/initiated by the MMRRI staff during July 1, 1987 to June 30, 1988. Most of the projects were the same as listed in 1987 annual report. Work on lignite resource evaluation, use/disposal technology for fly ash and other energy industry waste products, and characterization of overburden and gasification ashes and phases continued. Information about the educational and training activities, staff, and MMRRI advisory committee is also included.

Analysis of Conclusions

The information contained in this report covers a wide range of energy and environment related research topics of much practical value to the mining and power industry. Some of these projects will require continued investigation.

Title: **NORTH DAKOTA MINING AND MINERAL RESOURCES RESEARCH INSTITUTE ANNUAL REPORT - 1989**

Authors: North Dakota MMRRI staff

Organization: North Dakota MMRRI, University of North Dakota, Grand Forks, ND

Format: Report

Reference: North Dakota Mining and Mineral Resources Research Institute Annual Report, 1989

Key Index Words: Waste Disposal, Fly Ash, FGD Waste, Lignite Resources, Hydrology, Trace Elements

Brief Description

This report contains information on thirty four ongoing research projects conducted/initiated by the MMRRI staff during July 1, 1988 to June 30, 1989. Only a few of these projects are related directly to mining and reclamation. A project on bacterial desulfurization of coal has just begun. Work on lignite resource evaluation, use/disposal technology for fly ash and other energy industry waste products, and characterization of overburden and gasification ashes and phases continued. Also projects on technical feasibility of underground gassification are included. Information on two National Mine Land Reclamation supported projects (1. Groundwater movement and chemical evolution from the root zone to water table: and 2. Stabilization of underground mine voids by filling with coal conversion residual materials) is provided. The report includes educational and training activities of the MMRRI, its staff and the advisory committee.

Analysis of Conclusions

The information contained in this report covers a wide range of energy and environment related research topics of much practical value to the mining and power industry. Some of these projects will require continued investigation.

Title: **ENERGY & ENVIRONMENTAL RESEARCH CENTER; NORTH DAKOTA MINING AND MINERAL RESOURCES RESEARCH INSTITUTE ANNUAL REPORT - 1990**

Authors: Energy & Environmental Research Center Staff

Organization: EERC and MMRRI, University of North Dakota, Grand Forks, ND

Format: Report

Reference: Energy & Environmental Research Center and North Dakota Mining and Mineral Resources Research Institute Annual Report, 1990

Key Index Words: Waste Disposal, Fly Ash, FGD Waste, Lignite Resources, Hydrology, Trace Elements, AML, Underground Gasification

Brief Description

This report contains technical information on several lignite mining and reclamation related projects conducted or initiated by the EERC and MMRRI staff during July 1, 1989 to June 30, 1990. Of particular interest are the projects that focus on coal resource evaluation, underground coal gasification, National Mine Land reclamation project, an AML project conducted at the Fritz mine, and some waste disposal and utilization technology.

Analysis of Conclusions

The information contained in this report covers a wide range of energy and environment related research topics of much practical value to the mining and power industry. Some of these projects are on-going.

Title: **ENERGY & ENVIRONMENTAL RESEARCH CENTER; NORTH DAKOTA MINING AND MINERAL RESOURCES RESEARCH INSTITUTE ANNUAL REPORT - 1991**

Authors: Energy & Environmental Research Center Staff

Organization: EERC and MMRRI, University of North Dakota, Grand Forks, ND

Format: Report

Reference: Energy & Environmental Research Center and North Dakota Mining and Mineral Resources Research Institute Annual Report, 1991

Key Index Words: Waste Disposal, Fly Ash, FGD Waste, Lignite Resources, Hydrology, Trace Elements, AML, Underground Gasification

Brief Description

This report contains information on several lignite mining and reclamation related projects conducted or initiated by the EERC and MMRRI staff during July 1, 1990 to June 30, 1991. Of particular interest are the projects that focus on coal resource evaluation, underground coal gasification, National Mine Land reclamation project, an AML project conducted at the Fritz mine, and waste disposal and utilization technology. Most of the projects are the same as summarized in the previous year's annual report, with any additional work accomplished during the current review period.

Analysis of Conclusions

The information contained in this report covers a wide range of energy and environment related research topics of much practical value to the mining and power industry.

Title: **STUDIES OF ACIDIC MINE SPOIL AND WATER QUALITY IN AN ABANDONED MINE IN WESTERN NORTH DAKOTA**

Authors: R.D. Butler, J. Solc, and V. Kuhnel

Organization: Energy & Environmental Research Center, University of North Dakota, Grand Forks, ND

Format: Abstract

Reference: Achieving Land use Potential Through Reclamation; Proceedings of the 9th Annual National Meeting of the American Society for Surface Mining and Reclamation, 536p., Duluth, Minnesota, June 1992

Key Index Words: AML, Salinity, Water Quality

Brief Description

This prereclamation study was conducted for the ND Public Service Commission to evaluate radiation hazard and potential to generate acid leachate in the abandoned mine spoils of Fritz Mine in western North Dakota. Laboratory tests on saturated pastes of 3200 spoil samples for vertical profiles of pH and EC indicated a significant potential for acid leachate with high amounts of dissolved solids. However, leachates collected in the field with pressure-vacuum porous cup lysimeters showed a more neutral, fresher water being generated in most locations. The discrepancy between the lab and field observations was explained as being possibly due to the greater amounts of water and mixing that are employed to make the saturated pastes. This would result in increased mineral/water interaction resulting in greater dissolution of solids and acid generation. X-ray diffraction analysis showed pyrite and other iron- and sulfur- bearing minerals in the spoil, with natrojarosite the most abundant and pyrite the least.

Analysis of Conclusions

The technique employed in this study, and the eventual mapping of the area with respect to salinity and other hazards distribution in the spoils, helped develop a reclamation plan for the site that was successfully implemented. This offers a good example of how scientific investigation can be productively coupled with the actual reclamation of an abandoned mine site. This type of study is useful for developing plans for slope stability, revegetation and groundwater protection.

Title: **ENERGY & ENVIRONMENTAL RESEARCH CENTER ANNUAL REPORT - 1992**

Authors: Energy & Environmental Research Center Staff

Organization: Energy & Environmental Research Center, University of North Dakota, Grand Forks, ND

Format: Report

Reference: Energy & Environmental Research Center Annual Report, 1992

Key Index Words: Waste Disposal, Fly Ash, FGD Waste, Lignite Resources, Hydrology, Trace Elements, AML, Underground Gasification

Brief Description

This report contains information on several mining and reclamation related projects conducted or initiated at the EERC during July 1, 1991 to June 30, 1992. Of particular interest to coal mining and reclamation are the projects that focus on advanced technologies, applied chemistry, energy policy, environmental microbiology, groundwater and waste management, national mineland reclamation, and underground coal gasification. Most of the projects are the same as summarized in the previous year's annual report, with any additional work accomplished during the current review period.

Analysis of Conclusions

The information contained in this report covers a wide range of energy and environment related research topics of much practical value to the mining and power industry.

Title: **ENERGY & ENVIRONMENTAL RESEARCH CENTER ANNUAL REPORT - 1993**

Authors: Energy & Environmental Research Center Staff

Organization: Energy & Environmental Research Center, University of North Dakota, Grand Forks, ND

Format: Report

Reference: Energy & Environmental Research Center Annual Report, 1993

Key Index Words: Waste Disposal, Fly Ash, FGD Waste, Lignite Resources, Hydrology, Trace Elements, AML, Underground Gasification

Brief Description

This report, among many other topics, contains information on several projects related to coal resource development, utilization, reclamation, groundwater, and waste management that were conducted or initiated at the EERC during July 1, 1992 to June 30, 1993.. Most of these projects are the same as summarized in the previous year's annual report, with any additional work accomplished during the current review period. The format of the report is different from that of the previous year.

Analysis of Conclusions

The information contained in this report covers a wide range of energy and environment related research topics of much practical value to the mining and power industry.

Title: **ENERGY & ENVIRONMENTAL RESEARCH CENTER BIENNIAL REPORT - 1995**

Authors: Energy & Environmental Research Center Staff

Organization: Energy & Environmental Research Center, University of North Dakota, Grand Forks, ND

Format: Report

Reference: Energy & Environmental Research Center Annual Report, 1993-1995

Key Index Words: Waste Disposal, Fly Ash, FGD Waste, Lignite Resources, Hydrology, Trace Elements, AML, Underground Gasification

Brief Description

This report, among many other topics related to energy and environment, contains information on coal resource development and utilization, reclamation, groundwater, and waste management, that were conducted or initiated at the EERC during July 1, 1993 to June 30, 1995.. Several of these projects are the same as summarized in the previous year's annual report, with any additional work accomplished during the current review period. The format of the report is different from that of the previous year.

Analysis of Conclusions

The information contained in this report covers a wide range of energy and environment related research topics of much practical value to the mining and power industry.

Title: **HYDROLOGIC CHARACTERIZATION OF WETLANDS IN SURFACE COAL MINELANDS OF NORTH DAKOTA**

Authors: P.P. Sharma and R.D. Butler

Organization: NDSU- Land Reclamation Research Center, Mandan, and UND- Energy & Environmental Research Center, Grand Forks, ND

Format: Abstract

Reference: Decades Later: A Time for Reassessment; Proceedings of 12th National ASSMR Meeting, pp. 839, Laramie, Wy, 1995

Key Index Words: Wetlands, Groundwater Recharge, Hydrology

Brief Description

This abstract of a poster presentation provides a brief account of a study on hydrology of various types of wetlands associated with surface coal minelands in North Dakota. The main emphasis was on the types of monitoring instruments used at the six study sites, with some brief discussion of preliminary results.

Analysis of Conclusions

The authors caution that the desirable near- and sub-surface hydroecological attributes of wetlands, associated with surface mines in North Dakota, may not be sustainable in normal and dry years.

Title: **COMPARATIVE ASSESSMENT OF GROUNDWATER CHEMISTRY EVOLUTION AT THREE ABANDONED MINES AND ITS PRACTICAL IMPLICATIONS**

Authors: J. Solc

Organization: UND- Energy & Environmental Research Center, Grand Forks, ND

Format: Abstract

Reference: Successes and Failures: Applying Research Results to Insure Reclamation Success; Proceedings of 13th Annual Meeting of the American Society for Surface Mining and Reclamation, pp. 826, Knoxville, Tennessee, May 1996

Key Index Words: Groundwater, Hydrology, Hydrologic Modeling

Brief Description

Hydro- and geochemical processes involved in pore and groundwater chemistry were investigated at three abandoned mine sites (Fritz, Indian Head, and Velva mines) in North Dakota. Site characteristics and differences were determined by using the geochemical model MINTEQUA2 and statistical analysis. The site differences were mostly related to the gypsum saturation index (Na, Mg, Ca) and Sodium. At the Fritz site about 80-90% soil samples showed saturation paste pH of less than 5.5. At other sites the pH was above 5.5. Fritz site had also higher salinity compared to the others sites. Increases tendency for gypsum saturation within the vadose zone of disturbed sites was noted. This was related to increased concentration of sulfate ions resulting from mineral oxidation.

Analysis of Conclusions

The author claims that geochemical modeling, statistical analysis, and soil extract pH and EC measurements proved to be reliable, fast, and cost-effective for assessing soil acidity, the extent of oxidation zone, and the potential of negative effect on pore and groundwater chemistry of these abandoned sites. The usefulness of these interpretative techniques in assessing pre-mine characteristics is also emphasized.

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MINING AND RECLAMATION (MR)

Title: **STUDY OF THE SPOIL BANKS ASSOCIATED WITH LIGNITE STRIP MINING IN NORTH DAKOTA**

Authors: C.G. Carlson and W.M. Laird

Organization: North Dakota Geological Survey, Grand Forks, ND

Format: Report

Reference: North Dakota Geological Survey, Miscellaneous Series 24. 28p., 1964

Key Index Words: AML, Mine Inventory

Brief Description

This report provides an inventory of 34 mined areas in western North Dakota which were surveyed by the authors to evaluate reclamation efforts made at these mines. Problems related to spoil reclamation are also discussed.

Analysis of Conclusions

The information provided in this report is useful for understanding pre-law reclamation status of several mines in North Dakota.

Title: **KNIFE RIVER SPOILS BANK STUDY**

Author: T.A. Gwynn

Organization: Knife River Coal Mining Company, Bismarck, ND

Format: Report

Reference: Knife River Coal Mining Company Private Records, 1964

Key Index Words: Revegetation, Spoil Properties, Planting Techniques,

Brief Description

This is a progress report of mine spoil reclamation efforts conducted by Knife River Coal Mining company's North and South Beulah mines in Mercer County, North Dakota. The work described took place during 1963 and 1964, and involved laboratory analyses of spoil materials, experimentation with field planting techniques, and communication with other researchers. The report also includes recommendations for future work.

Analysis of Conclusions

The results reported are based on reclamation techniques that were being followed at the time when there was no reclamation law in North Dakota, and segregation and respreading of topsoil was not practiced. This information may be useful in reclaiming abandoned mined lands.

Title: **REHABILITATION OF THE LIGNITE AREAS OF NORTH DAKOTA FOLLOWING SURFACE MINING**

Author: T.A. Gwynn

Organization: Knife River Coal Mining Company, Bismarck, ND

Format: Paper

Reference: Symposium on the Great Plains of North Dakota (C.C. Zimmerman and S. Russell, ed.), pp. 129-137. The North Dakota Institute for Regional Studies, Fargo, ND, 1967

Key Index Words: Revegetation, Erosion

Brief Description

This paper presents a compilation of reclamation data and information about surface coal mines in North Dakota. It is based on literature review and personal communications.

Analysis of Conclusions

The information presented may be useful for reclamation and revegetation of abandoned mined lands.

Title: **AN IMPROVED ENVIRONMENT THROUGH INTELLIGENT MINED LAND RECLAMATION**

Author: T.A. Gwynn

Organization: Knife River Coal Mining Company, Bismarck, ND

Format: Paper

Reference: AIME 1969 Fall Meeting, Preprint No. 69-F.343, 31p., Salt Lake City, UT, September 1969

Key Index Words: Reclamation Law, Revegetation, Legislation

Brief Description

The author discusses reclamation problems in general and the extent of reclamation conducted in the Northern Rockies and the Great Plains states. Reclamation laws, then in force, in North Dakota, Montana, and Wyoming are discussed. The difference in the reclamation problems and practices in the western and eastern United States are also addressed.

Analysis of Conclusions

This paper is of general information value.

Title: **REVEGETATION OF SOME NORTH DAKOTA LIGNITE STRIP MINE SPOIL BANKS**

Author: K.B. Switzer

Organization: University of North Dakota, Grand Forks, ND

Format: Thesis

Reference: M.S. Thesis, University of North Dakota, Grand Forks, ND, 1969

Key Index Words: Revegetation, Spoil Properties

Brief Description

Reported in this thesis are mine spoil reclamation efforts that were made at the North and South Beulah mines of Knife River Coal Mining Company in Mercer County, North Dakota from 1963 to 1968. The work involved literature research, laboratory analyses of spoil samples and experimentation with field planting techniques.

Analysis of Conclusions

This study was conducted when there were no reclamation laws in North Dakota, and revegetation efforts were mostly conducted directly on the spoil material without any topsoiling.

Title: **THE NORTH DAKOTA SURFACE MINING CONTROL AND RECLAMATION LAW**

Author: R.E. Beck

Organization: University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Some Environmental Aspects of Strip Mining in North Dakota (M.K. Wali, ed.), pp. 109-118. North Dakota Geological Survey Educational Series 5, 1973

Key Index Words: Reclamation Law, Revegetation, Performance Standards, Legislation

Brief Description

This paper reviews North Dakota's reclamation law as of 1973, indicating how it deals with particular reclamation problems. The author supplies his conclusions on the effectiveness of the reclamation law in accomplishing reclamation.

Analysis of Conclusions

This paper has a historical significance only, because since 1973 many changes in the North Dakota reclamation law have occurred.

Title: **A HISTORICAL OVERVIEW OF STRIP MINE RECLAMATION IN NORTH DAKOTA**

Author: I.T. Dietrich

Organization: North Dakota State University, Fargo, ND

Format: Paper

Reference: Some Environmental Aspects of Strip Mining in North Dakota (M.K. Wali, ed.), pp. 49-51. North Dakota Geological Survey, Education Series 5, 1973

Key Index Words: Revegetation, Topsoil

Brief Description

A brief historical overview of reclamation of surface mined lands in North Dakota is presented. The efforts of North Dakota Game and Fish Department and other agencies, dating back to late 1930's, in reclaiming some spoil banks are highlighted. Based on literature research and personal communication with people involved in research, the author has emphasized the importance of leveling and topsoiling in the reclamation of spoil banks.

Analysis of Conclusions

This paper provides some information of historical interest.

Title: **ENVIRONMENTAL IMPLICATIONS OF DEVELOPING OUR COAL RESERVES**

Author: T.A. Gwynn

Organization: Knife River Coal Mining Company, Bismarck, ND

Format: Paper

Reference: Some Environmental Aspects of Surface Mining in North Dakota (M.K. Wali, ed.), pp. 87-107. North Dakota Geological Survey Educational Series 5, 1973

Key Index Words: Revegetation, Legislation

Brief Description

This paper presents a historical overview of mine spoil reclamation problems in western North Dakota and the authors conclusions on the adequacy of present reclamation efforts. A summary of the state's surface mining and reclamation laws as of 1973 and a tabulation of various reclamation costs are also given.

Analysis of Conclusions

Useful for general information about earlier reclamation efforts in North Dakota.

Title: **ENVIRONMENTAL IMPACT OF STRIP MINING: THE ECONOMIC AND SOCIAL VIEWPOINT**

Authors: T.A. Hertsgaard and F.L. Leistritz

Organization: North Dakota State University, Fargo, ND

Format: Paper

Reference: Some Environmental Aspects of Surface Mining in North Dakota (M.K. Wali, ed.), pp. 73-85. North Dakota Geological Survey Educational Series 5, 1973

Key Index Words: Mining Impacts, Environmental Factors

Brief Description

This paper present the authors' conclusions about the economic and social aspects of strip mining in western North Dakota. Market values of farmland in the lignite mining area are discussed in relation to the economics of various reclamation practices. Also, possibility of the development of gasification industry and its socioeconomic impacts are considered.

Analysis of Conclusions

This is an important paper regarding socioeconomic impacts of surface mining in western North Dakota.

Title: **ENVIRONMENTAL IMPACT OF SURFACE MINING: THE BIOLOGIST'S VIEWPOINT**

Author: R.L. Morgan

Organization: North Dakota State Game and Fish Department

Format: Paper

Reference: Some Environmental Aspects of Strip Mining in North Dakota (M.K. Wali, ed.), pp. 61-71, North Dakota Geological Survey Educational Series 5, 1973

Key Index Words: Revegetation, Environmental Factors

Brief Description

This paper presents a brief review of the biological impacts of surface mining in the U.S. and particularly North Dakota. The adequacy of reclamation efforts made during early 70's is also discussed.

Analysis of Conclusions

The information presented is of general interest with emphasis on preserving the environmental quality in areas of surface mining activity.

Title: **RECLAMATION PROCESSES IN THE WESTERN COAL MINES**

Author: T.A. Gwynn

Organization: Knife River Coal Mining Company, Bismarck, ND

Format: Paper

Reference: AIME 1974 Annual Meeting, Preprint No. 74-F-82, 35p., Dallas, TX, February 1974

Key Index Words: Revegetation, Reclamation Law, Mine Inventory, Legislation

Brief Description

This paper itemizes all the surface coal mines in Arizona, Colorado, Montana, New Mexico, North Dakota, and Wyoming. Reclamation laws and statutory requirements of various western states are discussed and their variation from laws in the east are explained. Earth moving and other reclamation costs have been tabulated.

Analysis of Conclusions

This paper provides a general information regarding earlier surface mining laws in western states.

Title: **REHABILITATION POTENTIAL AND LIMITATIONS OF SURFACE MINED LAND IN THE NORTHERN GREAT PLAINS**

Author: P.E. Packer

Organization: USDA-FS, Intermountain Forest and Range Experiment Station, Ogden, UT

Format: Report

Reference: USDA-Forest Service General Technical Report INT-14, pp. 44, July 1974

Key Index Words: Revegetation, Environmental Factors, Spoil Properties

Brief Description

Factors such as the amounts and distribution of precipitation, soil productivity and stability, and suitability and availability of native vegetation for revegetation have been analyzed for each surface mineable coal-bearing area in portions of North Dakota, Montana, and Wyoming, to determine the revegetation potential for each area. Also discussed are the revegetation efforts which were being conducted on most of the mines in the Northern Great Plains, the cost of revegetation, and the legal basis for enforcement of regulations.

Analysis of Conclusions

This paper developed the concept of rehabilitation-response units, based on environmental factors. Much useful information has been presented.

Title: **CAN PRODUCTIVITY OF MINED LAND BE RESTORED IN WESTERN NORTH DAKOTA ?**

Authors: J.F. Power, W.O. Willis, F.M. Sandoval, and J.J. Bond

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: North Dakota Agricultural Experiment Station Farm Research 31(6):30-32, 1974

Key Index Words: Spoil Properties, Productivity

Brief Description

Described in this paper are problems that may be encountered in the reclamation of surface mined land in North Dakota, based mostly on the study of physical and chemical properties of overburden and some field experimentation conducted during 1970-73. Possible ways of correcting these problems to restore productivity are outlined.

Analysis of Conclusions

This is a general article describing the state of our knowledge about reclamation problems and their solutions as understood a couple of decades back; since then a more comprehensive picture about reclamation has emerged.

Title: **MINED LAND RECLAMATION ON THE NORTHERN GREAT PLAINS - INDIAN HEAD MINE**

Authors: T.C. Dudley and J.L. Becker

Organization: North American Coal Corporation, Bismarck, ND

Format: Paper

Reference: Mining Congress Journal 61(4):18-23, 1975

Key Index Words: Reclamation, Revegetation, Geohydrology

Brief Description

This paper presents a general overview of reclamation research that was being conducted in the Northern Great Plains by USDA-ARS, NDSU, and MSU, and discusses the reclamation practices followed at North American Coal Corporation's Indian Head Mine during the mid 70's.

Analysis of Conclusions

This paper is of general interest highlighting the importance of topography, climate, soil, native vegetation and wildlife, spoil properties and ground water hydrology in reclamation of specific areas.

Title: **STRIP MINING TECHNIQUES TO MINIMIZE ENVIRONMENTAL DAMAGE IN THE UPPER MISSOURI BASIN STATES**

Author: F.H. Persee

Organization: USDI, Bureau of Mines

Format: Report

Reference: USDI, Bureau of Mines Information Circular No. 8685, p. 53, 1975

Key Index Words: Waste Disposal, Water Quality

Brief Description

The report reviews both proven and untried methods of mined land reclamation. The information was collected from related literature dealing with mining in Montana, North Dakota, South Dakota, Wyoming and parts of Canada. Disposal of refuse and waste materials is also discussed.

Analysis of Conclusions

The techniques of reclamation and revegetation discussed in this report are based on the state-of-the-art which existed prior to the enactment of federal reclamation law.

Title: **PROGRESS REPORT ON RESEARCH ON RECLAMATION OF STRIP MINED LAND IN THE NORTHERN GREAT PLAINS**

Authors: J.F. Power, R.E. Barker, E.J. Doering, R.E. Ries, F.M. Sandoval, W.O. Willis, A. Bauer, G. Gee, J. Gilley, P. Nyren, F. Schroer, and W. Whitman

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND and NDSU-North Dakota Agricultural Experiment Station, Fargo, ND

Format: Report

Reference: USDA-ARS, Northern Great Plains Research Center, and NDSU-North Dakota Agricultural Experiment Station Progress Report, April 1975

Key Index Words: Spoil Properties, Amendments, Topsoil, Water Management

Brief Description

This report summarizes the results of various reclamation research projects that were being conducted by ARS and NDSU around that time. Limited research was being done in the areas of spoil/overburden characterization, use of amendments and topsoiling, water and nutrient relations of spoil plant systems etc. Plots with 2, 6, and 12 inches of topsoil had been established.

Analysis of Conclusions

Only preliminary findings had been made at this time which provided a basis for additional reclamation research in North Dakota.

Title: **FACTORS RESTRICTING REVEGETATION OF STRIP MINE SPOILS**

Authors: J.F. Power, R.E. Ries, F.M. Sandoval and W.O. Willis

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Proceedings of the Fort Union Coal Field Symposium (W.F. Clark, ed), pp. 336-346, Montana Academy of Science, Billings, MT, 1975

Key Index Words: Revegetation, Soil Properties, Plant Responses

Brief Description

This paper summarizes the field and laboratory studies initiated in 1970 at the Northern Great Plains Research Center, Mandan, North Dakota to develop technology for reclamation of surface mined lands. The objectives of research were to 1) determine the physical and chemical characteristics of spoils and overburden in major coal fields in the Fort Union Region, 2) evaluate the influences of these properties on the growth of various plant species and 3) develop reclamation methods whereby mined land could be restored to a level of productivity equal to or exceeding that which existed before mining.

Analysis of Conclusions

Studies summarized in this paper provided an impetus for further research work on problems and practices of mined land reclamation.

Title: **ANNUAL MINE MAPS SUBMITTED BY MINE OPERATORS: 1919-1975**

Authors: North Dakota, State Coal Mine Inspection Department

Organization: North Dakota State Coal Mine Inspection Department, Workman's Compensation Safety Division, Bismarck, ND

Format: Reports

Reference: North Dakota State Coal Mine Inspection Department Reports, 1919-1975

Key Index Words: AML, Mine Inventory

Brief Description

During the years that the State Coal Mine Inspection Department regulated mining in North Dakota, (1919-1975), every operator of every active mine was required to submit maps of their mine on a yearly basis. These maps were required for every seam being mined, constructed at a scale not less than 1 inch equals 200 feet and included the mine designation, the county and township it was located in, the north point and scale, the company or owners, and the surveyor's certificate. Maps depicting mines which had underground workings were required to show additionally all shafts, slopes, tunnels or other openings to the surface or other workings, all excavations, entries, rooms and crosscuts, the rise or dip of the seam, the location of permanent equipment, and the location of standing water. A surface map was also required and showed legal boundaries, lots, streets, railroads, rivers, ponds, streams, buildings and land marks. The mapping was required each year the mine was active and just prior to closing or abandoning the mine. There are approximately 190 final maps in the file.

Analysis of Conclusions

These reports provide a valuable source of information particularly for the abandoned mine lands program.

Title: **STATE COAL MINE INSPECTOR'S REPORT (ANNUAL): 1919-1975**

Authors: North Dakota, State Coal Mine Inspection Department

Organization: North Dakota State Coal Mine Inspection Department, Workman's Compensation Safety Division, Bismarck, ND

Format: Reports

Reference: North Dakota State Coal Mine Inspection Department Reports, 1919-1975

Key Index Words: AML, Mine Inventory

Brief Description

These reports contain information about all coal mines operating in the state of North Dakota during the years that mining was regulated by the State Coal Mine Inspection Department (1919-1975). Items contained in these reports include: the name, address, and operator of each mine active during that year, yearly production by county and by mine, the number and type of mines in each county, and the number of employees at each mine.

Analysis of Conclusions

These reports provide a valuable source of information particularly for the abandoned mine land program in North Dakota.

Title: **APPENDIX D: LOCATION OF LANDS DISTURBED BY PRE-1970 LIGNITE MINING**

Author: K. Thompson

Organization: North Dakota State Outdoor Recreation Agency, Mandan, ND

Format: Report

Reference: 1975 North Dakota SCORP: State Comprehensive Outdoor Reclamation Plan, 1975

Key Index Words: AML, Mine Inventory

Brief Description

This appendix is a compilation of data form Soil Conservation Service aerial photos and files. The appendix includes the acreages and legal descriptions of areas disturbed by lignite mining. The areas are presented by county with the mine owner's name given where known and they are divided into those areas disturbed by strip mining and those disturbed by subsidence above underground mines.

Analysis of Conclusions

The information provided in this report should be useful to abandoned mine land program.

Title: **MINING, STRIP -- WESTERN UNITED STATES**

Author: J.F. Power

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Article

Reference: McGraw-Hill Yearbook of Science and Technology, pp.303-305, 1976

Key Index Words: Revegetation, Environmental Factors

Brief Description

This article summarizes the problems and requirements for proper reclamation of mind lands in the western United States. The causes of the problems are explained and the available technology of reclaiming mined areas is reviewed.

Analysis of Conclusions

This article is good for general information on the subject of reclamation of surface miend lands in the arid and semi-arid west. However, because of many regulatory changes and technological advances made since 1976, this information is in need of updating.

Title: **MANAGEMENT OF MINE WASTES IN THE WESTERN UNITED STATES**

Authors: G.E. Schuman, W.A. Berg, and J.F. Power

Organization: USDA-ARS, Cheyenne, WY, Colorado State University, Ft. Collins, CO, USDA-ARS, Mandan, ND

Format: Paper

Reference: Land Application of Waste Materials (T.M. McCalla, ed.), pp. 180-184, Soil Conservation Society of America Meeting, Ankeny, IA, 1976

Key Index Words: Environmental Factors, Spoil Properties

Brief Description

This paper contains a compilation of reclamation data for the western United States.

Analysis of Conclusions

This paper is useful for general information on the problems of reclamation of surface mined lands in the western United States. The approaches followed in reclaiming the spoil banks are discussed.

Title: **NORTH DAKOTA PROGRESS REPORT ON RESEARCH ON RECLAMATION OF STRIP MINED LANDS - UPDATE 1977**

Authors: R. Barker, A. Bauer, E. Doering, L. Hofmann, R. Lorenz, J. Power, G. Reichman, R. Ries, F. Sandoval, T. Brown, G. Gee, F. Schroer, and W. Whitman

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND, and NDSU-North Dakota Agricultural Experiment Station, Fargo, ND

Format: Report

Reference: USDA-ARS, Northern Great Plains Research Center, and NDSU-North Dakota Agricultural Experiment Station Progress Report, March 1977

Key Index Words: Spoil Properties, Salinity, Sodicity, Amendments, Topsoil, Fertilizer Use, Water Management

Brief Description

This report provides a summary of the various ARS and NDSU reclamation research projects that were in progress in 1977. Results and preliminary conclusions are given for such studies as pre-mining characterization of the soil, overburden and vegetation resources, soil erosion and land stability, salt and sodium related problems, chemical reclamation, topsoiling, nutrient deficiencies and their correction, and vegetation establishment and utilization. This report contains some of the preliminary results of soil wedge plots set up by the ARS.

Analysis of Conclusions

This report is based on the premise that for successful reclamation of mined lands in the Northern Great Plains, enhancement of vegetative growth through proper understanding and management of soil overburden/spoil and plant resources is necessary. Some of the reported finding should be considered preliminary because the experiments on which they are based were still ongoing. The report recognizes that there are other areas of research (not addressed in the report) which are equally important to the development of reclamation technology.

Title: **RECLAMATION PRACTICES IN THE NORTHERN GREAT PLAINS COAL PROVINCE**

Author: R.C. Barth

Organization: Colorado School of Mines Research Institute, Golden, CO

Format: Paper

Reference: Mining Congress Journal 63(5):60-64, 1977

Key Index Words: Revegetation, Erosion

Brief Description

This paper reviews information, based on field observation, regarding the reclamation practices followed in Montana, North Dakota, South Dakota, Nebraska, and Wyoming.

Analysis of Conclusions

A useful reference for general understanding of the reclamation techniques which were being followed in the northern great plains in mid seventies.

Title: **PROTECTION OF SOIL AND WATER RESOURCES ON LAND DISTURBED BY MINING**

Authors: J.F. Power and O.L. Bennett

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND, and Appalachian Soil and Water Conservation Research Laboratory, Beckley, WV

Format: Paper

Reference: Proceedings of the Second National EPA Conference on Energy/Environment, Washington, DC, pp. 195-201, 1977

Key Index Words: Erosion, Hydrology

Brief Description

This paper discusses problems related to surface mining and reclamation in eastern and western United States. The reclamation research efforts of the USDA-Agricultural Research Service are reviewed and areas needing additional research are pointed out.

Analysis of Conclusions

This paper has general information value about the reclamation problems and the research conducted and needed to solve the problems

Title: **STRIP MINING - GETTING THE ENERGY WHILE KEEPING THE ENVIRONMENT**

Authors: J.F. Power, F.M. Sandoval, and R.E. Ries

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Article

Reference: Crops and Soils 29(4):12-14, 1977

Key Index Words: Spoil Properties, Topsoil

Brief Description

This article reviews the problems encountered in reclamation and outlines the technologies developed through research to overcome these problems. Included are discussions of current technology, moisture conservation, bulk density, soil fertility, sodicity and salinity of soils and spoils, and some benefits of covering spoils with soil material.

Analysis of Conclusions

Useful for general information on reclamation problems and their mitigation as was possible by the then available technology.

Title: **RECLAMATION OF DISTURBED LANDS IN THE LIGNITE AREA OF THE NORTHERN PLAINS**

Authors: R.E. Ries, F.M. Sandoval, and J.F. Power

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Technology and Use of Lignite (G.H. Groenewold and W.R. Kube, compliers), pp. 309-327, Energy Research and Development Administration, and University of North Dakota, Grand Forks, ND, GFERC/IC-77/1, 1977

Key Index Words: Soil Properties, Revegetation

Brief Description

This paper gives an overview of the reclamation work that was being conducted by the Northern Great Plains Research Center in 1977. It recommended analyzing soil and overburden in the laboratory before mining, removing and stockpiling suitable soil materials (a layer up to 5 feet thick, if available), removing overburden, extracting coal, reshaping spoil, replacing stockpiled soil material, fertilizing, and seeding to cropland or rangeland mixtures of plant species. Piping erosion, subsidence, and establishing vegetation with sustained productivity are considered as existing problems which would require additional work.

Analysis of Conclusions

This paper is important in that it provided some early guidelines for reclaiming mined lands in the Northern Great Plains.

Title: **KNOWN HISTORIC SITE SURVEY OF 21 WESTERN NORTH DAKOTA COUNTIES**

Author: D.J. Tweton

Organization: Department of History, University of North Dakota, Grand Forks, ND

Format: Report

Reference: North Dakota Regional Environmental Assessment Program Report No. 77-4, 11 p.+ Appendix, 1977

Key Index Words: AML, Historical Sites

Brief Description

The purpose of this study was to survey, locate, and evaluate the known historic sites in the 21 county area west of or east of but bordering the Missouri River. The counties are: Adams, Billings, Bowman, Burke, Burleigh, Divide, Dunn, Emmons, Golden Valley, Grant, Hettinger, McKenzie, McLean, Mercer, Morton, Mountrail, Oliver, Sioux, Slope, Stark, and Williams. Of the 1080 historic sites located by literature search and field verification, 264 were abandoned surface or underground lignite mines. The appendix to the report contains the names of the mines, the years they were actively mined, and legal descriptions of their locations at least to the section and often to the quarter or quarter quarter section.

Analysis of Conclusions

This report presents useful information regarding the location and history of some abandoned mines in western North Dakota.

Title: **ACREAGE AND GENERAL LOCATIONS OF PRE-1970 COAL MINE SPOILS IN NORTH DAKOTA**

Authors: USDA, Soil Conservation Service Staff

Organization: USDA, Soil Conservation Service, Bismarck, ND

Format: Report (unpublished)

Reference: USDA, Soil Conservation Service, unpublished record, 1977

Key Index Words: AML, Mine Inventory

Brief Description

This unpublished document contains inventory of acreages and general locations of areas strip mined in North Dakota prior to 1970. The information is presented by individual counties. This inventory may not contain 100% of the strip mined areas but is believed to be an extensive inventory available.

Analysis of Conclusions

The information provided in this unpublished report should be useful to abandoned mine land program in North Dakota.

Title: **SUMMARY OF CURRENT RECLAMATION RESEARCH OF THE NORTHERN GREAT PLAINS RESEARCH CENTER**

Authors: R.E. Barker, A. Bauer, J.D. Berdahl, E.J. Doering, A.B. Frank, J.E. Gilley, L. Hofmann, S. Melsted, S.D. Merrill, M. Pole, J.F. Power, G.A. Reichman, R.E. Ries, F.M. Sandoval and A.C. Wilton

Organization: USDA-SEA, Northern Great Plains Research Center, Mandan, ND, and North Dakota State University, Fargo, ND

Format: Report

Reference: Science and Education Administration (USDA) and North Dakota State University (soils) Report, March 1978

Key Index Words: Revegetation, Amendments, Irrigation, Topsoil, Grazing

Brief Description

In this report are summarized the objectives and conclusions of the various ARS (USDA-SEA) and NDSU reclamation research projects that were in progress in 1978. The ARS staff was involved in 23 projects which included work on spoil properties, effects of topsoiling, fertilization, mulching, amendments etc. on the establishment and growth of vegetation, and plant responses to salts, soil texture, supplemental irrigation, grazing, etc. The NDSU projects included chemical and physical characterization of shaped mined lands, properties of stockpiled materials, runoff, and erosion, water quality of impoundments, and fertilizer requirements.

Analysis of Conclusions

Some of the conclusions summarized in this report are based on experiments which had not been completed at that time. However, though preliminary in nature, the results and conclusions of these studies are highly useful in understanding the soil and revegetation problems involved in reclamation of mined lands and in providing some answers to these problems.

Title: **ATLAS OF WESTERN SURFACE MINED LANDS: COAL, URANIUM, AND PHOSPHATE**

Authors: A.K. Evans, E.W. Uhleman, and P.A. Eby

Organization: USDI, Fish and Wildlife Service, Office of Biological Services, Western Energy and Land Use Team.

Format: Report

Reference: USDI, Fish and Wildlife Service Coal Project, Contract No. 14-16-0009-77-004, FWS/OBS-78/20, 302 p., 1978

Key Index Words: Mine Inventory, AML

Brief Description

Active and inactive mines in excess of ten acres in western United States have been inventoried in this report. The inventory procedure consisted of agency and owner contacts, literature research and field review of selected mines. Factors inventoried include locations, owners, summaries of mining and reclamation plans, dates and acreage of operation, reclamation histories and current conditions of the mine sites.

Analysis of Conclusions

This report should be highly useful to the abandoned mine land program in North Dakota.

Title: **RECLAMATION RESEARCH ON STRIP MINED LAND IN DRY REGIONS**

Author: J.F. Power

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper (Chapter)

Reference: Reclamation of Drastically Disturbed Lands (W. Schaller and P. Sutton, eds.), pp. 521-535, SSSA, Madison, WI, 1978

Key Index Words: Revegetation, Natural Resources

Brief Description

This report outlines the history of reclamation research in the western United States and Canada. It describes the natural resources used in reclamation, reviews the kind of research information available and the kind needed to properly utilize each of the natural resources; and shows how this information can be used in developing reclaimed land. This report is an overview of the state of the art and indicates the direction of research needed in the future.

Analysis of Conclusions

Useful for general information on reclamation of arid lands. It does not catalog the various research activities that were in progress at that time.

Title: **RECLAMATION OF COAL MINED LAND IN THE NORTHERN GREAT PLAINS**

Authors: J.F. Power, R.E. Ries, and F.M. Sandoval

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Journal of Soil and Water Conservation 33(2):69-74, 1978

Key Index Words: Spoil Properties, Water Management, Revegetation

Brief Description

This paper summarizes the problems and techniques of reclaiming mined lands in the Northern Plains. Included is a discussion of available natural resources, water and its limitations, soil fertility, and salinity. Future problems and research needed to overcome these problems are also outlined.

Analysis of Conclusions

Useful for general information on reclamation problems in the Northern Great Plains.

Title: **RESTORATION OF PRODUCTIVITY TO DISTURBED LAND IN THE NORTHERN GREAT PLAINS**

Authors: J.F. Power, F.M. Sandoval and R.E. Ries

Organization: USDA-ARS-Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: The Reclamation of Disturbed Arid Lands (R.A. Wright, ed.), pp. 33-49, University of New Mexico Press, Albuquerque, NM, 1978

Key Index Words: Spoil Properties, Erosion, Water Management

Brief Description

This paper reviews information on the effects of mining on natural resources in the Northern Great Plains. The problems associated with conserving these resources are outlined. Research derived technology that can overcome these problems is described along with foreseeable problems that require further research.

Analysis of Conclusions

The information presented is based on the level of understanding and technology which was available prior to 1978. Since then additional knowledge has been gained.

Title: **NORTH DAKOTA LAND USE ELEMENT**

Authors: State Planning Division, State of North Dakota

Organization: State Planning Division, Bismarck, ND

Format: Report

Reference: Published by State Planning Division, April 1978

Key Index Words: Land Use, Natural Resources, Resource Management

Brief Description

This document was written to provide recommended state goals, objectives, and policies for land use and natural resource management. The intent is to encourage and promote proper management of land and related resources to meet the needs of the people of North Dakota now and in the future.

Analysis of Conclusions

The contents of this document have little relevance to the reclamation of mined lands. As a philosophical statement, regarding the State's land use policy in 1978, the "North Dakota Land Use Element" succeeds well.

Title: **1979 RECLAMATION RESEARCH SUPPLEMENT TO NORTH DAKOTA PROGRESS REPORT ON RESEARCH ON RECLAMATION OF STRIP MINED LANDS - UPDATE 1977**

Authors: R. Barker, E. Doering, L. Hofmann, R. Lorenz, S. Merrill, J. Power, G. Reichman, R. Ries, F. Sandoval, A. Wilton, H. Carvallo, M. Pole, S. Melsted, F. Shorer, and C.M. Smith

Organization: USDA-SEA, Northern Great Plains Research Center, Mandan, ND and North Dakota Agricultural Experiment Station, Department of Soils, Fargo, ND

Format: Report

Reference: Agricultural Research (USDA-SEA) and North Dakota Agricultural Experiment Station, Department of Soils Report, July 1979

Key Index Words: Revegetation, Nutrient Deficiencies, Erosion, Amendments, Fertilizer Use

Brief Description

This published report provides an update to the reclamation research progress report published in 1977. Included in this report is a summary of ARS wedge plot results which indicated upward migration of sodium. The use of at least four feet of replaced soil on regraded spoil was recommended.

Analysis of Conclusions

The results and conclusions of the studies summarized in this report are very important for the development of suitable methods of reclaiming mined lands to agricultural land uses.

Title: **RANGELAND ANALYSIS AND LAND COVER: A COMPUTERIZED APPROACH**

Author: L.A. Ogaard

Organization: Department of Botany, North Dakota State University, Fargo, ND

Format: Ph.D Dissertation

Reference: Ph.D. Dissertation, North Dakota State University, 1979

Key Index Words: Land Use, Computer Application

Brief Description

A portion of this dissertation involves a comparison of several land cover studies conducted for the primary coal impact region of Mercer, McLean, and Oliver Counties. The author postulates why acreage discrepancies for land cover categories occur between these studies. The other facet of this treatise is the computerization of Soil Conservation Service technical guide data and logic to provide a quick way to characterize rangeland in terms of potential forage production and carrying capacity.

