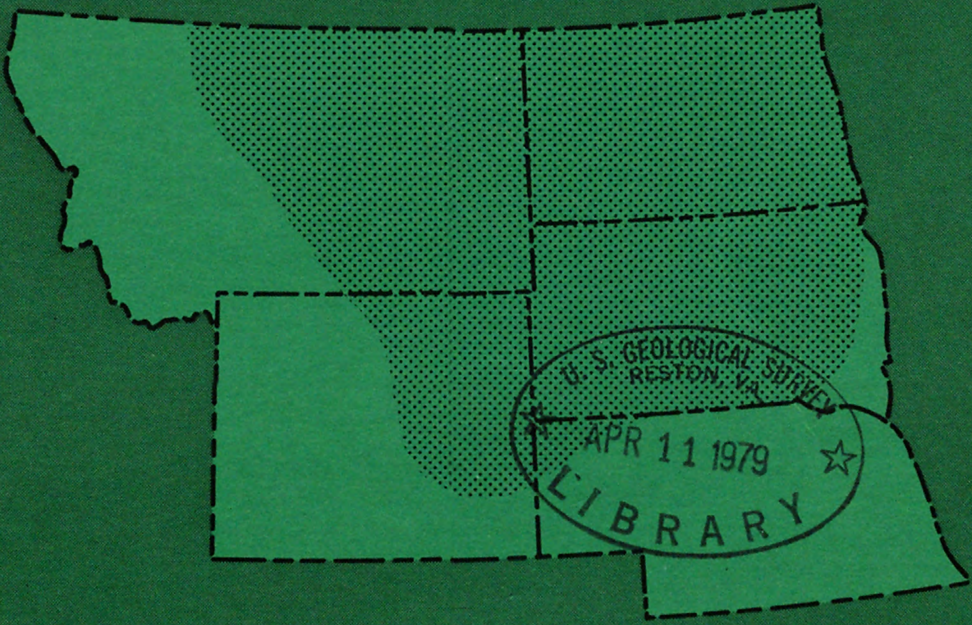
PLAN OF STUDY FOR THE NORTHERN GREAT PLAINS REGIONAL AQUIFER-SYSTEM ANALYSIS IN PARTS OF MONTANA, NORTH DAKOTA, SOUTH DAKOTA, AND WYOMING



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16. Abstracts

The Northern Great Plains, an area of about 250,000 square miles in parts of Montana, North Dakota, South Dakota, and Wyoming, is underlain by an accumulation of sediments eroded from the Black Hills and from mountains to the west. Principal aquifers are areally extensive beds of sandstone within these sedimentary rocks, some at great depths. Anticipated future water needs dictate that available ground-water supplies be evaluated for management of this natural resource. The U.S. Geological Survey has started (1978) a 4-year study of the Northern Great Plains aquifer system. The objective of this study is to define availability and quality of ground water and to predict the effects of using this resource. To achieve this objective, the ground-water system will be described in terms of spatial distribution, hydraulics, geology, and geochemistry. Once described, the ground-water system will be simulated by mathematical models that will be used to define responses of the system to various management alternatives and assumed development patterns.

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ABSTRACT

The Northern Great Plains, an area of about 250,000 square miles in parts of Montana, North Dakota, South Dakota, and Wyoming, is underlain by an accumulation of sediments eroded from the Black Hills and from mountains to the west. Principal aquifers are areally extensive beds of sandstone within these sedimentary rocks, some at great depths. Anticipated future water needs dictate that available ground-water supplies be evaluated for management of this natural resource. The U.S. Geological Survey has started (1978) a 4-year study of the Northern Great Plains aquifer system. The objective of this study is to define availability and quality of ground water and to predict the effects of using this resource. To achieve this objective, the ground-water system will be described in terms of spatial distribution, hydraulics, geology, and geochemistry. Once described, the ground-water system will be simulated by mathematical models that will be used to define responses of the system to various management alternatives and assumed development patterns.

ACKNOWLEDGMENTS

This plan of study was organized by George A. Dinwiddie, Project Chief of the Northern Great Plains Regional Aquifer-System Analysis. Several people from the District and Project Offices of the U.S. Geological Survey, Water Resources Division contributed significantly to the report. These contributors, in alphebetical order, are Larry O. Anna, John F. Busby, H. Lee Case III, Orlo A. Crosby, Joe S. Downey, William R. Hotchkiss, Lewis W. Howells, Dwight T. Hoxie, Quentin F. Paulson, and O. J. Taylor.

INTRODUCTION

The Northern Great Plains region, except for the Black Hills, is a fairly flat, gently rolling surface, underlain mostly by sandstone and shale. The surface is interrupted at places by several hundred feet of topographic relief where streams have dissected relatively soft rock. The Northern Great Plains study area, shown in figure 1, covers about 250,000 square miles, and is bounded on the west by the central and northern Rocky Mountains, on the east by the Red River, on the south by the Central High Plains, and on the north by the United States-Canadian border. The rocks consist of sediments that were eroded from present and ancestral mountains to the west, and from the Black Hills, and deposited into the subsiding Williston and Powder River Basins and surrounding areas, to thicknesses of more than 15,000 ft at some places.

