HYDROLOGY OF THE WHITE TAIL BUTTE AREA, NORTHERN CAMPBELL COUNTY, WYOMING

By Marlin E. Lowry and James G. Rankl

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CONTENTS

FIGURES

TABLES

CONVERSION FACTORS

For use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	*By*	*To obtain*
acre	0.4047	hectare
acre-foot (acre-ft)	1,233	cubic meter
foot (ft)	0.3048	meter
foot per mile (ft/mi)	0.1894	meter per kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
inch (in.)	25.40	millimeter
inch per hour	25.40	millimeter per hour
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
foot squared per day (ft^2/d)	0.0929	meter squared per day

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ABSTRACT

Quantity of runoff and peak discharge from one small basin in the White Tail Butte area, determined from a calibrated rainfall-runoff model, is less than the quantity computed using results of a regional study. The difference is caused by the extensive beds of exposed, permeable clinker in the basin.

Potentiometric surfaces in the White Tail Butte area indicate that, regionally, it is a discharge area. This is consistent with the information obtained elsewhere in Campbell County, Wyo. The chemical quality of water from springs and alluvium, however, is characteristic of water found in recharge areas, so movement of water in the regional system is apparently small compared to local recharge.

If surface coal mining occurs in the area, the principal adverse impact to the ground-water system would be the destruction of springs and seeps in the mined area. These could be restored with special reclamation procedures. There are adequate quantities of water of suitable quality below the coal for stock or domestic use; therefore, postreclamation supplies could be obtained.

Impacts of surface mining on runoff could not be evaluated. However, sensitivity of runoff to infiltration indicates a 10-percent change in runoff for a 1-percent change in infiltration.

INTRODUCTION

Purpose and Scope

A study of the hydrology of the Powder River basin in Wyoming was begun in 1975 to determine the water supply in the basin and to assess the impacts of mining on water resources. A detailed study of the basin was not possible within the scope of the project. However, several small areas were chosen for detailed study to test and improve conceptual models of the hydrologic system that were developed from reconnaissance data. The White Tail Butte area was one of the small areas initially selected as a site for detailed ground-water study.

Subsequently, the U.S. Bureau of Land Management designated part of the area as an Energy Minerals Rehabilitation Inventory and Analysis (EMRIA) study. The main purposes of EMRIA studies were to determine the reclamation potential, the problems that would be involved in reclaiming the area, and the measures required to establish satisfactory conditions. EMRIA studies include both ground and surface water; therefore, the work by the U.S. Geological Survey at White Tail Butte was expanded to include surface water, and the water-resources part of the EMRIA study was incorporated into this report.

Location

The White Tail Butte area is in the Powder River basin, Wyoming, about 8 miles south of the Montana State line (fig. 1). The total area is about 288 mi^2 and was selected to include locations of test wells drilled for the Geological Survey, the model-mine study at Recluse, Wyo., the EMRIA study, and enough adjoining area to include water wells in the principal aquifers that are used in Campbell County, Wyo.

Site-Numbering System

Ground-water sites are numbered according to the Federal system of land subdivision in Wyoming. The first number indicates the township, the second the range, and the third the section in which the site is located. Letters following the section number indicate the position of the site in the section. The first letter denotes the quarter section, the second letter the quarter-quarter section, and the third letter, if given, the quarter-quarter-quarter section (10-acre tract). The subdivisions of a section are lettered A, B, C, and D in a counterclockwise direction, starting in the northeast quarter. The first site in a tract is assigned a sequence number of 01. Additional sites in the tract are numbered consecutively.

Acknowledgments

Data incorporated into this report were obtained from an EMRIA study funded by the Bureau of Land Management, an energy program of the Geological Survey, a cooperative water-resources program with the State of Wyoming, and a project funded by the U.S. Environmental Protection Agency to obtain ground-water data in conjunction with the Recluse model-mine study of the Geological Survey. The work would not have been possible without the cooperation of the land owners who permitted access to their land.

GEOLOGIC SETTING

The Powder River basin is an asymmetrical basin with the deepest part along the western side. The general stratigraphy of the basin is shown in figure 2. Only the formations exposed in the White Tail Butte area and those from which water has been developed in the area are described in this report. The following descriptions, except for the alluvium, are adapted principally from descriptions by Robinson and others (1964).

Fox Hills Sandstone

The Fox Hills Sandstone of Late Cretaceous age is the youngest marine formation in the basin. Robinson and others (1964, p. 95-96) describe the Fox Hills on the northern and western flanks of the Black Hills as a sequence of sandstone and shale 125 to 200 ft thick. The Fox Hills is poorly exposed east

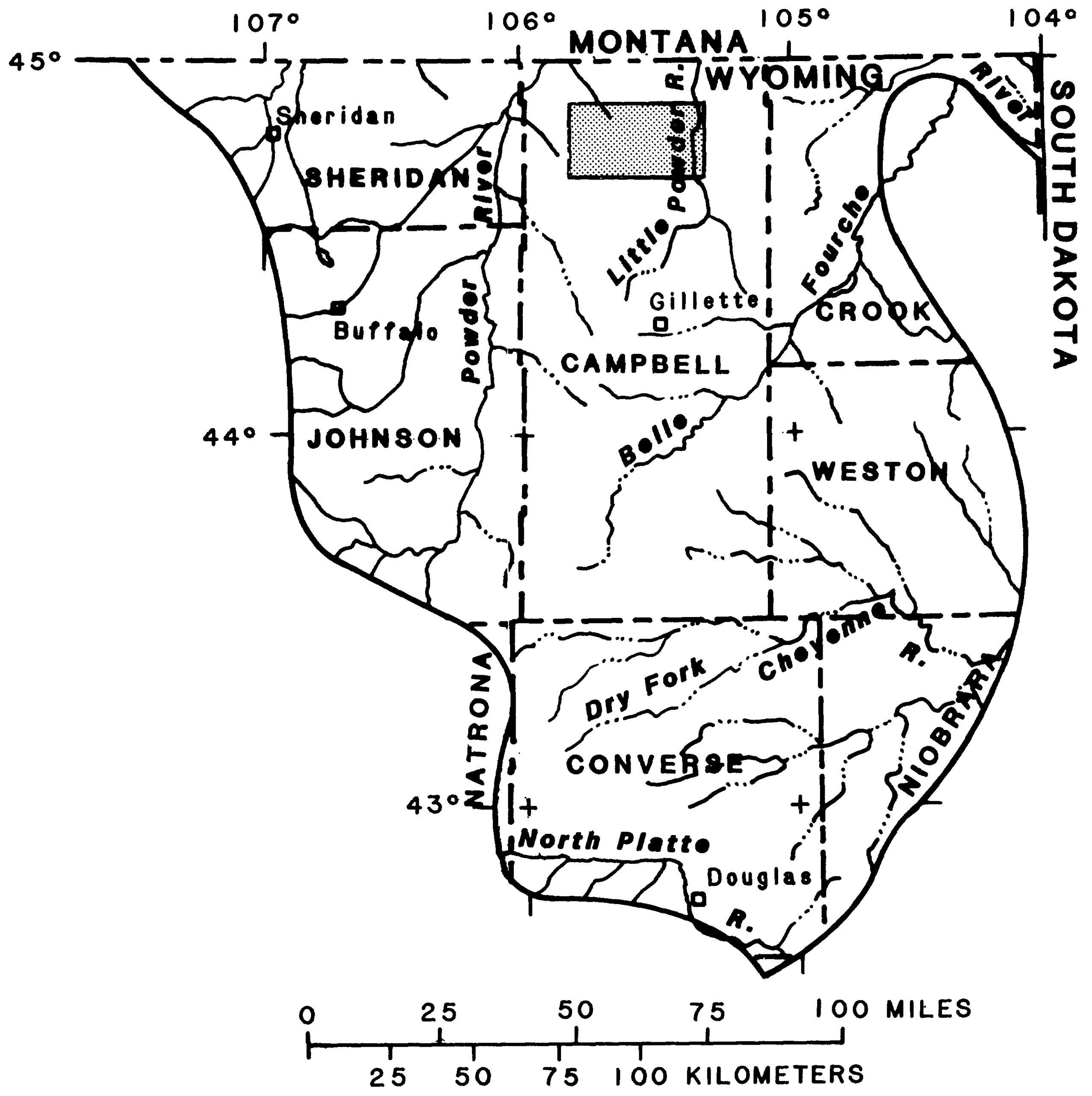


Figure 1.--Location of White Tail Butte area (patterned) in Wyoming part of the Powder River basin.

ERATHEM	SYSTEM	SERIES	GEOLOGIC UNITS: West side of Powder River Basin	GEOLOGIC UNITS: East side of Powder River Basin
CENOZOIC	QUATERNARY	Pleistocene and Holocene	Alluvium	Alluvium
CENOZOIC	TERTIARY	Miocene	Arikaree Formation	Arikaree Formation
CENOZOIC	TERTIARY	Oligocene	White River Formation	White River Formation
CENOZOIC	TERTIARY	Eocene	Wasatch Formation	Wasatch Formation
CENOZOIC	TERTIARY	Paleocene	Fort Union Formation	Fort Union Formation
MESOZOIC	CRETACEOUS	Upper	Lance Formation	Lance Formation
MESOZOIC	CRETACEOUS	Upper	Fox Hills Sandstone	Fox Hills Sandstone
MESOZOIC	CRETACEOUS	Upper	Lewis Shale	Pierre Shale
MESOZOIC	CRETACEOUS	Upper	Mesaverde Formation	Pierre Shale
MESOZOIC	CRETACEOUS	Upper	Cody Shale	Niobrara Formation
MESOZOIC	CRETACEOUS	Upper	Cody Shale	Carlile Shale
MESOZOIC	CRETACEOUS	Upper	Frontier Formation	Greenhorn Formation
MESOZOIC	CRETACEOUS	Upper	Frontier Formation	Belle Fourche Shale
MESOZOIC	CRETACEOUS	Lower	Mowry Shale	Mowry Shale
MESOZOIC	CRETACEOUS	Lower	Thermopolis Shale	Newcastle Sandstone
MESOZOIC	CRETACEOUS	Lower	Thermopolis Shale	Skull Creek Shale
MESOZOIC	CRETACEOUS	Lower	Cloverly Formation	Inyan Kara Group: Fall River Formation
MESOZOIC	CRETACEOUS	Lower	Cloverly Formation	Inyan Kara Group: Lakota Formation
MESOZOIC	JURASSIC	Upper	Morrison Formation	Morrison Formation
MESOZOIC	JURASSIC	Upper	Sundance Formation	Sundance Formation
MESOZOIC	JURASSIC	Middle	Gypsum Spring Formation	Gypsum Spring Formation

ERATHEM	SYSTEM	SERIES	GEOLOGIC UNITS (continued): West side of Powder River Basin	GEOLOGIC UNITS (continued): East side of Powder River Basin	
MESOZOIC	TRIASSIC		Chugwater Formation	Spearfish Formation	Spearfish Formation
PALEOZOIC	PERMIAN		Goose Egg Formation *(Includes equivalent rocks in northwest part of area)*	Spearfish Formation	Spearfish Formation
PALEOZOIC	PERMIAN		Goose Egg Formation	Minnekahta Limestone	Minnekahta Limestone
PALEOZOIC	PERMIAN		Goose Egg Formation	Opeche Shale	Opeche Shale
PALEOZOIC	PENNSYLVANIAN		Tensleep Sandstone	Hartville Formation	Minnelusa Formation
PALEOZOIC	PENNSYLVANIAN		Amsden Formation	Hartville Formation	Minnelusa Formation
PALEOZOIC	MISSISSIPPIAN	Upper	? Madison Limestone *(Includes Jefferson Formation of Late Devonian age in extreme northwest part of area)* ?	?	?
PALEOZOIC	MISSISSIPPIAN	Lower	Madison Limestone	Guernsey Formation	Pahasapa Limestone
PALEOZOIC	DEVONIAN	Upper		Guernsey Formation	Englewood Formation
PALEOZOIC	ORDOVICIAN	Upper	Bighorn Dolomite	Whitewood Dolomite	Whitewood Dolomite
PALEOZOIC	ORDOVICIAN	Middle	Bighorn Dolomite	Winnipeg Formation	Winnipeg Formation
PALEOZOIC	ORDOVICIAN	Lower		Deadwood Formation	Deadwood Formation
PALEOZOIC	CAMBRIAN	Upper	Gallatin Formation	Deadwood Formation	Deadwood Formation
PALEOZOIC	CAMBRIAN	Upper	Gros Ventre Formation	Deadwood Formation	Deadwood Formation
PALEOZOIC	CAMBRIAN	Middle	Flathead Sandstone		
PRECAMBRIAN			Igneous and metamorphic rocks	Igneous and metamorphic rocks	Igneous and metamorphic rocks

From Hodson and others, 1973

Figure 2.--Stratigraphic relation of geologic units in Wyoming part of the Powder River basin.

of the White Tail Butte area but is described from exposures elsewhere as consisting of two members. The lower member is 50 to 100 ft thick and consists of fine-grained sandstone interbedded with shale and siltstone. Shale is abundant near the base; the Fox Hills grades downward through an interval 10 to 50 ft thick into the Pierre Shale of Late Cretaceous age. The upper member is fine- to medium-grained, massive sandstone from 50 to 100 ft thick. The upper member, in places, pinches out or grades laterally into sandstone and shale similar to that in the lower member. Geophysical logs in the White Tail Butte area indicate the presence of the twofold division in part of the area and that the thickness of the formation is about 100 ft.

Lance Formation

The Lance Formation of Late Cretaceous age consists of a continental sequence of alternating sandstone, sandy shale, claystone, and carbonaceous shale. The sandstone is fine to medium grained and friable, and the thickness of individual beds ranges from less than 1 in. to more than 25 ft (Robinson and others, 1964, p. 98). Geophysical logs indicate the Lance is about 1,200 ft thick in the White Tail Butte area.

Fort Union Formation

The Fort Union Formation of Paleocene age is divided into three members: the Tullock, Lebo Shale, and Tongue River. The Tullock, the lowermost member, crops out east of the Little Powder River in a series of dissected ridges. The Tullock consists of fine-grained sandstone; gray, sandy or silty shale; and numerous beds of carbonaceous shale and coal. Most of the sandstone is soft and friable (Robinson and others, 1964, p. 99). The thickness of the Tullock in the White Tail Butte area is about 600 ft. The middle member, the Lebo Shale, crops out along the valley of the Little Powder River and consists mostly of light- to dark-gray claystone, subordinate lenses of fine-grained sandstone, and carbonaceous shale (Robinson and others, 1964, p. 99-100). The shale is 200 to 250 ft thick.

The Tongue River Member is the upper member of the Fort Union Formation and is exposed in the White Tail Butte Area along the bluffs west of the Little Powder River and in much of the uplands. It consists of interbedded fine-grained sandstone, siltstone, sandy shale, carbonaceous shale, and coal. The coal in this member is of current (1982) interest for mining in the area. The principal coals, in order of increasing depth, are the Anderson, Dietz, Canyon, Cook, Wall, Pawnee, and Cache. Robinson and others (1964, p. 100) state that the Tongue River Member is about 800 ft thick where exposed along the bluffs west of the Little Powder River.

The Tongue River Member thickens toward the center of the Powder River basin. It is 1,200 to 1,300 ft thick in the Spotted Horse coalfield on the west side of the White Tail Butte area (Olive, 1957, p. 10).

Wasatch Formation

The Wasatch Formation of Eocene age caps the divides in the central part of the White Tail Butte area and thickens westward toward the center of the Powder River basin. The lithology of the Wasatch is similar to the Fort Union. The maximum local thickness in the Spotted Horse coalfield is more than 700 ft (Olive, 1957, p. 14).

Alluvium

Alluvium of Pleistocene and Holocene age occurs in the small drainages of the area. The material is locally derived, and the gravel-sized particles consist of sandstone and clinker. Test holes along Elk Creek penetrated a maximum of 30 ft of alluvium (56N 071W 30DBB02), and the thickness probably is not much greater elsewhere.

TOPOGRAPHY

The topography of the White Tail Butte area can be divided into two principal forms--the lowland associated with the Little Powder River and a western highland. The lowland is floored by the Lebo Shale Member. The remainder of the area is a broad, well-dissected highland. The steep escarpment separating the highland from the lowland generally is capped with clinker. Clinker is the rock most resistant to erosion in the area and is largely responsible for the existence of the escarpment.

SURFACE-WATER HYDROLOGY

Description of Small Basins

North Divide Draw drains 1.72 mi^2 of the rugged upland divide between Elk Creek to the north and Whitetail Creek to the south. Altitudes range from 3,907 ft above sea level at the outlet of the basin to 4,345 ft on top of White Tail Butte. Clayey soils, developed from the Fort Union, are relatively impermeable. A three-dimensional sketch of the basin is shown in figure 3.

Elk Creek tributary, which adjoins North Divide Draw on the east, drains an area of 2.10 mi^2. The terrain and soils are similar to North Divide Draw, except for a large, flat, upland area in the western part of the basin. The physical characteristics of the two drainages and the area of exposed clinker are listed in table 1. A three-dimensional sketch of Elk Creek tributary is shown in figure 4.