Analysis of Conclusions

Land cover acreage is tabulated and graphically depicted on a section-by-section basis at a scale of one inch to two miles for over 3000 square miles. This examination of land use in the mid-1970's provides an historic record to which reclaimed land in the future may be compared.

Title: **LAND USE ANALYSIS/TECHNICAL EXAMINATION/ENVIRONMENTAL ASSESSMENT RECORD: FALKIRK COAL LEASE APPLICATION M-31053 (ND)**

Authors: C. Steele, J. Pittman, R. Gunnufson, L. Chase, D. Rufledt, C. Pettee, K. Burke, A. Caldwell, M. Richmond, L. Cabe, B. Williams, and M. Ingeroi

Organization: Bureau of Land Management, U.S. Department of Interior

Format: Report

Reference: Bureau of Land Management Report No. MT-030-48-9-3, July 1979

Key Index Words: Land Use, Legislation, Coal Leasing

Brief Description

Land use planning, technical examination, and environmental assessment are prerequisites to federal coal leasing. This document is a record of those actions for the Falkirk Mining Company's mine near Underwood, ND. Application of unsuitability criteria, resource trade-offs, surface owner views, relationship to state and local planning and initial leasing and special stipulation recommendations are the general topics addressed within this report.

Analysis of Conclusions

This is a site specific characterization of land use at the Falkirk Mine. This report is a typical example of the land use analysis process that is triggered when federal coal is encountered.

Title: **ANNUAL REPORT, 1981: LAND RECLAMATION RESEARCH CENTER**

Authors: Land Reclamation Research Center Staff

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Land Reclamation Research Center Annual Report, 1981

Key Index Words: Topsoil, Prime Farmland, Spoil Properties, Erosion

Brief Description

This report contains summary of the research projects that the LRRC was conducting in 1981. These include investigations on the chemical and physical characteristics, surface and root zone hydrology, and plant establishment and culture on shaped surface mined lands. Also, surface and ground water problems associated with potential strip mine sites were investigated. The report also provides a discussion on the agricultural research needs for mined land reclamation.

Analysis of Conclusions

The results and conclusions provided in this report are preliminary but very useful in understanding the nature of some of the reclamation problems of reshaped mined lands and their possible solutions.

Title: **ANNUAL REPORT, 1982: LAND RECLAMATION RESEARCH CENTER**

Authors: Land Reclamation Research Center Staff

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Land Reclamation Research Center Annual Report, 1982

Key Index Words: Topsoil, Prime Farmland, Spoil Properties, Erosion

Brief Description

This report contains a summary of the LRRC research projects being conducted in 1982, projects proposed for 1983, and agricultural research needs for mined land reclamation. Additional data on the projects listed in the 1981 Annual Report is presented. This report also includes a summary of LRRC's initial prime farmland research projects and a discussion of sodium migration in reclaimed soils .

Analysis of Conclusions

The results and conclusions provided in this report are very useful in understanding the nature of some of the reclamation problems of reshaped mined lands and their possible solutions.

Title: **A DECADE OF RESEARCH ON RECLAMATION OF SURFACE COAL MINED LANDS IN NORTH DAKOTA**

Author: N.M. Safaya

Organization: North Dakota Public Service Commission, Bismarck, ND

Format: Paper

Reference: Agronomy Abstract p. 37-38, 1982

Key Index Words: Revegetation, Research Needs

Brief Description

This paper, presented in the American Society of Agronomy meeting in Anaheim, CA, provided an overview of the reclamation research conducted in North Dakota. Developments in research on the problems and practices of surface mined land reclamation were traced from those of the earlier efforts at soil and overburden characterization to the currently followed multidisciplinary approach involving research on landscape stability, hydrogeochemistry, soil reconstruction and amelioration, soil - plant relations and plant adaptability, revegetation methods and management, and plant succession on abandoned and active mined lands. Additionally, an elaborate list of current and future reclamation research needs was also presented.

Analysis of Conclusions

The review of reclamation research conducted in North Dakota indicated that there is a tremendous need for synthesizing the available data and develop additional information in a number of areas in a manner that makes the development of predictive models possible. Future research needs should be carefully evaluated and geared to provide solutions to high priority problems. The necessity for shifting the emphasis from analytical to synthetical type of research was stressed.

Title: **RECLAMATION RESEARCH IN NORTH DAKOTA**

Authors: E.C. Doll, G.A. Halvorson, S.A. Schroeder, and N.C. Wollenhaupt

Organization NDSU-Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: North Dakota Agricultural Experiment Station Farm Research 41(6):36-39, 1983

Key Index Words: Research Needs, Soil Replacement, Soil Water, Topography

Brief Description

This paper provides an overview of LRRC reclamation research program in North Dakota. Mining impacts to the state, the development of reclamation technology, and the history of USDA/ARS reclamation research in North Dakota are briefly discussed. Future research programs need to focus on the interrelationships between topographic configuration, soil respread depths, postmining land use planning, and other factors in order to suggest ways to achieve optimum reclamation at the lowest practical cost.

Analysis of Conclusions:

Useful for general information on past and present LRRC research programs and specific future research needs in mined land reclamation.

Title: **COMPUTER APPLICATIONS IN THE REGULATION OF SURFACE COAL MINING AND RECLAMATION: THE NORTH DAKOTA EXPERIENCE**

Authors: L.A. Ogaard and N.M. Safaya

Organization: North Dakota Public Service Commission, Bismarck, ND

Format: Paper

Reference: Agronomy Abstract P. 39, 1983

Key Index Words: Computer Application,

Brief Description

This paper presentation, made in the American Society of America Meeting in Washington, D.C., discusses the North Dakota Public Service Commission's computerized system for management of data bases on ground and surface water monitoring and bonding information, and for the development of pre- and post-mining topography, area slope, difference, and other maps with the use of interactive graphics. The functional aspects of this computerized data processing system were discussed in relation to the regulatory needs.

Analysis of Conclusions

The importance of computerization for regulatory purposes is emphasized.

Title: **ANNUAL REPORT, 1984: LAND RECLAMATION RESEARCH CENTER**

Authors: Land Reclamation Research Center Staff

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Unpublished Progress Report

Key Index Word: Research Needs, Soil Development, Water Use, Revegetation

Brief Description

This report summarizes the results of research projects conducted by LRRC during 1984. These projects included investigations of soil development and stability, water relations and vegetative reestablishment on reshaped mined lands. Also included is a summary of predictive model development for reclamation planning.

Analysis of Conclusions:

The information which is presented is not conclusive, but is useful for understanding research problems and approaches.

Title: **LRRC REPORT TO NORTH DAKOTA LEGISLATIVE COUNCIL, 1984**

Authors: Land Reclamation Research Center Staff

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Unpublished Progress Report

Key Index Word: Sodium Migration, Prime Farmland, Runoff, Erosion

Brief Description

This report summarizes the results of research projects on optimum depths of soil replacement, sodium and salt movement in reclaimed soils, prime farmland, runoff and erosion, and restoration of productivity on reclaimed soils. Recommendations for implementation of the results of some of these studies are also given.

Analysis of Conclusions:

This report is an excellent summary of recent LRRC research projects and also provides useful recommendations for application of results in policy making.

Title: **PHYSICAL AND CHEMICAL METHODS FOR ENHANCING PRODUCTIVITY OF ABANDONED MINE LANDS IN THE NORTHERN GREAT PLAINS**

Authors: S.D. Merrill and N.M. Safaya

Organization: USDA-ARS Northern Great Plains Research Center, Mandan, ND, and Public Service Commission, Bismarck, ND

Format: Paper

Reference: Proceedings of the National Symposium and Workshops on Abandoned Mine Land Reclamation (L.L. Schloesser, G.S. Anderson, N.M. Safaya, D.J. Thompson, eds.), pp. 563-600, Bismarck, ND, 1984

Key Index Words: Abandoned Mine Land, Amendments, Topsoil, Nutrient Deficiencies

Brief Description

This paper describes the methods of reclaiming abandoned mine lands, with emphasis on landscape restoration, surface manipulation, and ameliorative additives. The use of soil and good quality overburden materials, organic and inorganic amendments and fertilizers in enhancing vegetation establishment and productivity are discussed.

Analysis of Conclusions

The reclamation techniques discussed in this paper apply to a wide range of conditions encountered at both abandoned and currently mined lands. Some of these techniques have proved quite successful.

Title: **LRRC REPORT TO NORTH DAKOTA LEGISLATIVE COUNCIL, 1985**

Authors: Land Reclamation Research Center Staff

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: LRRC Report to North Dakota Legislative Council, 1985

Key Index Words: Revegetation, Prime Farmland, Productivity, Soil Development, Topography, Runoff, Erosion

Brief Description

This report summarizes the results and conclusions of studies conducted on: 1) prime farmland soil productivity, 2) productivity indices for reclaimed lands, 3) depth of soil replacement, and 4) erosion and runoff from reclaimed lands. Recommendations made included: 1) that mixing of similar prime and nonprime subsoil materials should be allowed, 2) the requirements for segregating prime and nonprime topsoil materials should be relaxed, 3) soil parameters and vegetative vigor should be used to evaluate reclamation success, 4) soil replacement depths should be adjusted based on physical and chemical properties of the underlying spoil, and 5) runoff and erosion data should be used to adjust constants in equations used for determining the size of sediment ponds.

Analysis of Conclusions:

The results and conclusions presented in this report are the same as given in the 1985 LRRC annual report.

Title: **1985 MINE-LAND RECLAMATION RESEARCH REVIEW**

Authors: Land Reclamation Research Center and Northern Great Plains Research Laboratory Staff

Organization: NDSU - Land Reclamation Research Center, and USDA-ARS Northern Great Plains Research Center, Mandan, ND

Format: Report

Reference: Presented at: Reclamation Research Review, Bismarck, ND, March 19, 1985

Key Index Word: Spoil Properties, Productivity, Water Use

Brief Description

This report summarizes research results from ongoing projects conducted by USDA-ARS and NDSU-LRRC as presented at the Reclamation Research Review meeting held in Bismarck in March 1985.

Analysis of Conclusions:

The results and conclusions which are presented are only tentative, but provide useful information about current problems in reclamation research and approaches being taken to study those problems.

Title: **PRIME LAND RECLAMATION IN NORTH DAKOTA - A STATUS REPORT**

Authors: E.C. Doll

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Land Reclamation Research Center Technical Report No. 7, 1986

Key Index Words: Prime Soils, Prime Farmland, Revegetation, Topsoil, Topography, Reclamation Law

Brief Description

This report presents: 1) a brief discussion of the laws and rules governing reclamation of prime farmland, 2) an overview of research on prime soils conducted in North Dakota, and 3) a proposed experimental program for additional research needed to improve reclamation of prime farmlands in terms of both quality and cost. Factors related to the productivity of western North Dakota soils are also discussed.

Analysis of Conclusions:

The need for additional research on prime soils has been emphasized. The author has suggested that at least three factors must be studied to determine the reasons for productivity differences that exist between prime and non-prime soils. These factors include: 1) topographic position effects on soil moisture, 2) differences in prime and non-prime topsoil characteristics and their relation to productivity, and 3) the effect of prime topsoil depths on productivity. The research program proposed in this report deserves funding and support.

Title: **ANNUAL REPORT-1986, LAND RECLAMATION RESEARCH CENTER**

Authors: Land Reclamation Research Center Staff

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Land Reclamation Research Center Annual Report, 1986

Key Index Words: Revegetation, Prime Farmland, Productivity, Soil Development, Topography, Runoff, Erosion.

Brief Description

This report summarizes the results of ongoing research projects conducted by LRRC during 1986, and provides some background information about the Center's scientists, advisory committee, and other professional activities. The overall objectives were the same as given in LRRC's 1985 annual report. However, the specific projects conducted to meet those objectives included: 1) topographic control of soil-water content, 2) management and water relations of reshaped minelands, 3) vegetative re-establishment on mine lands, and 4) site specific land reclamation systems.

Analysis of Conclusions:

As ongoing studies from previous years, the general methodology of these projects has remained largely unchanged. Some new data has been added, but the need for continued research on these projects has been indicated.

Title: **LRRC REPORT TO NORTH DAKOTA LEGISLATIVE COUNCIL, 1986**

Authors: Land Reclamation Research Center Staff

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: LRRC Report to North Dakota Legislative Council, 1986

Key Index Words: Revegetation, Productivity, Prime soils, Erosion, Runoff

Brief Description

This report contains research findings and recommendations regarding: 1) prime farmland soil productivity, 2) productivity indices for reclaimed lands, 3) soil replacement depths, and 4) Runoff and erosion from reclaimed lands. Productivity difference in prime and non-prime soils were attributed to moisture differences due to topographic position. Research on the development of productivity indices included data collection for quantification and modeling of topography - soil water relationships. Studies on the development of a model which would predict the properties of regraded spoils based on pre-mine overburden data continued. runoff and erosion studies revealed that hte constants now being used for the Universal Soil Loss Equation (USLE) are not adequate for use on reshaped spoil.

Analysis of Conclusions:

The report recommends that requirements for segregation of prime and non-prime topsoil materials should be allowed; evaluation of reclamation success should be made on the basis of soil parameters and plant vigor and production; OSM should approve adoption of new regulations allowing soil replacement thickensses to be based on the properties of regraded spoils; and new constants developed by LRRC for the USLE should be used. The report also mentions that erosion and runoff from the reclaimed lands is effectively controlled when the total ground cover is 70% or more.

Title: **ENVIRONMENTAL TRAINING TO MAINTAIN REGULATORY COMPLIANCE AT A SURFACE COAL MINE**

Authors: J.D. Friedlander

Organization: Coteau Properties Company, Freedom Mine, Beulah, ND

Format: Paper

Reference: Proceedings of the Fourth Biennial Symposium on Surface Mining and Reclamation on the Great Plains, and Fourth Annual Meeting of the American Society for Surface Mining and Reclamation, pp. c-1-1 to c-1-3, Billings, MO, 1987

Key Index Words: Training, Safety, Policy

Brief Description

This paper describes the importance and actual procedures of training followed at the Coteau Properties Company's Freedom Mine in North Dakota. Coteau provides all new miners general environmental training, focusing on soil and water handling, history of reclamation, regulatory inspection procedures, permit requirements, dust control, blasting operations, sign and setback requirements, and handling of hazardous wastes. Refresher courses in each operation and engineering area are given annually, and continuos training is provided through memo, news flyers, displays, and a bulletin board. Personal responsibility and team effort for environmental compliance is stressed.

Analysis of Conclusions

The information provided in this paper is very useful in that it can serve as a model for other mining companies to tailor their training programs. A well trained mining and reclamation staff is essential for meeting the high standards of compliance, preventing environmental damage, and reducing the risks to human health and safety.

Title: **ANNUAL REPORT- 1987: LAND RECLAMATION RESEARCH CENTER**

Authors: Land Reclamation Research Center Staff

Organization: NDSU - Land Reclamation Research Center, Mandan, ND40

Format: Report

Reference: Land Reclamation Research Center Annual Report, 1987

Key Index Words: Revegetation, Prime Farmland, Productivity, Soil Development, Topography, Runoff, Erosion

Brief Description

This report summarizes the results of four ongoing research projects conducted by LRRC during 1987, and provides some background information about the Center's staff and facilities, advisory committee, and other professional activities. The main objectives of research were the same as reported for 1985 and 1986; e.g., prime farmland soil productivity; development of productivity indices for reclaimed land; soil replacement depths; and runoff and erosion on reclaimed land. However, the specific studies to meet these objectives included: 1) soil development and stability on reclaimed minelands, 2) management of water relations of reshaped minelands, 3) vegetative reestablishment on mined lands, and 4) site specific land reclamation systems. These studies concentrated on determining the effects of soil construction and age, and initial cropping on physical properties of mine soils, comparisons of physical properties of soil reclaimed under prime and nonprime regulations; soil properties and root distribution in reclaimed and undisturbed soils, spatial variability in the properties of regraded spoils; and topographic effects on erosion, runoff, soil moisture, productivity etc.

Analysis of Conclusions:

These studies showed that during the reclamation process, soil compaction and disruption of macropore channels result in the respread subsoil. Therefore, critical levels for bulk density and saturation conductivity need to be established. The effects of deep tillage and different methods of respreading soil materials on compaction were initiated. Regarding the productivity of prime VS: nonprime soils, it was concluded that topography plays a more important role than the soil materials themselves. Attempts to predict properties of regraded spoil from the pre-mine overburden data were not successful.

Title: **LRRC REPORT TO NORTH DAKOTA LEGISLATIVE COUNCIL, 1987**

Authors: Land Reclamation Research Center Staf

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Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: LRRC Report to North Dakota Legislative Council, 1987

Key Index Words: Revegetation, Productivity, Prime Soils, Erosion, Runoff, Saturation Percentage, Compaction, Bulk Density

Brief Description

This report contains research findings and recommendations regarding: 1) prime farmland soil productivity, 2) productivity indices, 3) soil replacement depths and 4), runoff and erosion from reclaimed lands. The 1987 results of these ongoing studies were similar to those reported to the legislative committee in 1986. Differences in soil moisture because of topographic position was formed as the main cause for differences in the productivity of prime and non-prime soils. Work on development of productivity indices continued and included evaluation of bulk density, pore-size distribution and hydraulic conductivity. Studies on the spatial variability in regraded-spoil properties, and attempts to develop a model which could predict these properties on the basis of pre-mine overburden characteristics, indicated that the current methods of regrading spoils make it difficult to apply such a model. Use of saturation percentage (SP) as a parameter for determining respread thicknesses of topsoil plus subsoil was considered as an unnecessary cost to reclamation. Higher runoff from reclaimed areas was found to be due to higher bulk density, lower macropore content, and lower rate of water movement in the reclaimed soils.

Analysis of Conclusions:

The recommendations made in this report are essentially the same as those made in the 1986 report. However, this report also recommended that the use of SP parameter for determining soil respread depths be dropped because SP evaluation has very little practical value. However, this recommendation is based on the fact that 58% of spoil samples, whose SAR was between 12 - 20, had SP values less than 95. Since there were about 42% samples (SAR 12 - 20) which had SP values greater than 95, the recommendation to drop SP parameter seems to be premature.

Title: **1987 MINE-LAND RECLAMATION RESEARCH REVIEW**

Authors: Land Reclamation Research Center and Northern Great Plains Research Center Staff

Organization: NDSU - Land Reclamation Research Center and USDA-ARS Northern Great Plains Research Center, Mandan, ND

Format: Report

Reference: Mined-Land Reclamation Research Review, Bismarck, ND, February 24, 1987

Key Index Words: Revegetation, Spatial Variability, Bulk Density, Topography, Water Use, Sodicity, Saturation Percentage

Brief Description

This report contains thirteen presentations that were made at the Reclamation Research Review held in Bismarck in February 1987. Each presentation summarized the results of a specific reclamation research project conducted by the LRRC or ARS staff. The subjects covered include soil, spoil and revegetation studies conducted on North Dakota mined lands.

Analysis of Conclusions:

The results reported are from completed as well as ongoing studies. Some of these results were previously published. The conclusions drawn from the unpublished results are only tentative and subject to change. Overall, the report contains much useful information, which will be helpful to the lignite industry, regulatory agency and the scientist working on reclamation research.

Title: **LRRC REPORT TO NORTH DAKOTA LEGISLATIVE COUNCIL, 1988**

Authors: Land Reclamation Research Center staff

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: LRRC Report to North Dakota Legislative Council, 1988

Key Index Words: Revegetation, Productivity, Prime Soils, Erosion, Runoff, Saturation Percentage, Compaction, Bulk Density

Brief Description

This report contains research findings and recommendations regarding: 1) prime farmland soil productivity, 2) productivity indices, 3) soil replacement depths, and 4) runoff and erosion. The 1988 results of these ongoing studies were similar to those reported to the legislative committee in 1986 and 1987.

Analysis of Conclusions:

This report reiterates the conclusions and recommendations that were made in the previous years' reports to the Legislative Council. Consideration to topographic configuration for returning prime soils to original productivity is emphasized. It is recommended that the PSC Reclamation Division, coal companies, and LRRC research staff should develop tentative criteria for bond release evaluations. Elimination of saturation percentage parameter for determining soil respread depths is also recommended again in this report.

Title: **AN OVERVIEW OF TWO DECADES OF REGULATION OF SURFACE COAL MINING AND RECLAMATION IN NORTH DAKOTA**

Authors: W.E. Dodd, J.R. Deutsch, E.E. Englerth, and N.M. Safaya

Organization: North Dakota Public Service Commission, Reclamation Division, Bismarck, ND

Format: Paper

Reference: Proceedings of the Conference "Reclamation, A Global Perspective," (D.G.Walker, C.B.Powter and M.W. Pole, eds.), pp. 471-479, Calgary, Alberta, August 1989

Key Index Words: Reclamation Law, Resource Management, Lignite

Brief Description

This paper presents information on the history, importance, and impacts of lignite mining in North Dakota, and on the development of a regulatory program to control the environmental impacts of mining. Mining and reclamation laws enacted by the state since 1969 are reviewed, and their impacts on the state's lignite industry and on the environment are discussed.

Analysis of Conclusions

Lignite coal mining and its regulation in North Dakota has had a unique history. This paper is recommended to those with an interest in the development of the state's lignite industry and the parallel development of a regulatory program to control the environmental impacts of mining.

Title: **MINING AND RECLAMATION OF PRIME FARMLANDS IN WESTERN NORTH DAKOTA**

Authors: J.D. Friedlander

Organization: Coteau Properties Company, Freedom Mine, Beulah, ND

Format: Paper

Reference: Proceedings of the Conference "Reclamation, A Global Perspective," (D.G.Walker, C.B.Powter and M.W. Pole, eds.), pp. 447-457, Calgary, Alberta, August 1989

Key Index Words: Prime Farmland, Prime Soils, Reclamation Law

Brief Description

Federal and state regulations for prime farmland reclamation are more stringent than those for non-prime areas. These entail special segregation of prime topsoils and a minimum total respread depth of 48" on reclaimed prime farmland areas. Since previous research indicates that favorable landscape position is the most important factor in distinguishing prime from non-prime areas in North Dakota, it is suggested that some of the special requirements for prime farmlands are unnecessary and sometimes counterproductive. Data comparing prime and non-prime soils and illustrations of the operational inefficiency of prime farmland reclamation are presented. Recommendations for statutory changes that would enhance reclamation, reduce environmental disturbance, and lower costs for prime farmland reclamation are also given.

Analysis of Conclusions:

Federal and state agencies that regulate mining place high value on prime farmlands. Therefore a high emphasis is placed on conservation of these areas. This paper is important in identifying the characteristics of prime farmlands in North Dakota and in suggesting more efficient ways of enhancing success of the reclamation of cropland areas, both prime and non-prime, in the state.

Title: **LRRC REPORT TO NORTH DAKOTA LEGISLATIVE COUNCIL, 1989**

Authors: NDSU - Land Reclamation Research Center Staff

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: LRRC Report to North Dakota Legislative Council, 1989

Key Index Words: Revegetation, Productivity, Prime Soils, Erosion, Runoff, Saturation Percentage, Compaction, Bulk Density

Brief Description

This report contains research findings and recommendations regarding: 1) prime farmland reclamation, 2) productivity indices, 3) soil replacement depths and 4), runoff and erosion from reclaimed lands. It is concluded that the yield differences between the prime and the nonprime soils are primarily due to their topographical location. Therefore, it is recommended that the USDA Soil Conservation Service should be urged to approve mixing of prime and suitable non-prime topsoils. The research on productivity indices showed that in most cases complete restoration of properties (viz. bulk density, pore size distribution, and hydraulic conductivity) in the reclaimed soils to their premine levels is not needed for optimum production. It is claimed that the data on productivity indices research and that obtained from run off and erosion studies will help LRRC to develop criteria for evaluation of reclamation success for bond release. Research on predicting soil replacement requirement for graded and recontoured spoils based on overburden properties has not yielded easily useable results. However, the report recommends that the parameter of Saturation Percentage is not needed for determining soil respread thicknesses and must be eliminated from the existing reclamation rules. No recommendations have been made in the report based on runoff and erosion studies.

Analysis of Conclusions:

The recommendations made in this report are essentially the same as those made in the 1986, '87, and '88 reports to the North Dakota Legislative Council.

Title: **1989 MINED-LAND RECLAMATION RESEARCH REVIEW**

Authors: Land Reclamation Research Center and Northern Great Plains Research Center Staff

Organization: NDSU - Land Reclamation Research Center, and USDA - ARS Northern Great Plains Research Center, Mandan, ND

Format: Report

Reference: Mined-Land Reclamation Research Review, Bismarck, ND, March 21, 1989

Key Index Words: Revegetation, Spatial Variability, Bulk Density, Topography, Water Use, Grazing, Sodicity, Hydraulic Conductivity

Brief Description

This report contains eleven presentations that were made at the Reclamation Review held in Bismarck in March 1989. Each presentation summarized the results of a specific reclamation research project conducted by the LRRC and ARS staff. The subjects covered include soil, spoil, revegetation, and animal production studies conducted on North Dakota mined lands. One of the presentations was based on a growth chamber study of morphology of grass seedlings as affected by planting depth.

Analysis of Conclusions:

The results reported are from completed as well as ongoing research projects. Some of these results were previously published. The conclusions drawn from the unpublished results are only tentative and subject to change. Overall, the report contains much useful information, which will be helpful to the lignite industry, regulatory agency and the scientists working on reclamation research.

Title: **LRRC REPORT TO NORTH DAKOTA LEGISLATIVE COUNCIL, 1990**

Authors: Land Reclamation Research Center Staff

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: LRRC Report to North Dakota Legislative Council, 1990

Key Index Words: Revegetation, Productivity, Prime Soils, Erosion, Runoff, Saturation Percentage, Compaction, Bulk Density

Brief Description

This report contains research findings on the following mining and reclamation aspects, and provides suggestions for implementing these into the regulatory program: 1) criteria for evaluating reclamation success for bond release based on vegetative reestablishment and soil parameters, 2) effect of postmine topography on soil moisture levels and crop yields, 3) effects of reclamation techniques on soil compaction and productivity, and 4), methods of evaluating and controlling run-off and erosion from reclaimed lands. The results of an experiment on water infiltration at the Indian Head mine, and the studies conducted at the Center and Glenharold mines on soil parameters related to grassland productivity, would be used to establish optimum levels of the soil parameters critical to productivity on reclaimed lands. Research on topographical effects on soil moisture and yield were conducted at the Center, Falkirk, and Freedom Mines. Drought conditions in 1989 caused poor yields and the results were inconclusive. Tillage treatments to alleviate compaction were conducted at the Center, Freedom, Beulah and Glenharold Mines, but the results were again inconclusive. No runoff/erosion studies were conducted in 1989.

Analysis of Conclusions

No specific or new conclusions have been drawn. Although four recommendations have been made, they are non-specific and essentially promissory of working closely with the regulatory agency and the lignite industry.

Title: **ANNUAL REPORT-1985, LAND RECLAMATION RESEARCH CENTER**

Authors: Land Reclamation Research Center Staff

Organization: NDSU - Land Reclamation Research Center

Format: Report

Reference: Land Reclamation Research Center Annual Report, 1985

Key Index Words: Revegetation, Prime Farmland, Productivity, Soil Development, Topography, Runoff, Erosion

Brief Description

This report summarizes the results of ongoing research projects conducted by NDSU-LRRC during 1985, and provides some background information about the center's scientists, advisory committee, and general objectives. Specific projects include: 1) soil development and stability on reclaimed lands, 2) management and water relations of reshaped minelands, 3) vegetative establishment on mined lands, and 4) site specific land reclamation systems. These projects were aimed to address prime farmland soil productivity, development of productivity indices for reclaimed lands, soil replacement depths, and erosion and runoff on reclaimed lands.

Analysis of Conclusions:

The results of the completed and ongoing studies presented in this paper are very useful to the mining industry as well as the regulatory agency. Continuation of these studies, with the exception of determining optimum soil replacement thicknesses for graded spoils of different quality, is strongly urged.

Title: **1991 MINE-LAND RECLAMATION RESEARCH REVIEW**

Authors: Land Reclamation Research Center and Northern Great Plains Research Center Staff

Organization: NDSU - Land Reclamation Research Center, and USDA - ARS Northern Great Plains Research Center, Mandan, ND

Format: Report

Reference: Mined-Land Reclamation Research Review, Bismarck, ND, March 21, 1991

Key Index Words: Revegetation, Spatial Variability, Bulk Density, Topography, Water Use, Grazing, Sodicity, Hydraulic Conductivity

Brief Description

This report contains twelve presentations that were made at the Reclamation Review conference held in Bismarck in March 1991. Each presentation summarized the results of a specific reclamation research project conducted by the LRRC and ARS staff. The topics covered include: 1) use of alternative soil materials and chemicals in reclamation, 2) sample adequacy for ground cover, 3) relation of cover to erosion, 4) relation of topography to moisture and yield, 5) soil moisture in undisturbed lands, 6) root zone hydrology, 7) compaction, root development and yield, 8) relation of soil depth to cover, yield and diversity of reclaimed grasslands, 9) water infiltration in mineland profiles, 10) physical properties on prime and nonprime soils, 11) reclamation of brine contaminated soils, 12) grass seedling establishment.

Analysis of Conclusions:

The report contains much useful information, which will be helpful to the lignite industry, regulatory agency and the scientists working on reclamation research. However, the conclusions drawn in some studies were tentative and subject to change because the project was not completed.

Title: **TOPOGRAPHIC EFFECTS ON SPRING WHEAT YIELDS AND WATER USE**

Authors: G.A. Halvorson and E.C. Doll

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: Soil Science Society of America Journal 55(6) 1680-1685, 1991

Key Index Words: Topographic Factor, Topography, Water Use, Productivity

Brief Description

The effects of landscape (hence, water distribution) on water use and wheat yield were studied over a period of five years at two locations in North Dakota. At each location, four soil series (Tonka, Bowbells, Williams and Zahl) occupying different topographic positions were monitored. Topographic factor was calculated at each site by measuring the slope in four directions and adding the slopes together. A positive topographic number would indicate that the site would receive water by runon, and a negative number would indicate that water would runoff from the site. Topographic factors were calculated for field locations 3, 6, 15, and 30 m apart from each other. Wheat yields were generally correlated to water use, but when the topographic factor was included in the regression of yield vs. total water use , the coefficient of determination increased, especially in the normal wet years.

Analysis of Conclusions:

The topographic factor provides a quantitative method to measure water distribution in a landscape. In mineland reclamation where the disturbed land has to be graded to a specified topography, this line of research will help develop better productivity models. Conversely, it will also help to make decisions as to the type of topography a mined area may need to be returned to.

Title: **LRRC REPORT TO NORTH DAKOTA LEGISLATIVE COUNCIL, 1991**

Authors: NDSU - Land Reclamation Research Center Staff

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: LRRC Report to North Dakota Legislative Council, 1991

Key Index Words: Revegetation, Productivity, Prime Soils, Erosion, Runoff, Saturation Percentage, Compaction, Bulk Density

Brief Description

This report contains research findings on the following mining and reclamation aspects, and provides suggestions for implementing these into the regulatory program: 1) criteria for evaluating reclamation success for bond release based on vegetative re-establishment and soil parameters, 2) effect of postmine topography on soil moisture levels and crop yields, 3) effects of reclamation techniques on soil compaction and productivity, and 4), methods of evaluating and controlling run-off and erosion from reclaimed lands. Infiltration studies at Indian Head and velva Mines showed that hydraulic conductivity of reclaimed soils are significantly lower than the undisturbed soils. This was attributed to low permeability of micropores and lack of macropores due to spreading, layering and compaction during reclamation. Grassland productivity was found to be related more to the topographic position than to the thickness of replaced soil. However, unlike wheat, forage yields were unaffected by topographic position. In experiments with different tillage treatments (applied to respread subsoil and topsoil) compaction was not alleviated in subsoil. Work on estimation of soil losses from reclaimed lands continued.

Analysis of Conclusions

A model to quantify the relationship of soil and landscape factors to productivity was developed. If future testing validates the model, it will be of much use to the industry. Beta or mosaic diversity was rated as a better index of diversity large reclaimed tracts than alpha diversity. Alleviation of compaction by topsoil or subsoil tillage methods was found to be ineffective. These and other conclusions discussed in this report make it valuable to the industry and the regulatory agency

Title: **LRRC REPORT TO NORTH DAKOTA LEGISLATIVE COUNCIL, 1992**

Authors: Land Reclamation Research Center Staff

Organization: NDSU- Land Reclamation Research Center and Agricultural Experiment Station , Mandan, ND

Format: Report

Reference: LRRC Report to North Dakota Legislative Council, 1992

Key Index Words: Revegetation, Productivity, Prime Soils, Erosion, Runoff, Saturation Percentage, Compaction, Bulk Density

Brief Description

Like the 1991 report presented to the North Dakota Legislative Council, this report contains research findings on the following mining and reclamation aspects, and provides suggestions for implementing these into the regulatory program: 1) criteria for evaluating reclamation success for bond release based on vegetative re-establishment and soil parameters, 2) effect of postmine topography on soil moisture levels and crop yields, 3) effects of reclamation techniques on soil compaction and productivity, and 4), methods of evaluating and controlling run-off and erosion from reclaimed lands.

Analysis of Conclusions

A model to quantify the relationship of soil and landscape factors to productivity was developed. If future testing validates the model, it will be of much use to the industry. Beta or mosaic diversity was rated as a better index of diversity large reclaimed tracts than alpha diversity. Alleviation of compaction by topsoil or subsoil tillage methods was found to be ineffective. These and other conclusions discussed in this report make it valuable to the industry and the regulatory agency.

Title: **ANNUAL REPORT- 1992, LAND RECLAMATION RESEARCH CENTER**

Authors: Land Reclamation Research Center Staff

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Land Reclamation Research Center Annual Report, 1992

Key Index Words: Revegetation, Prime Farmland, Productivity, Soil Development, Topography, Runoff, Erosion

Brief Description

This report summarizes the results of seven ongoing research projects conducted by LRRC during 1992. Three of the projects (6101, 6102, 6103) were supported by state appropriated moneys and the remaining (5801, 5802, 5804, and 5805) by grant funds. Project 5801: Relations of compaction and soil physical parameters to productivity of reclaimed soils. --No consistent effects on soil bulk density or productivity were noted following different tillage treatments. Project 5802: Surface and root zone hydrology of mined lands. --Research conducted at the Indian Head and Velva Mines indicated that the hydraulic conductivity and hence subsoil recharge of reclaimed mine lands is significantly lower than the undisturbed lands due to low permeability of miropores and lack of macropores. Project 5804: Seedstocks enhancement for conservation reserve program. --Near infrared reflectance spectroscopy (NIRS) technique for plant material analysis for various quality components was used to develop calibration equations for western grasses. Project 5805: Wetland hydrology of minelands. -- Initiated in 1992, this project aims to investigate the groundwater recharge potential of natural, reclaimed and abandoned mineland wetlands. Project 6101: Soil development on reclaimed minelands. --Started in 1986 and continued through 1992, this project studied temporal changes in soil properties of reclaimed prime and nonprime soils. Bulk density of replaced topsoils decreased over time due to organic matter accumulation. No significant changes occurred in the respread subsoils. Project 6102: Management and water relations of reshaped mineland. --Soil loss from reclaimed areas was in linear proportion to the extent of bare surface. Project 6103: Vegetative reestablishment on mined lands. Includes several independent studies - effects of topography on grain yield, effects of good quality spoil on wheatgrass and alfalfa, comparisons of premine overburden properties with those of the graded spoil, etc.

Analysis of Conclusions:

The report contains much useful information, which will be helpful to the lignite industry, regulatory agency and the scientists working on reclamation research.

Title: **APPLICABILITY OF U.S. ENVIRONMENTAL LAWS IN THE DEVELOPING COUNTIRES: AN ANALYSIS OF ECOLOGICAL AND REGULATORY CONCEPTS**

Authors: N.M. Safaya and M.K. Wali

Organization: North Dakota Public Service Commission, Bismarck, ND, and State University of New York, Syracuse, NY

Format: Paper (Chapter)

Reference: Environmental Rehabilitation; Preamble to Sustainable Development (M.K. Wali, ed.), pp. 143-155, SPB Academic Publishing bv, The Hague, The Netherlands, 1992

Key Index Words: Environmental Laws, Environmental Regulations, Developing Countries

Brief Description

The objectives of the paper were: 1) to provide a broad outline of four U.S. environmental laws that have a direct relevance to the degradation and rehabilitation of ecosystems, and 2) to explore ways in which the concepts and mechanisms of environmental protection in these laws can be of relevance to the developing countries. Laws pertaining to clean air, clean water, waste disposal and mining and reclamation have been briefly discussed, and the applicability of their ethics to other countries explored. The paper also provides a brief discussion on the problems, policies and perceptions currently prevailing in the U.S. and some of the developing countries in the world.

Analysis of Conclusions:

This paper provides a broad outline of some of the present day environmental concerns, and the policies and regulatory mechanisms that have been developed in the U.S. and other countries to mitigate these concerns. By focusing discussions on air, water, waste disposal, and mining and reclamation - environmental issues of closely related significance - the authors advocate that several developing countries will benefit from U.S. experience in developing policies and regulatory mechanisms designed to meet the specific problems faced by these countries.

Title: **PRESSURE GROUT RECLAMATION PROCESSES CONDUCTED INSIDE A BUILDING**

Author: B.E. Beechie

Organization: North Dakota Public Service Commission, Bismarck, ND

Format: Paper

Reference: Presented at the 15th Annual Meeting of the Association of Abandoned Mine Land Programs, Jackson, WY, September 13-15, 1993

Key Index Words: AML, Subsidence, Pressure Grouting

Brief Description

A pressure grouting reclamation project was conducted by the Public Service Commission's AML Division in the fall of 1992 at Beulah, ND. This paper describes the methodology followed in the investigation and implementation of the reclamation project. The objective of the project was to stabilize and prevent collapsing of a high use area over a 60 acre underground mine in the town of Beulah, ND. A total of 12,000 cubic yards of cementitious grout was injected into the abandoned mine workings, of which 500 cubic yards was injected from inside the Eagles Club building. The grout used consisted of powdered sodium bentonite, portland cement and sufficient water to produce a ten inch slump grout.

Analysis of Conclusions

Large scale drilling and grouting projects from inside buildings are an exception rather than the rule. Conventional methods of rotary drilling, angle drilling and grouting will suffice in most situations. However, in situations where large structures are located over a collapsing mine, conventional methods may not work and grouting from inside such structures may become necessary.

Title: **TOPOEDAPHIC UNIT ANALYSIS: A SITE CLASSIFICATION SYSTEM FOR RECLAIMED MINED LANDS**

Authors: K. Krabbenhoft, D. Kirby, M. Biondini, G. Halvorson, and D. Nilson

Organization: NDSU, LRRC, and Basin Cooperative

Format: Paper

Reference: Catena 20:289-301,1993

Key Index Words: Topoedaphic Units, Revegetation

Brief Description

This paper provides a land classification system for reclaimed mined lands based on delineation of topoedaphic units. The validity and usefulness of this classification system for evaluating revegetation success was field tested at the Glenharold Mine. Topoedaphic Units are delineated on the basis of soil physical, chemical and topographic characteristics of a reclaimed mine site. The authors claim that vegetation sampling of topoedaphic units or stratified sampling of topographic positions will provide a more objective analysis of reclamation success.

Analysis of Conclusions:

The general approach followed in this study is in agreement with the existing concept of stratified sampling. In the present case two topoedaphic units were identified, one restricted to upper slope positions and the other to the more mesic downslope positions. The authors contend that vegetation measurements and analyses required for evaluation of reclamation success, would be best done by stratifying the sampling area into topoedaphic units

Title: **LRRC REPORT TO NORTH DAKOTA LEGISLATIVE COUNCIL, 1993**

Authors: Land Reclamation Research Center Staff

Organization: NDSU- Land Reclamation Research Center and Agricultural Experiment Station , Mandan, ND

Format: Report

Reference: LRRC Report to North Dakota Legislative Council, 1993

Key Index Words: Revegetation, Productivity, Prime Soils, Erosion, Runoff, Saturation Percentage, Compaction, Bulk Density

Brief Description

This report provides data, conclusions, and recommendations based on the following 11 major projects: 1) Influence of revegetation on reclaimed mineland erosion, 2) Relation of compaction and soil physical parameters to productivity of reclaimed soils, 3) Soil development on reclaimed Minelands, 4) Predicting required spoil quality from overburden quality, 5) Use of good quality spoil and chemical amendments on abandoned minelands, 6)Comparison of the productivity of prime and nonprime topsoils, 7) Spatial variability of spring wheat yields from small watershed, 8) Topographical effects on reclaimed soils, 9) Soil depth and quality requirements for reclamation of rangeland, 10) Surface and rootzone hydrology of Minelands.'

Analysis of Conclusions

The recommendation made in this report are noteworthy. Soil loss through erosion was found to decrease linearly as the vegetative cover increases beyond 30 percent. Subsoil tillage to alleviate compaction is not effective. Predicting the quality of regraded spoil from overdurden data is difficult. Respreading good quality spoil on sodic spoil facilitates to establish vegetation on abandoned mines. The difference in prime and non prime soils with regard to crop yield is primarily water related. Lesser respread soil depths may be needed for rangeland. Reclaimed soils have less macropores which lowers their permeability.

Title: **1993 MINE-LAND RECLAMATION RESEARCH REVIEW**

Authors: Land Reclamation Research Center and Northern Great Plains Research Center Staff

Organization: NDSU - Land Reclamation Research Center, and USDA - ARS Northern Great Plains Research Center, Mandan, ND

Format: Report

Reference: Mined-Land Reclamation Research Review, Bismarck, ND, March 15, 1993

Key Index Words: Revegetation, Infiltration, Tillage, Prime soils, Spatial Variability, Cover, Erosion

Brief Description

This report contains eleven scientific papers presented at the Reclamation Review conference held in Bismarck in March 1993. Each presentation summarized the results of a specific reclamation research project conducted by the LRRC and ARS staff. The topics covered include: 1) Infiltration and soil water distribution of pre- and post-mine soil profiles, 2) Tillage influences on physical properties and forage yields, 3) soil physical properties and crop yields, 4) Effect of time after reclamation on physical properties of prime and nonprime soils, 5)Spatial variability of spring wheat yields from a small watershed, 6) Wetland hydrology of minelands, 7) Topsoil depth on reclaimed rangelands, 8) Forage & beef production and water use from seasonlong reclaimed & native pasture, 9) Erosion versus cover on revegetated reclaimed areas, 10) Comparison of premine bore hole data with regraded spoil characteristics, 11) Use of good quality spoil and chemical amendments on abandoned minelands.