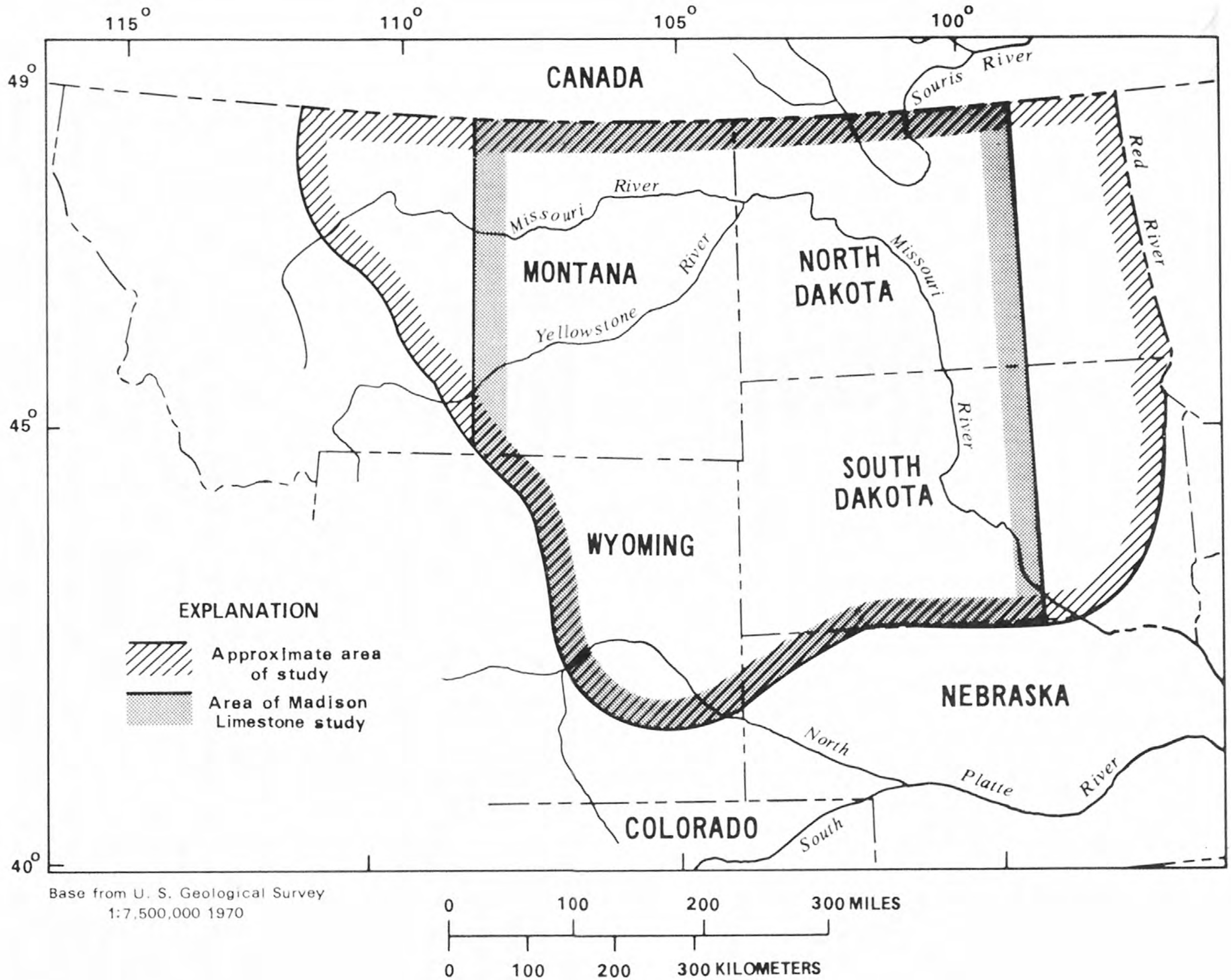

Figure 1.--Map showing location of study area.

Subsequently, several hundred feet of these sedimentary rocks were eroded, leaving remnants of more resistant rock. The principal aquifers (water-transmitting rock), which generally are areally extensive, crop out along the flanks of two major basins, and along other major structural features. Significant aquifers are also in unconsolidated glacial drift in North Dakota and South Dakota.

The general flow pattern of the major aquifers is northeastward across the project area. The source of most of the recharge is precipitation and loss of streamflow in topographically higher areas near the Black Hills, Bighorn Mountains, the eastern flank of the northern Rocky Mountains, and other major structurally positive areas. Most of the discharge is through springs and streamflow gains near topographically lower areas of eastern North Dakota and South Dakota, and as outflow into Canada. System discharge also occurs as upward flow of water between aquifers.

Flow characteristics may vary significantly between dominantly carbonate aquifers of Paleozoic age (such as the Madison Limestone), and the dominantly clastic aquifers of Mesozoic age (such as the Dakota Sandstone) and Cenozoic age. However, potentials for flow between the two systems exist near recharge and discharge areas and in the interior part of the study area where hydraulic heads vary significantly.

Problem

Development of energy resources, power generation, industrial development, increasing irrigation, and greater requirements for domestic and municipal water in the Northern Great Plains area will depend in a large part on development of supplies of ground water. Streamflow has historically satisfied many of the water needs; however, surface water is fully appropriated in much of the area and is not always a dependable supply because flows are extremely variable. Long-term, large-scale water needs will require development of productive aquifers, some of which have been little used heretofore. Large, sustained yields of ground water cannot be efficiently produced and sound management plans cannot be formulated without a knowledge of the physical and hydrologic characteristics of the ground-water system and of its response to withdrawals. Ground water, or any other natural resource, should not be indiscriminately developed and used without regard for the consequences of extraction and consumption. The U.S. Geological Survey has begun a 4-year study of the Northern Great Plains aquifer system(s) and is scheduled to complete the study in September 1981. This report describes the objectives and work plan of that study.

Objectives

The objectives of the Northern Great Plains Regional Aquifer-System Analysis derive from the problem of development and management of ground-water resources to satisfy increasing needs. Historically, ground-water studies have been limited by political boundaries or by anticipated local needs. The Northern Great Plains study is an analysis of a total regional ground-water system; the study is prompted by anticipated requirements for additional supplies of water on a regional scale.

