ASSESSMENT OF THE HYDROLOGIC SYSTEM AND HYDROLOGIC EFFECTS OF URANIUM EXPLORATION AND MINING IN THE SOUTHERN POWDER RIVER BASIN URANIUM DISTRICT AND ADJACENT AREAS, WYOMING, 1983

By Marlin E. Lowry, Pamela B. Daddow, and Samuel J. Rucker, IV

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 90-4154

Prepared in cooperation with the

WYOMING STATE ENGINEER and the

WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY

Cheyenne, Wyoming

1993

U.S. DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
2617 E. Lincolnway, Suite B
Cheyenne, Wyoming 82001

Copies of this report can be purchased from:

U.S. Geological Survey
Books and Open-File Reports
Box 25425, Federal Center
Denver, Colorado 80225

CONTENTS

PLATES

FIGURES

FIGURES--Continued

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
acre	0.4047	hectare
cubic foot per day per foot	0.09290	cubic meter per day per meter
cubic foot per second	0.02832	cubic meter per second
foot	0.3048	meter
foot squared per day	0.09290	meter squared per day
mile	1.609	kilometer
square mile	2.590	square kilometer
ton, short	0.9072	megagram

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

$$^{\circ}F = 9/5\ (^{\circ}C) + 32$$

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

ASSESSMENT OF THE HYDROLOGIC SYSTEM AND HYDROLOGIC EFFECTS OF URANIUM EXPLORATION AND MINING IN THE SOUTHERN POWDER RIVER BASIN URANIUM DISTRICT AND ADJACENT AREAS, WYOMING, 1983

By Marlin E. Lowry, Pamela B. Daddow, and Samuel J. Rucker, IV

ABSTRACT

In the Southern Powder River Basin Uranium District an estimated 115,000 exploration holes had been drilled by 1981, and there were five major mining operations. Local residents were concerned that these activities potentially could affect the availability and quality of ground water used for domestic and stock-watering supplies.

The oldest formation to which water wells had been drilled is the Fox Hills Sandstone of Late Cretaceous age. Most water, however, is developed from the Wasatch Formation of Eocene age and the Fort Union Formation of Paleocene age, and most uranium mined is from the Wasatch Formation. These formations consist of a discontinuous series of sandstones and coal beds, with intervening shales and siltstones. Generally, the sandstones and coal beds are confined aquifers.

Two concepts of ground-water flow in the area have been hypothesized: one with a large component of vertical flow and natural discharge to streams predominantly at stream level, and one with restricted vertical flow with most natural discharge above stream level. The hypotheses were tested using potentiometric-surface data, locations of ground-water discharge points and flowing wells, vertical flow in response to pumping, and locations of uranium-ore deposits. The hypothesis of a system with large vertical flow is not supported by hydro- logic information and on-site inspections. The system with restricted vertical flow is accepted as more likely for this area and is used for evaluating the effects of uranium exploration and mining on ground water.

No regional pattern of water-level change as a result of exploration or mining in the area could be discerned. Water-level declines in some agricultural wells were greater in the past because of pumping than declines measured during 1981 and 1982.

In spite of the large number of exploration holes drilled, only a few could be located for inspection. There was no evidence of substantial vertical flow of ground water at exploration holes or in some collapsed older workings inspected in the Highland underground mine. However, one site was found where water levels probably had been lowered as a result of exploration drilling.

Within the five lease areas, pumping ground water for supplies at mines and mills and to dewater underground mines adversely affected water levels only in stock-water and domestic wells completed in the same stratigraphic unit as the mine wells. This occurred at the Bear Creek Mine, where agricultural wells are relatively deep because artesian flows can be obtained. Pumping at the Highland, Golden Eagle, and Kerr-McGee mine-lease areas did not affect water levels in stock-water and domestic wells, because the aquifers used for stock-water and domestic supplies are shallower than those used for mine supplies.

No evidence was found to indicate that water quality was adversely affected by mixing of water of different salinity as a result of vertical flow of water in ineffectively plugged exploration holes. Wells for stock water and domestic use, completed in aquifers throughout the vertical section drilled for uranium, continued in use with no reported substantial increases in salinity.

INTRODUCTION

In 1980, the U.S. Geological Survey (USGS) started an investigation of potential hydrologic effects of development of uranium resources in the southern part of the Powder River structural basin in northeastern Wyoming. The structural basin is referred to as the Powder River Basin in this report. The investigation plan was revised in 1981 to focus on activities of the uranium industry in the Southern Powder River Basin Uranium District and adjacent areas in Converse County (fig. 1).

By 1981, thousands of exploration holes had been drilled in the area. Many of the holes were unplugged or ineffectively plugged, potentially allowing flow between previously isolated aquifers and, in some places, uncontrolled discharge at the surface. Surface, underground, and (or) in-situ mining was taking place at several locations in five major lease areas, identified (pl. 1) as: Bear Creek (Rocky Mountain Energy Corp.), Golden Eagle and Morton Ranch (Tennessee Valley Authority/United Nuclear Corp.), Highland (EXXON Minerals Co.), and Kerr-McGee (Kerr-McGee Nuclear Corp.). Additional mines were being planned in 1981.

The revised investigation was conducted by the USGS in cooperation with the Wyoming State Engineer and the Wyoming Department of Environmental Quality, in response to concerns expressed through the Converse County Organization for Groundwater Studies. Because there are no perennial streams crossing the area, ground water is the only source for domestic and stock-watering supplies. Ranchers and other local residents were concerned mainly about declining water levels in domestic and stock-water wells, including loss of pressure in flowing wells.

The investigation was terminated in 1983, as uranium development was declining rapidly, and the mines and mills were being shut down. The results of the investigation provide information about the hydrologic system in a large part of Converse County, Wyoming that is of current (1990) interest because of plans to develop coal-bed methane in the area. Because water will be pumped in the process of obtaining the methane, there is concern about the effects of the withdrawals on agricultural water supplies in the area.

Purpose and Scope

This report describes: (1) The hydrologic system in the Southern Powder River Basin Uranium District, and (2) the nature and extent of hydrologic effects of uranium exploration and mining in the area. The hydrologic effects are evaluated for the period 1980-83.

A network of observation wells was established at the start of the investigation using stock-water, domestic, and other wells. Water levels were measured, and samples from a few wells were collected to determine water quality. Streamflow and water-quality data were collected at miscellaneous

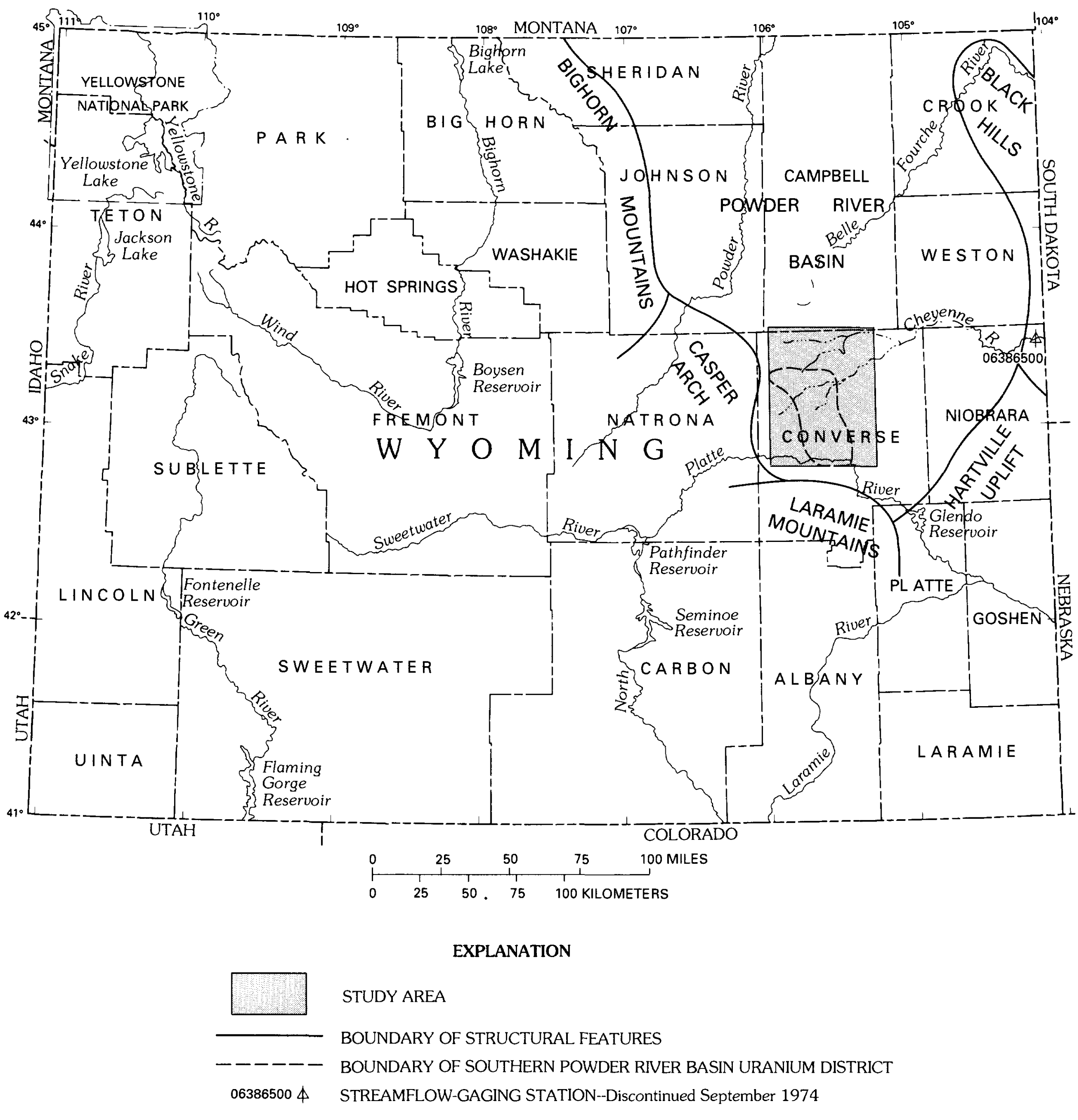

Figure 1.--Location of the study area, the Powder River Basin, the Southern Powder River Basin Uranium District, and the streamflow-gaging station on the Cheyenne River near Spencer, Wyoming.

surface-water sites, mostly downstream from uranium mines and mills. Analyses of water-quality samples collected prior to 1980 at several wells and one surface-water site also are included in this report. Generally, however, few pre-mining hydrologic data are available, so detailed comparisons of hydrologic conditions before and after mining are not possible. Analysis of radiochemical hazards and in-situ mining is beyond the scope of this study.

Conclusions about the hydrologic system and the hydrologic effects of development of uranium resources are based upon on-site observations, examination of hydrologic data, and other evidence, such as interviews with local residents and representatives of mining companies. Surface-water indicators of ground-water flow, such as perennial flow in some reaches of otherwise ephemeral streams and intermittent flow in some streams, are used extensively. Data deficiencies preclude the use of rigid, quantitative analyses. Two hypotheses of the flow system are compared. The one not supported by available information is rejected; the other is accepted as the more likely hypothesis. The hydrologic effects of uranium exploration and mining are evaluated on the basis of the hypothesis of the flow system accepted in this report.

Previous Investigations

Several reports prepared since 1970 describe some aspect of water resources in the area. Hodson and others (1973), and Lowry, Wilson, and others (1986) described the general hydrology and water resources of the Powder River Basin. Rankl and Lowry (1990) described regional ground-water flow. Hotchkiss and Levings (1986) used a digital flow model to assess the regional ground-water flow system. Hagmaier (1971) described ground-water flow, hydrogeochemistry, and uranium deposition in the Powder River Basin in Wyoming. Dahl and Hagmaier (1976) described the genesis of uranium deposits, including the related chemistry and flow of ground water.

Well-Numbering System

Ground-water wells are numbered in this report according to the Federal system of land subdivision. An example is illustrated in figure 2. The first number indicates the township north of the 40th Parallel Base Line; the second number indicates the range west of the Sixth Principal Meridian; and the third number indicates the section in which the well is located. The subdivisions of a section are denoted by letters a, b, c, and d in a counterclockwise direction, starting in the northeast quarter. The first letter denotes the quarter section (160 acres), the second letter the quarter-quarter section (40 acres), and the third letter the quarter-quarter-quarter section (10-acre tract). The first well in a tract is assigned a sequence number 01; additional sites are numbered consecutively.

GEOLOGY

The study area is in the southern part of the Powder River Basin in northeastern Wyoming. The Wyoming part of the basin is flanked on the west by the Bighorn Mountains and the Casper Arch, on the south by the Laramie Mountains, and on the east by the Hartville Uplift and the Black Hills (fig. 1). The basin is asymmetrical--the north-plunging axis is closer to the west side (pl. 1). The stratigraphic sequence of interest in this study is shown in figure 3.

