U.S. DEPARTMENT OF THE INTERIOR,
U.S. GEOLOGICAL SURVEY

WATER-RESOURCES NOTES

BLACK HILLS HYDROLOGY STUDY

U.S. GEOLOGICAL SURVEY

Open-File Report 94-344

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The Black Hills area of western South Dakota (fig. 1) is a valuable resource center. The area has attracted numerous residents and industries because of the availability of mineral, timber, agricultural, recreational, and water resources. The water resources of the area have been stressed locally by increasing population, periodic drought, and development of other resources. In response to residents' concerns about these stresses on the water resources, the Black Hills Hydrology Study was initiated in 1990 as a cooperative effort among the U.S. Geological Survey (USGS), the South Dakota Department of Environment and Natural Resources (DENR), and the West Dakota Water Development District. West Dakota represents the various local and county cooperators. This report describes the purpose, scope, approach, and status of the study and presents highlights from the first project data report produced for the study (Driscoll and Bradford, 1994).

PURPOSE, SCOPE, AND APPROACH OF STUDY

The Black Hills Hydrology Study is planned as a 10-year investigation, to assess the quantity, quality, and distribution of surface and ground water in the Black Hills area (Driscoll, 1992). The purpose of the study is to investigate the regional hydrogeologic characteristics of the area, rather than to address site-specific problems of local concern. Specific objectives of the study are to: (1) Inventory and describe precipitation, streamflow, ground-water levels, and water-quality characteristics; (2) develop hydrologic budgets defining relations among precipitation, streamflow, and aquifer response; (3) describe the hydrogeologic characteristics of bedrock aquifers in the Black Hills area; and (4) develop conceptual models of the hydrogeologic system for use in ground-water flow modeling.

The study is divided into two phases because of the large study area and complex hydrologic system. Phase I emphasizes completion of Objective 1, and is scheduled for completion in 1995. Phase II emphasizes completion of the three remaining objectives. Work on the last three objectives has begun, and will intensify following completion of Phase I.

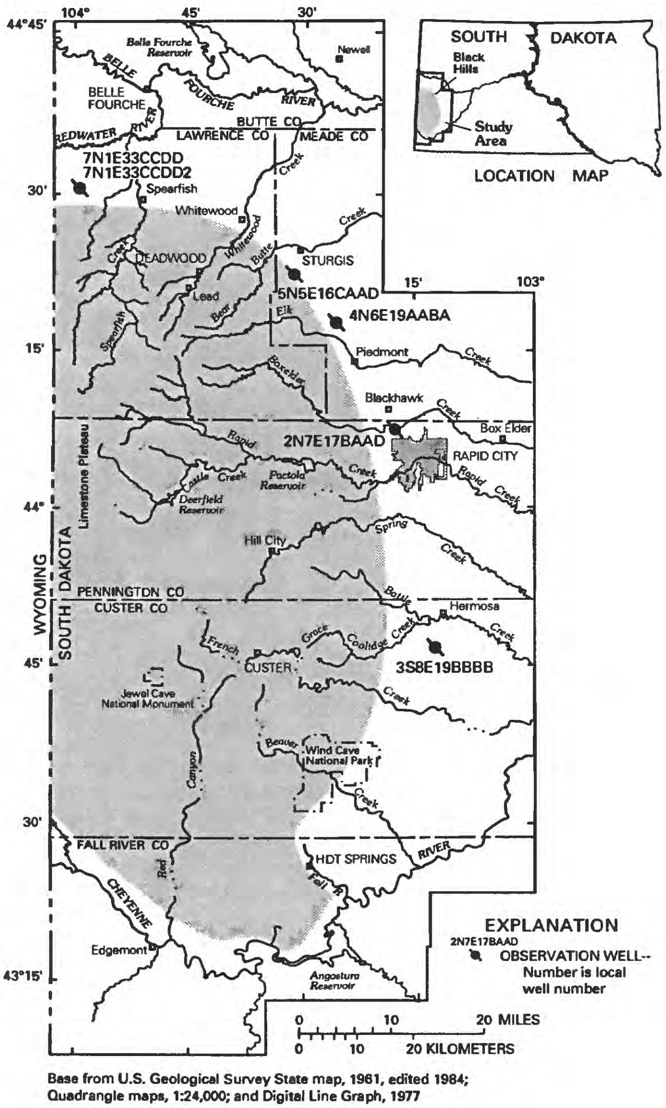

Figure 1.--Location of study area and observation wells for which hydrographs are presented.