In general, the principal objectives of this study are: (1) to define the regional aquifer system and ground-water flow of the northern Great Plains sufficiently well that ground-water supplies can be developed expeditiously; and (2) to predict the effects of using this resource according to various management plans designed to satisfy predictable needs for ground water. Specifically, the availability and quality of ground water need to be described in terms of spatial distribution, hydraulics, geology, and geochemistry. Once the three-dimensional system has been conceptually defined, predictive capability will be required. Stresses, such as withdrawal of ground water, particularly for long periods of time, will produce effects such as lowered water levels and reduction of streamflow. Computers provide the opportunity to mathematically simulate aquifers and observe long-term responses of the system to different conditions of stress. Therefore, the effects of management alternatives for developing ground-water supplies can be predicted by mathematically simulating the ground-water flow system, imposing conditions of use, and documenting the simulated responses. Management alternatives will be based on assumed development patterns that will be predicted from forecasts of ground-water needs and aquifer uses. These forecasts will be defined principally in consultation with State agencies and officials responsible for planning use and development of ground-water resources.

Approach

To accomplish the objectives, available data will be assembled and compiled for the Northern Great Plains study area. Required data will consist of hydrologic, geochemical, and geologic information. The principal sources of data will be U.S. Geological Survey files, previously published reports and present studies, as well as other Federal- and State-agency, university, commercial-laboratory, consultant, and private-company files. Additional data will be acquired by field inventory and sampling; by limited exploratory drilling, testing, and sampling; and by selected special studies. Although the northern boundary of the project is the United States-Canadian border, the aquifer system continues on northward; therefore, data will also be obtained from Canada, as possible.

When the data are compiled, they will be transcribed to a consistent machine-readable, -manageable form. The resultant data file and retrieval system will be an important product of the study and can be updated as new data become available.

When conceptual models and maps have been developed and the computer data file is in order, preliminary mathematical models will be prepared. A state-of-the-study model will probably be available in early fiscal year 1981, when all data have been included and all hydraulic conditions are in balance. Mathematical models of the hydrologic system will be important products of the study. Through their use, a basis will be provided for planning the most economical and beneficial development of ground-water supplies with as little damaging stress as possible on the system. Value of the models as management and predictive tools can be enhanced by modification and refinement through addition of data available in the future.

PLAN OF STUDY

The Northern Great Plains Regional Aquifer-System Analysis project area (fig. 1) encompasses the Madison Limestone project area (U.S. Geological Survey, 1975, Plan of study of the hydrology of the Madison Limestone and associated rocks in parts of Montana, Nebraska, North Dakota, South Dakota, and Wyoming: U.S. Geological Survey Open-file Report 75-631, 35 p.). The work on the two studies is closely coordinated, and the final reports on the two projects will be published in a single report series. The Northern Great Plains project will include study of the geologic section overlying the section being studied in the Madison Limestone project. These geologic sections of study, although stratigraphically separable, are hydraulically connected. The eastern limit of the Northern Great Plains study is farther east than that of the Madison Limestone study and includes the extent of younger aquifers through which ground-water from the Madison discharges. This extension of the project area provides for a more complete definition of the flow system of the aquifers in the Northern Great Plains and Madison projects. Depending on position within the ground-water flow system and on distribution of hydraulic potential, water can have potential to move upward, downward, or laterally and exchange between aquifers. Together, then, the Madison and Northern Great Plains studies will include the entire geologic section and ground-water flow system above the Precambrian.

The Northern Great Plains study was started in fiscal year 1978 and is presently scheduled to be concluded at the end of fiscal year 1981 (September). General work units to be accomplished during the scheduled 4-year study are outlined as follows and are shown graphically in figure 2.

A. Planning and staffing

   1. Detailed work plans prepared in coordination with U.S. Geological Survey District offices in Montana, North Dakota, South Dakota, and Wyoming.

   2. Staffs assembled in the project office and in District offices.

B. Collection and compilation of data

   1. Aquifer dimensions

      a. Areal distribution
      b. Thickness
      c. Altitude
      d. Relation to land surface
      e. Structural controls

2. Aquifer and hydraulic properties

   a. Hydraulic conductivity
   b. Specific yield and (or) storage coefficient
   c. Effective porosity
   d. Percent sand and clay
   e. Head

3. Ground-water recharge and discharge

   a. Recharge from streams
   b. Recharge from precipitation
   c. Exchange of water between aquifers
   d. Pumpage from wells
   e. Discharge to streams
   f. Discharge by evapotranspiration

4. Water quality

   a. Concentrations of principal constituents
   b. Zones of poor-quality water

C. Development of data-management system

1. Requirements for data storage and retrieval
2. Availability of data-storage and retrieval systems
3. Data-management systems developed for the project

D. Evaluation of data and storage in computer

1. Validity of data
2. Spatial distribution of data
3. Entry of data on System 2000

E. Studies of geologic framework, geochemical systems, and potentiometric surfaces

1. Framework

   a. Stratigraphic correlation
   b. Structural analysis
   c. Relationships between lithology, structure, and aquifer characteristics

2. Study of geochemistry

   a. Nature and distribution of hydrochemical facies
   b. Geochemical controls on quality of water
   c. Definition of recharge areas, leakance of water between aquifers, relationship between hydrochemical facies and ground-water flow patterns.