Analysis of Conclusions:

The report contains much useful information, which will be helpful to the lignite industry, regulatory agency and the scientists working on reclamation research.

Title: **ANNUAL REPORT- 1994, LAND RECLAMATION RESEARCH CENTER**

Authors: Land Reclamation Research Center Staff

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Land Reclamation Research Center Annual Report, 1994

Key Index Words: Revegetation, Prime Farmland, Productivity, Soil Development, Topography, Runoff, Erosion

Brief Description

In this brief report, LRRC has listed the programmatic areas, goals, and accomplishments of their current reclamation research activity. The programmatic areas were divided into: 1)Effects of Reclamation on soil physical properties and land productivity; 2) Management of water relations of reshaped minelands; 3) Vegetative establishment of mined lands. Several goals are listed under each programmatic area. Crop yield data collected from compaction studies showed no consistent differences between chiseling and subsoiling (ripping), nor was there any effect produced by prior forage crops on wheat. Research on surface and root zone hydrology indicated severe lack of effective pore space at deeper depths in reclaimed lands. Comparative evaluation of wetland hydrology continued to be studied. Experiments on prime and nonprime soils placed at different topographical locations needed one more year of study. A new project to review soil depth requirements was initiated.

Analysis of Conclusions:

As mentioned above, some of the projects had not been completed to derive any meaningful conclusions. Research on alleviation of compaction gave disappointing results, which raises the question how this problem can be dealt with. Obviously research will have to continue on this important issue. The conclusions drawn from root zone hydrology work are very cogent and must be considered when developing reclamation plans.

Title: **QUANTIFYING TOPOGRAPHIC DIFFERENCES BETWEEN PREMINING AND RECLAIMED LANDSCAPES AT A LARGE SURFACE COAL**

Authors: J. D. Friedlander

Organization: The Coteau Properties Company, the Freedom Mine, Beulah, ND

Format: Paper

Reference: Presented at the International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of Acidic Drainage, Pittsburgh, PA, April 24-29, 1994

Key Index Words: Topography, Landuse

Brief Description

Topographic comparision of premine and reclaimed landscape was made for 2300 acres at the Freedom Mine. Weighted average slope of the entire premine acreage was 3.8% compared to 3.0% for the reclaimed. The average slope for the premine cropland was 2.7% and for the reclaimed cropland 2.1%., and for rangeland 7.0% and 5.5%, respectively. There was a 50% decrease in the rangeland acreage with slopes >9%. Thus mining and reclamation at the Freedom Mine have allowed some flattening of the topography and, thereby, loss of topographic diversity.

Analysis of Conclusions

The author believes that landscape improvement with reclamation causes loss of diversity in the terrain, which may conflict with the regulatory requirement of vegetation diversity for successful reclamation. This conclusion is not completely valid because the AOC and landuse requirements will not allow acute changes in the postmining landscapes from those existing before mining.

Title: **1995 MINELAND RECLAMATION RESEARCH REVIEW**

Authors: Land Reclamation Research Center and Northern Great Plains Research Center Staff

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Mined-Land Reclamation Research Review, Bismarck, ND, March 29, 1995

Key Index Words: Revegetation, Infiltration, Tillage, Prime Soils, Spatial Variability, Cover, Erosion

Brief Description

This report contains abstracts of fourteen scientific papers presented by the NDSU-LRRC, PSC, OSM, NRCS and USDA-ARS staff, at the Reclamation Review conference held in Bismarck in March 1995. The topics covered include: 1) Flyash grout testing in a simulated wet mine environment, 2) Wetland hydrology of minelands, 3) Proposal for classifying and mapping disturbed lands in North Dakota, 4) Soil pore characteristics as measures of quality of minesoil, 5) Reclamation of prime and nonprime soils, 6) Reliability of SCS curve number method on semi-arid reclaimed minelands, 7) Success of current soil depth requirements, 8) Tillage and prior cropping effects on soil physical properties and production, 9) Plant diversity of reclaimed grasslands, 10) Woodland reclamation on reclaimed mineland lands, 11) Historical development of ecological reclamation, 12) OSM's technology transfer program, 13) Electronic permitting, 14) A fresh look at reclamation research needs.

Analysis of Conclusions

The report does not contain all the information and data that were presented in the conference. However, it is an excellent source for obtaining further information from the authors on the wide variety of reclamation topics that were discussed in the conference. The conclusions drawn in the report are based on several years of research work and, therefore, quite important for the lignite industry and the state and federal regulatory agencies as such.

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SOIL/SPOIL PROPERTIES (SP)

Title: **LIGNITE SPOILS IN THE NORTHERN GREAT PLAINS - CHARACTERISTICS AND POTENTIAL FOR RECLAMATION**

Authors: F.M. Sandoval, J.J. Bond, J.F. Power and W.O. Willis

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Proceedings of the First Annual Research and Applied Technology Symposium on Mined Land Reclamation, pp. 117-133, Pittsburgh, PA., March 1973

Key Index Words: Spoil Properties, Overburden Analysis, Topsoil, Amendments, Fertilizer Use

Brief Description

This paper describes the results of laboratory and field investigations on the coal mine spoils of North Dakota, Montana and Wyoming. The physicochemical properties of the spoil materials provide a very poor environment for vegetative growth. Materials from the Tongue River and Sentinel Butte formations within the Fort Union group were often extremely fine textured (Montmorillonitic), moderately saline, and highly sodic. Severity of the problems associated with high clay and high adsorbed sodium content increased with depth from the original surface. Low organic matter combined with fine texture enhances the sodium dispersion effect, which makes the spoil materials extremely unstable, highly impermeable, and erodible. The content of available phosphorus in spoil materials was very low. The content of available nitrogen varied considerably, depending on the age of the exposed spoils. Treatments showing promise for reclamation include fertilization (especially with phosphorus) in combination with the use of topsoil, vegetative (straw) mulches, and possibly gypsum as a calcium amendment. The response to gypsum in field studies has been disappointingly slow.

Analysis of Conclusions

The conclusions drawn in this study are still generally valid. This research provided impetus for reclamation research and development of better regulations in North Dakota.

Title: **LIGNITE MINE SPOILS IN THE NORTHERN GREAT PLAINS - CHARACTERISTICS AND POTENTIAL FOR RECLAMATION**

Authors: F.M. Sandoval, J.J. Bond, J.F. Power, and W.O. Willis

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Some Environmental Aspects of Strip Mining in North Dakota (M.K. Wali, ed.), North Dakota Geological Survey Series No. 5, pp. 1-24. North Dakota Geological Survey, Grand Forks, ND, 1973

Key Index Words: Spoil Properties, Overburden Analysis, Topsoil, Fertilizer Use, Amendments

Brief Description

This paper is similar to the preceding one. It provides information on the physical and chemical properties of lignite spoils, pointing out consequent problems in reclamation.

Analysis of Conclusions

The conclusions drawn in this study are still generally valid. This research provided impetus for reclamation research and development of better regulations in North Dakota.

Title: **NITRIFICATION IN PALEOCENE SHALE**

Authors: J.F. Power, J.J. Bond, F.M. Sandoval, and W.O. Willis

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Science 183:1077-1079, 1974

Key Index Words: Paleocene Shale, Overburden Analysis, Nitrification, Nitrogen

Brief Description

This paper reported that exchangeable ammonium nitrogen is present in Paleocene (Fort Union) shale below a depth of 33 feet in North Dakota and eastern Montana. Above 33 feet, exchangeable ammonium nitrogen is nitrified in situ. The lack of viable nitrifying organisms and the probable lack of oxygen prevent in situ nitrification below 33 feet. Shale samples incubated at 27°C under nonsterile conditions and those exposed to atmospheric contamination showed active nitrification without additional treatment.

Analysis of Conclusions

This study is very important for understanding the dynamics of nitrogen transformation and availability in the Fort Union mine spoils.

Title: **CHEMICAL RECLAMATION OF SODIC STRIP MINE SPOILS**

Authors: E.J. Doering and W.O. Willis

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Report

Reference: USDA-Agricultural Research Service, North Central Region, ARS-ND-20:1-8, 1975

Key Index Words: Amendments, Sodicity, Infiltration

Brief Description

This study shows that the hydraulic conductivity of sodic strip mined spoils is established and maintained at an acceptable level by leaching with water high in salts. Sodic spoil material can be reclaimed chemically by using highly soluble calcium salts. It was calculated that the salt (calcium chloride) required for chemical reclamation of the spoil material used would cost more than $1,300 per acre per foot of depth reclaimed.

Analysis of Conclusions

Although chemical reclamation is effective, it is not recommended for large scale application on strip mined spoils because of the cost. A better alternative is to apply a suitably thick layer of nonsodic topsoil and subsoil on the strip mined spoils. However, some situations may require the use of chemical amendments with or without the use of topsoil.

Title: **THE PROPERTIES OF IMPORTANT AGRICULTURAL SOILS AS CRITERIA FOR MINED LAND RECLAMATION**

Authors: H.W. Omodt, F.W. Schroer and D.D. Patterson

Organization: North Dakota State University, Fargo, ND

Format: Bulletin

Reference: North Dakota State University, Agricultural Experiment Station, Bulletin, No. 492, 1975

Key Index Words: Soil Properties, Soil Types

Brief Description

This report contains a detailed discussion on the profile and various physical and chemical characteristics of soils that are important in determining what soil materials are suitable for reclaiming mined land in North Dakota.

Analysis of Conclusions

This paper provided a general basis for topsoil and subsoil criteria established by the NDPSC-Reclamation Division.

Title: **PHYSICAL, CHEMICAL AND BIOLOGICAL ASPECTS OF STRIP MINED LANDS IN WESTERN NORTH DAKOTA**

Authors: A. Bauer, G.W. Gee and J.E. Gilley

Organization: North Dakota State University, Fargo, ND

Format: Report

Reference: North Dakota Agricultural Experiment Station Final Report. Old West Regional Commission Grant No. 10470016, 605 p., 1976

Key Index Words: Revegetation, Spoil properties, Topsoil

Brief Description

This report presents the results of reclamation research conducted by NDSU from 1974 to 1976 in western North Dakota. The research involved: the determination of the physical and chemical characteristics of shaped mined lands and their effect on the establishment and performance of plants; the characteristics of surface and root zone hydrology of shaped spoil materials; and, plant establishment and culture on surface mined lands. The results were obtained through literature research, laboratory testing and analyses and field sampling and experimentation.

Analysis of Conclusions

The conclusions drawn in this report are based on studies conducted prior to 1976 when the reclamation performance standards were not as stringent as they are now. However, many observations made in this report are still valid and provide useful information for reclamation planning.

Title: **CHEMICAL AND PHYSICAL PROPERTIES OF STOCKPILED MATERIALS AT A MINESITE IN WESTERN NORTH DAKOTA**

Authors: G.W. Gee and A. Bauer

Organization: North Dakota State University, Fargo, ND

Format: Paper

Reference: North Dakota Agricultural Experiment Station Farm Research 34(2):44-51, 1976

Key Index Words: Topsoil, Soil Properties, Stockpiled Soil

Brief Description

Stockpiled topsoil materials from Indian Head Mine near Zap, ND, were analyzed for selected physical and chemical properties, along with soil samples collected from adjoining undisturbed areas. The stockpile materials had generally lower susceptibility to wind erosion than the nonmined surface soils; exhibited moderate to high crust strengths, and varied in their permeability to water. Chemically the stockpiled materials did not contain excess soluble salts, and the SAR value were generally less than 16. Nitrate nitrogen ranged from very low to high , phosphorus was invariably low, and potassium was high to very high. The results indicated that stockpiled materials reflect the mixing of surface and subsurface (A, B, and perhaps C horizon) materials.

Analysis of Conclusions

This study emphasized that stripping operations must be controlled better to segregate the soil horizons if the goal is to have materials for respreading that are physically and chemically similar to the undisturbed soils. Since this study was conducted, control on stripping depth has been improved considerably. Materials removed to serve as topsoil generally include A horizon and a part of B horizon depending upon their meeting the criteria of suitability as provided in the North Dakota reclamation rules.

Title: **THE SOIL MAP - A PREREQUISITE TO MINING AND RECLAMATION**

Author: D.D. Patterson

Organization: North Dakota State University, Fargo, ND

Format: Paper

Reference: North Dakota Agricultural Experiment Station Farm Research 34(1):12-13, 1976

Key Index Words: Soil Maps, Soil Properties

Brief Description

This paper stresses the need for inventorying and mapping soils prior to mining an area. soil information with proper interpretations is considered as one of the most important steps in the reclamation planning process.

Analysis of Conclusions

The use of soil maps and other soil related information in the reclamation of surface mined lands has already received acceptance.

Title: **EFFECTS OF SAMPLING METHOD ON RESULTS OF CHEMICAL ANALYSIS OF OVERBURDEN SAMPLES**

Authors: J.F. Power and F.M. Sandoval

Organization: USDA-ARS, North Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Mining Congress Journal 63:31-41, 1976

Key Index Words: Overburden Analysis, Sampling Methods

Brief Description

The results of an experiment are presented in which the effects of different methods of obtaining overburden samples on the chemical analysis of the materials were assessed. Least contamination occurred in samples obtained by pneumatic drilling. Probably no single drilling method can be recommended for all conditions and types of overburden, and for all sampling purposes. Several drilling methods may be necessary to accommodate varying conditions or materials.

Analysis of Conclusions

This study has provided important insight about some of the analytical errors that may be caused or introduced in chemical characterization of overburden samples collected by various sampling procedures. However, the effects of sampling procedures have been assessed for only a limited number of analytical parameters. Additional work in this area would be desirable.

Title: **POTASSIUM RELEASE CHARACTERISTICS OF SPOIL MATERIALS**

Author: M. Saeed

Organization: Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Proceedings of North Dakota Academy of Science 31(1):27, 1976

Key Index Words: Spoil Properties, Soil Properties, Nutrient Requirements

Brief Description

In this presentation were discussed the preliminary results of laboratory studies conducted to determine the potassium release characteristics of four different spoil materials and one unmined soil from western North Dakota.

Analysis of Conclusions

The results suggested that the North Dakota coal mine spoils are mostly well buffered against potassium depletion.

Title: **IN SITU SOIL WATER HOLDING CAPACITIES OF SELECTED NORTH DAKOTA SOILS**

Authors: D.K. Cassel and M.D. Sweeney

Organization: NDSU-Agricultural Experiment Station, Fargo, ND

Format: Bulletin

Reference: North Dakota Agricultural Experiment Station Bulletin No. 495, 1976

Key Index Word: Soil Water, Water Use, Soil Properties, Plant Responses

Brief Description

Water holding capacity of selected North Dakota soils is discussed in relation to several factors, including, but not limited to, soil depth, bulk density, particle size, relief, parent material, and soil moisture tension.

Analysis of Conclusions

An excellent paper on plant available water in North Dakota soils. Although actual measurements of changes in this parameter are somewhat lacking, the paper is still very useful.

Title: **CHEMICAL AND PHYSICAL CHARACTERIZATION OF COAL OVERBURDEN**

Author: F.W. Schroer

Organization: North Dakota State University, Fargo, ND

Format: Paper

Reference: North Dakota Agricultural Experiment Station Farm Research 34(1):5-11, 1976

Key Index Words: Overburden Analysis, Soil Properties, Spoil Properties

Brief Description

This paper describes the results of laboratory analysis conducted on soil overburden materials collected from several sites in Mercer and Dunn counties, including some reclaimed fields at four mine sites. The materials have been characterized with respect to their physical and chemical properties.

Analysis of Conclusions

This is one of the many studies in which soils and overburden materials of coal mining areas have been analyzed.

Title: **EFFECT OF LEONARDITE ON DIFFUSION OF PHOSPHORUS IN COAL MINE SPOILS**

Authors: J.W. Harrell, Jr. and M. Saeed

Organization: Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Soil Science 125(5):285-290, 1977

Key Index Words: Spoil Properties, Fertilizer Use, Amendments, Leonardite

Brief Description

This paper discusses the results of laboratory experiments in which phosphorus diffusion coefficients were measured (using P^{32}) in 1) Glenharold mine spoil, 2) spoil amended with 10% leonardite, and 3) leonardite alone, as a function of applied P, water soluble P, and NH_4F - extractable P. The phosphorus diffusion coefficient values were in the relative order: spoil, spoil + leonardite, leonardite. The addition of leonardite to spoil was found to reduce the phosphorus diffusion coefficients. Leonardite adsorbed phosphorus much more than did the spoil.

Analysis of Conclusions

The results of this investigation are important as they indicate that addition of leonardite to mine spoils or soils may increase the need for phosphorus application.

Title: **LABORATORY METHODS RECOMMENDED FOR CHEMICAL ANALYSIS OF MINED LAND SPOILS AND OVERBURDEN IN WESTERN UNITED STATES**

Authors: F.M. Sandoval and J.F. Power

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Handbook

Reference: USDA, Agriculture Handbook No. 525, 1977

Key Index Words: Spoil Properties, Overburden Analysis, Analytical Methods

Brief Description

This handbook provides guidelines for sampling and for chemical analysis of mine spoils and overburden samples. It was compiled to meet an urgent need for uniform laboratory methods to evaluate plant growth capabilities and limitations associated with coal lands in the Western United States. Salinity, sodicity, and nutritional deficiencies commonly characterize these materials. The procedures selected are those used by the authors and are accepted most widely as reference or standard procedures for western mined lands and associated spoils.

Analysis of Conclusions

This is a valuable reference material for spoil and overburden analysis methods. standardization of analytical methods suitable for mined lands requires further study because some of the normal soil analysis methods do not seem to predict the behavior of disturbed soils or spoil materials as well as they do in case of undisturbed soils.

Title: **CORRECTION OF NUTRIENT DEFICIENCIES AND TOXICITIES IN STRIP MINED LANDS IN SEMIARID AND ARID REGIONS**

Authors: A. Bauer, W.A. Berg, and W.L. Gould

Organization: USDA-ARS, Mandan, ND, Colorado State University, Fort Collins, CO, and New Mexico State University, Las Cruces, NM

Format: Paper (Chapter)

Reference: Reclamation of Drastically Disturbed Lands (F.W. Schaller and P. Sutton, eds.), pp. 451-466. ASA, CSSSA, SSA, Madison, WI, 1978

Key Index Words: Spoil Properties, Soil Properties, Nutrient Deficiencies, Toxicity, Revegetation

Brief Description

The paper provides an overview of research findings regarding nutrient deficiency and toxicity problems in the strip mined lands of Western United States. Evaluation of conventional soil tests for predicting fertilizer requirements on mined lands, plant responses to fertilizers, techniques of fertilizer application, and role of soil water in determining response to fertilizers are topics included in this paper.

Analysis of Conclusions

This paper emphasizes that interpretation of soil tests for determining rate of fertilizer applications needed to correct nutrient deficiencies on reclaimed mined lands may depend on the kind of plant rooting medium present at the spoil surface and its thickness. Where the plant rooting medium consists of soil materials from essentially all of the solum, corrective rates of fertilizers and other soil amendments may be excepted to equal those required on undisturbed soils of equal deficiency. However, as the thickness of organic matter containing plant-rooting medium decreases, corrective rates for a given deficiency level will be higher if another factor does not alter the potential yield level of the crop grown. This is an important conclusion as it points out the limitations of conventional soil tests for determining the fertilizer requirements on variously reclaimed mined lands. Additional work on perfecting soil tests appropriate for mined land conditions is required.

Title: **FERTILIZATION OF WHEAT, CORN, AND GRASS / LEGUME GROWN ON RECLAIMED SPOILBANKS**

Authors: A. Bauer, P. Nyren, G. Reichman, G.W. Gee, and J.E. Gilley

Organization: North Dakota State University, Fargo, ND

Format: Report

Reference: North Dakota Agricultural Experiment Station Research Center Report No. 67, 1978

Key Index Words: Soil Properties, Fertilizer Use, Analytical Methods, Overburden

Brief Description

The suitability of soil tests developed for determining nitrogen and phosphorus availability in undisturbed soils in North Dakota to predict their deficiencies and fertilizer requirements was evaluated on reclaimed sites with three crops over a 2 year period. Yield responses of wheat, corn, and grass/legume to applications of phosphorus and nitrogen fertilizers confirmed a deficiency or sufficiency of each nutrient as predicted by the soil test. The nutrient status predictive capability of the soil test was considered suitable for reclaimed sites. Rate of nutrient application to correct the deficiency, however, was considered to require adjustment from those utilized for undisturbed sites.

Analysis of Conclusions

This study also points to the need for developing better methods of predicting fertilizer requirements for variously reclaimed mined lands.

Title: **PHYSICAL ANALYSES OF OVERBURDEN MATERIALS AND MINE LAND SOILS**

Authors: G.W. Gee, A. Bauer, and R.S. Decker

Organization: North Dakota State University, Fargo, ND

Format: Paper (Chapter)

Reference: Reclamation of Drastically Disturbed Lands (F.W. Schaller and P. Sutton, eds.), pp. 665-686, ASA, CSSA, and SSSA, Madison, WI, 1978

Key Index Words: Soil Properties, Overburden Analysis, Water Management

Brief Description

This article focuses on characterization of physical properties of overburden materials of western United States coal mine lands in relation to soil water storage, water availability, surface erosion and land stability. Methods of evaluating the changes in soil water storage and availability etc. are discussed.

Analysis of Conclusions

A very informative article, useful in developing better soil-plant water management techniques for revegetation on mined lands.

Title: **USE OF SORPTION ISOTHERMS FOR EVALUATING THE EFFECT OF LEONARDITE ON PHOSPHORUS AVAILABILITY IN COAL MINE SPOILS**

Author: M. Saeed

Organization: Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Soil Science 126(3):157-165, 1978

Key Index Words: Spoil Properties, Fertilizer Use, Nutrient Requirements, Amendments

Brief Description

Laboratory and growth chamber experiments were conducted to study the effect of leonardite on the availability of phosphorus in Glenharold spoil. Phosphorus sorption capacity of leonardite was higher than that of the spoil. Growth chamber studies indicated that phosphorus uptake by plants was reduced when the spoil was supplied with 10% leonardite. Leonardite decreased the growth of the thickspike wheatgrass but increased that of alfalfa.

Analysis of Conclusions

The results of this study indicate that leonardite, if used as a soil amendment, will necessitate heavier applications of phosphate because of its higher sorption capacity for this element. Additional work on the use of leonardite, a humic and fulvic acid rich material, would be desirable.

Title: **IMPROVEMENT OF SALINE- AND SODIUM-AFFECTED DISTURBED LANDS**

Authors: F.M. Sandoval and W.L. Gould

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND, and New Mexico State University, Las Cruces, NM

Format: Paper (chapter)

Reference: Reclamation of Drastically Disturbed Lands (F.W. Schaller and P. Sutton, eds.), pp. 485-504. ASA, CSSA, SSA, Madison, WI, 1978

Key Index Words: Salinity, Sodicity

Brief Description

This paper reviews research information on saline and sodium-affected agricultural soils and discusses the application of this information to mined lands of the Western United States. Reclamation problems that are specific to sodic and saline spoils are discussed in relation to soil/spoil-plant relationships, and the best known technology available to overcome these problems is reviewed.

Analysis of Conclusions

The information presented in this paper is based on the fundamental principles of reclamation applicable to undisturbed agricultural soils, as well as from recent studies on the lands disturbed by mining. Advances in reclamation technology are well documented.

Title: **POTASSIUM RELEASE CHARACTERISTICS OF COAL MINE SPOILS**

Author: M. Saeed

Organization: Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Pakistan Journal of Scientific and Industrial Research 22:168-172, 1979

Key Index Words: Spoil Properties, Soil Properties, Nutrient Requirements

Brief Description

Potassium release characteristics of four coal mine spoils and one unmined soil from western North Dakota were studied in a growth chamber by exhaustive cropping with barley. The exchangeable K was determined by leaching with neutral ammonium acetate and total K by boiling with 1N HNO_3. The spoil materials, with the exception of that from Center mine, were found to contain a large reservoir of exchangeable (313 to 679 kg/ha) and total (1205 to 1763 kg/ha) K. The release of K from non-exchangeable sources varied from 746 to 1478 kg/ha. Mobilization of non-exchangeable K was closely related to the amounts of K extracted by barley. Non-exchangeable K accounted for 58% of the total K utilized by the test plants.

Analysis of Conclusions

The results suggest that the North Dakota coal mine spoils tested are well buffered against K depletion. Also, this study showed that the HNO_3-extractable K was a better indicator of potassium release and removal by intensive cropping than initial exchangeable-K or Woodruff's energy exchange.

Title: **WATER MOVEMENT IN A RECLAIMED SITE AND ASSOCIATED SOILS AT A MINE SITE IN WESTERN NORTH DAKOTA**

Authors: M.W. Pole, T.H. Brown, and L. Zimmerman

Organization: NDSU-Soil Science Department Fargo, ND

Format: Paper

Reference: North Dakota Agricultural Experiment Station Farm Research 37(6): 5-8, 1980

Key Index Words: Infiltration, Reclaimed Soil, Soil Properties

Brief Description

Infiltration, water retention, and internal drainage characteristics were determined for several undisturbed soils and a reclaimed soil at the Falkirk Mine. Infiltration and water movement through the soils was generally unimpeded. The infiltration equation provided excellent results in quantifying infiltration into all of the soils investigated. A water movement model developed in Montana was applied to the soils; however, it was not applicable to the reclaimed soil.

Analysis of Conclusions

Additional research is needed to determine infiltration, water movement, and drainage characteristics of reclaimed soil profiles. The data presented in this paper is only applicable to nonsaline and nonsodic soils.

Title: **THE EFFECTS OF MOISTURE ON PHOSPHORUS DIFFUSION IN COAL MINE SPOILS**

Authors: J.W. Harrell and M. Saeed

Organization: Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Soil Science 129:261-265, 1980

Key Index Words: Spoil Properties, Topsoil, Fertilizer Use

Brief Description

Phosphorus diffusion coefficients were measured as a function of water tension and water content in topsoil and spoil samples from two coal mine sites in western North Dakota. The results showed that phosphorus diffusion coefficient was almost zero for water content below that held at 15 bar and increased rapidly as the water in excess of that held at 15 bar increases. For most of the measurements diffusion coefficient for the spoil material was greater than for the topsoil at a given moisture tension.

Analysis of Conclusions

The results of this investigation have a great bearing on the phosphate fertilization of mined land spoils and soils. The role of moisture in the diffusion of phosphorus in soils and spoils is elucidated.

Title: **SOIL-ALGAL RELATIONSHIPS FROM SURFACE MINED SOILS**

Authors: L.E. Shubert and T.L. Starks

Organization: University of North Dakota, Grand Forks, ND

Format: Paper

Reference: British Phycology Journal 15: 417-428, 1980

Key Index Word: Microbiology, Soil Algae, Soil Properties

Brief Description

This study was conducted to gather baseline data on chemical and physical properties of the soil and the presence of algae in surface mined soils in selected arid and semi-arid environments. Integration of analytical data suggested distinct relationships between physical and chemical properties of the soils and the algae present in them. This investigation was part of a long term project to evaluate the relationships of algae to their soil environment.

Analysis of Conclusions

This is an important study because it creates a base for further projects to investigate the role of algae in soil genesis and reclamation in arid and semi-arid areas.

Title: **TEMPORAL AND AMENDMENT EFFECTS ON SELECTED PHYSICAL AND CHEMICAL PROPERTIES OF SOME NORTH DAKOTA COAL MINE SPOILS AND TOPSOILS**

Authors: R.H. Bares, N.M. Safaya, N. Malakondaiah and M.K. Wali

Organization: Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Agronomy Abstract, p. 172, 1981

Key Index Words: Spoil Properties, Amendments

Brief Description

In this paper presentation, made in the American Society of Agronomy meeting in Atlanta, Georgia, the effects of several amendments on some physical and chemical properties of spoil and soil material from six field experiments conducted in Mercer and Oliver Counties were discussed. Changes in spoil and soil properties were monitored over a period of six years; considerable site-to-site and year-to-year variability was recorded.

Analysis of Conclusions

The results of this long-term study are very useful because the effects of some uncommonly used amendments (leonardite, slack coal, boiler slag, etc.) on mine soils and spoils have been examined.

Title: **TRACE ELEMENT STATUS OF SOME COAL MINE SPOILS AND TOPSOILS IN WESTERN NORTH DAKOTA**

Authors: N.M. Safaya, R.H. Bares, N. Malakondaiah and M.K. Wali

Organization: Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Agronomy Abstract, p. 190, 1981

Key Index Words: Soil Properties, Trace Elements, Amendments, Topsoil

Brief Description

This paper, presented in the American Society of Agronomy meeting at Atlanta, Georgia, discussed the results of trace elements analyses made on soil and spoil samples from six field experiments conducted at Center, North Beulah, South Beulah, and Glenharold mines in North Dakota. The effects of several amendments on aluminum, boron, cadmium, copper, iron, lead, lithium, manganese, nickel, strontium, and zinc status of mine soils/spoils were monitored over a five-year period.

Analysis of Conclusions

This is an elaborate study on the trace element status of North Dakota mine spoils and soils.

Title: **ECOLOGICAL STUDIES ON THE REVEGETATION PROCESS OF SURFACE COAL MINED AREAS IN NORTH DAKOTA: 2. PHYSICAL AND CHEMICAL PROPERTIES OF OVERBURDEN AND TOPSOIL AS AFFECTED BY TIME AND AMENDMENTS**

Authors: N.M. Safaya, R.H. Bares, N. Malakondaiah, and S.A. Nicholson

Organization: Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Report

Reference: A minerals research contract report to USDI-Bureau of Mines, 177 p., 1982

Key Index Words: Spoil Properties, Amendments

Brief Description

This report discusses the long-term effects of some amendments on the physical and chemical properties of spoil and topsoil materials collected from test plots established at a total of six sites in North Beulah, South Beulah, Center, and Glenharold mines. The amendments included fertilizers, leonardite, slack, boiler slag, scoria, sand, topsoil etc. A number of soil properties including the status of elements such as nitrogen, phosphorus, potassium, calcium, magnesium, sodium, iron, manganese, zinc, copper, boron, aluminum, cadmium, lithium, nickel, lead, silicon, and strontium were quantified.

Analysis of Conclusions

The information contained in this report is very useful, for it provides a relatively long-term assessment of a large number of soil and spoil properties as affected by several common and uncommon amendments. Inclusion of a large body of data on the status of several trace elements in the North Dakota mined land is a distinguishing feature of this report.

Title: **COLONIZATION AND SUCCESSION OF ALGAE AND SOIL-ALGAL INTERACTIONS ASSOCIATED WITH DISTURBED AREAS**

Authors: T.L. Starks and L.E. Shubert

Organization: University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Journal of Phycology 18: 99-107, 1982

Key Index Word: Microbiology, Soil Algae, Soil Properties, Succession

Brief Description

This study was based on the idea that algae can serve as model organisms for studying soil ecosystems. An attempt was made to correlate algal colonization and succession with the chemical content of disturbed soils. Linear regressions were generated to compare soil-algal interactions on sites with or without respread topsoil in order to develop a conceptual model to demonstrate the relationship between algal abundance and various chemical properties of soil. No chemical property of the topsoil correlated significantly with algal abundance. Changes in chemical properties in regraded spoil resulting from percolation and leaching, plant growth, and other factors directly affected algal abundance.

Analysis of Conclusions

This study illustrates the complexity of the soil-algal relationships or disturbed lands, generates a preliminary conceptual model and gives direction to future studies in this area.

Title: **THE ROLE OF TOPOGRAPHY IN REVEGETATION OF DISTURBED LANDS**

Authors: N.C. Wollenhaupt and J.L. Richardson

Organization: North Dakota State University, Fargo, ND

Format: Paper

Reference: Symposium on surface coal mining and reclamation in the Northern Great Plains, Billings, MT, 1982

Key Index Words: Topography, Water Management, Vegetation

Brief Description

The relation of topography to water management, vegetative composition, density, and yield is discussed.

Analysis of Conclusions

Topographic conditions are important considerations for optimum post-mining use over a reclaimed area.

Title: **WATER REPELLENCY OF DEGRADED LIGNITE IN A RECLAIMED SOIL**

Authors: J.L. Richardson and N.C. Wollenhaupt

Organization: NDSU-Soils Department, Fargo, and Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: Canadian Journal of Soil Science 63; 405-407, 1983

Key Index Words: Lignite, Water Repellency

Brief Description

Soil profile samples were collected from a sparsely vegetated location in a 8- to 9-year old reclaimed site at the Indian Head Coal Mine, and analyzed in the laboratory. Presence of water-repellent lignitic material at 35-53 cm in the soil profile was postulated as being the cause of poor vegetation stand. No root growth was found in or below this layer. Lignitic material was also found at 105-120 cm below the surface. No lignitic material existed at sites supporting thick vegetation. Laboratory test showed that the lignitic materials were severely resistant to water penetration. Reduced availability of water and possible chemical toxicities caused by the lignitic material were recognized as probable causes for the poor growth of vegetation.

Analysis of Conclusions

These observations lend support to the regulatory requirement that all coal materials must be covered by suitable thicknesses of soil for revegetation purpose. Presence of lignitic material in the root zone of reclaimed lands can also give a false idea about their organic matter content if appropriate tests are not conducted.

Title: **ALKALINE NEUTRALIZATION CAPACITY OF WEST CENTRAL NORTH DAKOTA OVERBURDEN MATERIALS**

Authors: G. Groenewold, S. Lucken, D. Johansen, and R.D. Koob

Organization: North Dakota MMRRI, University of North Dakota, Grand Forks, ND; and Department of Chemistry, North Dakota State University, Fargo, ND

Format: Paper

Reference: Proceedings of Conference on Municipal, Hazardous and Coal Waste Management, Miami, FL, December 1983

Key Index Words: Trace Elements, Groundwater, Waste Disposal, Fly Ash, Overburden Analysis

Brief Description

Fly ash generates a highly alkaline leachate (pH of 10-12.5). Arsenic and selenium are highly mobile under these high pH conditions. This relationship of trace metals to pH pose a potential groundwater contamination problem. These concerns would be minimized if a natural neutralization capacity existed in the overburden materials surrounding the fly ash disposal sites. The natural carbonate buffer system known to exist may provide this neutralization capacity. Cation exchange capacity was found to be an additional source of neutralization capacity.

Analysis of Conclusions

It is apparent from this study that all of the North Dakota overburden materials tested have the capacity to neutralize alkaline solutions to some degree. If liners in fly ash disposal areas are being required to prevent the migration of trace metals, it appears from this study that there is no sound basis for such a requirement.

Title: **SPATIAL VARIABILITY AND MINERALOGY OF SELECTED MINE SPOILS FROM WESTERN NORTH DAKOTA**

Author: F.E. Rhoton

Organization: NDSU - Land Reclamation Research Center, Mandan, ND.

Format: Report

Reference: North Dakota Agricultural Experiment Station Research Report No. 101, 1983

Key Index Words: Spoil Properties, Spatial Variability, Topography

Brief Description

This study was conducted to determine the spatial variability in some selected physical and chemical properties, and in the clay mineralogy of reshaped spoil materials in a 400-acre area at the Indian Head mine, near Zap, ND. Samples were collected from the root zone in four plots located at summit, shoulder, backslope, and footslope positions along a slope created by regrading operations. The minimum number of samples required to obtain an acceptable estimate of EC, pH, and particle size were used as indicators of spoil variability. Greatest variability in spoil materials, based on EC and sand content, was found at summit and shoulder positions. The mineralogy of the soils and topsoiled spoils was similar, each being dominated by smectite and illite.

Analysis of Conclusions

Determination of spatial variability in reshaped spoils and topsoiled mined lands is important for determining the topsoil thickness requirements and fertilizer management practices, respectively. Research on spatial variability of mine soils should be promoted.

Title: **AN ANALYSIS OF SOIL AND OVERBURDEN PARAMETER REQUIREMENTS FOR NORTH DAKOTA**

Author: N.M. Safaya

Organization: North Dakota Public Service Commission, Bismarck, ND

Format: Paper

Reference: Proceedings of Conference on Soil and Overburden Requirements for Successful Revegetation" (M.B. Berg, ed.), pp. 153-163, Denver, CO, 1983

Key Index Words: Soil properties, Soil Requirements, Soil Types, Toxicity

Brief Description

The North Dakota regulatory requirements pertaining to soils and overburden are discussed in relation to the available scientific information about the types of soils and geological materials found in this area. Adequacy of analytical parameters used for determining the suitability or unsuitability of soil and overburden materials is also discussed. A re-examination of the critical limits established for SAR and EC for suitability of subsoil materials has been stressed in view of some recent work on plant responses to sodicity and salinity.

Analysis of Conclusions

This paper provides a comprehensive picture of the soil and overburden requirements in the North Dakota's current reclamation regulatory program, along with the scientific rationale for the use of various parameters in determining the suitability of soil materials.

Title: **RELATIONSHIP OF SALT MOVEMENT IN RECLAIMED PROFILES TO TOPOGRAPHY**

Author: G.A. Halvorson

Organization: NDSU-Land Reclamation Research Laboratory, Mandan, ND

Format: Paper

Reference: Proceedings of Symposium on Soil and Overburden Requirements for Successful Revegetation, Denver, CO, 1983

Key Index Word: Sodicity, Sodium, Topography, Leaching,

Brief Description

This study focused on the movement of salts (primarily sodium, calcium, and magnesium) across the spoil-topsoil interface. Sodium had moved across the interface into replaced topsoil although the quantity and distance of upward movement was dependent on the replaced soil depth. Calcium and magnesium had not moved appreciably. Where no topsoil was replaced, leaching of salts occurred.

Analysis of Conclusions

Data presented in this report, although preliminary, will serve to determine where upward salt movement is occurring in reclaimed land and the extent to which it will occur at a given landscape position. This information, along with data from other studies (See SP-38, SR-6, SR-7), can be used to predict salt movement in reclaimed lands, and to determine post-mining land use.

Title: **SOIL WATER VARIATION IN SPOIL AND UNDISTURBED SITES IN NORTH DAKOTA**

Authors: S.A. Schroeder and A. Bauer

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: Soil Science Society of America Journal 48:656-659, 1984

Key Index Words: Soil Water, Hydraulic Conductivity, Infiltratiom, Field Capacity

Brief Description

Soil water contents were monitored over a 7 year period on reshaped, vegetated spoil and nearby undisturbed grassland sites at Center, Stanton, Beulah and Zap in North Dakota. During the length of the study, very little, if any, water percolated beyond the rooting zone (0-122 cm) at either the spoil or undisturbed sites. Measured soil water contents never approached estimated field capacity for the spoil or undisturbed sites.

Analysis of Conclusions

The study indicated that precipitation retained at the point of fall did not percolate beyond the 122 cm depth and, therefore, probably does not contribute to groundwater recharge in this area. This suggests that groundwater recharge due to precipitation probably occurs only on landscape positions where ponding results from runoff. The conditions needed for downward saturated flow in medium and fine textured spoil materials are unlikely in a semiarid region except for run-on landscape positions. Additional research should include coarse textured spoil materials and reconstructed soils.

Title: **IN-SITU SATURATED HYDRAULIC CONDUCTIVITY AND WATER-HOLDING CAPACITY OF UNDISTURBED AND SURFACE MINED SITES**

Authors: J.E. Gilley, S.A. Schroeder, and D.D. Schlenker

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: North Dakota State University Agricultural Experiment Station Research Report No. 102, May 1984

Key Word Index: Hydraulic Conductivity, Water Holding Capacity, Infiltration

Brief Description

In this study, water transmission and storage characteristics of undisturbed soil, nonsodic spoil, sodic spoil and topsoiled spoil were studies. The test sites were established at the Indian Head Mine. Each site consisted of a 10-foot square study area (monolith) which was isolated from the surrounding area by polyethylene sheeting to prevent lateral water movement. Water movement in the profile was restricted at the undisturbed and topsoiled sodic spoil sites. Infiltration on the sodic spoil was minimal. Saturated hydraulic conductivity of 1.5 inches per hour was measured at the nonsodic spoil sites.

Analysis of Conclusions

The study concluded that for determining water transmission and storage capacity of reclaimed lands, it may be necessary to identify the properties of soil profile up to a depth of 10 feet. This conclusion has a strong bearing on the current efforts of LRRC scientist to establish productivity indices for reclaimed lands.

Title: **REPORT TO BAUKOL-NOONAN, INC. ON RESEARCH CONDUCTED AT THE BAUKOL-NOONAN, INC. MINE NEAR CENTER, ND, 1984**

Authors: NDSU-Land Reclamation Research Center Staff

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Unpublished

Key Index Word: Stockpiled Soil, Soil Properties

Brief Description

Core samples were taken at 1-foot increments to a depth of 10 feet at four locations on a topsoil stockpile at Baukol Noonan's Center Mine. These samples were then tested for bulk density and moisture content.

Analysis of Conclusions

No conclusions were drawn at this time. However, this study will provide information about the changes that occur in the physical properties of soils when stockpiled.

Title: **DIAGNOSTIC ASPECTS OF ALGAL ECOLOGY IN DISTURBED LANDS**

Authors: L.E. Shubert, and T.L. Starks

Organization: University of North Dakota, Grand Forks, ND

Format: Chapter

Reference: Soil Reclamation Processes - Microbiological Analyses and Application (R.L. Tate and D.A. Klein, eds.) 1985 Marcell Dekker, Inc., New York

Key Index Word: Microbiology, Soil Properties, Soil Productivity, Soil Algae

Brief Description

This chapter consolidates past studies on the microbiological aspects of mined lands and correlates patterns of algal colonization and succession with soil properties in order to generate conceptual models to predict the degree of re-establishment of equilibrium in the recovery process. Microbial populations appear to offer a rapid and sensitive method of determining the resiliency and stability of reclaimed surface soil ecosystems.

Analysis of Conclusions

The study of soil algae as an ecological indicator in the reclamation of mined lands is still in its infancy. Further research in areas of physiology and nutrition, ecosystem stability and other pertinent ecological premises are required for the development of more sophisticated models. This concept could be advanced to many other areas in which environmental impacts are considered.