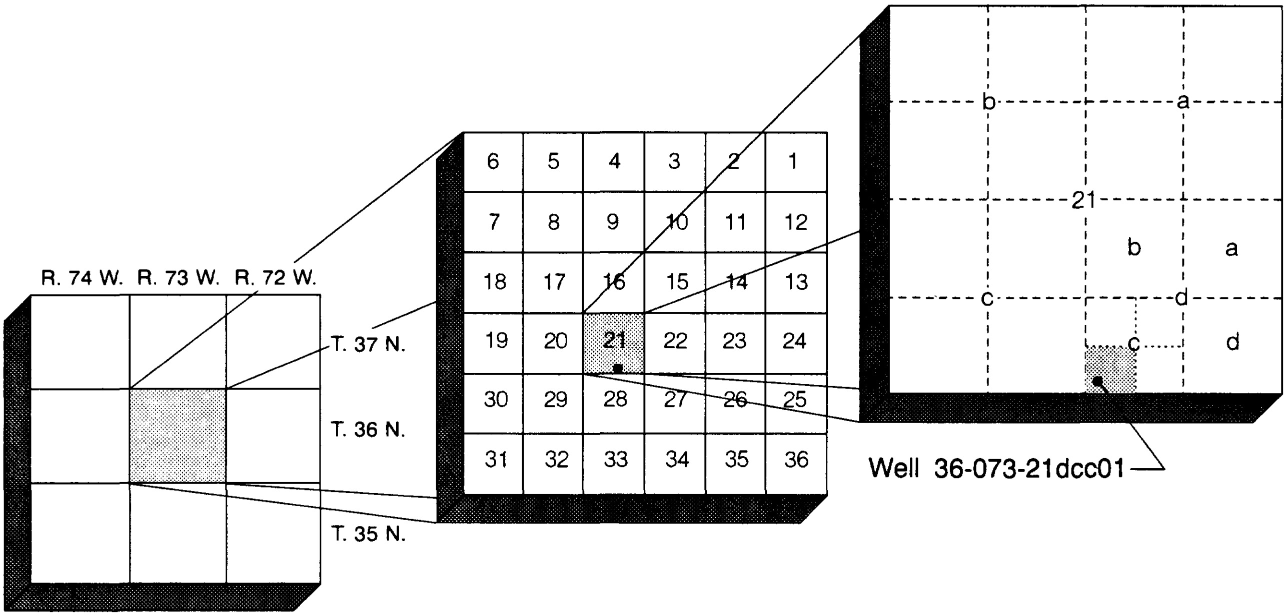

Figure 2.--System for numbering wells.

The Fox Hills Sandstone of Late Cretaceous age is the oldest formation for which information is included in this report. The Fox Hills consists of marine sandstone and shale and is about 450 feet thick in an oil test in sec. 16, T. 36 N., R. 74 W. The formation crops out in the southern part of the study area, but it is deeply buried in most of the area. It is more than 2,000 feet below sea level in the northwestern part of the area (pl. 1).

The Lance Formation of Late Cretaceous age, which overlies the Fox Hills Sandstone, consists of shale and massive lenticular sandstone. Many thin coal beds are present in the lower part of the Lance Formation, but coal generally is not present in the upper part of the formation. The Lance Formation and overlying Tertiary rocks are of continental origin. The Lance Formation is about 3,000 feet thick in the southwestern part of the Powder River Basin (Denson and Horn, 1975) and thins northward.

SYSTEM	SERIES	STRATIGRAPHIC UNIT	
QUATERNARY	Holocene	Dune sand; alluvium	
TERTIARY	Eocene	Wasatch Formation	
	Paleocene	Fort Union Formation	Lebo Member
			Tullock Member
CRETACEOUS	Upper Cretaceous	Lance Formation	
		Fox Hills Sandstone	

Figure 3.--Stratigraphic sequence of interest in this study.

The Fort Union Formation of Paleocene age, which overlies the Lance Formation, consists of the Tullock and Lebo Members in the southern part of the Powder River Basin. However, beds mapped within the Tongue River Member of the Fort Union Formation in the northern part of the Powder River Basin are included with the Lebo Member in this area (Denson and others, 1980). The Tullock Member (the lower member) consists of interbedded sandstone, shale, carbonaceous shale, and thin coal beds. The sandstones are massive to thin and are evenly bedded. The thickness of the Tullock Member ranges from 1,000 to 1,500 feet (Denson and Horn, 1975). The overlying Lebo Member generally has a predominance of siltstone and shale but contains some very-fine-grained to conglomeratic sandstone, carbonaceous shale, and coal. Some of the coal beds are more than 4 feet thick. The Anderson coal bed occurs near the top of the Lebo in the northern part of the study area but is absent in the south, probably because of erosion. The thickness of the Lebo Member ranges from about 1,700 to 2,800 feet (Denson and Horn, 1975).

The Wasatch Formation of Eocene age, which overlies the Fort Union Formation, consists of conglomeratic to fine-grained arkosic sandstone interbedded with siltstone, shale, carbonaceous shale, and coal. Connor and others (1976) describe criteria, using heavy minerals, to distinguish between the Fort Union and the Wasatch. The largest percentage of sandstone is at the southwestern edge of the basin, in a zone trending northward, parallel to the axis of the basin (Santos, 1981, p. 2). This zone also has been mapped as the coarse-grained facies of the Wasatch by Raines and Santos (1980, sheet 1). Sharp and others (1964, p. 553) described individual sandstones in an area 9.5 miles north of the study area. They state that "Most of the sandstone lenses * * * are as much as 6 to 8 miles by 4 to 5 miles in areal extent and from a few to 50 feet thick. The largest mappable sandstone * * * is traceable for more than 12 miles northwestward across the area." Most of the uranium deposits are in the Wasatch. The maximum thickness of the Wasatch is about 1,800 feet (Denson and Horn, 1975).

The White River Formation of Oligocene age was deposited throughout the study area but subsequently was removed by erosion. The White River was the probable source of uranium in the area (Zielinski, 1983).

Deposits of Holocene age include dune sand and alluvium. Small areas of dune sand occur throughout the area. The most widespread deposits are in the southwest and are the only deposits extensive enough to show on plate 1. The deposits are as thick as 200 feet (Denson and Horn, 1975). Alluvium underlies most stream valleys; however, the deposits generally are less than 30 feet thick and less than 0.5 mile wide. Bedrock outcrops are common in stream channels.

URANIUM EXPLORATION AND MINING

Uranium mining in the study area began in 1953. Ninety percent of the 50,000 tons of ore produced in the Powder River Basin prior to 1966 was from the Monument Hill area (T. 37 N., R. 73 W., pl. 1) in the Southern Powder River Basin Uranium District (Davis, 1969, p. 131). Beginning in 1966, exploration for uranium in the study area increased substantially because of the demand for fuel for nuclear powerplants. The first of the new mines began production in 1972 on the Highland lease (pl. 1). By 1981 there were five major mining operations; the location of uranium mine-lease areas and reported uranium-ore bodies is shown on plate 1. The annual tonnage of ore produced from 1971 to 1982 from the Southern Powder River Basin Uranium District is listed in table 1.

Exploration methods varied with the intensity of uranium exploration. Near-surface deposits, mined first, were located using radiometric surveys of the land surface. During early exploration and mining, excavated trenches commonly were used to validate mining claims; few exploration holes were drilled. With the resurgence of exploration in 1966, systematic surveys using airborne gamma-ray radiometry and water-sampling programs were succeeded shortly by land acquisition and exploration drilling (Davis, 1969, p. 131). Initial drilling was to depths of only a few hundred feet, but by 1982 exploration drilling to depths of about 1,000 feet was common. Much of the drilling was in the area of known near-surface deposits.

Table 1.--Uranium-ore production from the Southern Powder River Basin Uranium District, 1971-82

[Sources: 1971-77, Quality Development Associates, Inc. (1978); 1978-82, Wyoming State Inspector of Mines (1978-82)]

Year	Ore production (tons)
1971	0
1972	256,150
1973	659,401
1974	767,630
1975	888,052
1976	1,117,302
1977	1,377,090
1978	2,163,009
1979	1,950,645
1980	1,724,603
1981	1,095,000
1982	1,333,500

In a typical exploration program, holes were drilled in a regular pattern, such as at section corners, throughout a large area. If the presence of ore was indicated by data from the initial set of exploration holes, additional holes were drilled to determine the trend of the ore body. Subsequently, lines of holes spaced 50 to 100 feet apart were drilled at 0.5- to 1.0-mile intervals across the trend line. Finally, holes were drilled in a grid with a spacing of 100 feet or less, to evaluate the deposit for mining.

Thus, in some places thousands of holes were drilled in a relatively small area, particularly where more than one company prospected the same area. One rancher in the study area estimated that about 6,000 uranium exploration holes had been drilled on his property within an area of about 7 square miles. The U.S. Department of Energy estimated that 100,000 to 150,000 holes were drilled in Converse County by 1981, with a best estimate of 115,000 holes.

Exploration and mining had decreased by 1982; still, more developmental and exploratory drilling occurred that year in Converse County, Wyoming, than in any other county in the United States (U.S. Department of Energy, 1983, p. 49). By the mid-1980's, exploration essentially had ceased in the county, and most mines had closed.

HYDROLOGIC SYSTEM

An understanding of the hydrologic system is fundamental to the evaluation of the effects of uranium exploration and mining. The ground-water and surface-water components of the hydrologic system are discussed separately, but the interrelation of the two components is an important part of the hydrology.

Ground Water

Most ground water in the Southern Powder River Basin Uranium District and adjacent areas is developed from the Wasatch Formation or the Fort Union Formation. The oldest formation developed for water is the Fox Hills Sandstone. The hydrogeologic framework in the Wasatch and Fort Union Formations is not isotropic and homogeneous, but is a series of sandstone, siltstone and coal beds with intervening shale. The sandstone and siltstone are discontinuous; some coal beds are extensive. Generally, the sandstones and coal beds are confined aquifers. In some places, uranium ore is present in sandstone between beds of coal or carbonaceous shale.

Ground-Water Flow

Two concepts of the ground-water flow system in the Wasatch Formation and, where present, in the Tongue River Member of the Fort Union Formation, have been hypothesized on the basis of previous investigations. One is a system in which the vertical component of flow is large enough that natural ground-water discharge to major streams is predominantly at stream level (see Hagmaier, 1971, figs. 14-16). The other concept is a system in which vertical flow is restricted, so that most natural discharge occurs above stream level, and ground water does not contribute measurable flow to major streams (Rankl and Lowry, 1990). The concept of ground-water flow similar to that of Hagmaier (1971) is depicted in figure 4A; the alternative concept is depicted in figure 4B. Large head differences may exist in either system, but the two systems differ in the ease of flow vertically between the sandstone lenses.

Because the hydrologic effects of uranium exploration and mining would be different for each hypothesized system, the two hypotheses were tested for the Southern Powder River Basin Uranium District and adjacent areas. Although uranium mining is not currently (1990) a major issue in the area, the information about the flow system could be useful for future ground-water-management decisions.

Information collected during the investigation is suitable for four different tests of the two hypotheses of ground-water flow: (1) The configuration of a potentiometric surface, (2) the distribution of natural discharge points and flowing wells, (3) the vertical flow of water, and (4) the location of uranium-ore deposits. The discussion of the location of the uranium deposits is in the section on ground-water quality; discussion of the other three tests follows.

Potentiometric surface.--"The potentiometric surface, *** is defined by the levels to which water will rise in tightly cased wells" (Lohman and others, 1972, p. 11). Differences in hydraulic head with changes in depth are a characteristic of both flow systems shown in figure 4. If an aquifer has large hydraulic-head differences with changes in depth, a potentiometric surface is meaningful only if it represents a particular stratum in that aquifer. In the study area, coal beds generally are the most continuous and correlatable horizons for which a potentiometric-surface map can be drawn.

