DESCRIPTION OF TECHNIQUES TO DRILL, COMPLETE, AND DEVELOP WELLS AND TO TEST AND SAMPLE AQUIFERS AT A SURFACE COAL MINE IN NORTHWESTERN COLORADO

by Robert S. Williams, Jr., and Gregory M. Clark

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CCONVERSION FACTORS

Multiply	*By*	*To obtain*
acre-foot	1,233	cubic meter
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
foot squared per day (ft^2/d)	0.0929	meter squared per day
mile (mi)	1.609	kilometer
gallon per minute (gal/min)	0.0630	liter per second

Degree Celsius (°C) can be converted to degree Fahrenheit (°F) by using the following equation:

$$F = 9/5(°C) + 32$$

National Geodetic Vertical Datum of 1929 (NVGD of 1929): A Geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

DESCRIPTION OF TECHNIQUES USED TO DRILL, COMPLETE, AND DEVELOP WELLS AND TO TEST AND SAMPLE AQUIFERS AT A SURFACE COAL MINE IN NORTHWESTERN COLORADO

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ABSTRACT

Techniques used to obtain hydrologic information at a surface coal mine in northwestern Colorado are described in this report. Drilling, completion, and development techniques for wells in bedrock and reclaimed spoils are described. Aquifer hydraulic properties and water quality were measured for confined bedrock aquifers and unconfined reclaimed spoil aquifers. To the extent possible, techniques for testing aquifer hydraulic properties and for obtaining water-quality samples were compared. Flowing-well tests, recovery tests, slug tests, and pressure slug tests were used in the confined bedrock aquifers. The flowing-well test was used for wells that flowed sufficiently to permit easy measurement of discharge. Recovery tests were used to check results of two flowing-well tests. The slug test was used for confined bedrock aquifers where the water level in the well was above land surface but below the top of the well casing. The pressure slug test was used for confined bedrock aquifers that did not produce enough discharge to be easily measured. Pumping tests were used for the unconfined reclaimed spoil aquifers.

Well water was sampled using three techniques. Samples were collected when the first water flowed or was pumped from the well, when measurements of field water-quality properties were stable, and when three casing volumes of water were removed. Sampling after three casing volumes of water were removed from the well generally was the preferred technique.

INTRODUCTION

During surface mining of coal, the vegetation and overburden are removed, the coal is mined, and the overburden is replaced and the surface is reclaimed. After mining, the reclaimed spoil undergoes weathering, settling, and compacting for an unknown period of time before reaching equilibrium. Full evaluation of this disturbed and changing system and understanding of reclaimed-spoil hydrogeologic processes is essential to regulatory agencies for support of leasing, permitting, and reclamation related to coal mining on Federal lands.

In 1987, the U.S. Geological Survey, in cooperation with the U.S. Bureau of Land Management and the U.S. Office of Surface Mining Reclamation and Enforcement, began a study to describe the processes controlling the hydrology of reclaimed coal spoils in northwestern Colorado. However, although several techniques are available for evaluating aquifer hydraulic properties and aquifer water quality, some of the techniques may not be suitable for use at surface coal mines in northwestern Colorado. Regulatory and management agencies must evaluate hydrologic data submitted by various groups who have collected data using some of the several techniques. Direct comparison of these data may not be valid and may result in erroneous conclusions about the effects of surface coal mining on the local hydrology. Therefore, the techniques for drilling, completing, and developing wells and for testing aquifer hydraulic properties and aquifer water quality used in this study are described. References describing the theoretical background for techniques are listed where appropriate. The results of this study may be directly applicable to other similar coal-mine areas or the techniques may be applicable to other areas that are hydrologically different.

Purpose and Scope

This report describes techniques for obtaining hydrologic information at a surface coal mine in northwestern Colorado. Confined bedrock aquifers and unconfined reclaimed spoil aquifers were studied. Reclaimed spoil, as described in this report, is material excavated from the mine pit that has been replaced, regraded, covered with topsoil, and revegetated. Well-drilling, well-completion, and well-development techniques are described. To the extent possible, different techniques for testing aquifer hydraulic properties and for obtaining water-quality samples from aquifers are compared. The equipment and techniques associated with testing aquifer hydraulic properties and collecting water-quality information are described. The techniques evaluated commonly are used for hydrogeologic studies in the area. The techniques may be transferable, in varying degrees, to other surface coal-mine areas.

This report includes work done as part of a study to evaluate the hydrology and geochemistry of a surface coal mine in northwestern Colorado. Wells were constructed, and monitoring equipment and instrumentation were installed in the summer of 1987. Four sites were instrumented for the study. Eighteen wells were completed in confined bedrock aquifers, and seven wells were completed in unconfined reclaimed spoil aquifers. Aquifer tests were done on selected wells in 1987-90. Water-sampling tests on selected wells were done during June 1988 using three different techniques.

Description of Study Area

The study area is located at the Seneca II Coal Mine in northwestern Colorado (fig. 1). The study area is about 20 mi west and 5 mi south of Steamboat Springs, Colorado. The area is shown on the U.S. Geological Survey topographic maps of the Mount Harris and Milner quadrangles (fig. 2). The area ranges in altitude from about 6,800 to 8,000 ft. The vegetation primarily is sagebrush and grasses with scattered stands of scrub oak, serviceberry, and aspen. Average yearly rainfall for the area is 16 in (ENMAP Corporation, 1981). Warm days and cool nights characterize the summer; winter is relatively cold. The average date of the first killing frost is September 14, and the average date of the last killing frost is June 10.

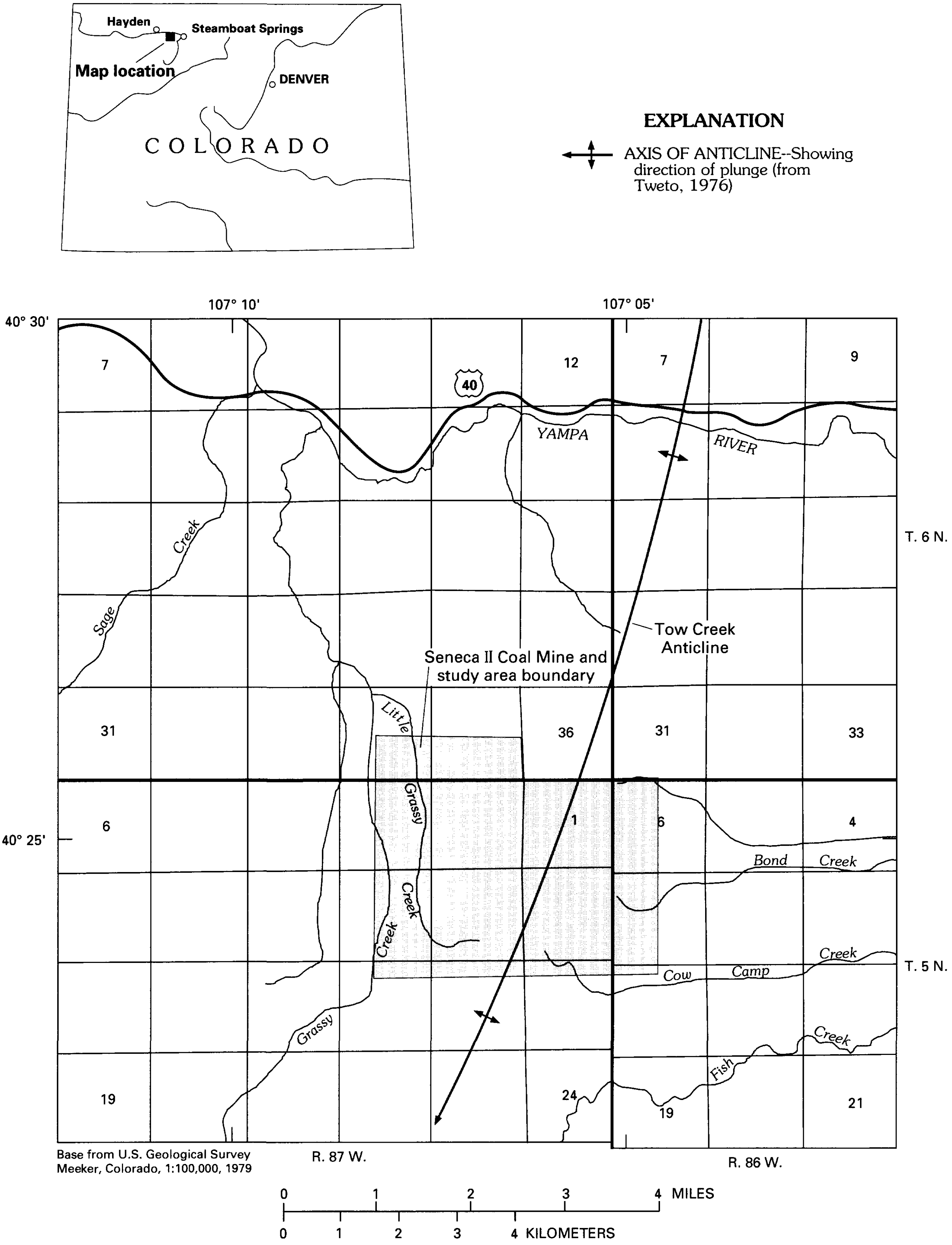


Figure 1.--Location of the study area (modified from Clark and Williams, 1990).

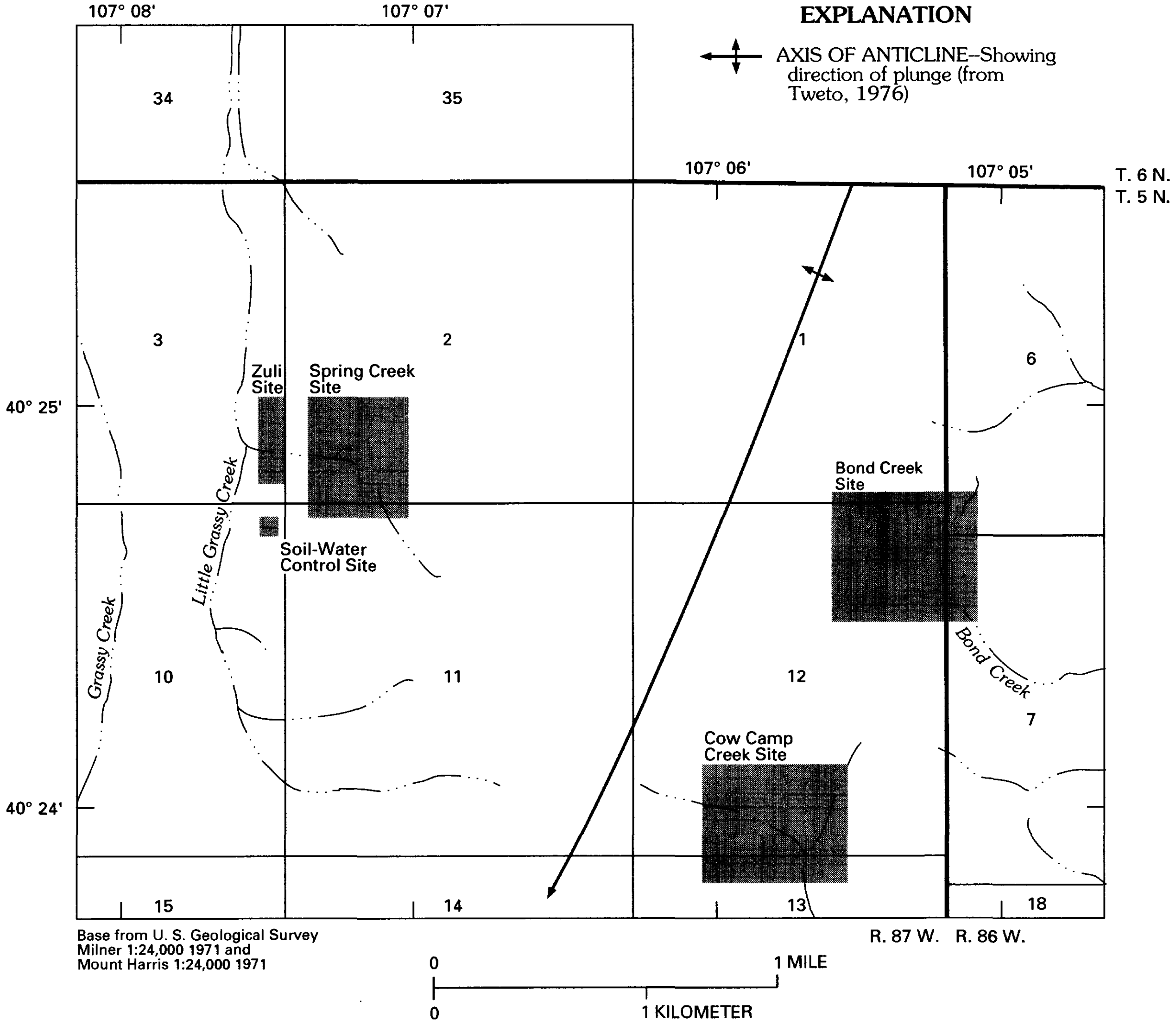


Figure 2.--Study area and data-collection sites.

A prominent feature in the study area is the Tow Creek anticline, a northeastward-trending asymmetrical fold (Bass and others, 1955) (fig. 1). The anticline approximately divides the Seneca II Coal Mine in half. Rocks east of the axis of the anticline dip to the east, and rocks west of the axis of the anticline dip to the west. The eastern part of the area is drained by Bond Creek, Cow Camp Creek, and other unnamed streams that are tributary to Fish Creek. The western part of the area is drained by Little Grassy Creek, which is tributary to Grassy Creek. In the southern part of the study area at the plunging, southern tip of the anticline, rocks dip to the south. The coal seams of interest in this study are the Lennox and the Wadge (fig. 3) of the Williams Fork Formation of Cretaceous age.

Confined bedrock aquifers are present in the study area. Wells completed in the aquifers near the toe of slopes often will produce flowing wells. The wells generally flow at less than 5 gal/min. Hydraulic heads in the wells range from a few to tens of feet above land surface.

Aquifers develop in the reclaimed spoil during and following mining. A diagrammatic hydrogeologic section of one of these aquifers is shown in figure 4. The aquifers generally are at the toe of the slope at the location of the mine pit low wall. A spring(s) will form when the water level rises above the land surface of the reclaimed spoil.

Acknowledgments

Personnel from the Peabody Coal Company at the Flagstaff, Arizona, headquarters office and at the Seneca II Coal Mine supplied technical information and machinery throughout the study. Bulldozers and backhoes were provided during well construction, roads were snowplowed and graded as needed, and wells were surveyed and mapped at all sites. The work and assistance was helpful and appreciated.

LOCATION OF WELLS COMPLETED IN BEDROCK AND RECLAIMED SPOIL

Wells are located at four sites at the study area. Two sites, Spring Creek (figs. 2 and 5) and Cow Camp Creek (figs. 2 and 6), have wells completed in bedrock (hereinafter referred to as bedrock wells) and reclaimed spoil (hereinafter referred to as reclaimed spoil wells). Two other sites, Zuli (figs. 2 and 5) and Bond Creek (figs. 2 and 7), have wells completed only in the bedrock. The Zuli site is downgradient from the Spring Creek site and probably will not be mined. Mining began at the Bond Creek site in 1989. The mine pit is the area of active mining, and the spoil ridge is the unreclaimed spoil area (fig. 7).

Eighteen bedrock wells are located in the study area. At each of the four sites within the study area a separate bedrock well is completed in the Lennox coal, the interburden (bedrock zone between the Lennox coal and the Wadge coal), the Wadge coal, and the underburden (bedrock zone below the Wadge coal). In addition, two bedrock wells (SSU287 and SSD487, table 1) are completed deeper in the underburden at the Spring Creek site, each in separate aquifers.