Title: **ENUMERATION AND CHARACTERIZATION OF NITROGEN-FIXING BACTERIA IN A STRIPMINE SITE**

Authors: M.J. Jacobs, B.R. Funke and S.D. Merrill

Organization: Department of Bacteriology, NDSU and USDA-ARS Northern Great Plains Research Laboratory, Mandan, ND

Format: Paper

Reference: Plant and Soil 84: 3-10, 1985

Key Index Word: Nitrogen, Microbiology

Brief Description

The inputs of microorganisms capable of heterotrophic nitrogen fixation, while limited to a few kilograms per year, are considered to be significant in the successful establishment of grasslands. This study was conducted to enumerate and identify nitrogen-fixing bacteria in the rhizospheres of perennial grasses in graded spoil, with or without cover topsoil, during active growing and dormant periods. The total number of bacteria were higher in the no topsoil plots, however, the ratio of nitrogen-fixers to other bacteria was higher in the plots with covered with topsoil. The species of nitrogen-fixers identified were comparable to those observed in other similar habitats except that Bacillus spp. outnumbered the Enterobacteriacea in this study.

Analysis of Conclusions

An interesting study which begins to explore the role of soil bacteria in the reclamation of mined lands.

Title: **USE OF SOIL PARAMETERS IN THE EVALUATION OF RECLAMATION SUCCESS IN NORTH DAKOTA**

Authors: E.C. Doll and N.C. Wollenhaupt

Organization: USDA-ARS, Northern Great Plains Research Laboratory, Mandan, ND

Format: Paper

Reference: Proceedings of National Meeting of American Society for Surface Mining and Reclamation, pp. 91-94, Denver, Colorado, 1985.

Key Index Word: Reclamation Success, Productivity

Brief Description

The authors contend that vegetative productivity comparisons of reclaimed to reference areas with 90% statistical confidence, a current determinant of reclamation success in North Dakota, are both difficult and unreliable because of variation in climatic, biotic and management factors. They suggest that the degree of productivity re-establishment can be reliably estimated from measurements of total pore space and pore space continuity in reclaimed soils. They have provided a model to calculate the productivity indices of soils to quantify these types of data. Vegetative measurements would be, however, necessary in this system to estimate the stage of soil restorations and to verify the measured root zone properties.

Analysis of Conclusions

Field research is necessary to determine the accuracy and applicability of these criteria for determining reclamation success.

Title: **PREDICTING UNSATURATED HYDRAULIC CONDUCTIVITY OF SODIC SOILS**

Authors: S.D. Merrill and E.J. Doering

Organizations: USDA-ARS Northern Great Plains Research Laboratory, Mandan, ND

Format: Paper

Reference: American Society of Agricultural Engineers, 1985 Summer Meeting, East Lansing, MI, June 24-26, 1985

Key Index Word: Sodicity, Infiltration, Soil Properties

Brief Description

Spoil materials from four mines in the Northern Great Plains were used to experimentally determine unsaturated hydraulic conductivity for comparison with theoretically determined values. Theoretical values, which were based on the relationship between water content and matric potential, were higher than the experimentally determined values for sodic spoils. The results indicated that theoretical determination of unsaturated hydraulic conductivity is not completely reliable for sodic, dispersed, clayey spoils.

Analysis of Conclusions

This paper contributes additional information to our understanding of sodic, clayey spoils and their effect on water movement and availability. The study clearly shows the influence of sodicity on water movement.

Title: **SOIL-WATER CHARACTERISTICS OF CONSTRUCTED MINESOILS AND ASSOCIATED UNDISTURBED SOILS IN SOUTHWESTERN NORTH DAKOTA**

Author: N. Wollenhaupt

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: M.S. Thesis

Reference: M.S. Thesis, College of Agriculture and Applied Science, North Dakota State University, Fargo, ND, P., 1985

Key Index Word: Reclamation Success, Soil Properties, Productivity

Brief Description

Reclaimed and undisturbed soils were compared using measurements of bulk density, aggregate stability, water retention, and hydraulic conductivity. A soil root growth environment model was used to predict the potential productivity of constructed soils. Bulk density of reclaimed soils was significantly higher than undisturbed soils in the upper 60 cm. Available water holding capacities and aggregate size distribution of the two soils were similar. The hydraulic conductivity of reclaimed soils was consistently lower than that of undisturbed soils.

Analysis of Conclusions

This study provided very useful information concerning changes in physical soil properties during mining and reclamation. The difference in bulk density between reclaimed and undisturbed soils is critical to calculation of suitable plant growth material (SPGM) volumes available for respread. The productivity index model has the potential to become an indicator of revegetation success which eliminates problems associated with climatic variability and varying management practices. The model also may be used to plan SPGM salvage and respread operations and maximize the use of available SPGM. The model will need further refinement and correlation with actual yields before it can be implemented. Moreover, additional studies may be necessary to evaluate the effects of soil texture, moisture content and respreading techniques on the degree of compaction (increase in bulk density) of respread soils.

Title: **SALT MOVEMENT IN 9-YEAR-OLD RECLAIMED SOIL-SPOIL PROFILES**

Author: B.M. Holmes

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: M.S. Thesis

Reference: M.S. Thesis, College of Agriculture and Applied Science, North Dakota State University, Fargo, ND P., 1985

Key Index Word: Salinity, Sodicity, Spoil Properties

Brief Description

This study examined the magnitude and direction of salt movement in 9-year-old experimental plots. Core samples were taken from the Stanton wedge experiment and analyzed for soluble salts, sodium, calcium, magnesium, carbonates, bicarbonates, chlorides, and sulfates. Results indicated that all measured ions leached downward into spoil in profiles with 90 cm or less topsoil and subsoil. Salts had leached from the upper 60 cm in profiles containing more than 90 cm topsoil and subsoil. The author concluded that no evidence existed which would indicate that significant upward sodium migration had occurred. Sodium ion concentration peaks remained as sharp as calcium and magnesium peaks below 90 cm in plots with 90 cm or more topsoil and subsoil.

Analysis of Conclusions

Results of this study indicated that sodium accumulation near the soil/spoil interface may be a result of leaching of sodium from topsoil rather than upward migration from sodic spoil. Although peak concentrations remained below the soil spoil interface, raw data from the study indicated that elevated sodium and SAR levels were found above the soil/spoil interface. Sodification of at least 10 to 15 cm of subsoil had occurred in several profiles. This information along with data from other studies (See SP-31, SR-6, SR-7) can be used to evaluate the potential for salt movement in reclaimed lands.

Title: **NEUTRON MOISTURE METER CALIBRATION FOR MINE SPOILS CONTAINING COAL**

Author: G.A. Halvorson

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: Soil Science Society of America Journal 50: 496-498, 1986

Key Index Words: Soil Moisture, Neutron Moisture Meter, Spoil Properties

Brief Description

The objective of this study was to determine the effects of coal fragments in mine spoil on soil-water determinations by the neutron meter method. Calibrations were conducted on clay loam and loamy sand mine spoils, in the presence and absence of a known amount of added coal. In the presence of coal, the volumetric water content of the spoil materials was over-estimated by the neutron moisture meter method because of the structural hydrogen in coal. By accounting for the water equivalent from the hydrogen content of coal, the calibration curve could be corrected.

Analysis of Conclusions

Because of large variability in the amount and size of coal fragments in mine spoils, accurate calibration and precise measurement of moisture meter method are difficult. However, the method is suitable where only relative differences in water content over time are to be determined.

Title: **A RAPID METHOD FOR ESTIMATING WEIGHTED SOIL SALINITY FROM APPARENT SOIL ELECTRICAL CONDUCTIVITY MEASURED WITH AN ABOVEGROUND ELECTROMAGNETIC INDUCTION METER**

Authors: N.C. Wollenhaupt, J.L. Richardson, J.E. Foss, and E.C. Doll

Organization: NDSU - Soils Department, Fargo, and Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: Canadian Journal of Soil Science 66: 315-321, 1986

Key Index Words: Salinity, Soil Properties, Electromagnetic Induction

Brief Description

This paper describes a method for calibrating electromagnetic induction (EM) meters used for measuring electrical conductivity (soil salinity). The EM meter readings (representing integrated values of electrical conductivity over the meter's response depth) were correlated with weighted electrical conductivity values for the soil profile determined by the saturation paste method. The resulting regression equation provided a reliable method for quick assessment of salinity in the rooting zone.

Analysis of Conclusions

This is a quick technique for measuring salinity in soil associations of similar parent materials, and therefore useful for soil and range surveys. However, it does not replace soil sampling and testing by conventional method where specific data for electrical conductivities is needed.

Title: **OVERWINTER SOIL WATER ACCUMULATION IN VEGETATED RECLAIMED MINE LAND SPOIL**

Authors: S.A. Schroeder, J.W. Enz, and A. Bauer

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Land Reclamation Research Center Technical Report No. 6, 1986

Key Index Words: Soil Water, Infiltration, Spoil Properties, Groundwater

Brief Description

The objectives of this study were to measure the accumulation of soil water from winter precipitation in profiles of vegetated spoils at the Center, Beulah and Indian Head Mines, and to determine which physical or chemical site characteristics are most important in this respect. Soil water was measured in 1-foot increments to a depth of 4 feet by neutron moisture probe; physical and chemical characteristic of soil profiles were studies up to 5 feet depth, and vegetation and topographic data was also collected. Soil water accumulation ranged from -2.0 to 4.4 inches during a 4-year period. Total water monitored over time showed very slight changes at depths greater than 2 feet.

Analysis of Conclusions

Soil water accumulation models based on data from each site were better than those based on data from all sites. Inclusion of other site related data improved the models but further studies would be required to define their effects. This research needs to be continued and expanded to include subsoiled plus topsoiled sites. The need for continuing such studies is dictated both by revegetation and groundwater recharge considerations.

Title: **SATURATION PERCENTAGE**

Authors: S.D. Merrill, J.R. Deutsch, and M.W. Pole

Organization: USDA-ARS, Northern Great Plains Research Laboratory, Mandan; North Dakota Public Service Commission, Bismarck; and the North American Coal Corporation, Bismarck, ND

Format: Chapter

Reference: Reclaiming Mine Soils and Overburden in the Western United States - Analytic Parameters and Procedures (R.D. Williams and G.E. Schuman, eds.), pp. 35-58, SCSA, Ankeny, Iowa, 1987

Key Index Words: Saturation Percentage, Sodicity, Sodium Adsorption Ratio, Exchangeable Sodium Percentage, Soil Water, Water Holding Capacity

Brief Description

This paper reviews research information on saturation percentage and discusses the application of this information to mined lands in the western United States. The discussion includes a review of analytical and procedural methods, the relationship of saturation percentage to other soil parameters, and quantitative guidelines for regulators.

Analysis of Conclusions

This paper provides an excellent summary of research data on saturation percentage. This information is applicable to North Dakota reclamation since saturation percentage is one of the criteria used to determine the suitable plant growth material respread thickness under the current regulations.

Title: **CADMIUM AND ZINC**

Authors: N.M. Safaya, J.E. McLean, and G.A. Halvorson

Organization: North Dakota Public Service Commission, Bismarck, ND, Utah Water Research Laboratory, Logan, UT, and NDSU-Land Reclamation Research Center, Mandan, ND

Format: Paper (Chapter)

Reference: Reclaiming Mine Soils and Overburden in the Western United States: Analytic Parameters and Procedures (R.D. Williams, G.E. Schuman, eds.), pp.283-311, Soil Conservation Society of America, Ankeny, IO, 1987

Key Index Words: Trace Elements, Spoil Properties, Toxicity, Overburden Analysis

Brief Description

This paper provides an overview of the biological importance, geochemical abundance, chemistry and bioavailability, and methods of measuring cadmium and zinc in soil and overburden materials. Soil, plant, and management factors controlling the uptake of these elements by plants and subsequent distribution in the food chain are also discussed. The objective of this paper was to determine, from literature survey, whether the routine analysis of these elements in the western soil and overburden materials is warranted; and if so, what methods of analysis are appropriate for this purpose.

Analysis of Conclusions

The information provided in this paper is useful to both basic and applied scientists dealing with agricultural or environmental issues. It was concluded that cadmium and zinc may pose some serious problems in the reclamation of acidic mine spoils encountered in the eastern U.S., but in the western U.S., where the overburden materials are generally neutral to alkaline, the likelihood of these problems is small. However, some abandoned mine lands in the western U.S. are acidic, and may therefore require monitoring for cadmium and zinc toxicities.

Title: **PHYSICAL PROPERTIES OF CONSTRUCTED AND UNDISTURBED SOILS**

Authors: K.N. Potter, F.S. Carter, and E.C. Doll

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: Soil Science Society of America Journal 52:1435-1438, 1988

Key Index Words: Bulk Density, Pore Size Distribution, Hydraulic Conductivity

Brief Description

Physical and hydrologic characteristics of 4- and 11-year old reconstructed mine soils at the Glenharold Mine were studied. The reclaimed soils were compared to a similar soil from an undisturbed soil area. Bulk density, pore size distribution, and hydraulic properties were substantially different in the reclaimed soil than in the undisturbed soil. Hydraulic conductivity was lower in the reclaimed soils than in the undisturbed soil. Bulk density of the reclaimed soils was greater than in the undisturbed soils. Macroporosity was affected more than microporosity by reclamation activities.

Analysis of Conclusions

The results of this study suggest that soil physical and chemical parameters have potential for use as an index of reclamation success. However, this would require additional research to establish minimum acceptable standards.

Title: **SOIL WATER DEPLETION UNDER CROPS ON RECLAIMED AND UNDISTURBED LANDS**

Authors: S.A. Schroeder and G.A. Halvorson

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: Journal of Environmental Quality 17(1):130-134, 1988

Key Index Words: Soil Water, Water Use, Productivity, Topsoil

Brief Description

Undisturbed and simulated reclaimed soils at the Falkirk Mine were compared over a four year period for such factors as soil water depletion, total water useage, and crop yields. Net soil water depletion under small grain or corn was consistently, but not always significantly, less in reclaimed than in undisturbed soil profiles. Soil water depletion in the reclaimed soil was affected by topsoil thickness and spoil texture through effects on available water at planting and root penetration. When precipitation was inadequate or poorly distributed, yields were significantly less on reclaimed soils. This is probably due to shallower rooting on the reclaimed soils.

Analysis of Conclusions

Additional research is needed to determine if different methods of soil or crop management can enhance water and root penetration in reclaimed soils.

Title: **TILLAGE EFFECTS ON BULK DENSITY DURING RECLAMATION OF MINED SOIL**

Author: S.A. Schroeder

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: North Dakota Agricultural Experiment Station Farm Research 46(1):13-16, 1988

Key Index Words: Compaction, Bulk Density, Soil Replacement, Tillage

Brief Description

This study was conducted at the Center and Coteau (Freedom) Mines to determine if soil compaction can be reduced during reclamation operations. Several different treatments to the subsoil layer such as, deep ripping with a dozer, grader ripping, chiseling, and deep lift respread (respreading subsoil as thick as possible with minimum traffic), were employed. Following topsoil respreading several additional tillage treatments were performed. Soil compaction was then tested by taking soil cores at 6" vertical increments from each of the treatment areas and checking them for bulk density. None of the subsoil treatments were found to be effective because heavy equipment traffic during topsoil respreading negated any positive effects of the treatments. Some effect of the topsoil tillage treatments on bulk density remained in that values near the surface were lower than those at greater depths.

Analysis of Conclusions

Soil compaction is a serious problem in reclaimed soils. Further research is necessary to identify methods of reducing compaction after most or all traffic necessary for reclamation has been completed.

Title: **SPATIAL VARIABILITY IN THE CHEMICAL AND PHYSICAL PROPERTIES OF REGRADED MINE SPOIL**

Author: G. Halvorson

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: Proceedings of the Conference "Reclamation, A Global Perspective (D.G. Walker, C.B. Powter and M.W. Pole, eds.), pp. 589-595, Calgary, Alberta, August 1989

Key Index Words: Spoil Properties, Overburden Analysis, Reclamation, Sampling Methods

Brief Description

An expanding square sampling scheme was used on graded spoil areas at four mines in North Dakota to compare spoil variability from a small area with that in a large area. An attempt was then made to match premine overburden properties with those from the regraded spoil. This was done to determine the variability of regraded spoil, the depth of sampling necessary to characterize this variability, and ultimately to predict regraded spoil properties from premining overburden sampling data. Results indicated that considerable mixing of the overburden occurs during the mining and reclamation process. Difficulties were encountered in matching the premine overburden with regraded spoil properties because the degree of surface grading was not predictable. Sampling to a depth of 1.2 m in 0.3 m increments did not significantly improve information on variability of spoil properties compared to the surface 0.3 m alone.

Analysis of Conclusions

This project illustrates the difficulty in developing an accurate model which could predict the properties of regraded spoil based on premine overburden data. More research is needed in this area.

Title: **PREDICTING REGRADED SPOIL QUALITY FROM OVERBURDEN PROPERTY**

Author: G.A. Halvorson

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Report to the North Dakota Legislative Council, Pursuant to Section 5 of H.B.1005 of the fifty-second Legislative Assembly; pp. 9, June 30, 1993.

Key Index Words: Spoil Properties, Overburden Analysis, Sampling Methods

Brief Description

This report contains the results of sampling experiments conducted at the Coteau and Falkirk Mines to determine if the properties of the graded spoil could be predicted by the bore hole data of the undisturbed overburden. If such a prediction were possible, it would help estimate the amount of topsoil and subsoil that would need to be removed for eventual respreading at depths determined by the properties of the underlying spoil. The properties studied included SAR, EC, pH and percent sand, silt and clay. The results indicated that predictability of spoil properties was limited by the degree of variability in the overburden properties and the extent of regrading involved.

Analysis of Conclusions

As concluded in the previous research brief, this report affirms that predicting the properties of regraded spoil based on premine overburden data analysis is difficult in most cases.

Title: **STATUS OF A PRODUCTIVITY INDEX FOR EVALUATING RECLAMATION SUCCESS FOR BOND RELEASE**

Authors: G. A. Halvorson, S. A. Schroeder, and M. Nathan

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Report to the North Dakota Legislative Council, Pursuant to Section 5 of H.B.1005 of the fifty-second Legislative Assembly; pp. 31, June 30, 1993.

Key Index Words: Productivity Index, Topography, Soil Properties

Brief Description

This report summarizes the concept of Productivity Index (PI) - a measure of soil productivity based on soil and landscape properties instead of plant production data - as a method for assessing reclamation success. It also provides some discussion and data on those soil and landscape properties that are included in the PI model. The data provided in support of the PI concept and its further development have been taken from a large number of independent studies with absolutely different objectives.

Analysis of Conclusions

No final conclusions are drawn in this report; neither is there a productivity index developed and/or tested. The need for additional work in this area has been stressed.

Title: **WATER RETENTION BY SOILS CONTAINING COAL**

Author: P. P. Sharma, F. S. Carter, and G. A. Halvorson

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: Soil Science Society of America Journal 57:311-316, 1993.

Key Index Words: Infiltration, Coal, Lignite, Spoil Properties

Brief Description

Water retention by minesoils containing various amounts of commercial (highly water repellent) and degraded (low water repellent) lignite was studied under laboratory conditions. Subsoil and minespoil of sandy loam, loam, and sodic silty clay loam characteristics were used to obtain bulk mixtures with coal content of 5, 10, 15, 25, and 50%. Subsamples of the components and mixtures were wetted with water and desorbed at air pressures ranging from 5 to 1500 kPa. Water content of the mixtures was linearly proportional to the coal content. From the soil water content vs. pressure head relationships of the ingredients (soil and coal), water contents of soil-coal mixtures were predicted by using mass and volume balance interpolation equations. At all pressure heads, the predicted volumetric water contents approximated the measured values with a high degree of accuracy.

Analysis of Conclusions

Since coal fragments are always present in reclaimed soils, this study is definitely relevant for understanding how coal may affect water retention and infiltration in minesoils. However, in the present study coal was mixed homogeneously with soil, which does not reflect the actual field conditions. The authors are aware of this, and have indicated that this study provides a basic framework for understanding water retention properties of mine soils.

Title: **CHANGES IN BULK DENSITY OVER TIME OF SEMIARID RECLAIMED MINELANDS IN NORTH DAKOTA**

Author: S. A. Schroeder

Organization: NDSU-Land Reclamation Research Center, Mandan, ND.

Format: Paper

Reference: Planting, Rehabilitation and Treatment of Disturbed Lands, Seventh Billings Symposium, pp. 9-16, Billings, MO, 1996.

Key Index Words: Compaction, Bulk Density, Infiltration, Root Zone

Brief Description

Minesoil bulk density data collected from five reclaimed sites was reviewed to assess if any changes had occurred over a period of five or more years. Most soil cores were taken to a depth of 1.5m. The temporal effects on bulk density were generally non significant. The mean bulk density values of the upper 0.3 m thick layer remained relatively stable. At depths greater than 0.3 m the bulk densities increased with time.

Analysis of Conclusions

The author postulates that tillage, weather, and root proliferation in the are the main factors that caused the bulk density in the upper soil layer to remain stable with time. Increase in bulk density with in the deeper soil layers is attributed to soil settling and drawdown of soil water. These conclusions are valid, and point to the fact that compaction in the deeper layers of reclaimed lands is a problem that begs for a solution.

Title: **SOIL QUALITY EVALUATION FOR RECLAMATION SUCCESS: AN ALTERNATIVE MITIGATION PARADIGM**

Authors: P. P. Sharma and E. Doll

Organization: NDSU-Land Reclamation Research Center, Mandan, ND.

Format: Paper

Reference: Planting, Rehabilitation and Treatment of Disturbed Lands, Seventh Billings Symposium, pp. 17-27, Billings, MO, 1996.

Key Index Words: Root Zone, Water Management, Infiltration, Compaction, Wetlands

Brief Description

This paper critiques the present practice of spoil regrading and soil respreading and proposes to replace this paradigm with another based on the concept of soil quality and its effect on landscape hydrology. The reclaimed lands have a compacted subsoil layer that limits root growth, and transport and storage of water. The reclamation success is proposed to be evaluated on the basis of pore structural basis of root zone soil quality. This proposition is based on the premise that by routing water through root zone instead of collecting in the sedimentation basins and then releasing it off mine, the agricultural sustainability of uplands, quality of wetlands, and groundwater recharge will be improved.

Analysis of Conclusions

There is much scientific merit and economic sense in this integrated approach. The time to test this idea has come, but it will require a commitment of adequate funds.

SOIL RESPREADING (SR)

Title: **USE OF SOIL MATERIALS ON SPOILS - EFFECTS OF THICKNESS AND QUALITY**

Authors: J.F. Power, R.E. Ries, and F.M. Sandoval

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: North Dakota Agricultural Experiment Station Farm Research 34(1):23-24, 1976

Key Index Words: Soil Requirements, Spoil Properties, Topsoil, Productivity

Brief Description

This paper summarizes the grass and wheat yields data from the wedge plot experiments at Glenharold for 1975 and 1976. The findings during this time frame were that yields did not increase when a soil thickness greater than 28 inches was respread. Also, yield did not vary much when the topsoil thickness was increased from 8 to 24 inches. It was emphasized that both thickness and quality of soil material spread on spoil will affect the crop yields. On sodic spoils, as little as two inches of soil material was found to be highly beneficial but it was found that at least 30 inches of soil material would be required for maximum production.

Analysis of Conclusions

The above findings were regarded by the authors as being tentative. Additional data would be required to draw proper conclusions.

Title: **SODIUM MIGRATION UPWARD ON RECLAIMED SODIC MINE SPOILS**

Authors: F.M. Sandoval, J.F. Power, and R.E. Ries

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Western Society of Soil Science Meeting, 1978

Key Index Words: Soil Requirements, Spoil Properties, Sodium Migration, Topsoil, Fertilizer Use

Brief Description

Research was conducted in the Northern Great Plains to restore productivity of disturbed lands by returning topsoil to cover sodic spoils. Infiltration and water use efficiency were increased and productivity was found to be directly related to the thickness of good quality soil placed over the poor quality spoil. Grass establishment was difficult on silty clay loam sodic spoil (SAR or ESP greater than 25),and as little as 5 cm of respread topsoil considerably increased the productivity. High grass yields were obtained initially with 30 cm of topsoil plus NP fertilizer but the high productivity was not sustained. Productivity decline was partly attributed to upward sodium migration which deteriorated the respread topsoil.

Analysis of Conclusions

Further studies on the upward migration of sodium and other salts into the respread topsoil are necessary and should be continued.

Title: **EFFECTS OF TOPSOIL THICKNESS PLACED ON SPOILBANKS ON WHEAT AND CORN YIELDS IN NORTH DAKOTA**

Authors: M.W. Pole, A. Bauer, L. Zimmerman, and S.W. Melsted

Organization: North Dakota Agricultural Experimental Station (NDSU), Fargo, ND and Northern Great Plains Research Center, USDA-SEA, Mandan, ND

Format: Paper

Reference: Proceedings of 4th Annual Meeting of the Canadian Land Reclamation Association, Regina, Saskatchewan, 1979

Key Index Words: Soil Requirements, Spoil Properties, Topsoil, Productivity

Brief Description

This paper describes the results of field plot experiments conducted at Beulah where 2, 6, 12, and 24 inches of topsoil had been replaced over moderately saline and sodic spoil. Yields of spring wheat and corn were greatest with 24 inches of topsoil, with yield on 12 inches of topsoil often as good. Differences in yield due to greater topsoil thickness decreased with succeeding years; (the experiment was run for four years). No evidence of upward migration of sodium or other salts was observed.

Analysis of Conclusions

These yields were not compared to undisturbed soils and there is no indication that the plots with 24 inches of topsoil produced optimum yields.

Title: **TOPSOIL/SUBSOIL REQUIREMENTS TO RESTORE NORTH DAKOTA MINED LAND TO ORIGINAL PRODUCTIVITY**

Authors: J.F. Power, F.M. Sandoval, and R.E. Ries

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Mining Engineering, pp. 1708-1712, December 1979

Key Index Words: Soil Requirements, Spoil Properties, Topsoil, Subsoil, Sodium Migration, Productivity

Brief Description

This paper summaries the various research projects conducted at the Northern Great Plains Research Center to determine the minimum thickness of topsoil and subsoil to achieve maximum production. The conclusions were that 1) at least 70 cm of soil material is needed to achieve maximum production, 2) topsoil must be segregated and spread separately from subsoil, 3) production depends on the quality of the soil materials returned, and 4) erosion and upward salt movement must be controlled for sustained production.

Analysis of Conclusions

Questions on the magnitude of sodium migration and adequate controls have not been answered.

Title: **ROOT ZONE MANAGEMENT IN NORTH DAKOTA COAL MINE RECLAMATION**

Authors: G.A. Halvorson, S.W. Melsted, S.A. Schroeder, M.W. Pole, C.M. Smith, and E. Deibert

Organization: Department of Soil Science, North Dakota State University, Fargo, ND

Format: Paper

Reference: North Dakota Agricultural Experiment Station Farm Research 37(6):9-12, 1980

Key Index Words: Soil Requirements, Topsoil, Subsoil, Compaction, Productivity

Brief Description

This paper describes the results of the first growing season following the establishment of the trench plots of Falkirk. Various soil thicknesses were placed over different textured nonsaline, nonsodic overburden. The preliminary results indicated that wheat yields improved with increasing thickness of topsoil from 9 to 18 inches; replacing topsoil and subsoil improved the yields over the gravelly sandy loam compared to the replacement of only topsoil. Compaction of overburden material placed in the trenches caused by scrapers resulted in lowering of wheat yields. Subsidence was almost equal on compacted and non-compacted trenches after one year.

Analysis of Conclusions

The results are based on one year yield data, and should therefore be considered preliminary.

Title: **CHANGES OF SODICITY AND SALINITY IN SOILS RECONSTRUCTED ON STRIP MINED LAND**

Authors: S.D. Merrill, E.J. Doering, and J.F. Power

Organization: USDA-SEA-AR, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: North Dakota Agricultural Experiment Station Farm Research 37(6):13-16, 1980

Key Index Words: Soil Requirements, Spoil Properties, Sodicity, Salinity

Brief Description

The upward migration of sodium and other salts into replaced soil materials at several reclamation research sites in western North Dakota is discussed. Evidence is presented in the paper that indicates chemical diffusion played an important role in this process. The potential for degrading the respread soil with upward migration of sodium is greatest when the underlying spoil consists of dispersed mine spoils with SAR of 20 or more, and where only 12 inches or less of high quality soil material is available for respreading.

Analysis of Conclusions

The magnitude of degradation of soil materials and consequent effect on vegetation production when greater thickness of topsoil and subsoil are replaced has not been quantified. Although on the basis of theoretical calculations it has been concluded that the zone of sodium accumulation will become greater as the thickness of the replaced soil is increased, the experimental verification of this assumption has not been made.

Title: **SALINITY AND SODICITY FACTORS AFFECTING SUITABILITY OF MATERIALS FOR MINED LAND RECLAMATION**

Authors: S.D. Merrill, F.M. Sandoval, J.F. Power, and E.J. Doering

Organization: USDA-SEA-AR, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Adequate Reclamation of Mined Lands? A Symposium, pp. 3-1 to 3-25, Soil Conservation Society of America and WRCC-21 Committee, Billings, MT, March 1980

Key Index Words: Soil Requirements, Spoil Properties, Salinity, Sodicity

Brief Description

The upward migration of sodium into replaced soil materials of reclamation research sites in western North Dakota is discussed. The conditions for the greater migration of sodium are when the spoil has a high level of sodicity (SAR greater than 20), very low hydraulic conductivity, fine-texture, and montmorillonite clay fraction. If the hydraulic conductivity of the spoil is sufficient to allow some leaching of soluble salts, it is postulated that upward migration of sodium will not be a problem. Salinity and sodicity guidelines are included in the paper.

Analysis of Conclusions

This paper contains guidelines that are useful when dealing with only limited amounts of topsoil and subsoil and when the spoil is predominantly sodic clay material.

Title: **WATER USE EFFICIENCY AS INFLUENCED BY TOPSOIL THICKNESS AND FERTILITY ON RECLAIMED LAND**

Authors: S.A. Schroeder, M.W. Pole and A. Bauer

Organization: Department of Soil Science (NDSU) and Northern Great Plains Research Center (USDA-SEA-AR), Mandan, ND

Format: Paper

Reference: North Dakota Agricultural Experiment Station Farm Research 37(6):24-26, 1980

Key Index Words: Soil Requirements, Spoil Properties, Topsoil, Fertility, Water Use, Productivity

Brief Description

Water use efficiency (WUE) was determined on research plots at the Beulah and Glenharold mines. The plots had different treatments of topsoil (2, 6, 12, and 24 inches). The WUE of wheat and corn increased significantly in 2 and 3 years out of 5 years, respectively, as the thickness of respread topsoil was increased. Nitrogen fertilizer had minimal effects on WUE for wheat and some effect on corn silage.

Analysis of Conclusions

There was concern expressed in this paper about the variability in the experimental plots caused by the reclamation process that may have overshadowed some statistically significant differences. Also, differential damage by insects within plots had occurred during some years which may have further affected the data.

Title: **EFFECT OF SOIL THICKNESS UPON SOIL WATER AND NITROGEN USE BY CRESTED WHEATGRASS IN THE NORTHERN GREAT PLAINS**

Authors: S.D. Merrill, J.F. Power, and R.E. Ries

Organization: USDA-ARS, Northern Great Plains Center, Mandan, ND

Format: Paper

Reference: Agronomy Abstracts, p. 184, 1981

Key Index Words: Soil Requirements, Topsoil, Subsoil, Fertility, Water Use, Productivity

Brief Description

Soil water and nitrogen uses by crested wheatgrass over various thicknesses of topsoil and subsoil over sodic spoil are discussed. Nitrogen uptake was nearer to the surface with less thickness of soil. Water use above the 30 cm depth was greater with less thickness of soil. Conclusion was lower yields with less soil.

Analysis of Conclusions

This information is based on a published abstract and not a full length paper. For adequate analysis of the conclusions, additional data and details are needed.

Title: **EFFECTS OF TOPSOIL AND SUBSOIL THICKNESS ON SOIL WATER CONTENT AND CROP PRODUCTION ON A DISTURBED SOIL**

Authors: J.F. Power, F.M. Sandoval, R.E. Ries, and S.D. Merrill

Organization: USDA-SEA-AR, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Soil Science Society of America Journal 45(1):124-129, 1981

Key Index Words: Soil Requirements, Spoil Properties, Topsoil, Subsoil, Sodicity, Water Use, Productivity

Brief Description

Crop production and water use data from the soil wedge plots of the Glenharold Mine is discussed. Yields of the crops grown on the plots increased as the total soil thickness increased to the 90-150 cm range. Yields with this amount of soil equaled or exceeded that expected on similar undisturbed soil types. Water was extracted from the upper 30 to 90 cm of spoils when the soil/spoil interface was within 90 cm of the soil surface. There was no evidence of any accumulation of soil water just above the soil/spoil interface.

Analysis of Conclusions

This is a very important study regarding optimization of topsoil and subsoil respreading depths. Monitoring should continue to detect any upward migration of sodium and consequent degradation of replaced soil and reduced productivity.

Title: **TOPSOIL MANAGEMENT ON MINED LANDS**

Authors: G.E. Schuman and J.F. Power

Organization: USDA-SEA-AR, High Plains Grasslands Research Station, Cheyenne, WY and University of Nebraska, Lincoln, NE

Format: Paper

Reference: Journal of Soil and Water Conservation 36(2): 77-78, March-April, 1981

Key Index Words: Soil Requirements, Spoil Properties, Topsoil, Sodicity

Brief Description

This paper summarizes various research projects that have been conducted in the Northern Great Plains on the amount and quality of topsoil and subsoil necessary for mined land reclamation. The paper contains several general recommendations for topsoil (and subsoil) management.

Analysis of Conclusions

The paper is of a rather general nature. For more specific details on the various aspects, see the materials that are referenced in this paper.

Title: **SOIL DEPTH REQUIREMENTS TO RECLAIM SURFACE MINED AREAS IN THE NORTHERN GREAT PLAINS**

Authors: R.C. Barth and B.K. Martin

Organization: Colorado School of Mines Research Institute, Golden, CO

Format: Report

Reference: Colorado School of Mines Research Institute Report for U.S. Bureau of Mines, Contract No. J0265025, 1982

Key Index Words: Spoil Properties, Soil Requirements, Topsoil, Subsoil, Productivity

Brief Description

Fourteen wedge plots were established at different mines in the Northern Great Plains. Soil was replaced over different types of spoil with soil thicknesses varying from 0 to 152 cm in each plot. Yield data was obtained to determine optimum soil depths for each type of spoil. Also, a microbiological study was conducted on four of the plots. Findings were that soil depth requirement for optimum productivity varied with the type of underlying spoil. The optimum amount of soil thickness over nonsaline, nonsodic spoil varied from 40 to 85 cm and 70 to 96 cm over sodic spoil.

Analysis of Conclusions

It would be desirable to monitor some of these sites to study if any changes have occurred in the respread soil due to an upward migration of sodium from the underlying spoil.

Title: **EFFECT OF SUBSOIL QUALITY AND THICKNESS UPON CROP GROWTH AND WATER USE ON MINE SOIL RECLAIMED BY TOPSOIL AND SUBSOIL RESPREADING**

Authors: S.D. Merrill, R.E. Ries, and J.F. Power

Organization: USDA-ARS, Northern Great Plains Center, Mandan, ND

Format: Paper

Reference: Agronomy Abstract, p. 253, 1982

Key Index Words: Soil Requirements, Spoil Properties, Productivity, Water Use, Subsoil

Brief Description

The differences in productivity and water use of two forage grass species and spring wheat due to the use of different types (texture and salinity) and thickness (0-110 cm) of subsoil, with a uniform layer (20 cm) of topsoil, respread on a sodic mine spoil are discussed. Maximum yields occurred with total soil thickness of 60 to 90 cm. Under favorable precipitation the yields and water use of wheat were greatest on saline soils, but grass yields were little affected by subsoil quality except at midslope positions where salinity had an adverse effect.

Analysis of Conclusions

The results demonstrate that a complex interaction exists among soil quality factors, crops and water availability. However, being an abstract rather than a full length paper it does not provide enough explanation as to the reasons for some of the variations in yield caused by subsoil quality.

Title: **QUALITY PARAMETERS OF SPRING WHEAT AND FORAGE CROPS RELATED TO TOPSOIL AND SUBSOIL THICKNESS**

Authors: J.F. Power, R.E. Ries, and F.M. Sandoval

Organization: USDA-ARS Northern Great Plains ResearchLaboratory, Mandan, ND

Format: Paper

Reference: Soil Science Society of America Journal 46: 381-386, 1982

Key Index Words: Plant Responses, Topsoil, Subsoil, Nitrogen, Nutrient Deficiencies

Brief Description

This experiment was conducted on wedge plots at two western North Dakota mines to determine the effects of different thicknesses of topsoil and subsoil over sodic spoil on N and P content of spring wheat, grasses, and alfafa, and on the milling and baking qualities of wheat. Crop growth and yield for all species increased with total soil depths to about 90 to 120 centimeters. Generally, the presence of topsoil enhanced crop quality by increasing nutrient uptake. Reduced water storage and availability caused by decreasing subsoil depth tended to accumulate higher N concentrations and increase associated quality parameters in grain and forage, but with a corresponding decrease in yield.

Analysis of Conclusions

This study highlights the importance of topsoil and subsoil thicknesses as they are related to crop quality and yield.

Title: **PLANNING THE POST-MINING LANDFORMS FOR OPTIMUM USE OF AVAILABLE SOIL MATERIALS**

Authors: N.C. Wollenhaupt and J.L. Richardson

Organization: North Dakota State University, Fargo, ND

Format: Paper

Reference: Can Mined Land be Made Better Than Before Mining?, Proceedings of a conference held at North Dakota, pp. 69-76, November 1982

Key Index Words: Soil Requirements, Prime Soils, Land Use

Brief Description

This paper advocates that the approach of exactly replacing the pre-mining soil is not valid. A land use oriented soil reclamation procedure has been given. Reclamation of "prime landscapes" rather than the philosophy of "preserving prime soils" has been stressed.

Analysis of Conclusions

Two approaches - "preservationist" and "constructionist"- in reclamation strategy have been discussed with the "constructionist" approach favored. In its emphasis on optimum use of soil materials, the paper provides interesting but familiar information, which is useful in planning reclamation procedure in a given situation.

Title: **WHEAT YIELDS ON PRIME AND NONPRIME SOILS AND SOIL MIXTURES IN A GREENHOUSE STUDY**

Authors: F.S. Carter and E.C. Doll

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Land Reclamation Research Center, NDSU-Agricultural Experiment Station Technical Report No. 3, 1983

Key Index Words: Soil Productivity, Prime Soils, Productivity

Brief Description

This report describes the results of two greenhouse experiments comparing the productivity of prime farmland topsoil, nonprime topsoil, and mixtures of prime and nonprime topsoils. Comparisons were made between Bowbells loam (prime) and Williams loam (nonprime) soils collected from the Coteau Mine. Also, the productivity of the A horizon soil material was compared to that of a mixture of the A and upper B horizon materials. No productivity differences were observed in the A horizon materials compared to a mixture of A and upper B horizon materials. In the first experiment, wheat yields were higher on prime soil and on mixtures containing 50% or more of prime soil. In the second experiment, where a second crop was grown in the same potted soils, no yield differences in the prime and nonprime soil were observed.

Analysis of Conclusions

Field experiments studying the productivity of prime and nonprime soils should be established. Such studies should include other soil types also.

Title: **SOIL CONSTRUCTION FOR RECLAMATION OF SALINITY AND SODICITY AFFECTED MINE SOILS**

Authors: S.D. Merrill and E.J. Doering

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Symposium on Soil and Overburden in Arid/Semiarid Mined Land Reclamation, Casper, WY, January 1983

Key Index Words: Soil Requirements, Spoil Properties, Salinity, Sodicity, Productivity

Brief Description

This paper provides a summary of reclamation research that has been conducted by the USDA-Agricultural Research Service staff at Mandan, ND, on the dynamics of salinity and sodicity in the reconstructed mined lands and their effects on plant growth.

Analysis of Conclusions

The results of studies summarized in this presentation are very useful in understanding the relationships between the quality of spoil and soil materials and the respreading depths of topsoil and subsoil for achieving optimum growth and yield of plants.

Title: **SODIUM MOVEMENT IN SOIL-MINESPOIL PROFILES: DIFFUSION AND CONVECTION**

Authors: S.D. Merrill, E.J. Doering, J.F. Power, and F.M. Sandoval

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Soil Science 136(5):308-316, 1983

Key Index Words: Sodicity, Topsoil, Spoil Properties

Brief Description

This paper discusses the results of model calculations and laboratory experiments conducted to study the upward movement of sodium and other ions from spoil into the respread topsoil. Upward migration of sodium was found to be considerably more due to diffusion than by convective flow generated by soil-water evaporation. More sodium movement occurred in columns without evaporation than in columns subject to evaporation; reduced water content reduced diffusion, and very low minespoil hydraulic conductivity severely restricted convective flow.

Analysis of Conclusions

Application of these model calculations and laboratory results to field observations of salt movement in topsoil-covered minespoil under semiarid, continental climatic conditions indicated that salt diffusion is a significant mechanism for sodium accumulation in soil, provided the spoil is highly dispersed and the necessary chemical gradient is present. These data also showed that significant quantities of sodium will diffuse only 10 to 15 cm upward in materials of this nature.

Title: **RECLAMATION OF SODIC MINESPOILS WITH TOPSOILING AND GYPSUM**

Authors: S.D. Merrill, E.J. Doering, and F.M. Sandoval

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Paper No. 83-2141, Presented in ASAE 1983 Summer Meeting, Bozeman, MT, June 1983

Key Index Words: Revegetation, Spoil Properties, Topsoil, Amendments

Brief Description

The effects of topsoiling and gypsum applications on the growth of crested wheat grass was studied at four mined sites in western North Dakota. The test sites were located at Center, South Beulah, Glenharold, and Indian Head Mines. With only 30 cm of respread topsoil the forage yield increased by 8%, 25%, and 84%, respectively, on minespoils of non-sodic, moderate sodicity, and high sodicity character. Gypsum increased forage yield by 23% on non-topsoiled, moderately sodic spoils, and by 19% on topsoiled, highly sodic spoil. Although gypsum treatment produced yield increases, but it was not as effective as topsoiling. The chief limitation for gypsum amendment was the constraint on downward leaching.

Analysis of Conclusions

This research has proved that even relatively small thicknesses of topsoil are beneficial for increasing plant growth on mined lands. Also, the use of gypsum was not found to be greatly profitable. Research needs to be continued on the determination of optimum soil respreading requirements under various conditions of spoil and soil properties, topography, and land use.

