PLAN OF STUDY FOR THE BLACK HILLS HYDROLOGY STUDY, SOUTH DAKOTA

By Daniel G. Driscoll

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CONVERSION FACTORS

Multiply	By	To obtain
foot	0.3048	meter
inch	25.4	millimeter
mile	1.609	kilometer

Temperature can be converted to degrees Fahrenheit (°F) or degrees Celsius (°C) by the following equations:

$$°F = 9/5\ (°C) + 32$$

$$°C = 5/9\ (°F-32)$$

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ABSTRACT

The Black Hills Hydrology Study is a long-term investigation (10 years) that was initiated in 1990 as a cooperative effort between the U.S. Geological Survey, the South Dakota Department of Environment and Natural Resources, and the West Dakota Water Development District (which represents local and county cooperators). The study is designed to assess the quantity, quality, and distribution of surface and ground waters in the Black Hills area of South Dakota. The study will investigate regional hydrogeologic characteristics of selected aquifer units in the recharge area near the Black Hills, with an emphasis on quantifying interactions between surface water and ground water. The study is not intended or designed to address various site-specific problems that are not of regional concern. The study will be divided into two phases because of the large study area and complex hydrologic system. Phase I will consist primarily of data collection and compilation necessary to describe precipitation amounts, streamflow rates, ground-water levels, and water-quality characteristics of the study area. Phase II will concentrate on: quantifying relations among precipitation, streamflow volume, and aquifer response for three diverse stream-aquifer systems; describing the significance on the hydrologic system of four areally extensive aquifer units (the Madison Limestone, Minnelusa Formation, Deadwood Formation, and Minnekahta Limestone); and possible development of regional ground-water flow models.

INTRODUCTION

The Black Hills area is a unique and valuable asset to the State of South Dakota. In addition to its historic landmarks, scenic beauty, timber, and mineral resources, the Black Hills area is a major source of water. The water resources of the Black Hills area have been stressed by increasing population, resource development, and periodic droughts. The availability, quality, and efficient use of water have become frequent topics of both the news media and general public. Local residents and water managers have responded with a request for a regional study of Black Hills area water resources.

The Black Hills Hydrology Study is a long-term investigation (10 years) that is designed to assess the quantity, quality, and distribution of surface and ground waters in the Black Hills area of South Dakota. The purpose of the study is to investigate the regional hydrogeologic characteristics of the Black Hills area. The study is not intended or designed to address various site-specific problems that are not of regional concern. It is intended to obtain background information that may be generically valuable for a variety of purposes. Site-specific issues will still need to be addressed on an individual basis.

The Black Hills Hydrology Study was initiated in 1990 as a cooperative effort between the U.S. Geological Survey (USGS), the South Dakota Department of Environment and Natural Resources (DENR), and the West Dakota

Water Development District (WDWDD), which represents local and county cooperators. Work will be performed primarily by the USGS with technical advice and assistance from DENR. The WDWDD will act as a liaison to local and regional governmental agencies, will acquire local funding, and will serve as the primary local cooperating agency. A steering committee consisting of area residents will assist WDWDD in this capacity. Expertise, resources, and technical assistance from other entities such as the U.S. Department of Interior, Bureau of Reclamation; U.S. Department of Agriculture, Forest Service; U.S. Department of Agriculture, Soil Conservation Service; and the South Dakota School of Mines and Technology (SDSM&T) will be utilized as much as possible.

Problem

The geohydrology of the Black Hills area is very complex. Surface-water basins are crossed by State and county boundaries; ground-water basins, divides, and flow paths are largely undefined. Recharge of several major, interconnected aquifers provides water to many distant users. These factors, coupled with increasing resource development and recent drought conditions, pose several questions: (1) What is the development potential of the Madison aquifer and other aquifers near the Black Hills; (2) what effects will development of ground-water resources have on surface-water resources, and vice versa; (3) what is the degree of hydraulic connection between the Madison aquifer and the overlying Minnelusa aquifer; and (4) what are the recharge rates for the major bedrock aquifers exposed in the Black Hills? A comprehensive, regional study of the complex Black Hills area hydrologic system is needed to provide water managers with adequate information to assess how resource development will affect the quantity and quality of surface and ground waters.