Table 1.--*Physical basin characteristics*

Site	Drainage area (square miles)	Basin slope (feet per mile)	Channel slope (feet per mile)	Maximum relief (feet)	Orientation from north (degrees)	Exposed clinker (percent)
North Divide Draw	1.72	904	78.0	438	30	37
Elk Creek tributary	2.10	899	96.3	334	80	51

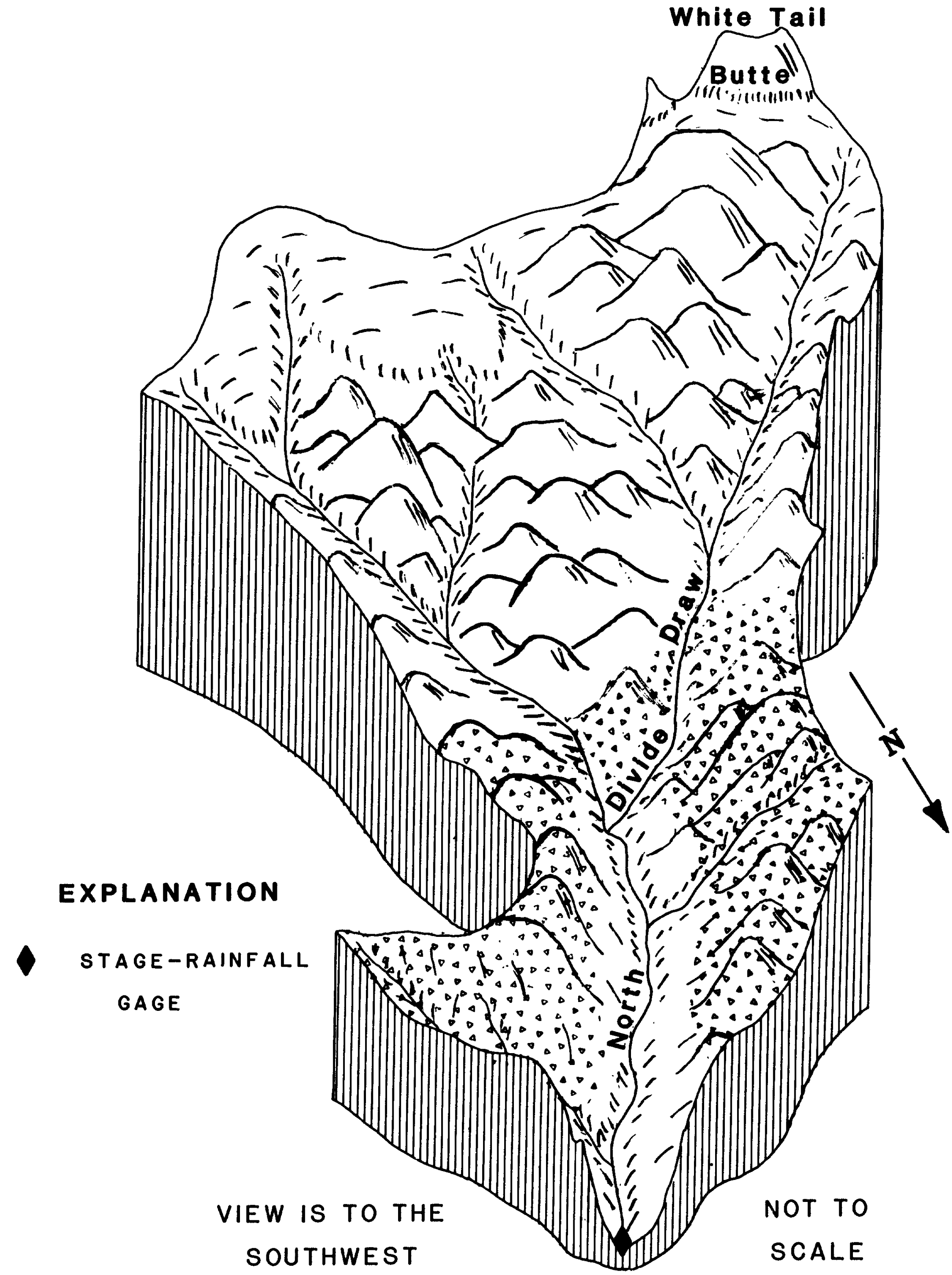


Figure 3.--Sketch of North Divide Draw near Recluse. Area of exposed clinker is patterned.

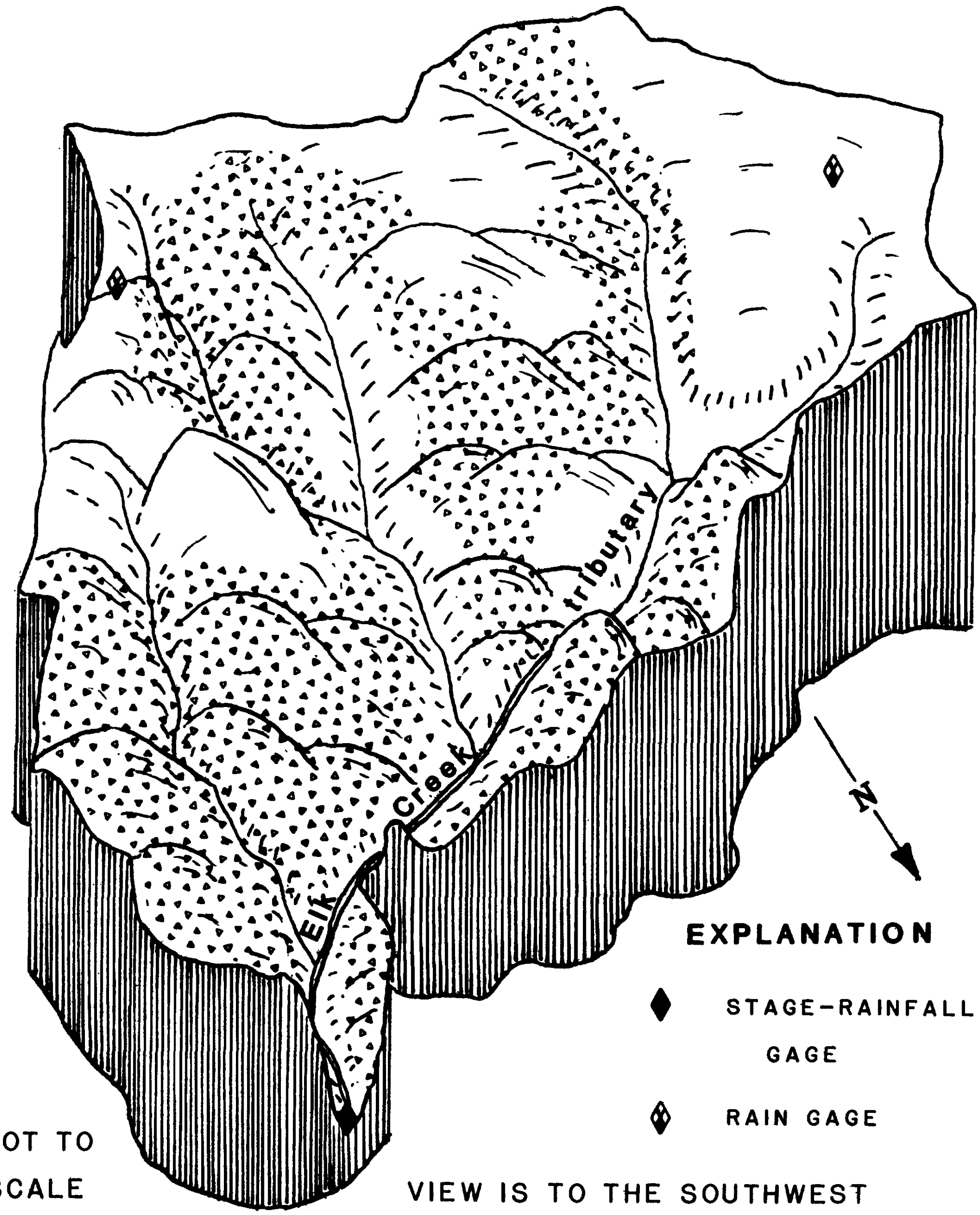


Figure 4.--Sketch of Elk Creek tributary near Recluse. Area of exposed clinker is patterned.

Runoff-Data Collection

Data collection began with the installation of stage and rainfall recorders in June and July 1976. A dual stage-rainfall gage was installed in the channel at the outlets of North Divide Draw and Elk Creek tributary. Three additional rain gages were installed near the headwaters of the two basins. The location of instrumentation used in this study is shown in figure 5.

The ephemeral nature of these two streams makes it extremely difficult to be present at the time of peak flows. Therefore, stage-discharge relations were developed using step-backwater methods for high flow. Current-meter measurements were used to define the low end of the stage-discharge curve.

Chemical-quality and sediment samples were collected at low flows and by single-stage sediment samplers at preset stages. Samples were submitted to the sediment laboratory for analysis, provided the samplers had functioned properly.

Data collection was discontinued in late August 1977 when the stage and rainfall recorders were removed. Reference marks and staff gages were left for future reference at the outlet of each basin.

Total runoff from North Divide Draw from June 24, 1976, to June 23, 1977, was 61.0 acre-ft. Elk Creek tributary had a total runoff of 19.2 acre-ft from July 9, 1976, to July 8, 1977. Missing record due to recorder malfunction was estimated using high-water marks, range-in-stage records, and precipitation records from nearby stations.

A snow survey was conducted on January 18, 1977, at two sites in the North Divide drainage basin. The upper site, located near the upper rain gage, had an average snow depth of 9.8 in., and the lower site, near the stage gage, had an average snow depth of 13.0 in. The moisture content was 23 percent by volume. Estimated moisture available for runoff on January 18, 1977, from North Divide Draw was 2.6 in. (240 acre-ft). A snow pack of similar depth could be expected on the Elk Creek tributary basin.

Snowmelt runoff occurred on April 5 and 6, 1977. The runoff from snowmelt in the North Divide Draw basin was estimated at 3.2 acre-ft, or about 5 percent of the total runoff from June 24, 1976, to June 23, 1977. The estimate was based on the peak discharge (1.6 ft^3/s), observation by the authors, and the temperature record at Recluse. Total snowmelt runoff on Elk Creek tributary was 0.2 acre-ft.

Convective storms produced about 58 acre-ft of runoff during the 1 year of record, or 95 percent of the total runoff from North Divide Draw. Rainfall produced about 19 acre-ft of runoff, almost 100 percent of the runoff on Elk Creek tributary. The largest runoff, peak and volume, for both basins occurred on June 12, 1977. The cumulative rainfall that produced the runoff and hydrographs of the resulting discharge are shown in figure 6.

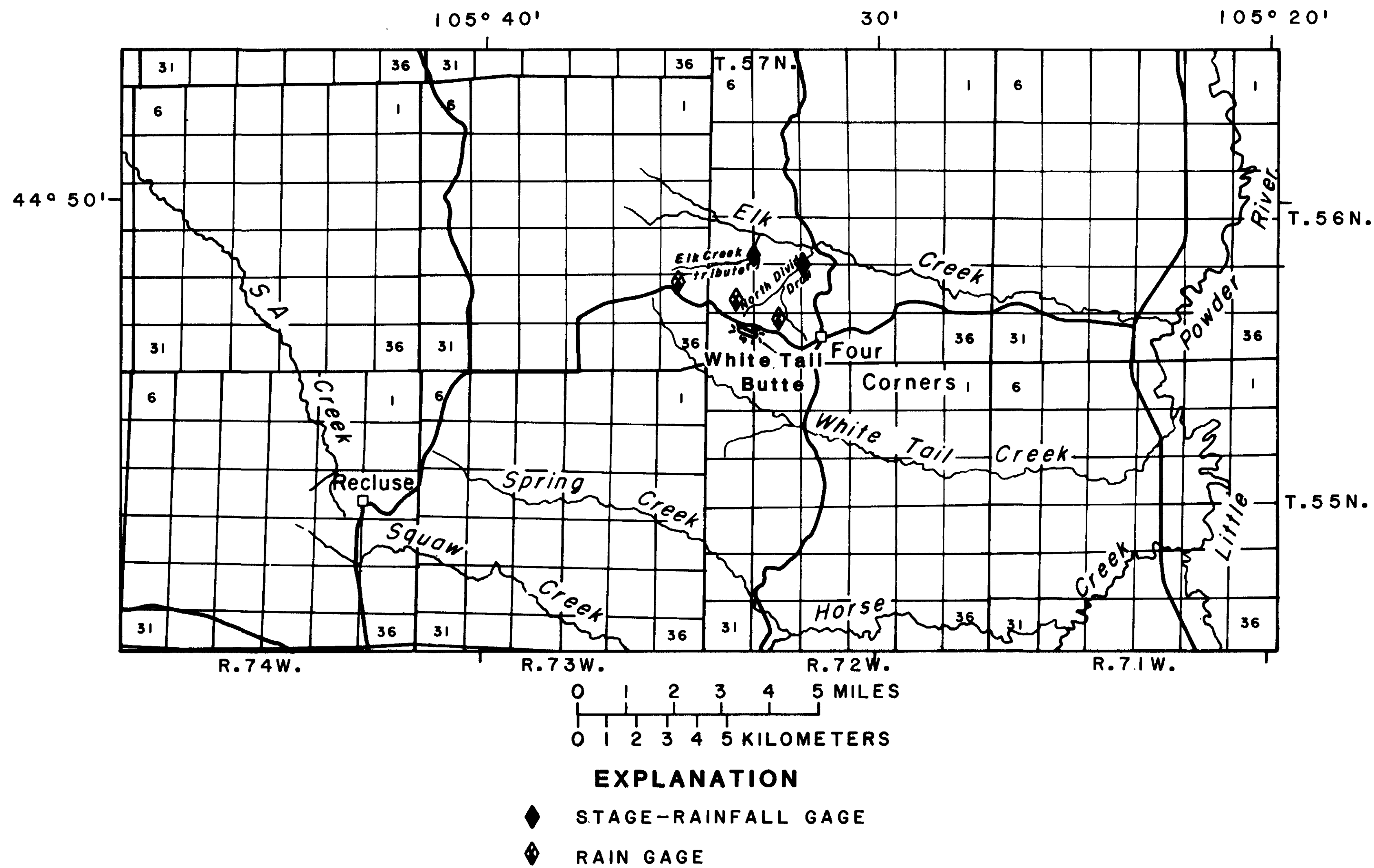


Figure 5.--Location of gages for surface-water studies.

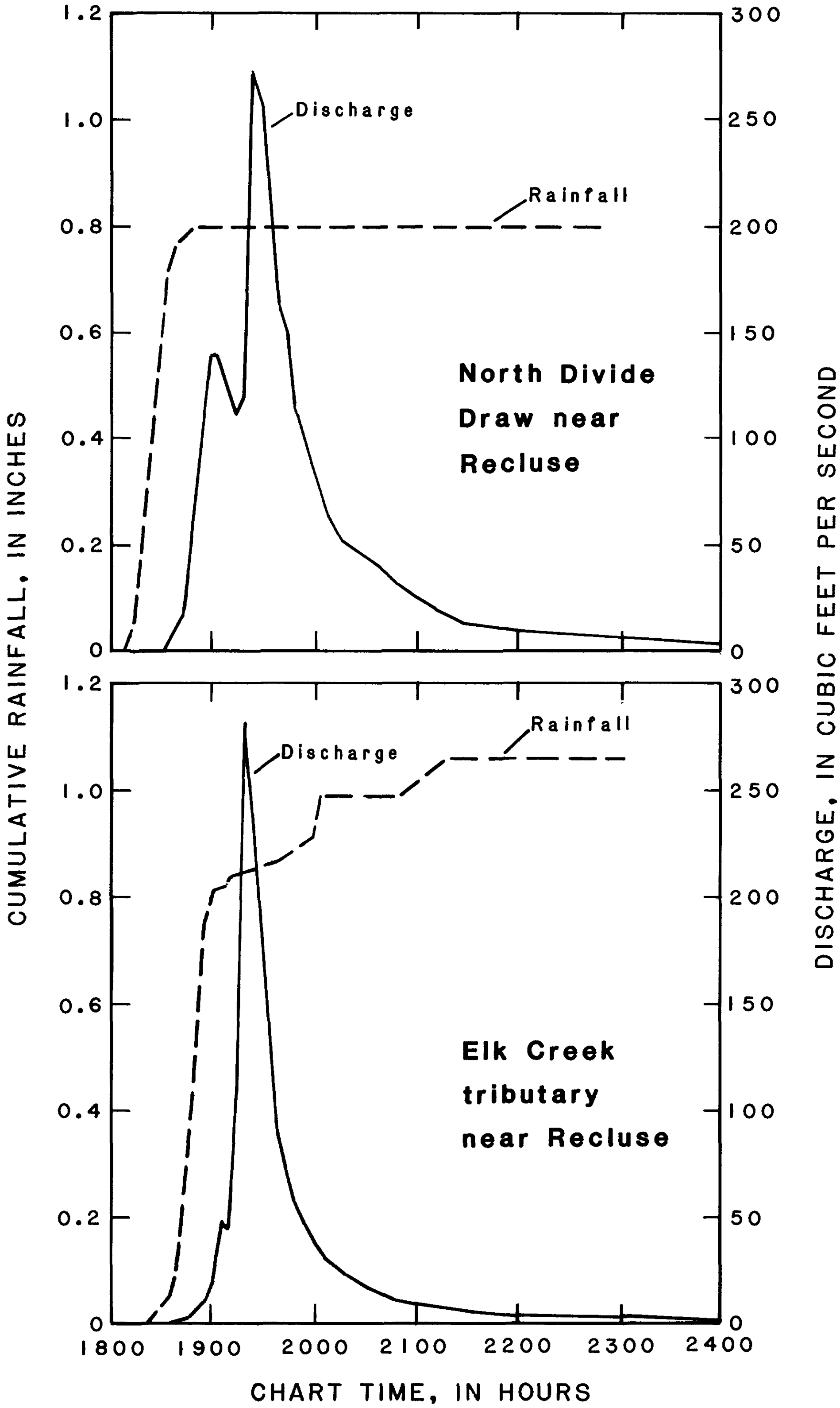


Figure 6.--Maximum runoff for basins used in runoff investigations, June 12, 1977.

Craig and Rankl (1978) established a relation between the volume of runoff resulting from convective storms on small, ephemeral streams and the maximum discharge. This relation is useful for design purposes to determine the volume of runoff for a stream where the peak discharge is known. The peak-volume relation developed for North Divide Draw and Elk Creek tributary near Recluse are shown in figures 7 and 8.

Quality of Water

Chemical Quality

Adequate data for describing the chemical quality of surface water were not obtained during this study. The analyses of samples that were collected are included in table 8, page 36.