Adequate data to define a potentiometric surface are available for only one horizon in the study area, the School coal bed. The area for which the data are available is where the School coal bed underlies Sage Creek Divide

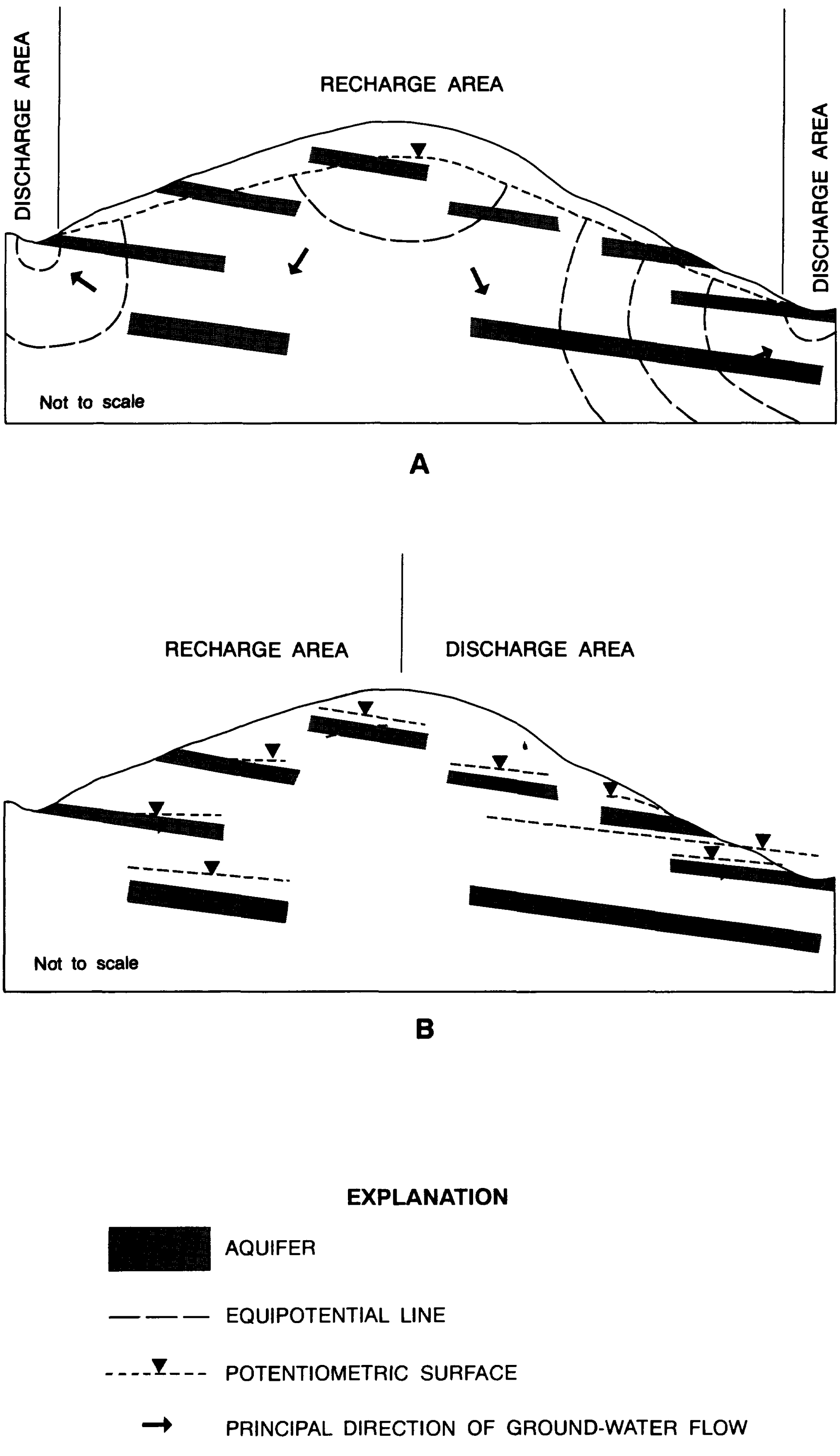

Figure 4.--Diagrammatic sections showing two concepts of the ground-water flow system for the study area.

(the drainage divide between the North Platte River basin and the Cheyenne River basin), and the drainage divide between the Sage Creek and Sand Creek drainage basins (fig. 5). Therefore, the area is an ideal location for testing the two hypotheses.

The contours defining the potentiometric surface for the School coal bed (fig. 5) do not indicate flow toward the west underneath the divide between Sage Creek and Sand Creek, which would occur if the flow pattern was similar to that shown in figure 4A. The potentiometric surface indicates that recharge is from the outcrop area west of the Sage Creek drainage basin and flow is to the east and to the north. This flow corresponds to that shown in figure 4B.

Natural discharge points and flowing wells.--The distribution of natural discharge points and flowing wells also can be used to test the two hypotheses of the flow system. If the system shown in figure 4A prevailed in the area, natural discharge points and flowing wells would be present on both sides of major drainage divides; if the concept of flow depicted in figure 4B prevailed, the natural discharge points and flowing wells would be dominantly downdip from the recharge area, and springs would be present on hillsides as well as near stream level (see area in T. 37 N., R. 74 W., pl. 2).

The distribution of springs and flowing wells is shown in figure 6. With one exception, all the known discharge points are in the Cheyenne River drainage basin. The exception is a spring that discharges from a near-surface sandstone at the drainage divide. On the basis of this information, together with the location of perennial and intermittent reaches of small streams (discussed in a subsequent section), the hypothesis of the flow system shown in figure 4A would be rejected, and that shown in figure 4B would be accepted as the more likely.

Vertical flow.--Vertical flow would occur in either flow system shown in figure 4. However, vertical flow would be much larger in the concept depicted in figure 4A than in 4B, and the nature of the flow can be used as an indicator of which hypothesis of ground-water flow is more likely in the study area. The position of springs with respect to the base of the Wasatch Formation, as well as the vertical flow of water in response to pumping from an underlying aquifer, generally do not support the hypothesis of a flow system with large vertical permeability (fig. 4A).

The Wasatch Formation is considered by some investigators to be an aquifer and the underlying Lebo Member of the Fort Union Formation a confining unit (Lewis and Hotchkiss, 1981, sheet 1; Hotchkiss and Levings, 1986, p.10). If the Wasatch were a single hydrologic unit in the area, then a line of contact springs should be present at the base of the formation. One spring shown in figure 6 (T. 40 N., R. 71 W.) is a contact spring at the base of the Wasatch. This spring is from an outlier of the main body of the Wasatch.

The response of water levels in shallow aquifers to pumping from underlying aquifers is shown by the response of two wells at the Bill Smith Mine--an underground mine on the Kerr-McGee lease (pl. 2). Well 36-074-25ccc01 is open to aquifers in the Wasatch Formation from 94 to 536 feet below land surface, and well 36-074-25ccc02 is open to aquifers in the Wasatch Formation from 586 to 943 feet. The underground mining at the Bill Smith Mine was within the depth interval open to the deeper well, for which a water level of about

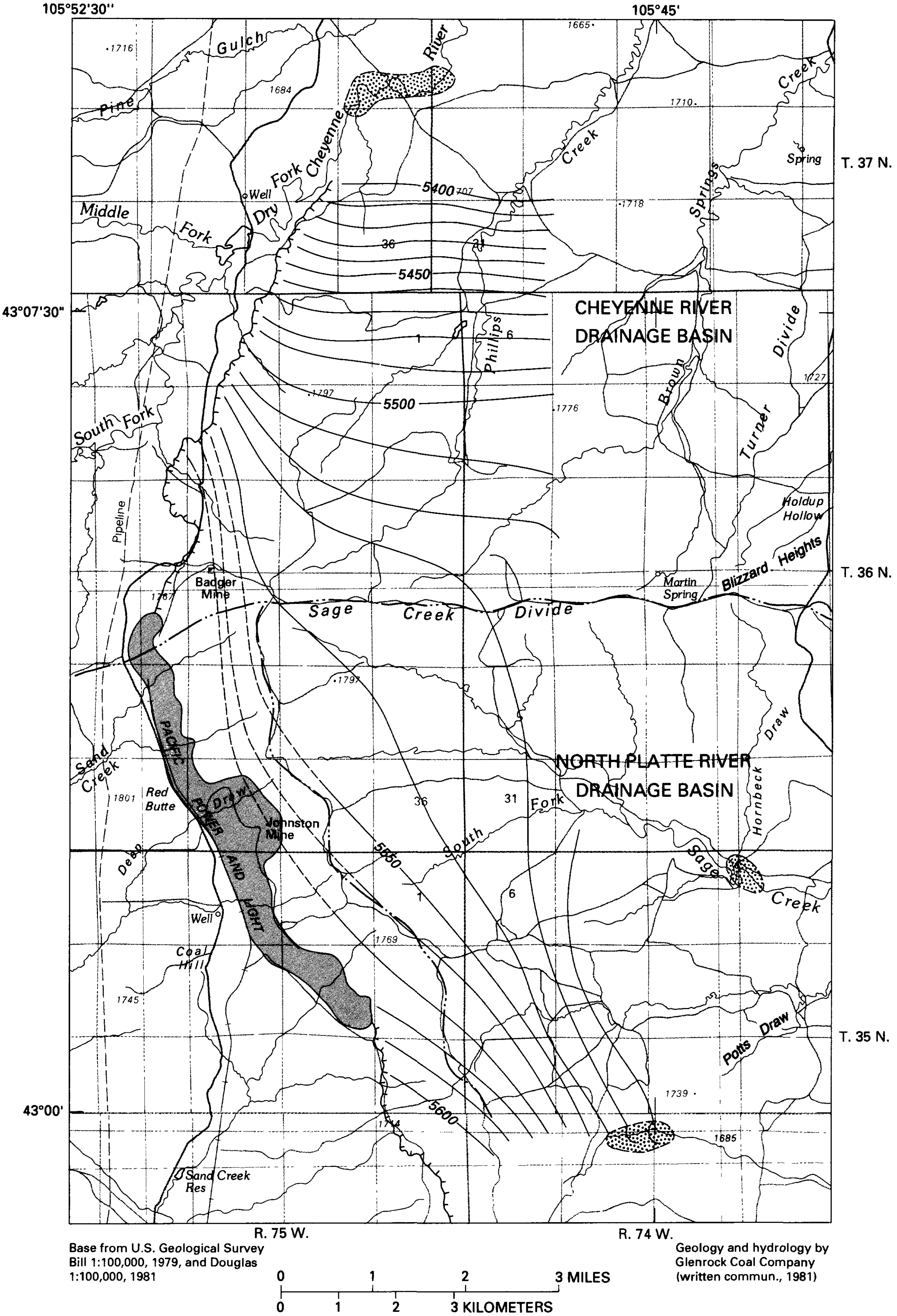

Figure 5.--Potentiometric surface of the School coal bed.

604 feet below land surface was measured in April 1980, when the mine was being dewatered. Although the bottom perforation of the shallow well is only 50 feet higher than the top perforation of the deep well, the water level in the shallow well apparently was not affected by 9 years of dewatering, but remained at a depth of about 150 feet below land surface. Nine months after dewatering of the mine ceased, the water level in the deep well had risen about 118 feet, and the water level in the shallow well was only about 1 foot higher than the highest water level measured from 1980 to 1981. The water-level change in the shallow well was within the range of natural water-level changes in wells that were distant from mines during a comparable period from 1981 to 1982, such as 36-073-21dcc01 and 02 (see table 2). At this site the data support the concept depicted in figure 4B.

Uranium-ore deposits.--The presence of the uranium ore in sandstone that is between beds of coal or other carbonaceous shale at the Highland and Bear Creek Mines supports the hypothesis that ground-water flow in the study area is predominantly horizontal (fig. 4B). Uranium, being soluble in the oxidized state but not in the reduced state, was readily leached from the tuffaceous rocks of the White River Formation, which do not contain organic carbon, and was redeposited in the underlying rocks in the zones where the geochemical conditions changed from oxidizing to reducing. If flow were vertical, the uranium ore would be located in the coal rather than in the underlying sandstone.

EXPLANATION

DAVE JOHNSTON COAL MINE

PROJECTED DISCHARGE AREA FOR SCHOOL COAL BED

5500 — POTENTIOMETRIC CONTOUR--Dashed where approximately located. Shows altitude at which water level would have stood in tightly cased wells completed in the School coal bed, April 1981. Contour interval 10 feet. Datum is sea level

OUTCROP OF SCHOOL COAL BED

SURFACE-WATER DRAINAGE DIVIDE

Figure 5.--Continued.

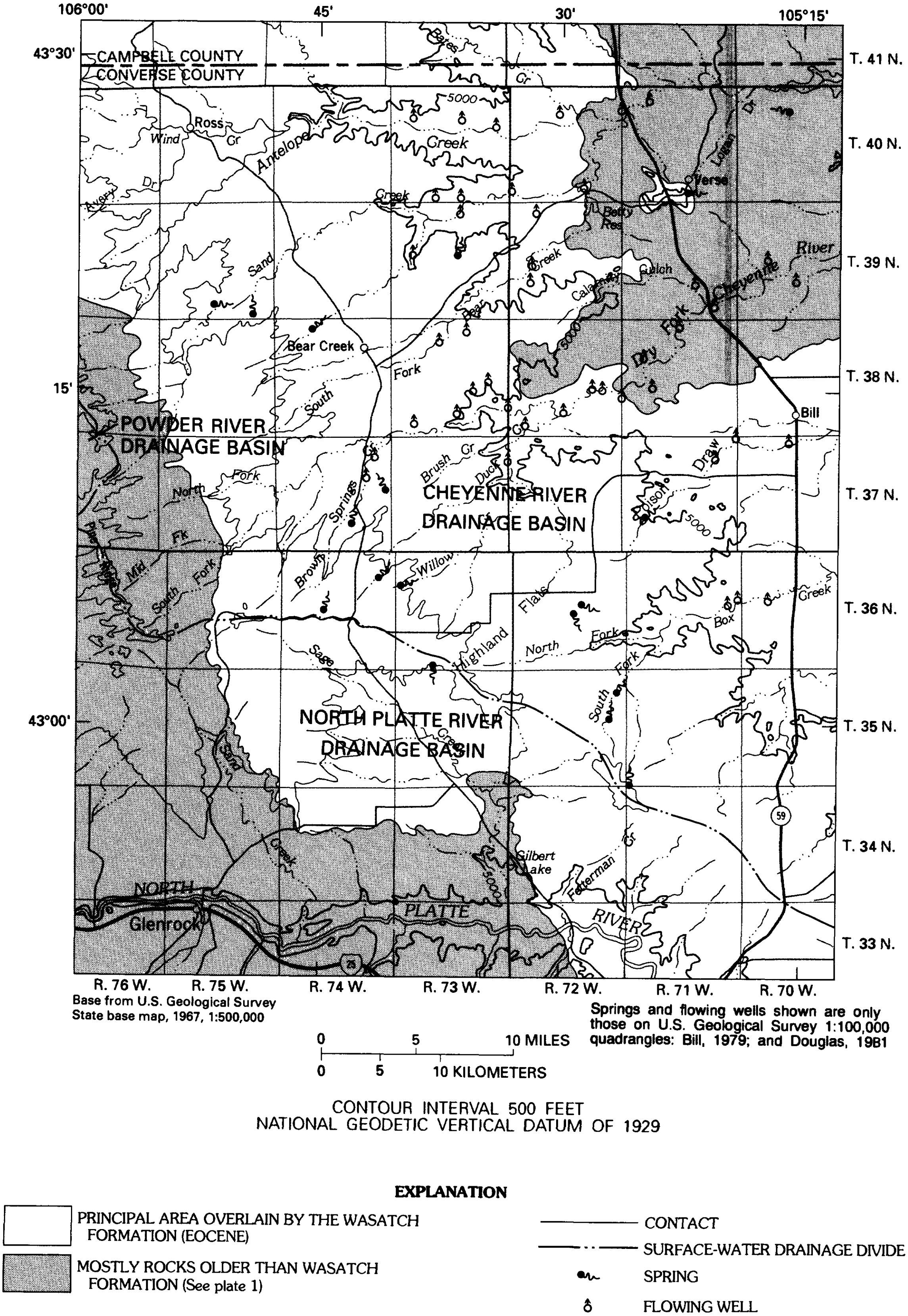

Figure 6.--Relation of springs and flowing wells to surface-water drainage basins and the Wasatch formation.