Purpose and Scope

The Black Hills Hydrology Study is a long-term study designed to assess the quantity, quality, and distribution of surface and ground waters in the Black Hills area of South Dakota. The purpose of this plan of study is to summarize a preliminary work plan that describes the objectives, approach, specific work elements, and tentative products of the study.

Objectives

Specific objectives of the Black Hills Hydrology Study are to:

1. Inventory and describe precipitation amounts, streamflow rates, ground-water levels of selected aquifer units, and selected water-quality characteristics for the Black Hills area.

2. Develop hydrologic budgets to define relations among precipitation, streamflow, and aquifer response for selected Black Hills watersheds.

3. Describe the significance of the bedrock aquifers in the Black Hills area hydrologic system, with an emphasis on the Madison and Minnelusa aquifers, through determination of:

    a. aquifer properties (depth, thickness, structure, storage coefficient, hydraulic conductivity, etc.);

b. the hydraulic connection between the aquifers;

c. the source aquifer(s) of springs;

d. recharge and discharge rates, and gross volumetric budgets; and

e. regional flow paths.

4. Develop or select local and regional conceptual models of the geohydrologic system and use ground-water flow modeling, as appropriate, for:

a. enhancement of understanding of the geohydrologic system;

b. evaluation of estimates of recharge and discharge rates;

c. evaluation of estimates of aquifer characteristics; and

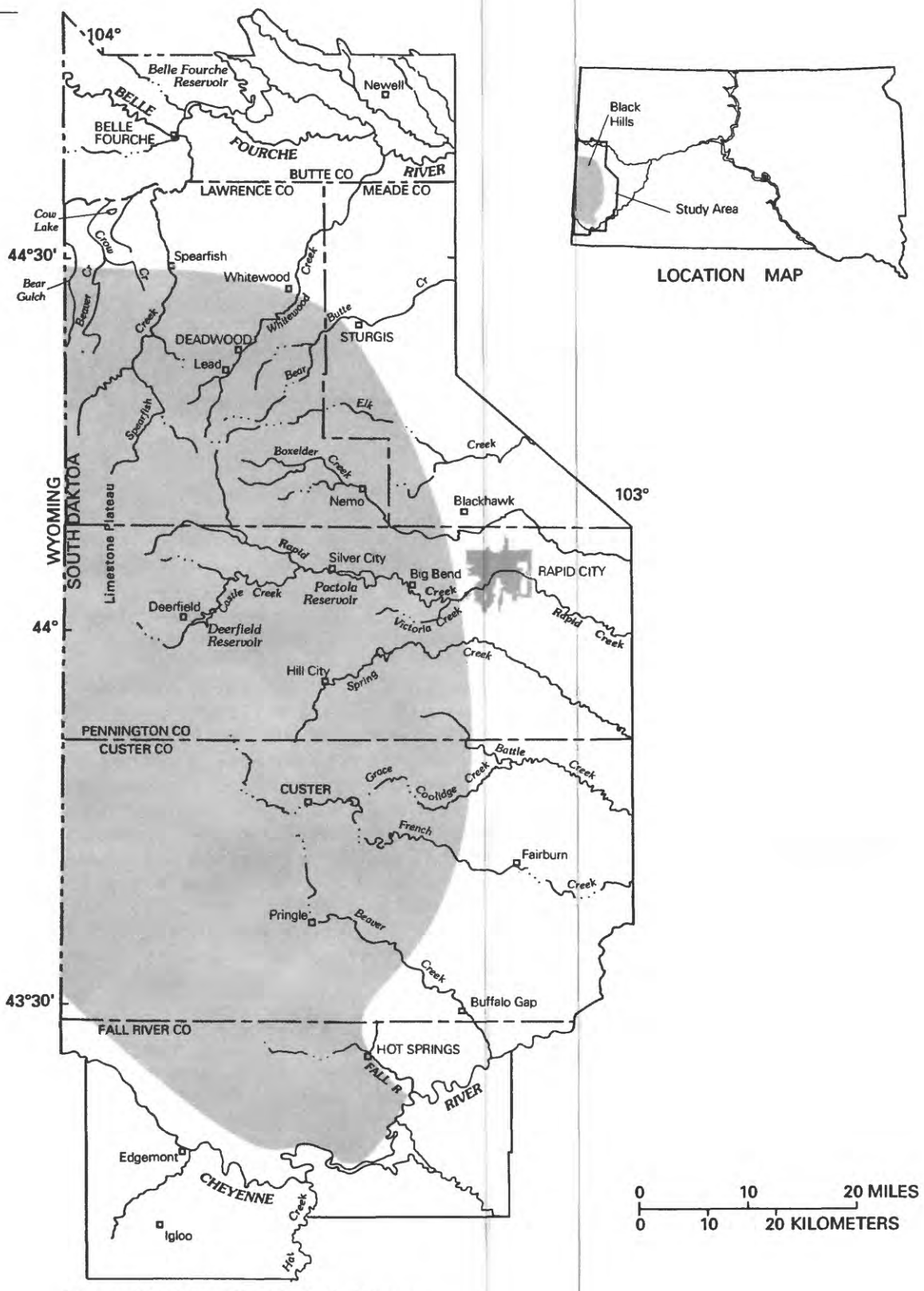
d. predictive purposes, if possible.