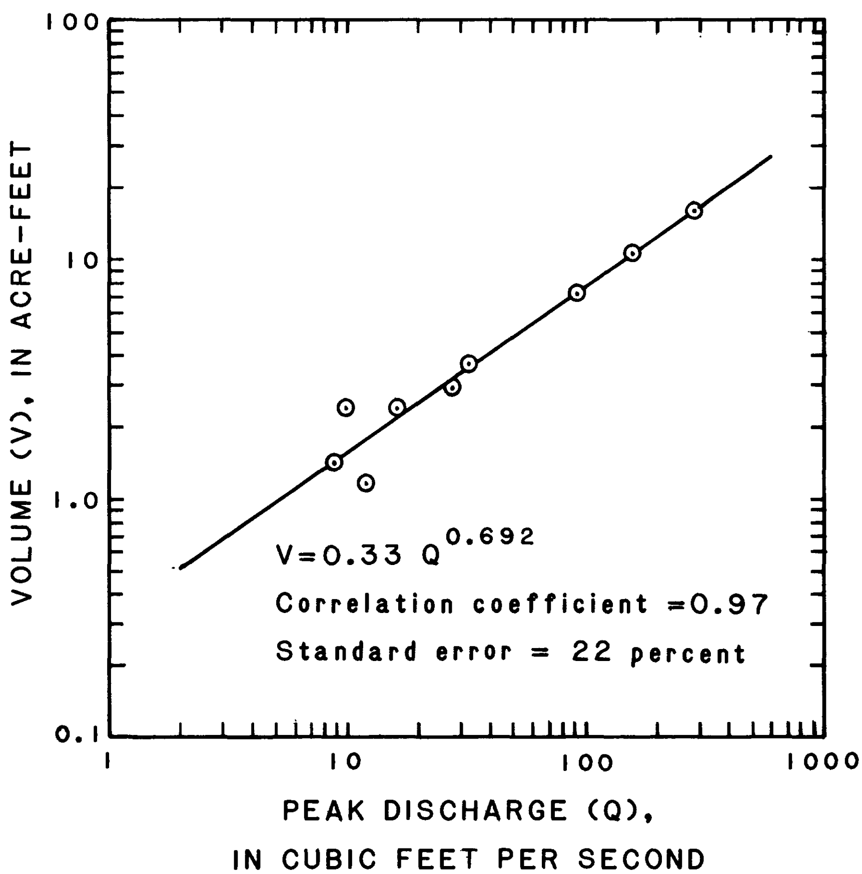


Figure 7.--Peak-volume relation for North Divide Draw near Recluse.

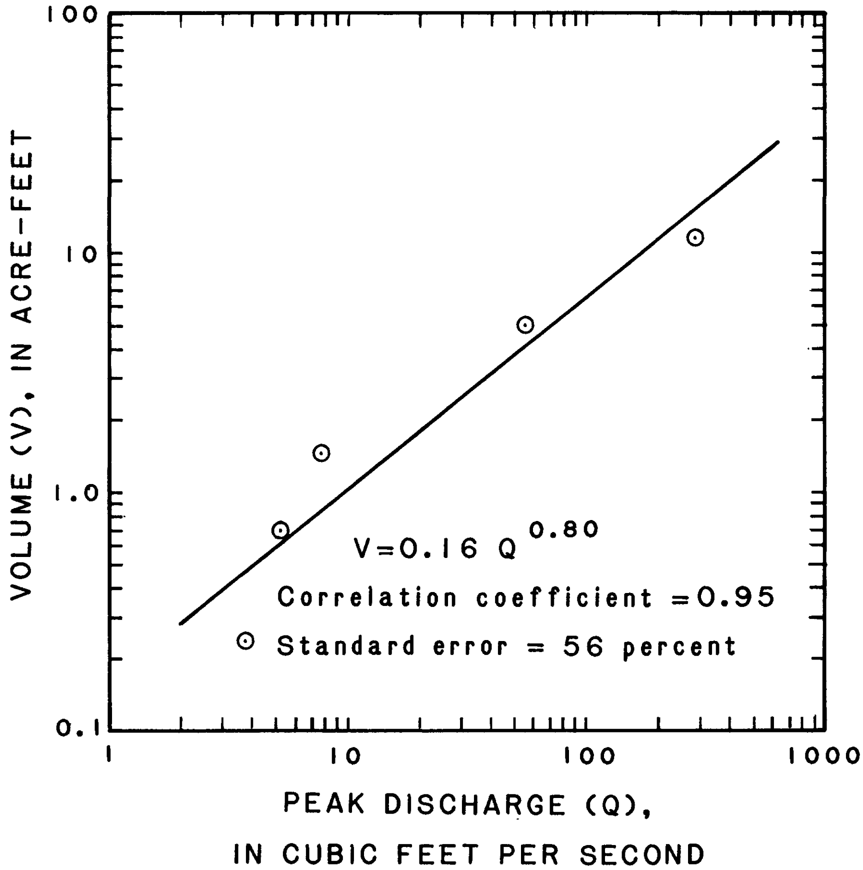


Figure 8.--Peak-volume relation for Elk Creek tributary near Recluse.

Sediment

Computations of the annual transport of sediment require a defined discharge-concentration rating curve, water temperature, and samples collected during both rising and declining streamflow stage. Automatic sediment samplers and accessible sites are needed to collect sufficient data to compute the sediment discharge for ephemeral streams which have flashy peak flows.

A qualitative analysis of sediment load cannot be made for North Divide Draw and Elk Creek tributary because of a lack of the required data. Table 2 lists the dates; the stage at which the sample was taken; the peak discharge; and the concentration, in milligrams per liter (mg/L), of each sediment sample collected during the study.

Table 2.--*Single-stage sediment samples collected during the study*

Site	Date	Sampler stage (feet)	Peak discharge (cubic feet per second)	Concentration (milligrams per liter)
North Divide Draw	4-16-77	0.81	52	6,050
	5-18-77	.81	26	8,360
	6-11-77	.81	8.1	[1]79,900
	6-12-77	2.12	272	36,300
	7-11-77	.81	12	19,600
Elk Creek tributary	6-12-77	.76	282	38,400
	6-12-77	2.04	282	50,600

[1]Large concentration may be result of sediment from runoff on June 11 and 12, 1977.

Flow-Frequency Analysis

The magnitude and frequency of peaks and runoff volumes are flow characteristics that are required for the design of storage reservoirs, hydraulic structures, and channel relocation. These flow characteristics can be used to establish hydrologic conditions prior to a possible hydrologic change, such as a change that may result from strip mining.

Statistical analysis of long-term records of streamflow can be used to determine the desired flow characteristics, or the information can be computed from regional flow-frequency analysis using either basin or channel characteristics. Because long-term flow records were not available for the study sites and the regional flow-frequency investigations did not include basins with large areas of surface clinker, it was decided to collect short-term rainfall-runoff data, calibrate basin models, and extend the records using long-term precipitation and pan-evaporation data.

Rainfall-Runoff Model

A digital rainfall-runoff model developed by Dawdy and others (1972) and modified by Craig and Rankl (1978) was used in this study. This model uses three parameters for infiltration evaluation, four for soil-moisture accounting, three to account for variation of infiltration with time, and three flow-routing parameters. The objective function, which is the sum of the squared errors divided by the number of storms, is minimized to obtain the best fit of the parameters. Table 3 lists the model parameters, their function, and their description and application.

Table 3.--*Function, description, and application of model parameters*

[Modified from Dawdy and others (1972) and Craig and Rankl (1978)]

Parameter	Units of measure	Function	Description and application
PSP	Inches	Infiltration	Suction at the wetted front for soil moisture at field capacity.
RGF	----	Infiltration	Ratio of the suction at the wetted front for soil moisture at wilting point to that at field capacity.
KSAT	Inches per hour.	Infiltration	The minimum saturated value of hydraulic conductivity used to determine soil-infiltration rates.
BMSM	Inches	Soil-moisture accounting.	Soil-moisture storage volume at capacity.
EVC	----	Soil-moisture accounting.	Coefficient to convert pan evaporation to potential evapotranspiration values.
DRN	Inches per hour.	Soil-moisture accounting.	A constant drainage rate for redistribution of soil moisture.
RR	----	Soil-moisture accounting.	Proportion of daily rainfall that infiltrates the soil.
CKMX	----	Variation of infiltration with time.	Exponent that establishes the maximum potential-infiltration rate in a given year.
CKMN	----	Variation of infiltration with time.	Exponent that establishes the minimum potential-infiltration rate in a given year.
CKEX	----	Variation of infiltration with time.	Controls the rate of decrease between CKMX and CKMN.
KSW	Hours	Flow routing	Time-storage characteristic for linear reservoir routing.
TC	Minutes	Flow routing	Time of concentration for the time-discharge histogram.
TP	Minutes	Flow routing	Time to peak for the time-discharge histogram.

An in-depth discussion of the model parameters, derivations, and functions are in Dawdy and others (1972). Modifications of the model for semiarid conditions are discussed by Craig and Rankl (1978).

Several runoff-producing rains were not used for model calibration because the total hydrographs were not recorded, and rainfall data were missing. North Divide Draw had 10 runoff-producing rains that provided data for calibration of the digital model, and Elk Creek tributary had 6. Table 4 lists the date, total rainfall, peak discharge, and volume of runoff for the two basins.

Table 4.--*Rainfall and runoff data for North Divide Draw and Elk Creek tributary*

[Runoff rounded to three significant figures]

Date	Rainfall (inches)	Peak discharge (cubic feet per second)	Runoff (acre-feet)	Runoff (inches)
		North Divide Draw near Recluse, Wyo.		
07-03-76	0.44	26	2.97	0.032
07-11-76	.41	32	3.72	.041
07-13-76	.55	93	7.13	.078
07-21-76	.31	10	2.48	.027
07-27-76	1.07	153	11.1	.121
09-15-76	.20	9.1	1.45	.016
06-11-77	.43	8.1	1.39	.015
06-12-77	.40	16	2.51	.027
06-12-77	.80	272	16.2	.177
07-11-77	.21	12	1.20	.013
		Elk Creek tributary near Recluse, Wyo.		
07-11-76	0.41	5.2	0.70	0.006
07-13-76	.55	7.8	1.45	.013
07-21-76	.21	3.7	.24	.002
07-26-76	1.20	55	5.00	.045
06-12-77	1.06	282	11.6	.103
08-08-77	.15	1.5	.06	.001

Initial model-parameter values were obtained by using an average value for each parameter from 22 small basins studied by Craig and Rankl (1978). Six parameters were optimized to obtain a model fit for the two basins: PSP, RGF, KSAT, BMSM, DRN, and RR. The pan-evaporation coefficient (EVC) and the parameters that represent variation of infiltration with the time of the year (CKMX, CKMN, and CKEX) were held constant and not optimized. The routing parameters of the model were fitted by holding the optimized excess-runoff parameters constant and optimizing the routing parameters (KSW, TC, TP). This resulted in a skewed fit of the peak discharges. The skew was removed by using trial-and-error values of the storage coefficient (KSW) and optimizing the time-area histogram parameters (TC and TP). Model parameters and values for the two basins are listed in table 5. These parameter values were used in conjunction with long-term precipitation and pan-evaporation data to generate the annual runoff volumes and peaks.

Table 5.--*Model parameters and values*

Parameter[1]	North Divide Draw	Elk Creek tributary
PSP[2]	4.45	31.78
RGF[2]	11.99	44.36
KSAT[2]	.087	.173
BMSM[2]	3.95	1.01
EVC	.664	.664
DRN[2]	.105	.099
RR[2]	.300	1.00
CKMX	1.75	1.75
CKMN	1.53	1.53
CKEX	27.5	27.5
Volume objective function-------	0.032	0.149
KSW[2]	.620	.399
TC[2]	7.37	8.30
TP[2]	5.08	6.14
Peak objective function---------	0.080	0.289

[1]Units and description of parameters given in table 3.
[2]Optimized parameters.

Long-Term Climatic Records

Long-term precipitation records were obtained from the National Weather Service for the station at Cheyenne. The period of record was from April 1, 1901, to September 30, 1973, providing 73 years of data. Pan-evaporation data were obtained for 1913-73 from the Archer Field Station located about 9 mi east of Cheyenne. The Cheyenne precipitation record and the Archer Field Station record are the longest continuous records available in Wyoming and are similiar to rainfall patterns and evaporation conditions in the Recluse area (Craig and Rankl, 1978). Precipitation and evaporation data need to be for the same period of record; therefore, the evaporation data were extended back to 1901 by relating evaporation to seasonal precipitation. Climatic data could have been obtained for 1974-77, but in this report a comparison of runoff characteristics from the two modeled basins is made with results from a regional study based only on the 1901-73 record.

The rate of infiltration of rainfall from a given storm is partly controlled by the soil moisture at the beginning of the storm. Therefore, it is important that the quantity of daily rainfall and evaporation at the long-term station represent climatic conditions at or near the study sites. This is accomplished by adjusting the long-term daily precipitation and evaporation data by a correction factor. The correction factor for daily precipitation is a ratio of the mean-annual (MA) precipitation (ppt) at a nearby short-term station and the mean-annual precipitation at the long-term station. The correction factor for daily precipitation was computed as follows:

$$\text{Daily precipitation correction factor} = \frac{\text{MA ppt Recluse} = 13.59 \text{ inches}}{\text{MA ppt Cheyenne} = 15.06 \text{ inches}} = 0.90.$$

The correction factor for daily evaporation (evap) was computed in the same manner as daily precipitation:

$$\text{Daily evaporation correction factor} = \frac{\text{MA evap Gillette 2E} = 43.75 \text{ inches}}{\text{MA evap Archer} = 41.54 \text{ inches}} = 1.05.$$

Precipitation frequency of short-duration, intense rainfall was investigated to determine if the storms that produced the annual runoff were similar in duration to the storms used to calibrate the model. The 50-year, 6-hour storm was selected for this comparison. Data for comparison was obtained from a precipitation-frequency atlas of the Western United States (Miller and others, 1973). The correction factor for unit precipitation was computed as follows:

$$\text{Unit-precipitation correction factor} = \frac{\text{50-year, 6-hour storm, Recluse 2.8 inches}}{\text{50-year, 6-hour storm, Cheyenne 2.6 inches}} = 1.08.$$

The unit-precipitation correction factor was applied to each 5-minute increment of each storm of the long-term record at Cheyenne.

A long-term simulation program was used to compute the maximum annual runoff and peak. This program used the parameters from the calibrated basin model and the adjusted long-term precipitation and evaporation records to generate the 73 years of data.

A log-Pearson Type III cumulative probability distribution was assumed for the data samples of volumes and peaks (U.S. Water Resources Council, 1967). The first three moments of the distribution, mean of logarithms, standard deviations of logarithms, and coefficient of skewness were computed to estimate the statistics of the population. Peak discharges and runoff volumes were computed for selected recurrence intervals using the sample statistics. A frequency line is shown by plotting the runoff characteristic versus the recurrence interval. The recurrence interval, in years, of the volume of runoff and of peak discharge for North Divide Draw and Elk Creek tributary are shown in figures 9 and 10.

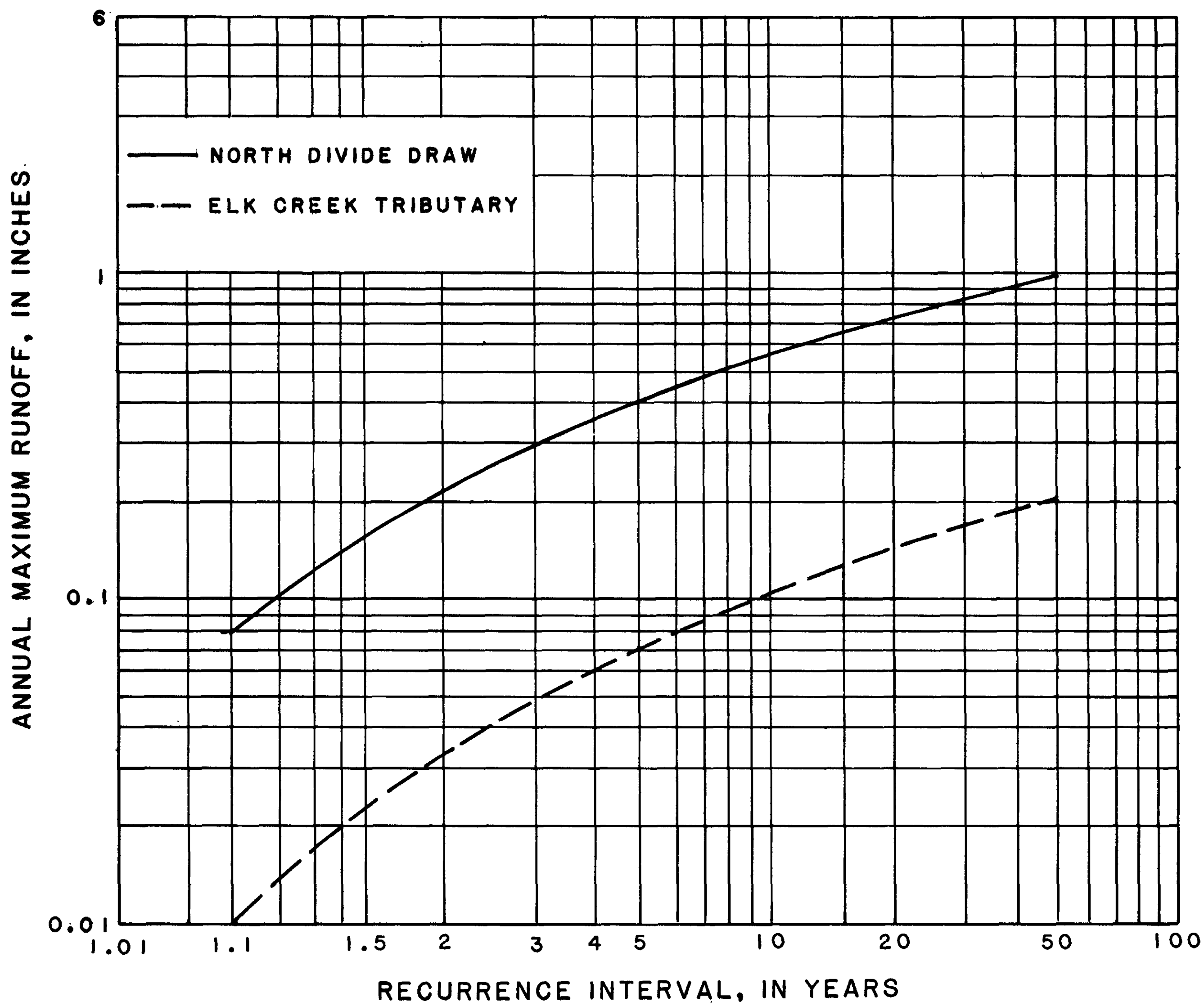


Figure 9.--Log-Pearson Type III frequency curves for annual maximum runoff, North Divide Draw and Elk Creek tributary near Recluse, based on 73 years of simulated data.