Indicated Flow System

The preceding four tests of the two hypotheses do not support the hypothesis of a system with a large component of vertical flow in the Southern Powder River Basin Uranium District and adjacent areas. Therefore, the hypothesis of a system with restricted vertical flow is accepted as more likely for this area. The hypothesis of a system with restricted vertical flow is used in evaluating the effects of uranium exploration and mining on ground water. The responses to 9 years of pumping at the Bill Smith Mine indicate that the assumption of a system with restricted vertical flow is appropriate for projects requiring water for periods of at least 9 years. The absence of measurable ground-water contribution to major streams, described by Rankl and Lowry (1990), indicates that this system probably can be assumed appropriately for much longer periods.

Water Quality

Water in aquifers at shallow depth (less than 500 feet) in the study area generally contains less than 500 mg/L (milligrams per liter) dissolved solids, and generally the dominant ions are calcium and bicarbonate (relatively indicated by alkalinity; see table 3 at back of this report). There is an initial increase in dissolved-solids concentration by solution of sodium and sulfate as the water moves deeper into an aquifer. An example of this increase is indicated by the analyses of water collected May 8, 1980, from wells 36-073-21dcc01, which is 19 feet deep, and 36-073-21dcc02, which is 165 feet deep (table 3). The ratios of constituents in water from the shallow well to that from the deeper well was about 1:7 for sodium, about 1:3 for sulfate, and about 1:2 for dissolved-solids concentration. The calcium and bicarbonate concentrations in the two waters were about the same.

Subsequent changes in the chemical quality of water as it moves through aquifers in the Wasatch-Fox Hills sequence have been described by several investigators. Riffenburg (1925) described the chemistry of the water in the Fort Union and Hell Creek (Lance) Formations in the northern Great Plains of Montana. Thorstenson and others (1979) described the chemistry of the water in the lower part of the Hell Creek Formation and the Fox Hills Sandstone in North Dakota. Hagmaier (1971) described changes in chemical quality of ground water in the Powder River Basin in Wyoming, and Dahl and Hagmaier (1976) described changes in the Southern Powder River Basin Uranium District.

Changes described by these investigators are dominated by cation exchange and sulfate reduction. As water moves into the deeper parts of the aquifer farther from the outcrop, calcium in solution is replaced by sodium from the solid phase and the sulfate is reduced, leaving bicarbonate as a product. Bacteria are the probable cause of sulfate reduction in the water (Dockins and others, 1980). Bacterial reduction of sulfate, which requires a source of organic carbon, can occur throughout the Wasatch-Fox Hills sequence because organic carbon is disseminated throughout the sequence. However, the process is accelerated in water in coal and carbonaceous material, compared to water in sandstone (Thorstenson and others, 1979, p. 1493).

Thus, sodium is the dominant cation and bicarbonate is the dominant anion in water in deep aquifers. Water from well 35-071-23cc01 (table 3) is an example of this type of water; it also illustrates the small dissolved-solids concentrations (634 mg/L in this sample) that may occur at depth. The well, which is 6,330 feet deep, is completed in the Lance Formation and the Fox Hills Sandstone.

Surface Water

Surface-water data for the study area practically were nonexistent. Because all major streams that originate in the study area are ephemeral, there has been little interest historically in obtaining such data. Some of the streams have perennial or intermittent reaches, and the locations of these reaches were useful in testing the hypotheses of the hydrologic system. Information for streams outside the study area was used to characterize the general flow and water quality of streams in the study area. The major river basins are the North Platte, Powder, and Cheyenne (fig. 6).

Streamflow

Flow at the long-term streamflow-gaging station on the Cheyenne River near Spencer is considered to be representative of streamflow from the study area. Although the station is about 60 miles east of the study area (fig. 1), about 76 percent of the study area is within the drainage area of the station (25 percent of the total drainage area).

Rankl and Lowry (1990) analyzed streamflow data for the Cheyenne River near Spencer and concluded that for average conditions there was no base flow from ground water at the site. As indicated by the distribution of monthly flows (fig. 7A), flow begins as early as January from snowmelt runoff, and most flow occurs during May through July. Maximum precipitation occurs during March through June. Average-daily discharge during October through December is nearly zero; there was no flow or negligible flow more than 50 percent of the time during the 26 years of record (fig. 7B).

Knowledge of ground-water discharge to streams is useful in developing a concept of the ground-water-flow system. Although the general absence of base flow at the station near Spencer is typical of major streams originating in areas underlain by the Wasatch-Fox Hills sequence, in many places in the study area there is ground-water contribution to small streams. These small streams occur mainly in areas underlain by coarse-grained facies of the Wasatch Formation mapped by Raines and Santos (1980, maps 2 and 4). In order of potential magnitude of ground-water discharge, the indicators are: (1) Perennial reaches of some streams in the Cheyenne River drainage basin, such as Box Creek and Sand Creek, (2) intermittent flow in some streams, such as Brown Springs Creek, and (3) what appear to be perennial pools. In addition to streamflow indicators of ground-water discharge, springs are more numerous in the coarse-grained facies of the Wasatch Formation.

Water Quality

The chemical quality of water in the streams in the study area varies with the source of the flow, the effects of evaporation and transpiration, and antecedent flow. Where most of the surface water is derived from springs, the surface water usually is chemically similar to the ground water. The analysis for Brown Springs Creek (sampling site 7, table 4 at back of this report), a

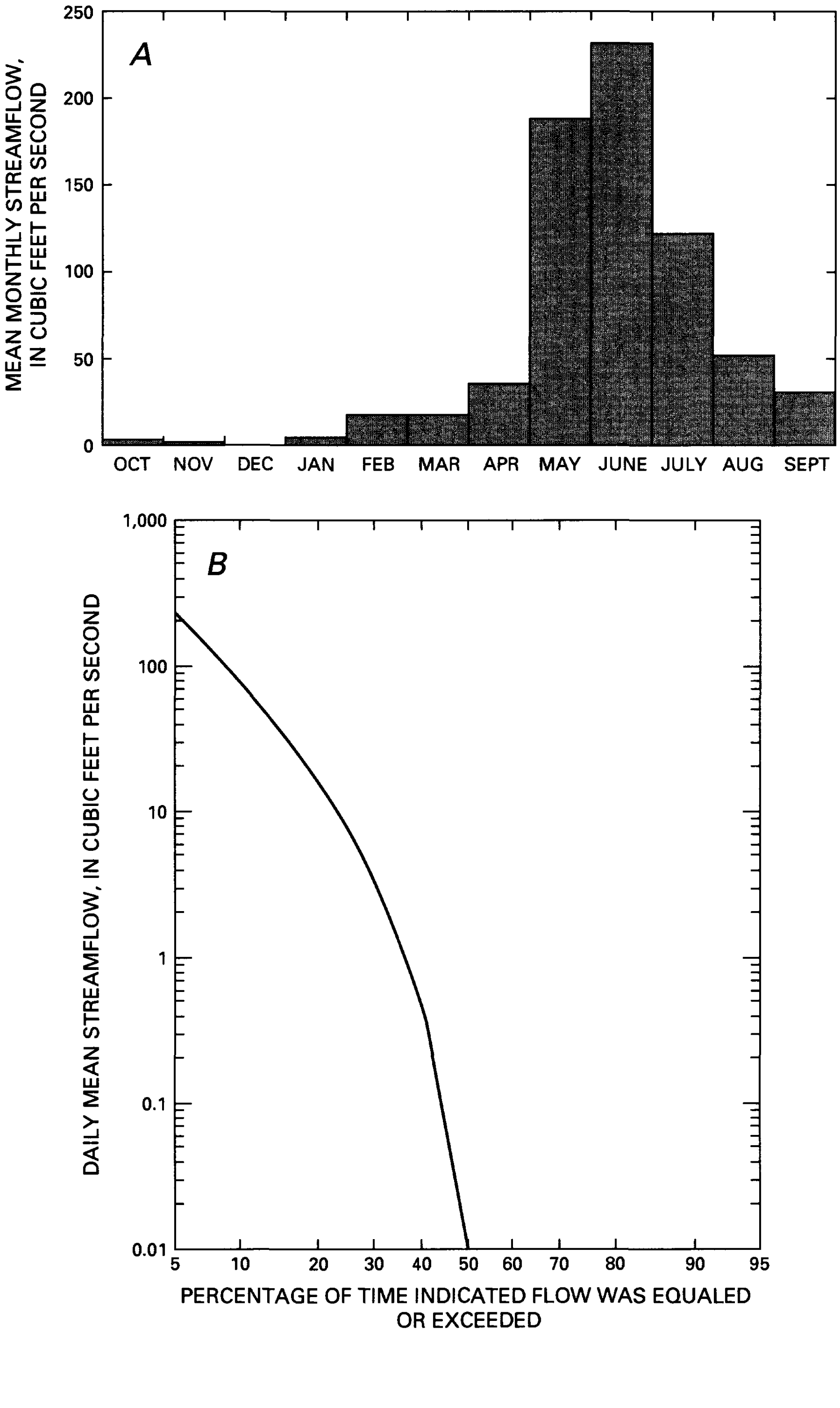

Figure 7.--Mean monthly streamflow and flow-duration curve for Cheyenne River near Spencer, Wyo., water years 1949-74. (From Peterson, 1988, p. 261.)

site of intermittent flow, indicates a chemical similarity to the ground water from which it was derived--the dominant ions are calcium and bicarbonate, and the dissolved-solids concentration is 560 mg/L.

Dissolved-solids concentrations usually increase with distance downstream from springs, because of decreases in flow by evaporation and transpiration. When most of the surface water is derived from rainfall or snowmelt runoff, dissolved-solids concentrations may be diluted, because concentrations in precipitation are small. However, during long dry periods, large amounts of salts may accumulate in dry stream channels and other surfaces in the contributing basin; the salts are readily soluble and are flushed from the channel and other basin surfaces during runoff. Therefore, after long dry periods, dissolved-solids concentrations in the initial flow may be relatively large. DeLong (1986, p. 8-9) described this process for ephemeral and intermittent streams in southwestern Wyoming.

EFFECTS OF URANIUM EXPLORATION AND MINING ON GROUND WATER

Uranium exploration and mining potentially can affect water levels or water quality in wells. The effects of mining on water levels was the main concern of the landowners in, and adjacent to, the Southern Powder River Basin Uranium District. Improving understanding of these effects was an emphasis of this investigation.

Water Levels

Water levels in wells completed in aquifers used for agriculture declined in some areas due to uranium exploration and development. The water-level declines, which varied in magnitude, resulted from the following causes: (1) Ineffectively plugged exploration holes, which allowed flow between aquifers; (2) pumping for mine and mill supplies; and (3) pumping for dewatering of open-pit mines. In this study, no regional pattern of water-level changes due to uranium exploration and mining could be determined; however, some local changes occurred.

Most of the water-level changes in observation wells ranged from 0 to 2 feet from fall 1981 to fall 1982 (table 2). Water-level changes of about 2 feet resulting from annual differences in natural recharge probably would be normal in many wells in the area. Well 44-072-22cad01, in Campbell County about 12 miles north of the Converse County line, is an observation well in which annual water-level changes of about 2 feet are representative of natural conditions (see Ragsdale and Oberender, 1985 p. 13). It is the nearest observation well to the study area that is completed in the Wasatch Formation, has a long (17-year) record of water-level measurements, and is in an area where ground water is withdrawn only for stock watering and domestic use. The largest decline in water level measured in the study area between the fall of 1981 and the fall of 1982 was 60.89 feet in well 37-074-30dbb01. The decline was caused by pumping from the well for stock water during that period. The water level had risen 41 feet between 1977 and 1981 during recovery after a period of similar pumping of water for drilling an oil well.