Title: **PHYSICAL AND CHEMICAL REQUIREMENTS OF OVERBURDEN LOCATED WITHIN THE POTENTIAL ZONES OF PLANT ROOTS AS INFLUENCED BY FIRST AND SECOND LIFT MATERIALS**

Authors: NDSU-Land Reclamation Research Center Staff

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: NDSU-LRRC Final Report, April 1983

Key Index Words: Soil Requirements, Spoil Properties, Productivity, Topsoil, Subsoil

Brief Description

Trench plot experiments were established at Falkirk to determine the amount of topsoil and/or subsoil needed to produce optimum yields over different textured, nonsaline, nonsodic overburden materials. Findings were that at least 18 inches of topsoil produced optimum yields over nonsaline, nonsodic spoil with an adequate water holding capacity. Additional topsoil or subsoil is needed when the spoil has a low water holding capacity, this amount is probably less than 60 inches total.

Analysis of Conclusions

The study did not determine the minimum soil thickness needed to produce optimum yields over nonsaline, nonsodic spoil with a low water holding capacity.

Title: **PRODUCTIVITY OF PRIME, NONPRIME AND RECLAIMED SOILS IN WESTERN NORTH DAKOTA**

Authors: S.A. Schroeder and E.C. Doll

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Preliminary Report and Paper*

Reference: North Dakota Agricultural Experiment Station Farm Research, 41(5):3-6,31, 1984

Key Index Words: Prime Soils, Productivity

Brief Description

Field studies were conducted at the Beulah and Center Mines to identify factors related to productivity of undisturbed prime and nonprime soils and reclaimed areas using corn, wheat and barley as test crops. Yield differences between the prime and nonprime sites were noted. At Beulah the nonprime site yielded better than the prime site, at Center the opposite occurred. After the third year of the experiment, the reclaimed sites appeared to yield similar to the average yield of the undisturbed sites.

Analysis of Conclusions

Additional research should be conducted to determine the productivity of reclaimed lands as compared to undisturbed prime farmland and nonprime areas. In doing so, the differences or similarities in the physical and chemical characteristics of the prime and nonprime soils must be considered.

Title: **PLANNING AND EVALUATING CROPLAND RECLAMATION AFTER STRIPMINING IN NORTH DAKOTA**

Authors: E.C. Doll, N.C. Wollenhaupt, G.A. Halvorson, and S.A. Schroeder

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: Proceedings of the Third Biennial Symposium on Surface Coal Mine Reclamation on the Great Plains, pp. 88-101, Billings, MT, March 1984

Key Index Words: Topography, Prime Soils, Productivity

Brief Description

A high percentage of lands affected by stripmining in North Dakota are designated to cropland postmining use. The factors involved in returning reconstructed soils to a mature, steady state must be better understood in order to more effectively plan and evaluate cropland reclamation. In this paper emphasis is given to topographic design strategies, methods of overburden and soil characterizations, and to using soil parameters as they relate to productivity in assessing reclamation success. It discusses regulatory changes that may be necessary in order to develop more effective and cost efficient reclamation programs and better criteria to evaluate the success of reclamation.

Analysis of Conclusions

This is a useful step in a progessive system of research in the development and evaluation of reclamation in North Dakota. It combines past experience with present understanding and gives direction to future research in this area.

Title: **SOIL REPLACEMENT FOR RECLAMATION OF STRIPMINED LANDS IN NORTH DAKOTA**

Authors: E.C. Doll, S.D. Merrill, and G.A. Halvorson

Organization: NDSU-Land Reclamation Research Center and USDA-ARS Northern Great Plains Research Laboratory, Mandan, ND

Format: North Dakota State University, Agricultural Experiment Station Bulletin

Reference: North Dakota State University Agricultural Experiment Station Bulletin 514, 1984

Key Index Words: Soil Replacement, Spoil Properties

Brief Description

This bulletin summarizes the results of several field experiments which were conducted at various mine sites in North Dakota to study the response of some crops to different thicknesses of replaced suitable plant growth materials. The authors developed recommendations for topsoil and subsoil replacement thicknesses based on spoil properties such as sodium adsorption ratio and texture, assuming a rooting depth of four feet. A range of subsoil respread thicknesses has been proposed for various types of regraded spoil. The bulletin emphasizes the need for basing soil respread thicknesses on the properties of the underlying graded spoil rather than salving and respreading of all the available soil materials.

Analysis of Conclusions

This report provides an excellent summary of research data on soil replacement thicknesses and forms the basis for the rule changes made in 1986 regarding soil salvage and replacement.

Title: **EFFECT OF SOIL THICKNESS ON NITROGEN DISTRIBUTION AND USE BY CRESTED WHEATGRASS**

Authors: J.F. Power, S.D. Merrill and S.J. Smith

Organization: USDA-ARS Lincoln, NE; USDA-ARS, Mandan, ND; and USDA-ARS Durant, OK

Format: Paper

Reference: Soil Science Society of America Journal 49:1461-1465, 1985

Key Index Words: Soil Replacement, Soil Productivity, Nitrogen

Brief Description

This study was conducted to evaluate the effects of soil thickness on the distribution and use of both available soil and fertilizer N. Microplots were established at four locations on reconstructed mine soils where total respread thicknesses were 0.25, 0.50, 0.75 and 1.00 m, over graded sodic (SAR 29.5) spoil. Enriched 15N fertilizer was applied to those microplots in either the spring or fall, forage was harvested, and the plots were excavated (in either the first or second year after application) to determine relationships between soil thicknesses and uptake of soil and fertilizer N.

Analysis of Conclusions

Increased soil thicknesses greatly increased forage and root growth, but much lesser effect on N concentration in plants. Uptake of labeled N was not greatly influenced by soil depth but uptake of soil N generally increased two to threefold as thicknesses of respread soil increased from 0.25 to 1.0 m. One of the most important conclusions to be drawn from this experiment is that increased plant N uptake resulting from increased soil thickness comes largely from better utilization of indigenous soil N. Further research is suggested to elucidate the role of microbial activity to the N transformations that occurred to account for better utilization of indigenous soil N in areas of increased soil respread thicknesses.

Title: **EFFECT OF DISTURBED SOIL THICKNESS ON SOIL WATER USE AND MOVEMENT UNDER PERENNIAL GRASS**

Authors: S.D. Merrill, S.J. Smith, and J.F. Power

Organizations: USDA-ARS, Northern Great Plains Research Laboratory, Mandan, ND

Format: Paper

Reference: Soil Science Society of America Journal 49: 196-202, 1985

Key Index Words: Water Use, Sodicity, Soil Replacement

Brief Description

Water use and movement and root growth were monitored in constructed soil profiles of 0.25, 0.50, 0.75, and 1.0 meter depth over sodic mine spoil. Forage yield was 2 to 3.5 times greater on 1.0 m profiles than on 0.25 m profiles. Water uptake from spoil was much lower than that from topsoil and subsoil. Low hydraulic conductivity was the dominant factor which limited water storage and use in spoil. Root growth and soil water potentials in spoil were not significantly different between spoil and subsoil. Reduced soil thickness resulted in reduced water use efficiency.

Analysis of Conclusions

This study describes the relationship between soil depth over sodic spoil and productivity. Because low hydraulic conductivity of sodic spoil inhibits soil water storage and release, soil depth becomes the limiting factor in water availability and, hence, productivity.

Title: **TOPSOIL AND SUBSOIL REPLACEMENT ON STRIPMINED LAND IN NORTH DAKOTA**

Authors: G.A. Halvorson and E.C. Doll

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: Second Annual Meeting American Society for Surface Mining and Reclamation Proceedings, pp. 232-241, Denver CO, October 8-10, 1985

Key Index Words: Spoil, Water Holding Capacity, Soil Replacement

Brief Description

This paper summarizes the results of several field trials conducted at various North Dakota mine sites to study the effects of different thicknesses of replaced suitable plant growth material on crop yields. The authors developed recommendations for topsoil and subsoil replacement thicknesses based on spoil properties. The importance of an adequate premine characterization of all soil and overburden materials was emphasized.

Analysis of Conclusions

This paper provides an excellent summary of research data on soil replacement thicknesses needed to achieve optimum yields. The authors felt additional research is needed to 1) study the use and amelioration of poor quality soil and overburden materials, 2) to adequately characterize the changes that occur in unweathered spoil materials placed within the root zone, and 3) to predict sodium movement in reclaimed soils over sodic spoils.

Title: **TOPSOIL AND SUBSOIL THICKNESS REQUIREMENTS FOR RECLAMATION OF NONSODIC MINED-LAND**

Authors: G.A. Halvorson, S.W. Melsted, S.A. Schroeder, C.M. Smith, and M.W. Pole

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: Soil Science Society of America Journal 50:419-422, 1986

Key Index Words: Soil Replacement, Soil Texture, Topsoil, Subsoil

Brief Description

Eight trenches were excavated to a depth of 4.6 m and filled with three different textures of spoil to evaluate topsoil and subsoil thickness requirements for crop production on nonsaline, nonsodic spoil material at the Falkirk Mine, near Underwood, ND. Wheat, barley and corn yields were compared on plots with 0.23, 0.46, or 0.69 m of topsoil replaced over loamy sand spoil with and without subsoil, over clay loam spoil, or over silty clay loam spoil. Some of the plots were also irrigated.

Analysis of Conclusions

Crop yields increased with increasing thickness of replaced topsoil, especially on trenches filled with loamy sand spoil. The study suggested that at least 0.7 m of topsoil and/or subsoil should be respread over coarse textured, nonsodic spoil for maximum yields. This is consistent with the current North Dakota regulations which require 36 inches of SPGM over coarse textured, nonsodic, nonsaline spoil.

Title: **CORN AND WHEAT RESPONSE TO TOPSOIL THICKNESS AND PHOSPHORUS ON RECLAIMED LAND**

Authors: G.A. Halvorson, A. Bauer, S.A. Schroeder, and S.W. Melsted

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: Journal of Environmental Quality 16(1):73-76, 1987

Key Index Words: Productivity, Soil Replacement, Sodicity, Plant Responses, Fertility, Water Use

Brief Description

This paper examines the effects of topsoil respread thickness and rates and placement of P on yield of wheat and corn on reclaimed land. Placement of 0.15 to 0.60 m of sandy loam topsoil over moderately sodic spoil increased corn and wheat yields compared to only 0.05 m. Yields consistently increased with topsoil thickness up to 0.30 m. However, results indicated that respreading of more than 0.30 m of coarse textured topsoil may actually reduce productivity because of poorer water holding capacity. Response to P broadcast at the topsoil-spoil interface or on the topsoil surface were small, and occurred at the low P rate. Wheat yields were not increased by drill applied P. Corn silage yields were improved by banded application at moderate rates in two out of of four years.

Analysis of Conclusions

This study confirms that topsoil replacement increases crop yield on reclaimed lands. It also indicates that the texture of soil and underlying spoil have an effect on the ability to continuously supply water to the growing crop, and should therefore be considered in determining soil respread thicknesses. Current North Dakota soil test recommendations for P were found to be accurate for reclaimed soils.

Title: **CORN AND WHEAT RESPONSE TO TOPSOIL THICKNESS AND PHOSPHORUS ON RECLAIMED LAND**

Authors: G.A. Halvorson, A. Bauer, S.A. Schroeder, and S.W. Melsted

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Analysis of Conclusions

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Title: **EFFECT OF LANDSCAPE POSITION ON SPRING WHEAT YIELDS AND WATER** USE

Authors: G.A. Halvorson

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: Planning, Rehabilitation and Treatment of Disturbed Lands, Billings Symposium, 1990

Key Index Words: Topography, Soil Water, Soil Moisture, Runoff

Brief Description

A 4-year study of wheat yields and water use from different soil series in Underwood and Beulah, ND, areas is reported. The soil series included Zahl, Williams, Bowbells, and Tonka , which are located on hilltops, sideslopes, foot- and toeslopes, and depression areas, respectively. At each site topo factor was calculated by measuring the slope in 4, right-angle apart, directions, and adding them up. The downward slopes were considered positive (i.e., the site would receive water due to run-on) and the upward slope negative (i.e., the site would lose water due to runoff). The topo factor was calculated from 3, 6, 15, and 30 m from each site. Wheat yields on different soils were related to water use and occurred in the order Tonka, Bowbells, Williams, Zahl. Inclusion of topo factor in the regression between wheat yield and water use increased coefficient of determination in all cases. Topo factor measured at 15 m distance from the sampling site gave the best result.

Analysis of Conclusions

The results presented in this paper underscore the importance of topographic location and wheat yield, and relate it to the distribution The relationship of landform to water distribution has been quantified by using an easily derivable topo factor, which can be plugged into a regression model to predict wheat yields. This concept is quite useful for predicting wheat yields on undisturbed as well as reclaimed lands.

Title: **RELATION OF SATURATION PERCENTAGE TO SODIUM ADSORPTION RATIO IN NORTH DAKOTA SPOIL**

Author: E.C. Doll and F.S. Carter

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: NDSU-Land Reclamation Research Center Technical Report No. 8, 1991

Key Index Words: Saturation Percentage, Sodium Adsorption Ratio, Spoils

Brief Description

This report recommends that the spoil saturation percentage (SP) parameter, required by ND reclamation rules to be used in conjunction with SAR to determine the soil replacement thickness, should be eliminated. It further recommends that the total depth of soil replacement over all spoils with SAR between 12 and 20 should be 36 inches. These recommendations are based on the authors' evaluation of a large number of spoil samples from the Falkirk, Beulah, Indian Head and Glenharold mines, with respect to the distribution and relationship of their SP and SAR values. The authors claim that in North Dakota soils and spoils SP is primarily dependent on the level of SAR rather than on the kind oramount of clay present in them. Basing their arguement on the effective rooting depth of most crops in North Dakota as being 4 feet, the authors claim that by replacing 36 rather than 42 inches of soil over the regraded spoils having SAR between 12 and 20 and SP greater than 95%, only a 3% loss in soil productivity is likely to occur.

Analysis of Conclusions

The data and discussion presented in this report are important in determining whether the SP parameter should be dropped from the existing rule regarding soil replacement depths.

Title: **TOPOGRAPHIC POSITION EFFECTS ON SOIL WATER AND WHEAT YIELDS ON RECLAIMED**

Author: S.A. Schroeder

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: North Dakota Farm Research 48(5):3-5, 1991

Key Index Words: Topography, Soil Water, Productivity

Brief Description

This field investigation was conducted at the Center and Falkirk mines to study the effect of landscape position on water distribution and wheat yield. The topographic effects on available soil water at planting and wheat yield were significant. Available soil water and wheat yields were generally higher on the downslope compared to upslope landscape positions. However, year to year variations were also noted.

Analysis of Conclusions

The results presented in this paper, and several other papers of similar theme, suggest that higher crop yields on the prime farmland soils in North Dakota are due to their favorable topographic position rather than due to any intrinsic differences in the quality of their soils. This line of research is useful as it will help determine if segregation of prime and non-prime topsoil is necessary.

Title: **TILLAGE EFFECTS ON WATER USE AND YIELDS OF WHEAT FROM RECLAIMED SOILS**

Authors: K.C. Vining and S.A. Schroeder

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: ND Farm Research 49(4):8-11, 1992

Key Index Words: Tillage, Soil Water, Subsoil

Brief Description

Field experiments were conducted over a period of three years at the Glenharold and Beulah Mines to study the effects of conventional chisel and subsoil tillage treatments on compaction, root growth, soil water status, and crop yield. This paper focuses on soil water usage and spring wheat yields only. Chiseling was done to a depth of 6 inches with 12-inch shank spacing, and subsoiling was done to a depth of 24 inches with 42-inch shank spacing. The tillage treatments had an inconsistent effect on wheat yield as well as the usage of soil water. Also, responses varied with the location.

Analysis of Conclusions

The inconsistent results do not allow any valid conclusions. Deep tilling of the subsoil did not seem to improve soil water storage or use.

Title: **SOIL DEPTH AND QUALITY REQUIREMENTS FOR RECLAMATION OF RANGELANDS**

Authors: G.A. Halvorson, and D.R. Kirby

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Report to the North Dakota Legislative Council, Pursuant to Section 5 of H.B.1005 of the fifty-second Legislative Assembly, June 30, 1993

Key Index Words: Soil Replacement, Topoedaphic Unit, Alpha Diversity, Productivity, Cover

Brief Description

This report consists of a large number of data tables with one and a half page of text, summing up the results of an investigation conducted at the Center, Indian Head, and Glenharold Mines on the relationship of rangeland vegetation yield, cover and diversity to replaced soil depths. Topoedaphic land units were identified, using stepwise multivariate analysis on soil physical, chemical and topographic information, and proposed as a classification system for reclaimed lands. A major conclusion of the study was that replaced soil thicknesses lesser than those required by the North Dakota rules may be needed for adequate revegetation of post-mine rangelands.

Analysis of Conclusions

The assumption made in this report that meeting 90 percent of the standard (as required by the federal rules) would be considered as successful revegetation in North Dakota is not correct. Otherwise, the study is quite important and significant for the lignite industry and the regulatory agency to determine if any changes in the SPGM replacement requirements are needed.

Title: **RELATION OF COMPACTION AND SOIL PHYSICAL PARAMETERS TO PRODUCTIVITY OF RECLAIMED SOIULS**

Authors: S.A. Schroeder and K. Vining

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Report to the North Dakota Legislative Council, Pursuant to Section 5 of H.B.1005 of the fifty-second Legislative Assembly, June 30, 1993

Key Index Words: Compaction,Tillage, Bulk Density, Soil Strength, Soil Water

Brief Description

The report contains the results of field experiments initiated in 1987 at the Center and Freedom Mines to investigate 1) the initial and long term effects of various tillage treatments on compaction of respread soils and on crop yield, 2) quantify the effects of plant species, root growth, and climate on compaction, and 3) the effects of precropping with forage species on spring wheat yield. The tillage treatments included chiselling, grader ripping and deep ripping. The results indicated that subsoil tillage teatments applied prior to topsoil respreading did not alleviate compaction because the subsoil was recompacted in the topsoiling process. Bulk density and soil strength increased with time due to reconsolidation. Tillage treatments did not affect crop yield or root growth either. Wheat yields were unaffected by precropping with forages. Weather alone played a dominant role in affecting forage and wheat yields.

Analysis of Conclusions

The study clearly indicates that other approaches to solving the compaction problem in respread soils needs to be explored and developed.

Title: **RESEARCH ON THE RECLAMATION OF PRIME FARMLAND IN NORTH DAKOTA**

Authors: G.A. Halvorson and M.V. Nathan

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Report to the North Dakota Legislative Council, Pursuant to Section 5 of H.B.1005 of the fifty-second Legislative Assembly, 58p, June 30, 1993

Key Index Words: Prime Farmland, Prime Soils, Topsoil, Subsoil, Topography

Brief Description

This report reviews the findings of past and recent research on the reclamation of prime agricultural soils in North Dakota. Most of the experimental data examined showed that topography plays an important role in determining the productivity of a given area. The studies reviewed include field plot experiments (initiated at the Glenharold Mine in 1974, Indian Head in 1975, Falkirk in 1978, Beulah and Center Mines in 1980, Freedom and Falkirk in 1992); greenhouse studies conducted in 1983, and other topography related research conducted at several reclaimed as well as undisturbed sites.

Analysis of Conclusions

Much of the scientific evidence collected indicated that productivity differences between prime and nonprime soils are not as much due to any inherent differences in the quality of the soil materials *per se* , but are due to their topographic location and, thus, related to the availability of moisture for plant growth. If this conclusion is correct, then the regulations addressing prime soil removal/respreading would have to be amended, which would lower reclamation cost without sacrificing other standards.

Title: **PREDICTING REGRADE SPOIL QUALITY FOLLOWING RECLAMATION AT A SURFACE COAL MINE**

Author: J.D. Friedlander

Organization: The Coteau Properties Company, Freedom Mine, Beulah, ND.

Format: Paper

Reference: Proceedings of 10th National ASSMR Meeting, pp. 796-814, Spokane, WA, 1993

Key Index Words: Soil Replacement, Soil Thickness, Spoil Properties

Brief Description

This paper analyzes the state regulatory policy (formula) for determining the amount of suitable plant growth material that must be salvaged to meet the respread depth requirement, which is tied to the properties of the regraded spoil It involved an in-depth review of field data regarding the predicted and the actual thicknesses of soil respread on a large acreage of graded spoil. The paper also discusses the research that led to the current soil replacement rule. The analysis showed that the actual replacement depths were about 10% less than predicted by the

Analysis of Conclusions

The author suggests that the assumptions used to determine the quantity of soil required for replacement should be reevaluated, as it may be possible to reduce this requirement by as much as 10%, thereby saving some cost in soil salvage. How widely would this conclusion be applicable to other mines remains to be tested.

Title: **EFFECTS OF SOIL DEPTH AND DROUGHT ON RECLAIMED WOODLANDS IN WEST CENTRAL NORTH**

Authors: D. Nilson, D. Kirby, and K. Krabbenhoft

Organization: Basin Cooperative Services, Glenharold Mine, Stanton, and NDSU- Animal and Range Science Department, Fargo, ND

Format: Paper

Reference: Decades Later: A Time for Reassessment, Proceedings of 12th National ASSMR Meeting, pp. 141-150, Laramie, WY, 1995

Key Index Words: Soil Replacement, Drought, Woodlands, Diversity, Plant Species

Brief Description

Survival, stem densities, and diversity of deciduous woodlands reestablished on reclaimed land a the Glenharold mine were studied over a period of 1983 to 1994. Stem densities declined following drought in 1988, but increased with the onset of cool, wet weather in 1992. However, the recovery in stem density was nil on sites respread with 25 -50 cm of soil, but significantly higher on sites respread with 100-150 cm of soil. Species diversity was not significantly affected by drought. Diversity value (H')t increased from 1.207 to 1.462. over the study period and was similar to the premining woodland communities.

Analysis of Conclusions

This study emphasizes the importance of soil replacement depths and root zone characteristics for reestablishing woodlands on reclaimed land. The effects of drought on tree survival and its interaction with soil thickness (or moisture holding properties of root zone) are also underscored.

Title: **COMPARATIVE EVALUATION OF PRODUCTIVITY OF PRIME AND NONPRIME LAND**

Author: G.A. Halvorson

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Report on Contract No. LRC-XVIII-58 - Submitted to the Industrial Commission of North Dakota, 11p. March 20,.1996

Key Index Words: Prime Farmland, Prime Soils, Topography

Brief Description

The 1995 results of field plot experiments conducted at the Freedom and Falkirk Mines since 1992 are discussed. At each of these mines, plots had been constructed out of Bowbells, Williams and Zahl soils placed at topgraphically prime (runon) and nonprime (Runoff) locations. Each soil type was respread to two different soil depths. In 1995, wheat yield was unaffected by soil depth at both sites and affected by topographic position at the Freedom Mine only. Bowbells and Williams soils gave similar yields, but Zahl responded inconsistently.

Analysis of Conclusions

The author recommends that topsoil from Zahl locations can be mixed with Bowbells and Williams because its productivity potential is very close to the other two soils, and that the proportion of soil mass contributed by Zahl in a prime location would be quite low. The report purports that all soils may not need to be separately salvaged in prime farmland situations.

Title: **THE SUCCESS OF CURRENT SOIL DEPTH REQUIREMENTS ON MINELAND IN NORTH DAKOTA: AN ASSESSMENT**

Author: G.A. Halvorson

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Final Report on Contract No. ILRC-XV-50 - Submitted to the Industrial Commission of North Dakota, 13p. April 15,.1996

Key Index Words: Soil Replacement, Productivity

Brief Description

This report summarizes the results of a large number of investigations conducted to assess the relationship between the depth of soil replacement and crop yield. Wheat yields were measured from reclaimed and undisturbed lands and regressed with soil thickness in an attempt to determine whether the current soil replacement rules (based on spoil quality) are adequate to achieve or exceed the premining levels of productivity. The study was conducted in 1994 and 1995, and involved extensive sampling for yield assessment at the Center, Glenharold, Beulah, Freedom, and Falkirk Mines. The sampling sites selected included those that were reclaimed under the early as well as the current soil replacement rules. Data showed that in 1994 undisturbed lands yielded more than the reclaimed lands, which was ascribed to poorer management received by the latter. No difference was noted in average yields obtained under the two current alternative soil respreading options. No consistent relationship was found between the soil respread depth and yield, especially under the 'up to 60 inch soil salvage/respread' requirement.

Analysis of Conclusions

Evidence has been presented that yields from land reclaimed under soil respeading option No. 2 are similar to those produced under option No. 1. Based on the results, the author recommends that soil respreading option No. 2 could be made permanent. The enormous variability in the yield data is, however, a matter of concern to this reviewer.

Title: **PRODUCTIVITY OF PRIME AND NONPRIME TOPSOIL RECLAIMED IN EQUIVALENT TOPOGRAPHIC POSITIONS**

Author: G.A. Halvorson and M.V. Nathan

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: Successes and Failures: Applying Research Results to Insure Reclamation Success; Proceedings of 13th Annual Meeting of the American Society for Surface Mining and Reclamation, pp. 402-406, Knoxville, Tennessee, May 1996

Key Index Words: Soil Replacement, Productivity

Brief Description

Field experiments were conducted at the Freedom and Falkirk mines in North Dakota to compare the productivity of prime and nonprime topsoil materials placed side by side in different topographic locations. The ultimate purpose was to determine if separate handling of prime and nonprime topsoils, as required by rules, is really necessary. At each mine, Plots were located at 'prime' and 'nonprime' topographic locations. At the Freedom Mine, two topsoil respread thicknesses were employed. Topsoils used were from Bowbells series (prime) and from Williams and Zahl series (nonprime). Grain yield on Zahl was lower in the first year compared to the other soils, and this was attributed to lower initial moisture content in Zahl. In the years with good moisture, yields on the three soils were not significantly different, nor seemed to be affected by the thickness of the topsoil layer or the topographic position. But in drier years topographic position had a significant effect At the Freedom Mine, Zahl's productivity seemed to be consistently lower than the prime soils.

Analysis of Conclusions

The results of this study seem to point out that prime and nonprime soils have very little intrinsic difference with respect to their productivity potential. But their differences are either masked or accentuated by the sufficient or insufficient availability of soil water. The data presented in this paper has been the subject of many other reports and papers summarized in this volume.

Title: **COMPACTION EFFECTS ON MINELAND SOIL QUALITY**

Author: P.P. Sharma and F.S. Carter

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: Successes and Failures: Applying Research Results to Insure Reclamation Success; Proceedings of 13th Annual Meeting of the American Society for Surface Mining and Reclamation, pp. 430-441, Knoxville, Tennessee, May 1996

Key Index Words: Compaction, Soil Water

Brief Description

The authors emphasize that quantification of soil pore characteristics will allow evaluation of soil quality for reclamation success. Field saturated hydraulic conductivity and post infiltration redistribution of water was measured on 26 premine and postmine profiles at the Indian Head and Velva mines. The undisturbed soils had high effective porosities and associated hydraulic conductivities. The abandoned mineland locations had the widest range of variability in their pore structure attributes, depending on the presence/location of sodic spoil in the profile. The post-SMCRA reclaimed profiles with replaced subsoil and topsoil had improved pore structure but similar to that found in compacted soils.

Analysis of Conclusions

Under the North Dakota soil and climatic conditions regeneration of soil structure by natural processes is extremely slow to non existent. The current reclamation technology allows improvement in pore structure to a depth of about 0.3 m. At deeper depths, replaced subsoils lack pore space and pore continuity. This restriction in root zone limits productivity in reclaimed minelands. The authors' recommend that soil respreading techniques, post-reclamation land management, and the guidelines for evaluation of reclamation success must be focused on reclaiming the effective porosity of the entire root zone.

Title: **SUBSOIL CHARACTERISTICS AND LANDSCAPE POSITION AFFECT PRODUCTIVITY OF RECONSTRUCTED MINE SOILS**

Author: S.D. Merrill, R.E. Ries, and J.F. Power

Organization: USDA-ARS, Northern Great Plains Research Laboratory, Mandan, ND

Format: Paper (submitted for publication)

Reference: Unpublished draft

Key Index Words: Revegetation, Soil Water, Topography

Brief Description

Responses of spring wheat, crested wheatgrass, and Russian wildrye, grown on a reconstructed minesoil wedge-plot having different subsoil materials, were studied at the Indian Head Mine. The subsoil was of varying clay content (50%, 29%, and 13%), 1.2 m thick at its maximum, and covered by a 0.2 m thick layer of topsoil. Wheat grain yields were higher on plots with higher clay content. However, both crested wheatgrass and wildrye produced greater biomas on plots with least amount of clay in the subsoil. Greater water holding capacity of high-clay subsoil was cited as a reason for better wheat response. Wheat yields were also higher on the south sideslopes of two higher clay subsoils, reaching maximum at 1.0 m total soil depth. Forages yields were higher on the north sideslopes of the sandy loam subsoil plots.

Analysis of Conclusions

This study is important in that it shows how different species can meet their water requirement for best performance. In case of wheat the demand for water being highest in late vegetative and early reproductive stages, the presence of clayey subsoil with high water holding capacity in the soil profile fulfills that demand. On the contrary, forage grasses have a greater demand for water during their earlier stages of growth. In sand loam subsoils over impervious spoil, the easier interflow of water from higher to lower slope positions made water available to the forage species The results of this study further demonstrate that relatively lesser thicknesses of soil are required at the side slopes and lower landscape positions compared to the upper and summit positions of a reclaimed site.

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EROSION AND RUNOFF (ER)

Title: **USE OF SOIL PROPERTIES TO ESTIMATE SOIL LOSS BY WATER EROSION ON SURFACE MINED LANDS OF WESTERN NORTH DAKOTA**

Authors: G.W. Gee, J.E. Gilley, and A. Bauer

Organization: North Dakota State University, Fargo, ND

Format: Paper

Reference: North Dakota Agricultural Experiment Station Farm Research 34(2):40-43, 1976

Key Index Words: Erosion, Spoil Properties, Topsoil, K-Values

Brief Description

Using soil physical properties and Wischmeier's nomograph, soil erodibility (k) values were estimated for mined and unmined sites at Beulah, Center, Stanton, and Zap in North Dakota. Soil losses of up to 118 tons per acre were predicted to occur from reshaped mined land with steep slopes and covered with sandy loam topsoil. Seeding such areas into permanent pasture is advisable, but soil losses would still be high during the initial year of establishment. Reducing the slopes would minimize soil losses and optimize the land use.

Analysis of Conclusions

This paper discusses the implications of using the Universal soil loss equation and estimating soil erodibility factors for predicting water erosion from surface mined lands in western North Dakota. By comparing the erodibility of different soil types, spoil, and replaced soil materials, using calculated as well as SCS values, much useful information for developing water erosion control measures has been provided.

Title: **RUNOFF AND EROSION FROM SNOWMELT ON SURFACE MINE SITES IN WESTERN NORTH DAKOTA**

Authors: J.E. Gilley, G.W. Gee, and A. Bauer

Organization: North Dakota State University, Fargo, ND

Format: Report

Reference: North Dakota Agricultural Experiment Station Research Report No. 62, 1976

Key Index Words: Erosion, Runoff, Soil Properties, Topsoil

Brief Description

The results of runoff and erosion studies conducted at the Indian Head Mine from 1971-1975, involving a native range site, three mined sites with different spoil textures, and a topsoiled site are discussed in this report. Runoff averaged 41% for spoil and 71% of snow water equivalent for topsoiled plots. Soil loss averaged 0.04, 1.92 and 0.38 tons/ha for rangeland, spoil and topsoiled plots, respectively.

Analysis of Conclusions

This study has demonstrated that soil loss is greatest from bare spoils. Also useful data has been provided to determine the effects of slope and texture on the runoff and erosion occurring on disturbed and undisturbed areas.

Title: **PARTICLE SIZE DISTRIBUTION OF ERODED MATERIALS ON SURFACE MINE SITES IN WESTERN NORTH DAKOTA**

Authors: J.E. Gilley, G.W. Gee, and A. Bauer

Organization: North Dakota State University, Fargo, ND

Format: Paper

Reference: North Dakota Agricultural Experiment Station Farm Research 34(2):35-36, 1976

Key Index Words: Erosion, Runoff, Spoil Properties, Topsoil, Tillage

Brief Description

This paper describes the results of runoff and erosion studies conducted on shaped mine spoil at Indian Head Mine near Zap, ND. Particle size distribution was studied for surface soil material prior to runoff and of the eroded material under conditions of tillage and no tillage. Evaluations were made of changes in particle size distribution in runoff samples collected during the course of a storm occurrence.

Analysis of Conclusions

The particle size distribution of spoil materials eroded from nontilled plots was similar to surface conditions preceding rainfall. However, tillage caused changes in particle size distribution of eroded materials. These results are important in understanding the mechanism of water erosion on reshaped mined lands under different tillage systems.

Title: **WATER QUALITY OF IMPOUNDMENTS ON SURFACE MINED SITES**

Authors: J.E. Gilley, G.W. Gee, and A. Bauer

Organization: North Dakota State University, Fargo, ND

Format: Paper

Reference: North Dakota Agricultural Experiment Station Farm Research 34(2):37-39, 1976

Key Index Words: Impoundments, Water Quality, Erosion

Brief Description

This paper describes the results of water quality determinations made on samples collected from recently established impoundments on strip mined areas and from over 25 year old impoundments located outside the mine area. Values of some chemical parameters were found to be higher in water from the recently established impoundments, whereas values of other constituents were higher at older sites.

Analysis of Conclusions

This study established that water quality factors of potential concern include SAR, TDS, and sulfate. The authors recommended that chemical characteristics of an impoundment be determined before it is used as a livestock or irrigation source. This publication has been used as reference for performing probable hydrological consequences and cumulative hydrological impact assessments by the PSC staff. Additional research should be done in this area to identify long-term quality degradation.

Title: **EFFECT OF TILLAGE ON WATER MOVEMENT INTO SURFACE MINED MATERIALS**

Authors: J.E. Gilley, G.W. Gee, and A. Bauer

Organization: North Dakota State University, Fargo, ND

Format: Paper

Reference: North Dakota Agricultural Experiment Station, Farm Research 34(2): 37-39, 1976

Key Index Words: Infiltration, Spoil Properties, Tillage

Brief Description

This paper evaluates the effects of tillage on water movement into surface mined materials of high SAR at Indian Head Mine near Zap, ND. Single plots were located on noncultivated, moldboard plowed and disked spoil materials having SAR of 37. Tillage treatments were imposed immediately preceding topsoil placement in July, 1975. Tillage treatment depths were approximately 4 and 6 inches on the disked and moldboard plowed plots, respectively. About 3.1 inches of precipitation fell on these plots prior to testing. The infiltration study was conducted in November, 1975. Disking the spoil interface of high sodium adsorption ratio before topsoil placement increased the depth of water penetration into the spoil by about 3 inches. No significant difference appeared in water storage between nontilled and moldboard plowed spoil materials. The underlying spoil on both the tilled and nontilled treatments greatly restricted downward water movement.

Analysis of Conclusions

Additional research of this type, particularly on reclaimed sites, would be desirable.

Title: **INFILTRATION ON SURFACE MINE SITES IN WESTERN NORTH DAKOTA**

Authors: J.E. Gilley, G.W. Gee, A.W. Bauer, W.O. Willis, and R.A. Young

Organization: North Dakota State University, Fargo, ND

Format: Paper

Reference: North Dakota Agricultural Experiment Station Farm Research 34(2): 32-35, 1976

Key Index Words: Infiltration, Spoil Properties, Tillage

Brief Description

This paper reports the results of water infiltration studies conducted at the Indian Head Mine near Zap, ND. Water movement into a sandy loam soil at a native range site was found to be unrestricted. Infiltration was minimal on spoil plots left undisturbed. Although rototilling did not affect water movement into a sandy clay loam spoil, it did affect clay loam and silty clay loam spoil materials. Water movement into these materials was restricted, however, to a depth of less than 6 inches. Water storage on the topsoil sites was limited to the topsoil material. Disking of the topsoil interface had no effect on water movement into the spoil medium.

Analysis of Conclusions

The results of this study are useful in developing better water management practices on the mind lands. Additional research using sites with topsoil and subsoil are needed.

Title: **RUNOFF AND EROSION CHARACTERISTICS OF SURFACE MINED SITES IN WESTERN NORTH DAKOTA**

Authors: J.E. Gilley, G.W. Gee, A. Bauer, W.O. Willis, and R.A. Young

Organization: North Dakota State University, Fargo, ND

Format: Paper

Reference: Transactions of the American Society of Agricultural Engineers 20:697-700, 704, 1977

Key Index Words: Erosion, Runoff, Mulch

Brief Description

The results of runoff and erosion studies (under simulated rainfall) conducted in 1975 at Indian Head Mine near Zap, ND are described. Soil losses were greatest on bare topsoiled plots and least on the noncultivated rangeland site. Application of a straw mulch reduced erosion from topsoiled plots by over 90%. However, erosion and runoff from the mulched topsoil sites were still more than 50% higher than erosion and runoff from rangeland sites.

Analysis of Conclusions

This and other similar studies have provided valuable information on the erosion potential of mined lands in North Dakota. Confirmation of such studies on reclaimed sites in different stages of revegetation are necessary and should be encouraged.

Title: **SOIL EROSION BY WATER AND ITS CONTROL**

Authors: D.L. Dodds and E.H. Vasey

Organization: NDSU-Cooperative Extension Service, Fargo, ND

Format: Circular

Reference: North Dakota State University Cooperative Extension Service Circular SC-616, January, 1977

Key Index Word: Erosion, Runoff, Topography, Infiltration

Brief Description:

Discusses the problems of soil erosion on agricultural lands as a result of water being added (through rainfall or snowmelt) faster than it can be absorbed by the soil. The effect of agricultural practices and topography on erosion and runoff are addressed.

Analysis of Conclusions:

An excellent paper on water erosion processes, their resulting effects and conservation practices.

Title: **PRELIMINARY GUIDANCE FOR ESTIMATING EROSION ON AREAS DISTURBED BY SURFACE MINING ACTIVITIES IN THE INTERIOR WESTERN UNITED STATES**

Authors: USDA, Soil Conservation Service Staff

Organization: USDA, Soil Conservation Service

Format: Report

Reference: US EPA Interim Final Report No. 908/4-77-005. 26 p. + Appendixes A, B, and C, 1977

Key Index Words: Erosion, K-Values

Brief Description

This publication provides background information on the Universal Soil Loss Equation, and includes pertinent data needed to apply the equation to mined land situations. An illustrative example of an erosion study for lands disturbed by surface mining is also given.

Analysis of Conclusions

This is an important study describing the use of Universal Soil Loss Equation for determining erosion potential of mined lands.

Title: **RUNOFF AND EROSION FROM MINED LANDS IN WESTERN NORTH DAKOTA**

Author: J.E. Gilley

Organization: Colorado State University, Fort Collins, CO

Format: Paper

Reference: Adequate Reclamation of Mined Land? A Symposium, pp. 5-1 to 5-18, Soil Conservation Society of America and WRCC-21 Committee, Billings, MT, March 1980

Key Index Words: Erosion, Runoff, Mulch

Brief Description

This is an overview presentation of the results of erosion and runoff studies conducted by the author in North Dakota. Erosion and runoff, resulting from natural and simulated rainfall, were measured from plots representing pre-mined, mined, and post-mined conditions. Soil losses were greatest from bare topsoil plots and least from noncultivated rangeland site. Straw mulch on topsoil plots reduced erosion from simulated rainfall by 66%. Snowmelt runoff on rangeland, spoil, and topsoil plots was found to be minimal. The erosion potential was decreased as vegetation became established.

Analysis of Conclusions

This paper is useful in understanding the relative potential for erosion and runoff on mined lands under different conditions (or stages) of reclamation and revegetation. However, additional studies involving types and degrees of vegetative cover are very necessary.

Title: **SUSPENDED OR DISSOLVED SOLIDS IN RUNOFF FROM RANGELAND AND SURFACE MINED SITES IN WESTERN NORTH DAKOTA**

Authors: J. Gilley, F. Schroer, and L. Zimmerman

Organization: NDSU-Agricultural Experiment Station, Fargo, ND

Format: Report

Reference: NDSU-Agricultural Experiment Station Research Report No. 88, August 1981

Key Index Words: Erosion, Runoff, Water Quality

Brief Description

The investigators compared TDS & TSS concentrations in surface runoff generated by specific precipitation events on plots having various surface treatments. Surface treatments included 1) undisturbed rangeland, 2) spoil, and 3) 6 inches topsoil layer over spoil. Runoff for rangeland, spoil and topsoiled sites averaged 4, 22, and 31 percent of the rainfall amount. Concentration of dissolved solids was generally higher in runoff from spoil materials than from topsoiled or rangeland sites.

Analysis of Conclusions

Conclusions provided justification for requiring SO_4, and EC determinations in current water monitoring programs. The information is useful as reference in probable hydrologic assessment and cumulative hydrologic impact assessment determinations. Publication is quite valuable in identifying possible changes to surface water quality as a result of surface mining activities.

Title: **SOIL EROSION CONTROL-CLEAN WATER THROUGH CROP MANAGEMENT PROGRAMS**

Authors: C. Fanning, and T. Reff

Organization: NDSU-Cooperative Extension Service, Fargo, ND

Format: Circular

Reference: North Dakota State University Cooperative Extension Service Circular SC-710, 1981

Key Index Word: Runoff, Erosion, Nutrient Requirements, Eutrophication, Fertilizer Use

Brief Description:

Discusses the relationships between clean water, farmland, and erosion with respect to agricultural production. Problems addressed include phosphorus and algal growth, sedimentation, pesticide contamination, reservoir storage capacity loss, eutrophication, and fertilizer use and nutrients in stream flow. Acceleration of these problems via man's activities and identification of potential problems is discussed.

Analysis of Conclusions:

A very informative paper useful in maintaining water quality through recommended cropping practices.

Title: **EROSION AND NUTRIENT LOSS FROM INTERRILL AREAS ON STRIP-MINE LAND TOPSOILS**

Authors: K.J. Lang and L. Prunty

Organization: North Dakota State University, Fargo, ND

Format: Paper

Reference: North Dakota Agricultural Experiment Station Farm Research 41(2). 18-21, 1983

Key Index Word: Erosion, Stockpiled Soil, Nitrogen, Mulch

Brief Description:

Topsoil was taken from a stockpile at the Falkirk Mine which consisted of Arnegard and Bowbells soils with a history of cultivation. Topsoil was also taken from a stockpile at the Indian Head Mine which consisted of Cabba and Cohagen soils under native prairie. The soils were tested in an artificial rainfall situation for the effects of slope, straw mulch, and antecedent moisture condition on water runoff, soil loss, OM, and available N and P.

Analysis of Conclusions:

This study contains information on the effects of slope, straw mulch, and antecedent moisture on topsoil erosion and the effects that erosion has on land productivity. The conclusions are general and emphasize the need for more research to evaluate nutrient loss from mined land soils.