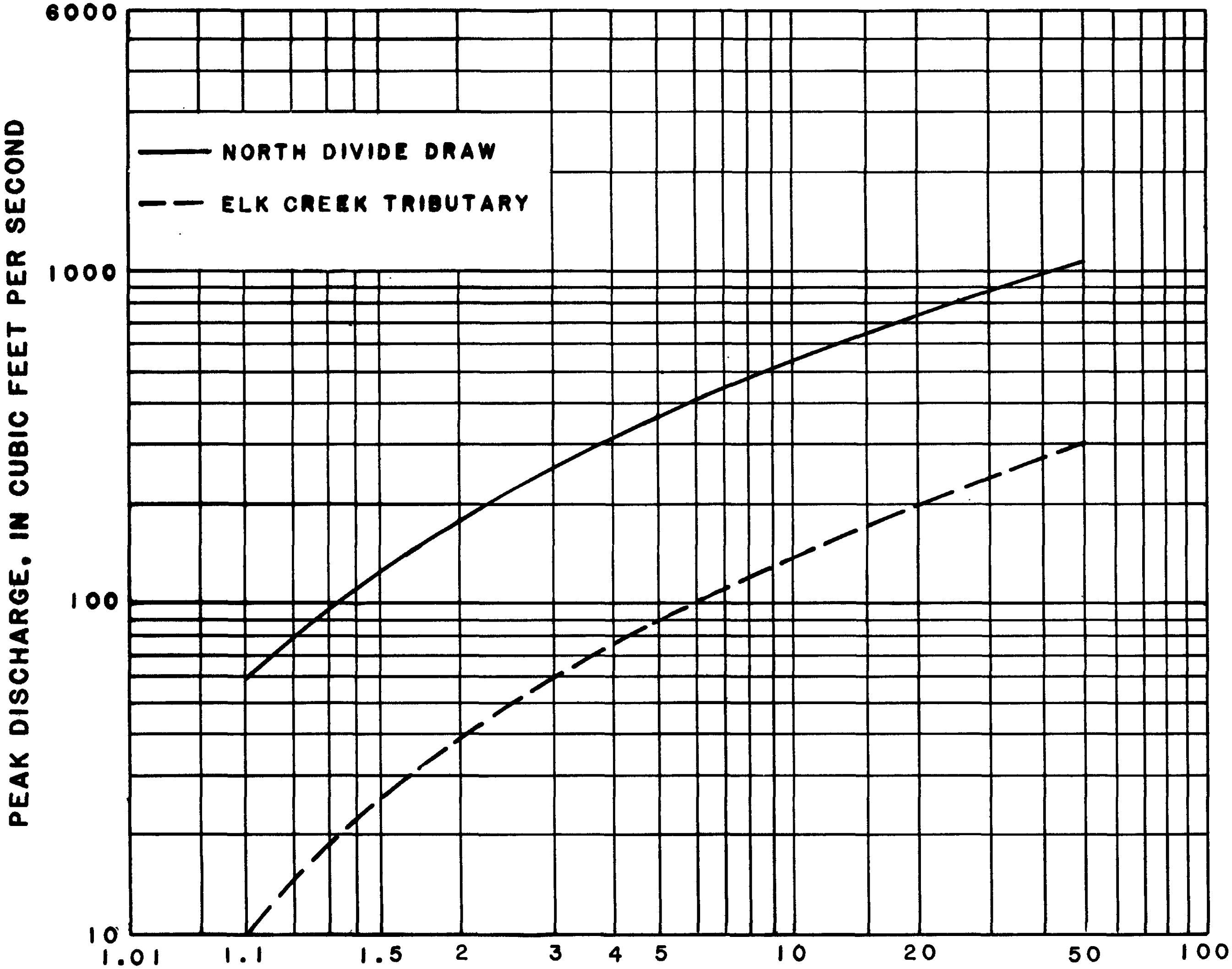


Figure 10.--Log-Pearson Type III frequency curves for annual maximum peak discharge, North Divide Draw and Elk Creek tributary near Recluse, based on 73 years of simulated data.

Comparison of Runoff from Basins

Runoff from North Divide Draw is five to eight times greater than runoff from Elk Creek Tributary, and peak discharges are three to five times greater. This comparison is shown in figures 9 and 10.

Infiltration, as used in the rainfall-runoff model, represents the total loss of precipitation from various hydrologic functions. These functions include depression storage, interception, channel loss, bank storage, and water uptake by the soil. Elk Creek tributary has a larger flat upland area with denser sage and more grass than North Divide Draw, which would result in greater depression storage and interception. Springs along the downstream reaches of North Divide Draw keep the channel saturated, decreasing channel loss. The major differences in infiltration between the two basins are caused by differences in area and distribution of exposed clinker as shown in figures 3 and 4. No evidence of flow was observed in the downstream tributary shown in figure 4 where it enters Elk Creek tributary upstream from the gage. The downstream tributary drains about one-fifth of the basin, which is underlain largely by clinker.

The results obtained by applying basin characteristics in table 1 to runoff equations by Craig and Rankl (1978, p. 27) were compared to the results of this study. Runoff characteristics, as defined by this study, were 19 to 33 percent more for North Divide Draw and 80 to 88 percent less for Elk Creek tributary than those obtained by applying basin characteristics to equations by Craig and Rankl (1978). Table 6 shows this comparison for peak discharge (Q) and volume (V) for selected recurrence intervals.

Table 6.--*Comparison of runoff characteristics computed by the rainfall-runoff model for this study with those computed from the basin-characteristics method*

Recurrence interval	North Divide Draw: Basin characteristics	North Divide Draw: Rainfall-runoff model	North Divide Draw: Percent difference	Elk Creek tributary: Basin characteristics	Elk Creek tributary: Rainfall-runoff model	Elk Creek tributary: Percent difference
Years	Cubic feet per second			Cubic feet per second		
Q_2	146	178	+22	315	39	-88
Q_5	306	368	+20	630	91	-86
Q_{10}	451	540	+20	904	140	-85
Q_{25}	684	816	+19	1,324	222	-83
Q_{50}	899	1,066	+19	1,712	298	-83
Years	Acre-feet			Acre-feet		
V_2	15.22	20.00	+31	30.89	3.70	-88
V_5	28.22	37.43	+33	53.36	8.06	-85
V_{10}	38.81	51.46	+33	70.93	11.87	-83
V_{25}	54.07	71.83	+33	96.32	17.58	-82
V_{50}	67.17	88.71	+32	113.6	22.62	-80

Confidence limits of two standard errors were constructed on each side of the centroidal point of the regression plane at selected recurrence intervals (figs. 11 and 12) for the regional model of Craig and Rankl (1978). Runoff and peak-frequency curves for North Divide Draw and Elk Creek tributary were plotted on the same graphs to determine if data from these basins are of the same population used in the regional study. Data for North Divide Draw are within the confidence limits of the regional study. Greater runoff caused by a larger unit-precipitation correction factor than any used in the regional study and decreased channel losses due to spring discharge may have compensated for the increased infiltration rates in areas of exposed clinker. Data for Elk Creek tributary are outside the confidence limits; therefore, there is only about a 5-percent chance that the data are from the same population as the data of the regional study.

Impacts of Mining

Effects of strip mining on surface-water hydrology can be evaluated in two ways: (1) Compare results of hydrologic investigations based on data collected before and after mining, and (2) estimate changes in the hydrologic system from detailed mining and reclamation plans. Because data are not available for the above methods, investigations for this report are restricted to sensitivity evaluation of selected hydrologic functions of the study area.

The rainfall-runoff model of North Divide Draw basin provides a tool to evaluate the effects of infiltration on runoff. A 1-, 2-, and 3-percent increase and decrease in infiltration were six conditions that were assumed. The model calibrates on runoff by optimizing a set of parameters that control infiltration; therefore, a new set of runoff values for each assumed condition was computed. The following equations were used to compute the adjusted runoff values:

$$I = RF - RO \quad (1)$$
$$I_a = I \times C \quad (2)$$
$$RO_a = RF - I_a \quad (3)$$

where I = total infiltration of a storm, in inches;
RF = total measured rainfall for a storm, in inches;
RO = total measured runoff for a storm, in inches;
I_a = adjusted infiltration, in inches;
C = assumed percent change in infiltration; and
RO_a = adjusted runoff value, in inches.

A new set of basin-model runoff parameters was optimized for the six assumed infiltration conditions. Analysis of the parameter values for suction at the wetted front (PSP) indicated a trend when plotted against percent change in infiltration. The parameter values for PSP were smoothed and held constant, and the remaining runoff parameters were optimized. This process was repeated for each runoff parameter used in the original basin calibration. The objective function of runoff was used to detect deterioration in quality of the fit, and each fit was plotted to check for skewness. Plots of parameter responses to the changes in total infiltration are shown in figures 13 through 18.

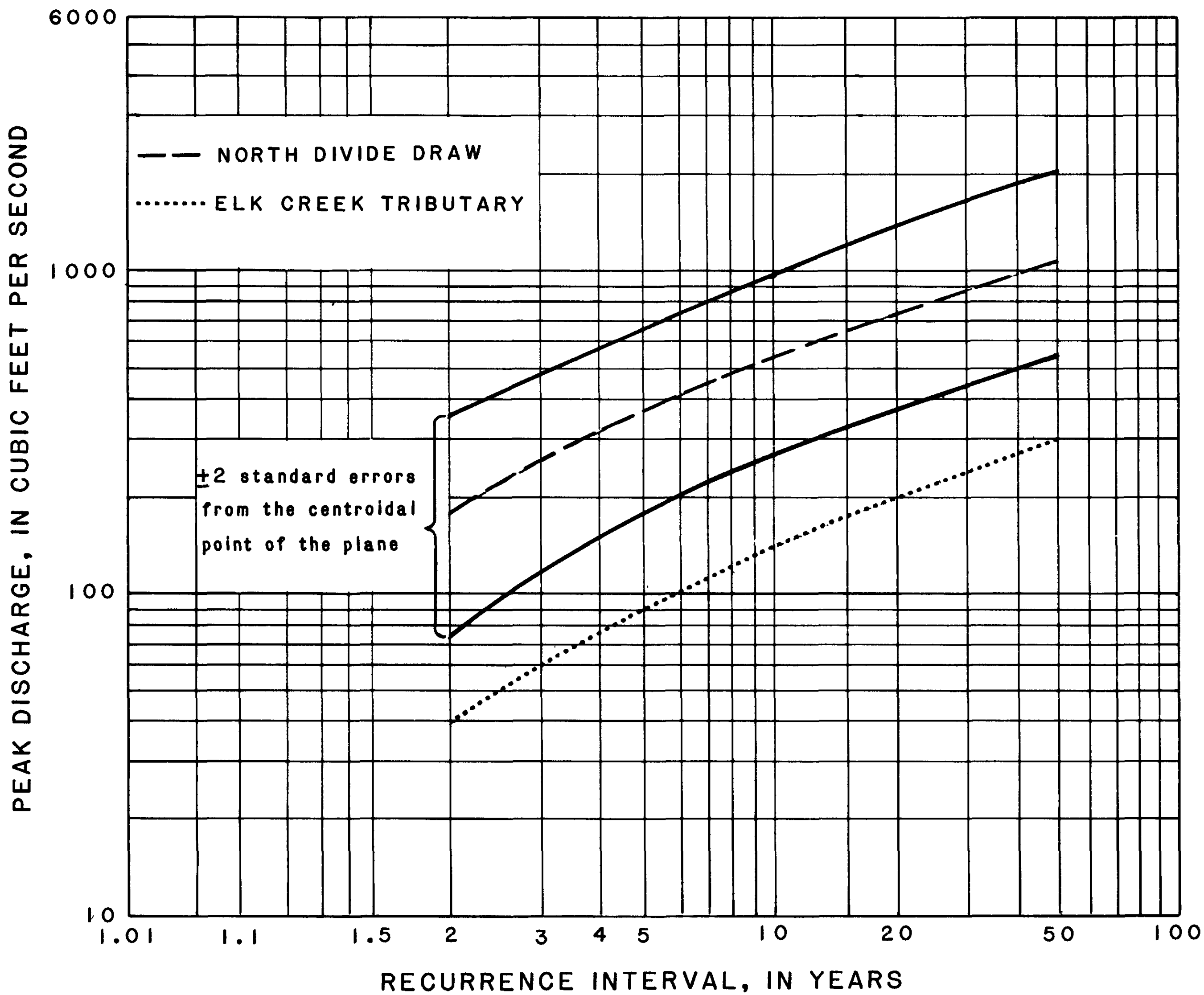


Figure 11.--Comparison of peak-flow frequency analysis with regional confidence limits.

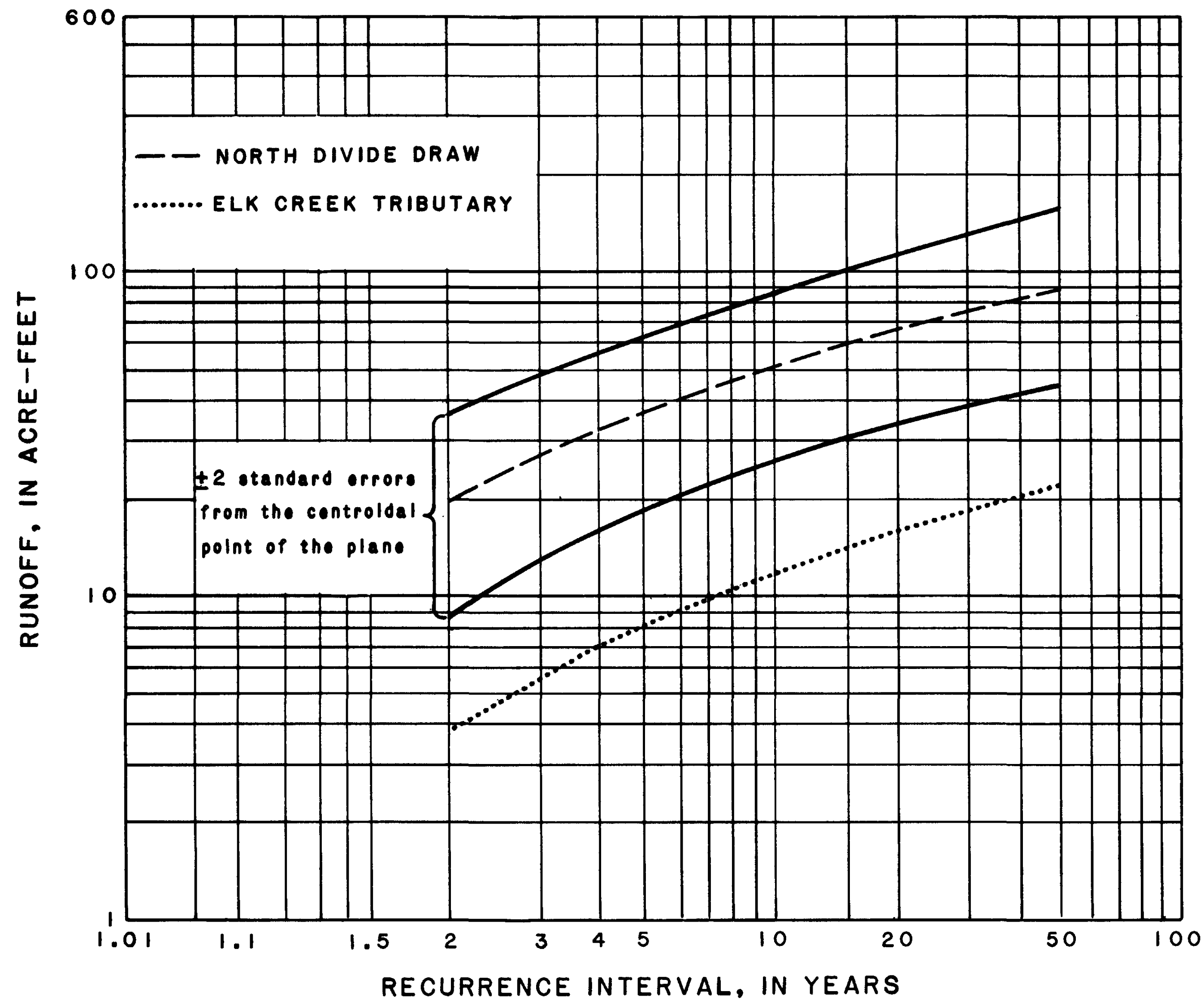


Figure 12.--Comparison of runoff-volume frequency analysis with regional confidence limits.

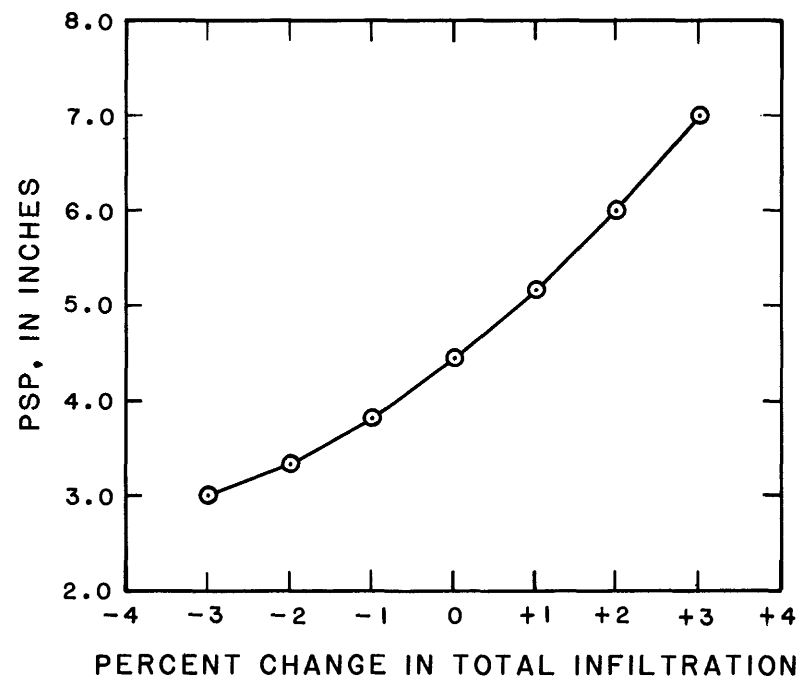


Figure 13.--Change in suction at the wetted front for soil moisture at field capacity (PSP) for change in total infiltration.