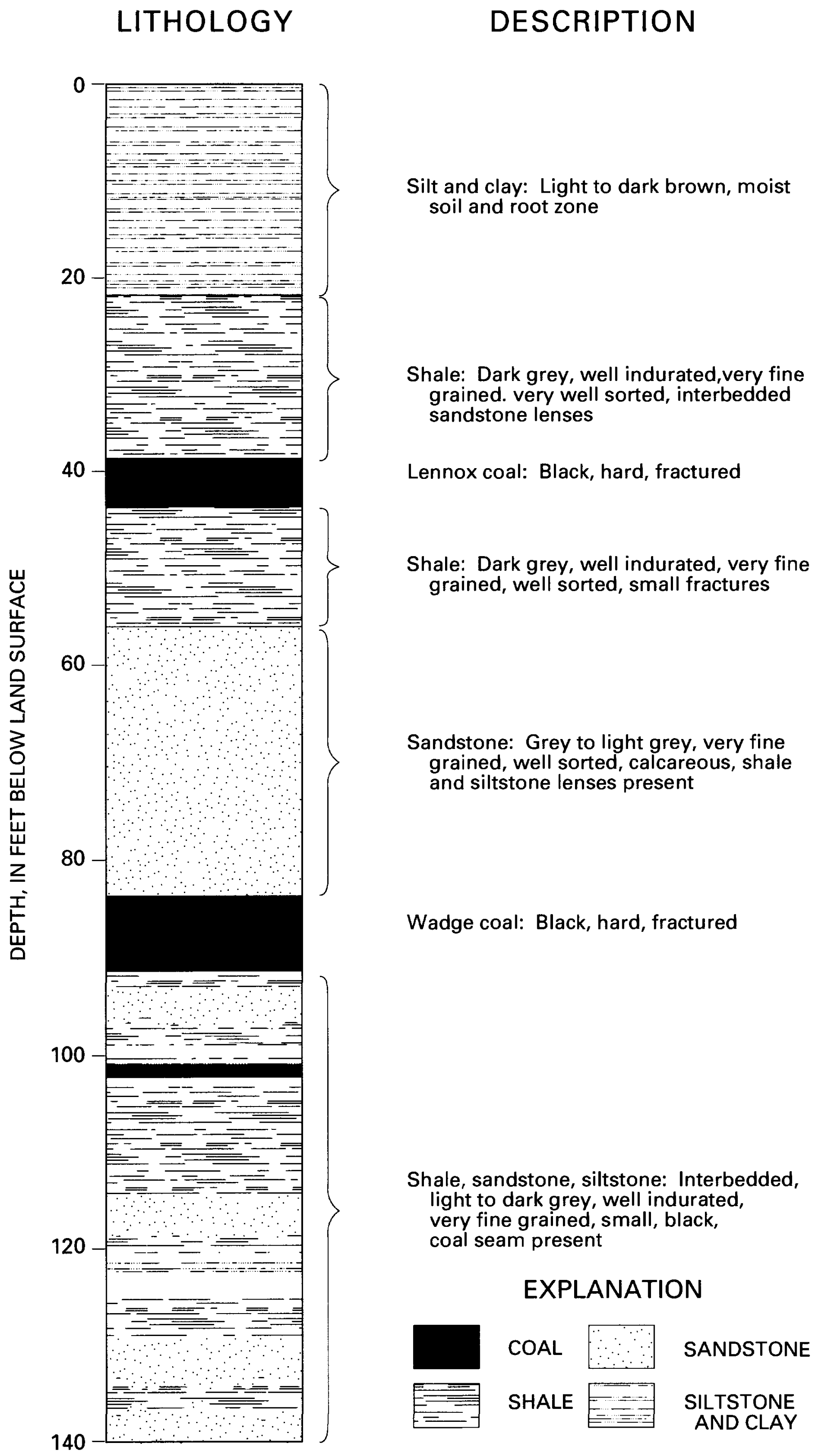


Figure 3.--General geologic log of the study area.

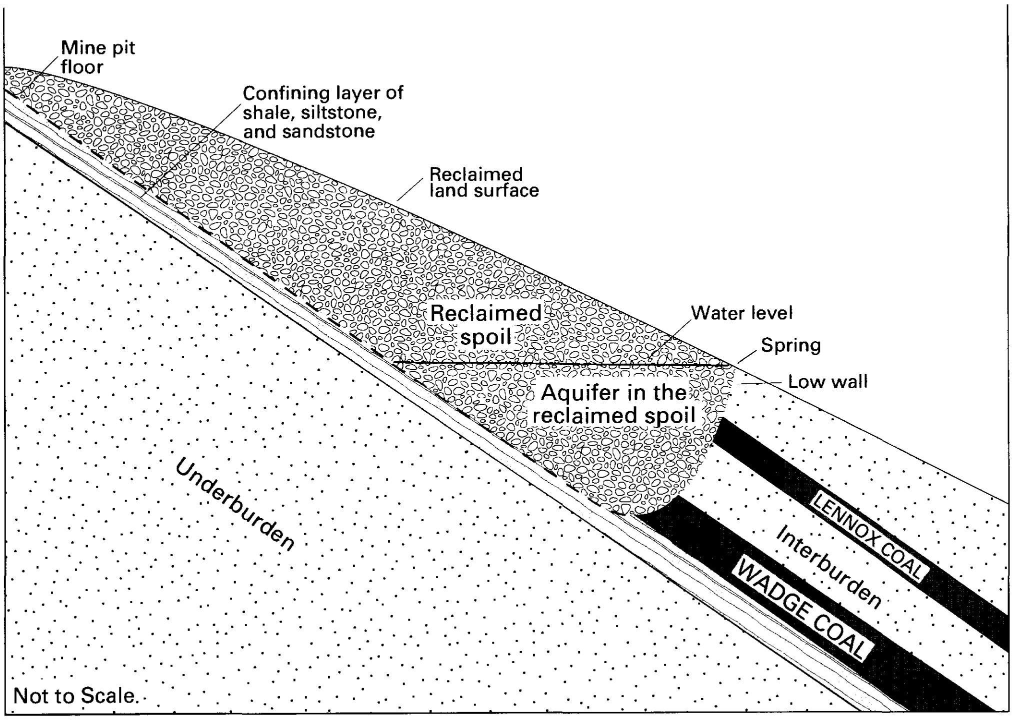
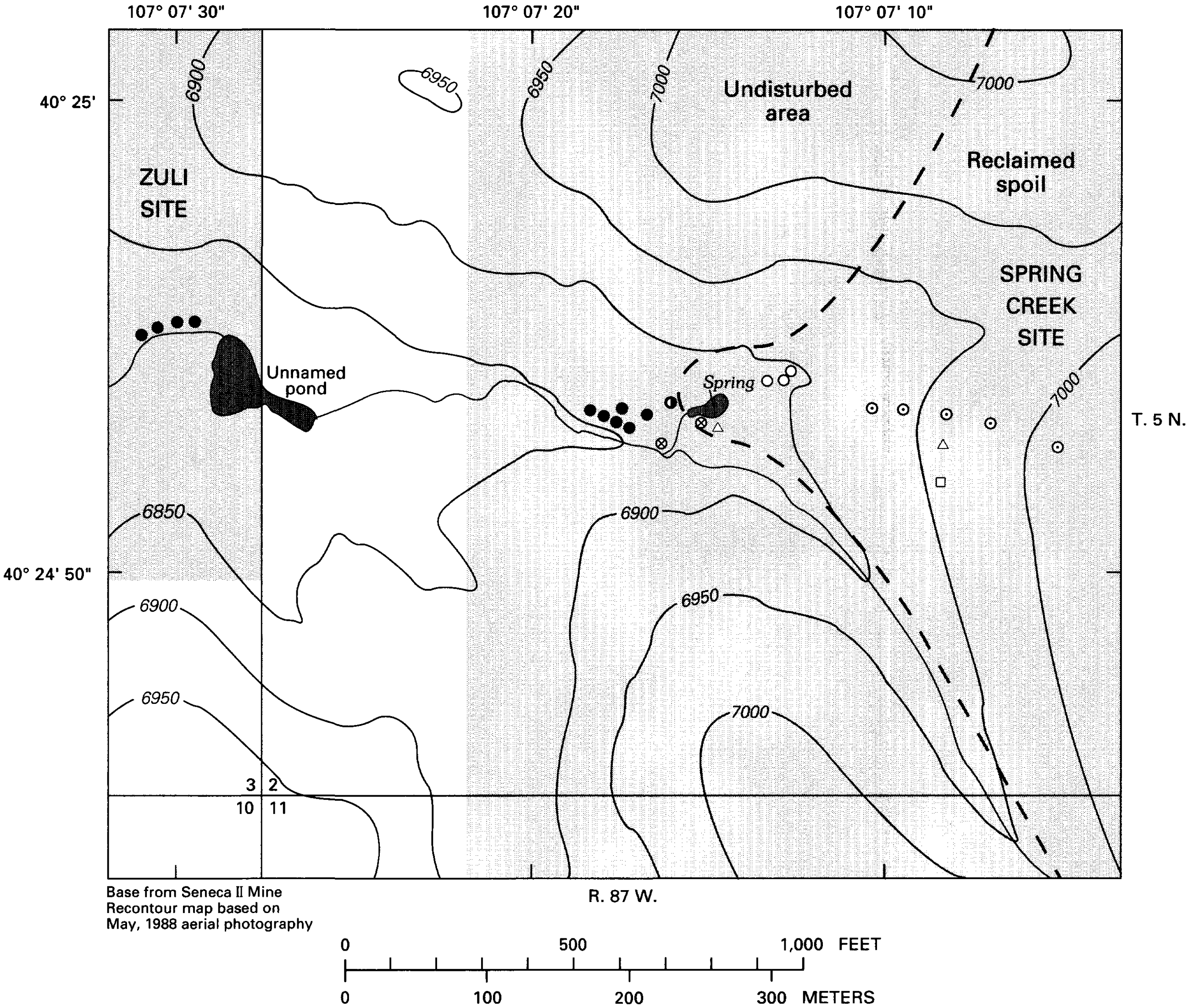


Figure 4.--Diagrammatic hydrogeologic section of reclaimed spoil and bedrock at the study area (modified from Clark and Williams, 1990).



Base from Seneca II Mine
Recontour map based on
May, 1988 aerial photography

Contour interval 50 feet
National Geodetic Vertical Datum of 1929

EXPLANATION

●	WELL COMPLETED IN BEDROCK
○	WELL COMPLETED IN RECLAIMED SPOIL
— — —	APPROXIMATE BOUNDARY OF RECLAIMED SPOIL
▨	STUDY SITES
□	LYSIMETER AND SOIL-WATER ACCESS TUBE
△	WEIGHING-BUCKET PRECIPITATION GAGE
⊙	SOIL-WATER ACCESS TUBE
⊗	SURFACE-WATER GAGE
◑	CLIMATE STATION

Figure 5.--Data-collection points at the Spring Creek and Zuli sites.

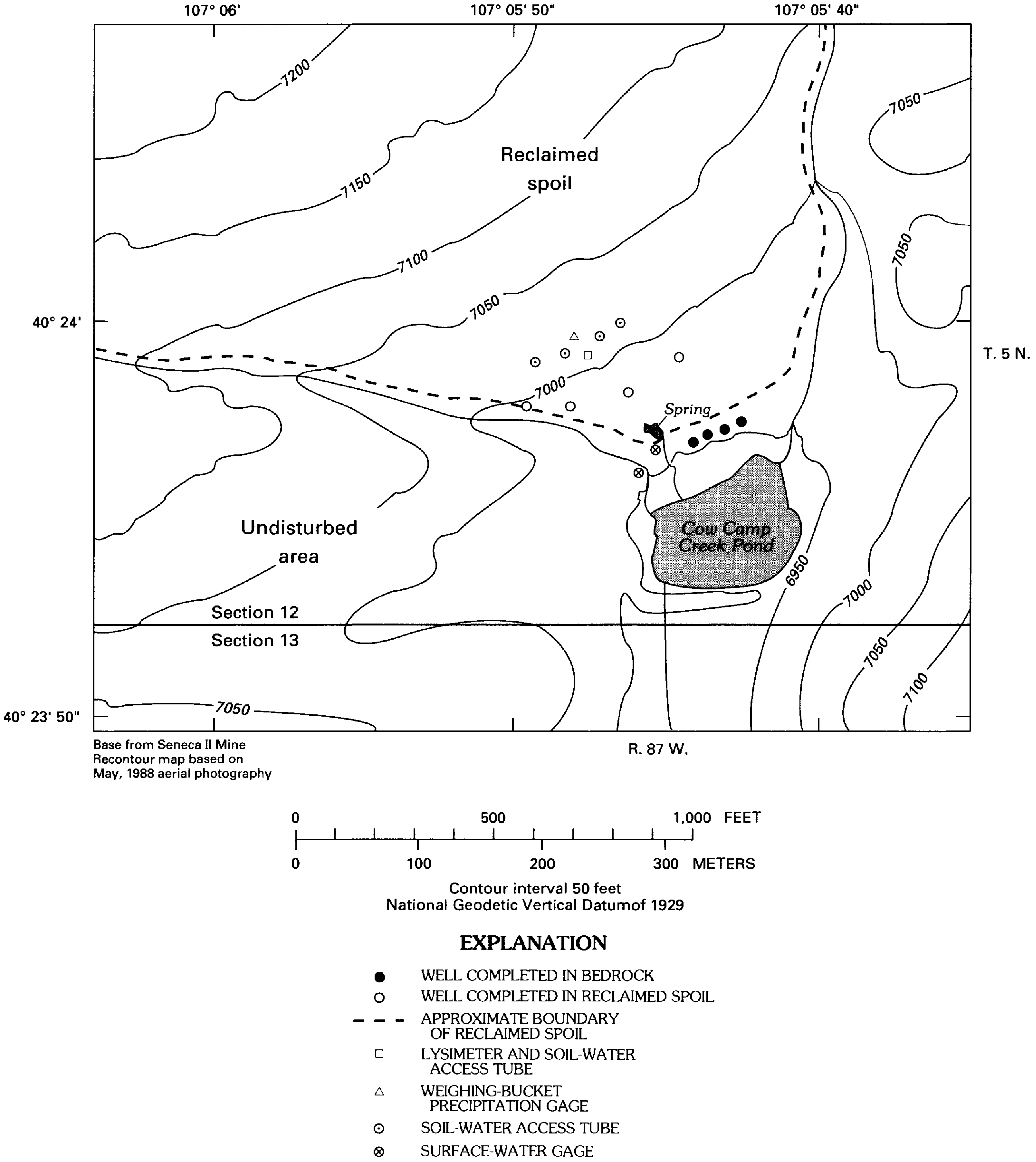


Figure 6.--Data-collection points at the Cow Camp Creek site (modified from Clark and Williams, 1990).

