Summary of Major Findings

This report summarizes results of the Black Hills Hydrology Study, which was initiated in 1990 to assess the quantity, quality, and distribution of surface water and ground water in the Black Hills area of South Dakota. A summary of major findings regarding precipitation, ground water, surface water, water quality, and hydrologic budgets in the Black Hills area is provided in this section of the report.

The Black Hills Hydrology Study was designed as a regional assessment of water resources and was not designed to address site-specific issues. Because the Black Hills area of South Dakota and Wyoming is an important recharge area for several regional bedrock aquifers and various local aquifers, the study concentrated on describing the hydrologic significance of selected bedrock aquifers. The major aquifers in the Black Hills area are the Deadwood, Madison, Minnelusa, Minnekahta, and Inyan Kara aquifers. The highest priority was placed on the Madison and Minnelusa aquifers, which are used extensively and heavily influence the surface-water resources of the area.

Precipitation

- For the study area, long-term (1931-98) annual precipitation averages 18.61 inches.
- Precipitation patterns are strongly influenced by topography, with annual averages ranging from less than 16 inches in low altitudes to as much as 28 inches in high altitudes.
- Potential evaporation exceeds precipitation throughout most of the study area. Average annual pan evaporation ranges from about 50 inches in low altitudes to slightly less than 30 inches in high altitudes.
- Much of the study period was dominated by extremely wet climatic conditions during the 1990's, which is the wettest period since 1931. Thus, extensive hydrologic data sets for this period are somewhat biased towards wet conditions.
- Hydrologic data sets are less extensive for short-term drought conditions that occurred during the late 1980's.
- Hydrologic data sets are sparse for prolonged drought conditions that occurred during the 1930's and 1950's. Thus, measured hydrologic responses to prolonged drought conditions generally are unavailable.