3. Study of potentiometric surfaces

    a. Vertical head distribution
    b. Areal head distribution in aquifers

F. Investigation of special problems

1. Gain-loss studies of low streamflow

2. Evapotranspiration

3. Water use

4. Exploratory drilling and testing

G. Models

1. Conceptual models of ground-water flow system

2. Development of coarse-grid model of entire system

3. Calibration of computer models

4. Development and simulation of management alternatives

    a. Assumed uses of aquifers
    b. Assumed development patterns

H. Preparation and publication of reports

1. Plan of study

2. Basic hydrologic, geologic, and geochemical data

3. Geohydrologic and geochemical maps

4. Special studies

5. Project report, by chapters that will be published at different times

    a. Introduction
    b. Geologic framework
    c. Geochemistry
    d. Hydrology, reported by hydrogeologic subunits yet to be selected
    e. Base streamflow and evapotranspiration
    f. Effects of management alternatives
    g. Summary; chapter will incorporate significant results of both the Northern Great Plains and Madison studies.

A schedule for completion of principal work units for the project is shown in figure 2. As the project proceeds, different needs may become obvious that require changing the emphasis or direction of some elements of the study.

Planning and Staffing

The National Program of Regional Aquifer-System Analysis represents a systematic effort to study a number of regional ground-water systems, which together cover much of the country and represent a significant element of the national water supply. Twenty-five systems have been identified for study under the program, and each investigation will be designed to fit the particular problems of the study area. The Northern Great Plains is one of these systems.

The objectives and general approach of the Northern Great Plains study have been coordinated with the U.S. Geological Survey, Water Resources Division, District offices in Montana, North Dakota, South Dakota, and Wyoming. Although detailed work plans of individual Districts may differ, the general approach is a regional solution to a regional problem by cooperation and communication between Districts, and between Districts and the Regional Office.

Manpower requirements have been difficult to satisfy in a timely manner at both District and Regional project levels. Neither the Regional nor the District staffs will be totally assembled during the first year of the project. However, it is anticipated that most staffing problems will be solved within the first few months of fiscal year 1979. Work on the project has proceeded during the first year, but progress has been slow, mostly because of delays in staffing.

Collection and Compilation of Data

Data compilation will involve both existing data and newly collected data. Existing data are available from reports and files of the U.S. Geological Survey, other Federal and State agencies, universities, private laboratories, and commercial data repositories. Data may also be available from Canada. The newly collected data will be mostly hydrologic information and analyses of water samples collected in areas not previously investigated or not thoroughly studied. All data concerned with aquifer boundaries, ground-water occurrence and movement, aquifer properties, ground-water recharge and discharge, and water quality will be coded and placed into computer storage for later retrieval and use.

In order to mathematically simulate the ground-water flow system, the aquifer dimensions and geologic framework must be defined as well as possible. Aquifer dimensions will be determined from data on areal distribution and thickness. The picture of geologic framework will be completed using data on altitude of formation tops, relationship between formations and land surface,

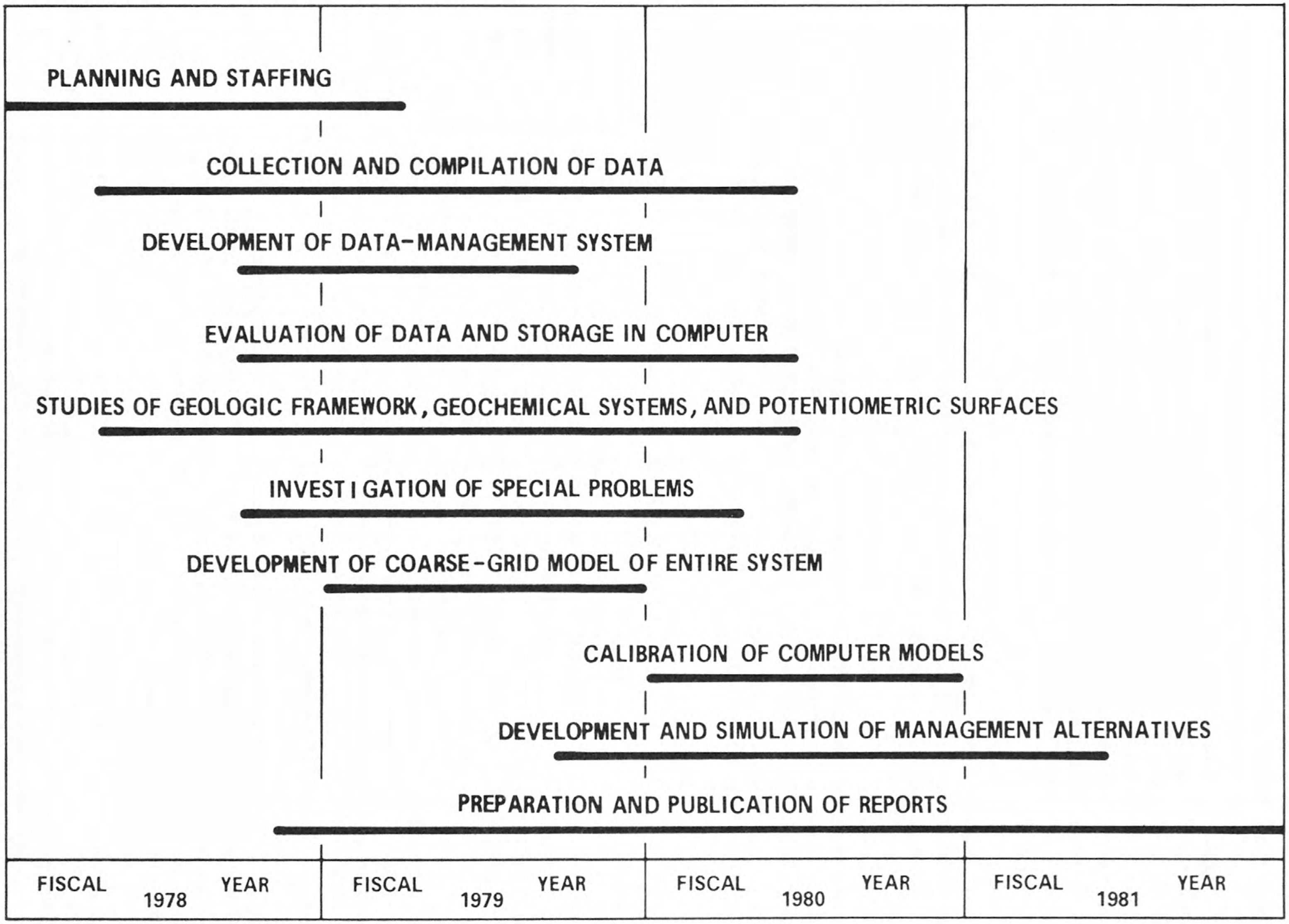

Figure 2.--Graph showing schedule of principal work units.

and the controls imposed in the system by geologic structure. Thus, the framework within which the ground-water system operates can be simulated by dimensional definition.