The Black Hills area is an important source of recharge for several regional and local aquifer systems (fig. 2). The emphasis of the Hydrology Study is on aquifers in the Madison Limestone and Minnelusa Formation because of stream water-loss zones, major springs, and the variable degree of interconnection between these aquifers. Aquifers in the Deadwood Formation and Minnekahta Limestone have a lower priority because of their lesser influence on the hydrologic system. The fractured Precambrian rocks, Inyan Kara Group, and various local aquifers have the lowest priorities for the study.

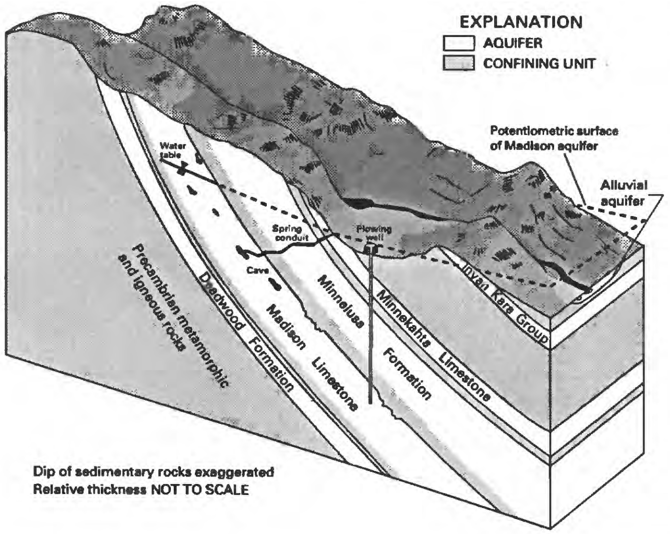

Figure 2.--Schematic showing simplified hydrogeologic setting of the Black Hills area.

HYDROGEOLOGIC SETTING OF STUDY AREA

The Black Hills are a dome-shaped uplift of Laramide age, about 125 miles long and 60 miles wide (Feldman and Heimlich, 1980). This uplift occurred about 60 million years ago. Altitudes range from about 7,200 feet at the higher peaks to about 3,000 feet in the surrounding plains. The overall climate of the area is continental, with relatively low precipitation amounts, hot summers, cold winters, and extreme variations in both precipitation and temperatures.

The oldest geologic units in the stratigraphic sequence are the Precambrian metamorphic and igneous rocks (fig. 2), which are exposed in the central core of the Black Hills, extending from near Lead to south of Custer. The Precambrian rocks generally are of low permeability; however, localized fracture systems do provide adequate well yields for limited use in many areas.

Surrounding the Precambrian core is a layered series of sedimentary rocks including limestones, sandstones, and shales that are exposed in roughly concentric rings around the uplifted flanks of the Black Hills. The more permeable of these sedimentary rocks are able to store and transmit significant quantities of water and are commonly used as aquifers within and beyond the study area. Alluvial deposits along streams and terrace deposits also are commonly used local aquifers.

Observation wells completed in aquifers within the Inyan Kara Group, Minnekahta Limestone, Minnelusa Formation, Madison Limestone, and Deadwood Formation are monitored for the Hydrology Study. These aquifers generally are separated by confining units, which are composed of less permeable rocks. Recharge to these aquifers is from precipitation on the outcrop areas and from stream infiltration along the flanks of the Black Hills. The aquifers and confining beds generally dip away from the flanks of the Black Hills (fig. 2). This results in artesian conditions, meaning that the water in a well will rise above the top of the aquifer in which it is completed. If the water level, or potentiometric surface, is above the land surface, a flowing well will result. Similarly, artesian springs that originate from subsurface aquifers are common around the periphery of the Black Hills.

The complex hydrogeologic system of the Black Hills area is further complicated by the heterogeneity (irregularity) of the geologic units. The thickness and permeability of aquifers and confining beds are known to change with location (Greene, 1993; Kyllonen and Peter, 1987; Peter, 1985). Numerous fractures, faults, and solution cavities allow flow of water in rocks that otherwise are relatively impermeable. This can allow flow to occur through confining units, as is the case for many artesian springs, and results in increased permeability and well yields for aquifers in localized areas. This is especially true of the Madison Limestone, which is well known for its karst features, including sinkholes and water-loss zones in streams, collapse features, solution cavities, and caves. Two of the largest caves in the world, Jewel Cave and Wind Cave, are located in the Madison Limestone.