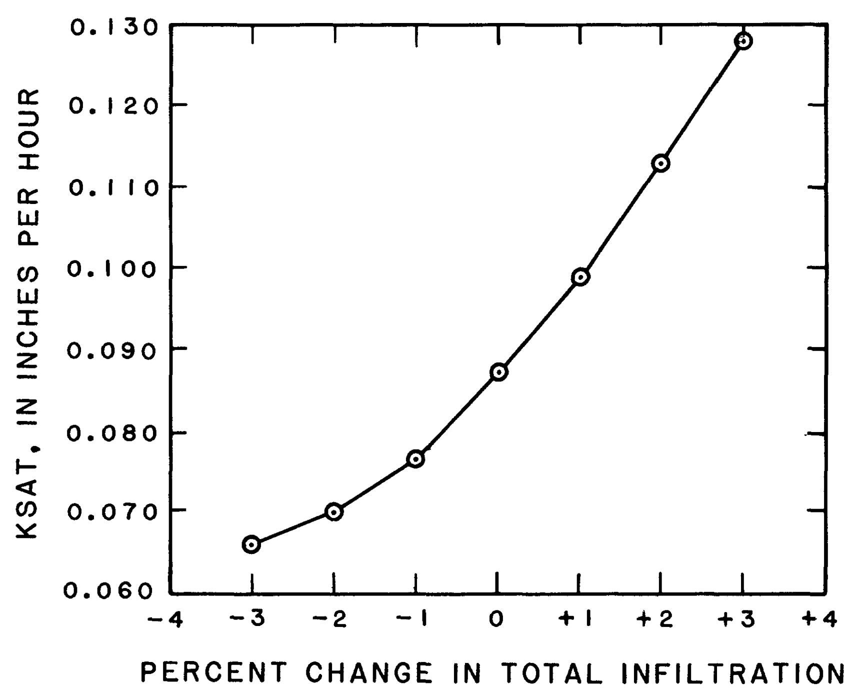


Figure 14.--Change in saturated hydraulic conductivity (KSAT) for change in total infiltration.

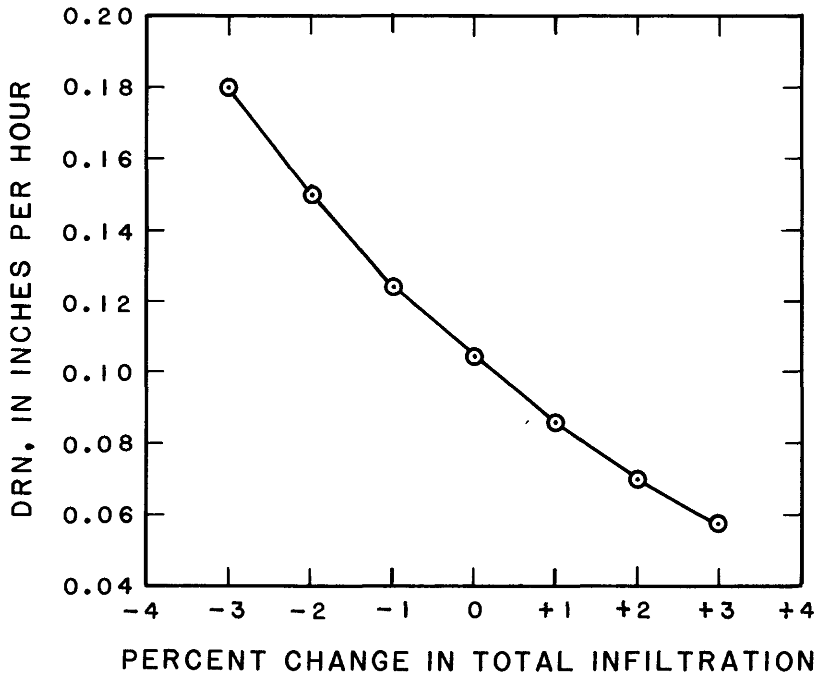


Figure 15.--Change in the constant drainage rate for redistribution of soil moisture (DRN) for change in total infiltration.

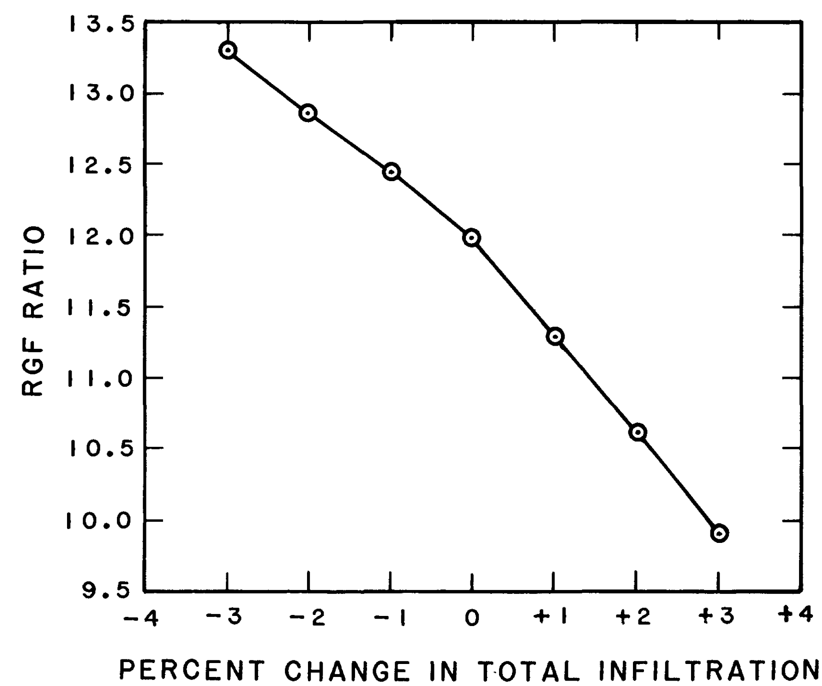


Figure 16.--Change in the ratio of the suction at the wetted front for soil moisture at wilting point to that at field capacity (RGF) for change in total infiltration.

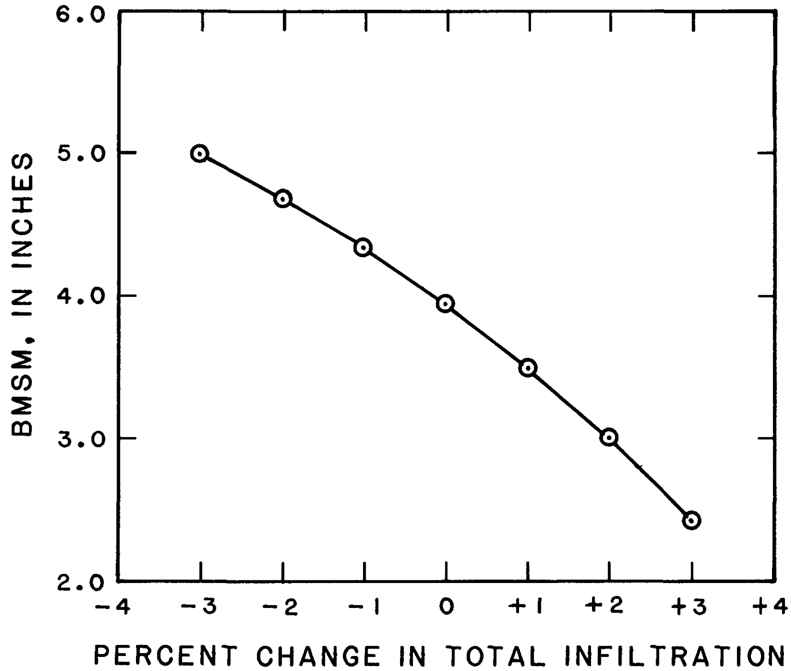


Figure 17.--Change in maximum soil moisture-storage volume (BMSM) for change in total infiltration.

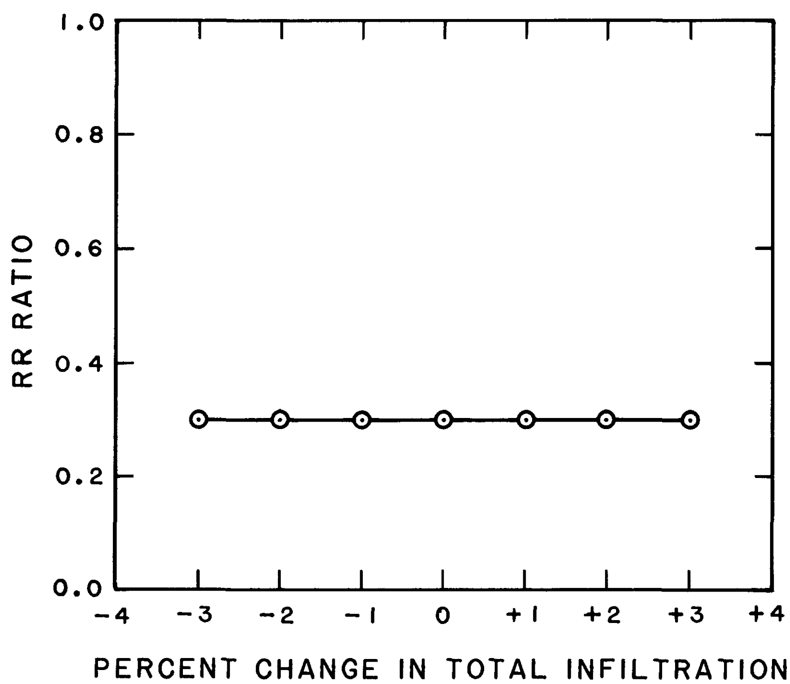


Figure 18.--Change in proportion of daily rainfall that infiltrates the soil (RR) for change in total infiltration.

Overland-flow parameters defined by the original basin calibration were used for all conditions of infiltration. Stress to the overland-flow parameters could not be determined because it is related to basin or channel characteristics and to hydrograph shape.

The new set of optimized parameters from the adjusted runoff values were used in conjunction with the long-term records of runoff and peaks. Log-Pearson Type III distribution was applied to the adjusted record to determine a set of frequency distributions showing change in runoff with change in infiltration. Runoff and peak discharges for selected recurrence intervals for changes in infiltration for North Divide Draw are shown in figures 19 and 20. A 1-percent change in infiltration results in about a 10-percent change in runoff and peaks.

GROUND-WATER HYDROLOGY

Occurrence and Availability

Ground water in adequate quantities for stock and domestic use occurs in sandstone, coal, clinker, and alluvium. Seeps are sometimes associated with small landslides but may be antecedent to, and partly responsible for, the slides. Clinker is the most permeable aquifer in the area but occurs only near the surface, and saturated thickness necessary for development by wells does not commonly occur. Well 55N 072W 03BB 01 is completed in clinker; however, springs produce most of the water from the aquifer.

No aquifer tests were conducted in the area in alluvial deposits. Similar deposits elsewhere have transmissivities as much as 160 ft^2/d, and this is probably the maximum that could be expected in the area.

Transmissivities of sandstone aquifers 1,000 ft deep or less range elsewhere in eastern Campbell County from about 50 to 1,200 ft^2/d, but deep sandstone aquifers have less transmissivity, possibly because of compaction with depth. A well tested in eastern Campbell County that is 2,918 ft deep and perforated in the lower part of the Lance Formation and the Fox Hills Sandstone has a transmissivity of only 45 ft^2/d.

Depth of wells and water levels representative of those in the White Tail Butte area are given in table 7. The locations of the wells, springs, and test holes are shown in figure 21.

Quality of Water

The chemical quality of ground water in the area is a function of the solubility of minerals that the water initially contacts in the recharge area and the exchange reactions and additional solution as the water moves through the aquifer. Clinker, which is relatively insoluble and porous, underlies large areas. Precipitation falling on these clinker areas dissolves little additional material, and the water moving through the clinker is a calcium bicarbonate type. (See analysis for spring 56N 072W 21CCC01 in table 8.) The dominant lithologies are sandstone, shale, and coal, which contain greater amounts of easily dissolved minerals than does clinker. The water in these

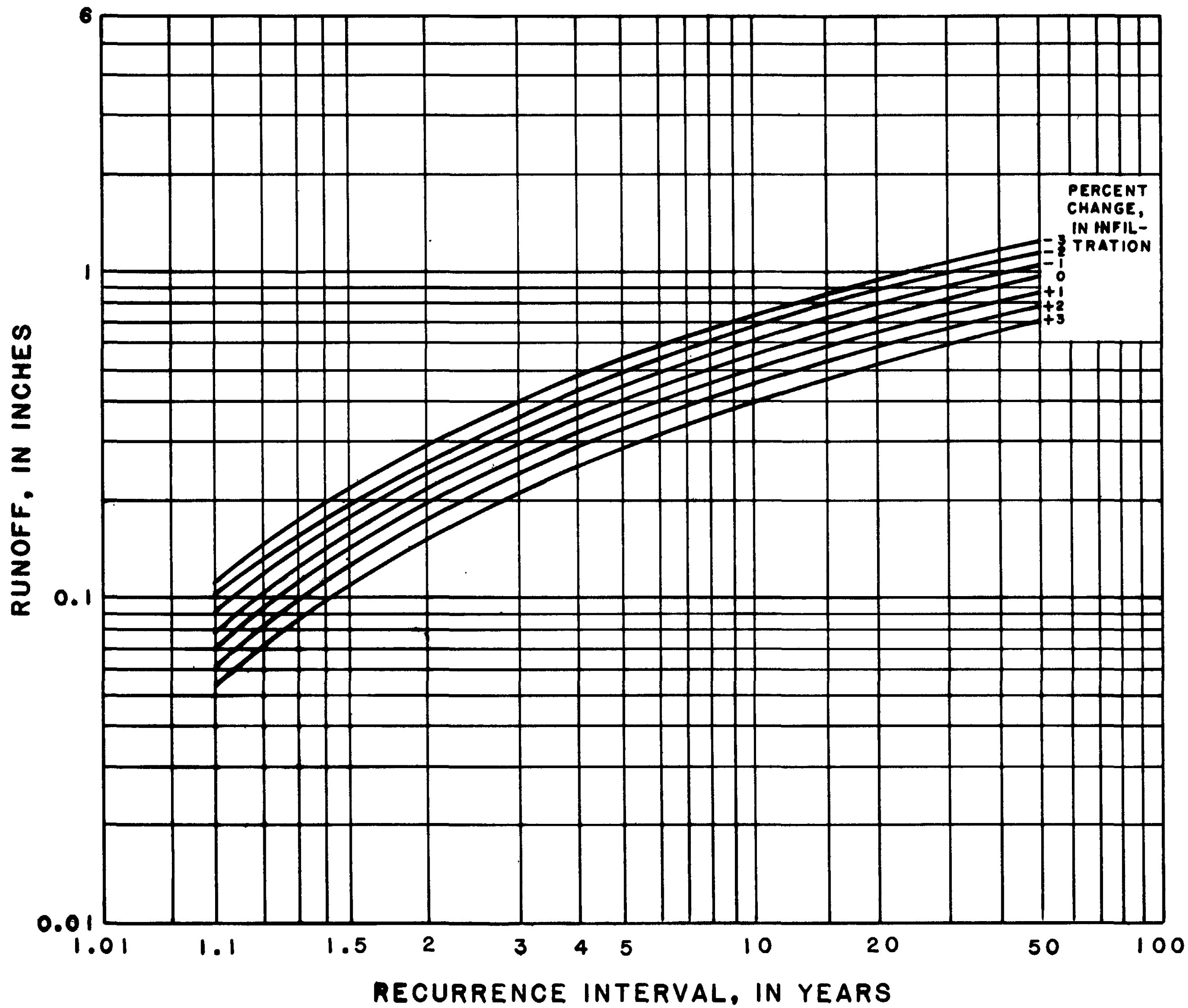


Figure 19.--Runoff-frequency curves for North Divide Draw adjusted for infiltration.

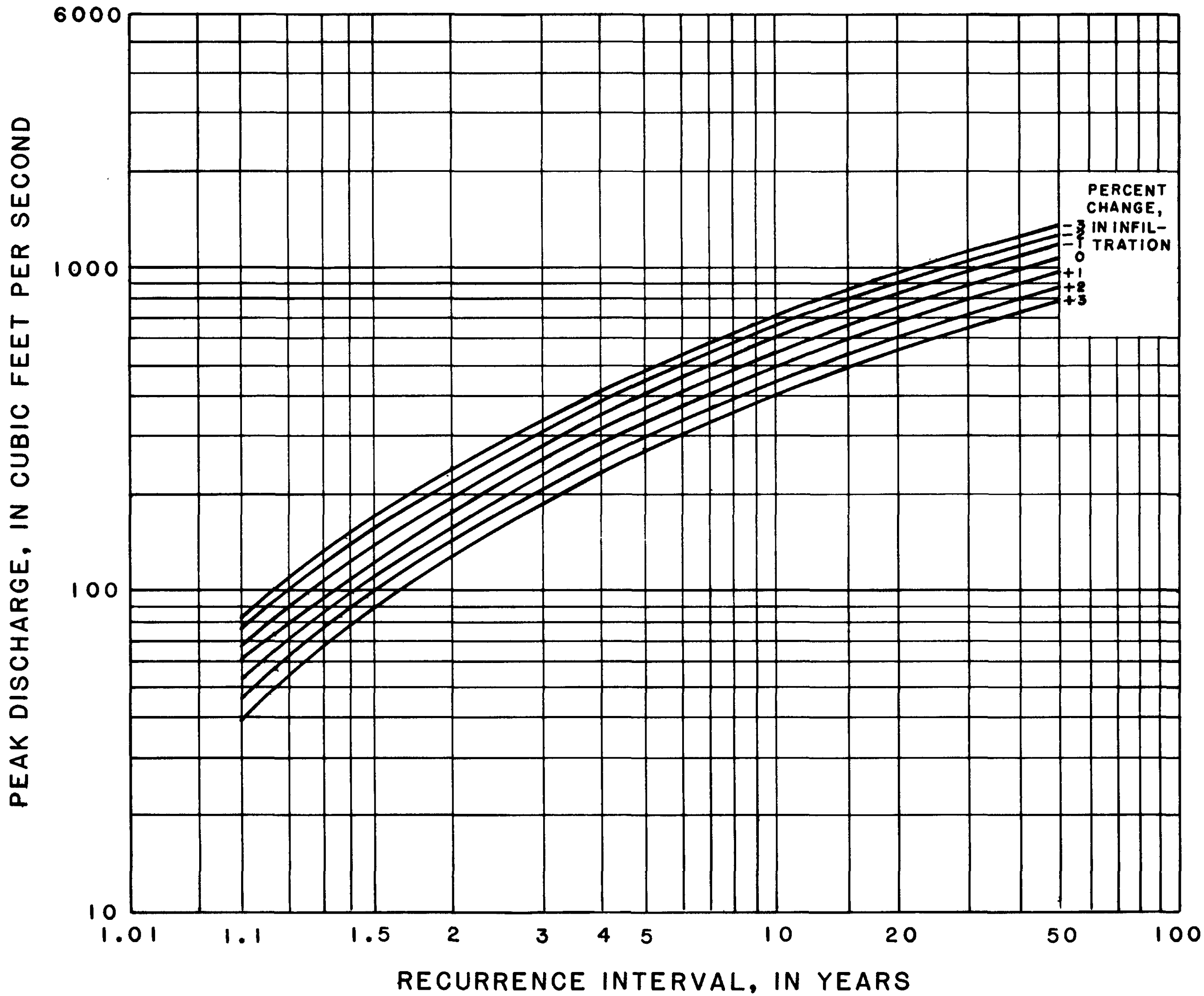


Figure 20.--Peak-discharge-frequency curves for North Divide Draw adjusted for infiltration.