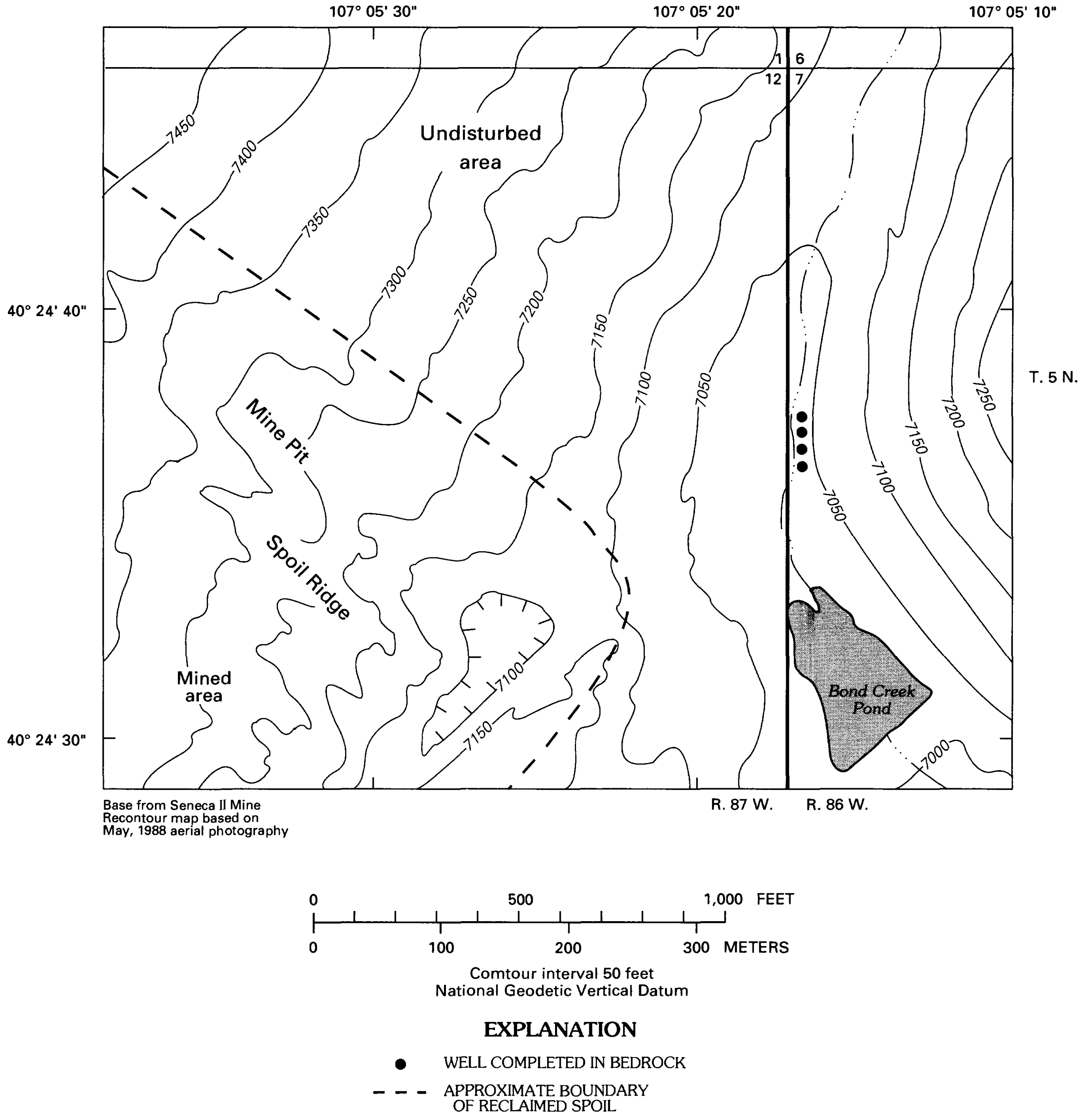


Figure 7.--Data-collection points at the Bond Creek site.

Table 1.--*Well information*

[Altitude, in feet, refers to distance above the NGVD of 1929; Interburden, bedrock zone between Lennox coal and Wadge coal; Underburden, bedrock zone below Wadge coal; Rec spoil, reclaimed spoil]

Site	Well identification	Well name	Land-surface altitude (feet)	Well depth[3] (feet)	Zone of completion
Spring Creek	SSL287	SL2	6,861	58	Lennox coal
Spring Creek	SSI287	SI2	6,860	80	Interburden
Spring Creek	SSW287	SW2	6,860	98	Wadge coal
Spring Creek	SSU487	SU4	6,861	105	Underburden
Spring Creek	SSU287	SU2	6,862	127	Underburden
Spring Creek	SSD487	SD4	6,860	194	Underburden
Spring Creek	SSS487-59	S59	6,899	33	Rec spoil
Spring Creek	SSS487-60	S60	6,893	23	Rec spoil
Spring Creek	SSS487-61	S61	6,892	26	Rec spoil
Cow Camp	SCL287	CL2	6,957	30	Lennox coal
Cow Camp	SCI287	CI2	6,957	70	Interburden
Cow Camp	SCW287	CW2	6,957	90	Wadge coal
Cow Camp	SCU287	CU2	6,957	122	Underburden
Cow Camp	SCS487-62	C62	6,976	52	Rec spoil
Cow Camp	SCS487-63	C63	6,982	38	Rec spoil
Cow Camp	SCS487-64	C64	6,980	37	Rec spoil
Cow Camp	SCS487-65	C65	6,997	25	Rec spoil
Zuli	SZL287	ZL2	6,822	182	Lennox coal
Zuli	SZI287	ZI2	6,819	222	Interburden
Zuli	SZW287	ZW2	6,823	228	Wadge coal
Zuli	SZU287	ZU2	6,820	265	Underburden
Bond Creek	SBL287	BL2	7,032	98	Lennox coal
Bond Creek	SBI287	BI2	7,031	150	Interburden
Bond Creek	SBW287	BW2	7,032	164	Wadge coal
Bond Creek	SBU287	BU2	7,030	175	Underburden

[1] Alphanumeric well identifications were assigned as follows: The first letter (S) designates the Seneca II Coal Mine. The second letter (S, C, Z, or B) designates the site as Spring Creek, Cow Camp Creek, Zuli, or Bond Creek. The third letter (L, I, W, U, D, or S) designates a specific zone of completion. These zones are the Lennox coal, Interburden, Wadge coal, Underburden, Deep underburden, and reclaimed Spoil. The number 2 or 4 designates the well-casing diameter, in inches, and 87 is the year the wells were drilled (1987). Wells completed in reclaimed spoil were assigned an additional well number by the Seneca II Coal Mine operators; these are indicated by a hyphen followed by the assigned well number.

[2] Alphanumeric well names were assigned to each well. For all wells, the first letter designates the site. For bedrock wells, the second letter designates the specific zone of completion (see footnote 1), and the number 2 or 4 designates well-casing diameter, in inches. For wells completed in reclaimed spoil, the last two numbers indicate the well number assigned by the Seneca II Coal Mine operators.

[3] Depths are rounded to nearest foot.

Seven reclaimed spoil wells are located in the study area. Three reclaimed spoil wells are at the Spring Creek site and four reclaimed spoil wells are at the Cow Camp Creek site.

Locations and names of ground-water wells (bedrock and reclaimed spoil wells) are listed in table 1. Well depths and zones of completion also are listed in table 1. Lithologic and geophysical logs for bedrock wells are listed in table 2.

Table 2.--*Summary of lithologic and geophysical logs for bedrock wells*

[C, caliper; NG, natural gamma; GG, gamma-gamma; N, neutron; R, resistivity SP, spontaneous potential; X, data; -, no data]

Well	Lithologic log		Geophysical log					
	Core	Cuttings	C	NG	GG	N	R	SP
SL2	-	X	X	X	X	-	X	-
SI2	-	X	X	X	X	-	X	-
SW2	-	X	X	X	X	-	X	-
SU4	X	-	X	X	X	X	-	X
SU2	-	X	-	-	-	-	-	-
SD4	-	X	X	X	X	-	X	X
CL2	-	X	-	-	-	-	-	-
CI2	-	X	X	X	X	-	X	X
CW2	-	X	X	X	X	-	X	X
CU2	X	-	X	X	X	-	X	X
ZL2	-	X	X	X	X	-	X	X
ZI2	-	X	X	X	X	-	X	X
ZW2	-	X	-	-	-	-	-	-
ZU2	X	-	X	X	X	-	X	X
BL2	-	X	X	X	X	-	X	X
BI2	-	X	X	X	X	-	X	X
BW2	-	X	X	X	X	-	X	X
BU2	X	-	X	X	X	-	X	X

[1] Alphanumeric well names were assigned to each well. For all wells, the first letter (S, C, Z, or B) designates the site as Spring Creek, Cow Camp Creek, Zuli, or Bond Creek. The second letter (L, I, W, U, and D) designates a specific zone of completion. These zones are the Lennox coal, Interburden, Wadge coal, Underburden, and Deep underburden. The number 2 or 4 designates the well-casing diameter, in inches.

TECHNIQUES FOR WELL DRILLING, WELL COMPLETION, AND WELL DEVELOPMENT

Techniques for well drilling, well completion, and well development have been discussed by several authors (Campbell and Lehr, 1973; U.S. Bureau of Reclamation, 1977; Freeze and Cherry, 1979; Barcelona and others, 1985; Driscoll, 1986). A primary concern in this study was to complete each well in only one aquifer. To address this concern, core-drilling and rotary-drilling techniques were used to drill the bedrock wells. Geophysical-log information was used to confirm lithologic information obtained from drilling.

Proper well-completion techniques are critical to a successful evaluation of the ground-water system. The importance of completing a well in only one aquifer needs to be emphasized. Completing a well with perforations open to more than one aquifer here is termed a "multiple-aquifer well completion." Generally, multiple-aquifer well completion initially is easier and less expensive than completing a separate well in each aquifer. However, the information obtained from the multiple-aquifer well completion may not meet study objectives. For example, these types of information may be difficult to determine: (1) potentiometric surface or water level of each contributing aquifer, (2) hydraulic properties of each aquifer, and (3) water quality of each aquifer. Consequently, determination of aquifer characteristics based on information obtained from multiple-aquifer well completions may be unclear.

Potentiometric-surface information may be a composite of two or more aquifers. The measured potentiometric surface will be some composite of the true maximum and minimum potentiometric surfaces of the aquifers intercepted by the multiple-aquifer well completion (Davis and DeWeist, 1966). Therefore, depiction of local and regional aquifer potentiometric surfaces would be difficult or impossible. Aquifer hydraulic properties obtained from aquifer tests also may be inaccurate. For instance, the hydraulic conductivity cannot be calculated accurately because the saturated thickness is unknown.

Water-quality samples collected from a multiple-aquifer well completion may be a composite of the water from more than one aquifer and may not be representative of the water quality in an individual aquifer. Analysis of the composite water may lead to underestimation or overestimation of water-quality changes due to mining. Erroneous inferences about offsite effects may result.

To obtain the most accurate information about individual aquifers each well should be completed in only one aquifer. Techniques for well drilling, well completion, and well development are discussed in the following sections.

Bedrock Drilling

At each site, one underburden-bedrock well was cored with a 3-3/4-in.-inside-diameter by 15-ft-long core barrel with a diamond drill bit. All other bedrock wells were rotary drilled with a 5-5/8- or 6-3/4-in.-outside-diameter triple-cone rock bit. Coring can provide precise information about composition and changes in bedrock lithology within the borehole. The lithologic information is needed to plan proper well completion.

Recovered core material was used onsite to examine lithologic change, degree of interbedding, and fractures. The existence of fractures can be seen directly by examining the core or surmised to exist when extensive core loss occurs. However, other factors, such as poorly consolidated material, also can contribute to core loss.

Rotary drilling was used for most boreholes because it is faster and less expensive than core drilling. Rotary cuttings provide information about lithology, but the information gained is less accurate than with core drilling. For instance, the depth of lithologic change cannot be determined as precisely. The accuracy also is decreased because the cuttings do not show fractures and because interbedding is not as apparent. The expertise and input of the driller can be very helpful in determining the depth of lithologic change. Deeper drill holes cause interpretive problems because the rate of return of cuttings varies with changes in cuttings material, drilling speed, and other factors. Inability to accurately determine the rate of return makes the depth of lithologic change more difficult to determine. In this study, wells were drilled with air until the first water-bearing zone was encountered. Water mist then was injected to keep the drill bit free of cuttings in the water-bearing zones.

Geophysical logs were run on all but three of the bedrock boreholes. The logs run on the core-drilled borehole were compared with logs run on the rotary-drilled boreholes. Information from core, cuttings, and geophysical logs was used to ensure proper well-screen placement in all bedrock wells.

Reclaimed Spoil Drilling

Hollow-stem auger drilling was one technique used to install wells in the reclaimed spoil. This technique prevents material from falling into the borehole prior to well completion. The wells were drilled with a 10-in.-outside-diameter hollow-stem auger and a fan-tail auger bit.

The hollow-stem auger drilling technique was better than core drilling or rotary drilling for the reclaimed spoil conditions. Core recovery in reclaimed spoil is extremely difficult. The reclaimed spoil primarily is composed of broken rock fragments that may fall out of the core barrel when it is removed from the borehole. The value of core drilling in reclaimed spoil also is questionable because of the heterogeneous nature of the reclaimed spoil. Any lithologic findings probably are applicable only within the immediate vicinity of the borehole.

The major problem with hollow-stem auger drilling is the inability to effectively drill through large sandstone boulders in the reclaimed spoil. This problem, in addition to making drilling difficult, makes it hard to determine when the hollow-stem auger and the fan-tail auger bit have drilled through the reclaimed spoil and into underlying bedrock.

A casing advancer drilling system manufactured by Christensen Mining Products[1] (1989) was used to drill one well in the reclaimed spoil. The casing advancer drilling system is shown in figure 8. A rotary drill rig was used for casing advancer drilling. During drilling, a steel casing was attached to a tungsten carbide casing shoe. Projecting slightly beyond the casing shoe and from inside the steel casing was a triple-cone rotary drill bit. The triple-cone rotary drill bit assembly is "latched" inside the casing shoe and steel casing during drilling. After drilling to the desired borehole depth, the triple-cone rotary drill bit was retrieved with a wire line cable. The outer steel casing was left in the borehole during well completion to keep the borehole open.

Well Completion and Well Development

Bedrock wells were completed immediately after drilling. The well casing was either 2- or 4-in.-inside-diameter polyvinylchloride (PVC) pipe. The aquifer of interest was screened with schedule 40 PVC pipe throughout the aquifer thickness. The rest of the well was cased with solid schedule 40 PVC pipe. One and one-quarter-inch steel tremie tube was temporarily placed in the annulus between the well casing and the borehole wall. Annular materials were poured down the tremie tube to ensure accurate placement of the materials and to prevent bridging. The level of the annular material in the annulus was frequently measured with a steel tape during the completion process. Washed pea-sized gravel was placed in the annulus around the well screen. Sand was placed on top of the gravel, and bentonite pellets were placed on top of the sand. The bentonite pellets were placed adjacent to a confining layer to prevent borehole cross-contamination and, thus, to ensure single-aquifer completions. A bentonite slurry was placed from the top of the bentonite pellets to within 5 to 10 ft of land surface. The top 5 to 10 ft of the annulus was cemented. A cement pad 2 ft wide by 2 ft long by 3-1/2-in. high was placed at land surface around the surface well casing.

Completing wells in the reclaimed spoil can be more difficult than in bedrock. Keeping the reclaimed spoil borehole open once it has been drilled and prior to well completion is difficult when using either core- or rotary-drilling techniques. In this study, hollow-stem auger flights or casing advancer steel casing were used to keep the borehole open.

Well completion for hollow-stem auger drilling and casing advancer drilling is similar. The hollow-stem auger completion technique will be described. The completion technique is depicted in figure 9. The hollow-stem auger temporarily was left in place after the borehole was drilled to keep the borehole open during well completion. Wells were completed in reclaimed spoil by lowering well casing through the hollow-stem auger (fig. 9A). Factory-slotted well casing (4-in.-inside-diameter schedule 40 PVC pipe) was placed

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[1] The use of trade, product, industry, or firm names in this report is for identification or location purposes only, and does not constitute endorsement of products by the U.S. Geological Survey, nor impute responsibility for any present or potential effects on the natural resources.