DESCRIPTION OF STUDY AREA

The study area includes the topographically defined Black Hills and adjacent areas as shown in figure 1. The area includes most of the larger communities in western South Dakota and contains about one-third of the State's population.

The Black Hills are a dome-shaped uplift of Laramide age about 125 miles long and 60 miles wide (Feldman and Heimlich, 1980). Altitudes range from about 7,200 feet at the higher peaks to about 3,000 feet in the surrounding Great Plains, resulting in an orographically induced microclimate characterized by generally greater precipitation and lower temperatures at the higher elevations. The overall climate of the area is continental, generally with low precipitation amounts, hot summers, cold winters, and extreme variations in both precipitation and temperatures (Johnson, 1933). Average annual precipitation for the Black Hills area is 21.30 inches, and ranges from 15.08 inches at Hot Springs to 28.65 inches at Lead. The average annual temperature is 43.9 degrees Fahrenheit and ranges from 47.6 degrees at Hot Springs to approximately 37 degrees near Deerfield Reservoir (U.S. Department of Commerce, 1990).

The oldest geologic units in the stratigraphic sequence are the Precambrian metamorphic and igneous rocks, which are exposed in the central core of the Black Hills, extending from Lead to south of Custer. Surrounding the Precambrian core is a layered series of sedimentary rocks including limestones, sandstones, and shales. Differential erosion rates of various units have resulted in a concentric series of ridges and valleys encircling the Black Hills. The Deadwood Formation, Madison Limestone, Minnelusa Formation, and Inyan Kara Group tend to form ridges and are the most commonly used bedrock aquifers in the study area. Alluvial deposits along streams and terrace deposits also are commonly used local aquifers.



Base modified from U.S. Geological Survey
State base map, 1961, edited 1984

Figure 1.--Area of investigation for the Black Hills Hydrology Study.

The base flow of most Black Hills streams originates from the headwater areas of the higher Hills, where increased precipitation and lower temperatures result in excess water being available for surface flows. Several streams, most notably Rapid Creek and Spearfish Creek, derive a steady and reliable base flow from springs located on the eastern fringe of an area called the Limestone Plateau. Stream reaches within the central, Precambrian core of the Black Hills are more responsive to precipitation than the limestone areas, with high flows during wet periods and low flows during dry spells. Most streams lose all or part of their flow in crossing the surface exposure of the Madison Limestone (water-loss zone) near the periphery of the Black Hills. Generally greater precipitation and lower temperatures in the northern Black Hills tend to produce greater stream discharges than in the southern Hills. Steep slopes make area streams prone to flash flooding; however, direct runoff is rare in some basins that are dominated by the more permeable limestone formations.

STUDY APPROACH

Because the Black Hills of South Dakota and Wyoming are an important recharge area for several regional, bedrock aquifer systems and various local aquifer systems, the Black Hills Hydrology Study will concentrate on describing the significance of selected bedrock aquifers in the hydrologic system. The highest priority will be placed on the Madison and Minnelusa aquifers because of the obvious importance of the water-loss zones and major springs and because of their unknown degree of interconnection. Of these, the Madison will receive greater attention because of the heterogeneity of this unit. The Deadwood and Minnekahta aquifers will have a lower priority because of their lesser influence on the hydrologic system. The fractured Precambrian rocks, Inyan Kara Group, and various local and alluvial aquifers will have the lowest priorities because: (1) The Precambrian, local, and alluvial aquifers are not regional aquifers with regional flow paths and may be studied on a site-by-site basis; and (2) the Inyan Kara Group is hydraulically isolated from the other priority units and also may be studied separately.