The next logical step in simulating the flow system by mathematical models is to simulate the nature of ground-water flow within the framework. To accomplish this, the basic aquifer properties that control the flow must be defined. The properties that control the rate and direction of flow and the ability of a hydrogeologic unit to yield water will be defined using data on hydraulic conductivity, storage coefficient (or specific yield, as appropriate), effective porosity, percent sand, and distribution of hydraulic head.

Simulation of the ground-water flow system cannot be completed without defining the dynamics of the system. Therefore, data on amount and distribution of recharge, of discharge, and of exchange of ground water within the system are necessary.

Water-quality data are important to the study and the model from both an economic and an interpretive point of view. Economically, the quality of water within the system must be known to plan the optimum use of the resource. In addition, knowledge of the water chemistry and its genesis may be very important to the interpretation of the system.

Data-Management System

Selection of the data-management system for computer storage and retrieval of data is a critical work element in the project. The data system will facilitate developing simulation models and various computer-generated map products. The data file (organized on System 2000) will be one of the most useful products of the project. The data-management system will be a foundation upon which a refined and larger data base can be built as more information becomes available with time; therefore, the system can become an even more valuable source of easily accessible data after the Northern Great Plains project has been completed. The data file will be maintained on the U.S. Geological Survey computer system to provide maximum accessibility.

System 2000 data-management system is a member of a larger class of computer programs called Data-Base Managers that perform data-management functions. System 2000 is a collection of computer programs that are used to enter, store, and retrieve both small and large amounts of data within computer systems. System 2000 programs maintain index files for locating each data item in the computer file, which allows rapid access to data items at minimum cost.

Because of the large amount of hydrologic data from the Northern Great Plains project area that must be processed and analyzed in a short period of time, the project staff will rely heavily on automatic data processing and advanced computer techniques. A Datapoint 5548[1/] central processor with disk

[1/] The use of brand names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

and tape-storage devices will be available for project use. In addition, the Datapoint processor will act as a remote-job-entry terminal for the U.S. Geological Survey IBM Model 370/155 computers located in Reston, Va. The Datapoint 5548 will also support a high-speed digital incremental plotter and digitizer, so various maps and charts may be quickly prepared from the regional data base with a minimum of manual effort. The Datapoint 5548 will also provide the capability of communicating directly with various U.S. Geological Survey District offices within the project area. This feature will allow rapid transmission of data between project personnel in the Districts and the Regional staff. In addition, this communication feature will permit use of various equipment items attached to the 5548 by District project personnel.

Evaluation of Existing Data

Existing data will be collected from many sources; therefore, the data must be evaluated not only for adequate distribution but also for validity and applicability. When the data have been evaluated for validity and entered into the computer file for retrieval, map products will be generated with which to evaluate the distribution of data. Areal deficiencies of data can be filled by field collection of new data at some places. However, data may not be available in many areas, and time may not be sufficient for extensive collection efforts.

Geologic Framework

The geologic framework of the Northern Great Plains, one of the most important elements of this study, is the framework within which the ground-water flow system operates, and it is by this framework that ground-water flow is controlled. Study of the geologic framework includes an evaluation of the structure and stratigraphy of Mesozoic and Cenozoic rock units and which of these units are aquifers and confining beds. Rock units underlying the aquifers in this study are presently being investigated in another closely related study, Hydrology of the Madison Limestone. The results of that study will be incorporated into the development of the Northern Great Plains Regional Aquifer-System Analysis. Close coordination is maintained between these related projects.

Generally, an understanding of geologic structure and stratigraphy will be accomplished by studying geologic history, outcrops, cores, drill-stem test data, and subsurface and surface geophysical data. Specifically: (1) lineament and nonlineament areas will be correlated with well-production and drill-stem test data; (2) time-stratigraphic units will be defined throughout the region by selecting formation tops from geophysical logs; (3) sedimentation patterns, lithology, and hydraulic conductivity will be related to structural trends and lineaments as possible; (4) lithology of aquifers will be related to hydraulic conductivity; and (5) the influence, if any, of regional structural features on ground-water movement will be determined.

Geochemistry

A great amount of data, both geologic and hydrologic, is available for use in the northern Great Plains study. Study and understanding of the geochemistry of the ground-water flow system will be utilized for interpreting the hydrology.

Specific objectives of studying the geochemistry are to determine the nature and spatial distribution of the hydrochemical facies and to develop an understanding of the geochemical controls on the quality of water in the system. Once these objectives have been achieved, the results will help resolve questions concerning identification of recharge areas, velocity of flow, and exchange of water between aquifers.

Anticipated report products from the geochemical study will include hydrologic-data reports, reports containing graphic displays, and a regional interpretation that will relate water quality to lithology and to the ground-water flow system.

Hydraulic Head

A good understanding of the distribution of head is essential to every analysis of ground-water flow systems. The large, complex system in the northern Great Plains is multilayered with several aquifers and confining zones; therefore, a well-defined, three-dimensional picture of head distribution is critical for describing the ground-water flow system.