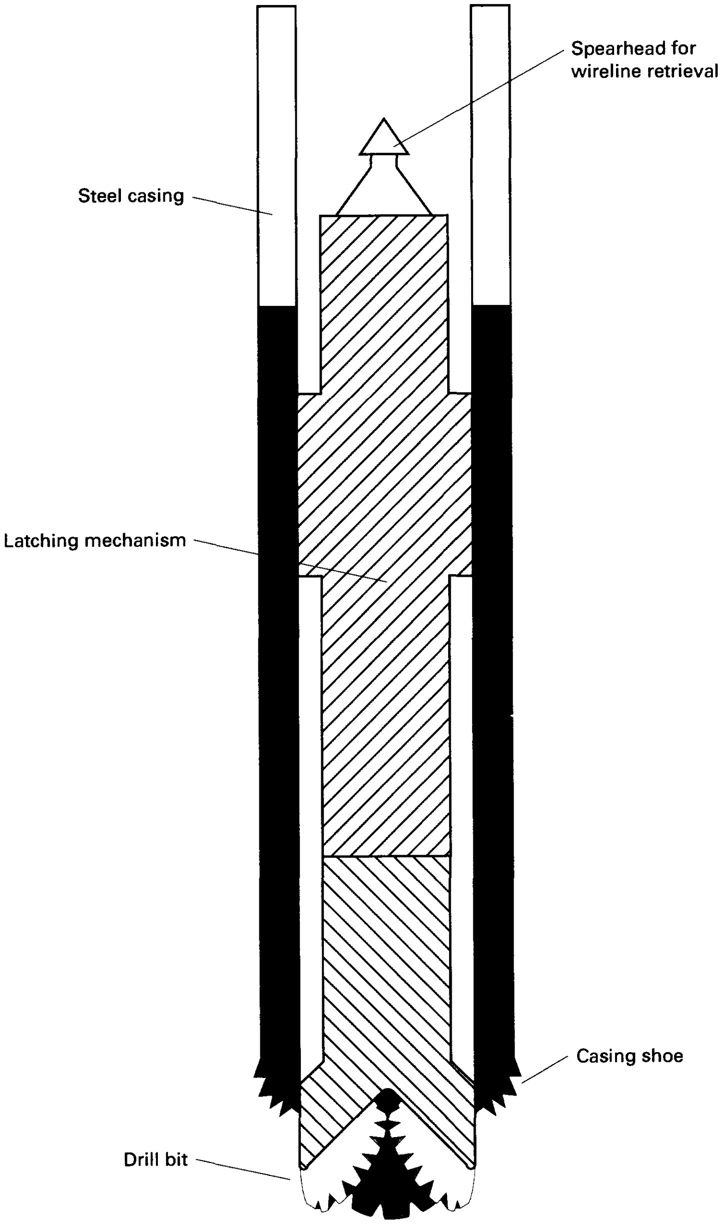
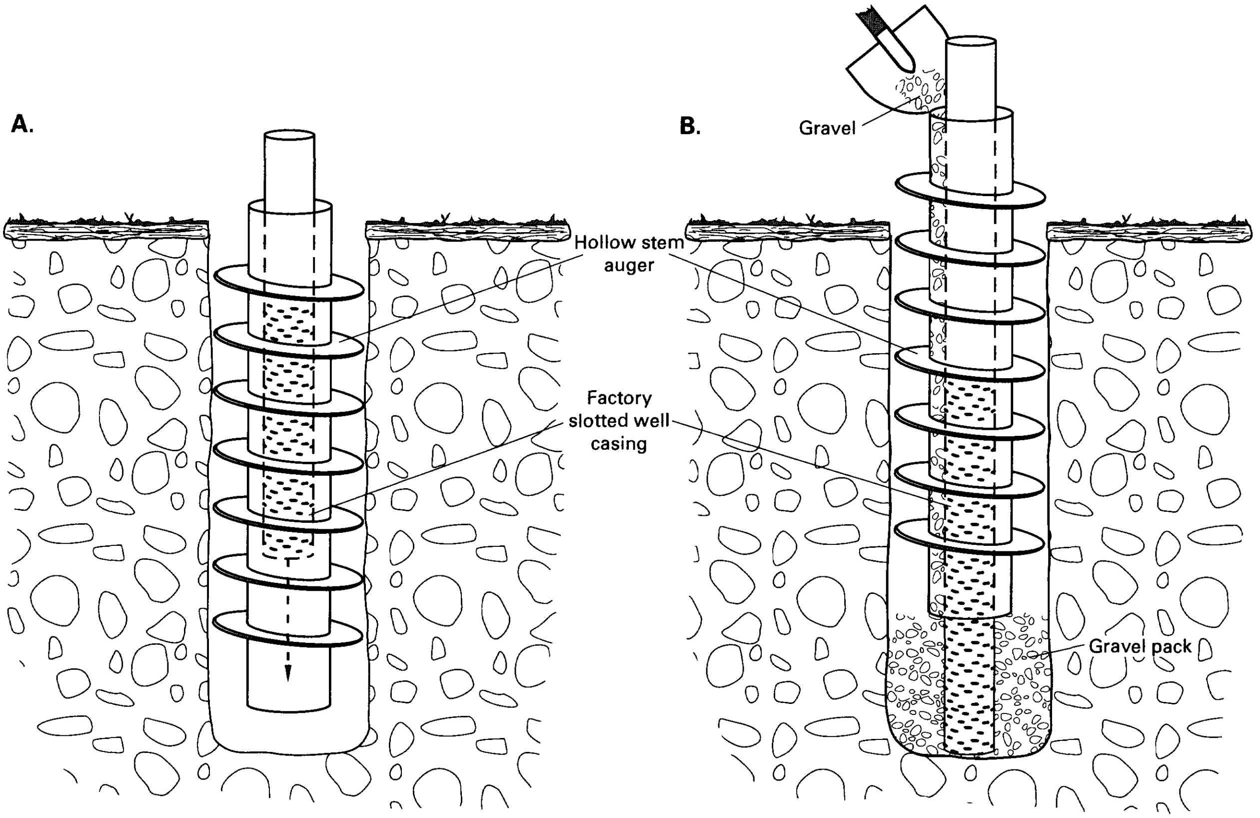
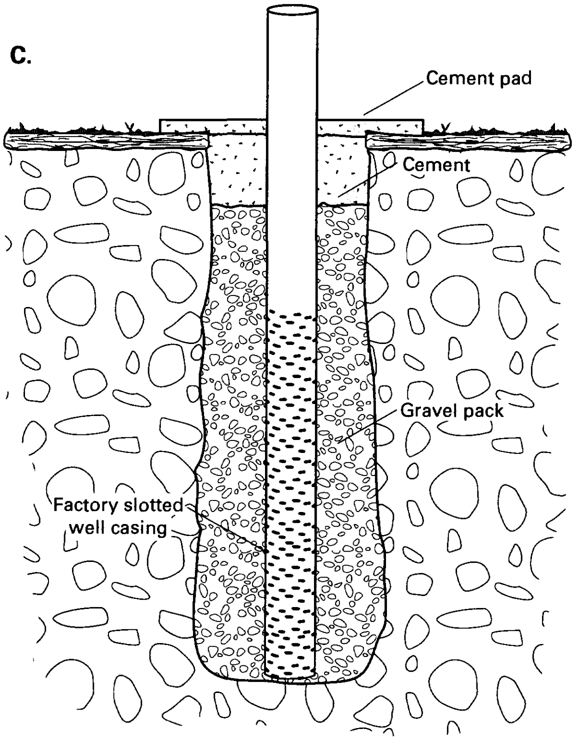


Figure 8.--Casing advancer drilling system (modified from Christensen Mining Products, 1989, and published with permission).



Lowering well casing through auger

Installing gravel pack



Completed well

Figure 9.--Well-completion procedure in reclaimed spoil. A, Lowering well casing through auger; B, Installing gravel pack; C, Completed well.

from the bottom of the well through the saturated interval to within 10 or 20 ft of land surface. Solid well casing (4-in.-inside-diameter schedule 40 PVC pipe) was used for the rest of the well. After all the well casing was in place, the hollow-stem auger was partially pulled out of the borehole, and one or two flights of hollow-stem auger were removed. Gravel was poured between the hollow-stem auger and the well casing and permitted to flow from the bottom of the hollow-stem auger to place a gravel pack between the reclaimed spoil and the factory-slotted well casing (fig. 9B). Care needs to be taken to prevent bridging of the gravel between the hollow-stem auger and the well casing. To prevent bridging, the well casing was hand vibrated as the gravel was poured slowly. The level of the gravel in the borehole was measured periodically. When the top of the gravel neared the bottom of the hollow-stem auger, another section of hollow-stem auger was removed from the borehole. Wells completed in the reclaimed spoil were gravel packed to within 5 to 10 ft of land surface. The top 5 to 10 ft of the annulus was cemented (fig. 9C). Bentonite was not used in the completion of reclaimed spoil wells.

Wells need to be developed to restore natural aquifer hydraulic properties that are altered during well drilling because of drilling techniques, drilling fluid, or well-construction techniques (Driscoll, 1986). Drilling fluids have the potential to push cuttings or other materials into the formation. Well development is done to remove the introduced materials. Bedrock wells were developed by lowering the drill stem to near the bottom of the well and allowing the water level in the well to equilibrate with the aquifer. Air was injected through the drill stem near the well screen to produce an air bubble that would lift the overlying water column. When the water began to rise, air injection was stopped, which permitted the water column in the well to fall back down the well. This action produced a surging effect near the well screen. Surging brings water in and out of the well screen and through the gravel pack. The action aids in removal of clays, silts, sands, and residual drilling fluids from the gravel pack and the surrounding aquifer. Periodically, the entire column of water was evacuated from the well with air, and the well was allowed to recover. The development procedures were continued until well water was clear and the onsite measured water-quality properties from several successive water samples stabilized.

Reclaimed spoil wells were drilled with an auger rig that did not have an air compressor. Therefore, a trailer-mounted air compressor was used to develop the reclaimed spoil wells. The air compressor was used to inject air into the well to evacuate water from the well. The development procedure was repeated until the water coming from the well was clear for several repeated injections of air.

TECHNIQUES FOR TESTING AQUIFER HYDRAULIC PROPERTIES

Five types of aquifer tests were used to evaluate aquifer hydraulic properties in the study area. The five tests were flowing-well tests (measured with an orifice plate system or measured with a bucket), recovery tests, slug tests, pressure slug tests, and pumping tests. The hydrogeologic settings at the sites included confined bedrock aquifers and unconfined reclaimed spoil aquifers.

Flowing-well tests, recovery tests, slug tests, and pressure slug tests were used in the confined bedrock aquifers. The flowing-well test was used for wells that flowed sufficiently to permit easy measurement of discharge. The recovery tests were used to check results of two flowing-well tests. The slug test was used for confined bedrock aquifers where the water level in the well was below the top of the well casing. The pressure slug test was used for flowing wells in confined bedrock aquifers that did not produce enough discharge to be easily measured. Pumping tests were used in the unconfined reclaimed spoil aquifers. Numerous references (Davis and DeWiest, 1966; Walton, 1970; Lohman, 1972; McWhorter and Sunada, 1977; Freeze and Cherry, 1979) are available about techniques to calculate and evaluate aquifer hydraulic properties and may be consulted to supplement information presented in this report.

Aquifer tests in unconfined reclaimed spoil aquifers may be difficult because the aquifer often is bounded by nearby structural features and the aquifer is in a heterogeneous spoil. Aquifer tests of spoil aquifers were done on one well at the Spring Creek site and one well at the Cow Camp Creek site. For example, the low wall, the side walls, and the sloping floor of the mine pit may present impermeable or semipermeable boundary conditions if unfractured shales or clays are present. Inflow of water from underlying aquifers may present a leaky boundary condition. However, these conditions may have minor effect on the aquifer test. Faults and fractures often are present in bedrock near the unconfined reclaimed spoil aquifer. The extent and occurrence of the faults and fractures often is unknown. However, faults and fractures generally increase porosity and permeability (Davis and DeWiest, 1966). Because of the structural variations in hydrogeologic settings of reclaimed spoil, exact measurement of aquifer hydraulic properties is difficult. For most reclaimed spoil settings, aquifer tests may be used to determine hydraulic properties within an order of magnitude, or more.

Transmissivity and hydraulic conductivity often are calculated in aquifer tests. The transmissivity is "... an aquifer characteristic which is defined by the rate of flow per unit width through the entire thickness of an aquifer per unit hydraulic gradient" (Bear, 1979). "The hydraulic conductivity is loosely defined as a measure of the ease with which water can be transmitted through a porous material" (McWhorter and Sunada, 1977). The hydraulic conductivity depends on properties of the aquifer material and fluid properties.

Flowing-Well Tests

Flowing-well tests were done by allowing a well penetrating a confined bedrock aquifer to flow at land surface. Confined aquifers, however, do not always produce flowing wells. Many confined aquifers have a potentiometric surface below land surface. Prior to the test, the well was shut in, and the hydraulic head in the aquifer was allowed to equilibrate. During the test, drawdown was assumed to be constant (the difference between the static head prior to the test and the elevation of the discharge pipe during the test). During the test, the well was opened and allowed to flow for 2 to 4 hours (Lohman, 1972), and the decreasing rate of discharge was measured.

Equations for determining transmissivity from flowing-well tests were developed by Jacob and Lohman (1952). Curve-matching methods and straight-line solutions are available (Ferris and others, 1962). The straight-line solution generally is simpler and easier to use. The aquifer is assumed to be homogeneous, isotropic, and extensive laterally. Transmissivity is assumed to be constant at all times and places (Lohman, 1972).

Equipment used during the flowing-well test consisted of a Baski flowing-well cap (Baski Water Instruments, Inc., 1989), a pressure gage, and a gate valve. Discharge was measured with either an orifice pipe, a piezometer, and an orifice plate, here termed an orifice plate system (fig. 10), or a bucket. Initial hydraulic head is determined before the test begins by using the pressure gage. Next, the gate valve is opened, and the water level in the piezometer is read or water is collected in a bucket at selected intervals. Piezometer water levels can be converted to discharge using a rating table supplied by the manufacturer of the orifice plate system.

When using the orifice plate system, a pressure gage was installed on the flowing well cap before the flowing-well test began. The hydraulic head always decreased to near or at zero when the gate valve was opened. The hydraulic head was stable for the duration of the test. Transmissivity values were in the same order of magnitude regardless of whether discharge was measured using a bucket or an orifice plate system (table 3).