The study will be divided into two phases because of the large study area and complex hydrologic system. Phase I will concentrate on completion of Objective 1, and will consist primarily of data collection and compilation necessary to describe precipitation amounts, streamflow rates, groundwater levels, and water-quality characteristics of the study area. Phase I is expected to be completed in FY (fiscal year) 1995.

Phase II will concentrate on completion of the three remaining objectives. Work on the other objectives has already begun, but will intensify following completion of Phase I. A specific work plan and final product for Phase II cannot be developed until Phase I is near completion. Likewise, a completion date for Phase II depends on funding levels available and what specific ground-water flow modeling efforts (Objective 4) are implemented. The ability to successfully complete an accurate, regional ground-water flow model (Objective 4) of the Madison and Minnelusa aquifers and if necessary, the Deadwood aquifer, is desirable, but not prerequisite to completion of the study. If it is determined that regional ground-water flow modeling is likely to be unsuccessful, the study will be ended following completion of the second and third objectives.

Objective 1 will be accomplished using a network of precipitation gages, streamflow-gaging stations, and observation wells to collect basic hydrologic data. Baseline water-quality sampling was initiated in 1988 at 16 surface-water sites as part of studies of the northern and central Black Hills. Similar water-quality sampling will be initiated at selected existing and new streamflow-gaging stations and at other selected sites. Samples also will be collected from selected springs and wells to determine baseline water quality, to define spatial variation, and to help determine the degree of interconnection of the regional aquifers.

Objective 2 will concentrate on quantifying relations among precipitation, streamflow volume, and aquifer response for three diverse stream-aquifer systems using available observation wells. This will involve hydrologic budgeting and development of regression equations. Results should have applications for gross volumetric budgeting efforts for the bedrock aquifers. This effort will involve Spearfish Creek in the northern Black Hills, Spring Creek in the central Black Hills, and Beaver Creek in the southern Black Hills. In addition to these three basins, relations between precipitation and streamflow will be defined for additional basins for which sufficient data are available.

Objective 3 will concentrate on describing the significance of the Madison Limestone and Minnelusa Formation, and to a lesser degree the significance of the Deadwood Formation and Minnekahta Limestone, on the hydrologic system. Determination of aquifer properties, with an emphasis on the Madison, will be accomplished using test wells, geophysical logs, and single- and multiple-well aquifer tests. Mapping of these characteristics, in both plan and cross-sectional view, will occur early in Phase II.

Interconnections between the Madison aquifer and other components of the hydrologic system will be examined in detail. Significant streamflow losses are known to occur to the Madison Limestone through sinkholes. Many large springs, believed to originate in the Madison Limestone, may also be connected to the Minnelusa Formation and Minnekahta Limestone. The degree of connection between the Madison Limestone and Deadwood Formation also is uncertain. A more thorough understanding of the degree of connection of these aquifer systems is prerequisite to the entire study. This will be examined to the greatest extent possible using chemical tracers, water levels, and aquifer-test data.

The source aquifer, or relative contribution of various aquifers, as the case may be, will be determined for as many springs as possible. This will be done using chemical analyses, natural tracers, water-level data, and pumping data. This work will be directly related to Objectives 3b and 3d.

An estimate of recharge and discharge rates for the bedrock aquifers is necessary for gross volumetric budgeting. Recharge to the Madison Limestone from streamflow loss can be measured using the streamflow-gaging network. Precipitation falling directly on the outcrop areas of the various aquifer units can be measured using the precipitation-gaging network. However, additional work must be done to determine the amount of precipitation on the outcrops that becomes effective recharge. Several possible study approaches exist. One is simple water budgeting, using porosity values and changes in water levels to calculate changes in storage. This is directly related to Objective 2. Another is using isotopic analysis, especially for waters of the Madison Limestone, to determine the relative contributions of streamflow

and precipitation recharge. Another option may be to measure rates of cave drip in various places. Discharge rates are a combination of spring discharge, which can be measured; withdrawal rates, which can be estimated; and rates of underflow and leakage to other aquifers, which can be calculated using hydraulic heads and aquifer properties. Computer methods of volumetric budgeting probably will be useful for this complex aquifer system.