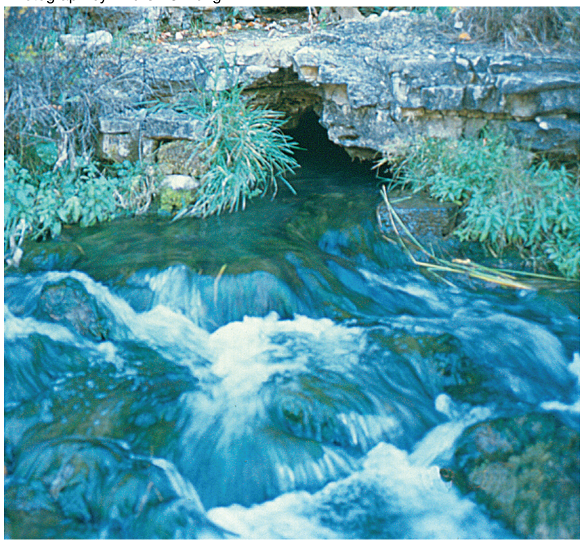
Ground Water

- A series of 1:100,000-scale maps showing ground-water resources have been produced, including maps showing the distribution of hydrogeologic units, potentiometric surfaces of the major bedrock aquifers, and altitudes of the tops of selected geologic formations. Smaller versions of selected maps and derivative products are provided in this report.
- Total recoverable storage for the major aquifers (including the Precambrian aquifer) within the study area is estimated as 256 million acre-feet. Estimates for individual aquifers are provided.
- Water-level records have been collected for 71 observation wells completed in bedrock aquifers, providing useful information for hydrologic analyses and management of water resources. There is very little indication of declining water levels from ground-water withdrawals; a decline of about 4 feet over 16 years was observed in one observation well.
- A large percentage of the observation wells are completed in the Madison and Minnelusa aquifers, where water levels in many wells respond quickly to changes in climatic conditions. Rapid water-level increases result from the large recharge capacity of these aquifers. Relatively rapid declines are caused by decreases in storage resulting from ground-water flow away from the uplift and artesian springflow.
- In the Madison and Minnelusa aquifers, water-level fluctuations in the northern Black Hills generally are larger than in the southern Black Hills, which results, in part, from larger recharge rates in the northern Black Hills.
- The Limestone Plateau area on the western flanks of the Black Hills is a major recharge area for the Madison and Minnelusa aquifers because of large outcrop areas and high recharge rates. Flowing streams are uncommon within the Plateau because of high infiltration rates; however, large "headwater" springs are common, especially near the base of the Madison Limestone along the eastern edge of the Plateau.
- A ground-water divide was identified for the Madison aquifer in the Limestone Plateau area. West of the divide, ground-water flowpaths in the Madison and Minnelusa aquifers are primarily to the west. East of the divide, recharge contributes primarily to headwater springflow, which also includes some discharge from the Deadwood aquifer.
- The Madison and Minnelusa aquifers are the primary sources of water to large artesian springs that occur in various locations around the periphery of the Black Hills. Hydraulic connection between the Madison and Minnelusa aquifers probably occurs at many artesian spring locations.
- Upward leakage of water from the Madison aquifer and associated dissolution of anhydrite in the Minnelusa aquifer are instrumental in the formation of breccia pipes within the Minnelusa Formation. This probably is the process by which most artesian springs are formed.

Photograph by Mark D. Fahrenbach, South Dakota Department of Environment and Natural Resources

Photograph by Ralph W. Teller

Photograph by Andrew J. Long



Photograph by Joyce E. Williamson

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- Leakage between the Madison and Minnelusa aquifers must occur at many locations where a gradient exists between the two aquifers, but leakage probably is minor, relative to artesian springflow.
- Regional flowpaths in the Madison and Minnelusa aquifers are largely deflected around the Black Hills. The dominant proportion of water in these aquifers within the study area is recharged within the Black Hills area.
- Age-dating analyses indicate that ground-water flow velocities in the Madison and Minnelusa aquifers are extremely variable. Extremely high velocities can occur in close proximity to areas with relatively slow velocities.
- Many artesian springs have higher tritium concentrations than water from wells because artesian springs preferentially occur along high-permeability flowpaths, which have relatively fast traveltimes. Headwater springs generally have high tritium concentrations indicating relatively large proportions of water recharged since initiation of nuclear testing.
- Artesian springs act as a "relief valve" for the Madison and Minnelusa aquifers and are an important mechanism in controlling water levels in these aquifers. Springflow of many large springs changes very slowly in response to long-term climatic conditions. Some springs respond more quickly.
- Artesian springflow could be diminished by large-scale well withdrawals near springs, impacting surface-water resources. Reduced springflow may not necessarily be accompanied by large-scale declines in ground-water levels. Large-scale development of the Madison and Minnelusa aquifers has the potential to influence the balance of the unique and dynamic "plumbing system" that controls interactions between ground-water levels and artesian springflow.
- The large recharge potential of the Madison and Minnelusa aquifers may provide various options for future management of ground- and surface-water resources. Large recharge during prolonged wet conditions may have potential to replenish moderate reductions in springflow and ground-water levels relatively quickly.

Surface Water

- Five hydrogeologic settings were identified for the Black Hills area that have distinctive influences on streamflow and water-quality characteristics. These settings are the limestone headwater, crystalline core, artesian spring, loss zone, and exterior settings.
- Streamflow variability is small for the limestone headwater and artesian spring settings because of dominance by ground-water discharge. The largest headwater springs are in the Rapid Creek and Spearfish Creek Basins. The largest artesian spring discharge areas are located near the northern and southern axes of the Black Hills uplift. The single largest discharge area is a complex of springs that includes Cox Lake and Crow Creek.
- The crystalline core setting consists primarily of igneous and metamorphic rocks within the central core of the Black Hills. Streamflow characteristics in this setting are influenced by direct runoff and by relatively small ground-water discharge, which tends to diminish rather quickly during periods of dry climatic conditions.
- The loss zone setting consists of areas influenced by streamflow losses that occur as streams cross outcrops of the Madison Limestone and Minnelusa Formation. During periods of base flow, most streams lose their entire flow when crossing these outcrops, which provides an important source of recharge for the Madison and Minnelusa aquifers. Unique loss thresholds exist for individual streams, with measured thresholds ranging from negligible losses to as much as 50 cubic feet per second for Boxelder Creek.
- The exterior setting consists of areas beyond the outcrop of the Inyan Kara Group, which is used to represent the outer extent of the Black Hills area. Streamflow variability is large for exterior basins, which are heavily influenced by direct runoff but generally have only minor influence from ground-water discharge.