Water-level declines in some agricultural wells were greater in the past because of pumping than declines measured during the study; these changes are noted in the remarks column of table 2. Although flow from some artesian wells

Table 2.--Water-level changes in wells from the fall of 1981 to the fall of 1982

[Water-level change: -, decline; no sign given, rise; --, no data]

Well number	Water-level change (feet)	Remarks
34-074-11ada01	-0.02	
34-074-11dcc01	.24	
35-070-16aab01	.17	
36-071-16ca01	7.86	
36-072-07acc01	-.19	
36-072-13acb02	1.71	
36-072-14dbb01	6.28	
36-073-19aab01	-.67	
36-073-21dcc01	.88	
36-073-21dcc02	.31	
36-073-24aba01	-3.11	
36-074-18cdb01	--	Rose 3.96 feet from July 1969 to Oct. 1981
36-074-25ccc01	.32	
36-074-27dc01	3.92	
36-075-02bca01	--	Rose 3.42 feet from Oct. 1978 to Oct. 1982
37-070-09dcc01	1.11	
37-070-10ccb01	.49	
37-071-06dcc01	3.00	
37-071-18ca01	.99	
37-071-30cdc01	7.76	
37-072-17cd01	11.3	
37-072-36dbc01	-.33	
37-073-17cdd01	.65	
37-073-19dcc01	-.19	
37-073-22adb01	.47	
37-074-07cb01	-1.98	Declined 0.55 foot from June 1979 to Oct. 1982
37-074-09dcc01	-1.72	
37-074-14aac01	--	Declined 3.95 feet from Nov. 1978 to July 1979
37-074-18bbd01	-1.07	
37-074-30dbb01	-60.89	Decline due to pumping of well; rose 41.00 feet from Nov. 1977 to Nov. 1981
37-074-34dcb01	-.19	
37-074-35caa01	-.53	
37-075-13dba01	.04	Declined 3.38 feet from June 1979 to Oct. 1982
37-075-27ddd01	.00	Declined 2.41 feet from Nov. 1978 to Oct. 1982
38-071-32ddd01	.54	
38-073-04aba01	1.09	Water level 15.65 feet below land surface, 1982[a]
38-073-08bd01	1.38	
38-073-08bd02	-2.67	Pumped recently, recovering at a rate of 0.05 foot in 5 minutes
38-073-09ab01	-10.99	Water level 35.32 feet below land surface, 1982[a]
38-073-17aba01	-4.51	Water level 25.48 feet below land surface, Oct. 1982[a]

Table 2.--Water-level changes in wells from the fall of 1981 to the fall of 1982--Continued

Well number	Water-level change (feet)	Remarks
38-073-18baa01	1.43	
38-073-24bbc01	--	Water level 25.01 feet below land surface, Jan. 1983[a]
38-073-27cdb01	1.43	Water level 14.64 feet below land surface, Oct. 1982[a]
38-073-35aca01	-1.76	Water level 11.01 feet below land surface, Oct. 1982[a]
38-074-03aaa01	--	Declined 0.8 foot from July 1979 to Mar. 1983
38-074-13ca01	.73	
38-074-24aac01	.91	
38-074-27dab01	--	Rose 0.07 foot from Oct. 1981 to Mar. 1983
39-073-23cca01	2.45	
39-073-29bda01	-.36	
39-073-33dad01	--	Declined 47.09 feet from July 1976 to Oct. 1981
39-073-33dad02	3.29	
39-073-34cdd01	-.06	
39-074-32bd01	1.52	
39-074-34bdd01	-.63	
40-071-23bcb01	.40	
40-074-05ca01	-.25	
40-074-06bdc01	.61	
40-074-31cca01	1.05	
40-074-32cb01	3.95	

[a]Previously flowing well; original shut-in pressure not known.

ceased during 1981 and 1982, the total water-level decline in these wells is not known because pressure prior to mining is not known.

Declines Caused by Exploration Holes

Declines of water levels or artesian pressures in wells in some aquifers as a result of exploration drilling might be expected, given the large number of exploration holes and that some holes might be ineffectively plugged. The spacing of exploration holes 50 or 100 feet apart in a grid would not be unusual in and near the areas of the uranium-ore deposits shown on plate 1. Most of the estimated 115,000 exploration holes drilled in Converse County were in the area of the uranium district; even if the holes had been evenly distributed throughout the county, an area of 4,283 square miles, they would be spaced only about 1,000 feet apart.

Exploration holes were inspected that were open at the surface but plugged at depth, possibly because of caving. Seeps were observed at some exploration holes. Ineffectively plugged holes could allow increased vertical flow of water between aquifers, which could raise the water level in the receiving aquifer and lower the water level (or decrease the hydraulic head) in the contributing aquifer. Also, if an artesian aquifer is penetrated by an exploration hole, then a previously dry, near-surface sand could become partly saturated.

In spite of the large number of exploration holes that had been drilled, it was difficult to locate holes for inspection, even with assistance from the mining companies. A search for exploration holes was made at the Bear Creek and Kerr-McGee open-pit mines and the Highland underground mine. It was reasoned that, with the number of exploration holes drilled in the area by different contractors, there would be no difficulty in finding them.

In an effort to determine the condition of exploration holes at depth, inspections were made at open-pit mines; at an area where topsoil was being stripped in preparation for road construction; and at one underground mine. No exploration-hole sites could be identified at the open-pit mines, although drilling was known to have extended below the pits inspected and the spacing of the holes was known. Similarly, no exploration-hole sites could be identified in the area of road construction, although holes had been drilled in the area. The road was for a haulway between two mines, and the area inspected was within one-fourth mile of another ore body that had been evaluated by exploration drilling.

Representatives of companies with underground operations were asked if water could be seen draining into mines from exploration holes intersected during mining; they responded that such drainage, if present, was not conspicuous. As a part of this study, two exploration holes intersected by the Highland Mine were inspected. One hole was open an undetermined distance above the roof of the working. A bentonite plug was at the roof level in the other. No water was draining from either hole.

A comparison of new workings with some of the older workings in the Highland Mine probably was a better indicator of the general conditions than the two exploration holes inspected. The senior author inspected the workings. It was not possible to enter the older workings because of roof collapse, but the roof collapse effectively would link all exploration holes intersected by the working, and the working would form a high-permeability zone for discharge of water into the open part of the mine. However, the amount of water observed in the area of these older workings was not greater than that in the new workings inspected.

Only one site was identified where water levels probably had been lowered as a result of exploration drilling. A water well in sec. 21, T. 36 N., R. 73 W., in use before exploration and mining began in 1966, had been dug into a shallow sand that also was the source of water to a nearby spring. In 1980 the well and the spring were dry. A mining company had drilled a replacement well (36-073-21dcc01), 19 feet deep, into the same sand, but there no longer was sufficient saturated thickness to supply water for stock, so the company drilled a second, deeper well (36-073-21dcc02). On the basis of the watermark visible on the casing of the original well and the depth of the water in the first replacement well, it was calculated that the water level in the aquifer had declined about 5 feet. The adverse effect of exploration drilling at this site was that a deeper (165 feet) replacement well had to be drilled. However, the shallow sand was not completely dewatered; water that leaked from the aquifer was not lost to the system, but probably recharged a deeper aquifer; and the effects of the exploration drilling were local. Had the effects been more widespread, other shallow wells shown on plate 2 on Highland Flats also would have had to be abandoned.

The only site where exploration drilling probably caused cessation of artesian flow was observed at well 37-073-14add01. Although this conclusion cannot be proved or disproved, there is sufficient information to indicate that mine dewatering, a possible alternative, was not the cause. The well was completed in sandstone between coals that are tentatively correlated with the School and Anderson coal beds. Although uranium-ore-bearing sandstones between the School and Anderson coal beds were dewatered during mining in the Monument Hill area prior to 1981, mine dewatering evidently was not the cause of the decrease in artesian pressure in the well, as the water level did not recover after dewatering was stopped. In 1982 the water levels in the abandoned pits were about 100 feet higher than the altitude of the well. Bear Creek Mine also dewaters uranium-ore-bearing sandstone in this interval; however, water levels in wells completed in sandstone above the Anderson coal bed and that are closer to the mine than well 37-073-14add01, were not measurably affected. Similarly, water levels in wells completed in the first sandstone interval below the School coal bed at the Bill Smith Mine were not affected by pumping at that mine.

Deterioration of the casing was suggested as a possible cause of cessation of flow from well 37-073-14add01. Corrosion of metal well casing in coal beds is common in the Powder River Basin in Wyoming. However, a replacement well (37-073-14add02) was drilled a few feet away, at a slightly lower site, and the flow from this well reportedly was less than that of the original well.

In addition to exploration holes, water wells in the area could allow vertical flow of water that will change the water levels in some aquifers and allow water of different chemical quality to mix. The areal density of exploration holes is considerably greater than that of water wells, but water can move vertically more easily in the cased water wells than in the uncased exploration holes. About 50 percent of the water wells drilled deeper than 500 feet and for which the perforated interval was known were perforated through an interval greater than 200 feet. Thus, well-construction methods used in the area make possible the same vertical movement of water in formations that is of concern in unplugged exploration holes. No one interviewed cited problems regarding vertical flow of water because of well construction.

Declines Caused by Pumping

Initial discharge of water from a well is derived from ground-water storage, which causes a cone of depression to form in the aquifer around the well. As discharge continues, water levels within the cone of depression decline, and the cone enlarges until it intersects an area large enough that the discharge can be offset by an increase in recharge, a decrease in natural discharge, or some combination of the two. Because there is very little ground-water discharge to streams that originate in the area that is not consumed within the area, any natural discharge intercepted by a cone of depression would not increase the water available in the area.

Because of the above constraints on intercepting natural discharge or increasing recharge to offset water discharge from wells, much of water from wells will come from ground-water storage by enlargement of the cone of depression. Therefore, the cones of depression of nearby wells completed in the same aquifer may overlap.

Water levels in stock-water and domestic wells were adversely affected by pumping for mining and milling near the Bear Creek Mine. Most of the wells that had stopped flowing and for which the producing interval could be determined were completed in sandstone below the Anderson coal bed in the Lebo Member of the Fort Union Formation and were within 10 miles of the mine. This would be expected, on the basis of aquifer properties determined for production well 1 at the Bear Creek Mine, also completed in sandstone lenses below the Anderson coal bed in the Lebo Member. A transmissivity of 134 cubic feet per day per foot (134 feet squared per day) and a storage coefficient of 0.0004 were reported by the company. On the basis of these properties and the 8 years of pumping that had elapsed, the cone of depression would have extended 10 miles. Wells that had stopped flowing by 1983 are shown on plate 2.

The effect of pumping at the Bear Creek Mine on stock-water and domestic wells was a major problem because of the small artesian pressures in the aquifers. Water-level declines that might go unnoticed in a well equipped with a pump were large enough to cause artesian flow from some wells to diminish or stop. For example, an original shut-in pressure for a well in sec. 10, T. 35 N., R. 70 W. was reported in the files of the Wyoming State Engineer's Office (permit P4294P) to be equivalent to 4.62 feet of water, whereas the maximum shut-in pressure measured in the study area was equivalent to 30 feet of water.

Pumping at the Highland, Golden Eagle, and Bill Smith (Kerr-McGee) Mines had not affected water levels in wells used by the agricultural sector. Heads decrease with depth in the areas of these mines, in contrast to the area near the Bear Creek Mine, where artesian flows are possible. Adequate water for stock watering and domestic use can be obtained from relatively shallow depth; therefore, deep wells were not drilled, except by industry for supplies and mine dewatering. This contrast is illustrated by the distribution of stock-water and domestic wells 500 feet deep or greater (fig. 8). The seven wells on Highland flats were originally drilled for industrial purposes, but later were enlarged for stock or domestic use.

The negligible effects of pumping from deep aquifers on the water levels in shallow aquifers is indicated by the response of deep and shallow observation wells to pumping to dewater the Bill Smith Mine (see page 13) and by the continued use of well 36-072-09acc01. This well, constructed to a depth of 10 feet in 1910, is about 2 to 3 miles from the Highland and Golden Eagle underground mines. The water level was 3.54 feet below land surface on November 3, 1981. The mines were being dewatered at the time of measurement.