Definition of flow paths will be accomplished using flow nets, natural tracers such as stable isotopes, and ground-water flow modeling where applicable. Age dating of waters and geochemical analyses also will be used.

Objective 4 deals with development of regional ground-water flow models. Ultimately, a predictive, regional model of the Madison, Minnelusa, and if necessary, the Deadwood aquifers, would be a desirable product. It is uncertain whether an adequate data base for a successful model of this magnitude can be developed within the expected time frame of the study. The nonhomogeneous nature of the karstic Madison aquifer may prohibit modeling by conventional methods. Computer modeling undoubtedly will be used for various components of the system and for localized geographic areas. Modeling may be useful for evaluation of conceptual models of the aquifer systems and their degree of interconnection; for evaluation of recharge and discharge estimates; and for evaluation of estimates of aquifer characteristics. The decision to proceed with regional modeling for predictive purposes will have to be made at a later date. This decision will be made with cooperator participation, based on financial considerations, the success of modeling for the aforementioned purposes, and the success of localized modeling where more data are available.

Specific tasks have been identified to accomplish the objectives. A detailed description of each task is contained in the detailed work plan for the Black Hills Hydrology Study. The anticipated timeframe associated with each task is presented in figure 2.

BUDGET REQUIREMENTS

The Black Hills Hydrology Study is cooperatively funded by the USGS, DENR, WDWDD, and the Counties of Lawrence, Custer, Meade, and Fall River. The contribution by each agency may vary but historically has been 50 percent from the USGS, 25 percent from DENR, and 25 percent in total from the local Black Hills agencies represented by WDWDD. The USGS, through its Federal-State Cooperative Program, can provide no more than 50 percent of the total funding.

A long-term budget cannot be prepared because annual funding levels cannot be reliably predicted. Fiscal year 1992 funding was $570,000, and it is anticipated that similar funding levels continued through FY 1995 should allow for adequate completion of Phase I activities necessary to meet Objective 1. Smaller funding levels may increase the time frame necessary to complete Phase I. Larger funding levels may provide an earlier start on many Phase II activities.