Recovery Tests

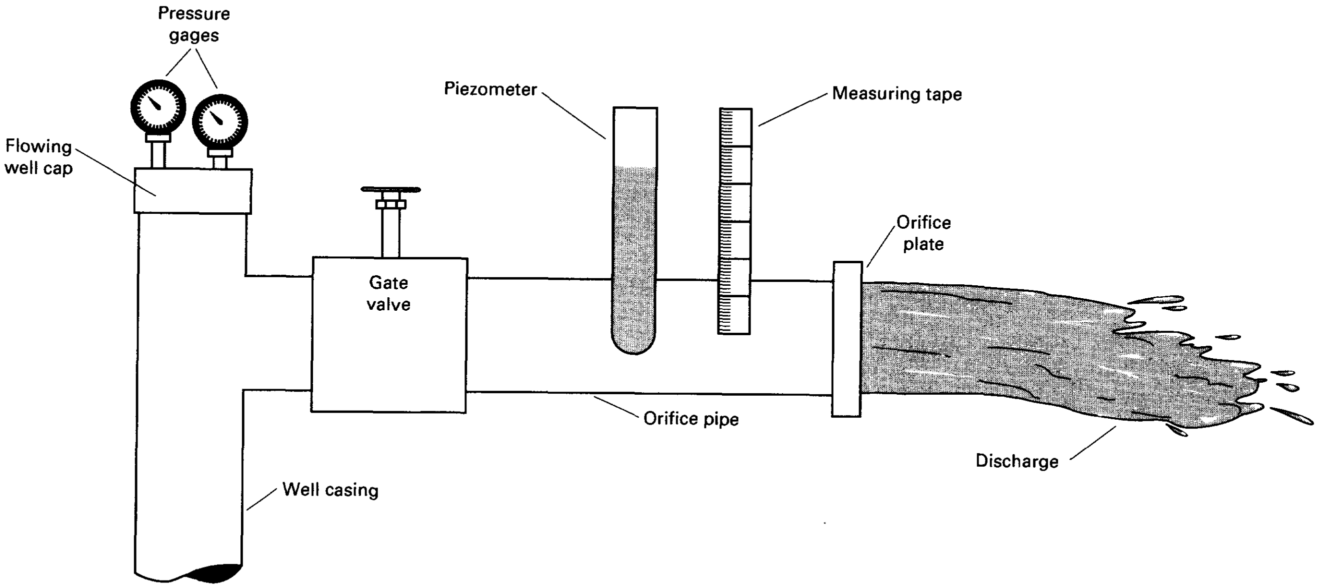
The recovery test primarily is applicable to tests of constant discharge and variable drawdown in contrast to the flowing-well test, which involves constant hydraulic head and decreasing discharge. However, the recovery test provides values of transmissivity that are close to those obtained by the flowing-well test and, therefore, is a useful check (Lohman, 1972).

The recovery test consists of monitoring hydraulic-head recovery for an aquifer once flow from the well has been stopped. For water-table conditions, a steel tape, an electrical tape, or a transducer can be used to measure the rising water level. For a flowing well, a pressure gage can be used to measure the recovery of hydraulic head.

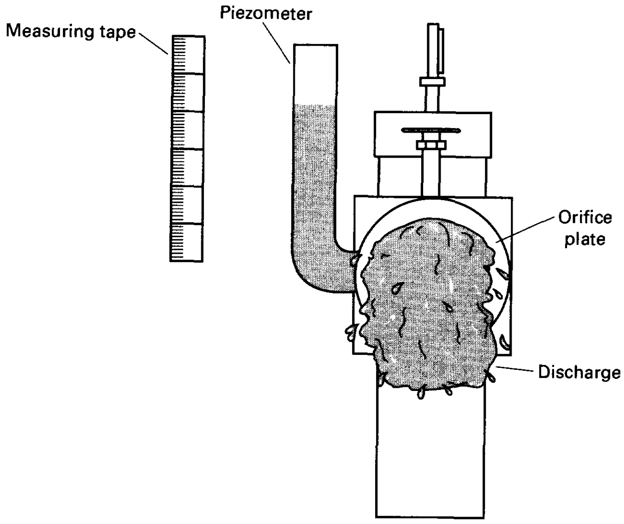
Slug Tests

A slug test is an aquifer test that uses an "instantaneous" injection or removal of a known volume to stress the aquifer (removal techniques also are known as bail tests). Changes in water level are measured by electric tape, steel tape, or transducers. The technique is explained by Cooper and others (1967) for use in fully penetrating wells in confined aquifers. The aquifer should have a transmissivity value of less than about 7,000 ft^2/d (Lohman, 1972). Slug-test methods are available for a partially penetrating well in an unconfined aquifer (Bouwer and Rice, 1976; Bouwer, 1989).

The slug test was used for two aquifers in the study area (table 3). The water level in both wells was above land surface but below the top of the well casing.



SIDE VIEW



NOTE: Not to scale

END VIEW

Figure 10.--Diagrammatic representation of an orifice plate system (modified from Layne and Bowler, Inc., 1958, and published with permission).

Table 3.--*Aquifer-test information*

[ft^2/d, feet squared per day; FWB, flowing-well test measured with bucket; PS, pressure slug test; FWOP, flowing-well test measured with orifice plate system; R, recovery test; PMP, pumping test; S, slug test]

Site	Well name[1]	Date of test	Test number	Technique	Transmissivity (ft^2/d)
Spring Creek	SL2	08-07-87	1	FWB	7.0
		06-26-88	2	FWB	4.9
Spring Creek	SI2	08-08-87	1	FWB	4.2
		06-14-88	2	FWB	4.7
Spring Creek	SW2	08-07-87	1	FWB	5.4
		06-25-88	2	FWB	6.6
Spring Creek	SU4	08-08-87	1	FWB	4.5
		06-15-88	2	FWOP	6.2
		06-15-88	3	FWB	7.0
Spring Creek	SU2	08-07-87	1	FWB	12
		06-14-88	2	FWOP	9.7
		06-14-88	3	FWB	12
Spring Creek	SD4	08-09-87	1	FWB	2.7
		06-25-88	2	FWOP	4.2
		06-25-88	3	R	4.3
Spring Creek	S61	09-21-88	1	PMP	5,600
Cow Camp Creek	CL2	06-22-88	1	FWB	460
Cow Camp Creek	CI2	06-22-88	1	S	3.0
Cow Camp Creek	CW2	08-10-87	1	S	5.1
		06-22-88	2	S	14
Cow Camp Creek	CU2	08-10-87	1	FWB	150
		06-16-88	2	FWOP	140
		06-16-88	3	R	170
Cow Camp Creek	C62	09-22-88	1	PMP	2,300
Zuli	ZL2	06-23-88	1	FWB	[2].28
		06-23-88	2	PS	.44
Zuli	ZI2	06-23-88	1	FWB	1.1
Zuli	ZW2	04-24-90	1	PS	2.3
Zuli	ZU2	06-23-88	1	PS	.00089
Bond Creek	BL2	06-24-88	1	PS	2.5
		09-18-89	2	PS	[3].2
		10-03-89	3	PS	[3].17
Bond Creek	BI2	06-24-88	1	FWOP	210
		09-19-89	2	FWOP	190
Bond Creek	BW2	06-24-88	1	PS	.025
		09-18-89	2	PS	.016
Bond Creek	BU2	06-24-88	1	PS	.0019
		09-18-89	2	PS	.011

[1] Alphanumeric well names were assigned to each well. For all wells, the first letter (S, C, Z, or B) designates the site as Spring Creek, Cow Camp Creek, Zuli, or Bond Creek. For bedrock wells, the second letter (L, I, W, U, and D) designates a specific zone of completion. These zones are the Lennox coal, Interburden, Wadge coal, Underburden, and Deep underburden. The number 2 or 4 designates the well-casing diameter, in inches. For wells completed in reclaimed spoil, the second and third numbers indicate the well number assigned by the Seneca II Coal Mine operators.

[2] Late-time data yielded a value of 0.046 ft/d, but these data may have been affected by a nearby boundary.

[3] Wells were affected by a landslide February 14 and 15, 1989.

Pressure Slug Tests

Slug tests cannot be used in confined aquifers that have a hydraulic head above the top of the well casing because removal of the well cap releases hydraulic head in the aquifer before the well can be tested. Consequently, the hydraulic head in the confined aquifer is in a state of disequilibrium before the slug test even can begin.

The pressure slug test is a modification of the slug test described by Cooper and others (1967). The modification uses a method for determining the aquifer hydraulic properties of tight formations as described by Bredehoeft and Papadopulos (1980). A further modification is provided by Neuzil (1982) to calculate compressibility of the shut-in well rather than water compressibility.

Before beginning the pressure slug test, initial hydraulic head is measured. Next, water is instantaneously released from a valve at the well head. The volume of water released is measured and used to calculate compressibility. A pressure gage is used to record the recovering hydraulic head. After the water has been released, the recovering hydraulic head is measured at selected intervals.

A flowing well cap or similar device is needed to do the pressure slug test. The flowing well cap seals the well to permit initial aquifer equilibration and to facilitate pressure monitoring. The flowing well cap that was used had two valves. One valve was used for installation of the pressure gage, and the other valve was used to release water. The pressure gage needs to be selected to include the range of pressures expected and needs to be calibrated to ensure accurate pressure readings. At the start of the test, water needs to be released quickly (instantaneously) through the water-release valve. The water-release valve needs to be closed before the pressure on the gage decreases to zero. The pressure slug tests were used for aquifers that have minimal permeability. These aquifers barely flowed at land surface but had hydraulic heads 10 ft or higher above land surface.

Pumping Tests

The pumping test was the only test used in the unconfined reclaimed spoil aquifer. Two methods commonly used to evaluate transmissivity from pumping tests are the Theis curve-matching method (Theis, 1935) and the Jacob straight-line method (Cooper and Jacob, 1946; Jacob, 1950; Jacob and Lohman, 1952). The Theis method and the Jacob method also can be used if there are no observation wells; thus, drawdown is measured in the well being pumped. This method is subject to the limitation that the radius of the discharging well must be estimated and may be difficult to determine.

Pumping tests were done by using a submersible pump with a maximum capacity of 100 gal/min. The pump is installed in the well deeper than maximum expected drawdown. The well is permitted to reequilibrate after pump placement, and the initial water level is measured. The test begins when the pump is turned on. Discharge needs to be constant and was regulated using a gate valve and monitored using an orifice plate system (fig. 10). The discharge rate should be sufficient to cause drawdown but not to pump the well dry.

Water levels in the well and the piezometer need to be measured and recorded at selected intervals. A stopwatch is useful for timing measurements. A steel tape, an electrical tape, or a transducer can be used to monitor drawdown in the well. Care needs to be taken to discharge the water far enough away from the pumping well to prevent reintroducing the discharge water into the aquifer. Hoses, pipe, or plastic sheeting can be used to convey the water downgradient from the pumping well and away from an observation well(s).

Aquifer-Test Results

On several wells, more than one type aquifer test was done (table 3). Aquifer tests were done in 1987-90. Calculated transmissivity values for each aquifer at a site generally are within one order of magnitude (or less) regardless of the type of test.

The appropriate aquifer test to use depends on the hydrogeologic conditions at the site. All bedrock aquifers at the study area were confined. If the aquifer is confined and the well is flowing at a fast enough rate so discharge is accurately measured, then a flowing-well test can be used. The rate of discharge may be measured using a calibrated bucket, a graduated cylinder, or a similar device. An orifice plate system also may be used to measure discharge if hydraulic head does not change once the test begins. If the aquifer is confined and the water level in the well is below the top of the well casing, then a slug test may be used. A pressure slug test may be used if discharge from the well is so slow that water dribbles down the well casing. Recovery tests were used to check the results of two flowing-well tests.

Pumping tests were used for testing unconfined reclaimed spoil aquifers. Discharge was monitored using an orifice plate system because discharge was greater than 50 gal/min during the tests. When discharge rates are large, measuring discharge using an orifice plate system is much easier than collecting water in buckets.

WATER-SAMPLING TECHNIQUES

Water samples for chemical analyses can be obtained from wells using a variety of techniques. For all techniques, the objective is to obtain a sample that is representative of the aquifer water.

Three water-sampling techniques were compared. The three techniques were to sample the first water that flowed or was pumped from the well, to sample water when measurements of field water-quality properties were stable, and to sample the water after three casing volumes were removed from the well. The volume of water in well storage and the extent of time needed to evacuate the well three times can be calculated.

The chemical analyses from water samples collected at selected wells using the three techniques are listed in tables 4 through 11 in the "Supplemental Data" section at the back of the report. The first water that flows or is pumped from the well is water from well-bore storage and may not represent aquifer water. The techniques for stable field water-quality properties and three casing volumes indicated similar water quality for several but not all water-quality properties. Removing three casing volumes of water generally is the preferred technique to remove ground-water samples for water-quality analysis. Water samples from the unconfined reclaimed spoil aquifer had virtually the same water quality regardless of the water-sampling technique.

Various problems may occur when trying to obtain a representative ground-water sample. The aquifer may be of minimal permeability, and the well may be pumped dry before three casing volumes of water are removed. To avoid pumping the well dry, the well can be pumped at a slow discharge rate. If drawdown still becomes excessive, pumping needs to be stopped until the water level in the well recovers. Because of possible fractures and leakage between adjacent aquifers, flowing-well discharge or prolonged pumping may cause water to flow from one aquifer to another. This flow may result in continuous drift in values of field water-quality properties. Knowledge of the particular hydrologic system is needed prior to choosing a sampling technique.

A submersible pump lowered into the well can be used to obtain a water sample from the well. Several types of pumps are available. The pump needs to have enough horsepower to lift a water sample from the desired depth. The pump diameter needs to be small enough to ensure that it will easily fit down the well casing. If the annular space between the well and the pump is too small, then any well-casing abnormalities (such as slightly bent well casing) may prevent the pump from being lowered to the desired depth.

Equipment for measuring field water-quality properties (such as specific conductance, pH, and temperature) is available from many manufacturers. Proper calibration of the equipment is needed to ensure accurate measurement of field water-quality properties.

TECHNIQUES FOR MONITORING FLOWING WELLS

All wells completed in confined bedrock aquifers had hydraulic heads above land surface. Wells completed in the Lennox coal, the interburden, the Wadge coal, and the underburden aquifers in the study area flow at land surface. To obtain accurate hydraulic-head information, the wells were sealed with a flowing well cap to prevent the well from flowing throughout the year. Hydraulic head then was measured without removing the flowing well cap and releasing well pressure. The wells also were backpressured with nitrogen during the winter to prevent freezing and breaking of the well casing.

A flowing well cap manufactured by Baski Water Instruments (Baski Water Instruments, Inc., 1989) was used during measurement of hydraulic head and to prevent well freezing during the winter. The flowing well cap is a custom-made aluminum cap that fits on the top of a well casing (fig. 11). Additional information about the operation of the flowing well cap can be obtained from the manufacturer. Hydraulic head was monitored using a pressure gage attached to a regulator on a pressurized nitrogen tank. Pressure-head measurements were obtained by allowing nitrogen to flow from the pressurized nitrogen tank through a downhole airline attached to the flowing well cap. The downhole airline pressure and the casing pressure may be measured directly by attaching pressure gages to the flowing well cap. Procedures for calculating hydraulic head are explained in the manufacturer's information that accompanies the flowing well cap.