Title: **RELATIONSHIP OF RUNOFF AND SOIL LOSS TO GROUND COVER OF NATIVE AND RECLAIMED GRAZING LAND**

Authors: L. Hofmann, R.E. Ries, and J.E. Gilley

Organization: USDA-ARS, Northern Great Plains Research Laboratory, Mandan, ND

Format: Paper

Reference: Agronomy Journal 75:599-602, 1983

Key Index Words: Grazing, Sediment, Soil Loss, Runoff

Brief Description:

A simulated rainfall study was conducted near Center, North Dakota to determine the relationship of ground cover factors to runoff and soil loss. A ten-point frame was used to estimate both first-hit and basal vegetation cover. Artificial rain was applied at a rate of 46 mm/h. Ungrazed, lightly grazed, moderately grazed, heavily grazed, and burned treatments were established on reclaimed areas. Native range treatments were ungrazed, closely grazed, and burned. Soil loss, runoff and soil loss/runoff ratios were similar among reclaimed light and ungrazed treatments and closely grazed native grassland, while live surface cover was greatest on native ungrazed areas. Live surface cover was not the primary cover component controlling these runoff factors. Total cover was determined to be the primary component. The authors concluded that bare ground, the complementary of total cover, can be measured to evaluate whether the vegetative cover is adequate to control water erosion and stabilize soil on permanently vegetated grasslands.

Analysis of Conclusions:

This study addresses the amount of ground cover necessary to control surface erosion on reclaimed mine lands. It also emphasizes that measurements of bare ground also can be used to evaluate erosion and runoff potential.

Title: **INTERRILL EROSION AS AN INDEX OF MINED LAND SOIL ERODIBILITY**

Authors: K.J. Lang, L. Prunty, S.A. Schroeder, and L.A. Disrud

Organization: North Dakota State University, Fargo, ND

Format: Paper

Reference: Transactions of the ASAE 27(1):99-104, 109, 1984

Key Index Words: Erosion, Runoff, Soil Properties

Brief Description

Laboratory investigations using rainfall simulation techniques were conducted to study the influence of slope steepness, mulch rate, and antecedent soil moisture condition on runoff and soil loss from interrill areas on two mined land topsoils. Topsoils were obtained from stockpiles at Falkirk and Indian Head mines. Soil type and slope was found to have no effect on interrill runoff. Mulching reduced runoff during dry runs but not during the wet runs. Soil loss was greater from Falkirk topsoil than Indian Head topsoil; increasing slope steepness increased soil loss, but mulching reduced the same. Soil in splash was rich in sand while interrill sediment was rich in clay and fine silt.

Analysis of Conclusions

The information presented in this paper is highly useful in developing and refining the management techniques required for controlling erosion from topsoiled mined lands. Research along these lines needs to be continued to study the long term effects of erosion control measures.

Title: **EFFECT OF CRUSTING ON RUNOFF AND EROSION FROM RESHAPED SPOIL**

Authors: S.A. Schroeder

Organization: NDSU-Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Proceedings of the Second Annual Meeting of the American Society for Surface Mining and Reclamation, PP. 205-211 Denver, CO October 8-10, 1985

Key Index Word: Runoff, Erosion, Spoil Properties, K Values

Brief Description:

Runoff and sediment yield from crusted and roughened spoil surfaces were compared using a rainfall simulator at two mine sites. Under dry conditions, the crusted surface produced more runoff and soil loss than the roughened surface. Under wet conditions, the difference was not always discernible. Slope effects and spoil quality had different effects for the two mine sites. The surface seal which formed during the dry test resulted in similar runoff and erosion under wet conditions at both sites.

Analysis of Conclusions:

This study contributes additional data for prediction of K values in the Universal Soil Loss Equation, which is used to determine sediment pond size on mines.

Title: **REPORT TO KNIFE RIVER COAL MINING COMPANY ON RESEARCH CONDUCTED AT THE KNIFE RIVER MINE NEAR BEULAH**

Authors: NDSU-Land Reclamation Research Center Staff

Organization: NDSU-Land Reclamation Research Center,
Mandan, ND

Format Report

Reference: Land Reclamation Research Center Report, 1985

Key Index Word: Erosion, Spoil Properties, K-Values

Brief Description:

Replicated (6 x 16 ft.) plots were constructed at two sites, one in crusted spoil and one in freshly respread spoil. At each site plots with 2, 4, and 11% slopes were used. A 2.2 iph rainfall was simulated and hydrology and sedimentology samples were taken over 10 minute intervals.

Analysis of Conclusions:

This report compares the hydrology and sedimentology of spoil material in a crusted and fallow condition. It contains data on the tons per acre lost of spoil material and the inches of runoff. Further analysis of this data is in process.

Title: **REPORT TO BASIN ELECTRIC POWER COOPERATIVE ON RESEARCH CONDUCTED AT THE GLENHAROLD MINE NEAR STANTON, ND**

Authors: NDSU-Land Reclamation Research Center Staff

Organization: NDSU-Land Reclamation Research Laboratory, Mandan, ND

Format: Report

Reference: Land Reclamation Research Center Report, 1985

Key Index Word: Erosion, Runoff, K-Values, Topography

Brief Description:

Replicated 6 x 16 foot plots were installed at three sites at Stanton, ND in 1985. At each site plots with approximately 3, 6, and 9% slopes were used. The sites consisted of a four-year old reclamation site, a seven year old reclamation site, and a native site. A rainfall simulation was used to simulate a 2.2 iph rainfall. Both sedimentology and hydrology measurements were taken over ten minute intervals.

Analysis of Conclusions:

This report compares the hydrology and sedimentology of native and reconstructed soils. It compares the effect gradient has on the native, 4-year old, and 7-year old reclamation sites. This report also contains information dealing with universal soil loss equation factors.

Title: **SEASON-LONG GRAZING EFFECTS ON EROSION FROM RECLAIMED PASTURES**

Authors: S.A. Schroeder

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Land Reclamation Research Center Technical Report No. 5, 1986

Key Index Words: Erosion, Runoff, Revegetation, Grazing

Brief Description:

Effects of season-long grazing on erosion and runoff from reclaimed and undisturbed native grasslands were studies at the Baukol-Noonan Mine, using simulated rainfall technique. Grazing increased runoff from both reclaimed, and native grasslands under wet surface conditions, but the increased runoff was not highly erosive because of good vegetative cover. Soil losses from well managed reclaimed grasslands were only slightly higher compared to undisturbed grasslands. Soil conservation service CN values estimated for reclaimed and undisturbed grasslands were statistically similar. The report also includes soil erodibility K values for undisturbed and reclaimed lands.

Analysis of Conclusions:

Although increased runoff from well-managed reclaimed grasslands may not be accompanied by increased soil losses, yet lack of opportunity for infiltration and storage of water in the soil profile may cause decreases in vegetation production, especially in dry years. Surface roughness, soil porosity, vegetative cover, and grazing intensity are some of the factors that require further evaluation in relation to erosion and runoff on reclaimed mine lands.

Title: **RUNOFF CURVE NUMBER ESTIMATIONS FOR RESHAPED FINE-TEXTURED SPOILS**

Authors: S.A. Schroeder

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: Reclamation and Revegetation Research, 6: 129-136, 1987

Key Index Words: Slope Gradient, Sodium Adsorption Ratio, Runoff

Brief Description

The objectives of this study were to 1) estimate runoff curve number (CN) values for reshaped fine-textured spoil areas for use in sediment pond designs, and 2) determine the effects of spoil surface conditions - (crusted vs. noncrusted, slope gradient (0.1 to 11.1%) and SAR (2.0 50 20.0) - on the resultant CN values. Field experiments were conducted at the Center and Beulah Mines, using a portable rainfall simulator to apply three consecutive rainfall applications. Differences in slope gradient and SAR had no effect on the estimated CN values. The results of this study indicated that CN values in the mid 90's should be used for designing sediment ponds for controlling runoff from graded fine-textured spoils.

Analysis of Conclusions

The conclusions that CN values were not affected by slope gradient and SAR because of low hydraulic conductivity of the fine-textured spoils have not been supported by actual measurement of hydraulic conductivity. The CN values recommended for pond design are only approximate. Moreover, due to the variability of other elements in the SCS runoff estimation formula, the recommendations made in this study have only a limited application.

Title: **RUNOFF FROM RECLAIMED GRASSLANDS COMPARED TO UNDISTURBED GRASSLANDS**

Authors: S.A. Schroeder

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: Combine Fourth Biennial Billings Symposium on Mining and Reclamation in the West and the National Meeting of the American Society for Surface Mining and Reclamation, pp. G-8-1 to G-8-7, Billings, MT, March 1987

Key Index Words: Erosion, Runoff, Grassland, Revegetation, Hydraulic Conductivity

Brief Description

This investigation was conducted to study the effects of slope gradient, antecedent moisture conditions, and age-after-revegetation on runoff, using artificial rainfall simulation techniques. The revegetated sites included a 2-year old site at the Center Mine and a 4-year and 7-year old site at the Glenharold Mine. The undisturbed grassland sites, used for control, were located on a Williams soil at the Center Mine and a Temvik-Zahl soil association at the Glenharold Mine. Under initial dry conditions, the runoff and SCS curve numbers for revegetated and undisturbed sites was similar. But under wet and very wet conditions both parameters measured significantly higher on the revegetated sites compared to undisturbed sites. Reduced porosity and hydraulic conductivity in the respread topsoil of revegetated sites were given as the possible reasons for these differences. Age-after-revegetation seemed to have little effect on the amount of runoff.

Analysis of Conclusions

The author's suggestion that until the values of total porosities and hydraulic conductivities of the reclaimed grasslands approach those of the undisturbed sites, quick establishment of vegetative cover and use of sedimentation ponds to manage runoff on mined lands is in keeping with the current regulatory practice.

Title: **SLOPE GRADIENT EFFECTS ON EROSION OF RESHAPED SPOIL**

Authors: S.A. Schroeder

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: Soil Science Society of America Journal 51: 405-409, 1987

Key Index Words: Erosion, Universal Soil Loss Equation, Crusting, Slope Gradient

Brief Description

The objective of this research was to determine the applicability of the Universal Soil Loss Equation's (USLE) slope function for predicting spoil erosion rates. The effect of slope gradient on sediment losses from reshaped spoil at two surface mines (Center and Beulah) was quantified by using a rainfall simulator. Slope gradient ranged from 0.1 to 11.1%, and surface conditions included crusted and non-crusted (tilled) spoil. Sediment losses increased with increasing slope, but no differences in the slope gradient equations were found under surface crusted conditions. The USLE curvilinear soil loss ratio (SLR) function underestimated the slope gradient effects on sediment loss for slopes less than 9% and overestimated at slopes greater than 9%.

Analysis of Conclusions

The author claims that the use of developed spoil SLR function and USLE monograph K values should provide adequate prediction of spoil erosion losses for designing sediment ponds. However, additional research is needed to determine the reliability of the empirical spoil SLR function and K prediction model, especially for steeper and longer slopes, coarse-textured spoils, and high SAR spoils.

Title: **SOIL LOSS COMPARISONS BETWEEN RECLAIMED STRIP-MINED AND UNDISTURBED GRASSLANDS IN NORTH DAKOTA**

Authors: S.A. Schroeder

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: Journal of Environmental Quality 18(1):30-34, 1989

Key Index Words: Revegetation, Erosion, Runoff, Cover

Brief Description

Field experiments were conducted at the Center and Glenharold Mines to determine the erodibility of reclaimed vs. undisturbed lands. Soil-loss/runoff (SLRO)ratios were calculated following collection of relevant data from field plots on reclaimed and undisturbed land subject to simulated rainfall. No differences were found in SLRO or soil losses between the reclaimed and undisturbed land at the Center Mine, but at the Glenharold Mine these parameters showed differences under all (dry, wet, and very wet) surface conditions. The author concludes that as the reclaimed lands in North Dakota become well vegetated their productivity will not be impaired by soil loss through erosion because it is similar to that occurring on the undisturbed lands.

Analysis of Conclusions

The conclusions drawn underscore the importance of establishing a good vegetative cover on the reclaimed lands as quickly as possible. Also, the reclaimed areas may not behave similarly with regard to their erodibility or revegetation potential.

Title: **ANTECEDENT MOISTURE CONDITIONS FOR NORTH DAKOTA RUNOFF PREDICTIONS**

Authors: S.A. Schroeder, J.W. Enz, and J.K. Larsen

Organization: NDSU - Land Reclamation Research Center, Mandan, and Department of Soil Science, Fargo, ND

Format: Paper

Reference: North Dakota Farm Research 48(3):8-11, 1990

Key Index Words: Erosion, Runoff, Soil Moisture

Brief Description

The Soil Conservation Service's curve number (CN) method for determining runoff volumes from watersheds uses soil type, surface condition, and antecedent moisture condition (AMC) as variables to describe the hydrologic properties of the catchment basin. There are three AMC groups recognized, namely low runoff potential (AMC I), average condition (AMCII), and highest runoff potential (AMCIII). However, because of low rainfall and high evapotranspiration these AMC groups are suspect in North Dakota,. Therefore, the authors studied the frequency distribution of the AMC categories during the North Dakota growing season, developed frequency distributions based on smaller increments within AMC groups I and II, and compared the log-term average 5-day precipitation totals at 50 percent probability level between the growing and dormant seasons. The results of this analysis indicated that the use of CN with AMCI, during the North Dakota growing season, would be appropriate 90 percent of the time, but AMCII would overestimate the expected runoff mat least 95 percent of the time.

Analysis of Conclusions

The authors conclude that the AMC groupings are not as applicable under the semiarid climates as they are in areas of high rainfall amounts and frequency. This implies that by using the present AMC groupings, the runoff volume from mine disturbance sites could be overestimated resulting in unnecessary oversize designing of sedimentation ponds.

Title: **REVEGETATION INFLUENCE ON RECLAIMED MINELAND SOIL EROSION**

Authors: S.A. Schroeder

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: Report to the North Dakota Legislative Council, pursuant to Section 5 of H.B. 1005 of the Fifty-second Legislative Assembly, pp. 13, June 30, 1993.

Key Index Words: Revegetation, Erosion, USLE, Soil Loss, Cover Factor

Brief Description

Experiments were conducted at the Center and Glenharold Mines to study the relationship between soil erodibility and vegetation established on reclaimed lands. Specifically, the objective was to develop a first estimate of the amount of basal cover necessary to control soil erosion by water to acceptable limits. Weighted soil losses were regresses with cover factor (cover as a fraction of the bare ground) and found to have a linear relationship. As plant cover increased, soil loss decreases.

Analysis of Conclusions

The general conclusion that "rapid establishment of vegetation will reduce soil erosion to permissible levels and prevent both on site and off site problems caused by transported sediment" is quite well known. However the derived regression may be helpful in estimating the amount of cover needed to retain soil loss to a predetermined level.

Title: **COVER/SOIL EFFECTS ON RECLAIMED MINELAND EROSION**

Authors: S.A. Schroeder

Organization: NDSU - Land Reclamation Research Center, Mandan, ND.

Format: paper

Reference: Planning, Rehabilitation and Treatment of Disturbed Lands, pp. 116-123, Sixth Billings Symposium, 1993.

Key Index Words: Revegetation, Erosion, USLE, Soil Loss, Cover Factor

Brief Description

Erosional losses to simulated rainfall were studied at some of the reclaimed sites at the Center and Glenharold Mines. The objective was to develop a relationship between basal cover and soil loss on reclaimed minelands. Linear relations were noted between cover and adjusted soil loss values.

Analysis of Conclusions

The study provides some basic data which may be helpful in determining the amount of plant cover needed to minimize soil losses occurring on reclaimed lands due to water erosion.

Title: **RELIABILITY OF SCS CURVE NUMBER METHOD ON SEMI-ARID, RECLAIMED MINELANDS**

Authors: S.A. Schroeder

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: paper

Reference: International Journal of Surface Mining, Mining, Reclamation and Environment 8: 41-45, 1994.

Key Index Words: Erosion, Runoff, Soil Moisture

Brief Description

Using simulated rainfall, runoff was measured from reclaimed plots located at the Center and Glenharold Mines, representing various gradients, topsoil textures and basal cover. The objective was to determine the relationship and accuracy of the SCS-generated values for initial abstraction (Ia), maximum potential retention (S), and curve number (CN) as compared to field measured values, and to determine the effect of vegetative cover on CN. The SCS method overestimated Ia and CN values and underestimated S when Ia was assumed to be 20% of S. Basal cover had much greater influence on CN values for dry compared to wet conditions.

Analysis of Conclusions

The author concludes that overall the SCS curve number method is reliable for predicting the runoff characteristics of semiarid, reclaimed minelands. The calculated vales for initial abstraction and retention were close enough to those assumed in the SCS method.

Title: **FIRST ESTIMATION OF COVER FOR RECLAIMED MINELAND EROSION CONTROL**

Authors: S.A. Schroeder

Organization: NDSU - Land Reclamation Research Center, Mandan, ND

Format: Paper

Reference: Journal of Soil and Water Conservation 50(6) 668-671, 1995

Key Index Words: Revegetation, Erosion, Cover

Brief Description

The objective of this study was to evaluated the effect of established vegetation on reducing erosion losses from reclaimed lands with different soil textures and slope gradients, so that the percentage of cover necessary to meet the regulatory requirements could be estimated. Field experiments were carried out at the Center and Glenharold Mines under various simulated rainfall conditions. Regression analysis between the adjusted (by RUSLE) soil loss values and measured cover factor showed a linear decreases in soil loss as the percent cover increased. The author contends that since all factors , except cover, within RUSLE are known, a first estimate of the needed cover can be easily made.

Analysis of Conclusions

If all the assumptions made in this study are valid, the method proposed to estimate the percentage of plant cover needed to satisfy the regulatory requirements provides a valuable tool to the industry and the regulators.

REVEGETATION AND VEGETATION (RV)

Title: **PROGRESS REPORT OF REVEGETATION STUDIES ON COAL MINE SPOILS OF NORTH DAKOTA**

Authors: J.J. Bond, F.M. Sandoval, J.F. Power and W.O. Willis

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Report

Reference: USDA-ARS, SWC Research Report No. 427, 1971

Key Index Words: Spoil Properties, Water Management, Revegetation

Brief Description

Results of field investigations and laboratory analyses are included in this progress report of reclamation efforts conducted in North Dakota. The research discussed was carried out during 1970 and 1971 primarily at the Consolidated Coal Company's Glenharold Mine at Stanton, ND and in the laboratories of the Northern Great Plains Agricultural Research Center.

Analysis of Conclusions

These investigations were conducted mainly with the spoil materials, because there were no topsoiling requirements in force then. However, studies showed that even very small amount of respread topsoil was good for vegetation establishment.

Title: **ECOLOGY OF SOME MINED AREAS IN NORTH DAKOTA**

Authors: M.K. Wali and P.G. Freeman

Organization: Biology Department, University of North Dakota, and US Bureau of Mines Energy Research Laboratory, Grand Forks, ND

Format: Paper

Reference: Some Environmental Aspects of Strip Mining in North Dakota (M.K. Wali, ed), North Dakota Geological Survey Educational Series 5, 1973

Key Index Words: Revegetation, Spoil Properties, Topsoil, Trace Elements

Brief Description

Spoil materials and undisturbed soils were sampled from several mine sites in North Dakota in the summers of 1972 and 1973. The samples were analyzed for a number of parameters, and the vegetation surrounding the sample sites was inventoried. The authors compared the results to determine the spoil characteristics hindering revegetation.

Analysis of Conclusions

This study is particularly useful for reclamation of abandoned mine lands as it provides considerable data on physical and chemical properties of spoil and soil materials collected from a number of abandoned mines.

Title: **REGIONAL SITE FACTORS AND REVEGETATION STUDIES IN WESTERN NORTH DAKOTA**

Authors: M.K. Wali and F.M. Sandoval

Organization: Project Reclamation, University of North Dakota, Grand Forks, ND, and USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Practices and Problems of Land Reclamation in Western North Dakota, (M.K. Wali, ed), University of North Dakota Press, Grand Forks, ND, 1975

Key Index Words Revegetation, Environmental Factors, Land Use, Spoil Properties

Brief Description

This paper provides information on regionally important site factors and their effects on reclamation. The revegetation potential of mined lands in North Dakota is considered in the light of experiments conducted by various research groups working in this state.

Analysis of Conclusions

This is a paper of general as well as specific importance: the revegetation potential of typical sites is discussed in terms of geological, climatic, topographic, and edaphic factors. The research conducted in the early 70's is reviewed.

Title: **ESTABLISHMENT OF WESTERN WHEAT GRASS ON SURFACE MINED COAL SPOILS UNDER CONTROLLED ENVIRONMENTAL CONDITIONS**

Authors: E.J. Finck and M.K. Wali

Organization: Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Proceedings of North Dakota Academy of Science 30(1):13, 1976

Key Index Words Revegetation, Plant Responses, Productivity, Amendments, Leonardite

Brief Description

Growth chamber and laboratory experiments were conducted to study the effects of slack and leonardite on the establishment and growth of western wheatgrass on Glenharold coal mine spoil. The effects of these materials on the physical and chemical spoil were also studied. Both materials tended to decrease the growth of western wheatgrass, particularly when supplied in the absence of NPK fertilizers.

Analysis of Conclusions

This is only a preliminary study on the use of oxidized lignite products (slack and leonardite) as possible reclamation agents.

Title: **SOME CHRONOSEQUENCES OF VEGETATION IN THE SURFACE MINED AREAS OF WESTERN NORTH DAKOTA**

Authors: R.H. Pemble and M.K. Wali

Organization: Moorhead State University, Moorhead, MN and University of North Dakota, Grand Forks, ND.

Format: Paper

Reference: Proceedings of North Dakota Academy of Science 30(1):37, 1976

Key Index Words AML, Revegetation, Succession, Soil Development

Brief Description

During the summer of 1975 a study was conducted to determine the relationship between vegetation pattern and local site conditions on mined and unmined areas in southeastern Ward County, North Dakota. The vegetation from a range of topographic positions was examined in the field on both unmined sites and spoils material belonging to five different age classes. The preliminary results of this investigation were discussed.

Analysis of Conclusions

The conclusions of this study are discussed elsewhere in this inventory.

Title: **POTENTIAL USE OF SUPPLEMENTAL IRRIGATION FOR ESTABLISHMENTS OF REVEGETATION ON SURFACE MINED LANDS**

Authors: R.E. Ries, J.F. Power, and F.M. Sandoval

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: North Dakota Agricultural Experiment Station Farm Research 34(2): 21-22, 1976

Key Index Words Revegetation, Irrigation

Brief Description

This study emphasizes the importance of supplemental irrigation as a potential tool in reestablishing vegetation, especially perennial rangeland vegetation, on surface mined lands.

Analysis of Conclusions

Additional research would be needed to better define the technique and the benefits of supplemental irrigation as a reclamation tool.

Title: **PERENNIAL FORAGE SPECIES RESPONSE TO SODIUM AND MAGNESIUM SULFATE MINE SPOILS**

Authors: R.E. Ries, F.M. Sandoval, J.F. Power, and W.O. Willis

Organization: USDA-ARS, Norther Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Proceeding of the Fourth Symposium on Surface Mining and Reclamation, NCA, pp. 173-183, Louisville, KY, 1976

Key Index Words Revegetation, Plant Responses, Salinity

Brief Description

This paper describes the results of some growth chamber experiments in which the effects of sodium and magnesium sulfate on the germination, emergence/establishment and growth of eight (8) perennial forage species were studied. For the emergence/establishment and growth portion of this study, the salts were applied to mine spoils of two different textures from a mine near Colstrip, MT. Results showed that plant species responded differently to similar kinds or concentrations of salt and that individual species responded differently to a given salt at different developmental stages. In general, three types of plant responses were observed: 1) No effect of kind or concentration of salt, 2) sensitive to salt concentration but not to specific kind of salt, and 3) sensitive to both kind and concentration of salt. Growth of some species was affected by soil texture.

Analysis of Conclusions

This study reinforces the current thinking that selective use of plants based on their tolerance or adaptability to the prevailing edaphic stress(es) is important in revegetation of mined lands. It is therefore essential that the relative adaptability of the regional plants to various stresses and conditions are properly understood.

Title: **EFFECTS OF LEONARDITE ON THE GERMINATION OF SOME PRAIRIE GRASS AND LEGUME SPECIES**

Authors: N.M. Safaya and M.K. Wali

Organization: Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Proceedings of North Dakota Academy of Science 31(10:27, 1976

Key Index Words Revegetation, Amendments, Plant Responses

Brief Description

In this laboratory study, the germination of some grass and legume species on a sodic mine spoil was tested in the presence or absence of two types of leonardite material. Most of the species whose germination was poor on the spoil material responded favorably to leonardite treatment. However, a differential response of the species to leonardite types was observed.

Analysis of Conclusions

This study indicated that the germination of some plant species can be enhanced by the use of leonardite as soil amendment. However, different types of leonardite may have altogether different effects on the same species.

Title: **FORAGE SPECIES ESTABLISHMENT AND PRODUCTIVITY ON MINED LAND**

Authors: R.E. Barker, R.E. Ries, and P.E. Byron

Organization: USDA-ARS, Northern Great Plains Research Center, Mandan, and North Dakota State University, Fargo, ND

Format: Paper

Reference: North Dakota Agricultural Experiment Station Farm Research vol. 34(6):8-12, 1977

Key Index Words Revegetation, Plant Adaptability, Species Selection, Productivity

Brief Description

The objective of this study was to determine which forage species work best for reclamation and how they compare in establishment and productivity. A site established at the Glenharold mine represented the reclaimed area and a site established at the Mandan ARS station represented an undisturbed area. Only preliminary results were provided with the recommendation that the ability of each species to establish, survive and produce be carefully considered when selecting the composition of a species mix for seeding.

Analysis of Conclusions

A preliminary study on which there has been a large amount of subsequent work by the SCS.

Title: **EFFECTS OF GRAZING INTENSITY ON VEGETATION AND ANIMAL PERFORMANCE ON RECLAIMED STRIP MINED LAND**

Authors: L. Hofmann, R.E. Ries, J.F. Power, and R.J. Lorenz

Organization USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference Proceedings of the Fifth Symposium on Surface Mining and Reclamation, pp. 306-310, Louisville, KY, October 1977

Key Index Words Revegetation, Grazing, Erosion, Animal Performance, Productivity

Brief Description

The effects of grazing intensity on forage production and animal performance over a two-year period on a reclaimed (under ND 1969 law) piece of land near Center, ND, are discussed in this paper. The area was seeded with a mixture of cool season grasses and legume in 1973 and the grazing study began in 1976. Pastures were stocked at 0, 0.6, 1.2, and 1.8 acres/yearling steer to obtain control, heavy, moderate and light grazing intensities, respectively. During 1976, the ungrazed control pastures produced 3,331 lbs/acre dry matter, and 80, 44, and 32 percent of the forage was grazed at the heavy, moderate and light grazing intensities, respectively. When grazing was stopped in 1977, no harvestable forage remained on the heavily grazed pastures, and beef production equaled 49, 52, and 36 lbs/acre for the heavily, moderately and lightly grazed areas, respectively.

Analysis of Conclusions

From these preliminary data, it was concluded that reclaimed mined land should be suitable for grazing, but additional research would be required to establish good grazing management guideline for reclaimed land. Research of this type should also be conducted on lands reclaimed under recent reclamation laws.

Title: **AN ECOLOGICAL - LEGAL ASSESSMENT OF LAND RECLAMATION LAWS**

Authors: A.C. Imes, and M.K. Wali

Organization Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: North Dakota Law Review 53:359-399, 1977

Key Index Words Revegetation, Legislation, Reclamation Law

Brief Description

In this paper the reclamation laws are reviewed and discussed as passed by the federal government and the states of Colorado, Montana, New Mexico, North Dakota, South Dakota, Utah, and Wyoming. Analysis of the reclamation laws has been made from an ecological standpoint, and their implications on reclamation and revegetation performance standards have been examined.

Analysis of Conclusions

The information presented in this paper is useful for understanding the complex relationship between the legal and ecological aspects of reclamation.

Title: **THE ROLE OF PIONEERING VEGETATION IN ECOLOGICAL SUCCESSION OF SURFACE MINED AREAS IN NORTH DAKOTA**

Authors: L.R. Iverson and M.K. Wali

Organization Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Proceedings of North Dakota Academy of Science 32(1):3, 1977

Key Index Words Revegetation, Allelopathy, Competition, Succession

Brief Description

Preliminary results of growth chamber, laboratory and field studies on the role of kochia, a weedy species, in the revegetation of mined lands were discussed. Complete results of this investigation were published later, and are discussed in this inventory elsewhere.

Analysis of Conclusions

This ecophysicological study is very interesting and instructive of our lack of complete knowledge about the role of pioneering species in the early succession of vegetation on mined lands. Additional work in this area would be desirable.

Title: **POTENTIAL USE OF NATIVE SHRUBS FOR STRIP MINE RECLAMATION**

Author: K.E. Kissel

Organization North Dakota State University, Fargo, ND

Format: Thesis

Reference: M.S. Thesis, North Dakota State University Botany Dept., 1977

Key Index Words Revegetation, Plant Adaptability, Planting Techniques, Shrub Establishment

Brief Description

Field plot studies at Dickinson and greenhouse studies at Fargo were conducted to determine best methods for propagation of 15 shrub species in different planting media. A preliminary study which shows most species can be successfully established as transplants, but each species has special requirements for successful establishment from seed or cuttings.

Analysis of Conclusions

The results of the study are very preliminary. Further work needs to be conducted on individual species.

Title: **RESPONSE OF A GRASS - LEGUME MIXTURE TO VARIOUS AMENDMENTS AND NUTRIENTS ON A SODIC SPOIL MATERIAL**

Authors: N.M. Safaya and A. Kollman

Organization Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Reclamation Review, p. 14, 1977

Key Index Words Revegetation, Fertilizer Use, Plant Responses, Amendments, Nutrient Requirements

Brief Description

Discussed in this presentation were the preliminary results of some laboratory and growth chamber experiments conducted to study the effects of some fertilizers and amendments on a grass - legume mixture grown on a calcareous sodic mine spoil from Glenharold mine. The effects of fertilizers and amendments on the properties of the spoil material were also discussed.

Analysis of Conclusions

This study indicated that phosphorus was predominantly deficient in the soil; and that leonardite had a beneficial effect on the legume but an adverse effect on the grass species.

Title: **GROWTH AND NUTRIENT RELATIONS OF SOME GRASS AND LEGUME SPECIES ON A SODIC MINE SPOIL AS AFFECTED BY DIFFERENT AMENDMENTS AND NUTRIENT APPLICATIONS**

Authors: N.M. Safaya and M.K. Wali

Organization Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Agronomy Abstracts, p. 130, 1977

Key Index Words Revegetation, Fertilizer Use, Plant Responses, Amendments, Nutrient Requirements

Brief Description

In this presentation, the nutrient deficiencies and imbalances characterizing the sodic mine spoils and their detection by soil test and plant growth response studies were discussed. The effects of fertilizers and different types of amendments on the spoil properties and plant growth were also discussed.

Analysis of Conclusions

This investigation demonstrated the occurrence of some major and micronutrient deficiencies in the mine spoils from western North Dakota mines. Also the use of sulfuric acid as a suitable amendment for calcareous sodic spoils was established.

Title: **MOLYBDENOSIS: A POTENTIAL PROBLEM IN RUMINATS GRAZING ON COAL MINE SPOILS**

Authors: J.A. Erdman, R.J. Ebens and A.A. Case

Organization USGS, Denver, CO, and University of Missouri, Columbia, MO

Format: Paper

Reference: Journal of Range Management 31(1):34-36, 1978

Key Index Words Revegetation, Trace Elements, Animal Performance, Grazing

Brief Description

This paper reports the results of analyses conducted on sweet clover plants collected from eight surface mines in North Dakota, Montana and Wyoming. Copper to molybdenum ratios in all but two sweet clover samples ranged from 0.44:1 to 5:1. Ratios of 5:1 or less in forage are reported to cause molybdenosis, a nutritional disease occurring in molybdic regions of the world. Therefore, if the major forage on coal mine spoils is sweet clover or other species with similar Cu:Mo ratios, molybdenosis may be expected to occur in cattle and sheep grazing in these areas.

Analysis of Conclusions

A very important study, revealing for the first time that sweet clover growing on some coal mine spoil banks may be sufficiently high in molybdenum which can induce metabolic imbalances in cattle and possibly other ruminants fed predominately on this or similar legumes. Further investigations in this area of research are necessary. Indeed, not much work has been done in determining the nutritional quality of forages grown on mined lands.

Title: **INFLUENCE OF POINT FRAME QUADRAT ORIENTATION ON VEGETATIVE ANALYSES OBTAINED ON DISTURBED LAND RESEEDED IN ROWS**

Authors: L. Hofmann, R.E. Ries, J.F. Power, and R.J. Lorenz

Organization USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Proceedings of the First International Rangeland Congress (Donald Hyder, ed), pp. 521-523, Denver, CO, August, 1978

Key Index Words Revegetation, Cover

Brief Description

This study was conducted at the Baukol-Noonan Center Mine on reclaimed areas to determine if orientation of a point frame quadrat in relation to vegetation occurring in rows influences the results of cover estimation. Plant cover was measured under four grazing intensities using point-frame quadrats that were oriented diagonally, parallel or perpendicular to the seeded row, or randomly located. The conclusion was that there is no significant difference in estimation of plant cover due to quadrat orientation.

Analysis of Conclusions

A very interesting and informative study which will be useful when sampling for the determination of reclamation success.

Title: **GRAZING RECLAIMED STRIP MINED SITES**

Authors: L. Hofmann, R.E. Ries, J.F. Power, and R.J. Lorenz

Organization USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: North Dakota Agricultural Experiment Station Farm Research 36(1):3-5, 1978

Key Index Words Revegetation, Grazing, Animal Performance, Cover, Erosion

Brief Description

This paper presents some preliminary results obtained in an initial grazing study on a reclaimed site at Baukol-Noonan's Center Mine. The effects of grazing management on soil and vegetation were being studied in this ongoing long-term study. For details see Hofmann et al 1977.

Analysis of Conclusions

This long-term study has provided important data useful for developing grazing management technique for reclaimed lands.

Title: **PRAIRIE HAY AS A SEED SOURCE FOR STRIP MINED LAND REVEGETATION**

Author: R.E. Ries

Organization USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Ecological Society of America Bulletin 59(2):51, 1978

Key Index Words Revegetation, Prairie Hay, Seed Source, Mulch

Brief Description

Earlier research in North Dakota had shown that mature prairie hay can serve as a seed source for native prairie species when revegetating strip mined land. This paper presents information on how harvest date of the prairie hay may affect the seed source available in the prairie hay. Prairie hay was harvested from a range community in fair range condition at 5 monthly intervals during the 1977 growing season. Species composition of the hay material was determined and the material was air-dried and stored. In mid-November, the hay material was mulched over sterilized soil in flats in the greenhouse at a rate of 3,360 kg/ha. Results showed the October 1 harvest date to have the seeds of mostly weedy species.

Analysis of Conclusions

More research is needed to determine the use of prairie hay as seed source for reclamation purposes.

Title: **USE OF IRRIGATION IN RECLAMATION IN DRY REGIONS**

Authors: R.E. Ries and A.D. Day

Organization USDA-ARS, Mandan, ND

Format: Paper (Chapter)

Reference: Reclamation of Drastically Disturbed Lands Schaller and P. Sutton, eds.), pp. 505-520, ASA, CSSA, SSSA, Madison, WI, 1978

Key Index Words Revegetation, Irrigation

Brief Description

This article presents an overview of the use of irrigation in revegetation efforts of surface mined land in the western United States. The reasons for irrigation are presented and the development of specific methods and techniques is described. The future use of irrigation for reclamation is also discussed. It is contended that supplemental irrigation might improve deteriorated rangeland communities by establishing new communities with more desirable species.

Analysis of Conclusions

It is a good source of information on the use of supplemental irrigation in reclamation. Additional work in this area of research would be desirable.

Title: **RE-ESTABLISHMENT OF GRASSES ON LAND DISTURBED BY MINING IN THE NORTH GREAT PLAINS.**

Authors: R.E. Ries, F.M. Sandoval, and J.F. Power

Organization USDA-ARS, Northern Great Plains, Plains Research Center, Mandan, ND

Format: Paper

Reference: Proceedings of the First International Rangeland Congress, pp. 700-703, Denver, CO, August 1978

Key Index Words Revegetation, Soil Requirements, Fertilizer Use, Topsoil

Brief Description

Field studies were conducted to determine the effects of topsoil thickness and fertilization on introduced and native grass species. Topsoil replacement was found to be essential to vegetative stand establishment and productivity on mine spoil. Fertilizer increased stand production, but did not influence stand density. Selection of grass species that are readily established is essential to establishing fully stocked initial stands.

Analysis of Conclusions

A good study which provides documentation on the need of topsoil for grassland reclamation and the potential uses of fertilizer in reclamation.

Title: **EFFECTS OF FOLIAR APPLICATION OF NUTRIENTS ON BARLEY AND ALFALFA GROWTH ON COAL MINE SPOILS**

Authors: N. Malakondaiah, N.M. Safaya, and M.K. Wali

Organization Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Agronomy Abstract p. 157, 1978

Key Index Words Revegetation, Plant Responses, Nutrient Requirements, Fertilizer Use, Foliar Fertilization

Brief Description

In this presentation, the results of experiments conducted to determine the efficacy of foliar versus soil applications of N and P fertilizers to plants grown on a calcareous mine spoil were discussed. The complete results of this study were published in a full length paper in 1981, the details of which are included in this research inventory.

Analysis of Conclusions

The results of this investigation demonstrated that foliar applications of N and P fertilizers to plants grown on nutrient deficient spoil materials can be as or more effective than supplying these nutrients to the spoil.

Title: **DELINEATION OF MINERAL STRESSES IN MINE SPOILS AND SCREENING PLANTS FOR ADAPTABILILTY**

Authors: N.M. Safaya

Organization Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Key Index Words Ecology and Coal Resource Development (M.K. Wali, ed.), pp. 830-849, Pergamon Press, NY 1978

Key Index Words Revegetation, Nutrient Requirements, Amendments, Plant Adaptability

Brief Description

Edaphic stresses resulting from mineral deficiencies, toxicities and imbalances are among the important plant growth limiting factors encountered in surface mined lands. This paper emphasizes the synchronized approach of identifying the site specific nature of these stresses, and screening plants for their tolerances to specific stresses. The advantages and practical feasibility of this approach in mined land revegetation have been discussed in the light of current knowledge pertaining to both of these aspects.

Analysis of Conclusions

The conclusions drawn in this paper are based on the review of literature as well as the data obtained by the author from experiments conducted by him. It is being increasingly realized that revegetation of drastically disturbed areas must follow an approach which combines soil improvement on one hand and use of adapted species on the other.

Title: PLANT RESPONSES TO NUTRIENT APPLICATIONS IN COAL MINE SPOILS OF NORTH DAKOTA

Authors: N.M. Safaya and M.K. Wali

Organization Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: 144th National Meeting of the American Association for the Advancement of Science, Washington, Abstract No. 204, p. 130, 1978

Key Index Words Spoil Properties, Nutrient Requirements, Fertilizer Use, Revegetation

Brief Description

In this paper the nutrient availability problems of calcareous, sodic mine spoils from western North Dakota were discussed. Growth chamber experiments were conducted with oats, slender wheatgrass and alfalfa as test crops. Nitrogen fertilization, under adequate supply of phosphorous, increased the dry matter yields of oats and slender wheatgrass 4 to 8 times, but that of alfalfa by only 46%. However, nitrogen fertilization decreased the manganese concentration in all the three species, and phosphate fertilization decreased the concentration of zinc in plants. Addition of manganese increased the yield response of alfalfa to 85% and with manganese plus zinc to 99%. Oats and slender wheatgrass did not show any growth response to manganese or zinc. The response to manganese was related to high iron/manganese ration in this species.

Analysis of Conclusions

This study has shown that some North Dakota spoils are generally deficient in plant available nitrogen and phosphorous, and for some species the availability of manganese and zinc may also be low. Moreover, conventional soil tests do not necessarily indicate these deficiencies.

Title: **SOME NUTRIENT DEFICIENCY AND TOXICITY SYMPTOMS IN SLENDER WHEAT GRASS**

Authors: P.A. Schwartz and N.M. Safaya

Organization Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Proceedings of North Dakota Academy of Science 31(II):50-57, 1978

Key Index Words Nutrient Requirements, Plant Responses, Revegetation

Brief Description

This paper reports the results of growth chamber and laboratory experiments which were conducted to study the effects of various nutrient deficiencies and toxicities on the growth and nutrient composition of slender wheatgrass. The study was designed to provide a visual diagnostic criteria for recognizing nutrient deficiencies in the filed using this species as an indicator plant. Growth of slender wheatgrass was severely retarded by depleting nitrogen, phosphorus, or potassium from the growth medium but this species seemed to be most sensitive to potassium deficiency. Its requirement for zinc appeared to be relatively low. Potassium deficient plants were found to contain extremely high amounts of iron.

Analysis of Conclusions

Though not directly related to mined land reclamation and revegetation, this study has shown that there is a great need for understanding the nutritional requirements of many forage species which are generally used for revegetation of mined lands.

Title: **FIELD EVALUATION PLANTING**

Authors: USDA-SCS, Bismarck Plant Material Center Staff

Organization USDA-SCS, Bismarck Plant Materials Center, Bismarck, ND

Format: Report

Reference: 1976 Annual Technical Report, pp. 119-168, 1978

Key Index Words Revegetation, Plant Adaptability, Species Selection, Reclamation

Brief Description

This report presents the results of the mine spoil reclamation efforts of the Bismarck Plant Materials Center for the years 1975 to 1977. The reclamation work was conducted at four mine sites in western North Dakota, namely: Baukol-Noonan's, Center Mine (Oliver County); North American Coal Corporation's, Indian Head Mine (Mercer County); Wilton Mine Game Management Area, (Burleigh and McLean Counties); and North Beulah Mine Game Management Area (Mercer County). The work involved a variety of techniques including: plot preparation with leveling, planting of grasses, legumes, forbs and woodland vegetation, vegetation management, and the evaluation of the survival success of the vegetation.

Analysis of Conclusions

This report provides information on revegetation techniques which may be useful for reclamation of abandoned as well as currently mined areas.