Water Quality

- Water quality of the major aquifers generally is very good in and near outcrop areas but deteriorates progressively with distance from outcrops. In the Minnelusa aquifer, concentrations of dissolved sulfate increase markedly over short distances, where a zone of active anhydrite dissolution exists.
- Most limitations for the use of ground water are related to aesthetic qualities associated with high concentrations of common ions or the trace elements iron and manganese. Water from carbonate aquifers may be hard, and high sulfate concentrations occur in many aquifers.
- Very few health-related limitations exist for ground water; most are associated with constituents associated with radioactive decay, such as radon and uranium.

- Surface-water quality is distinctively influenced by the hydrogeologic settings that have been identified. For most streams, concentrations of dissolved solids increase as streamflow decreases. However, for streams in the limestone headwater and artesian spring settings, which are dominated by ground-water discharge, concentrations of common ions have little variability.
- Most streams generally meet water-quality standards established for designated beneficial uses. The primary exceptions are streams in the exterior setting, which frequently fail to meet standards for temperature and dissolved oxygen during low-flow conditions.
- Human influences have the potential to degrade water quality for both ground water and surface water. For ground water, the potential for contamination can be large because of development on outcrop areas, large secondary porosity, and relatively fast flow velocities. For surface water, various land-use practices can affect water quality. Two Superfund sites have been listed in the Black Hills area primarily related to concentrations of various trace elements resulting from mining activities. Various urban and suburban influences also can degrade stream quality.
- Various trace elements can be concentrated in irrigation return flows. Elevated concentrations of selenium can occur in some marine shales that are common to the area; however, various studies have indicated that effects of irrigation are minimal in the study area.

Hydrologic Budgets

- Hydrologic budgets were developed for 1950-98, during which time precipitation in the study area averaged 18.98 inches per year, which is equivalent to an average flow rate of about 7,240 cubic feet per second. This is equivalent to about one-third of the average flow of the Missouri River where it enters South Dakota from the north.
- About 92 percent of annual precipitation is returned to the atmosphere via evapotranspiration. About 3.5 percent of annual precipitation recharges aquifers in the study area, and about 4.5 percent of annual precipitation is generated as runoff from the land surface.
- Total consumptive use within the study area from both ground-water and surface-water resources was estimated as 218 cubic feet per second, which includes well withdrawals of 40 cubic feet per second, reservoir evaporation of 38 cubic feet per second, and consumptive streamflow withdrawals of 140 cubic feet per second.
- Net tributary flows, after consumptive streamflow withdrawals, accounted for about 201 cubic feet per second in the Cheyenne River drainage basin and about 107 cubic feet per second in the Belle Fourche River drainage basin. Thus, streamflow contributions from the study area to the Missouri River amount to about 4 percent of the average flow of the Missouri River where it enters South Dakota.
- Ground-water budgets for the study area are dominated by the Madison and Minnelusa aquifers. Artesian springflow is the single largest discharge component from the Madison and Minnelusa aquifers, and accounts for 38 percent of the total discharge from these aquifers.
- Recharge to the Madison and Minnelusa aquifers for 1931-98 in South Dakota and Wyoming averaged about 344 cubic feet per second. Recharge ranged from about 62 cubic feet per second in 1936 to about 847 cubic feet per second in 1995.

Photograph by Brenda J. Athow