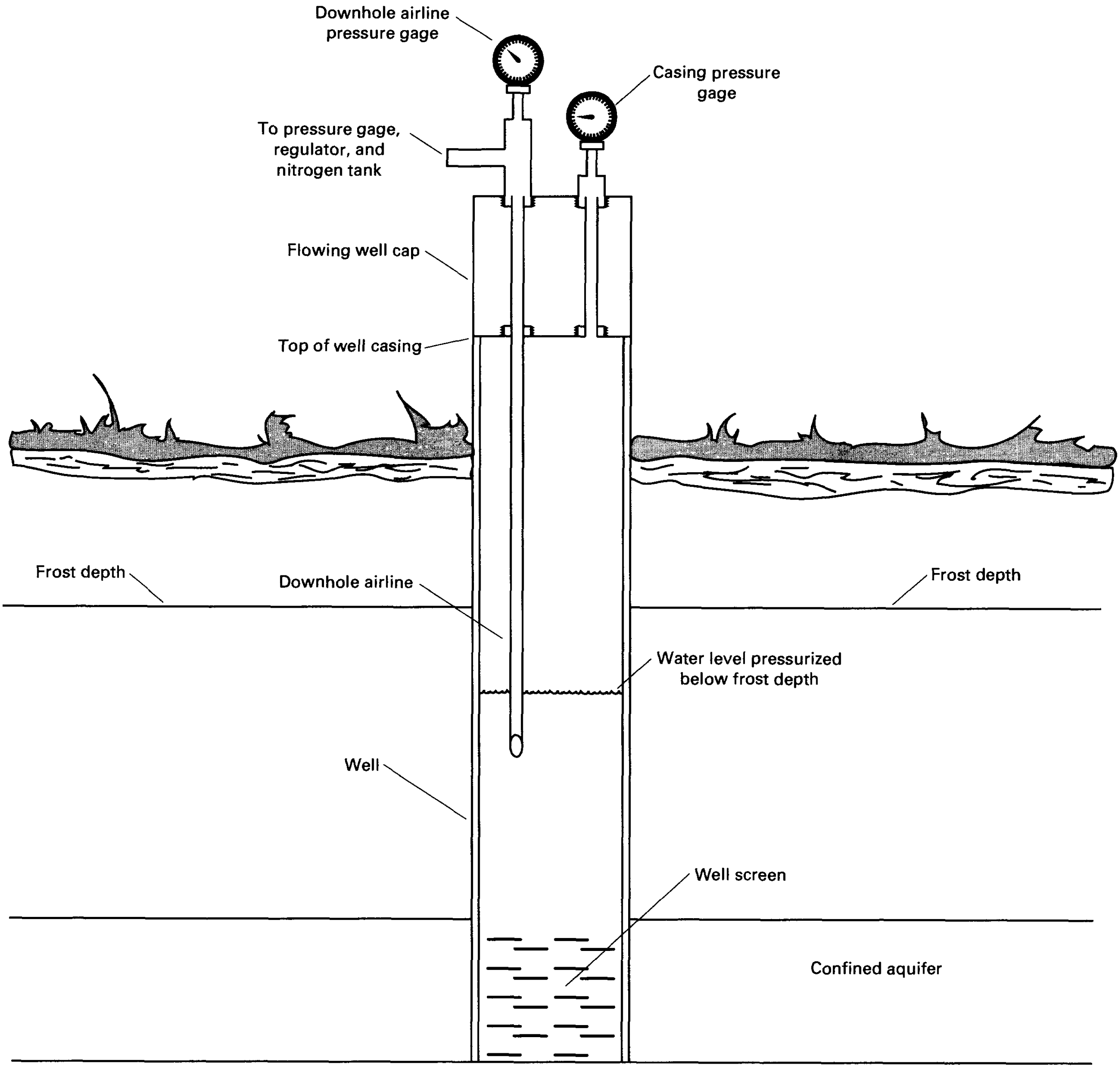


Figure 11.--Flowing well cap system with confined aquifer water level pressurized below frost depth (modified from Baski Water Instruments, Inc., 1989, and published with permission).

To prevent well freezing during the winter, nitrogen is injected into the well through the flowing well cap. This injection introduces a column of nitrogen on top of the water in the well casing. Sufficient nitrogen needs to be injected to force the water level below the frost depth. The pressure required will be a function of the aquifer hydraulic head. In general, forcing the water level 5 to 10 ft below land surface is sufficient to prevent freezing. During months when well freezing is not a problem, the nitrogen column can be released, and water can fill the entire well casing. The hydraulic head can be measured directly with a calibrated pressure gage attached to the top of the flowing well cap.

SUMMARY

Techniques for drilling, completing, and developing wells and for testing aquifer hydraulic properties and aquifer water quality at a surface coal mine in northwestern Colorado are described. Confined bedrock aquifers and unconfined reclaimed spoil aquifers were tested. Reclaimed spoil is material excavated from the mine pit that has been replaced, regraded, covered with topsoil, and revegetated. The techniques evaluated can be used by management and regulatory agencies and mine operators to obtain hydrologic information. Techniques for testing aquifer hydraulic properties and for obtaining water-quality samples that worked well for the hydrogeologic setting are compared to the extent possible.

The study area is located about 20 mi west and 5 mi south of Steamboat Springs, Colorado. Four sites were instrumented for the study. Eighteen wells were completed in confined bedrock aquifers, and seven wells were completed in unconfined reclaimed spoil aquifers.

The bedrock wells were completed in the Lennox coal, the interburden (bedrock zone between the Lennox coal and the Wadge coal), the Wadge coal, and the underburden (bedrock zone below the Wadge coal). At each site, one underburden-bedrock well was cored and the other wells were rotary drilled. Geophysical logs were run on all but three of the bedrock boreholes. Core data were used to provide precise information about lithology at each site. The core information, the rotary cuttings, and geophysical logs were used to design well completions.

Wells also were completed in the unconfined reclaimed spoil aquifers. To prevent material from falling into the borehole, the reclaimed spoil aquifer wells were augered with a hollow-stem auger to facilitate well completion. The hollow-stem auger had difficulty drilling through the large sandstone boulders that are present in the reclaimed spoil. One well was drilled in the reclaimed spoil using casing advancer drilling.

Bedrock wells were completed using either 2- or 4-in.-inside-diameter polyvinylchloride pipe. Reclaimed spoil wells were completed by using 4-in.-inside-diameter polyvinylchloride pipe. Well screen was placed adjacent to the aquifer of interest. Gravel was placed in the annular space next to the well screen. The gravel was isolated from the rest of the annular space with a bentonite seal or cement.

Five types of aquifer tests were used to evaluate aquifer hydraulic properties. The five tests were flowing-well tests, recovery tests, slug tests, pressure slug tests, and pumping tests. Flowing-well tests, recovery tests, slug tests, and pressure slug tests were used for the confined bedrock aquifers. The flowing-well tests were used for wells that had sufficient flow to be easily measured with an orifice plate system or a bucket. Recovery tests were used to check the results of two flowing-well tests. Slug tests were done on confined bedrock aquifers where the water level in the well was above land surface but below the top of the well casing. Pressure slug tests were done on confined bedrock aquifers that did not produce enough discharge to be easily measured. Pumping tests were used in the unconfined reclaimed spoil aquifers. For most reclaimed-spoil settings, aquifer tests may be used to determine hydraulic properties within an order of magnitude, or more. Hydrogeologic conditions at a site will determine which type of test is most appropriate.

Water samples for aquifer water-quality analyses were collected from wells using three techniques. The techniques were to sample the first water to flow or be pumped from the well, to sample water after measurements of field water-quality properties stabilized, and to sample water after three casing volumes of water were removed from the well. Removing three casing volumes of water before sampling generally was the preferred technique used for the study.

All of the bedrock wells at the study area had hydraulic heads above land surface. Efforts were made to prevent water in the wells from freezing during the winter. Nitrogen was injected through flowing well caps to force the water level below the frost depth to prevent the water from freezing and breaking the well casing.

REFERENCES CITED

Barcelona, M.J., Gibb, J.P., Helfrich, J.A., and Garske, E.E., 1985, Practical guide for ground-water sampling: U.S. Environmental Protection Agency Report EPA/600/2-85/104, 169 p.

Baski Water Instruments, Inc., 1989, Flowing well cap documentation: Englewood, Colo., 5 p.

Bass, N.W., Eby, J.B., and Campbell, M.R., 1955, Geology and mineral fuels of parts of Routt and Moffat Counties, Colo.: U.S.Geological Survey Bulletin 1027-D, p. 143-250.

Bear, Jacob, 1979, Hydraulics of groundwater: New York, McGraw-Hill, 567 p.

Bouwer, H., 1989, The Bouwer and Rice slug test--An update: Ground Water, v. 27, no. 3, p. 304-309.

Bouwer, H., and Rice, R.C., 1976, A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells: Water Resources Research, v. 12, no. 3, p. 423-428.

Bredehoeft, J.D., and Papadopulos, S.S., 1980, A method for determining the hydraulic properties of tight formations: Water Resources Research, v. 16, no. 1, p. 233-238.

Campbell, M.D., and Lehr, J.H., 1973, Water well technology: New York, McGraw-Hill, 681 p.

Christensen Mining Products, 1989, Casing advancer system: Salt Lake City, Utah, 4 p.

Clark, G.M. and Williams, R.S., Jr., 1990, Hydrologic and geochemical characterization of recharge and groundwater flow in a reclaimed-coal-mined-land, northwestern Colorado: *in* Fifth Billings Symposium on Disturbed Land Rehabilitation--volume II, Hazardous waste management; wildlife; hydrology; drainages, erosion and wetlands; soils, minesoils and overburden; linear disturbances; oil and gas [1990 Proceedings]: Bozeman, Montana State University, Reclamation Research Unit Publication 9003, p. 173-185.

Cooper, H.H., Bredehoeft, J.D., and Papadopulos, S.S., 1967, Response of a finite-diameter well to an instantaneous charge of water: Water Resources Research, v. 3, no. 1, p. 263-269.

Cooper, H.H., Jr., and Jacob, C.E., 1946, A generalized graphical method for evaluating formation constants and summarizing well-field history: American Geophysical Union Transactions, v. 27, no. 4, p. 526-534.

Davis, S.N., and DeWiest, R.J., 1966, Hydrogeology: New York, John Wiley and Sons, Inc., 463 p.

Driscoll, F.G., 1986, Groundwater and wells (2d ed.): St. Paul, Johnson Division, 1,089 p.

ENMAP Corporation, 1981, Guide to Colorado's weather and climate: Boulder, Colo., map pamphlet.

Ferris, J.G., Knowles, D.B., Brown, R.H., and Stallman, R.W., 1962, Theory of aquifer tests: U.S. Geological Survey Water-Supply Paper 1536-E, p. 69-174.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, N.J., Prentice-Hall, 604 p.

Jacob, C.E., 1950, Flow of groundwater, _in_ Rouse, Hunter, ed., Engineering hydraulics: New York, John Wiley and Sons, p. 321-386.

Jacob, C.E., and Lohman, S.W., 1952, Nonsteady flow to a well of constant drawdown in an extensive aquifer: American Geophysical Union Transactions, v. 33, p. 559-569.

Layne and Bowler, Inc., 1958, Measurement of water flow through pipe orifice with free discharge: Memphis, Tenn., Bulletin 501, 28 p.

Lohman, S.W., 1972, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 70 p.

McWhorter, D.B., and Sunada, D.K., 1977, Ground-water hydrology and hydraulics: Fort Collins, Colo., Water Resources Publications, 280 p.

Neuzil, C.E., 1982, On conducting the modified 'slug' test in tight formations: Water Resources Research, v. 18, no. 2, p. 439-441.

Theis, C.V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: American Geophysical Union Transactions, v. 16, p. 519-524.

Tweto, Ogden, 1976, Geologic map of the Craig 1°×2° quadrangle, northwestern Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I-972, scale 1:250,000.

U.S. Bureau of Reclamation, 1977, Ground water manual--A water resources technical publication: Washington, U.S. Government Printing Office, 480 p.

Walton, W.C., 1970, Groundwater resource evaluation: New York, McGraw-Hill, 664 p.

(p.31 follows)

SUPPLEMENTAL DATA

Table 4.--*Water-sampling data for well SSL287*

[Well identification corresponds to wells listed in table 1. Water-sampling technique: F, first water that flowed or was pumped from the well; P, stable field water-quality properties in well water; V, three casing volumes of water removed from well; altitude in feet, refers to distance above the NVGD of 1929; FLD, field; µS/CM, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; MG/L, milligrams per liter; NONCARB, noncarbonate; WH, whole; WAT, water; TOT, total; LAB, laboratory; AC-FT, acre-feet; <, less than; µg/L, micrograms per liter; --, no data collected]

Date	Water sampling technique	Depth of well, total (feet)	Land-surface altitude (feet)	Specific conductance, FLD (µS/CM)	pH, FLD (standard units)	Temperature water (°C)	Hardness, total (MG/L as $CaCO_3$)	Hardness, NONCARB WH WAT TOT FLD (MG/L as $CaCO_3$)	Calcium, dissolved (MG/L as Ca)	Magnesium, dissolved (MG/L as MG)	Sodium, dissolved (MG/L as Na)	Sodium percent
June 1988												
14...	F	58	6,861	4,650	7.42	14.2	930	460	140	140	910	68
14...	P	58	6,861	4,740	7.57	12.3	920	410	150	130	910	68
14...	V	58	6,861	4,820	7.50	11.4	780	280	130	110	960	73

Date	Sodium adsorption ratio	Potassium, dissolved (MG/L as K)	Alkalinity LAB (MG/L as $CaCO_3$)	Sulfate, dissolved (MG/L as SO_4)	Chloride, dissolved (MG/L as Cl)	Fluoride, dissolved (MG/L as F)	Silica, dissolved (MG/L as SiO_2)	Solids, residue at 180°C dissolved (MG/L)	Solids, sum of constituents dissolved (MG/L)	Solids, dissolved tons per AC-FT)
June 1988										
14...	13	8.7	471	2,500	25	1.1	8.3	4,100	4,030	5.58
14...	13	8.4	504	2,400	22	1.1	9.3	4,000	3,950	5.44
14...	15	8.1	505	2,400	20	1.0	8.6	4,050	3,950	5.51

Date	Nitrogen, nitrite, dissolved (MG/L as N)	Nitrogen, NO_2+NO_3, dissolved (MG/L as N)	Nitrogen, ammonia, dissolved (MG/L as NH_4)	Nitrogen, ammonia, dissolved (MG/L as N)	Nitrogen, organic, dissolved (MG/L as N)	Nitrogen, nitrite, dissolved (MG/L as NO_2)	Nitrogen, ammonia + organic, dissolved (MG/L as N)	Phosphorus, dissolved (MG/L as P)	Phosphorus, ortho, dissolved (MG/L as P)	Phosphate, ortho, dissolved (MG/L as PO_4)	Phosphorus, organic, dissolved (MG/L as P)
June 1988											
14...	0.010	<0.100	5.9	4.60	0.00	0.03	4.5	0.010	0.010	0.03	0.00
14...	.010	<.100	5.4	4.20	.00	.03	3.8	.030	.040	.12	.00
14...	.020	<.100	4.6	3.60	.30	.07	3.9	.020	.020	.06	.00

Date	Water sampling technique	Aluminum, dissolved (µG/L as Al)	Arsenic, dissolved (µG/L as As)	Barium, dissolved (µG/L as Ba)	Beryllium, dissolved (µG/L as Be)	Boron, dissolved (µG/L as B)	Cadmium, dissolved (µG/L as Cd)	Chromium, dissolved (µG/L as Cr)	Cobalt, dissolved (µG/L as Co)	Copper, dissolved (µG/L as Cu)	Iron, dissolved (µG/L as Fe)
June 1988											
14...	F	<10	<1	21	<0.5	350	<1	<5	<3	<10	610
14...	P	<10	<1	22	<.5	310	<1	<5	<3	<10	170
14...	V	<10	<1	17	<.5	320	<1	<5	<3	<10	120

Date	Lead, dissolved (µG/L as Pb)	Lithium, dissolved (µG/L as Li)	Manganese, dissolved (µG/L as Mn)	Molybdenum, dissolved (µG/L as Mo)	Nickel, dissolved (µG/L as Ni)	Selenium, dissolved (µG/L as Se)	Silver, dissolved (µG/L as Ag)	Strontium, dissolved (µG/L as Sr)	Vanadium, dissolved (µG/L as V)	Zinc, dissolved (µG/L as Zn)
June 1988										
14...	<10	210	490	<10	<10	<1	1.0	5,900	<6	970
14...	<10	200	690	<10	<10	<1	<1.0	6,000	<6	20
14...	<10	190	280	<10	<10	<1	<1.0	2,600	<6	6