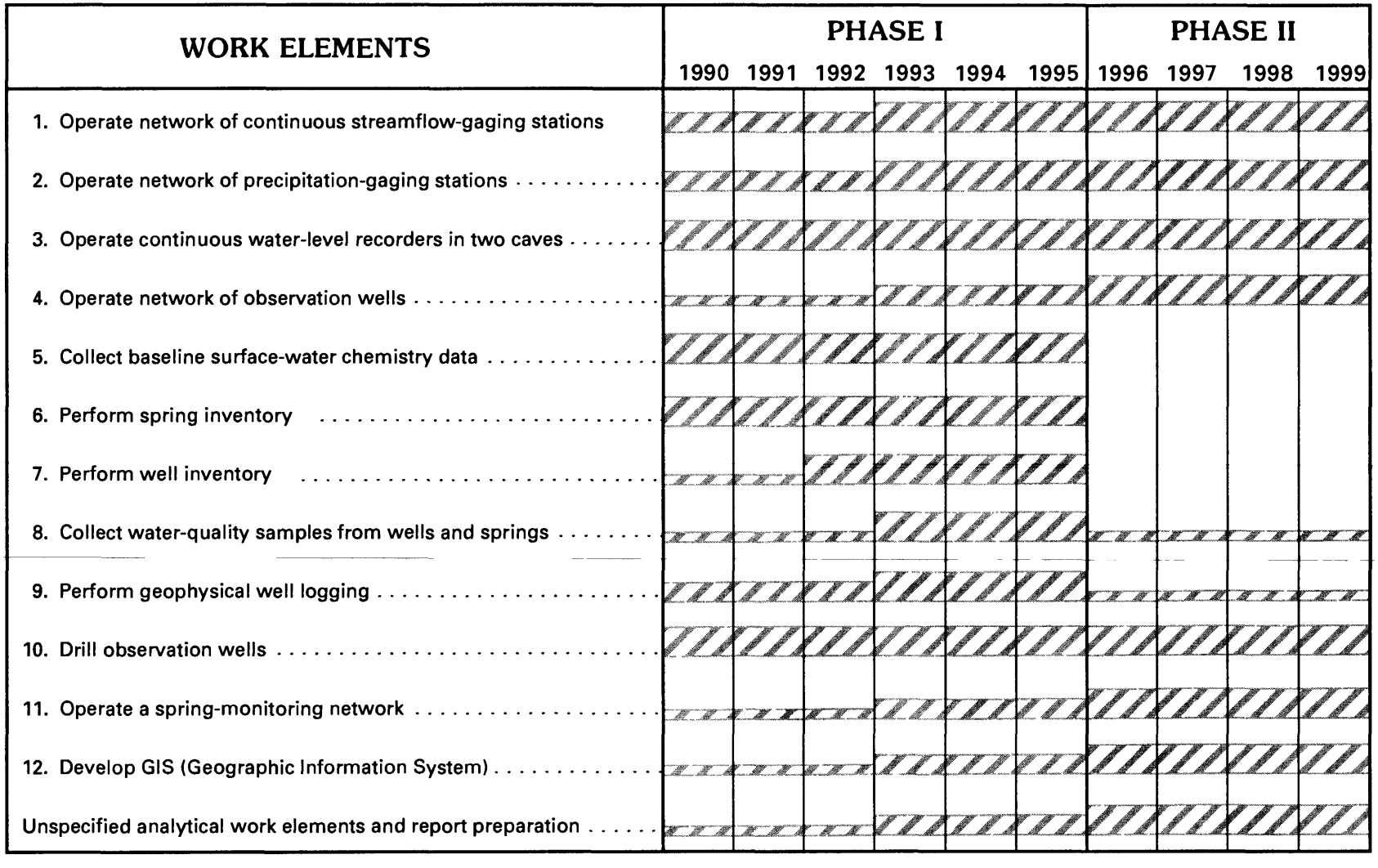


Figure 2.--Projected timeframe for identified Black Hills Hydrology Study work elements (height of bar depicts relative level of annual effort for each task).

STUDY PRODUCTS

The net result of this effort will be a better understanding of the complex hydrologic interactions between precipitation, streamflow, and ground water in the Black Hills area. It is difficult to specify a definite publication schedule for a multi-year study, especially when future funding levels are uncertain. A tentative list of key products for the study is presented in this section. A number of additional reports may be generated as opportunity arises, using a goal of a minimum of one publication annually. In addition to the tentative publications listed here, a number of related M.S. theses by SDSM&T graduate students are anticipated over the duration of the study.

1. Streamflow, precipitation, and ground-water-level data will be published in the annual USGS Water Resources Data report for South Dakota.

2. A report entitled "Sources and Summaries of Water-Quality Information for Lawrence County, South Dakota" is planned for publication during FY 1992.

3. A report entitled "History of Stream Gaging and Statistical Summary of Selected Streamflow Records for the Black Hills Area, Western South Dakota" is planned for publication during FY 1993.

4. A bibliography of Black Hills area geohydrology-, water-quality-, and earth-science-related publications is planned for publication during FY 1993.

5. An interim report is planned for publication during FY 1996, following the completion of Phase I in FY 1995. The purpose of this report will be to describe precipitation amounts, streamflow rates, ground-water levels, and water-quality characteristics of the Black Hills area (Objective 1).

6. Soon after the completion of Phase I, a report presenting hydrologic budgets for selected watersheds is planned (Objective 2).

7. Early in Phase II, a report presenting the physical characteristics of the major aquifers is planned (Objective 3a). This document will be prerequisite to many other Phase II activities.

8. Map data and other spacially related data will be input to a Geographic Information System, which will be available to local and State agencies.

9. Construction of an isohyetal map of the Black Hills area, based on the additional precipitation data collected, is planned at the end of the study period.

10. A final, comprehensive report entitled "The Hydrology of the Black Hills" is planned (Objective 3). This will include information on bedrock aquifer characteristics, surface- and ground-water quality, and interactions between surface water and ground water.

11. It will not be possible to specify a product for the fulfillment of Objective 4 until the extent to which ground-water flow modeling will be performed has been determined. Any modeling efforts agreed upon with the cooperators will be presented in an appropriate report.

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