Declines Caused by Open-Pit Mining

Water levels in wells completed in aquifers near open-pit mines declined because of flow from the aquifers into the mines. Where open-pit mining intersects an aquifer, the ground water will drain into the mine, and water levels in the aquifer will decline. The magnitude of decline and the distance

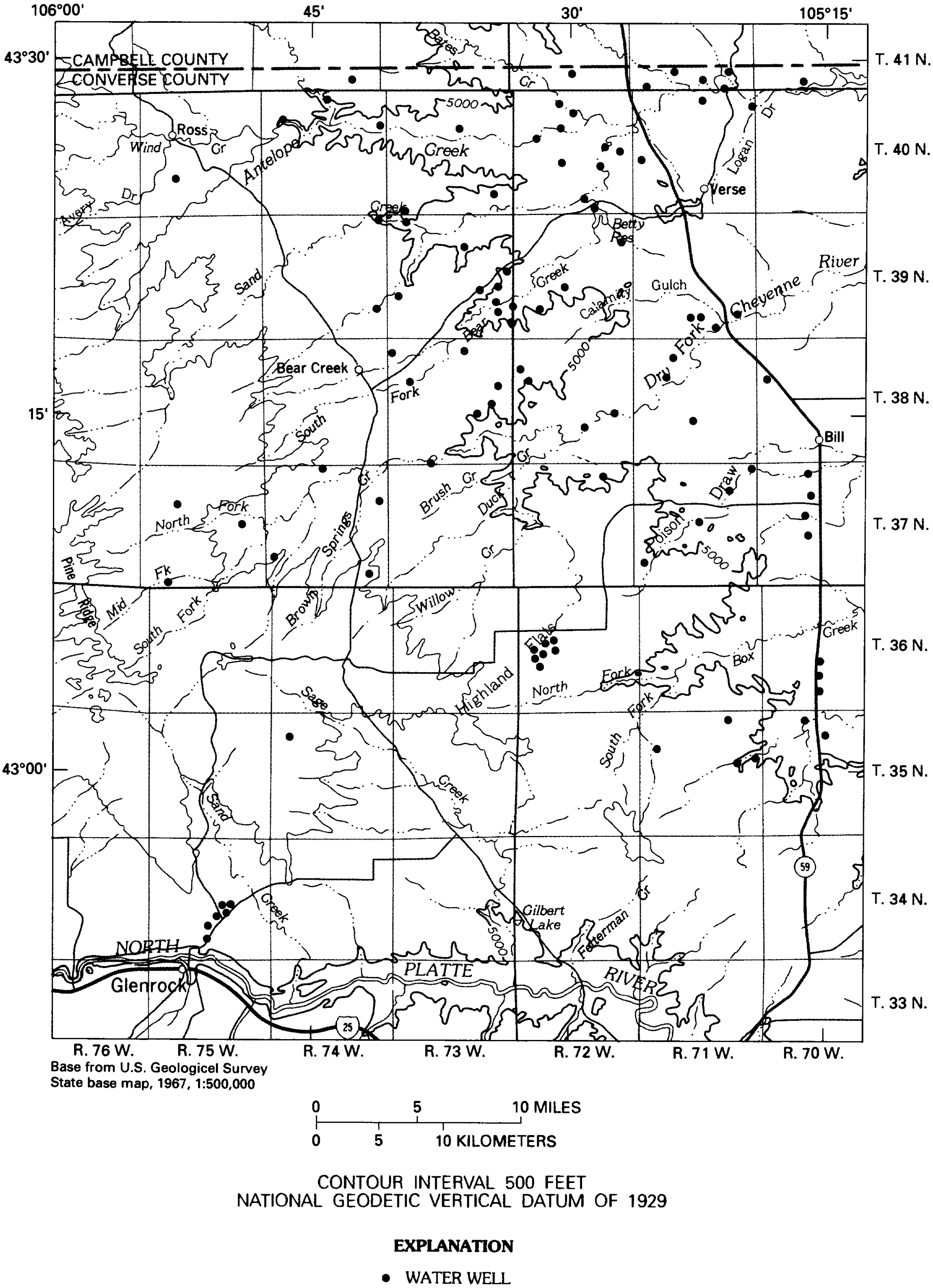

Figure 8.--Distribution of wells 500 feet deep or greater that had been permitted by the Wyoming State Engineer's Office for stock watering and (or) domestic use, as of 1982.

from the mine that the water levels are affected are dependent on transmissivity and the rate and duration of discharge, as described previously for declines caused by pumping.

Observed effects of open-pit mining on water levels in stock-water and domestic wells near the mines were minimal. Because of the independence of each aquifer, the decline in water level is by adjustment to a new discharge point, which is the base of each aquifer where it is exposed in the pit, rather than adjustment to the altitude of the bottom of the pit. The long-term effects will be dependent on reclamation, but the effects of open-pit mining will be more permanent than the effects of pumping, as the aquifers will not be restored to pre-mining conditions.

Water Quality

No evidence was found to indicate that there were problems caused by mixing of water of different salinity because of vertical flow of water in ineffectively plugged exploration holes. Wells for stock water and domestic use, developed from aquifers throughout the vertical section drilled for uranium, continued in use with no reported significant increases in salinity.

It was suggested by the owner that nitrate concentrations in water from well 36-073-27abb01 had been increased by uranium exploration. A comparison of data collected during the study with historical data indicates that the casing probably was corroded and leaking. Water samples were collected from the well in June 1982 when the pump was first turned on and 4, 10, and 45 minutes later. The variation in nitrate (table 3) is indicative of accumulation of water in the well from a source other than the aquifers in which the well is completed, during the time the well is not pumped. The initial sample contained 1.8 mg/L and represented water in the drop pipe after the last period of pumping. The sample collected after 4 minutes of pumping contained 5.5 mg/L nitrate because of contaminated water that built up in the casing after the last pumping period. Subsequent samples show a decrease in nitrate to 1.8 mg/L after 45 minutes of pumping as the water standing in the casing was removed and water from the principal aquifer entered the well. Corrals near the well were a possible source of the nitrate. Comparison with the analysis of a water sample collected June 6, 1969, does not indicate deterioration of water quality from 1969 to 1982.

EFFECTS OF URANIUM EXPLORATION AND MINING ON SURFACE WATER

The quantity and quality of water in the streams in the area may be affected by ponds used at the uranium mines and mills. Discharge from a pond may result in flow in an otherwise dry streambed; although most of the flow is diverted, the ponds also may decrease peak flows. The chemical quality of the water will be similar to that in the ponds.

The samples (table 4 at back of this report) from sites 3 (Bill Smith Mine), 6 (Golden Eagle Mine), and 10 (Bear Creek Mine) are from ponds that receive water pumped to dewater the mines. The water is stored temporarily in the ponds to precipitate radium from the water before the water is released to streams. Barium chloride is added, and sulfate in the water reacts with the barium to form barium sulfate. The barium sulfate precipitates, the radium co-precipitates with the barium, and the chloride remains in solution. Radium concentrations in ponds sampled ranged from 0.55 (sampling site 8) to 2.5 picocuries per liter (sampling site 6), and chloride ranged from 5.9 (sampling site 3) to 24 mg/L (sampling site 8).

Tailings ponds, also used at mills, are designed to trap sediment and keep contaminated water from entering streams. Water is retained in the ponds for evaporation; seepage from the impoundment structures is pumped back into the ponds.

There were no reports of adverse effects of uranium exploration or mining on flow or quality of water in streams that originate in the area. There were beneficial effects, however, in that some water pumped from the mines was used by ranchers. In 1983 sprinkler irrigation in the Frank Draw drainage basin and on Highland Flats was being done using water pumped to dewater mines.

SUMMARY

In the Southern Powder River Basin Uranium District an estimated 115,000 exploration holes had been drilled by 1981, and there were five major mining operations. Because agriculture in the area is dependent on ground water for domestic and stock-watering supplies, local residents were concerned about declining water levels, including loss of pressure in flowing wells.

Exploration and mining of uranium resources in the Southern Powder River Basin Uranium District began in 1953 and increased substantially in 1966. Uranium-ore production from the district increased annually from 0 in 1971 to more than 1.3 million tons in 1982. By the mid-1980's, however, both exploration and production had all but ceased.

Most ground water in the area is developed from the Wasatch and Fort Union Formations, and most mined uranium was from the Wasatch Formation. The Wasatch and Fort Union predominantly consist of a series of discontinuous sandstone and coal beds, with intervening shales and siltstones. Generally, the sandstones and coal beds are confined aquifers. The oldest formation in the area to which water wells have been drilled is the Fox Hills Sandstone.

Two concepts of ground-water flow have been hypothesized for the area: one with a large component of vertical flow and natural discharge to streams predominantly at stream level, and one with restricted vertical flow, with most discharge above stream level. The hypothesis of a system with large vertical flow in the Southern Powder River Basin Uranium District and adjacent areas is not supported by potentiometric-surface data, the distribution of areas of natural ground-water-discharge points and flowing wells, vertical flow in response to pumping, or the location of uranium-ore deposits. The hypothesis of a system with restricted vertical flow is accepted as more likely for this area. Therefore, the assumption of restricted vertical flow was used in evaluating the effects of uranium exploration and mining on ground water in the area.

Water in aquifers less than 500 feet deep generally contains dissolved-solids concentrations less than 500 milligrams per liter, and calcium and bicarbonate are the dominant ions. In deeper aquifers, sodium and bicarbonate are the dominant ions.

Some ephemeral streams that originate in the area have perennial or intermittent reaches; the locations of the reaches, which are indicators of ground-water discharge to streams, were used in testing the hypotheses of the ground-water-flow system. There is little flow out of the area in these streams. Where most of the surface water is derived from springs, the surface water usually is chemically similar to the ground water. Dissolved-solids concentrations in water in the streams usually are small during runoff, but may be relatively large in initial flow following long dry periods, due to the flushing of accumulated salt.

No regional pattern of water-level change as a result of exploration or mining in the area could be discerned. Most of the water-level changes in observation wells during 1981 and 1982 were within the range of normal fluctuations. Water-level declines in some agricultural wells were greater in the past because of pumping than declines measured during the study.

The large number of exploration holes had the potential to increase vertical flow between aquifers, because not all the exploration holes were effectively plugged. Adequate drill sites for inspection, however, could not be identified in the open-pit mines inspected or in an area where topsoil was being removed for road construction, even though drilling was known to have been done in those areas. There was no evidence of substantial vertical flow of ground water at two drill holes and some collapsed older workings inspected in the Highland underground mine. Only one site was found where water levels probably had been lowered as a result of exploration drilling; the aquifer had not been drained, but a replacement well in a deeper aquifer was necessary.

Ground-water pumping for mining and milling supplies adversely affected water levels in stock-water and domestic wells only where pumping was from the same stratigraphic unit as the stock-water and domestic wells. This occurred near the Bear Creek Mine, but the effects of 8 years of pumping did not extend farther from the mine than might have been anticipated from calculations based on data provided by the company. The effect was great, however, in that pumping was from an artesian aquifer with small artesian pressure. Even a small decrease in the artesian pressure was enough to cause some flows to diminish or stop. The effects of pumping from deeper aquifers at the Highland, Golden Eagle, and Bill Smith Mines on water levels in wells completed in shallow aquifers, however, were negligible.

Water levels in wells completed in aquifers near the open-pit mines declined because of flow from the aquifers into the mines. The level to which the water could decline would be the base of the particular aquifer where it is exposed in the pit.

No evidence was found to indicate that water quality was affected by mixing of water of different salinity as a result of vertical flow of water in ineffectively plugged exploration holes. Wells for stock water and domestic use, developed from aquifers throughout the vertical section drilled for uranium, continued in use with no reported substantial increases in salinity.

There were no reports of adverse effects of uranium exploration or mining on flow or quality of water in streams that originate in the area. Beneficial effects noted, however, include use of water pumped from mines for sprinkler irrigation.

REFERENCES CITED

Connor, J.J., Denson, N.M., and Hamilton, J.C., 1976, Geochemical discrimination of sandstone of the basal Wasatch and uppermost Fort Union Formations, Powder River basin, Wyoming and Montana, in Geology and energy resources of the Powder River basin, 1976: Wyoming Geological Association Guidebook, 28th Annual Field Conference, p. 291-297.

Dahl, A.R., and Hagmaier, J.L., 1976, Genesis and characteristics of the southern Powder River basin uranium deposits, Wyoming, in Geology and energy resources of the Powder River basin, 1976: Wyoming Geological Association Guidebook, 28th Annual Field Conference, p. 243-252.

Davis, J.F., 1969, Uranium deposits of the southern Powder River basin: Laramie, University of Wyoming, Contributions to Geology, v. 8, no. 2, part 1, p. 131-141.

DeLong, L.L., 1986, Water quality of streams and springs, Green River basin, Wyoming: U.S. Geological Survey Water-Resources Investigations Report 82-4008, 36 p.

Denson, N.M., Dover, J.H., and Osmonson, L.M., 1980, Lower Tertiary coal bed distribution and coal resources of the Reno Junction-Antelope Creek area, Campbell, Converse, Niobrara, and Weston Counties, Wyoming: U.S. Geological Survey Miscellaneous Investigations Map I-1201, scale 1:125,000.

Denson, N.M. and Horn, G.H., 1975, Geologic and structure map of the southern part of the Powder River basin, Converse, Niobrara, and Natrona Counties, Wyoming: U.S. Geological Survey Miscellaneous Investigations Map I-877, scale 1:125,000, 2 sheets.

Dockins, W.S., Olson, G.J., Turback, S.C., and Lee, R.W., 1980, Sulfate reduction in ground water of southeastern Montana: U.S. Geological Survey Water-Resources Investigations Report 80-9, 13 p.

Hagmaier, J.L., 1971, Groundwater flow, hydrogeochemistry, and uranium deposition in the Powder River basin, Wyoming: Grand Forks, University of North Dakota Ph.D thesis, 166 p.