The base flow of most Black Hills streams originates at the higher altitudes, where increased precipitation and reduced evapotranspiration result in excess water being available for springflow and streamflow. Several streams, most notably Rapid Creek and Spearfish Creek, derive a steady and reliable base flow from large headwater springs on the eastern fringe of an area called the Limestone Plateau. Unlike the artesian springs described above, the headwater springs originate in the limestone outcrop and drain by gravity under water-table conditions. Stream reaches within the central, Precambrian core of the Black Hills are more responsive to precipitation than reaches within the limestone areas, with high flows during wet periods and low flows during dry spells. Most streams lose all or part of their flow as they cross the outcrop of the Madison Limestone (water-loss zone) near the periphery of the Black Hills. These loss zones provide an important source of recharge to the Madison.

STATUS OF BLACK HILLS HYDROLOGY STUDY

A large amount of hydrologic information is being collected, compiled, and distributed through the Black Hills Hydrology Study. As of March 1994, 19 continuous-record streamflow gages, 16 partial-record streamflow gages, and 38 precipitation gages were in operation. All streamflow and precipitation data are published annually in the Water Resources Data Report for South Dakota (U.S. Geological Survey, 1991-93). Continuous-record water-level data were being collected at 38 observation wells and 2 cave sites. Water-level records through water year 1992 (WY92; the water year ends on September 30 of the year given) were recently published in the first in a series of data reports for the Hydrology Study (Driscoll and Bradford, 1994). Water-quality data for surface- and ground-water sites are routinely collected and published, either in the project data reports or in interpretive reports. Considerable progress has been made on inventories of springs and wells in the Black Hills area. Geophysical logging of wells is conducted on an ongoing basis. The observation-well network is being expanded, as several new wells generally are drilled each year by DENR in support of the Hydrology Study. Control structures have been installed at 10 streams and springs to provide accurate streamflow data.

Significant progress also has been made on interpretive work for the Hydrology Study. A Geographic Information System (GIS) for the study area has been developed for the analysis and display of spatially referenced data. The GIS base coverages include political and public land-survey boundaries, hydrographic features, roads, and simplified surface geology at the 1:100,000 scale. Finally, a series of planned USGS publications is in preparation. Updates on the status of various publications, as well as on the progress of other activities, are provided in quarterly and annual progress reports.

SIGNIFICANT RECHARGE TO BLACK HILLS AQUIFERS OCCURS DURING 1993

There is concern that increased demand on ground-water resources has the potential to decrease water levels in the Black Hills area. Water levels in wells can be affected by several factors. Short-term declines can result from pumping of nearby wells or dry climatic conditions. Long-term declines generally indicate that discharge from the aquifer exceeds recharge for a given period of time. Conversely, increases in water levels generally correspond with periods of wet climatic conditions when aquifer recharge exceeds discharge. A long-term decline in water levels in the Black Hills area could have various effects, including changes in ground-water flow patterns, reduction of springflow, increased pumping costs, and perhaps even dry wells.

Some short-term declines in water levels in the Black Hills area have occurred, as indicated by hydrographs contained in a report entitled "Compilation of selected hydrologic data, through water year 1992, for the Black Hills Hydrology Study" (Driscoll and Bradford, 1994). In addition to water-quality and springflow data, this report presents water-level records for 32 observation wells and 2 cave sites. Hydrographs for about one-half of the wells show a downward trend in water levels for the periods of record presented in the report, and about one-half of the hydrographs show no trend. Most of the hydrographs that show downward trends have less than 10 years of record. These water-level declines can be attributed partially to dry climatic conditions in the Black Hills area during the late 1980's that continued into the early 1990's in some localized areas. During this period, recharge generally was less than normal and withdrawals from wells probably were larger than normal, which resulted in some water-level declines. Hydrographs for six wells that show generally declining water levels through WY92 are presented in figure 3. A dashed, vertical line near the right side of each hydrograph shows the end of WY92. Locations of these wells are shown in figure 1.

Precipitation amounts generally increased to near normal during 1991-92 and were above normal for most of the Black Hills area during 1993. This has resulted in significant recharge to Black Hills aquifers during WY93, subsequent to preparation of the aforementioned report. Hydrograph A in figure 3 is for a well completed in the Inyan Kara Group, which shows no response to the effects of climatic conditions through the entire period of record. The rate of decline, while smaller than for the other hydrographs, is nearly constant. The effect of annual recharge on water levels in the other five wells is more apparent (fig. 3, hydrographs B-F). The declining trend through WY92 could be reversed for some of these wells if significant recharge continues.