Table 5.--*Water-sampling data for well SSU487*

[Well identification corresponds to wells listed in table 1. Water-sampling technique: F, first water that flowed or was pumped from the well; P, stable field water-quality properties in well water; V, three casing volumes of water removed from well; altitude in feet, refers to distance above the NVGD of 1929; FLD, field; µS/CM, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; MG/L, milligrams per liter; NONCARB, noncarbonate; WH, whole; WAT, water; TOT, total; LAB, laboratory; AC-FT, acre-feet; <, less than; µg/L, micrograms per liter; --, no data collected]

Date	Water sampling technique	Depth of well, total (feet)	Land-surface altitude (feet)	Specific conductance, FLD (µS/CM)	pH, FLD (standard units)	Temperature, water (°C)	Hardness, total (MG/L as $CaCO_3$)	Hardness, NONCARB WH WAT TOT FLD (MG/L as $CaCO_3$)	Calcium, dissolved (MG/L as Ca)	Magnesium, dissolved (MG/L as MG)	Sodium, dissolved (MG/L as Na)	Sodium percent
June 1988												
15...	F	105	6,861	3,970	7.88	11.0	430	0.00	91	49	850	81
15...	P	105	6,861	3,590	7.97	10.7	130	.00	30	12	800	93
15...	V	105	6,861	3,800	7.90	11.0	170	.00	40	16	840	91

Date	Sodium adsorption ratio	Potassium, dissolved (MG/L as K)	Alkalinity LAB (MG/L as $CaCO_3$)	Sulfate, dissolved (MG/L as SO_4)	Chloride, dissolved (MG/L as Cl)	Fluoride, dissolved (MG/L as F)	Silica, dissolved (MG/L as SiO_2)	Solids, residue at 180°C dissolved (MG/L)	Solids, sum of constituents dissolved (MG/L)	Solids, dissolved tons per AC-FT)
June 1988										
15...	18	7.4	457	1,800	48	0.70	9.3	3,140	3,140	4.27
15...	32	5.3	484	1,400	40	1.10	7.8	2,570	2,590	3.50
15...	29	5.8	472	1,500	44	.80	7.9	2,740	2,740	3.73

Date	Nitrogen, nitrite, dissolved (MG/L as N)	Nitrogen, NO_2+NO_3, dissolved (MG/L as N)	Nitrogen, ammonia, dissolved (MG/L as NH_4)	Nitrogen, ammonia, dissolved (MG/L as N)	Nitrogen, organic, dissolved (MG/L as N)	Nitrogen, nitrite, dissolved (MG/L as NO_2)	Nitrogen, ammonia + organic, dissolved (MG/L as N)	Phosphorus, dissolved (MG/L as P)	Phosphorus, ortho, dissolved (MG/L as P)	Phosphate, ortho, dissolved (MG/L as PO_4)
June 1988										
15...	0.010	<0.100	0.6	2.000	0.10	0.03	2.1	<0.010	<0.010	--
15...	.010	<.100	1.2	0.940	.76	.03	1.7	<.010	.010	0.03
15...	.010	<.100	2.2	1.700	.20	.03	1.9	<.010	<.010	--

Date	Water sampling technique	Aluminum, dissolved (µG/L as Al)	Arsenic, dissolved (µG/L as As)	Barium, dissolved (µG/L as Ba)	Beryllium, dissolved (µG/L as Be)	Boron, dissolved (µG/L as B)	Cadmium, dissolved (µG/L as Cd)	Chromium, dissolved (µG/L as Cr)	Cobalt, dissolved (µG/L as Co)	Copper, dissolved (µG/L as Cu)	Iron, dissolved (µG/L as Fe)
June 1988											
15...	F	<10	<1	43	<0.5	160	<1	<5	<3	<10	10
15...	P	<10	<1	26	<1	140	<3	<10	<9	<30	44
15...	V	<10	<1	29	<.5	160	<1	<5	<3	<10	63

Date	Lead, dissolved (µG/L as Pb)	Lithium, dissolved (µG/L as Li)	Manganese, dissolved (µG/L as Mn)	Molybdenum, dissolved (µG/L as Mo)	Nickel, dissolved (µG/L as Ni)	Selenium, dissolved (µG/L as Se)	Silver, dissolved (µG/L as Ag)	Strontium, dissolved (µG/L as Sr)	Vanadium, dissolved (µG/L as V)	Zinc, dissolved (µG/L as Zn)
June 1988										
15...	<10	220	120	<10	<10	<1	<1.0	3,600	<6	<3
15...	<30	180	14	<30	<30	<1	<3.0	1,500	<18	12
15...	<10	200	17	<10	<10	<1	2.0	1,900	<6	17

Table 6.--*Water-sampling data for well SSS487-61*

[Well identification corresponds to wells listed in table 1. Water-sampling technique: F, first water that flowed or was pumped from the well; P, stable field water-quality properties in well water; V, three casing volumes of water removed from well; altitude in feet, refers to distance above the NVGD of 1929; FLD, field; μS/CM, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; MG/L, milligrams per liter; NONCARB, noncarbonate; WH, whole; WAT, water; TOT, total; LAB, laboratory; AC-FT, acre-feet; <, less than; μg/L, micrograms per liter; --, no data collected]

Date	Water sampling technique	Depth of well, total (feet)	Land-surface altitude (feet)	Specific conductance, FLD (μS/CM)	pH FLD (standard units)	Temperature water (°C)	Hardness, total (MG/L as $CaCO_3$)	Hardness, NONCARB WH WAT TOT FLD (MG/L as $CaCO_3$)	Calcium, dissolved (MG/L as Ca)	Magnesium, dissolved (MG/L as MG)	Sodium, dissolved (MG/L as Na)	Sodium percent
June 1988												
09...	F	26	6,892	3,600	6.63	13.0	2,300	1,800	420	300	140	12
09...	P	26	6,892	3,680	6.60	11.8	2,300	1,800	420	300	140	12
09...	V	26	6,892	3,680	6.58	11.8	2,300	1,800	410	300	150	13

Date	Sodium adsorption ratio	Potassium, dissolved (MG/L as K)	Alkalinity LAB (MG/L as $CaCO_3$)	Sulfate, dissolved (MG/L as SO_4)	Chloride, dissolved (MG/L as Cl)	Fluoride, dissolved (MG/L as F)	Silica, dissolved (MG/L as SiO_2)	Solids, residue at 180°C dissolved (MG/L)	Solids, sum of constituents dissolved (MG/L)	Solids, dissolved tons per AC-FT)
June 1988										
09...	1	10	446	2,200	44	0.40	10	3,660	3,460	4.98
09...	1	10	446	2,200	44	.40	9.9	3,660	3,460	4.98
09...	1	10	445	2,200	44	.40	10	3,670	3,400	4.99

Date	Nitrogen, nitrite, dissolved (MG/L as N)	Nitrogen, NO_2+NO_3, dissolved (MG/L as N)	Nitrogen, ammonia, dissolved (MG/L as NH_4)	Nitrogen, ammonia, dissolved (MG/L as N)	Nitrogen, organic, dissolved (MG/L as N)	Nitrogen, nitrite, dissolved (MG/L as NO_2)	Nitrogen, ammonia + organic, dissolved (MG/L as N)	Phosphorus, dissolved (MG/L as P)	Phosphorus, ortho, dissolved (MG/L as P)
June 1988									
09...	0.110	13.0	0.13	0.100	1.2	0.36	1.3	<0.010	<0.010
09...	.120	14.0	.14	.110	1.3	.39	1.4	<.010	<.010
09...	--	--	--	--	--	--	--	<.010	--

Date	Water sampling technique	Aluminum, dissolved (μG/L as Al)	Arsenic, dissolved (μG/L as As)	Barium, dissolved (μG/L as Ba)	Beryllium, dissolved (μG/L as Be)	Boron, dissolved (μG/L as B)	Cadmium, dissolved (μG/L as Cd)	Chromium, dissolved (μG/L as Cr)	Cobalt, dissolved (μG/L as Co)	Copper, dissolved (μG/L as Cu)	Iron, dissolved (μG/L as Fe)
June 1988											
09...	F	10	1	20	<0.5	480	<1	<5	3	<10	6
09...	P	10	<1	20	<.5	470	<1	<5	3	<10	5
09...	V	10	<1	22	<.5	470	<1	10	<3	<10	7

Date	Lead, dissolved (μG/L as Pb)	Lithium, dissolved (μG/L as Li)	Manganese, dissolved (μG/L as Mn)	Molybdenum, dissolved (μG/L as Mo)	Nickel, dissolved (μG/L as Ni)	Selenium, dissolved (μG/L as Se)	Silver, dissolved (μG/L as Ag)	Strontium, dissolved (μG/L as Sr)	Vanadium, dissolved (μG/L as V)	Zinc, dissolved (μG/L as Zn)
June 1988										
09...	<10	150	600	<10	<10	<1	<1.0	6,800	<6	21
09...	<10	150	590	<10	<10	<1	1.0	6,700	<6	19
09...	<10	150	600	10	10	<1	3.0	6,900	<6	21

Table 7.--*Water-sampling data for well SCU287*

[Well identification corresponds to wells listed in table 1. Water-sampling technique: F, first water that flowed or was pumped from the well; P, stable field water-quality properties in well water; V, three casing volumes of water removed from well; altitude in feet, refers to distance above the NVGD of 1929; FLD, field; µS/CM, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; MG/L, milligrams per liter; NONCARB, noncarbonate; WH, whole; WAT, water; TOT, total; LAB, laboratory; AC-FT, acre-feet; <, less than; µg/L, micrograms per liter; --, no data collected]

Date	Water sampling technique	Depth of well, total (feet)	Land-surface altitude (feet)	Specific conductance, FLD (µS/CM)	pH, FLD (standard units)	Temperature water (°C)	Hardness, total (MG/L as $CaCO_3$)	Hardness, NONCARB WH WAT TOT FLD (MG/L as $CaCO_3$)	Calcium, dissolved (MG/L as Ca)	Magnesium, dissolved (MG/L as MG)	Sodium, dissolved (MG/L as Na)	Sodium percent
June 1988												
16...	F	122	6,957	1,510	8.43	17.7	15	0.00	4.1	1.1	300	97
16...	V	122	6,957	1,560	8.59	10.9	14	.00	3.9	1.0	290	97

Date	Sodium adsorption ratio	Potassium, dissolved (MG/L as K)	Alkalinity LAB (MG/L as $CaCO_3$)	Sulfate, dissolved (MG/L as SO_4)	Chloride, dissolved (MG/L as Cl)	Fluoride, dissolved (MG/L as F)	Silica, dissolved (MG/L as SiO_2)	Solids, residue at 180°C dissolved (MG/L)	Solids, sum of constituents dissolved (MG/L)	Solids, dissolved tons per AC-FT)
June 1988										
16...	35	2.1	588	110	4.9	2.20	8.4	811	786	1.10
16...	35	2.1	463	220	6.5	.80	7.9	825	811	1.12

Date	Nitrogen, nitrite, dissolved (MG/L as N)	Nitrogen, NO_2+NO_3, dissolved (MG/L as N)	Nitrogen, ammonia, dissolved (MG/L as NH_4)	Nitrogen, ammonia, dissolved (MG/L as N)	Nitrogen, organic, dissolved (MG/L as N)	Nitrogen, nitrite, dissolved (MG/L as NO_2)	Nitrogen, ammonia + organic, dissolved (MG/L as N)	Phosphorus, dissolved (MG/L as P)	Phosphorus, ortho, dissolved (MG/L as P)	Phosphate, ortho, dissolved (MG/L as PO_4)	Phosphorus, organic, dissolved (MG/L as P)
June 1988											
16...	0.010	<0.100	0.15	0.120	0.18	0.03	0.30	0.030	0.040	0.12	0.0
16...	.010	<.100	.19	.150	--	.03	<.20	.020	.040	.12	.0

Date	Water sampling technique	Aluminum, dissolved (µG/L as Al)	Arsenic, dissolved (µG/L as As)	Barium, dissolved (µG/L as Ba)	Beryllium, dissolved (µG/L as Be)	Boron, dissolved (µG/L as B)	Cadmium, dissolved (µG/L as Cd)	Chromium, dissolved (µG/L as Cr)	Cobalt, dissolved (µG/L as Co)	Copper, dissolved (µG/L as Cu)	Iron, dissolved (µG/L as Fe)
June 1988											
16...	F	<10	<1	110	<0.5	90	<1	<5	<3	<10	51
16...	V	<10	<1	120	<.5	60	<1	<5	<3	<10	26

Date	Lead, dissolved (µG/L as Pb)	Lithium, dissolved (µG/L as Li)	Manganese, dissolved (µG/L as Mn)	Molybdenum, dissolved (µG/L as Mo)	Nickel, dissolved (µG/L as Ni)	Selenium, dissolved (µG/L as Se)	Silver, dissolved (µG/L as Ag)	Strontium, dissolved (µG/L as Sr)	Vanadium, dissolved (µG/L as V)	Zinc, dissolved (µG/L as Zn)
June 1988										
16...	<10	58	20	<10	<10	<1	1.0	170	<6	5
16...	<10	63	6	<10	<10	<1	<1.0	180	<6	5

Table 8.--*Water-sampling data for well SCS487-62*

[Well identification corresponds to wells listed in table 1. Water-sampling technique: F, first water that flowed or was pumped from the well; P, stable field water-quality properties in well water; V, three casing volumes of water removed from well; altitude in feet, refers to distance above the NVGD of 1929; FLD, field; μS/CM, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; MG/L, milligrams per liter; NONCARB, noncarbonate; WH, whole; WAT, water; TOT, total; LAB, laboratory; AC-FT, acre-feet; <, less than; μg/L, micrograms per liter; --, no data collected]

Date	Water sampling technique	Depth of well, total (feet)	Land-surface altitude (feet)	Specific conductance, FLD (μS/CM)	pH, FLD (standard units)	Temperature water (°C)	Hardness, total (MG/L as $CaCO_3$)	Hardness, NONCARB WH WAT TOT FLD (MG/L as $CaCO_3$)	Calcium, dissolved (MG/L as Ca)	Magnesium, dissolved (MG/L as MG)	Sodium, dissolved (MG/L as Na)	Sodium percent
June 1988												
16...	F	51	6,976	3,400	6.92	11.3	1,800	1,400	370	200	150	16
16...	P	51	6,976	3,490	6.94	9.7	1,800	1,400	370	200	140	15
16...	V	51	6,976	3,700	7.08	9.7	1,800	1,400	380	210	150	15

Date	Sodium adsorption ratio	Potassium, dissolved (MG/L as K)	Alkalinity LAB (MG/L as $CaCO_3$)	Sulfate, dissolved (MG/L as SO_4)	Chloride, dissolved (MG/L as Cl)	Fluoride, dissolved (MG/L as F)	Silica, dissolved (MG/L as SiO_2)	Solids, residue at 180°C dissolved (MG/L)	Solids, sum of constituents dissolved (MG/L)	Solids, dissolved tons per AC-FT)
June 1988										
16...	2	7.5	391	1,600	15	0.30	13	2,780	2,610	3.78
16...	1	7.8	399	1,600	16	.20	13	2,740	2,600	3.73
16...	2	7.4	392	1,700	15	.30	13	2,870	2,730	3.90

