RECLAMATION RESEARCH IN NORTH DAKOTA

PART A

RESEARCH PROJECTS AND NEEDS

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.