It is premature to draw firm conclusions from data through WY93 regarding water-level trends for Black Hills aquifers. It is however, apparent, that there is sufficient stress on these aquifers to cause declines during dry climatic periods. It also is apparent that in many areas these aquifers respond quickly to recharge during wet periods. If withdrawal rates become sufficient to cause long-term declines in water levels, the resulting problems and possible solutions will be addressed by State and local water managers. The Black Hills Hydrology Study will provide the regional hydrogeologic information necessary to aid in making sound decisions.

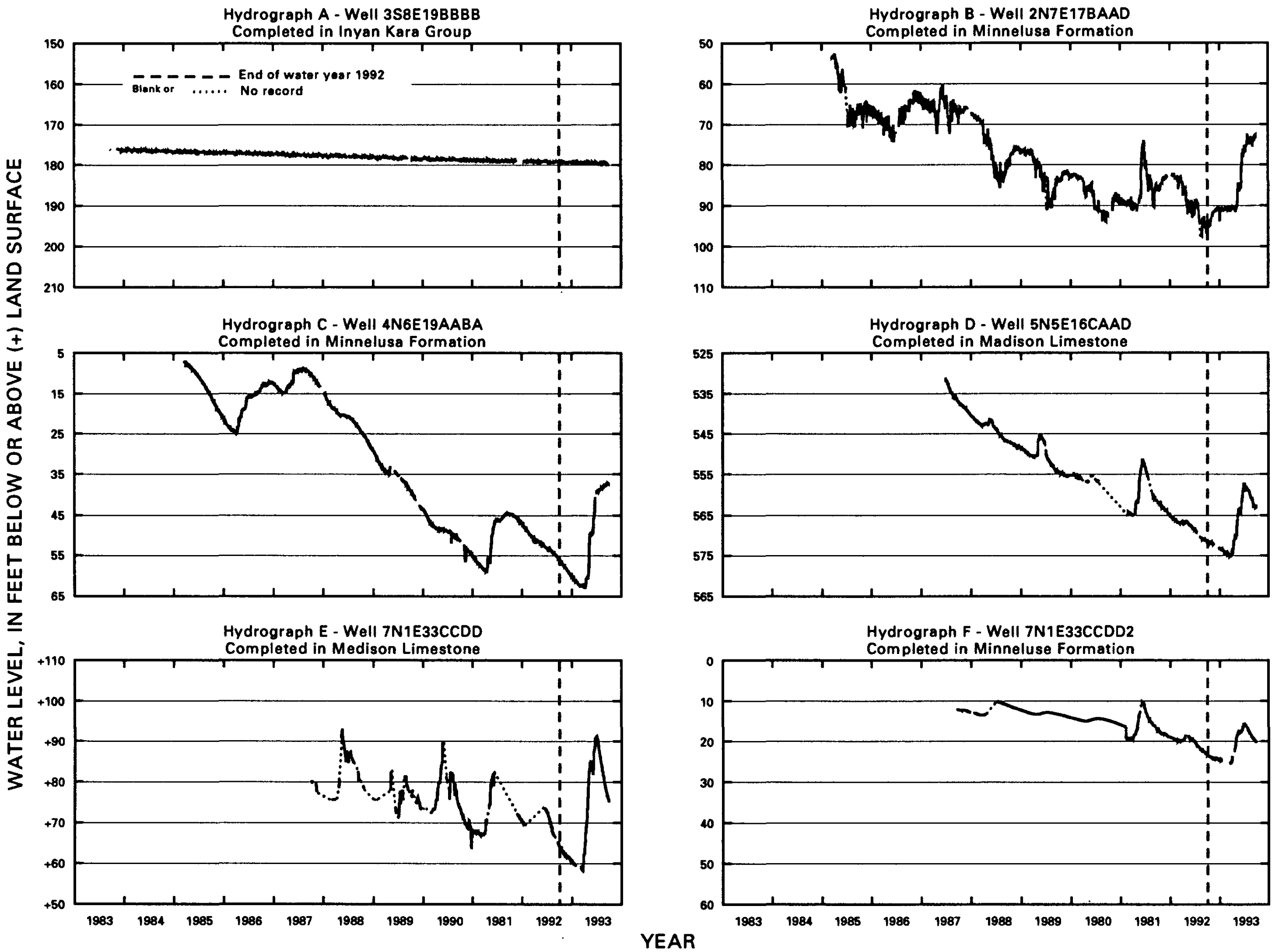

Figure 3.--Hydrographs for selected observation wells in the Black Hills area.

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