Vertical head distribution under natural conditions will define areas of natural recharge, discharge, and lateral flow within ground-water systems. Vertical and areal distribution of head will define direction of flow, areas where ground water can possibly be exchanged vertically upward or downward between aquifers, and areas where streamflow is lost to or gained from the ground-water system. The distribution of head can also indicate the areas of the ground-water system affected by pumping.

Special Investigations

Special investigations will supply information required to define the regional ground-water flow system of the northern Great Plains. Ground-water recharge from or discharge to streams will be defined, to the extent possible, by analysis of existing streamflow records augmented by field measurements of stream gains and losses during periods of low or base streamflow. To account for all losses of ground water, studies of loss to the atmosphere through evapotranspiration will be needed; methodology of such studies is being investigated.

Data on specific yield and storage coefficient of various hydrogeologic units being studied are not generally available. Methods of estimating specific yield and storage coefficient, either by laboratory or computer analysis of field data, will be investigated during the Northern Great Plains project. At least one exploratory hole will be drilled, tested, and sampled during the project. The cost of, and manpower required for, drilling and testing deep holes make continued exploration of this type impractical on a regional scale.

Models

Conceptual models will be developed as early as possible in the Northern Great Plains project. Conceptual models are the hypotheses of the framework and dynamics of the flow system derived from preliminary data and from studies reported in the literature. The conceptual models will form the basis upon which preliminary mathematical models will be designed. Alternative concepts of flow can be tested with the model to derive the system with the framework, boundary, and flow characteristics that conform best with the observed data.

Late in fiscal year 1979, a digital model will be developed to simulate flow in the entire system above the Precambrian. This simulation of the regional aquifer system will be a coarse-grid, finite-difference model, to be used for a preliminary evaluation of the flow-system and framework concepts.

The model will be used to determine head and flow conditions on arbitrary boundaries in order to make detailed models of smaller regions within the system.

Calibration of models will be based on steady-state simulation of flow in the aquifer system based on regional estimates of recharge and discharge. Where detailed historical data on pumpage and drawdown, or other responses are available, nonsteady-state simulations will be made. Such stress-response data are not available from broad areas, because most of the aquifers have not been extensively tapped. Therefore, time-varying, stress-response testing of the model by comparison with measured historic stress and response may not be possible except on a small local scale.

Because of lack of development in most of the aquifers under study, historical variations are available in only a few areas. Because of lack of time, a history of changes throughout the study area cannot be developed.

Computer models, with the associated data base, will serve as functional management tools with which planning or regulatory agencies can plan optimum use of available ground water in the northern Great Plains. Computer models will be used not only to simulate existing system conditions, but also to simulate stresses and stress responses, as indicated by selected management alternatives defined in consultation with other Federal and State agencies.

Reports

During fiscal years 1979 and 1980, several map reports will be produced to describe graphically the geologic framework, distribution of hydrochemical facies, modern potentiometric surfaces, and various aquifer-system parameters. Final reports on studies of geology, geochemistry, and hydraulic-head distribution are scheduled for completion in the summer of 1980.

When several study phases are completed, reports will be issued that document the accumulated data and results of special studies. These reports and some of the map reports will be issued from District (State) Offices through their standard report channels and appropriately referenced in summary reports.

The Madison Limestone project is closely related to the Northern Great Plains project and is to be completed in fiscal year 1980. Results of both projects will be published as chapters in Professional-Paper series. Close association of the projects dictates that certain basic studies and reporting in the Northern Great Plains project be completed in time to be complementary to the Madison project; therefore, a cooperative introductory chapter will be completed in 1980. Additionally, basic Northern Great Plains studies of geohydrology and geochemistry, particularly of the geologic section underlying the Cretaceous Pierre Shale, need to be completed and reported in 1980. This is important, so that state-of-the-study interpretations of management alternatives for use of ground water from the Madison aquifer system will be as accurate as possible. Studies and reporting unique to the Northern Great Plains project will be completed early in 1981. The project summary of results of the Northern Great Plains Regional Aquifer-System Analysis will be completed near the end of fiscal year 1981. This summary will present results of basic study elements of the project and document mathematical simulation of the aquifer system and interpretations of management alternatives. The summary will cover the entire system overlying the Precambrian and will incorporate principal results of the Madison and Northern Great Plains projects.

District Office project personnel will contribute their expertise and writing to all phases of project reporting, and authorship will be shared by contributing personnel on Central Region and District Office project staffs.

ORGANIZATION OF THE STUDY

The Northern Great Plains Regional-Aquifer Analysis project is one of 25 such studies identified to comprise a systematic national program to study regional ground-water systems. The national program is coordinated by Gordon D. Bennett, of the Branch of Ground Water, Water Resources Division, in Reston, Va. The Northern Great Plains Regional Aquifer-System Analysis project will be headquartered in Lakewood, Colorado, under the direct supervision of the Central Regional Office of the Water Resources Division, U.S. Geological Survey. Project-related studies will be undertaken in the Water Resources Division District (State) Offices to support and complement Project Headquarters. Although most responsibility and effort of each District Office will be within its State, such responsibility and effort will not be limited by political boundaries. The project is regional in nature and defined by geohydrologic systems; the studies will be designed accordingly. Complementary and coordinated effort will be maintained between District Offices, Project Headquarters, and between each of the District Offices. In addition, communication will be maintained with a liaison committee comprised of officials from the States. This communication will assure that the States are aware of project activities, and will offer the project opportunity to benefit from suggestions by the States.