Table 7.--*Records of wells, springs, and test holes*

[Site number: see text for description of site-numbering system. Perforations: top and bottom of interval of well open to aquifer (where known); if only bottom is listed, it is the depth of the well or test hole. Altitude of land surface: altitudes were estimated from topographic maps, or were reported by owner. Remarks: CA, chemical analysis given in table 4]

Site number	Type of site	Perforations Top (feet)	Perforations Bottom (feet)	Water-bearing formation	Zone unit	Altitude of land surface above sea level (feet)	Depth to water below land surface (feet)	Date of water-level measurement	Remarks
55N 071W 32BC 01	Well	-----	105	Fort Union	--	3,680	--	--	CA
55N 071W 32BD 01	Well	1,130	1,255	Fort Union	Sandstone	3,648	Flowing	--	--
55N 071W 33BDA01	Well	960	1,090	Fort Union	Sandstone	3,700	Flowing	--	--
55N 072W 03BB 01	Well	70	110	Fork Union	Clinker	4,100	70	--	--
55N 072W 05BC 01	Well	270	360	Fort Union	Sandstone and coal	-----	180	--	--
55N 072W 21CD 01	Well	90?	131	Fort Union	Sandstone	4,200	80	--	--
55N 072W 25CA 01	Spring	-----	-----	Fort Union	Clinker	4,160	--	--	CA
55N 072W 32CDD01	Well	-----	-----	Alluvium	--	-----	5.2	07-31-68	CA
55N 073W 05AC 01	Well	92	125	Fort Union	Sandstone	4,110	15	--	--
55N 073W 14BC 01	Well	2,670	3,402	Lance and Fox Hills	Sandstone	4,005	--	--	--
55N 073W 20CD 01	Well	78	90	--	Sandstone	4,050	55	--	--
55N 073W 26 01	Test	370	380	Fort Union	Coal	4,195	267.5	07-13-78	Cook Coal, CA
55N 074W 10DC 01	Well	80	133	Wasatch (?) Fort Union	Sandstone and coal	4,080	75	--	--
55N 074W 23ABB01	Well	76	92	Wasatch	Sandstone	4,200	68.0	08-02-68	--
56N 071W 30DBB01	Well	13	23	Alluvium	Sand and gravel	3,670	13.1	07-28-78	CA
56N 071W 30DBB02	Well	21	30	Alluvium	Sand and gravel	3,670	13.8	07-28-78	CA
56N 072W 08AB 01	Well	140	212	Fort Union	Sandstone	-----	127.2	10-16-68	--
56N 072W 19CDC01	Spring	-----	-----	Fort Union	Landslide	4,080	--	--	CA
56N 072W 21CCC01	Spring	-----	-----	Fort Union	Clinker	3,950	--	--	CA
56N 072W 29ACC01	Spring	-----	-----	Fort Union	Coal	3,950	--	--	Anderson Coal, CA
56N 072W 30BAB01	Spring	-----	-----	Fort Union	Coal	4,020	--	--	Canyon Coal, CA
56N 072W 31DDA01	Test	663	683	Fort Union	Coal	4,163	400.0	07-13-78	Cache Coal, CA
56N 072W 32AC 01	Test	245	260	Fort Union	Coal	4,238	240.6	01-08-76	Canyon Coal, CA
56N 072W 32BAD01	Test	214	252	Fort Union	Coal	4,226	220.5	07-13-78	Anderson Coal
56N 072W 33BCD01	Test	324	338	Fort Union	Sandstone	4,204	295.2	07-13-78	Sandstone underlying Canyon Coal, CA
56N 072W 34BD 01	Spring	-----	-----	Fort Union	Clinker and coal	4,000	--	--	CA
56N 072W 36AB 01	Spring	-----	-----	Fort Union	--	3,760	--	--	CA
56N 073W 21AB 01	Test	285	300	Fort Union	Coal	4,106	180.6	10-20-77	Canyon Coal, CA
56N 073W 25BBA01	Test	300	332	Fort Union	Coal	4,195	213.1	06-06-78	Canyon Coal, CA
56N 073W 25CC 01	Test	130	155	Fort Union	Coal	4,142	107.4	07-13-78	Anderson Coal, CA
56N 073W 25CC 02	Test	135	175	Fort Union	Coal	4,142	88.6	07-13-78	Anderson Coal, CA
56N 073W 25CC 03	Test	135	175	Fort Union	Coal	4,142	88.0	07-13-78	Anderson Coal, CA
56N 073W 25CC 04	Test	133	173	Fort Union	Coal	4,142	78.0	07-13-78	Anderson Coal
56N 073W 27DDC01	Test	359	396	Fort Union	Coal	4,186	213.2	01-08-75	Canyon Coal, CA
56N 073W 29BDB01	Well	95	179	Fort Union	Sandstone and coal	-----	50.4	08-01-68	CA
56N 074W 04CB 01	Well	2,670	3,402	Lance and Fox Hills	Sandstone	4,092	--	--	CA

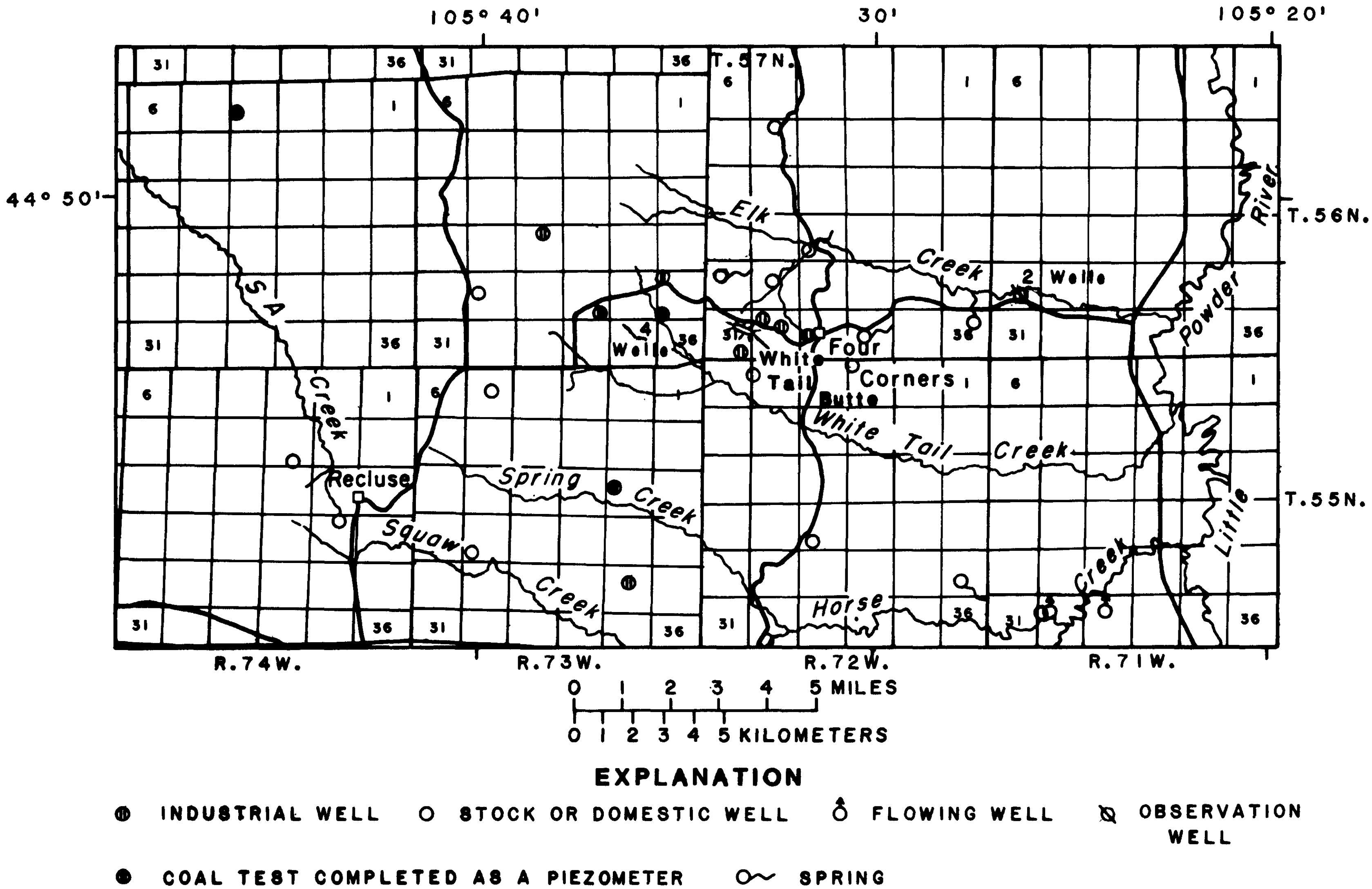


Figure 21.--Location of wells, springs, and test holes listed in table 7.

rocks in recharge areas is a calcium sulfate or calcium magnesium sulfate type, generally with a dissolved-solids concentration of 2,000 mg/L or more. Water moving through the aquifers undergoes cation exchange softening whereby sodium in the rocks is exchanged for calcium and magnesium in the water, and sulfate reduction whereby sulfate is reduced to form hydrogen sulfide with bicarbonate as a by product. This results in water distant from the recharge being a sodium bicarbonate type with a dissolved-solids concentration of about 1,000 mg/L. Riffenburg (1925) has described the chemical character of these waters in the northern Great Plains. The trilinear graph (fig. 22) shows that there is a definite distinction between the calcium and sodium types for water from wells in the area. There is a gradual transition from zones of high sulfate to zones in which the sulfate is reduced and bicarbonate is predominant.

Data collected from piezometers completed in the Canyon coal illustrate the relation expected from flow through the regional system and that resulting from local recharge. Graphs show that water levels in three of four piezometers completed in the Canyon coal (fig. 23) have little fluctuation, indicating the wells are far enough from the recharge area that fluctuation in water levels caused by variation in recharge is dampened. The water from the three wells is a sodium bicarbonate type (table 8), which also indicates recharge is distant from the wells.

The graph of the fourth well (56N 073W 25BBA01), however, does show a water-level fluctuation of more than 20 ft. This is attributed to local recharge conditions because there are no producing wells in the area. Water from this well is a sodium sulfate type, indicating that the distance the water has traveled in the aquifer was sufficient for ion exchange but not sufficient for sulfate reduction to be complete.

Although trace elements are found in coal and other minerals, only minor quantities are dissolved in the water (see table 9). Sulfate reduction is one mechanism limiting the trace elements, as metal sulfides are relatively insoluble at the pH of water in the area. The pH is maintained because, with cation-exchange softening, the water is undersaturated with respect to calcium carbonate, and further solution of the mineral increases the pH.

Movement

Because of the topographic relief the edges of individual aquifers in the Wasatch Formation and the Tongue River Member of the Fort Union Formation are exposed along the escarpment on the west side of the Little Powder River. However, aquifers below the Lebo Shale Member of the Fort Union do not crop out in the area, and boundary conditions are different for aquifers underlying and overlying the Lebo. Therefore, there is an upper and a lower ground-water system. The regional movement of water in the deeper aquifers is northward as shown in figure 24. Although not all wells used in the figure are completed in the same stratigraphic zone, completion in at least the lower part of the Lance or the Fox Hills or both is common. The map shown in figure 24 is in agreement with a map of the potentiometric surface in the Fox Hills-basal Hell Creek (Lance Formation) aquifer in Montana (W.R. Miller, U.S. Geological Survey, oral commun., 1978). Preliminary studies indicate that within the Tullock and older aquifers, the change from decreasing to increasing hydraulic head with depth occurs from south to north along the Little Powder River at about the latitude of Weston.

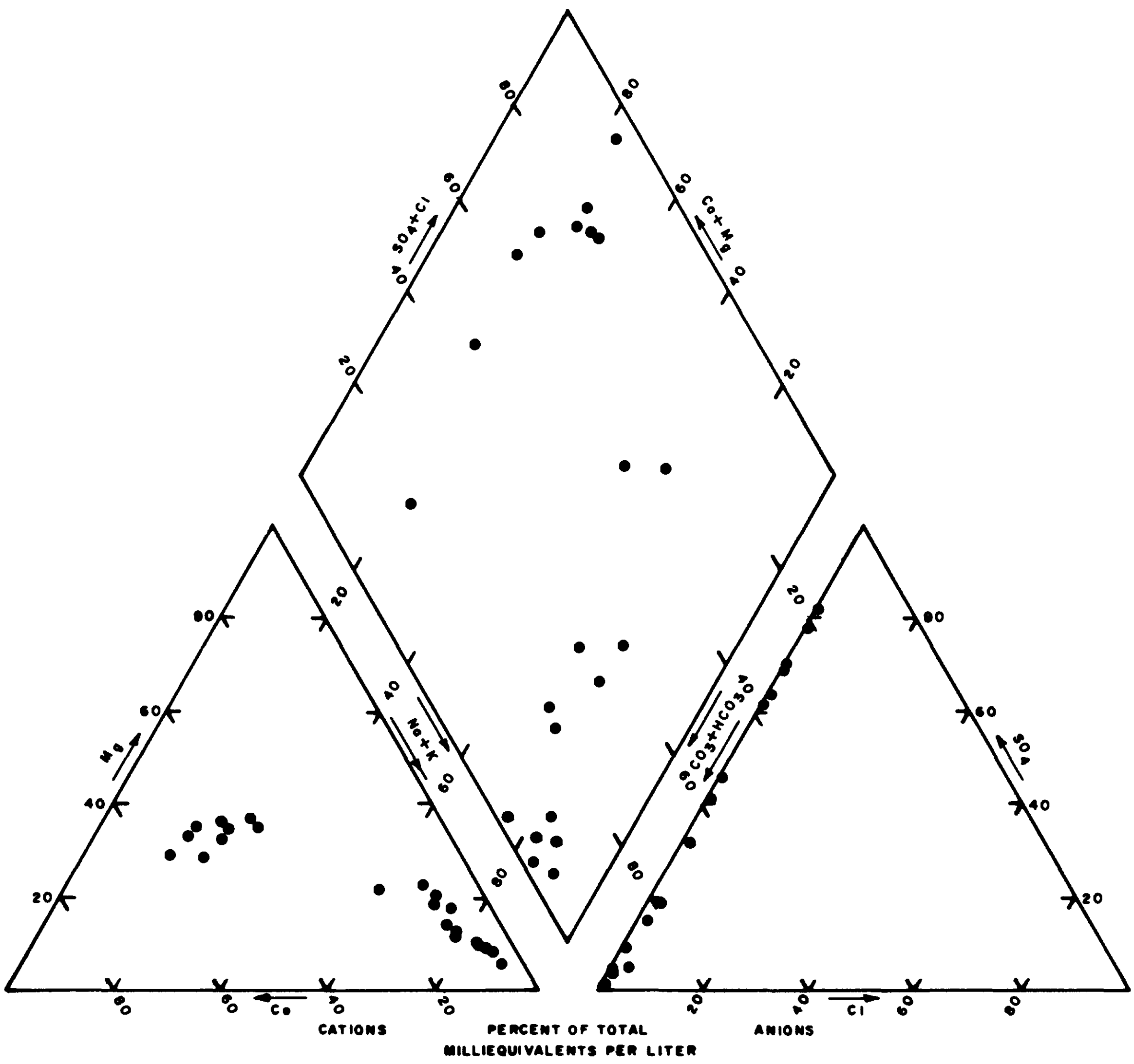


Figure 22.--Percentage of cations and anions in ground water.

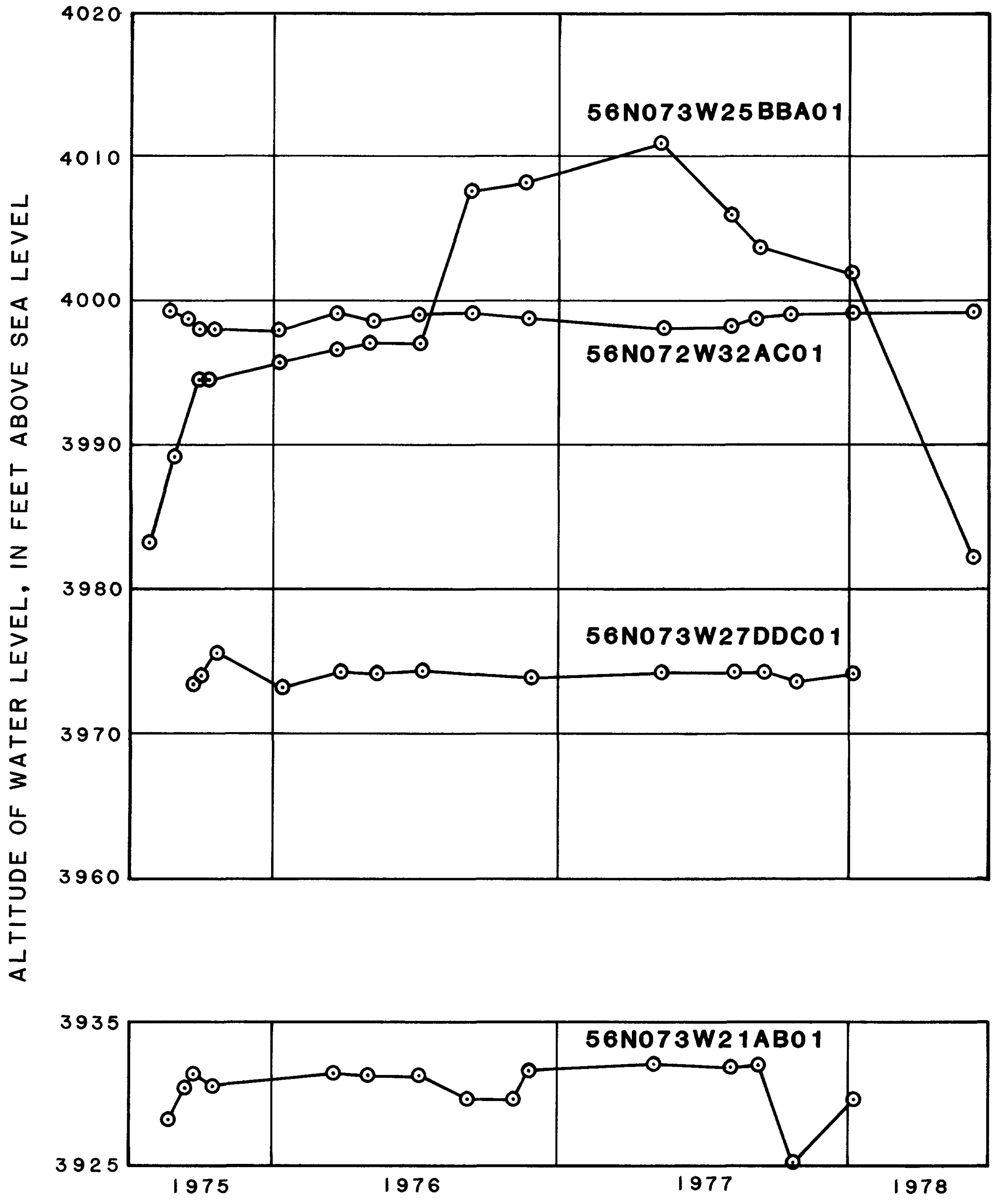


Figure 23.--Water-level fluctuations in piezometers completed in the Canyon coal bed in the Tongue River Member of the Fort Union Formation.