Hausel, W.D., Glass, G.B., Lageson, D.R., Ver Ploeg, A.J., and De Bruin, R.H., 1979, Wyoming mines and minerals: Laramie, The Geological Survey of Wyoming map, scale 1:500,000.

Hodson, W.G., Pearl, R.H., and Druse, S.A., 1973, Water resources of the Powder River basin and adjacent areas, northeastern Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas HA-465, scale 1:250,000, 4 sheets.

Hotchkiss, W.R., and Levings, J.F., 1986, Hydrogeology and simulation of water flow in strata above the Bearpaw Shale and equivalents of eastern Montana and northeastern Wyoming: U.S. Geological Survey Water-Resources Investigations Report 85-4281, 72 p.

Lewis, B.D., and Hotchkiss, W.R., 1981, Thickness, percent sand, and configuration of shallow hydrogeologic units in the Powder River basin, Montana and Wyoming: U.S. Geological Survey Miscellaneous Investigations Map I-1317, scale 1:1,000,000, 6 sheets.

Lohman, S.W., and others, 1972, Definitions of selected ground-water terms--revisions and conceptual refinements: U.S. Geological Survey Water-Supply Paper 1988, 21 p.

Lowry, M.E., Wilson, J.F., Jr., and others, 1986, Hydrology of area 50, Northern Great Plains and Rocky Mountain Coal Provinces, Wyoming and Montana: U.S. Geological Survey Water-Resources Investigations Open-File Report 83-545, 137 p.

Peterson, D.A., 1988, Streamflow characteristics of the Missouri River basin, Wyoming, through 1984: U.S. Geological Survey Water-Resources Investigations Report 87-4018, 431 p.

Quality Development Associates, Inc., 1978, Wyoming's uranium industry--Status, impacts, and trends: Report to the Mineral Division, Wyoming Department of Economic Planning and Development, variable pagination.

Ragsdale, J.O., and Oberender, C.B., 1985, Ground-water levels in Wyoming, 1974 through 1983: U.S. Geological Survey Open-File Report 85-403, 194 p.

Raines, G.L., and Santos, E.S., 1980, Maps showing lithofacies and limonite distribution of the Wasatch Formation in the southern Powder River basin, Wyoming: U.S. Geological Survey Miscellaneous Investigations Map I-1246, scale 1:125,000, 2 sheets.

Rankl, J.G. and Lowry, M.E., 1990, Ground-water flow systems in the Powder River structural basin, Wyoming and Montana: U.S. Geological Survey Water-Resources Investigations Report 85-4229, 39 p.

Riffenburg, H.B., 1925, Chemical character of ground waters of the northern Great Plains: U.S. Geological Survey Water-Supply Paper 560-B, p. 31-52.

Santos, E.S., 1981, Facies distribution in uranium host rocks of the southern Powder River basin, Wyoming: U.S. Geological Survey Open-File Report 81-741, 15 p.

Sharp, W.N., McKay, E.J., McKeown, F.A., and White, A.M., 1964, Geology and uranium deposits of the Pumpkin Buttes area of the Powder River Basin, Wyoming: U.S. Geological Survey Bulletin 1107-H, p. 541-638.

Thorstenson, D.C., Fisher, D.W., and Croft, M.G., 1979, The geochemistry of the Fox Hills-basal Hell Creek aquifer in southwestern North Dakota and northwestern South Dakota: Water Resources Research, v. 15, no. 6, p. 1479-1498.

U.S. Department of Energy, 1983, Statistical data of the uranium industry: U.S. Department of Energy Report GJO-100(83), 77 p.

Wyoming State Inspector of Mines, 1978-82, Annual report of the State Inspector of Mines of Wyoming: State of Wyoming (published annually since 1902).

Zielinski, R.A., 1983, Tuffaceous sediments as source rocks for uranium: a case study of the White River Formation, Wyoming: Journal of Geochemical Exploration, v. 18, p. 285-306.

(p. 31 follows)

WATER-QUALITY DATA

Table 3.--Chemical analyses of ground water

[Abbreviations: µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter. Symbol: --, no data]

Well number	Date	Depth of well (feet)	Specific conductance (µS/cm)	pH	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, on site (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)
						Wasatch Formation							
36-070-09ccb01	06-03-68	217	1,830	7.6	93	29	304	4.0	247	745	8.5	1,343	--
36-072-09dd01	06-06-69	212	877	7.7	36	8.5	146	2.4	151	278	5.0	568	0.00
36-072-21bad01	07-01-80	80	505	8.2	13	2.6	97	2.9	130	120	.9	325	.36
36-072-27bdb02	07-01-80	95	4,000	5.6	500	220	220	11	22	2,000	230	3,309	.02
36-072-29ba01	07-22-69	400	--	6.6	45	7.0	94	6.0	180	160	4.0	--	--
36-073-21dcc01	05-08-80	19	925	7.6	100	20	11	6.0	110	110	24	349	28
36-073-21dcc02	05-08-80	165	1,050	7.8	83	13	81	7.7	94	300	25	579	.46
36-073-26ada01	05-08-80	198	810	7.6	78	17	8.8	2.7	280	11	2.9	300	1.8
36-073-27abb01	06-06-69	180	645	7.7	69	15	53	5.7	213	136	3.8	426	62
	05-07-80	180	810	7.6	71	17	50	5.8	200	110	6.6	396	5.5
	06-12-82	180	--	--	--	--	--	--	--	--	--	392	1.8
	06-12-82	180	--	--	--	--	--	--	--	--	--	536	5.5
	06-12-82	180	--	--	--	--	--	--	--	--	--	412	2.4
	06-12-82	180	--	--	--	--	--	--	--	--	--	392	1.8
36-073-35dad01	05-07-80	20	950	7.6	84	25	49	1.1	320	100	4.0	465	.15
36-074-04dcd01	05-06-80	--	870	8.9	110	48	21	2.2	320	160	13	563	.07
36-074-18cdb01	07-29-69	35	627	7.8	82	21	21	1.2	194	98	13	384	.40
36-074-26ba01	05-28-80	149	1,000	7.6	120	31	15	1.5	230	100	24	441	17
36-074-36abb01	05-08-80	474	550	7.7	46	13	9.6	4.7	130	46	4.3	219	2.0

Table 3.--Chemical analyses of ground water--Continued

Well number	Date	Depth of well (feet)	Specific conductance (µS/cm)	pH	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, on site (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)
						Wasatch Formation--Continued							
37-074-02dca01	07-01-80	120	613	7.7	75	17	29	7.9	210	110	1.6	376	0.00
37-074-14aac01	07-02-69	255	409	--	50	8.3	21	5.9	163	41	2.8	243	.10
	10-07-77	255	420	7.8	48	11	20	6.2	170	41	2.9	248	--
37-074-35dc01	07-03-69	118	743	7.5	101	29	9.3	4.1	181	92	29	387	86
38-073-14bcb01	05-09-80	322	1,750	7.6	200	30	81	9.0	160	650	4.9	1,086	.12
38-073-17aba01	07-02-69	515	417	8.1	13	3.5	79	2.3	185	33	2.2	256	.00
38-073-27cdb01	05-09-80	370	570	7.9	39	7.4	58	4.6	160	100	2.4	323	.06
38-073-33ccb01	05-29-80	310	650	8.1	28	4.6	85	3.7	170	91	2.7	329	.00
38-074-13db01	07-02-69	160	2,000	7.9	343	8.1	62	10	1,110	980	14	2,094	.00
39-073-23cca02	07-05-80	310	1,950	8.2	310	55	63	12	240	880	11	1,494	.05
39-074-34bdd01	10-11-77	541	480	8.2	33	30	23	6.4	140	100	12	290	--
40-073-07bbc01	07-03-69	537	624	7.5	12	5.1	126	1.5	162	140	5.0	398	.20
40-073-17ba01	07-03-69	310	901	7.8	30	4.1	165	2.1	155	277	3.5	587	.20
40-074-21ac01	07-03-69	30	628	7.5	100	22	7.7	4.3	242	102	1.5	393	.30
						Fort Union Formation							
34-074-02dd01	07-29-69	165	925	8.0	142	17	28	8.6	247	178	24	564	33
34-074-09cc01	07-29-69	206	673	8.7	.7	.4	162	.4	234	104	3.0	425	.10
35-070-04ba01	06-19-69	415	708	8.1	9.8	.4	161	29	252	100	8.0	463	2.7
36-075-09cc01	09-29-69	360	326	6.9	40	11	2.7	3.6	77	75	1.6	208	4.4

Table 3.--Chemical analyses of ground water--Continued

Well number	Date	Depth of well (feet)	Specific conductance (μS/cm)	pH	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity, on site (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, $NO_2 + NO_3$ dissolved (mg/L as N)
Fort Union Formation--Continued													
37-073-10bac01	05-28-80	260	500	8.1	20	3.2	86	2.9	150	87	3.0	303	0.07
37-073-14add02	05-08-80	228	640	8.0	13	2.0	75	2.5	160	36	3.9	237	.11
39-070-29aa01	07-02-69	498	514	7.9	18	4.6	107	4.2	272	7.4	6.0	320	.00
39-072-06bd01	06-17-68	1,104	458	8.4	9.3	.5	94	1.4	144	81	2.8	290	.10
39-072-30ca01	07-03-69	1,020	385	7.4	9.9	2.8	72	1.9	133	56	2.8	238	.20
39-073-23dcd01	05-07-80	1,092	560	7.9	47	6.3	60	4.7	170	110	3.6	350	.02
39-073-24bdd01	05-07-80	730	680	8.2	41	9.9	84	4.7	170	140	3.5	403	.07
40-072-18bda01	06-17-68	530	603	8.3	9.3	.7	124	1.7	148	137	4.0	377	.10
	07-30-69	530	619	8.2	2.5	2.2	152	2.1	328	4.0	7.2	377	.00
Lance Formation and Fox Hills Sandstone													
35-071-23cc01	02-05-75	6,330	1,000	8.6	6.8	0.5	250	4.1	492	24	21	634	0.02
35-071-26bca01	06-11-81	--	--	--	7.0	1.1	250	5.2	--	12	39	660	.09
	06-12-81	--	950	7.8	3.5	16	240	3.3	--	27	23	636	.01

Table 4.--Chemical analyses of surface water

[Abbreviations: ft^3/s, cubic feet per second; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter. Symbols: --, no data; <, less than]

Date	Discharge (ft^3/s)	Specific conductance (µS/cm)	pH	Water temperature (°C)	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Sodium adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity, on site (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)
Sampling Site 1 - Dry Fork Cheyenne River near Bill, Wyo.													
05-04-77	0.12	1,700	8.1	16.0	840	180	94	90	1	11	330	620	16
05-31-77	.10	1,500	7.8	22.5	720	160	78	79	1	9.1	250	480	73
08-02-77	.03	1,000	7.7	25.0	510	130	45	27	.5	13	310	250	9.4
11-15-77	.10	1,350	7.9	4.0	820	180	89	73	1	15	320	570	19
01-06-78	.04	1,200	7.9	0.0	--	290	--	100	--	23	620	870	24
04-04-78	.18	1,850	8.1	12.0	880	200	92	68	1	9.7	370	600	13
05-16-78	.68	1,280	7.9	22.0	610	140	63	38	.7	10	280	380	9.4
07-25-78	1.3	630	7.6	24.0	260	71	20	--	--	9.7	150	110	7.4
09-19-78	.01	1,150	8.1	9.0	570	110	72	52	1	15	280	390	6.9
10-17-78	.04	1,600	8.1	9.0	770	160	90	68	1	14	300	590	15
11-14-78	.31	2,600	7.7	0.0	1,700	370	190	110	1	16	370	1,500	32
03-14-79	.68	1,550	7.7	1.0	800	190	80	44	.7	17	240	610	17
04-13-79	1.1	1,880	7.9	3.5	1,000	260	96	58	.8	13	300	750	15
05-08-79	3.1	2,400	7.7	6.5	1,300	280	150	81	1	18	350	1,100	20
06-08-79	.05	2,400	7.6	10.5	1,300	300	140	88	1	13	310	1,200	18
11-06-79	.16	2,600	7.5	1.0	1,500	350	160	100	1	14	360	1,200	24
11-29-79	.23	2,200	7.6	0.0	1,000	220	110	88	1	17	450	750	16
12-19-79	.06	1,900	8.0	.5	880	200	93	64	1	14	450	540	12
03-12-80	.89	1,460	--	0.0	810	180	87	55	.9	11	300	520	10
04-17-80	.18	1,500	--	11.0	800	180	86	61	1	10	270	630	11
05-13-80	4.0	1,800	--	10.5	900	180	110	66	1	13	240	730	13
06-10-80	.10	1,360	--	19.5	660	130	82	48	.8	11	320	450	5.3