District Offices will be responsible for compilation of data and for specific special studies required for the model. District Offices will also be responsible for preparing the data for storage in the data-management system and for developing small-scale models of discrete subareas and (or) subsystems. Project Headquarters staff will be responsible for developing the data-management system in close consultation with District personnel to assure continuity of operation and compatibility of equipment. The data file will be easily accessible directly by all Districts and Project Headquarters. The project staff will provide technical advice to District Offices, as necessary, to develop the data base and small-scale models. In addition, Project Headquarters will be responsible for summary reports and regional-system simulation; however, District personnel will participate actively in both. Principal studies in the project, such as geologic framework, geochemistry, potentiometric surface(s), and regional modeling, will be coordinated by members of the Project Headquarters staff.

Relation to Other Studies

State agencies historically have maintained cooperative studies with the U.S. Geological Survey as a basis for carrying out their responsibility for management and regulation of ground-water resources. The cooperative programs are generally directed toward studies designed to improve the efficiency of this management. In this regard, the Northern Great Plains Regional Aquifer-System Analysis will benefit State agencies by providing a regional picture of the total system for their planning use and a framework upon which to build future programs. Mutual interests between this project and ongoing studies will be accommodated within the context of the Northern Great Plains project whenever possible. Similarly, contributions to this project, particularly to the project data file, from State agencies will be both solicited and welcomed.

The U.S. Geological Survey presently is conducting a study of the quantity of water that may be available from the Madison aquifer. This study will also define the chemical and physical properties of the water in the Madison Limestone and other aquifers in the Paleozoic rocks. The results of these phases of study and of the study of geologic framework and ground-water flow system of the Madison aquifer will necessarily be integral parts of the Northern Great Plains project in the final analysis of the total system. Compatibility of results from the Madison and Northern Great Plains projects is assured by project planning and coordination and communication between project personnel. The Madison project is scheduled for completion in fiscal year 1980 and the Northern Great Plains project in fiscal year 1981.

Preliminary concepts developed in the Madison study indicate that the ground-water flow system in the Madison aquifer is not a unique, isolated system, but is closely interrelated with the flow system(s) in overlying geohydrologic units. Because of this interrelationship, certain program elements of the Northern Great Plains project must be well advanced in fiscal year 1980 to complement the results of the Madison project. Subsequently, in fiscal year 1981, the total flow system can be more closely defined with greater confidence, and a comprehensive product can be developed and refined within the limits of available data.

DISTRICT WORK PLANS

The degree of success achieved in the Northern Great Plains Regional Aquifer-System Analysis will depend on the ability of each of the Water Resources Division District Offices to respond and contribute to the study. Participation by each District will be basically similar; however, there will be some differences because of the approaches that Districts have taken in previous studies within their respective States. Some Districts will be able to fulfill data-file requirements and to model local systems more quickly than others, because local problems and cooperative programs may have generated studies within State boundaries similar to, but on a smaller scale than, the Northern Great Plains Regional Aquifer-System Analysis. In some Districts, studies may already have been conducted on important special problems, such as ground-water recharge-discharge relationships, land use, and potentiometric surfaces and hydrologic properties of specific aquifers. In other Districts, new special studies may have to be started to enable adequate response to program needs.

All District Offices will have basic responsibilities within their respective States and (or) areas of principal study. Each will be responsible for literature searches, compiling all available data, collecting new data as necessary, and transcribing all data into consistent machine-readable form on System 2000. The District Offices will develop various graphic products including potentiometric-surface maps, sand-percent maps, hydrochemical-facies fence diagrams, hydraulic-conductivity maps, geologic sections, isopach and isofacies maps, and maps of areas of recharge-discharge. Other data to be compiled by the District Offices include: water level or pressure, as appropriate; transmissivity; hydraulic conductivity; chemical analysis; recharge; discharge; specific yield or storage coefficient, as appropriate; type and quantity of water use; distribution of water use; and amount and distribution of precipitation, as possible. Additionally, District Offices will plan and perform special studies required to satisfy project objectives, advise and assist Regional project staff, contribute knowledge and effort toward report goals, and develop and (or) assist in developing mathematical simulations of hydrologic systems. District Offices will model local areas and systems as necessary. These simulations will be used directly in the context of the overall project, in most cases. Although certain aquifers are momentarily more interesting or significant than others to some District programs, the Northern Great Plains study is ultimately required to account for the entire ground-water flow system overlying the Precambrian.

Aquifers that may not previously have produced ground water or may be suspected of containing water of poor chemical quality are not to be ignored in the context of the Northern Great Plains study. This is an additional burden on District Offices because they must collect, compile, and work with data that probably are not readily at hand.

The schedule for completion of work elements by the Districts must be compatible with overall program requirements for completion; therefore, the schedule for District efforts is the same as that shown in figure 2. The following sections present progress on the Northern Great Plains study, status of District staffing, and descriptions of special investigations for each of the District Offices.

Montana

Collection and compilation of data began during the last half of fiscal year 1978, and the project is now well underway. Inventory and chemical sampling of about 400 deep wells has been completed in the area north of the Yellowstone River, and the Montana Bureau of Mines and Geology has begun processing these samples. Study of geologic framework has been started by collection of geophysical logs and selection of basic geologic units in Montana. The first series of seepage runs has been completed in the Powder River Basin; another series and infrared photography will be completed by November 1978. First runs on a mathematical model of the Powder River Basin will be made early in fiscal year 1979 when input data are ready.

The District project staff includes a full-time project chief/modeler, hydrologic specialist, geologic-framework specialist, geohydrologist, hydrologist/modeler, and two technicians. In addition, a geochemist is assigned part time to the project.

Special investigations and techniques include streamflow gains and losses; infrared areal photography; geochemical analysis of productive aquifers; mathematical simulation of the Powder River Basin, and shallow drilling, testing, and sampling by the Montana Bureau of Mines and Geology in structurally high areas. The test holes will be generally less than 800 feet deep and will be drilled at places where the greatest number of geologic formations are near land surface. The drilling program will continue into early fiscal year 1980 and will respond to data needs.