Title: **ALLELOPATHIC POTENTIAL OF *SALSOLA KALI* L. AND ITS POSSIBLE ROLE IN RAPID DISAPPEARANCE OF WEEDY STAGE DURING REVEGETATION**

Author: M.A.K. Lodhi

Organization Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Journal of Chemical Ecology 5(30):429-437, 1979

Key Index Words Revegetation, Succession, Allelopathy, Pioneer Species

Brief Description

This paper describes the results of a laboratory growth chamber study which was conducted to determine the factors which control the rapid disappearance of the weedy stage in surface mine spoils. Decaying leaves of *Salsola* in soil significantly reduced the root, shoot, and seedling growth of *Kochia* and *Salsola*. Several phytotoxins were identified which accumulate in the soil.

Analysis of Conclusions

The cause of the rapid disappearance of the weedy stage was identified. This is useful information for the management of reclaimed areas.

Title: **PLANTING DATE AND WATER AFFECT INITIAL ESTABLISHMENT OF PERENNIAL VEGETATIVE COMMUNITIES**

Authors: R.E. Ries, R.F. Follett, F.M. Sandoval, and J.F. Power

Organization USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Ecology and Coal Resource Development; Volume 2, (M.K. Wali, ed.), pp. 899-905, Pergamon Press, New York, NY, 1979

Key Index Words Revegetation, Irrigation, Planting Techniques

Brief Description

The objectives of this study were to determine if initial stand development is enhanced by additional water, does planting date affect stand establishment, and what interacting effects does additional water have. It is possible to successfully establish perennial vegetation on disturbed land. Planting date affected composition but not overall vegetation establishment.

Analysis of Conclusions

An important study which is applicable to all perennial species used for revegetation in the state.

Title: **RELEVANCE OF FLOW CULTURE STUDIES IN IDENTIFYING P-EFFICIENT SPECIES FOR MINE SPOILS**

Authors: N.M. Safaya, N. Malakondaiah, and M.K. Wali

Organization Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference Agronomy Abstracts, p. 180, 1979

Key Index Words Plant Adaptability, Species Selection, Nutrient Requirements

Brief Description

In this study a number of plant species were screened for their relative susceptibility or tolerance to phosphorus deficiency, using continuous flow culture and spoil culture techniques. The two screening techniques yielded similar results. The grass species tested were found to have lower requirements for phosphorus than the legumes, but two weedy species (Kochia and Russian thistle) were found to be most tolerant to phosphorus deficiency.

Analysis of Conclusions

This study indicated that continuous flow culture system provides a rapid method of screening plant species for their adaptability to mineral stresses characterizing mine soils. The high capacity and low intensity type of situation prevailing in mine spoils or soils with respect to phosphorus availability can be easily simulated in continuous flow culture system. Moreover, this study has shown that some plants can tolerate extremely low levels of phosphorus in the growing medium better than others. Using nutritionally efficient plants on mined lands with nutrient availability problems should prove advantageous.

Title: **GROWTH AND NUTRIENT RELATIONS OF A GRASS - LEGUME MIXTURE ON SODIC COAL MINE SPOIL AS AFFECTED BY SOME AMENDMENTS**

Authors: N.M. Safaya and M.K. Wali

Organization Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Soil Science Society of America Journal 43:747-753, 1979

Key Index Words Revegetation, Spoil Properties, Amendments, Fertilizer Use

Brief Description

Laboratory and growth chamber experiments were conducted to study the effects of fertilizers, gypsum, sulfuric acid, and leonardite on the growth and nutrient relations of a mixed crop of thickspike wheatgrass and yellow sweetclover on a calcareous sodic coal mine spoil. Application of NPK increased the dry matter yield of the two species by 10 and 37 times, respectively. However, sweet clover required P only but wheatgrass yields almost doubled when N was included with P. The two species exhibited differential response to leonardite, which was correlated with K^+/Na^+ ratios in the plants and their calcium uptake efficiency. Leonardite increased Na concentration in wheatgrass (ca inefficient species) and decreased its growth, but caused a reverse effect on sweetclover (ca efficient species). Sulfuric acid proved more effective than gypsum in releasing Na from the exchange sites in the spoil, and improved the P status of the plants.

Analysis of Conclusions

This is an important study which demonstrated that the effects of leonardite can vary with species, and that sulfuric acid is more effective than gypsum as a reclamation agent for calcareous sodic mine spoils. The importance of nitrogen and phosphorus fertilization for mine spoils was established.

Title: **FIELD EVALUATION PLANTING**

Authors: USDA-SCS, Bismarck Plant Materials Center Staff

Organization USDA-SCS, Bismarck Plant Materials Center, Bismarck, ND

Format: Report

Reference: 1977 Annual Technical Report, 1979

Key Index Words Revegetation, Plant Adaptability, Species Selection

Brief Description

This report presents the results of the mine spoil reclamation efforts of the Bismarck Plant Materials Center for the years 1975 to 1977. The reclamation work was conducted at four mine sites in western North Dakota, namely: Baukol-Noonan's, Center Mine (Oliver County); North American Coal Corporation's, Indian Head Mine (Mercer County); Wilton Mine Game Management Area, (Burleigh and McLean Counties); and North Beulah Mine Game Management Area (Mercer County). The work involved a variety of techniques including: plot preparation with leveling, planting of grasses, legumes, forbs and woodland vegetation, vegetation management, and the evaluation of the survival success of the vegetation.

Analysis of Conclusions

This report provides information on revegetation techniques which may be useful for reclamation of abandoned as well as currently mined areas.

Title: **RECLAMATION RESEARCH STUDY IN SLOPE COUNTY**

Author: J. Van Deussen

Organization USDA-FS, Rock Mountain Forest and Range Experiment Station, Bottineau, ND

Format: Report

Reference: USDA-FS, Unpublished Report (no date)

Key Index Words Revegetation, AML, Species Selection

Brief Description

This study focuses on the reclamation of an unleveled, abandoned uranium mine about 40 acres in size in north central Slope County. The study was initiated during the summer of 1975, and attempted to reclaim the area with several woody species. Data were collected on the percentage of survival of plantings. The survival of bare root versus containerized plantings was compared. Planting was discontinued in the summer of 1979 and the final evaluation and report was to be completed in the fall of 1979.

Analysis of Conclusions

The results of this study may be useful in the reclamation of abandoned mined lands.

Title: **COMPARISON OF VEGETATIVE COMPOSITION, COVER, AND PRODUCTION ON RECLAIMED AND NONMINED GRAZED LANDS**

Authors: L. Hofmann and R.E. Ries

Organization USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Proceedings of the Symposium on Adequate Reclamation of Mined Lands?, pp. 27-1 to 27-10, Billings, MT, 1980

Key Index Words Revegetation, Grazing, Cover, Animal Performance

Brief Description

This paper discusses the results of a long term grazing study in which animal performance and vegetative production, composition, and cover on reclaimed strip mined land and unmined grazing land near Center, ND, were compared. Dry matter yields harvested from moderately, lightly, and ungrazed reclaimed pastures were equal to or better than yields from two adjacent unmined range sites. Performance of yearling steers grazing reclaimed pastures at moderate or light intensities, equaled steer performance from unmined pastures at Mandan, ND, during spring and early summer. Four cool season, introduced plant species made up about 90 percent of the vegetation on the reclaimed site, and four native species made up over 75 percent of plant cover on native sites. Except for ungrazed controls, live plant cover was less on reclaimed land than on native range, as measured by foliage hits with a point frame. However, live vegetation plus litter was equal or better on reclaimed sites than on native sites, and cover was sufficient to prevent soil loss on both reclaimed pastures and native range, as predicted by the Universal Soil Loss Equation. If only live plant basal hits were used to estimate cover, neither the reclaimed nor native sites had sufficient cover to prevent unacceptable soil loss. The reclaimed area had equal or better vegetative production, equal animal performance.

Analysis of Conclusions

The observations and conclusions made in this study are very important in developing grazing management strategies for reclaimed and revegetated mined lands. Continued observations on these experimental plots would be highly desirable.

Title: **PRODUCTIVITY POTENTIAL OF SOME STOCKPILED TOPSOILS FROM COAL MINED LANDS IN WESTERN NORTH DAKOTA**

Authors: N. Malakondaiah, N.M. Safaya, and M.K. Wali

Organization Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Agronomy Abstracts, p. 171, 1980

Key Index Words Productivity, Stockpiled Soil, Fertilizer Use, Nutrient Requirements

Brief Description

In this study stockpiled topsoils from Center, Glenharold, and South Beulah mines in North Dakota were evaluated for their fertility status and productivity potential by growth chamber experiments and soil and plant analyses. Effects of 10 fertilizer treatments consisting of various combinations of N, P, K, Mn, Cu, and B on slender wheatgrass and yellow sweetclover were studied. Plants showed little response to N, some response to P, but a strong response to N+P. Responses to Zn occurred on Glenharold topsoil, and to B on South Beulah topsoil.

Analysis of Conclusions

This study has indicated that the availability of plant nutrients, especially N and P, in stockpiled topsoils can be extremely low. This can result in poor plant growth when such stockpiled soil materials are spread on reshaped spoils without proper fertilization.

Title: **POTENTIAL CONTROL AND VALUE OF SEEDS IN PRAIRIE HAY FOR REVEGETATION**

Authors: R.E. Ries, L. Hofmann, and W.C. Whitman

Organization USDA-ARS, Northern Great Plains Research Center, Mandan, and North Dakota State University, Fargo, ND

Format: Paper

Reference: Reclamation Review, 3:149-160, 1980

Key Index Words Revegetation, Prairie Hay, Mulch

Brief Description

This paper describes the results of a greenhouse study conducted at the ARS Station, Mandan. The objective of the study was to determine the relationship of amount and kinds of seeds available in prairie hay with range condition and harvest date of prairie hay. Prairie hay was found to be a seed source with potential to increase the diversity of native species on reseeded areas. However, excessive amount of certain species may result from prairie hay. By careful selection of range condition and harvest dates and the mixing of specific harvests the potential seedlings available from prairie hay may be matched to the intended use of the areas reclaimed.

Analysis of Conclusions

This was an excellent study which advanced the knowledge on the use of native hay mulch as a seed source. Follow-up studies should be conducted to see if seed dormancy or yearly climatic effects on potential seedling in hay are factors which need to be considered when harvesting or using native hay mulch.

Title: **SUPPLEMENTAL IRRIGATION WITH DIFFERENT WATER QUALITIES AND QUANTITIES TO INSURE REVEGETATION ESTABLISHMENT AFTER MINING**

Authors: R.E. Ries, J.F. Power, and F.M. Sandoval

Organization USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Report

Reference: Final Report, M-76-5, March, 1980

Key Index Words Revegetation, Irrigation

Brief Description

The study was conducted at the Knife River Gascoyne Mine. The objectives were to evaluate vegetation response during establishment and growth to supplemental water of different qualities and in different quantities, to evaluate soil salinity during and after application of irrigation and as a waste water disposal technique. The conclusions were that there are no detrimental effects on vegetative establishment and growth from the application of poor quality water. Soil quality was not adversely affected by the use of poor quality water. The use of poor quality water has potential for water disposal while benefiting the establishing of vegetation and having only moderate increases of the salt content in the root zone on permeable soil/spoil areas.

Analysis of Conclusions

A good study with results that can be applied to all reclamation areas which have moderate to high permeability. This study should be extended to fine textured materials.

Title: **RE-ESTABLISHING WOODY DRAWS ON THE NORTHERN GREAT PLAINS AFTER MINING: THE FIRST STEPS**

Authors: R.L. Williamson and K.W. Wangerud

Organization Consolidation Coal Company

Format: Paper

Reference: Adequate reclamation of mined lands? A Symposium, pp. 17-1 to 17-12, Soil Conservation Society of America and LRRC-1, Billings, MT, March, 1980

Key Index Words Revegetation, Woody Draws, Planting Techniques, Irrigation

Brief Description

The study was conducted at the Glenharold mine to determine which planting, bed preparation, and management techniques are most suitable for the establishment of woody vegetation. Results reported were preliminary and the only conclusion drawn was that irrigation enhances establishment as all plots exhibited good survival rates.

Analysis of Conclusions

This is one of the first studies conducted on North Dakota mine lands regarding the re-establishment of woody vegetation in the drainages. This study needs to be followed up and additional studies need to be conducted on woody draw establishment.

Title: **LIVESTOCK AND VEGETATIVE PERFORMANCE ON RECLAIMED AND NONMINED RANGELAND IN NORTH DAKOTA**

Authors: L. Hofmann, R.E. Ries, and R.J. Lorenz

Organization USDA-ARS, Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Journal of Soil and Water Conversation 36(1):41-44, 1981

Key Index Words Revegetation, Grazing, Animal Performance, Cover, Erosion

Brief Description

The study was conducted to determine the effect of grazing intensity on growth and persistence of vegetation, the ability of reclaimed lands to remain productive, and to compare livestock and vegetation performance on mined and unmined areas. The study was conducted at the Baukol-Noonan Center Mine. The results show that animal performance on reclaimed areas did not change significantly due to grazing, and the cover of the reclaimed area was adequate to control erosion, though both composition and cover varied from that found on unmined areas.

Analysis of Conclusions

This is an excellent study and is applicable to all reclaimed cool season pasture lands in the state. New grazing research should be conducted on a seasonally balanced cool/warm season with season long or deferred rest rotation grazing evaluated.

Title: **ECOLOGY OF *KOCHIA SCOPARIA* ON SURFACE MINED LANDS**

Authors: L.R. Iverson and M.K. Wali

Organization Project Reclamation, University North Dakota, Grand Forks, ND

Format: Paper

Reference: North Dakota Academy of Science 35:7, 1981

Key Index Words Revegetation, Succession, Pioneer Species, Allelopathy

Brief Description

The objective of this study was to increase the knowledge available on the ecology of *Kochia scoparia* and determine its role in revegetation of mined lands. A series of reclaimed areas near Beulah were studied. *Kochia* flourishes on newly reclaimed sites for a number of reasons; however, interspecific and intraspecific competition, loss of good germination sites, and the phenomenon of autotoxicity in *Kochia* all combine to decrease it the second and third years after reclamation. Some speculation were made as to why *Kochia* would produce phytotoxins.

Analysis of Conclusions

This paper presents a good summary on the traits of *Kochia* which allows it to flourish on newly reclaimed areas and why it decreases the following years. The study advanced the knowledge on *Kochia scoparia*, a common weed species which invades reclaimed areas. Understanding the ecology of and physiology of weedy species which invade and thrive on disturbed lands will be greatly helpful in controlling such species as well as in selection and breeding of desirable species with similar mechanisms for adaptability to impoverished soil conditions.

Title: **GROWTH AND CHEMICAL COMPOSITION OF SLENDER WHEATGRASS AND YELLOW SWEET CLOVER AS AFFECTED BY NUTRIENT APPLICATIONS TO COAL MINE SPOILS.**

Authors: N. Malakondaiah, N.M. Safaya and M.K. Wali

Organization Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Agronomy Abstract p. 183, 1981

Key Index Words Spoil Properties, Fertilizer Use, Nutrient Requirements, Revegetation

Brief Description

Laboratory and growth chamber studies were conducted to assess the fertility status and productivity potential of spoil materials collected from the Center, Glenharold and South Beulah Coal mines in western North Dakota. Slender wheatgrass and yellow sweetclover, used as test plants, produced less than 6% of maximum dry matter yield when the spoils were not fertilized. Responses to nitrogen and phosphorous, when applied singly, were nil to slight, respectively. However, near maximum yields were obtained when nitrogen and phosphorous were applied together. Some slight responses to potassium, zinc and manganese fertilization were also observed.

Analysis of Conclusions

This is one of the many studies conducted at the University of North Dakota, which have elucidated that mine spoils and soils are deficient in plant available phosphorus and nitrogen. In some cases manganese and zinc deficiencies are also evident in plants though conventional soil tests may show the levels of these nutrients in the spoil or soil materials in a seemingly adequate range. Moreover, these nutrient deficiencies are often masked in the field because of overriding water stress.

Title: **RESPONSES OF ALFALFA AND BARLEY TO FOLIAR APPLICATIONS OF N AND P ON A COAL MINE SPOIL**

Authors: N. Malakondaiah, N.M. Safaya, and M.K. Wali

Organization Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Plant and Soil 59:441-453, 1981

Key Index Words Nutrient Requirements, Fertilizer Use, Foliar Fertilization, Revegetation, Plant Responses

Brief Description

This paper discusses the results of several growth chamber experiments conducted to determine the effects of foliar fertilization with NaH_2PO_4, H_3PO_4, and urea on the growth and nutrient composition of alfalfa and barley grown on a calcareous, moderately saline and sodic mine spoil from South Beulah mine. The effects of various concentrations and frequencies of foliar fertilization were tested and compared with those obtained with soil applications of N and P.

Analysis of Conclusions

The results of these experiments have demonstrated that foliar applications of N and P to barley and that of P to alfalfa, grown on a freshly exposed mine spoil, can increase their growth significantly, and in some cases more effectively than do the applications of these nutrients to the spoil.

Title: **IMPROVING SPECIES COMPOSITION AND SEASONAL VARIETY ON RECLAIMED STRIP MINED GRASSLANDS THROUGH SELECTIVE GRAZING INTENSITIES AND TIME PERIODS**

Author: R.L. Williamson

Organization Consolidation Coal Company

Format: Paper

Reference: North Dakota Academy of Science Proceeding 35:5, 1981

Key Index Words Revegetation, Grazing, Grassland

Brief Description

The objectives of the study were to determine if grazing could be used as a management tool in improving species composition and seasonal variety of reclaimed grasslands and what levels of grazing could reclaimed grasslands withstand. The study was conducted at the Glenharold Mine. Three pastures were established, along with a control, and each pasture was grazed at a different intensity. The results indicated that grazing improved the seasonal variety and species diversity of the reclaimed grasslands. The more intense the grazing, the more the change. Good beef gains were obtained from all pastures. The control declined in condition.

Analysis of Conclusions

The study yielded excellent information about using grazing to manipulate vegetation. This is applicable to all mines reclaiming natural grasslands. The scale at which this study was conducted, was sufficient to provide the desired information. However, a large scale study should be conducted for several years to see how the vegetation withstands long term grazing in a season long grazing system.

Title: **RECLAIMING SEASONALLY BALANCED NATIVE GRASSLAND AFTER STRIP MINING**

Author: R.L. Williamson

Organization Consolidation Coal Company

Format: Paper

Reference: North Dakota Academy of Science Proceeding 35:3, 1981

Key Index Words Revegetation, Seeds, Grassland

Brief Description

The objective of this study was to see the effect of using different seed mixtures in reestablished at the Glenharold mine. Each site was mined, reshaped, respread with soil materials, and seeded. The seed mixture used differed between sites, one favoring sideoats grama (*Bouteloua gracilis*) and the other favoring little bluestem (*Schizachyrium scoparium*); the other species in the mixture were seeded at the same rate on both sites. The preliminary results reported were that by using specific reclamation techniques (delaying seeding until June, using irrigation, and weighting the seed mixture toward warm season species, a native seasonally balanced grassland can be established.

Analysis of Conclusions

This is an important study, the results of which are applicable to all mines where native grasslands are being reclaimed. However, the results of this study are only preliminary. This study should be continued to see what the long term requirements are for establishing native grassland. Also, this study looked at only a few of the techniques which may be usable for establishing a seasonally balanced native grassland. Additional work on management techniques would be desirable.

Title: **PHYSICAL AND ENVIRONMENTAL FACTORS OF WOODLAND ECOSYSTEMS ON THE GLENHAROLD MINE RESERVE IN WESTERN NORTH DAKOTA**

Authors: R.L. Williamson, J.L. Richardson, G. Clambey, B.J. Bermes, and W. Keammerer

Organization Consolidation Coal Company

Format: Paper

Reference: North Dakota Academy of Science Proceeding 35:8, 1981

Key Index Words Woody Draws, Environmental Factors, Land Use

Brief Description

The objective of this study was to identify the physical and vegetative characteristics of woody draws at the Glenharold Mine. Botanical, soils, landscape, and hydrogeologic investigations were conducted at six sites. Three main factors were identified as being important for the presence of woody vegetation and three vegetation types were described. The three factors are landform, slope aspect, and shallow water table outcrops. The three vegetation types are low shrublands, tall shurblands, and deciduous woodlands.

Analysis of Conclusions

This study is important in that it is the first time an analysis was conducted of woody draws to determine what physical factors contribute to the establishment and survival of woody vegetation in coulee and escarpment areas.

Title: **ECOLOGICAL STUDIES ON THE REVEGETATION PROCESS OF SURFACE COAL MINED AREAS IN NORTH DAKOTA: 3. SOIL AND VEGETATION DEVELOPMENT OF ABANDONED MINES**

Authors: M.K. Wali and R.H. Pemble

Organization Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Report

Reference: A minerals research contract report to USDI-Bureau of Mines, 1982

Key Index Words Revegetation, Soil Development, Spoil Properties, AML, Succession

Brief Description

A field study conducted at the Velva Mine, with laboratory work completed at UND. The objective was to analyze soil and vegetation development on abandoned mine sites from 1 to 45 years old and compare these sites to an unmined site. Species diversity was highest at the unmined site and lowest at the 1 year old site. Site ages were found to be the most important in influencing species diversity and composition based on stand ordinations. Stand environmental complex ordinations showed topographic variables the most important. Nutrient accumulation and carbon-nitrogen ratios data are provided.

Analysis of Conclusions

A good study on vegetation development on abandoned mine areas with good spoil conditions.

Title: **RECLAMATION OF COAL MINED LANDS: THE ROLE OF *KOCHIA SCOPARIA* AND OTHER PIONEERS IN EARLY SUCCESSION**

Authors: L.R. Iverson and M.K. Wali

Organization Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Reclamation and Revegetation Research, 1 :123-160, 1982

Key Index Words Revegetation, Succession, Pioneer Species, Allelopathy, Competition

Brief Description

This study was conducted on mined and unmined areas south of Beulah, and in the growth chambers and laboratories of UND. The objective was to determine the role of Kochia and other pioneer species early in succession. The authors found that *Kochia* dominated the first couple of years after mining, then declined and the seeded *Agropyron sp.* increased. Other pioneers showed a similar but less abrupt decline. Chemical changes in the soil also occurred during this time. *Kochia* was found to act as a nurse crop for *Agropyron sp.* the first year, but later shaded them. Autotoxicity in *Kochia* appeared to be the major factor in its decline.

Analysis of Conclusions

An informative study on the role of Kochia in early succession.

Title: **ECOLOGICAL STUDIES ON THE REVEGETATION PROCESS OF SURFACE COAL MINED AREAS IN NORTH DAKOTA: 9. VIABILITY AND DIVERSITY OF THE SEED BANK.**

Authors: L.R. Iverson and L. Brophy

Organization Project Reclamation, University of North Dakota, Grand Forks, ND.

Format: Report

Reference: A minerals research contract report to USDI-Bureau of Mines, 1982

Key Index Words Seed Source, Topsoil, Germination

Brief Description

Results of a laboratory and growth chamber study designed to determine the amounts and kinds of viable seeds in natural topsoil and stockpiled topsoil are discussed. The conclusions were that the top 7.5 cm of topsoil contains by far the highest quantity and quality of seeds, grazing of a site increases the seeds, stockpiled topsoil contained very few seeds, and there is a definite seasonality to the quality and quantity of the seed bank.

Analysis of Conclusions

An important study which if furthered should improve the reclamation technology.

Title: **ECOLOGICAL STUDIES ON THE REVEGETATION PROCESS OF SURFACE COAL MINED AREAS IN NORTH DAKOTA: 11. EFFECT OF AMENDMENTS ON SOIL - PLANT NUTRIENT RELATIONS UNDER CONTROLLED CONDITIONS**

Authors: N. Malakondaiah and N.M. Safaya

Organization Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Report

Reference: A mineral research contract report to USDI-Bureau of Mines 62 p., 1982

Key Index Words Revegetation, Amendments, Fertilizer Use, Nutrient Requirements, Productivity

Brief Description

This report discusses the results of a number of growth chamber and laboratory experiments which were conducted to study the effects of various amendments and nutrient applications on the germination, growth, and nutrient uptake of several grass and legume species grown on spoils and topsoils collected from various mining areas in North Dakota. Germination and growth responses to leonardite varied with species; sulfuric acid was found to be a better amendment than gypsum; plant growth on spoils and topsoils was greatly increased by nitrogen plus phosphorus applications, and in some cases responses to manganese and zinc were also observed.

Analysis of Conclusions

This report provides very useful information about the productivity and fertility characteristics of mine spoils and soils. The problems of nutrient availability in these materials have been examined in great detail, and the requirements for specific nutrients established. It is important to recognize, however, that any possible responses to fertilizer applications on mine spoils and soils can be completely masked by the overriding effect of moisture shortage.

Title: **ECOLOGICAL STUDIES ON THE REVEGETATION PROCESS OF SURFACE COAL MINED AREAS IN NORTH DAKOTA: 12. SCREENING PLANTS FOR PHOSPHORUS REQUIREMENTS.**

Authors: N.M. Safaya and N. Malakondaiah

Organization Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Report

Reference A minerals research contract report to USDI, Bureau of Mines, 46 p., 1982

Key Index Words Plant Adaptability, Nutrient Requirements, Species Selection

Brief Description

This report provides a review of literature on the adaptability of plants to mineral stresses (deficiencies and toxicities), and discusses the results of continuous flow culture and soil culture techniques used for screening some plant species and varieties for their relative susceptibility to phosphorus deficiency. Legumes were found to be the most susceptible to phosphorus deficiency and weedy species such as Russian thistle and kochia the least. The phosphorus uptake efficiency of the weedy species was three to five times higher than that of the legumes. The rating of species with respect to their susceptibility to phosphorus deficiency was more or less similar under both screening procedures.

Analysis of Conclusions

The importance of selecting plants for revegetation of mined lands on the basis of their tolerance to edaphic stresses, such as mineral deficiencies and toxicities, is emphasized. The relatively high phosphorus uptake efficiency of Russian thistle and kochia, as reported in this study, may perhaps be one of the reasons for their ability to grow well on the highly impoverished mine spoils and other disturbed areas. This study also indicated that screening of plants conducted in continuous flow culture system does not greatly differ from that conducted in the spoil system, and therefore continuous flow culture technique can be of much use in rapid screening of species for mined land use.

Title: **ECOLOGICAL STUDIES ON THE REVEGETATION PROCESS OF SURFACE COAL MINED AREAS IN NORTH DAKOTA: 6. RELATIONSHIP BETWEEN COVER AND ABOVEGROUND BIOMASS**

Author: D.K. Schemmelpfennig

Organization Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Report

Reference A minerals research contract report to USDI-Bureau of Mines, 1982

Key Index Words Revegetation, Productivity, Cover, Topsoil

Brief Description

A field study was conducted on both native and reclaimed grasslands to determine plant cover estimates by species, biomass estimates by species, the relationship between cover and biomass, the predictability of the relationship, and evaluate factors affecting the relationship. Correlations for individual species and native grassland sites were significant. Rough estimates of biomass of major species can be obtained by using aerial cover on these sites.

Analysis of Conclusions

A good study with some interesting possibilities for application. Accurate estimates of biomass from cover data would reduce determination of reclamation success. Further work should be done to see if correlations can be improved for reclaimed areas.

Title: **WARM-SEASON GRASSES FOR REVEGETATION IN THE NORTHERN GREAT PLAINS**

Authors: R.E. Ries

Organization USDA-ARS Northern Great Plains Research Center, Mandan, ND

Format: Paper

Reference: Proceedings, Symposium on Surface Coal Mining and Reclamation in the Northern Great Plains, Mont. Ag. Exp. Stat. Res. Rep. No. 194, 1982

Key Index Word: Revegetation, Grassland

Brief Description:

Literature pertaining to the ecology of warm-season grasses and their establishment on mined land is reviewed. Warm-season grasses, such as blue grama and buffalo grass are recognized for their value as forage and for erosion control. Difficulties in obtaining seeds and establishing them from seed have limited the use of warm-season species. Warm-season grasses require optimum seed placement depth and moisture conditions which are difficult to obtain.

Analysis of Conclusions

This paper is a good review of literature on warm-season grasses for establishment on reclaimed lands. Proper seeding techniques, including rate, depth, and date are given.

Title: **PLANT ROOT DISTRIBUTION IN UNDISTURBED AND RECLAIMED STRIPMINE SOILS IN WESTERN NORTH DAKOTA**

Authors: J.E. Gilley, D.D. Schlenker, and E.C. Doll

Organization NDSU-Land Reclamation Research Center, Mandan, ND

Format: Report

Reference: NDSU-Agricultural Experiment Station Research Report No. 92, October 1982

Key Index Words Root Growth, Sodicity, Topsoil

Brief Description:

This study, conducted at the Indian Head Mine, compared root growth in an undisturbed soil to that in reclaimed soils with underlain sodic or nonsodic spoils. It also evaluated the effects of topsoil thickness on root growth; the effects of tilling the spoil surface prior to topsoil replacement on root growth in the spoil were also studied. Similar root growth patterns were found for perennial grasses grown on the undisturbed soil, the reclaimed nonsodic spoil site, and the reclaimed sites with varying depths of topsoil over sodic spoil. However, the total amount of roots produced varied greatly at the 3 sites. Tillage of the spoil surface prior to topsoil replacement did not appear to improve root penetration into the spoil. Total depth of root penetration appeared to be independent of topsoil depth.

Analysis of Conclusions

Additional research should be conducted to further determine those factors which affect root growth and development in reclaimed soils. The research should also include mined lands that have been reclaimed with both topsoil and subsoil.

Title: **SURFACE MINE RECLAMATION PLANT MATERIALS STUDIES**

Authors: USDA-SCS, Bismarck Plant Materials Center Staff

Organization USDA-SCS, Plant Materials Center, Bismarck, ND

Format: Report

Reference: Progress Reports, June 1982 and December 1983

Key Index Words Revegetation, Plant Adaptability, Erosion, Species Selection

Brief Description

These progress reports provide information on studies which were conducted to: 1) determine plants best suited for mine spoil reclamation, 2) develop techniques for successful establishment of plants for erosion control and surface mined land reclamation, 3) determine equipment modification needed for seed collection and processing, and 4) propagate and provide for increase of seed and other plant materials. All studies are currently underway. No conclusions or findings have been provided.

Analysis of Conclusions

These are ongoing studies on the selection and evaluation of plant materials suitable for strip mine land reclamation. These studies need to be continued.

Title: **LIABILITY PERIOD AND MANAGEMENT OF RECLAIMED LANDS**

Authors: J.D. Friedlander

Organization The North American Coal Corp., Western Division, Bismarck, ND.

Format: Paper

Reference: Symposium on Western Coal Mining Regulatory Issues: Land use, Revegetation, & Management, (E. F. Redente, W. E. Sowards, D. G. Steward, Terry L. Ruiter, eds.). pp.103-4, Fort Collins, CO, 1983.

Key Index Word: Liability Period, Bond Release, Land Use, Management Practices

Brief Description:

The author contends that a 10-year liability period, imposed by the 1977 Surface Mining Control and Reclamation Act, for assessing reclamation success in the western states does not meet the site specific management needs because of the extreme variability in climate and land use in this region. Good arguments have been presented to underscore the importance of management practices in relation to the liability period and the degree of difficulty in establishing vegetation in different parts of the Western United States.

Analysis of Conclusions

There may be some truth in the author's contention that restarting the liability clock for instituting certain management practices actually penalizes operators, and discourages effective reclamation and postmining land use.

Title: **RE-ESTABLISHING NORTH DAKOTA GRASSLANDS AFTER MINING WITH EMPHASIS ON SEASONALITY AND USE OF NATIVE SPECIES**

Authors: R. L. Williamson

Organization Consolidation Coal Company

Format: Paper

Reference: Journal of Soil and Water Conservation 39(6):387-391. 1984

Key Index Word: Seasonality, Grassland, Planting Techniques

Brief Description:

This study was designed to demonstrate on large-scale pastures that a seasonally balanced grassland can be re-established with native species following mining. Techniques including seeding in late spring, irrigation during the first growing season, and weighting the seed plan to heavily favor native warm season species were evaluated to determine their necessity to insure a seasonal stand and to compare to traditional practices.

Analysis of Conclusions

Alternative methods of establishing grasslands that are seasonally balanced with native warm season grass species are more successful than traditional North Dakota grassland establishment practices. Particularly significant was a combination of seeding date and irrigation, although seed plan ratios were also important. Seeding later in the spring gives warm season species a more equal establishment chance. Irrigation, in the first growing season only, appears to be most helpful in late spring and early summer for establishing warm season species. Sideoats grama was especially responsive to first growing season irrigation. Seed plans for establishing grasslands that emphasize dual seasonality should include in excess of 70% perennial warm season grass varieties.

Title: **PASTURE AND HAYLAND: MEASURES OF RECLAMATION SUCCESS**

Authors: R.E. Ries and L. Hofmann

Organization ARS, Northern Great Plains Research, Laboratory, Mandan, ND

Format: Paper

Reference: Minerals and the Environment 6: 85-90, 1984.

Key Index Word: Vegetation, Cover, Pasture, Reclamation Success

Brief Description

Several characteristics of reclaimed tame pastureland were quantified and evaluated as a measure of determining reclamation success on surface mined lands. These include productivity (vegetation and animal), ground cover and soil loss, species composition and species numbers, and seasonality of use.

Analysis of Conclusions

Measurement of reclaimed grassland characteristics including beef gains, plant species numbers, soil loss, and seasonality of use are useful in evaluating reclaimed grassland from a research standpoint. However, these characteristics do not appear necessary for making management - oriented determinations of reclamation success. Important measures are vegetative productivity and ground cover. Measure of vegetation productivity translates into quantity of forage or hay produced following reclamation, while it also provides an evaluation of the effectiveness and permanence of the reclaimed grassland. Ground cover (vegetation and litter cover) provides a measure of soil protection from water erosion. Reclaimed grassland with a total surface ground cover of 73% or more (bare soil amount less than 27%) had soil loss similar to native non-mined grassland.

Title: **FACTORS AFFECTING REVEGETATION OF ABANDONED MINE LANDS IN THE NORTHERN GREAT PLAINS**

Authors: S. A. Nicholson

Organization Project Reclamation, University of North Dakota, Grand Forks, ND

Format: Paper

Reference: Proceedings of the National Sympoisum and Workshops on Abandoned Mine Land Reclamation) L.L. Schloesser, G.S. Anderson, N.M. Safaya, D.J. Thompson, eds.) pp. 548-561, Bismarck, ND 1984

Key Index Words AML, Microorganisms, Salinity, Sodicity, Water Stress

Brief Description

This paper discusses the key environmental and biotic factors that restrict or affect the revegetation of abandoned mine lands in the Northern Great Plains, with particular emphasis on those found in North Dakota. The reclamation problems caused by sodicity, salinity, acidity, nutrient deficiencies, instability caused by subsidence, and susceptibility to wind and water are discussed.

Analysis of Conclusions

The information provided in this paper will help to identify the problems encountered in revegetating abandoned mine lands in North Dakota. The discussion on the role of micro-organisms in the reclamation process enlarges the scope of this paper.

Title: **YIELD AND BOTANICAL COMPOSITION OF A GRASS-LEGUME MIXTURE ON RECLAIMED LAND AS AFFECTED BY N AND P FERTILIZER**

Authors: G.A. Halvorson and A. Bauer

Organization NDSU - Land Reclamation Research Center, Mandan, and Soils Science Department, Fargo, ND

Format: Paper

Reference: Agronomy Journal 76:355-358, 1984

Key Index Words Revegetation, Fertilizer Use, Plant Responses, Species Selection, Landuse Management

Brief Description:

The objective of this study was to determine the effect of N and P fertilizers on a grass-legume mixture consisting of alfalfa, yellow sweetclover, intermediate wheatgrass, crested wheatgrass and smooth bromegrass grown on reclaimed land at the Center Mine. Eleven P and three N treatments were applied in a split-plot design. Annual N applications increased total forage yield, by increasing the relative composition of smooth bromegrass and wheatgrasses. Alfalfa yields were reduced by N application. P applications did not increase total forage yields. Yield and percent composition of wheatgrass increased with increasing additions of P, but the percent composition of smooth bromegrass decreased. Yields of smooth bromegrass and wheatgrass were highly correlated with the cumulative P applications. The authors concluded that application of fertilizer P can be used as a management tool to influence species composition on reclaimed pasture.

Analysis of Conclusions

Vegetation responses to N and P fertilizers obtained in this study on reclaimed land are similar to those that would be expected on undisturbed lands. The observation that P fertilization can change the botanical composition of grasslands provides yet another method of managing reclaimed lands for meeting diversity and seasonality requirements.

Title: **GRAZING RECLAIMED MINED LAND: ANIMAL PERFORMANCE**

Authors: L. Hofmann and R.E. Ries

Organization ARS, Northern Great Plains Research, Laboratory, Mandan, ND

Format: Proceedings

Reference: American Society of Agronomy 76th Annual Meeting, 76:158. 1984.

Key Index Word: Animal Performance, Grazing

Brief Description

Yearling steers were grazed on fertilized surface-mined land-reclaimed to cool-season forage species for a six year period to determine animal gains. Steers were grazed at rates of 0.73, 0.49, and 0.24 ha/steer/season to determine effects of light, moderate, and heavy grazing intensities, respectively. Grazing occurred between late May and early July: 38 days for light and moderate intensities and 30 days for the heavy intensity. Surface soil compaction was estimated using a cone-tip penetrometer.

Analysis of Conclusions

Heavily grazed pastures produced significantly less (P=0.05) beef (31 kg/ha) than moderate or light grazing intensities (86 and 64 kg/ha respectively). Average daily gains were 0.3, 1.1, and 1.3 kg/ha for heavy, moderate and light grazing intensities, respectively. Overgrazing was especially detrimental in stressed years. In 1980, a drought year, steers grazed at the heavy intensity for 18 days lost weight, while steers at moderate and light grazing intensities gained. Increased grazing intensity increased soil compaction but had no effect on soil bulk density. There were no animal health problems. Animal gain and performance were comparable to long-term research experience on unmined lands.

Title: **GRAZING RESEARCH AND WATER-USE-EFFICIENCY ON RECLAIMED PASTURES IN NORTH DAKOTA**

Authors: R.E. Ries and L. Hofmann

Organization ARS, Northern Great Plains Research, Laboratory Mandan, ND

Format: Paper

Reference: Symposium on Reclamation of Lands Disturbed by Surface Mining: A Cornerstone for Communication and Understanding, pp. 151-163. 1984 National meeting, American Society for Surface Mining and Reclamation. Science Reviews Limited. Northwood, Middlesex, England. 1985.

Key Index Word: Revegetation, Performance Standards

Brief Description

This paper presents a review of grazing research on reclaimed, cool-season pastures in North Dakota and a comparison of water-use-efficiency of forage grown on unmined and mined land.

Analysis of Conclusions

Data has shown that vegetation and animal production from reclaimed pastures is similar to that from unmined pastures. Soil loss on reclaimed pastures was similar to soil loss from native rangeland providing reclaimed areas were not heavily grazed. Production of vegetation and surface ground cover (vegetation and litter) provide appropriate and adequate documentation to evaluate reclamation success of tame pastureland. Forage water use efficiency as effected by maximum air temperature and free water evaporation indicated water was more efficiently used in producing forage under cooler climatic conditions. Light and moderately grazed pastures produced more forage per unit water used as compared to ungrazed and heavily grazed pastures. Forage water use efficiency on reclaimed pastures was comparable to forage water use efficiency of non-irrigated unmined land.

Title: **TECHNIQUES USED TO ESTABLISH, MAINTAIN, AND ENHANCE GRASSLAND SEASONAL VARIETY ON THE GLENHAROLD MINE IN NORTH DAKOTA**

Authors: D.J. Nilson, R.L. Williamson, J.C. Thompson, and J.E. Shultz

Organization Consolidation Coal Company

Format: Paper

Reference: Proceedings, Second Annual Meeting, American Society for Surface Mining and Reclamation, Denver, Colorado, October 8-10, 1985

Key Index Word: Revegetation, Seasonality, Cover, Productivity

Brief Description

Establishment and management techniques which have enhanced seasonal variety on reclaimed native grasslands are described. Three reclaimed areas which were seeded with different mixes and managed differently were compared for cover, productivity, and frequency. Practices which enhanced seasonality are late spring seeding, irrigation, larger amounts of warm-season species in seed mixes, herbicide control of cool-season species, controlled burning in late spring, and interseeding.

Analysis of Conclusions

This paper presents state-of-the-art techniques used to establish seasonally balanced native grassland on reclaimed lands.

Title: **PRESCRIBED BURNING OF RE-ESTABLISHED GRASSLANDS ON RECLAIMED GRASSLANDS IN WESTERN NORTH DAKOTA**

Authors: M. Haupt

Organization Department of Botany, North Dakota State University, Fargo, ND

Format: Thesis

Reference: M.S. Thesis. North Dakota State University, Fargo, ND, 1985

Key Index Word Management Practices, Grassland

Brief Description:

Prescribed burning was conducted on three re-established grassland sites at the Glenharold Mine to determine the effect of fire on the diversity, cover and production of several reseeded grass species. Pre-burn physical and biological conditions were recorded in order to evaluate their influence on post-burn vegetation response. Six plots, approximately 0.10 ha in size, were located on each north and south exposure of each site. Burning date was chosen based on growth stages of western wheatgrass and sideoats grama. Burning dates included May 1, May 23, June 30, August 1, and October 23, 1983. A non-burned plot was included as a control. Basal cover, production and frequency of seeded and nonseeded species were recorded.

Analysis of Conclusions

Post-burn vegetation measurements in 1984 revealed total live basal cover, production and frequency of seeded species was the same or higher, compared to control plots, on all but August 1 burn-plots. Evaluation of pre-burn physical and biological conditions, and post-burn vegetation response, revealed that prescribed burn treatments on May 1 and May 23 produced the optimum response in vegetation cover, production and frequency while protecting topsoil from erosion.

Title: **MARGINAL WATER FOR VEGETATION ESTABLISHMENT**

Authors: R.E. Ries, F.M. Sandoval, and J.F. Power

Organization USDA-ARS Northern Great Plains Research Laboratory, Mandan, ND

Format: Abstract

Reference: Abstracts, 38th Annual Meeting, Society for Range Management, Salt Lake City, UT Feb. 11-15, 1986

Key Index Word: Irrigation, Grassland, Salinity, Sodicity

Brief Description

Medium and low quality water were applied as irrigation supplements to natural precipitation during initial establishment of perennial grass species. Response of seeded and weed species and changes in soil salinity and SAR were monitored. Production of seeded species increased while that of weed species decreased with increased amounts of water, regardless of quality. Soil salinity and SAR were minimal when water was applied for one growing season. After two growing seasons, low quality water had increased salinity and SAR; however, no adverse effects on vegetation production were observed.