[Analytical results in milligrams per liter, except as indicated. Analyses by U.S. Geological

Local identifier	Date of sample	Specific conduct-ance (μS/cm at 25°C)	pH	Temper-ature (°C)	Hardness (as $CaCO_3$)	Noncar-bonate hardness (as $CaCO_3$)	Dis-solved calcium (Ca)	Dis-solved magne-sium (Mg)	Dis-solved sodium (Na)	Sodium adsorp-tion ratio
										Surface
Elk Creek near mouth near Weston	76-06-15	1,600	---	11.0	-----	-----	-----	-----	---	-----
	76-06-15	500	---	11.0	-----	-----	140	-----	---	-----
	76-10-25	1,700	---	12.0	-----	-----	200	100	200	-----
Elk Creek near Recluse----------	76-06-15	1,500	---	18.0	-----	-----	-----	-----	---	-----
Elk Creek tributary near Recluse	76-06-15	2,000	8.3	1.8	910	580	-----	-----	---	1.7
North Divide Draw near Recluse--	76-06-15	1,050	---	6.0	-----	-----	-----	-----	---	-----
	77-04-07	-----	---	11.5	-----	-----	-----	-----	---	-----
										Allu
55N 072W 32CDD01----------------	68-07-31	1,520	8.4	9.0	252	0	35	40	262	7.2
56N 071W 30DBB01----------------	77-10-19	2,750	7.0	10.0	1,200	890	280	120	160	2.0
56N 071W 30DBB02----------------	76-10-25	3,350	6.8	9.0	-----	-----	-----	-----	---	-----
	76-10-26	2,350	6.8	9.0	1,100	790	250	120	150	2.0
										Fort Union
55N 071W 32BC 01----------------	75-08-21	432	8.5	14.2	47	0	8.5	6.2	140	8.9
55N 072W 25CA 01----------------	75-08-21	217	7.7	15.2	140	0	36	12	14	.5
55N 073W 26 01----------------	77-10-19	1,850	7.4	14.0	260	0	49	34	360	9.7
56N 072W 19CDC01----------------	76-10-29	1,900	8.2	13.0	840	600	170	100	130	2.0
56N 072W 21CCC01----------------	76-10-30	530	7.8	9.0	280	100	68	26	19	.5
56N 072W 29ACC01----------------	76-10-30	2,350	7.4	6.0	1,200	1,100	260	130	140	1.8
56N 072W 30BAB01----------------	76-10-29	2,600	6.7	11.0	1,200	850	250	140	220	2.8
56N 072W 31DDA01----------------	76-10-25	1,325	7.1	9.5	160	0	33	19	260	8.9
56N 072W 32AC 01----------------	77-10-18	2,300	7.5	13.0	380	0	61	55	420	9.4
56N 072W 33BCD01----------------	77-10-18	2,000	7.8	13.0	290	0	42	46	390	9.9
56N 072W 34BD 01----------------	75-08-21	439	8.0	10.0	280	160	76	23	16	.4
56N 072W 36AB 01----------------	75-08-21	655	6.5	11.3	430	270	100	43	40	.8
56N 073W 21AB 01----------------	77-10-17	1,550	7.9	15.0	80	0	17	9.0	320	16
56N 073W 25BBA01----------------	77-10-18	3,100	7.6	15.0	520	48	73	83	480	9.1
56N 073W 25CC 01----------------	77-10-17	2,050	7.2	10.5	200	0	37	27	450	14
56N 073W 25CC 02----------------	76-10-26	2,210	7.6	10.0	330	0	62	42	520	13
56N 073W 25CC 03----------------	77-10-12	1,900	7.8	11.0	170	0	32	22	390	13
56N 073W 27DDC01----------------	77-10-17	1,950	7.5	13.0	170	0	31	23	440	15
56N 073W 29BDB01----------------	68-08-01	2,100	8.0	11.0	504	18	100	62	330	6.4
										Lance Formation and
56N 074W 04CB 01----------------	76-08-11	1,750	8.4	41.5	4	0	1.3	.1	450	102

analyses of water

Survey. Abbreviation: μS/cm at 25°C, microsiemens per centimeter at 25 degrees Celsius]

Dis-solved potas-sium (K)	Bicar-bonate (HCO_3)	Car-bonate (CO_3)	Dis-solved sul-fate (SO_4)	Dis-solved chlo-ride (Cl)	Dis-solved fluo-ride (F)	Dis-solved silica (SiO_2)	Dis-solved solids sum of constit-uents	Total nitrite plus nitrate (N)	Total ammo-nia nitro-gen (N)	Total ammonia plus organic nitrogen (N)	Total organic nitro-gen (N)	Total nitro-gen (N)	Total phos-phorus (P)	Dis-solved boron (B)
Water														
----	-----	---	700	5.2	0.6	19	-----	----	----	-----	-----	-----	----	-----
23	-----	---	550	1.8	.1	20	-----	----	----	-----	-----	-----	----	-----
27	400	0	290	6.8	.4	4.7	-----	----	----	-----	-----	-----	----	-----
----	-----	---	180	2.6	.6	8.2	-----	----	----	-----	-----	-----	----	-----
----	-----	---	860	5.2	.7	10	947	0.00	0.00	0.29	0.29	0.29	0.01	160
----	-----	---	540	6.1	.4	4.7	-----	----	----	-----	-----	-----	----	-----
----	-----	---	-----	----	---	----	-----	----	----	-----	-----	-----	----	-----
vium														
18	679	15	258	13	.9	15	992	----	----	-----	-----	-----	----	120
27	370	0	1,300	7.9	.6	30	2,110	.12	.10	1.1	1.0	1.2	2.5	500
----	-----	---	-----	----	---	----	-----	.45	.04	1.3	1.3	1.7	.41	-----
29	400	0	1,100	7.0	.7	29	1,890	----	----	-----	-----	-----	----	490
Formation														
4.2	415	0	16	8.8	1.5	9.2	399	.03	.36	.46	.10	.49	.01	80
8.6	177	0	24	2.6	.8	24	209	.36	.00	.08	.08	.44	.02	160
12	1,290	0	8.3	6.3	.7	8.7	1,120	.02	1.9	2.4	.50	2.4	.08	90
29	289	0	900	5.7	.4	17	1,500	2.0	.02	.58	.56	2.6	.05	1,200
14	208	4	140	2.5	.8	25	402	----	----	.22	-----	-----	----	360
27	106	0	1,400	4.4	.6	14	2,030	.01	.04	.28	.50	.29	.02	1,000
24	423	---	1,400	7.7	---	----	2,270	.72	.01	.90	.80	1.6	.15	440
10	542	0	290	7.5	.7	3.4	891	----	----	-----	-----	-----	----	-----
12	1,220	0	220	26	.7	6.3	1,400	.03	2.2	3.5	1.3	3.5	.11	80
13	1,090	0	200	10	.7	8.0	1,250	.01	1.8	4.6	2.8	4.6	.24	90
16	156	0	210	2.8	.8	21	443	.60	.00	.08	.0	.68	.00	530
6.3	191	0	350	2.6	.8	16	655	.03	.07	.19	.1	.22	.00	410
7.6	960	0	34	6.6	.5	4.6	862	.01	1.4	-----	.00	.05	.44	90
15	580	0	990	6.4	.2	1.7	1,940	.01	3.0	3.2	.20	3.2	.06	100
8.2	1,410	0	48	5.0	1.0	8.0	1,280	.01	1.7	3.6	1.9	3.6	.36	90
11	1,250	0	480	5.4	.5	6.3	1,740	----	----	-----	-----	-----	----	-----
8.3	1,160	0	87	6.6	.9	7.8	1,130	.00	1.4	31	30	31	6.3	80
9.6	1,340	0	6.9	7.0	.6	7.9	1,190	.01	1.6	7.6	6.0	7.6	.99	100
8.0	592	0	724	6.3	.4	11	1,540	----	----	-----	-----	-----	----	80
Fox Hills Sandstone														
2.1	1,120	240	24	41	6.5	17	1,330	.15	1.1	.70	.00	.85	.02	380

Table 9.--*Trace-element*

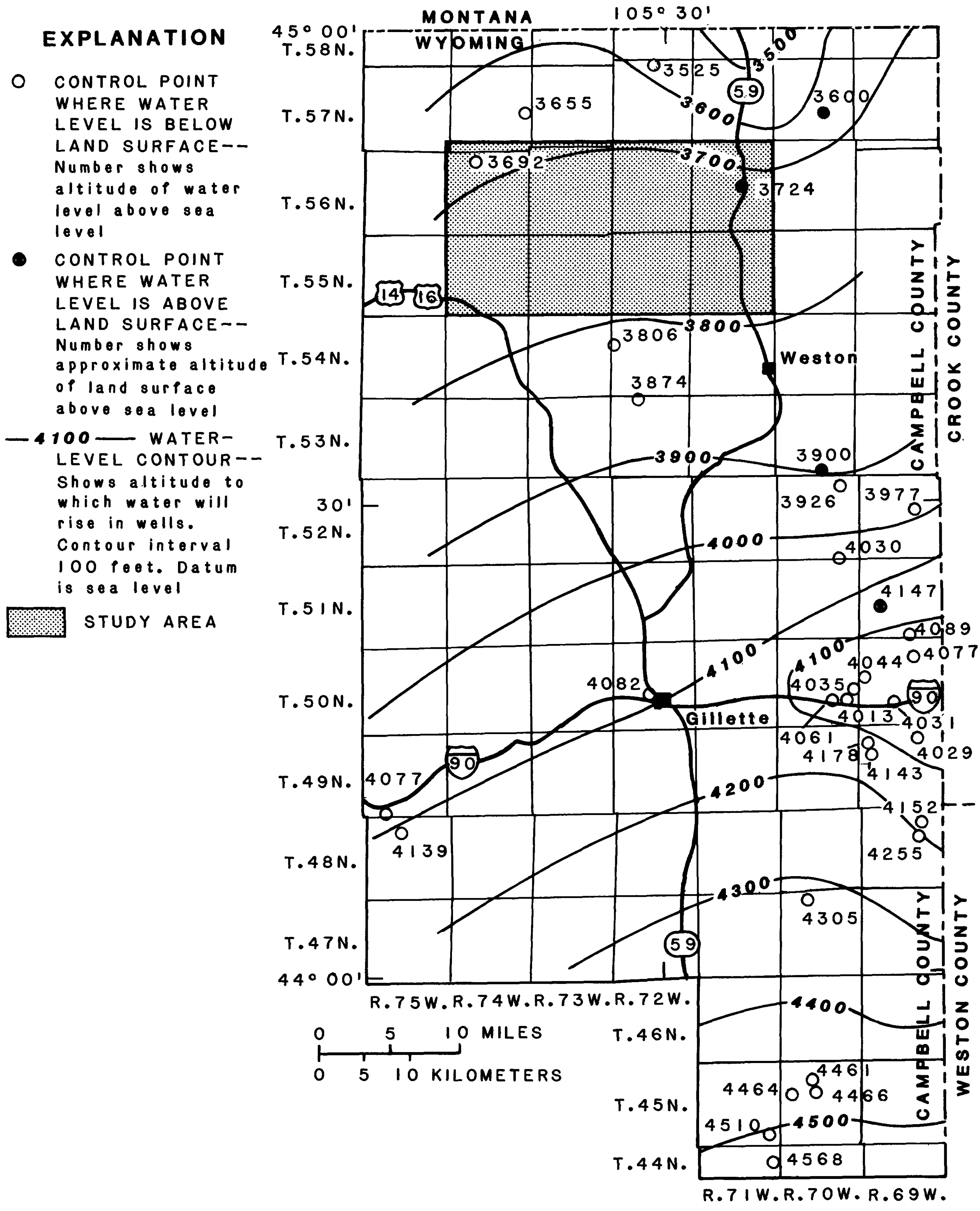
[Analytical results in micrograms per liter

Local identifier	Date of sample	Total recov- erable alu- minum (Al)	Dis- solved alu- minum (Al)	Total arsenic (As)	Total recov- erable barium (Ba)	Total recov- erable beryl- lium (Be)	Dis- solved beryl- lium (Be)	Total recov- erable cad- mium (Cd)	Dis- solved cad- mium (Cd)	Total recov- erable chro- mium (Cr)	Dis- solved chro- mium (Cr)	Total recov- erable cobalt (Co)	Total recov- erable copper (Cu)	Dis- solved copper (Cu)
														Surface
Elk Creek near mouth near Weston	76-06-15	-------	---	---	---	--	--	---	--	---	--	---	---	--
Elk Creek near mouth near Weston	76-10-25	70	10	1	---	10	0	<10	1	0	0	---	<10	1
Elk Creek near Recluse----------	76-06-15	-------	---	---	---	--	--	---	--	---	--	---	---	--
Elk Creek tributary near Recluse	76-06-15	-------	---	---	---	--	--	---	--	---	--	---	---	--
North Divide draw near Recluse--	76-06-15	-------	---	---	---	--	--	---	--	---	--	---	---	--
														Allu
56N 071W 30DBB01----------------	77-10-19	90	30	66	---	0	0	10	1	620	10	---	190	0
56N 071W 30DBB02----------------	76-10-26	47,000	10	1	---	10	0	10	1	80	0	---	160	1
													Fort Union	
55N 071W 32BC 01----------------	75-08-21	-------	---	---	---	--	--	--	--	---	--	---	---	--
55N 072W 25CA 01----------------	75-08-21	-------	---	---	---	--	--	--	--	---	--	---	---	--
55N 073W 26 01----------------	77-10-19	6,600	20	10	---	0	20	10	1	20	0	---	30	0
56N 072W 19CDC01----------------	76-10-29	-------	---	---	---	--	--	--	--	---	--	---	---	--
56N 072W 21CCC01----------------	76-10-30	-------	---	---	---	--	--	--	--	---	--	---	---	--
56N 072W 29ACC01----------------	76-10-30	-------	---	---	---	--	--	--	--	---	--	---	---	--
56N 027W 30BAB01----------------	76-10-29	-------	---	---	---	--	--	--	--	---	--	---	---	--
56N 072W 31DDA01----------------	76-10-25	90	---	9	200	0	--	<10	--	0	--	<50	20	--
56N 072W 32AC 01----------------	77-10-18	3,400	20	2	---	0	20	10	3	40	10	---	90	1
56N 072W 33BCD01----------------	77-10-18	25,000	10	60	---	0	0	10	2	180	10	---	350	0
56N 072W 34BD 01----------------	75-08-21	-------	---	---	---	--	--	--	--	---	--	---	---	--
56N 072W 36AB 01----------------	75-08-21	-------	---	---	---	--	--	--	--	---	--	---	---	--
56N 073W 21AB 01----------------	77-10-17	47,000	20	140	---	0	10	10	6	120	10	---	420	14
56N 073W 25BBA01----------------	77-10-18	3,800	10	5	---	0	0	<10	0	30	20	---	40	0
56N 073W 25CC 01----------------	77-10-17	12,000	60	45	---	10	0	10	9	60	20	---	80	2
56N 073W 25CC 02----------------	76-10-26	91,000	50	3	---	20	0	20	1	210	0	---	370	1
56N 073W 25CC 03----------------	77-10-12	140,000	140	290	---	0	20	30	17	270	10	---	460	2
56N 073W 27DDC01----------------	77-10-17	49,000	20	120	---	10	0	10	7	90	10	---	230	1
												Lance Formation and		
56N 074W 04CB 01----------------	76-08-11	-------	20	0	---	--	0	--	3	---	0	---	---	1

analyses of water

(μg/L). Analyses by U.S. Geological Survey]

Total recoverable iron (Fe)	Dissolved iron (Fe)	Total recoverable lead (Pb)	Dissolved lead (Pb)	Total recoverable lithium (Li)	Dissolved lithium (Li)	Total recoverable manganese (Mn)	Dissolved manganese (Mn)	Total recoverable mercury (Hg)	Dissolved mercury (Hg)	Total recoverable molybdenum (Mo)	Dissolved molybdenum (Mo)	Total recoverable nickel (Ni)	Dissolved nickel (Ni)	Total selenium (Se)	Dissolved selenium (Se)	Dissolved vanadium (V)	Total recoverable zinc (Zn)	Dissolved zinc (Zn)
water																		
310	-----	---	--	---	---	-----	-----	---	---	--	--	---	--	--	--	---	------	---
110	20	100	6	100	100	10	10	0.0	0.0	0	1	<50	2	0	0	0.1	20	20
1,700	-----	---	--	---	---	-----	-----	---	---	--	--	---	--	--	--	---	------	---
730	80	---	--	---	---	-----	-----	---	---	--	--	---	--	--	--	---	------	---
1,200	-----	---	--	---	---	-----	-----	---	---	--	--	---	--	--	--	---	------	---
vium																		
-------	120	400	3	230	130	2,600	300	.4	.0	35	8	150	2	6	0	2.0	430	10
110,000	10	200	1	200	120	3,000	2,000	.1	.0	3	4	100	4	7	1	.0	590	230
Formation																		
-------	120	---	--	---	---	-----	-----	---	---	--	--	---	--	--	--	---	------	---
-------	50	---	--	---	---	-----	-----	---	---	--	--	---	--	--	--	---	------	---
37,000	20	100	6	80	70	180	40	.0	.0	7	1	<50	10	0	0	1.3	100	0
-------	30	---	--	---	---	-----	-----	---	---	--	--	---	--	--	--	---	------	---
-------	20	---	--	---	---	-----	-----	---	---	--	--	---	--	--	--	---	------	---
-------	80	---	--	---	---	-----	-----	---	---	--	--	---	--	--	--	---	------	---
-------	2,900	---	--	---	---	-----	-----	---	---	--	--	---	--	--	--	---	------	---
53,000	60	100	--	50	---	460	-----	.0	---	3	--	<50	--	0	--	---	10,000	---
190,000	320	200	39	60	50	740	80	.0	.0	6	2	50	8	0	0	.0	140	10
370,000	50	200	10	80	60	2,700	70	2.1	.0	19	5	150	5	2	0	.0	400	0
-------	40	---	--	---	---	-----	-----	---	---	--	--	---	--	--	--	---	------	---
-------	1,900	---	--	---	---	-----	-----	---	---	--	--	---	--	--	--	---	------	---
300,000	210	300	72	100	40	2,800	20	.6	.0	11	4	300	5	4	0	1.9	800	0
190,000	60	100	3	110	90	940	180	.0	.0	11	3	50	1	0	0	.0	110	10
160,000	170	100	92	70	50	350	50	.0	.0	8	0	50	2	2	0	.3	220	10
250,000	40	600	2	220	80	7,800	40	1.1	.0	0	0	150	2	2	0	1.8	3,100	170
340,000	110	500	70	230	40	8,200	10	1.0	.0	7	0	150	0	8	0	3.1	2,100	10
250,000	60	300	63	140	50	1,300	50	.4	.0	11	1	150	1	5	0	.7	1,900	10
Fox Hills Sandstone																		
-------	40	---	4	---	20	-----	10	---	.2	--	1	---	0	0	0	.0	------	10



Hydrology from U.S. Department of the Interior, 1979.