North Dakota

Data are already available, in both reports and computer storage, on aquifer depth, thickness, areal extent, lithology, yields, water level, and water quality for aquifers overlying the Pierre Shale. These data provide reasonable areal coverage in about 80 percent of the study area, and additional data are presently being collected in the remainder of the study area. District work started slow and late because of staffing problems; however, ongoing hydrologic investigations associated with coal development will benefit the Northern Great Plains project.

The District staff will consist of a full-time project chief, a full-time hydrologist, a part-time hydrologist, and support personnel including part-time clerk, draftsman, computer technician, and publications editor.

Special investigations will include estimating aquifer recharge and discharge by measuring base streamflow. Specific yield or storage coefficient, as appropriate, will be determined by analysis of aquifer-test data, laboratory analysis of core, and examination of geophysical logs. A statewide network of observation wells will be maintained to develop potentiometric-surface maps and define water-quality variations in and between aquifers.

South Dakota

Available well logs and well data have been collected from the State Water Resources Commission, State Geological Survey, and several drilling contractors. These data and data from District Office files have been transferred to System 2000 well schedules. Many of these well schedules lack latitude, longitude, and aquifer designations; in addition, well schedules for well-log data do not presently include formation or aquifer tops, bottoms, or thicknesses. A computer program that converts legal description to latitude and longitude has been obtained and is being used to expedite data-processing procedures.

A revised map of the surface geology is available for Dewey, Corson, and Ziebach Counties. Also available are structure-contour maps, water-availability maps, and maps showing water-quality variations for the Paleocene Fort Union Formation, and Cretaceous Hell Creek and Fox Hills Formations. All logs of oil and gas test holes and of deep water wells have been interpreted for formation tops. These tops represent preliminary interpretations by District personnel, and some may require modification as additional data are acquired by the project stratigrapher. Structure-contour and isopach maps for selected deep hydrologic units have been prepared. All water-quality data for deep aquifers have been plotted, including samples from oil and gas drill-stem tests. Maps have been prepared that show sampling locations for all chemical analyses available for the Fort Union, Hell Creek, and Fox Hills Formations. All known deep wells within the project area of major interest have been sampled. Well inventorying began in June 1978. When a sufficient area has been covered, sampling points will be selected and samples collected, as available and as needed, for chemical analysis of water from all Cenezoic and Mesozoic age aquifers in the study area.

The District headquarters for the Northern Great Plains project is in Rapid City, and the project staff consists of a project chief/hydrologist, a hydrologist, a hydrologic technician, and a part-time hydrologist.

Special investigations will include development of a three-dimensional digital model of ground-water flow in the study area. The model will be calibrated by comparing simulated water levels with actual field measurements.

Wyoming

A large quantity of data has been collected and analyzed, and a number of interpretive studies have been conducted as part of the Wyoming District's existing coal-hydrology project within the Powder River Basin. These data and analyses pertain largely to the shallow aquifer systems within the basin but will provide insights to the operation of the overall ground-water flow system within the basin that will greatly benefit the Northern Great Plains Regional Aquifer-Systems Analysis project in Wyoming.

The Wyoming District project staff consists of a project chief/hydrologist, a geologist, a hydrologist, a geochemist, and a part-time hydrologist.

Special investigations, to be conducted by Wyoming District personnel, will include a study to determine the net rate of evapotranspiration at selected sites in stream valleys in Wyoming and Montana. This investigation will be based on a published method of estimating evapotranspiration combined with infrared aerial photography and ground-water level and streamflow monitoring. These data will be augmented by seepage runs to be conducted on a number of perennial streams within the Powder River Basin during August and October 1978.

To better perceive the three-dimensional framework affecting movement and quality of ground water within the Powder River Basin, a grid of isometric fence diagrams will be constructed for the stratigraphic interval between land surface and the top of the Paleozoic rocks. These diagrams will show both stratigraphy and structure and will provide a base on which potentiometric-surface and water-quality data may be graphically displayed.

High-altitude aircraft and Landsat imagery will be utilized to map surficial linear and fracture systems within the Powder River structural basin in Wyoming and Montana. These features will be correlated with the occurrence of springs and with gaining and losing reaches of streams, to determine how these features may be affecting movement of ground water within the basin.

Chemistry of waters at places within the Tertiary and Cretaceous rocks show anomalously high concentrations of boron, as well as fluoride and nitrate ions. A sampling program will be initiated to refine existing data to determine areal distribution and probable source areas of these chemical constituents.

The major undertaking of the Wyoming District will be to construct a ground-water flow model for the beds of sandstone of Early Cretaceous age within the overall project area. These beds of sandstone are stratigraphically equivalent to the Dakota Sandstone of eastern North Dakota, South Dakota, and Nebraska; they comprise what shall be designated here as the

Dakota aquifer system. Beds of sandstone of the Dakota aquifer are laterally continuous throughout much of the project area; they have been subjected to intensive ground-water development in eastern North and South Dakota. The geographic boundaries of the model will be delimited by the outcrop areas in Wyoming and Montana, by the Canadian border, and by discharge areas in North and South Dakota. Vertical flow into and out of the aquifer, as well as flow between individual sandstone units within the aquifer, will be treated by constructing an appropriate multilayer model to the extent that data allow.

Data for mapping potentiometric surfaces and hydrologic parameters will be obtained from existing water-well and oil-well test data. Because there has been little development of this aquifer within the project area, initial effort will concentrate on the construction of a steady-state flow model. Hypothetical future water withdrawals may then be imposed on this model to simulate the effects on this aquifer system.

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