Analysis of Conclusions

This study indicates the potential for supplemental irrigation with low quality water to enhance initial vegetation establishment.

Title: **SEASONALITY OF GRAZING RECLAIMED PASTURES: ANIMAL PERFORMANCE**

Authors: L. Hofmann and R.E. Ries

Organization ARS, Northern Great Plains Research, Laboratory,
Mandan, ND

Format: Proceedings

Reference: Society for Range Management 39th Annual Meeting, 1986

Key Index Word: Grazing, Animal Performance

Brief Description

Live weight gains of yearling steers grazing reclaimed pastures, dominated by smooth bromegrass and alfalfa, were compared to weight gains on adjacent unmined rangelands. Pastures were stocked at 0.93 ha/steer.

Analysis of Conclusions

Live weight gains from reclaimed pasture and native rangeland were, respectively: 65 and 64 kg/steer from June 15 to September 20; 75 and 61 kg/steer from May 25 to September 28; and 65 and 57 kg/steer from May 30 to October 3. Weight gains were equal or better on reclaimed introduced pasture as compared to native rangeland when identical stocking intensities, grazing dates, and management practices were used. Data suggest that cool-season species may be used to revegetate disturbed land designated for grazing without sacrificing animal performance.

Title: **IMPROVED PASTURE**

Authors: R.E. Ries and W.L. Stout

Organization USDA-ARS, Northern Great Plains Research Laboratory, Mandan, ND and Forage and Pasture Laboratory, University Park, PA

Format: Paper (Chapter)

Reference: Reclamation of Surface-Mined Lands, Volume II (L.R. Hossner, ed.), pp. 157-173, CRC Press, Inc., Boca Raton, FL 1988

Key Index Words Pasture, Rangeland, Revegetation, Animal Performance, Erosion, Land Use

Brief Description

This paper provides a brief review of the importance, management, and the present status of forage and animal production of improved pastures in the eastern and western U.S. Emphasis has been given on the development and management of improved pastures on reclaimed lands. Critical factors for successful establishment of pastures on mined lands have been discussed in relation to both reclamation and revegetation strategies.

Analysis of Conclusions

The information contained in this review is of much value to the coal mining industry, regulatory agencies, and plant and animal scientists. The authors have shown that forage and animal production from improved pastures established on mined lands can be equal to and in some case greater than, that from those on unmined lands, under similar management and climatic conditions. However, to establish productive pastures on reclaimed land requires that "mining and reclamation must be planned together and thought of as one goal".

Title: **IRRIGATION WATER FOR VEGETATION ESTABLISHMENT**

Authors: R.E. Ries, F.M. Sandoval, and J.F. Power

Organization USDA-ARS, Northern Great Plains Research Laboratory, Mandan, ND

Format: Paper

Reference: Journal of Range Management 41(3): 210-215, 1988

Key Index Words Revegetation, Irrigation, Sodicity, Salinity, Plant Responses, Productivity

Brief Description:

In this study, conducted at the Gascoyne Mine, the effects of supplemental irrigation with marginal quality water on the establishment of perennial forage on reclaimed land and changes in soil salinity and sodicity were evaluated. Nine combinations of various quantities of medium (EC 1; SAR 6.5) and low (EC 3.2 - 3.8; SAR 11.6 - 18.2) quality water were applied to augment soil moisture resulting from natural precipitation. The production of seeded species increased with all types of supplemental irrigation, and weed infestation decreased. Changes in soil salinity or sodicity were minimal following one season's irrigation, but when low quality water was applied for two seasons, an increase in these parameters was noted.

Analysis of Conclusions

The authors concluded that marginal quality water can be used for establishing perennial forage communities on reclaimed lands without any significant soil deterioration. This finding has practical application in the reclamation of semi-arid lands. However, research on the irrigation uses of marginal quality waters should include testing under more than one soil-plant condition and an assessment of trace elements, particularly boron, in such waters and their accumulation in the soil.

Title: **VEGETATION AND ANIMAL PRODUCTION FROM RECLAIMED MINED LAND PASTURES**

Authors: L. Hofmann and R.E. Ries

Organization USDA-ARS, Great Plains Research Laboratory, Mandan, ND

Format: Paper

Reference: Agronomy Journal 80:40-44, 1988

Key Index Words Grazing, Vegetation, Cover, Compaction, Land Use, Management Practices

Brief Description:

The objectives of this research were to study the effects of grazing intensity on standing crop vegetation, steer performance, and soil compaction; and to determine which vegetation measurement method would best reflect the response of cool-season pastures to grazing. Research was conducted near Center, North Dakota over a 5-year period. Pastures were divided into ungrazed, lightly grazed, moderately grazed and heavily grazed treatments. Reclaimed grasslands did not deteriorate with 50% or less total vegetation removal in early summer. Vegetation production and steer gain were highest on lightly grazed plots. Heavily grazed areas resulted in an increase in invader species. Grazing did not measurably affect soil bulk density in the top 150 mm, however, soil compaction increased with grazing intensity. Ground cover was effectively measured using either basal or aerial hits with the ten-point frame.

Analysis of Conclusions

This 5-year study of the effects of grazing intensities on steer performance, vegetation, and soil compaction provides much valuable data on the management and productive use of reclaimed lands in North Dakota. The study showed that assessment of ground cover adequacy for erosion control by point frame method can be made as reliably by using surface hit bar-ground cover estimates as by the first hit estimates of vegetation itself.

Title: **DIVERSITY AND SEASONAL VARIETY IN RECLAIMED NATIVE GRASSLANDS**

Authors: D.J. Nilson and K.J. Hirsch

Organization Basin Electric Power Cooperative, Glenharold Mine, Stanton, ND, and Public Service Commission, Bismarck, ND

Format: Paper

Reference: Proceedings of the Conference "Reclamation, A Global Perspective," (D.G.Walker, C.B.Powter and M.W. Pole, eds.) pp. 263-277, Calgary, Alberta, August 1989

Key Index Words Grassland, Seasonality, Revegetation Management Practices

Brief Description:

Production and cover data from a 216 ha reclamation area were collected between 1982 and 1988 to determine revegetation success and evaluate several grassland establishment and management practices. Data presented in this paper show that choice of seed mixture, seeding date, glyphosate (Roundup) herbicide treatments, and use of native hay mulch can affect species composition, diversity and productivity of reclaimed grasslands.

Analysis of Conclusions

North Dakota reclamation laws and rules require that reclaimed native grasslands be diverse, effective and permanent and of the same seasonal variety native to the area. This paper presents innovative management techniques that have been effective in achieving those standards.

Title: **WOODLAND RECLAMATION WITHIN THE MISSOURI BREAKS IN WEST CENTRAL NORTH DAKOTA**

Authors: D.J. Nilson

Organization Basin Electric Power Cooperative, Glenharold Mine, Stanton, ND

Format: Paper

Reference: Proceedings of the Conference "Reclamation, A Global Perspective," (D.G.Walker, C.B.Powter and M.W. Pole, eds.) pp. 345-355, Calgary, Alberta, August 1989

Key Index Words Woody Draws, Shrub Establishment

Brief Description:

This paper discusses the restoration of woody draws along the Missouri breaks at the Glenharold Mine. Natural woody draws in this geographic area usually occur in the drainages and hillsides and consist of shrub and mixed deciduous communities. Restoration of these sites requires reclamation techniques to create areas with geomorphology and slope aspect that maximize plant available water necessary for establishing woody vegetation. All the management methods that have led to the establishment of self perpetuating woodland systems at this mine are discussed.

Analysis of Conclusions

Woody draws are critical wildlife habitat in western North Dakota. This paper presents valuable reclamation and management strategies that have proven successful in reestablishing these woodland areas.

Title: **PROMISING NATIVE FORBS FOR SEEDING ON MINE SPOILS**

Authors: A.J. Bjugstad and W.C. Whitman

Organization USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Rapid City, SD and North Dakota State University, Fargo, ND

Format: Paper

Reference: Proceedings of the Conference "Reclamation, A Global Perspective," (D.G. Walker, C.B. Powter and M.W. Pole, eds.) pp. 255-262, Calgary, Alberta, August 1989

Key Index Words Revegetation, Shrub Establishment, Species Selection, Plant Responses, Pioneer Species

Brief Description:

Thirty one forb species were planted into minespoil near Dickinson, ND to determine which species would be most successful. Seed germination was tested using several different storage treatments. Plant height comparisons were made between seeded and transplanted plants. Several species showed exceptionally good emergence and vigorous growth.

Analysis of Conclusions

Although grazing systems are usually focused around grassy species, the forb component is also important, especially for wildlife. This paper gives valuable information on the pioneer species that can rehabitate mine spoils during early successional stages.

Title: **ANIMAL PERFORMANCE AND PLANT PRODUCTION FROM CONTINUOUSLY GRAZED COOL-SEASON RECLAIMED AND NATIVE PASTURES**

Authors: L. Hofmann and R.E. Ries

Organization USDA-ARS, Northern Great Plains Research Laboratory, Mandan, ND

Format: Paper

Reference: Journal of Range Management 42: 248-251, 1989

Key Index Words Revegetation, Pasture, Seasonality, Species Selection, Land Use

Brief Description

The objective of this study was to compare season-of-grazing use of reclaimed pastures comprised of introduced cool-season species with undisturbed rangeland pastures supporting native warm- and cool-season species. The study was conducted at the Center Mine over a period of 5 years, and data on vegetation cover and production and live weight gain of steers under various grazing intensities were collected. No differences were noted in the season-of-grazing use between the reclaimed cool-season pastures and the native mixed prairie. There was no evidence that species with the same growing season as those native to the area were necessary to provide season-long grazing use.

Analysis of Conclusions

The authors claim that since cool-season species are readily established, easier to seed, less expensive, and provide similar season-long grazing use as a mixture of warm- and cool-season species, there is no need to have a warm-season species component or prairie type of species diversity on reclaimed lands to provide comparable seasonal grazing. This conclusion has a significant bearing on some of the regulatory requirements for revegetation.

Title: **DROUGHT EFFECTS ON PLANT DIVERSITY OF RECLAIMED GRASSLANDS IN WESTERN NORTH DAKOTA**

Author: L. Frarck, K. Krabbenhoft, D. Kirby, and D. Nilson

Organization: NDSU-Animal & Range Science Department, Fargo, and Basin Cooperative Services, Glenharold Mine, Stanton, ND

Format: Paper

Reference: In: Proceedings of the 9th Annual National Meeting of the American Society for Surface Mining and Reclamation. pp 304-313, Duluth, Minnesota, June 1992

Key Index Words: Soil Replacement, Topoedaphic Unit, Alpha Diversity, Productivity, Cover

Brief Description

Effects of drought on plant diversity of reclaimed and undisturbed grasslands at the Glenharold Mine were studied. Species diversity of a reclaimed silty site was determined over a period of 1983-90. The period of 1988-90 was droughty. Drought had no effect on species diversity. However, on reclaimed grasslands, drought tended to diminish localized plant diversity. Effects on alpha-, beta-, and mosaic diversity are discussed

Analysis of Conclusions

This study is important in that it addresses the question of plant diversity on reclaimed lands in a broader context, namely alpha-, beta-, and mosaic diversity, and informs us as to what might happen to vegetation diversity during droughty periods. This type of study needs to be conducted at other mine sites as well.

Title: **IMPORTANCE OF POST-DISTURBANCE LAND USES TO RECLAMATION/RESTORATION SUCCESS**

Author: R.E. Ries

Organization: USDA-ARS Northern Great Plains Research Laboratory, Mandan, ND

Format: Paper

Reference: Proceedings of the 9th Annual National Meeting of the American Society for Surface Mining and Reclamation. pp 651-656, Duluth, Minnesota, June 1992

Key Index Words: Revegetation, Environmental Factors, Reclamation Success

Brief Description

In this scholarly presentation the author emphasizes that the potential, long term success of any reclamation or restoration is limited by the purported end use of the disturbed ecosystem. And the end use must be in harmony with the topographic, climatic and edaphic characteristics of that ecosystem. However, outside resource inputs may to an extent sustain uses that are not in total harmony with the ecosystem. If the natural ecological process is allowed to reclaim/rehabilitate a disturbed site, then there is little need to define when and what constitutes successful reclamation. But, where success of reclamation must be evaluated, the parameters of evaluation are determined by the end use.

Analysis of Conclusions

The thoughts expressed in this paper are worth taking into account when formulating a policy and methodology for evaluation of reclamation success. To a large extent this has been done. Also, the aptness of the argument: success need not be evaluated if reclamation has been allowed by natural ecological process, is clear when considering the reclamation of abandoned mines.

Title: **TRANSPLANTING AND ESTABLISHMENT OF WESTERN SNOWBERRY (*Symphoricarpos occidentalis* Hook.) ON RECLAIMED LAND**

Authors: J.D. Friedlander

Organization The Coteau Properties Company, Freedom Mine, Beulah, ND

Format: Paper

Reference: Decades Later: A Time for Reassessment, Proceedings of 12th National ASSMR Meeting, pp. 779-795, Laramie, WY, 1995

Key Index Words Revegetation, Shrub Establishment, Soil Moisture

Brief Description:

Described are the results of an attempt to reestablish western snowberry on reclaimed prairie grassland at the Freedom Mine. Shrub patches from an undisturbed area were removed with tractor and placed in two low drainage landscape sites. No management treatments were applied. Establishment and success of the replanted shrubs was most affected by October-July precipitation.

Analysis of Conclusions

The author cautions that special consideration should be given to site location and moisture conditions when transplanting western snowberry. This study may prove useful to other mines also.

Title: **EVALUATING THE SUCCESS OF RECLAIMED GRASSLANDS**

Author: D.R. Kirby

Organization: NDSU-Animal & Range Science Department, Fargo, ND

Format: Executive Summary

Reference: Report on Contract No. LRC-X-37, 12p, February 1, 1996

Key Index Words: Soil Replacement, Topoedaphic Unit, Alpha Diversity, Productivity, Cover

Brief Description

The stated objective of this research was to "provide a long-term data base upon which to evaluate grassland reclamation success and the regulations determining that success." Reclaimed and undisturbed grasslands at the Glenharold, Center, Indian Head, and Freedom were sampled for soil and vegetation characterization. The discussion in the report is focused on silty sites only. Soil characteristics studied included topographic position, soil depth, bulk density, SP, SAR, and EC. Vegetation analyses included yield, cover and alpha diversity. Herbaceous yield, cover, or diversity were found poorly correlated to the replaced soil depth. Topoedaphic land units were identified, using stepwise multivariate analysis on soil physical, chemical and topographic information, and proposed as a classification system for reclaimed lands. A major conclusion of the study was that replaced soil thicknesses lesser than those required by the North Dakota rules may be adequate for meeting the required revegetation standards. Replacement of 24 inches of SPGM over average quality spoil was considered as adequate for all topographic locations.

Analysis of Conclusions

The assumption made in this report that meeting 90 percent of the standard (as required by the federal rules and not the state rules) would be considered as successful revegetation in North Dakota is not correct. Otherwise, the study is quite important and significant for the lignite industry and the regulatory agency to determine if any changes in the SPGM replacement requirements are needed.

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WILDLIFE AND WETLANDS (WL)

Title: **THE USE OF THE AIRPLANE IN WILDLIFE HABITAT IMPROVEMENT**

Author: R.N. Bach

Organization: North Dakota State Game and Fish Department, Bismarck ND

Format: Report

Reference: North Dakota State Game and Fish Department, Division of Federal Aid, Project 7R, 1945

Key Index Words: Wildlife Habitat, Revegetation, AML

Brief Description

This report evaluates the preliminary results of aerial plantings tested near the Wilton Mine (McLean and Burleigh Counties, ND) in the spring of 1945.

Analysis of Conclusions

This is one of the earliest attempts at aerial planting made at an abandoned mined land in North Dakota.

Title: **THE USE OF THE AIRPLANE IN WILDLIFE HABITAT IMPROVEMENT**

Author: R.W. Stuart

Organization: North Dakota State Game and Fish Department, Bismarck ND

Format: Report

Reference: North Dakota State Game and Fish Department, Division of Federal Aid, Project 7R, 1947

Key Index Words: Wildlife Habitat, Revegetation, AML

Brief Description

This report provides a brief description of the techniques used in aerial planting around the Wilton Mine in the year 1946

Analysis of Conclusions

This is one of the earliest attempts at aerial planting made at an abandoned mined land in North Dakota.

Title: **A PRELIMINARY SURVEY AND PROPOSED DEVELOPMENT PLAN FOR WILTON MINE GAME MANAGEMENT AREA**

Author: C.R. Odin

Organization: North Dakota State Game and Fish Department, Bismarck, ND

Format: Report.

Reference: North Dakota State Game and Fish Department, Pittman-Robertson Division, Project W-39-R-2, 1955

Key Index Words: Wildlife Habitat, AML

Brief Description

This report discusses the results of a survey that was conducted during the summer and fall of 1954 to initiate a plan for future reclamation and development of Wilton Mine Game Management area (Burleigh and McLean counties, ND).

Analysis of Conclusions

The information provided in this report should be useful for the reclamation of abandoned mine lands.

Title: **DEVELOPMENT AND EVALUATION OF CUSTER MINE GAME MANAGEMENT AREA, 1955-1956**

Author: W. Boldt

Organization: North Dakota State Game and Fish Department, Bismarck, ND

Format: Report

Reference: North Dakota State Game and Fish Department, Pittman-Robertson Division, Project W-39-R-3, Job 3., 1957

Key Index Words: Revegetation, AML, Wildlife Habitat

Brief Description

This report discusses the results of some reclamation work conducted at the Custer Mine, near Garrison, ND, by the State Game and Fish Department during 1955 and 1956. The reclamation operations at this abandoned mine included spoil leveling, tree and shrub planting, and habitat evaluation.

Analysis of Conclusions

This study is relevant to abandoned mine land program in North Dakota.

Title: **DEVELOPMENT AND EVALUATION OF CUSTER MINE GAME MANAGEMENT AREA, 1956-1957**

Author: G.W. Enyeart

Organization: North Dakota Game and Fish Department, Bismarck, ND

Format: Report

Reference: North Dakota Game and Fish Department, Pittman-Robertson Division, Project W-37-R-4, Job 3, 1957

Key Index Words: Revegetation, Wildlife Habitat, AML

Brief Description

Tree and shrub planting methods, vegetation counts, and evaluation of planting success are included in this progress report of the reclamation effort at the Custer Mine, six miles east of Garrison, ND. The reclamation work was conducted by the State Game and Fish Department during 1956 and 1957.

Analysis of Conclusions

The information contained in this report should be useful for the reclamation of abandoned mine lands.

Title: **A PRELIMINARY SURVEY AND PROPOSED DEVELOPMENT PLAN FOR CUSTER MINE GAME MANAGEMENT AREA**

Author: C.R. Odin

Organization: North Dakota Game and Fish Department, Bismarck, ND

Format: Report

Reference: North Dakota Game and Fish Department, Pittman-Robertson Division, Project W-39-R-2, 1957

Key Index Words: Wildlife Habitat, AML, Revegetation

Brief Description

This report contains the preliminary findings of the Game and Fish Department at the Custer Mine, six miles east of Garrison, ND. A spoilbank slope survey and a vegetation inventory were conducted in the summer and fall of 1954. Soil samples for laboratory analysis were also collected. Recommendations are made as to the direction the reclamation of this area should take.

Analysis of Conclusions

The information contained in this report should be useful for the reclamation of abandoned mine lands.

Title: **ANNUAL PROGRESS REPORT OF CUSTER MINE GAME MANAGEMENT AREA (LIGNITE SPOIL PILES)**

Author: G.W. Enyeart

Organization: North Dakota Game and Fish Department, Bismarck, ND

Format: Report

Reference: North Dakota Game and Fish Department, Pittman-Robertson Division, Project W-39-R-5, Job 8, 1958

Key Index Words: Revegetation, Wildlife Habitat, AML

Brief Description

Tree and shrub planting methods, vegetation counts and evaluation of planting success are included in this progress report of the reclamation effort at the Custer Mine, near Garrison, ND. The reclamation work was conducted by the State Game and Fish Department during 1957 and 1958.

Analysis of Conclusions

The information contained in this report should be useful for the reclamation of abandoned mine land.

Title: **DEVELOPMENT AND EVALUATION OF CUSTER MINE GAME MANAGEMENT AREA**

Author: G. James

Organization: North Dakota Game and Fish Department, Bismarck, ND

Format: Report

Reference: North Dakota Game and Fish Department, Pittman-Robertson Division, Project W-39-R-6, Job 3, 1960

Key Index Words: Wildlife Habitat, AML, Revegetation

Brief Description

Tree and shrub planting methods, vegetation counts, and evaluation of planting success are included in this progress report of the reclamation effort at Custer Mine, six miles east of Garrison, ND. The reclamation work was conducted by the State Game and Fish Department during 1958 and 1959.

Analysis of Conclusions

The information provided in this report should be useful for the reclamation of abandoned mine lands.

Title: **RECLAIMING STRIP MINED LANDS IN NORTH DAKOTA BY ESTABLISHING GAME MANAGEMENT AREAS.**

Author: T.A. Gwynn

Organization: Knife River Coal Mining Company, Bismarck, ND

Format: Report

Reference: Knife River Coal Mining Company Progress Report, 41 p., January 1965

Key Index Words: Revegetation, Spoil Properties, Wildlife Habitat

Brief Description

This is a progress report discussing the techniques and success of reclamation efforts involving soil tests and spoil analyses, experimental planting, and habitat evaluation. The reclamation work reported took place from 1963 through 1964 at Knife River Coal Company's North Beulah and South Beulah mines in North Dakota, and was conducted in cooperation with the various state and federal agencies.

Analysis of Conclusions

This information on pre-law reclamation techniques may be useful for revegetation of abandoned mined lands.

Title: **A PROGRESS REPORT - RECLAIMING STRIP MINED LAND BY ESTABLISHING GAME MANAGEMENT AREAS**

Author: T.A. Gwynn

Organization: Knife River Coal Mining Company, Bismarck, ND

Format: Report

Reference: Knife River Coal Mining Company Progress Report, 27 p., July 1966

Key Index Words: Revegetation, Wildlife Habitat

Brief Description

This progress report discusses the techniques and success of reclamation efforts involving experimental leveling, tree, crop and grass planting, and habitat evaluation. The reclamation work was conducted from 1963 to 1966 at the North Beulah, South Beulah, Wilton, Underwood, and Gascoyne mining areas of North Dakota and the Savage Mine in Montana. Wildlife moving into planted areas was causing some damage to the trees, but willows seemed to be spreading enough to give extensive browsing for deer.

Analysis of Conclusions

This information on pre-law reclamation techniques may be useful for revegetation of abandoned mined lands.

Title: **CLASSIFICATION OF NATURAL PONDS AND LAKES IN THE GLACIATED PRAIRIE REGION**

Authors: R.E. Stewart and H.A. Kantrud

Organization: Northern Prairie Wildlife Research Center, Division of Wildlife Research, U.S. Fish and Wildlife Service, Jamestown, ND

Format: Report

Reference: Bureau of Sport Fisheries and Wildlife Resource Publication 92, 1971

Key Index Words: Wetlands, Prairie Potholes, Vegetation, Water Quality, Wildlife

Brief Description

This is the guide by which wetlands in the Prairie Pothole Region are classified. Seven "classes" are denoted. These include ephemeral ponds (Class I), temporary ponds (Class II), seasonal ponds and lakes (Class III), semipermanent ponds and lakes (Class IV), permanent ponds and lakes (Class V), alkali ponds and lakes (Class VI) and fen (alkali bog) ponds (Class VII). These classes may be further subdivided into subclasses based on average salinity of surface water. These subclasses are fresh (Subclass A), slightly brackish (Subclass B), moderately brackish (Subclass C), brackish (Subclass D) and subsaline (Subclass E). Vegetative cover may be used to further characterize a wetland.

Analysis of Conclusions

The question of what constitutes a reclaimed wetland is still open for discussion. The use of this classification standard will help wetland specialists to relate what is reclaimed to what occurs naturally.

Title: **VEGETATION OF PRAIRIE POTHOLES, NORTH DAKOTA, IN RELATION TO QUALITY OF WATER AND OTHER ENVIRONMENTAL FACTORS**

Authors: R.E. Stewart and H.A. Kantrud

Organization: U.S. Bureau of Sport Fisheries and Wildlife in collaboration with the U.S. Geological Survey

Format: Paper

Reference: Geological Survey Professional Paper 585-D, 1972

Key Index Words: Wetlands, Prairie Potholes, Vegetation, Water Quality

Brief Description

Salinity and water permanence are the primary factors which control the type and extent of wetland vegetation associated with prairie potholes in North Dakota. Vegetation typically occurs in concentric bands around and within these wetlands. Vegetational types include low-prairie, wet-meadow, shallow-marsh emergent, deep-marsh emergent, fen emergent, submerged and floating, natural drawdown, cropland drawdown, and cropland tillage vegetation.

Analysis of Conclusions

This is the classic treatise on wetland vegetation associated with prairie potholes. The proposition that salinity and water permanence are the principal contributing factors to wetland vegetative establishment is of penultimate significance in the contemplated design of reclaimed wetlands.

Title: **AQUATIC INVERTEBRATES AND WATER CHEMISTRY OF STRIP MINE IMPOUNDMENTS IN WESTERN NORTH DAKOTA**

Author: D.L. Batema

Organization: University of North Dakota, Grand Forks, ND

Format: M.S. Thesis

Reference: M.S. Thesis, Biology Department, University of North Dakota, Grand Forks, ND, 1979

Key Index Words: Wetlands, Impoundments, Water Quality, Trace Elements, Fauna

Brief Description

The chemical and biological properties of mine impoundments (ponds) in Mercer County, ND were studied. Samples of water, bottom sediments and the spoil surrounding the ponds were analyzed for twenty-seven (27) chemical variables. Invertebrate species were identified and their biomass and diversity measured. The water in the mine impoundments was relatively high in sodium and sulfate ions, but their levels were within the normal range for alkaline ponds in North Dakota. No trace element problems were noted. The common phyla in these ponds were Mollusca and Arthropoda. The class insecta comprised about 10% of all species identified.

Analysis of Conclusions

This study revealed that the chemical composition in the mine impoundments studied was not drastically different than what is found in many alkaline ponds in North Dakota. No heavy metal toxicity problems were reported. The conclusion drawn was that ponds on surface mined lands will tend to resemble naturally occurring ponds, both chemically and biologically, within a few years.

Title: **ECOLOGY OF WETLAND VEGETATION ON SELECTED STRIP MINE PONDS AND STOCKDAMS IN THE NORTHERN GREAT PLAINS**

Author: R.A. Olson

Organization: Department of Botany, North Dakota State University, Fargo, ND

Format: Ph.D. Dissertation

Reference: Ph.D Dissertation, North Dakota State University, Fargo, ND, 1979

Key Index Words: Wetlands, Vegetation, Impoundments, Stockdams

Brief Description

Wetland plant communities of strip mine ponds and stockdams were studied through intense field sampling during 1976-1978. Floristically, stockdams were richer with 106 vascular plant species identified in 28 families compared to 76 species in 20 families from strip mine ponds. The magnitude of summer drawdown and basin slope are major factors determining wetland community attributes.

Analysis of Conclusions

This study confirms the importance of pond morphometry as a primary factor to enhance the potential for wetland vegetation reestablishment. This seminal study on the reasons for wetland plant community development on mine sites has had a strong bearing on the engineering design of proposed reclaimed wetlands.

Title: **AQUATIC HABITAT OF WETLANDS, PONDS, AND LAKES OF SEMIARID REGIONS: AN ANNOTATED BIBLIOGRAPHY OF SELECTED LITERATURE**

Author: C.L. Hawkes

Organization: Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service, Rapid City, SD

Format: Report

Reference: NTIS PB81 131 682, 1980

Key Index Words: Wetlands, Vegetation, Wildlife Habitat, Fish

Brief Description

This bibliography was prepared to meet the needs of both research and management groups interested in developing water quality guidelines and design and management requirements for water impoundments in strip mine areas in the Northern Great Plains. Emphasis in selecting literature was placed on the following topics: water quality, rooted aquatic and wet meadow vegetation, phytoplankton, zooplankton, waterfowl, fish, other wildlife, and design and management of impoundments and associated plants and animals.

Analysis of Conclusions

Annotated bibliographies are extremely useful tools for both the experienced and beginning wetland reclamation specialist. Several citations within this particular report deal with work conducted in North Dakota.

Title: **BREEDING BIRDS OF NATURAL WOODLAND, SHELTERBELTS AND ORPHAN MINE SPOILS IN SOUTHWESTERN NORTH DAKOTA**

Author: G.A. Hiemenz

Organization: North Dakota State University

Format: M.S. Thesis

Reference: M.S. Thesis, Department of Zoology, North Dakota State University, Fargo, ND, 38 p., 1981

Key Index Words: Fauna, AML, Wildlife Habitat

Brief Description

Thirty-nine breeding birds were recorded within selected natural woodlands, tree plantings and mine spoils in southwestern North Dakota. Hardwood draws exhibited the highest number of breeding birds, followed by shelterbelts, mine spoils, and prairie. The prairie area served as a control area. Bird species diversity and density were correlated with foliage height, diversity and total vegetation cover.

Analysis of Conclusions

This study indicates why foliage diversity and cover are important parameters for wildlife diversity. These results support the current regulatory emphasis on the reestablishment of both tree diversity and herbaceous cover for wildlife use.

Title: **A HANDBOOK FOR MEETING FISH AND WILDLIFE INFORMATION NEEDS TO SURFACE MINE COAL**

Authors: C.R. Hinkle, R.E. Ambrose, and C.R. Wenzel

Organization: Science Applications, Inc, Oak Ridge, TN, for the Office of Surface Mining and Office of Biological Services, Washington, D.C.

Format: Reference Handbook

Reference: FWS/OBS 79/48.3.5, February 1981

Key Index Words: Wildlife Habitat, Fish

Brief Description

This handbook contains information that will assist people in protecting, enhancing, and reducing impacts to fish and wildlife resources during the surface mining of coal. It specifically gives information pertaining to consideration of fish and wildlife resources in the pre-mining, mining, reclamation, and compliance phases of surface mining. Several appendices provide information on agency contacts, technical references, and sources of plant materials for revegetation.

Analysis of Conclusions

The contextual elements of a fish and wildlife plan are presented complete with examples. This handbook would be useful to coal companies which are planning a wildlife inventory for a life-of-mine operation.

Title: **WETLAND HYDROLOGY: STATE-OF-THE-ART AND ANNOTATED BIBLIOGRAPHY**

Author: J.A. Leitch

Organization: Agricultural Experiment Station, North Dakota State University, Fargo, ND

Format: Report

Reference: North Dakota Research Report No. 82, July 1981

Key Index Words: Hydrology, Wetlands, Bibliography

Brief Description

This paper reviews the literature on the hydrologic aspects of prairie potholes and suggests areas of needed research. Five areas discussed are: 1) flood control, 2) erosion control, 3) sediment entrapment, 4) groundwater recharge, and 5) water supply. Additionally, an annotated bibliography is provided.

Analysis of Conclusions

Since probable hydrologic consequences (PHC) are of paramount importance as justification for the reestablishment of wetlands, this report is particularly useful as a background text.

Title: **SOILS, MICROBIOLOGY, AND CHEMISTRY OF PRAIRIE WETLANDS: RESEARCH METHODS AND ANNOTATED BIBLIOGRAPHY**

Author: L.A. Ogaard

Organization: Agricultural Experiment Station, North Dakota State University, Fargo, ND

Format: Report

Reference: North Dakota Research Report No. 84, July 1981

Key Index Words: Microbiology, Wetlands, Bibliography

Brief Description

The broad topics of wetland soils, wetland microbiology, and wetland chemistry are briefly discussed. Potential research and the methods one might employ to implement this research are provided along with a selected annotated bibliography.

Analysis of Conclusions

This report underscores the paucity of information regarding the soils, microbiology, and chemistry of prairie pothole wetlands. This is a background text for the wetland reclamation specialist.

Title: **WETLAND VEGETATION OF THE PRAIRIE POTHOLE REGION: RESEARCH METHODS AND ANNOTATED BIBLIOGRAPHY**

Author: L.A. Ogaard

Organization: Agricultural Experiment Station, North Dakota State University, Fargo, ND

Format: Report

Reference: North Dakota Research Report No. 85, July 1981

Key Index Words: Vegetation, Wetlands, Prairie Potholes, Bibliography

Brief Description

Primary production, nutrient cycling and plant distribution are topics briefly addressed in this report. Both the methods to measure these phenomena and suggested basic research needs are presented. An annotated bibliography surveys literature germane to the Prairie Pothole Region.

Analysis of Conclusions

For the neophyte in wetland vegetation this document provides an overview of past and potential research. The literature survey is a starting point on which to base a wetland reclamation plan.

Title: **THE FAUNA OF THE PRAIRIE WETLANDS: RESEARCH METHODS AND ANNOTATED BIBLIOGRAPHY**

Author: L.A. Ogaard

Organization: Agricultural Experiment Station, North Dakota State University, Fargo, ND

Format: Report

Reference: North Dakota Research Report No. 86, July 1981

Key Index Words: Wetlands, Fauna, Bibliography

Brief Description

The subjects of waterfowl, non-game birds, mammals and poikilothermic vertebrates and invertebrates are briefly addressed. An annotated bibliography of selected published literature in support of these and other wetland related topics is provided.

Analysis of Conclusions

This is an overview of the types of animals associated with prairie wetlands. This could be a general guide to what fauna one could potentially expect on reclaimed wetlands.

Title: **SOCIOECONOMIC VALUES OF WETLANDS: CONCEPTS, RESEARCH METHODS, AND ANNOTATED BIBLIOGRAPHY**

Author: J.A. Leitch

Organization: Agricultural Experiment Station, North Dakota State University, Fargo, ND

Format: Report

Reference: North Dakota Research Report No. 81, August 1981

Key Index Words: Wetlands, Bibliography

Brief Description

This report presents concepts and methods associated with estimating wetland values, and a selected, annotated bibliography in the area of socioeconomics. Three research projects are suggested as part of an overall, comprehensive systems approach to the question of wetland valuation.

Analysis of Conclusions

Although the contents of this report have little bearing on the physical and biological reclamation of wetlands, the "value" of a wetland has a profound influence on whether that wetland will be reclaimed. The concepts presented could further bolster the commitment to reclaim wetlands from the standpoint of both private industry and the state regulatory agency.

Title: **WETLAND FORAGE: IMPORTANCE IN A DROUGHT YEAR**

Author: L.A. Ogaard

Organization: Department of Agricultural Economics, North Dakota State University, Fargo, ND

Format: Report

Reference: NDSU-Agricultural Economics Miscellaneous Report No. 36, 1981

Key Index Words: Wetlands, Drought

Brief Description

A telephone survey of farmers and ranchers was conducted in early 1981 to assess the importance of wetland forage to these agriculturists during a drought, the summer of 1980. Conclusions drawn included: 1) most farmers using wetland hay would experience financial loss in very dry years if it were not available, 2) the magnitude of loss would be highly variable, 3) a significant amount of wetland hay was harvested in the 1980 drought, 4) most of the respondents did not intend to drain their wetlands, and 5) the per acre value of this wetland hay (total replacement value divided by total acres harvested) came to $64.44.

Analysis of Conclusions

Wetlands provide a multiplicity of uses. One such use is hayland. This study confirms the importance of this forage source to agriculturists during a dry year. This is a potential value accrued to a surface owner when wetlands are reclaimed.

Title: **PRACTICES FOR PROTECTING AND ENHANCING FISH AND WILDLIFE ON COAL SURFACE MIND LAND IN THE POWDER RIVER - FORT UNION REGION**

Authors: B.R. Proctor, R.W. Thompson, J.E. Bunin, K.W. Fucik, G.R. Tamm, and E.G. Wolf

Organization: Science Applications, Inc., for Western Energy Land Use Team (WELUT), U.S. Fish and Wildlife Service in cooperation with Bureau of Mines

Format: Handbook

Reference: FWS/OBS-83/10, 1983

Key Index Words: Wildlife, Mining Impacts

Brief Description

This handbook for mid-level managers, field inspectors and mine reclamation specialists was written to identify the points at which fish and wildlife resources can be protected and enhanced on a regional basis during the various phases of mine development and reclamation.

Analysis of Conclusions

This document is a practical guide by which fish and wildlife resources may be protected and enhanced during coal mining activities. This would be a useful tool to assist mining companies in the preparation of wildlife management plans.

Title: **THE IMPORTANCE OF RIPARIAN VEGETATION COMMUNITIES IN COLORADO, MONTANA, WYOMING, AND NORTH DAKOTA**

Author: S.A. Young

Organization: Reclamation Research Unit, Montana State University, Bozeman, MT

Format: Paper

Reference: Proceedings of the Coal Development Workshops, Grand Junction, CO and Casper, WY, Vol.II, pp. 1087-1164, July 1983

Key Index Words: Riparian Vegetation, Surface Water, Groundwater

Brief Description

Riparian vegetation associated with North Dakota wetlands, wet meadows, subirrigated and overflow sites, saline lowlands, and the Missouri River are characterized. The author indicates that riparian zones are particularly sensitive to disturbance and are unique from a reclamation standpoint because of their association with surface and/or groundwater systems.

Analysis of Conclusions

This paper emphasizes the importance of surface and/or groundwater to the reclamation of riparian vegetation. The "groundwater connection" may take a long time to establish, and this time delay may or may not impinge on the reclamation process of riparian vegetation. The importance of adequate water supply to the vitality of wetlands is a strong consideration in reconstructing watersheds of sufficient size to "fuel" the reclaimed wetland.

Title: **CLASSIFYING AQUATIC RESOURCES: A QUANTITATIVE APPROACH**

Author: M.A. Rumble

Organization: Rocky Mountain Forest and Range Experiment, South Dakota School of Mines and Technology, Rapid City, SD

Format: Paper

Reference: Proceedings of the Third Biennial Plains Aquatic Research Conference, Bozeman, MT, pp. 89-99, August 1983

Key Index Words: Wetlands, Water Quality

Brief Description

Twenty-seven water quality parameters from forty-one (41) coal and bentonite surface mine and livestock ponds were used to show how quantitative, multivariate procedures could be used to classify aquatic resources. Several sites were located within North Dakota. Data was subjected to polar ordination to define the groups of ponds based on water quality criteria, followed by analysis of variance and discriminant analysis to estimate the classification functions and coefficients.

Analysis of Conclusions

This approach to wetland classification is based on water quality parameters. The dynamic nature of the chemical milieu in wetlands suggests a given wetland could possibly be classified several ways based on the season, rainfall, etc. The utility of this quantitative classification system may be somewhat limited for reclamation work in North Dakota.

Title: **PRAIRIE POND MORPHOMETRY AND AQUATIC PLANT ZONATION - NORTHERN HIGH PLAINS**

Authors: A.J. Bjugstad, M.A. Rumble, R.A. Olson, AND W.T. Barker

Organization: U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station, Rapid City, SD

Format: Paper

Reference: Proceedings of Third Biennial Plains Aquatic Research Conference, Bozeman, MT, pp. 101-111, August 1983

Key Index Words: Wetlands, Vegetation, Pond Morphometry

Brief Description

Wetland plant communities were distributed in narrow, concentric bands around pre-law strip mine pond margins, compared to larger, more complex, mosaic patterns on livestock ponds.

Analysis of Conclusions

This paper confirms the importance of pond morphometry to enhance the potential for wetland vegetative reestablishment on reclaimed wetlands.

Title: **ROOTED AQUATIC PLANT REVEGETATION OF STRIP MINE IMPOUNDMENTS IN THE NORTHERN GREAT PLAINS**

Authors: G.W. Fulton, W.T. Barker, and A.J. Bjugstad

Organization: Department of Botany, North Dakota State University, Fargo, ND, Rocky Mountain Forest and Range Experiment Station, Rapid City, SD

Format: Paper

Reference: Proceedings of Third Biennial Plains Aquatic Research Conference, Bozeman, MT, pp. 113-117, August 1983

Key Index Words: Revegetation, Impoundments, Wetlands

Brief Description

Twelve species of emergent aquatic plants were successfully transplanted on shorelines of two abandoned strip mine ponds in North Dakota. Three planting techniques (pots, plugs, sprigs) compared planting labor to plant injury. A year after planting, survival was highest in pots, followed by plugs and sprigs. Survival decreased with increasing water depth for all techniques and species. Two years after planting, all plots had increased in area by vegetative spreading. Area occupied was influenced by interactions of species, planting technique, initial survival, water depth, slope, soil erosion/deposition, and soil texture.

Analysis of Conclusions

This is the only published study in North Dakota to date which addresses the question of transplanted aquatic vegetation. A follow-up study which compares naturally revegetated sites with those artificially assisted would confirm the efficacy of transplanting on reclaimed wetlands.

Title: **POTENTIAL FOR ENHANCING NON GAME BIRD HABITAT VALUES ON ABANDONED MINE LANDS OF WESTERN NORTH DAKOTA**

Authors: J.B. Burley and R.B. Hopkins

Organization: North Dakota State University, Fargo, ND

Format: Paper

Reference: Proceedings of Symposium on Surface Mining, Hydrology, Sedimentology, and Reclamation, Lexington, KY, 1984

Key Index Words: Wildlife Habitat, AML

Brief Description

Twelve measures are defined which could create potentially more diverse habitat for non game avifauna.

Analysis of Conclusions

Selected measures proposed to enhance abandoned mine sites for wildlife usage could also apply to contemporaneous mining where wildlife habitat is the primary or secondary land use. For example, the strategic placement of rock piles and snags could diversify the wildlife habitat while concomitantly supporting a rangeland land use.

Title: **ESTABLISHING A BALANCE IN RECLAMATION AND THE CREATION OF WILDLIFE HABITAT**

Authors: J. D. Friedlander

Organization: Coteau Properties Company, The Freedom Mine, Beulah, ND

Format: Paper

Reference: Land and Water: 15-19, November/December 1993

Key Index Words: Wildlife Habitat, Land Use, Revegetation

Brief Description

The Freedom Mine's efforts to create a balanced blend of , postmining land uses is discussed. The locally inherent conflict between production agriculture and wildlife land uses is resolved with careful planning, landowner consent, and maximization of the value of wildlife habitats. Designing and developing wildlife habitats such as wetlands, rockpiles, waterfowl nesting islands in sedimentation ponds, and shrub and tree communities are done with an eye to the future.

Analysis of Conclusions

This paper serves to affirm that balancing of interests between production agriculture and wildlife postmining land uses Is not an impossible task. Landowners whose first preference may be to return mined lands to purely agricultural land uses do see the importance of developing wildlife habitats where such habitats are dictated by ecological necessity and do not diminish the economic value of their land.

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