Figure 24.--Water levels in wells completed in one or more aquifers in the Fox Hills Sandstone, Lance Formation, and lower part of the Fort Union Formation in the Gillette area.

Data to describe regional flow in zones overlying the Lebo Shale Member are available only for the Wyodak coal in the Tongue River Member from the eastern outcrop of the Wyodak westward to the area where the coal is about 500 ft deep. The potentiometric surface in the Wyodak in central and southern Campbell County (fig. 25), compiled principally from data collected by mining interests, shows water levels when only the Wyodak Mine east of Gillette was operating. The map shows that although there is a very flat gradient in the southern part of Campbell County, recharge apparently occurs at the outcrop of the coal as far north as T. 46 N., and that the coal outcrop north of T. 49 N. is a discharge area.

The White Tail Butte area also is a discharge point for the coal-bed equivalents to the Wyodak and other beds above the Lebo Shale Member, because the potentiometric surface in piezometers generally is higher than nearby outcrops of the stratigraphic zones in which the piezometers are completed.

The decreasing hydraulic head with depth that occurs in aquifers overlying the Lebo Shale Member is consistent with a discharge area in this particular setting. The hydraulic-head differences are the result of the little vertical permeability caused by the large thickness of shale in the section and the different zones discharging at different base levels along the escarpment bordering the Little Powder River.

The relation between water levels in piezometers completed in the Canyon coal of the Tongue River Member and the outcrop of the coal is shown in figure 26. The water levels are the lowest measured. Water levels in some wells in the area are known to be affected by the discharge of coal gas; however, preliminary results of studies in the area to determine the effect of gas on water levels show it is not significant.

Vertical movement may not be the major source of recharge to the regional flow in the Wyodak and equivalent coals a short distance basinward of the outcrop in southern Campbell County. However, if horizontal flow predominates where the beds are relatively deep, the volume of water moving through this part of the system must be small relative to that in the outcrop where local recharge occurs. Water samples collected from natural discharge points and from the alluvium in the White Tail Butte area were of chemical types that occur near recharge areas rather than the sodium bicarbonate type that occurs distant from recharge areas.

Impacts of Mining

The long-term impacts of mining will depend on the method of resource recovery and the reclamation practices. Although any known method of coal-resource recovery is possible, it is assumed for the purpose of discussion that there will be a multiple-stripping operation beginning at the edge of the coal and that the land will be reclaimed for grazing by methods described in other mine plans for eastern Campbell County in 1982.

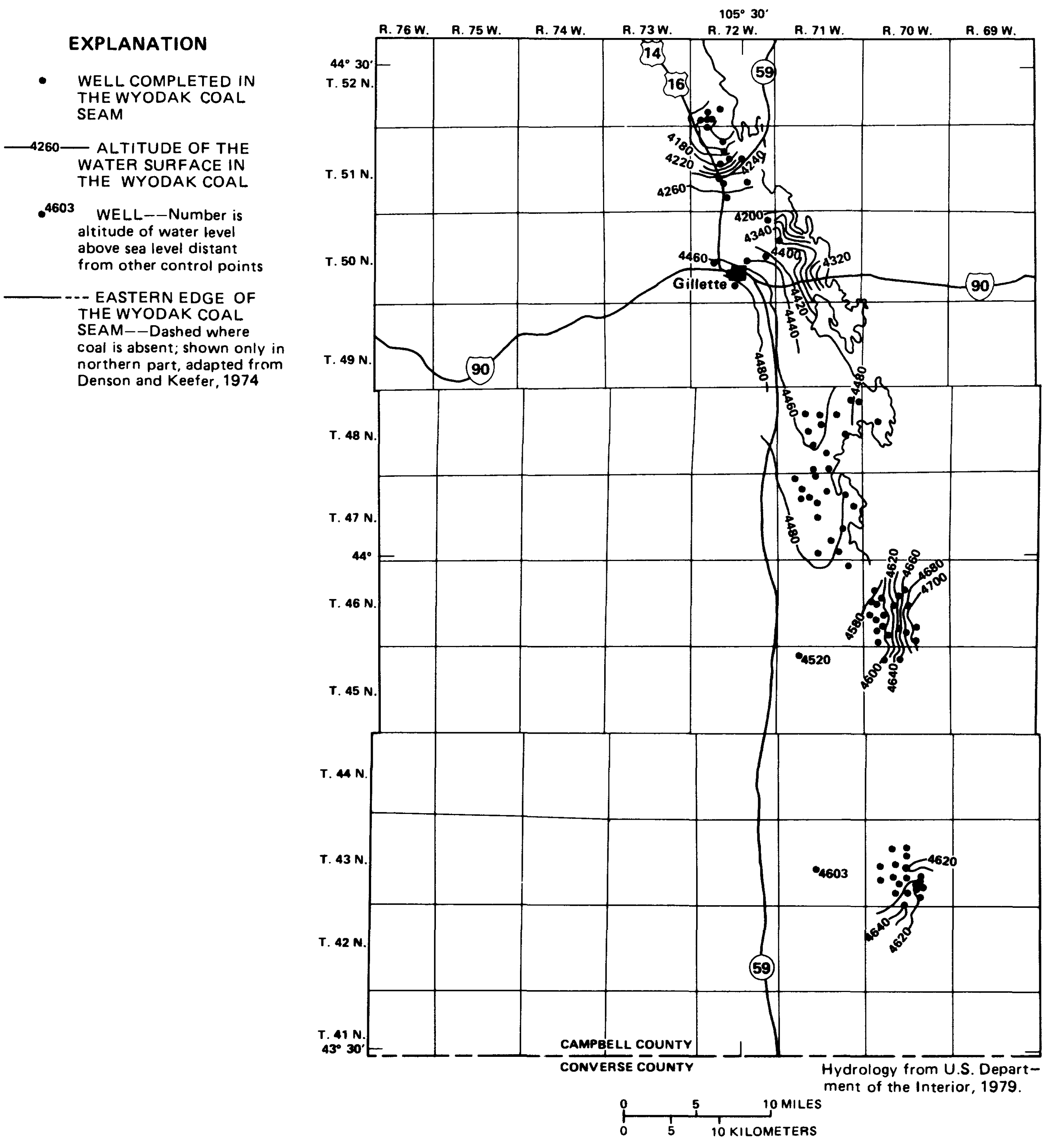


Figure 25.--Water surface in the Wyodak coal bed in the Tongue River Member of the Fort Union Formation in central and southern Campbell County.

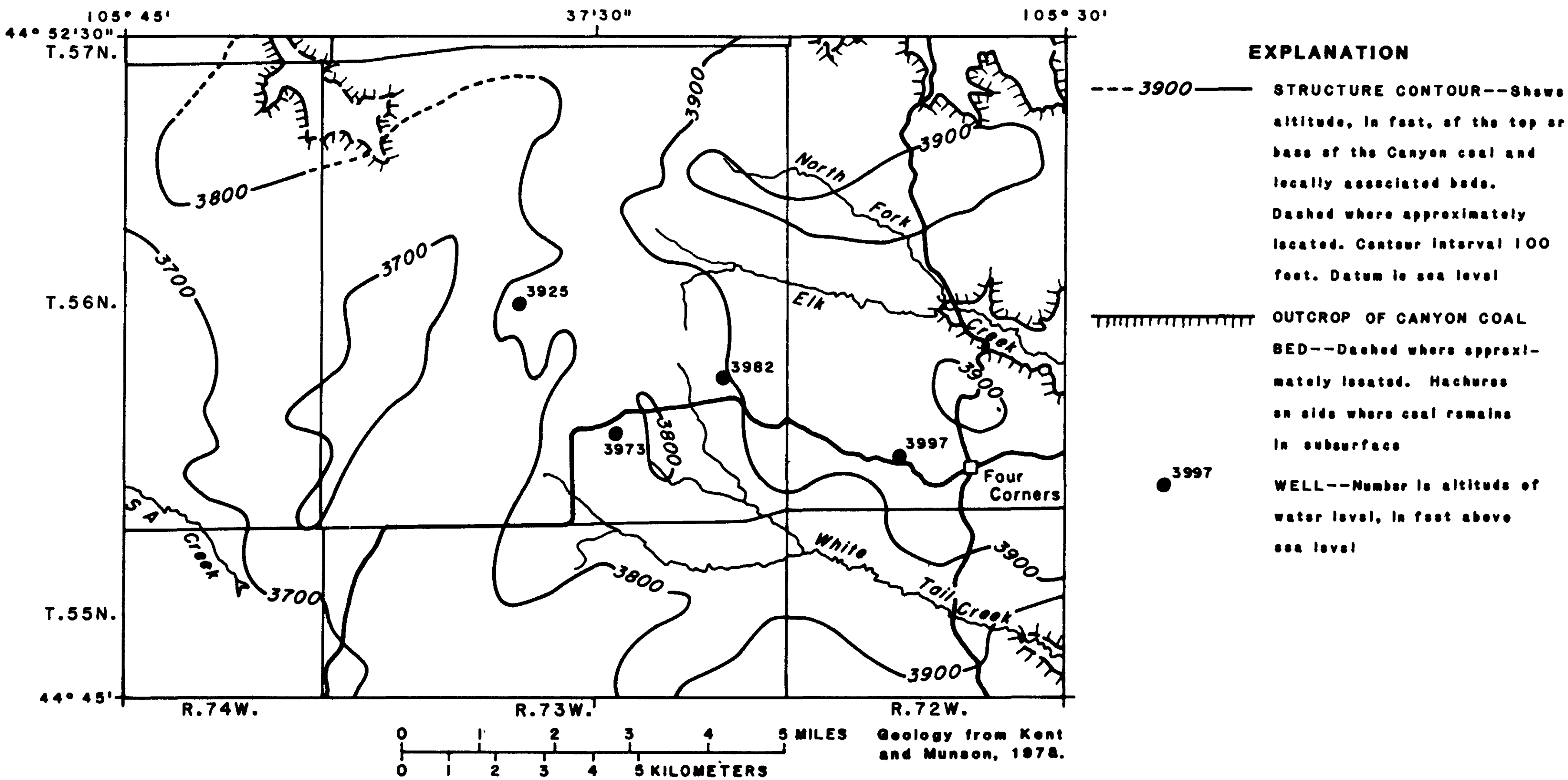


Figure 26.--Relationship of water levels in wells completed in the Canyon coal bed in the Tongue River Member of the Fort Union Formation to the coal.

The coal will be removed, and aquifers that occur above the coal will be destroyed. During reclamation, these aquifers will be replaced by spoil. Where the overburden-coal ratio is such that the increase in volume of the spoil above that of the undisturbed overburden permits restoration of the original land surface, water levels in at least the deeper aquifers adjacent to those destroyed by mining may not be affected. More likely, there will be an effective retreat of the escarpment where the coals crop out, and water levels in the lateral equivalents to the destroyed beds will adjust to a new boundary. The quality of water in the lateral equivalents of the disturbed aquifers and the deeper aquifers will not be affected because the direction of flow will be unchanged.

Soil permeability probably will be decreased as the result of mixing clay with the soil or soil material. However, moisture-retaining measures, such as pitting and contour furrowing that are part of most reclamation plans, will increase infiltration. This may cause a net increase in infiltration at most existing mines in Campbell County. However, infiltration in the White Tail Butte area may be decreased if the area of exposed clinker is decreased.

The spoil will not have the relatively continuous, almost impermeable shale layers of the original deposits; therefore, water will move vertically with greater ease, and springs and seeps will not occur on hillsides in reclaimed areas. Water from local recharge and regional movement will be discharged at topographic lows, probably at the present drainages. The water-bearing properties of the spoil from coarse-grained overburden may be equivalent to those aquifers it replaces (Rahn 1976, p. 54).

AVAILABILITY OF WATER FOR RECLAMATION AND POSTRECLAMATION USE

Surface Water

At present there are stock ponds on small draws and some flood irrigation along the major drainages. The availability of water for future use, as the availability is changed by mining, cannot be estimated.

Ground Water

Water of suitable quality for irrigation, such as that which occurs in alluvium, clinker, and sometimes at shallow depth in bedrock, is not available in adequate quantities in the area. Water in deep aquifers, where supplies adequate for supplementary irrigation can be obtained, has a large sodium-adsorption ratio and therefore has restricted use.

The quantity and quality of water in aquifers that are lateral equivalents of those disturbed will not be greatly affected by mining, and deeper aquifers will not be affected. It may not be necessary to drill deep wells in the mined area to replace the springs that will be destroyed. A mine will undoubtedly drill a deep well for a potable supply, and this well can perhaps be used to supply stock water after mining is completed. In some areas in Wyoming where it is necessary to drill deep wells to obtain suitable stock and domestic supplies, one well is sometimes drilled and the water distributed by pipeline rather than drilling a number of deep, expensive wells. A similar technique could be used in the reclaimed areas.

Such a distribution system, although it would fill the need for stock water, would require maintenance. If the cost-benefit ratio is favorable, or it is desired to restore springs in the uplands, clinker could be stockpiled separately and replaced on impermeable membranes in predesigned catchment areas to restore the shallow, perched aquifers. Techniques for use of the membranes are currently (1982) being investigated for protection of the water table below land fills, and the reverse application would be equally valid.

SUMMARY

Two small basins, North Divide Draw and Elk Creek tributary, were used to study surface-water hydrology of the White Tail Butte area. The two basins are similar in size and topography but different in the distribution and areal extent of exposed clinker.

Total annual runoff from North Divide Draw was 61.0 acre-ft and from Elk Creek tributary it was 19.2 acre-ft. Snowmelt runoff, from a snowpack which contained an estimated 240 acre-ft of water, produced about 5 percent of the annual runoff from North Dvide Draw. The remainder of runoff was produced by intense convective storms.

Rainfall-runoff models were calibrated for the two basins using rainfall and runoff data collected during the summers of 1976 and 1977. Model parameters defined by the calibration process were used with long-term precipitation and evaporation records to simulate 73 years of peak discharge and volume data. The long-term data, collected at Cheyenne, were adjusted to represent the climate of the White Tail Butte area.

Log-Pearson Type III probability distribution was applied to the 73 years of simulated data to define the runoff-frequency curves for the two basins. Results of the study show that an increase in area of exposed clinker decreases runoff.

The runoff characteristics estimated by the use of the rainfall-runoff model for North Divide Draw is 19 to 33 percent greater than that estimated from equations based on basin characteristics. Runoff estimated for Elk Creek tributary is 80 to 88 percent less.

Impacts of surface mining on runoff could not be evaluated, but sensitivity of runoff to infiltration was investigated. The study shows that for a 1-percent change in infiltration, runoff changes inversely by about 10 percent.

Work in Campbell County has resulted in a description of ground-water movement in the aquifers more than 1,000 ft deep and for movement in the Wyodak coal in the Tongue River Member of the Fort Union Formation. Movement in the deeper aquifers is northward in the northern part of Campbell County, as determined from a potentiometric map of deep wells open to one or more of the Tullock Member of the Fort Union Formation, the Lance Formation, and the Fox Hills Sandstone. It is not definitely known if the water levels in the deep wells represent the same potentiometric surface, but the contours agree with a potentiometric map for the Fox Hills-Hell Creek (= Lance Formation) aquifer to the north in Montana.

The potentiometric surface in the Wyodak coal, which is equivalent to the Anderson and Canyon coals in the Tongue River Member of the White Tail Butte area, indicates there is recharge at the coal outcrop from the southern part of Campbell County as far north as T. 46 N. and that discharge is from the coal outcrop near Gillette. The water levels in piezometers completed in the Anderson and Canyon coals in the White Tail Butte area are higher than nearby outcrops of the coals, indicating that water is discharging from the coal outcrop.

Although the White Tail Butte area seems to be a discharge point for part of the regional flow, the volume of water being discharged from the regional system in the area is small compared with water moving locally through the system. Water of a sodium bicarbonate type with dissolved-solids concentration of about 1,000 mg/L generally occurs in the aquifers where water has moved through them for distances of a few miles. However, neither the water sampled from springs nor that sampled from alluvium contained this combination of bicarbonate and dissolved solids. This implies that the water from these sources had not moved a great distance through the bedrock aquifers.

If surface mining occurs, hillside springs and seeps will be destroyed in the mined area and will not be restored unless special reclamation procedures are used. However, aquifers occur below the coal so there is enough water of suitable quality to reclaim the land for livestock grazing, which is the present land use.

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