Table 4.--Chemical analyses of surface water--Continued

Date	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, NO_2+ NO_3 dissolved (mg/L as N)	Iron, dissolved (μg/L as Fe)	Manganese, dissolved (μg/L as Mn)	Selenium, dissolved (μg/L as Se)	Gross alpha, dissolved (pCi/L as U-nat)	Uranium, natural dissolved (μg/L as U)	Gross alpha, dissolved (μg/L as U-nat)	Gross beta, dissolved (pCi/L as Sr/Yt-90)	Radium-226, dissolved radon method (pCi/L)	Gross beta, dissolved (pCi/L as Cs-137)
Sampling Site 1 - Dry Fork Cheyenne River near Bill, Wyo.--Continued													
05-04-77	0.70	11	1,200	--	90	--	--	--	--	--	--	--	--
05-31-77	.60	12	1,000	--	70	--	--	--	--	--	--	--	--
08-02-77	.60	16	680	--	130	510	2	--	--	--	--	--	--
11-15-77	.50	13	1,200	--	120	--	--	--	10	<17	17	0.22	19
01-06-78	.70	29	--	--	120	--	--	--	--	--	--	--	--
04-04-78	.50	10	1,200	--	20	50	<1	--	--	--	--	--	--
05-16-78	.50	4.6	810	--	120	--	--	--	--	--	--	--	--
07-25-78	.50	9.2	--	--	1,200	--	--	--	--	--	--	--	--
09-19-78	.30	9.5	820	--	190	--	--	--	--	--	--	--	--
10-17-78	.60	9.6	1,100	--	100	8	<1	--	9.1	21	16	.25	18
11-14-78	.50	13	2,400	--	90	--	--	--	--	--	--	--	--
03-14-79	.30	10	1,100	--	340	--	--	--	--	--	--	--	--
04-13-79	.50	11	1,400	--	100	--	--	--	--	--	--	--	--
05-08-79	.50	7.7	1,900	--	50	--	--	--	--	--	--	--	--
06-08-79	.50	5.8	2,000	--	70	--	--	--	--	--	--	--	--
11-06-79	.60	10	2,100	--	70	90	0	<22	18	<33	17	.31	16
11-29-79	.50	16	1,500	--	30	--	--	--	--	--	--	--	--
12-19-79	.50	18	1,200	--	40	--	--	--	--	--	--	--	--
03-12-80	.60	10	1,000	--	30	180	0	<14	11	<20	11	.24	10
04-17-80	.60	8.5	1,200	--	30	--	--	--	--	--	--	--	--
05-13-80	.40	8.4	1,260	--	40	--	--	--	--	--	--	--	--
06-10-80	.20	5.3	920	--	30	--	--	--	--	--	--	--	--

Table 4.--Chemical analyses of surface water--Continued

Date	Discharge (ft^3/s)	Specific conductance (µS/cm)	pH	Water temperature (°C)	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Sodium adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity, on site (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)
Sampling Site 1 - Dry Fork Cheyenne River near Bill, Wyo.--Continued													
07-01-80	0.10	--	--	--	1,300	240	180	120	1	15	110	1,400	28
10-09-80	.03	1,950	6.8	10.0	940	210	100	69	1	21	--	660	16
11-05-80	.10	1,740	8.0	10.0	1,000	230	110	80	1	16	--	780	17
12-04-80	.44	2,140	7.8	0.0	1,300	270	140	94	1	20	--	970	28
01-08-81	.16	1,990	7.8	1.5	1,100	260	120	85	1	13	--	790	24
02-05-81	.05	1,840	7.4	0.0	990	240	96	64	.9	13	--	680	13
03-04-81	.19	1,770	7.7	1.0	1,100	240	110	73	1	12	--	790	13
04-06-81	.71	1,920	8.2	8.5	990	200	120	95	1	13	--	1,000	37
05-05-81	.36	2,240	7.9	9.5	1,200	230	140	100	1	16	--	1,000	12
06-04-81	.12	1,320	7.6	15.0	670	150	71	42	.7	10	--	460	5.3
Sampling Site 2 - Sage Creek at Ross Road crossing near Orpha, Wyo.													
04-15-80	3.3	875	8.5	14.0	390	100	35	36	.8	7.6	170	310	9.1
Sampling Site 3 - Frank Draw tributary no. 2 near Orpha, Wyo. (flow from pond at Bill Smith Mine)													
04-11-80	2.5	750	--	9.5	--	--	--	--	--	--	--	--	--
04-15-80	3.2	700	8.5	13.5	320	85	25	29	.7	8.8	140	230	5.9
05-07-80	2.6	950	8.3	20.0	--	--	--	--	--	--	--	--	--
06-13-80	3.3	560	8.1	19.5	320	88	25	30	.8	8.9	190	220	5.2
08-27-80	3.1	750	--	19.5	--	--	--	--	--	--	--	--	--
09-22-80	2.6	725	8.5	16.5	--	--	--	--	--	--	--	--	--

Table 4.--Chemical analyses of surface water--Continued

Date	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, $NO_2 + NO_3$ dissolved (mg/L as N)	Iron, dissolved (μg/L as Fe)	Manganese, dissolved (μg/L as Mn)	Selenium, dissolved (μg/L as Se)	Gross alpha, dissolved (pCi/L as U-nat)	Uranium, natural dissolved (μg/L as U)	Gross alpha, dissolved (μg/L as U-nat)	Gross beta, dissolved (pCi/L as Sr/Yt-90)	Radium-226, dissolved radon method (pCi/L)	Gross beta, dissolved (pCi/L as Cs-137)
Sampling Site 1 - Dry Fork Cheyenne River near Bill, Wyo.--Continued													
07-01-80	0.50	0.5	2,000	0.00	60	20	0	<13	11	<27	14	0.18	14
10-09-80	.50	21	1,300	--	40	9	0	--	--	--	--	--	--
11-05-80	.50	19	1,500	--	20	--	--	<15	14	<22	22	.13	23
12-04-80	.50	16	1,700	--	50	--	--	--	--	--	--	--	--
01-08-81	.50	17	1,600	--	140	--	--	--	--	--	--	--	--
02-05-81	.50	17	1,400	--	230	--	--	--	--	--	--	--	--
03-04-81	.50	13	1,500	--	40	--	--	--	--	--	--	--	--
04-06-81	.10	12	1,600	--	80	--	--	--	--	--	--	--	--
05-05-81	.60	14	1,700	--	60	--	--	--	--	--	--	--	--
06-04-81	.50	16	950	--	80	--	--	--	--	--	--	--	--
Sampling Site 2 - Sage Creek at Ross Road crossing near Orpha, Wyo.--Continued													
04-15-80	.50	12	610	.10	20	170	4	140	250	140	57	1.4	56
Sampling Site 3 - Frank Draw tributary no. 2 near Orpha, Wyo. (flow from pond at Bill Smith Mine)--Continued													
04-11-80	--	--	--	--	--	--	--	--	--	--	--	--	--
04-15-80	.40	16	480	.03	90	8	7	300	340	440	70	2.0	68
05-07-80	--	--	--	--	--	--	--	--	--	--	--	--	--
06-13-80	.30	15	510	.08	<10	7	6	--	--	--	--	--	--
08-27-80	--	--	--	--	--	--	--	--	--	--	--	--	--
09-22-80	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 4.--Chemical analyses of surface water--Continued

Date	Discharge (ft^3/s)	Specific conductance (µS/cm)	pH	Water temperature (°C)	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Sodium adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity, on site (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)
Sampling Site 3 - Frank Draw tributary no. 2 near Orpha, Wyo. (flow from pond at Bill Smith Mine)--Continued													
03-12-82	--	630	8.8	7.5	--	--	--	--	--	--	--	--	--
03-12-81	--	610	8.9	14.5	--	--	--	--	--	--	--	--	--
03-12-81	--	630	8.8	11.0	--	--	--	--	--	--	--	--	--
03-12-81	--	600	8.7	8.0	--	--	--	--	--	--	--	--	--
03-12-81	--	630	8.6	7.0	--	--	--	--	--	--	--	--	--
03-12-81	--	590	8.6	6.0	--	--	--	--	--	--	--	--	--
Sampling Site 4 - EXXON seepage pump no. 1													
07-01-80	--	4,800	--	14.5	2,700	740	210	210	2	4.1	490	2,100	230
Sampling Site 5 - Box Creek at County Road 32 near Bill, Wyo.													
04-11-80	0.59	1,000	--	5.0	--	--	--	--	--	--	--	--	--
04-16-80	0.40	1,180	8.2	10.5	370	92	34	130	3	4.1	280	370	9.9
05-07-80	0.11	1,600	7.7	12.5	--	--	--	--	--	--	--	--	--
06-12-80	0.13	850	7.5	20.0	340	79	35	110	3	3.6	230	360	8.5
08-19-80	0.07E	1,170	--	21.5	--	--	--	--	--	--	--	--	--
09-23-80	0.10E	950	8.3	13.5	--	--	--	--	--	--	--	--	--
03-12-81	--	960	8.4	8.5	--	--	--	--	--	--	--	--	--
Sampling Site 6 - Discharge from pond at Golden Eagle Mine													
05-28-80	--	670	8.2	13.5	240	70	16	46	1	8.9	120	200	6.8

Table 4.--Chemical analyses of surface water--Continued

Date	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Iron, dissolved (μg/L as Fe)	Manganese, dissolved (μg/L as Mn)	Selenium, dissolved (μg/L as Se)	Gross alpha, dissolved (pCi/L as U-nat)	Uranium, natural dissolved (μg/L as U)	Gross alpha, dissolved (μg/L as U-nat)	Gross beta, dissolved (pCi/L as Sr/Yt-90)	Radium-226, dissolved radon method (pCi/L)	Gross beta, dissolved (pCi/L as Cs-137)
Sampling Site 3 - Frank Draw tributary no. 2 near Orpha, Wyo. (flow from pond at Bill Smith Mine)--Continued													
03-12-81	--	--	--	--	--	--	--	--	--	--	--	--	--
03-12-81	--	--	--	--	--	--	--	--	--	--	--	--	--
03-12-81	--	--	--	--	--	--	--	--	--	--	--	--	--
03-12-81	--	--	--	--	--	--	--	--	--	--	--	--	--
03-12-81	--	--	--	--	--	--	--	--	--	--	--	--	--
Sampling Site 4 - EXXON seepage pump no. 1--Continued													
07-01-80	0.20	10	3,800	0.09	320	400	17	59	140	87	<20	0.50	<22
Sampling Site 5 - Box Creek at County Road 32 near Bill, Wyo.--Continued													
04-11-80	--	--	--	--	--	--	--	--	--	--	--	--	--
04-16-80	.30	8.5	820	.02	10	150	0	28	33	41	11	.19	10
05-07-80	--	--	--	--	--	--	--	--	--	--	--	--	--
06-12-80	.10	7.5	740	.00	20	60	0	--	--	--	--	--	--
08-19-80	--	--	--	--	--	--	--	--	--	--	--	--	--
09-23-80	--	--	--	--	--	--	--	--	--	--	--	--	--
03-12-81	--	--	--	--	--	--	--	--	--	--	--	--	--
Sampling Site 6 - Discharge from pond at Golden Eagle Mine--Continued													
05-28-80	.20	10	430	.08	<10	3	73	1,200	1,300	1,700	130	2.5	130

Table 4.--Chemical analyses of surface water--Continued

Date	Discharge (ft^3/s)	Specific conductance (μS/cm)	pH	Water temperature (°C)	Hardness, total (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Sodium adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity, on site (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)
Sampling Site 7 - Brown Springs Creek near Bill, Wyo.													
05-06-80	--	870	8.9	15.0	470	110	48	21	0.4	2.2	320	160	13
Sampling Site 8 - Discharge to Brush Creek from pond at Kerr-McGee pit													
05-28-80	--	940	--	16.5	430	120	31	14	.3	7.8	150	250	24
Sampling Site 9 - Discharge to Bear Creek, dam site no. 1													
04-15-80	2.6	1,750	8.2	9.5	980	300	56	64	.9	11	170	910	23
Sampling Site 10 - Pond on Bear Creek below Bear Creek Mine													
04-15-80	2.6	1,800	8.2	10.5	970	290	59	65	.9	11	160	920	23

Table 4.--Chemical analyses of surface water--Continued

Date	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, $NO_2 + NO_3$ dissolved (mg/L as N)	Iron, dissolved (μg/L as Fe)	Manganese, dissolved (μg/L as Mn)	Selenium, dissolved (μg/L as Se)	Gross alpha, dissolved (pCi/L as U-nat)	Uranium, natural dissolved (μg/L as U)	Gross alpha, dissolved (μg/L as U-nat)	Gross beta, dissolved (pCi/L as Sr/Yt-90)	Radium-226, dissolved radon method (pCi/L)	Gross beta, dissolved (pCi/L as Cs-137)
Sampling Site 7 - Brown Springs Creek near Bill, Wyo.--Continued													
05-06-80	0.50	16	560	0.07	60	400	1	100	170	150	12	0.28	12
Sampling Site 8 - Discharge to Brush Creek from pond at Kerr-McGee pit--Continued													
05-28-80	.30	11	550	.01	10	10	71	620	1,000	910	100	.55	100
Sampling Site 9 - Discharge to Bear Creek, dam site no. 1--Continued													
04-15-80	.10	10	1,500	.09	20	40	22	520	910	770	170	.30	170
Sampling Site 10 - Pond on Bear Creek below Bear Creek Mine--Continued													
04-15-80	.10	6.8	1,500	.03	20	150	18	580	830	850	150	.24	150

*U.S. GOVERNMENT PRINTING OFFICE: 1993-775-011