Date	Nitrogen, nitrite, dissolved (MG/L as N)	Nitrogen, NO_2+NO_3 dissolved (MG/L as N)	Nitrogen, ammonia, dissolved (MG/L as NH_4)	Nitrogen, ammonia, dissolved (MG/L as N)	Nitrogen, organic, dissolved (MG/L as N)	Nitrogen, nitrite, dissolved (MG/L as NO_2)	Nitrogen, ammonia + organic dissolved (MG/L as N)	Phosphorus, dissolved (MG/L as P)	Phosphorus, ortho, dissolved (MG/L as P)
June 1988									
16...	0.020	2.30	0.37	0.290	0.81	0.07	1.1	<0.010	<0.010
16...	.010	2.00	.68	.530	.77	.03	1.3	<.010	<.010
16...	.020	2.60	.31	.240	.76	.07	1.0	<.010	<.010

Date	Water sampling technique	Aluminum, dissolved (μG/L as Al)	Arsenic, dissolved (μG/L as As)	Barium, dissolved (μG/L as Ba)	Beryllium, dissolved (μG/L as Be)	Boron, dissolved (μG/L as B)	Cadmium, dissolved (μG/L as Cd)	Chromium, dissolved (μG/L as Cr)	Cobalt, dissolved (μG/L as Co)	Copper, dissolved (μG/L as Cu)	Iron, dissolved (μG/L as Fe)
June 1988											
16...	F	<10	<1	49	<1	210	<3	<10	<9	<30	14
16...	P	<10	<1	53	<1	220	<3	<10	<9	<30	19
16...	V	<10	<1	45	<1	210	<3	<10	<3	<30	14

Date	Lead, dissolved (μG/L as Pb)	Lithium, dissolved (μG/L as Li)	Manganese, dissolved (μG/L as Mn)	Molybdenum, dissolved (μG/L as Mo)	Nickel, dissolved (μG/L as Ni)	Selenium, dissolved (μG/L as Se)	Silver, dissolved (μG/L as Ag)	Strontium, dissolved (μG/L as Sr)	Vanadium, dissolved (μG/L as V)	Zinc, dissolved (μG/L as Zn)
June 1988										
16...	<30	99	230	<30	<30	<1	<3.0	3,800	<18	28
16...	<30	95	480	<30	<30	<1	<3.0	3,900	<18	24
16...	<30	100	170	<30	<30	1	<3.0	3,800	<6	27

Table 9.--*Water-sampling data for well SZ1287*

[Well identification corresponds to wells listed in table 1. Water-sampling technique: F, first water that flowed or was pumped from the well; P, stable field water-quality properties in well water; V, three casing volumes of water removed from well; altitude in feet, refers to distance above the NVGD of 1929; FLD, field; µS/CM, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; MG/L, milligrams per liter; NONCARB, noncarbonate; WH, whole; WAT, water; TOT, total; LAB, laboratory; AC-FT, acre-feet; <, less than; µg/L, micrograms per liter; --, no data collected]

Date	Water sampling technique	Depth of well, total (feet)	Land-surface altitude (feet)	Specific conductance, FLD (µS/CM)	pH, FLD (standard units)	Temperature water (°C)	Hardness, total (MG/L as $CaCO_3$)	Hardness, NONCARB WH WAT TOT FLD (MG/L as $CaCO_3$)	Calcium, dissolved (MG/L as Ca)	Magnesium, dissolved (MG/L as MG)	Sodium, dissolved (MG/L as Na)	Sodium percent
June 1988												
16...	F	222	6,819	1,550	7.97	16.0	10	0.00	2.6	0.80	330	98
16...	P	222	6,819	1,630	7.98	9.8	10	.00	2.7	.84	320	98
16...	V	222	6,819	1,607	8.58	10.8	9	.00	2.0	.85	310	98

Date	Sodium adsorption ratio	Potassium, dissolved (MG/L as K)	Alkalinity LAB (MG/L as $CaCO_3$)	Sulfate, dissolved (MG/L as SO_4)	Chloride, dissolved (MG/L as Cl)	Fluoride, dissolved (MG/L as F)	Silica, dissolved (MG/L as SiO_2)	Solids, residue at 180°C dissolved (MG/L)	Solids, sum of constituents dissolved (MG/L)	Solids, dissolved tons per AC-FT)
June 1988										
16...	48	1.9	646	86	3.8	1.8	7.7	800	823	1.09
16...	45	1.9	647	93	3.7	1.9	7.5	830	820	1.13
16...	48	1.9	647	73	3.9	1.7	7.5	815	790	1.11

Date	Nitrogen, nitrite, dissolved (MG/L as N)	Nitrogen, NO_2+NO_3, dissolved (MG/L as N)	Nitrogen, ammonia, dissolved (MG/L as NH_4)	Nitrogen, ammonia, dissolved (MG/L as N)	Nitrogen, organic, dissolved (MG/L as N)	Nitrogen, nitrite, dissolved (MG/L as NO_2)	Nitrogen, ammonia + organic, dissolved (MG/L as N)	Phosphorus, dissolved (MG/L as P)	Phosphorus, ortho, dissolved (MG/L as P)	Phosphate, ortho, dissolved (MG/L as PO_4)	Phosphorus, organic, dissolved (MG/L as P)
June 1988											
16...	0.010	<0.100	0.35	0.270	0.33	0.03	0.60	0.030	0.020	0.06	0.01
16...	.040	<.100	.27	.210	0.00	.13	.20	.030	.040	.12	.00
16...	.010	<.100	.24	.190	--	.03	<.20	.020	.040	.12	.00

Date	Water sampling technique	Aluminum, dissolved (µG/L as Al)	Arsenic, dissolved (µG/L as As)	Barium, dissolved (µG/L as Ba)	Beryllium, dissolved (µG/L as Be)	Boron, dissolved (µG/L as B)	Cadmium, dissolved (µG/L as Cd)	Chromium, dissolved (µG/L as Cr)	Cobalt, dissolved (µG/L as Co)	Copper, dissolved (µG/L as Cu)	Iron, dissolved (µG/L as Fe)
June 1988											
16...	F	10	<1	120	<0.5	110	<1	<5	<3	<10	21
16...	P	<10	<1	120	<.5	90	<1	<5	<3	<10	26
16...	V	<10	<1	120	<.5	90	<1	<5	<3	<10	22

Date	Lead, dissolved (µG/L as Pb)	Lithium, dissolved (µG/L as Li)	Manganese, dissolved (µG/L as Mn)	Molybdenum, dissolved (µG/L as Mo)	Nickel, dissolved (µG/L as Ni)	Selenium, dissolved (µG/L as Se)	Silver, dissolved (µG/L as Ag)	Strontium, dissolved (µG/L as Sr)	Vanadium, dissolved (µG/L as V)	Zinc, dissolved (µG/L as Zn)
June 1988										
16...	<10	66	6	<10	<10	<1	<1.0	150	<6	5
16...	<10	68	6	<10	<10	<1	<1.0	150	<6	<3
16...	<10	63	5	<10	<10	<1	1.0	150	<6	<3

Table 10.--*Water-sampling data for well SBI287*

[Well identification corresponds to wells listed in table 1. Water-sampling technique: F, first water that flowed or was pumped from the well; P, stable field water-quality properties in well water; V, three casing volumes of water removed from well; altitude in feet, refers to distance above the NVGD of 1929; FLD, field; µS/CM, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; MG/L, milligrams per liter; NONCARB, noncarbonate; WH, whole; WAT, water; TOT, total; LAB, laboratory; AC-FT, acre-feet; <, less than; µg/L, micrograms per liter; --, no data collected]

Date	Water sampling technique	Depth of well, total (feet)	Land-surface altitude (feet)	Specific conductance, FLD (µS/CM)	pH, FLD (standard units)	Temperature water (°C)	Hardness, total (MG/L as $CaCO_3$)	Hardness, NONCARB WH WAT TOT FLD (MG/L as $CaCO_3$)	Calcium, dissolved (MG/L as Ca)	Magnesium, dissolved (MG/L as MG)	Sodium, dissolved (MG/L as Na)	Sodium percent
June 1988												
15...	F	150	7,031	773	7.23	10.2	280	0.00	53	35	88	41
15...	P	150	7,031	927	7.09	10.0	410	.00	82	50	54	22
15...	V	150	7,031	918	7.12	10.2	410	.00	82	50	53	22

Date	Sodium adsorption ratio	Potassium, dissolved (MG/L as K)	Alkalinity LAB (MG/L as $CaCO_3$)	Sulfate, dissolved (MG/L as SO_4)	Chloride, dissolved (MG/L as Cl)	Fluoride, dissolved (MG/L as F)	Silica, dissolved (MG/L as SiO_2)	Solids, residue at 180°C dissolved (MG/L)	Solids, sum of constituents dissolved (MG/L)	Solids, dissolved tons per AC-FT)
June 1988										
15...	2	2.9	411	63	4.1	0.40	15	493	512	0.67
15...	1	2.7	433	91	5.4	.20	17	532	566	.72
15...	1	2.7	431	84	5.4	.30	17	527	556	.72

Date	Nitrogen, nitrite, dissolved (MG/L as N)	Nitrogen, NO_2+NO_3, dissolved (MG/L as N)	Nitrogen, ammonia, dissolved (MG/L as NH_4)	Nitrogen, ammonia, dissolved (MG/L as N)	Nitrogen, organic, dissolved (MG/L as N)	Nitrogen, nitrite, dissolved (MG/L as NO_2)	Nitrogen, ammonia + organic, dissolved (MG/L as N)	Phosphorus, dissolved (MG/L as P)	Phosphorus, ortho, dissolved (MG/L as P)	Phosphate, ortho, dissolved (MG/L as PO_4)
June 1988										
15...	0.010	<0.100	1.5	1.20	0.40	0.03	1.6	0.010	<0.010	0.01
15...	.010	<.100	1.3	1.00	.20	.03	1.2	<.010	<.010	--
15...	<.010	<.100	1.3	.990	.21	--	1.2	<.010	<.010	--

Date	Water sampling technique	Aluminum, dissolved (µG/L as Al)	Arsenic, dissolved (µG/L as As)	Barium, dissolved (µG/L as Ba)	Beryllium, dissolved (µG/L as Be)	Boron, dissolved (µG/L as B)	Cadmium, dissolved (µG/L as Cd)	Chromium, dissolved (µG/L as Cr)	Cobalt, dissolved (µG/L as Co)	Copper, dissolved (µG/L as Cu)	Iron, dissolved (µG/L as Fe)
June 1988											
15...	F	<10	<1	300	<0.5	120	<1	<5	<3	<10	160
15...	P	<10	<1	240	<.5	90	<1	<5	<3	<10	140
15...	V	<10	<1	240	<.5	90	<1	<5	<3	<10	140

Date	Lead, dissolved (µG/L as Pb)	Lithium, dissolved (µG/L as Li)	Manganese, dissolved (µG/L as Mn)	Molybdenum, dissolved (µG/L as Mo)	Nickel, dissolved (µG/L as Ni)	Selenium, dissolved (µG/L as Se)	Silver, dissolved (µG/L as Ag)	Strontium, dissolved (µG/L as Sr)	Vanadium, dissolved (µG/L as V)	Zinc, dissolved (µG/L as Zn)
June 1988										
15...	<10	37	60	<10	<10	<1	<1.0	1,700	<6	4
15...	<10	36	94	<10	<10	<1	<1.0	1,900	<6	10
15...	<10	35	92	<10	<10	<1	1.0	1,800	<6	<3

Table 11.--*Water-sampling data for well SBW287*

[Well identification corresponds to wells listed in table 1. Water-sampling technique: F, first water that flowed or was pumped from the well; P, stable field water-quality properties in well water; V, three casing volumes of water removed from well; altitude in feet, refers to distance above the NVGD of 1929; FLD, field; μS/CM, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; MG/L, milligrams per liter; NONCARB, noncarbonate; WH, whole; WAT, water; TOT, total; LAB, laboratory; AC-FT, acre-feet; <, less than; μg/L, micrograms per liter; --, no data collected]

Date	Water sampling technique	Depth of well, total (feet)	Land-surface altitude (feet)	Specific conductance, FLD (μS/CM)	pH, FLD (standard units)	Temperature water (°C)	Hardness, total (MG/L as $CaCO_3$)	Hardness, NONCARB WH WAT TOT FLD (MG/L as $CaCO_3$)	Calcium, dissolved (MG/L as Ca)	Magnesium, dissolved (MG/L as MG)	Sodium, dissolved (MG/L as Na)	Sodium percent
June 1988												
15...	F	164	7,032	650	8.14	10.8	52	0.00	9.7	6.5	160	86
15...	P	164	7,032	755	8.17	9.9	52	.00	9.7	6.5	160	86
16...	V	164	7,032	881	8.29	9.6	52	.00	9.9	6.4	150	86

Date	Sodium adsorption ratio	Potassium, dissolved (MG/L as K)	Alkalinity LAB (MG/L as $CaCO_3$)	Sulfate, dissolved (MG/L as SO_4)	Chloride, dissolved (MG/L as Cl)	Fluoride, dissolved (MG/L as F)	Silica, dissolved (MG/L as SiO_2)	Solids, residue at 180°C dissolved (MG/L)	Solids, sum of constituents dissolved (MG/L)	Solids, dissolved tons per AC-FT)
June 1988										
15...	10	2.7	393	6.8	2.0	0.90	9.7	434	435	0.59
15...	10	2.8	392	4.8	2.3	1.00	9.7	433	433	.59
16...	9	2.8	396	9.7	2.1	.90	9.8	438	431	.60

Date	Nitrogen, nitrite, dissolved (MG/L as N)	Nitrogen, NO_2+NO_3, dissolved (MG/L as N)	Nitrogen, ammonia, dissolved (MG/L as NH_4)	Nitrogen, ammonia, dissolved (MG/L as N)	Nitrogen, organic, dissolved (MG/L as N)	Nitrogen, nitrite, dissolved (MG/L as NO_2)	Nitrogen, ammonia + organic, dissolved (MG/L as N)	Phosphorus, dissolved (MG/L as P)	Phosphorus, ortho, dissolved (MG/L as P)	Phosphate, ortho, dissolved (MG/L as PO)	Phosphorus, organic, dissolved (MG/L as P)
June 1988											
15...	<0.010	<0.100	0.44	0.340	0.16	--	0.50	0.030	0.010	0.03	0.02
15...	<.010	<.100	.48	.370	.53	--	.90	.020	<.010	--	.02
16...	.010	<.100	.53	.410	.00	0.03	.30	.020	.030	.09	.00

Date	Water sampling technique	Aluminum, dissolved (μG/L as Al)	Arsenic, dissolved (μG/L as As)	Barium, dissolved (μG/L as Ba)	Beryllium, dissolved (μG/L as Be)	Boron, dissolved (μG/L as B)	Cadmium, dissolved (μG/L as Cd)	Chromium, dissolved (μG/L as Cr)	Cobalt, dissolved (μG/L as Co)	Copper, dissolved (μG/L as Cu)	Iron, dissolved (μG/L as Fe)
June 1988											
15...	F	<10	<1	160	<0.5	250	<1	<5	<3	<10	54
15...	P	<10	5	180	<.5	250	1	<5	<3	<10	42
16...	V	30	<1	170	<.5	250	<1	<5	<3	<10	12

Date	Lead, dissolved (μG/L as Pb)	Lithium, dissolved (μG/L as Li)	Manganese, dissolved (μG/L as Mn)	Molybdenum, dissolved (μG/L as Mo)	Nickel, dissolved (μG/L as Ni)	Selenium, dissolved (μG/L as Se)	Silver, dissolved (μG/L as Ag)	Strontium, dissolved (μG/L as Sr)	Vanadium, dissolved (μG/L as V)	Zinc, dissolved (μG/L as Zn)
June 1988										
15...	<10	35	50	<10	<10	<1	<1.0	480	<6	8
15...	<10	36	45	<10	<10	<1	1.0	500	<6	13
16...	<10	35	50	<10	<10	<1	<1.0	490	<6	<3

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