A CONCEPT OF THE SHALLOW GROUND-WATER SYSTEM ALONG THE NORTH PLATTE RIVER, SOUTH-CENTRAL WYOMING

By Marvin A. Crist

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 89-4078

Prepared in cooperation with the

WYOMING STATE ENGINEER

Cheyenne, Wyoming

1990

DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, JR., Secretary

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information contact:

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

Copies of this report can be purchased from:

U.S. Geological Survey
Books and Open-File Reports Section
Federal Center, Bldg. 810
Box 25425
Denver, Colorado 80225

CONTENTS

PLATES

FIGURES

FIGURES--Continued

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
foot	0.3048	meter
inch	25.4	millimeter
mile	1.609	kilometer
acre	4,047	square meter
square mile	2.590	square kilometer
acre-foot	1,233	cubic meter
cubic foot per second	0.02832	cubic meter per second
foot per day	0.3048	meter per day
foot per mile	0.1894	meter per kilometer
foot squared per day (units simplified from cubic foot per day per foot)	0.09290	meter squared per day
inch per year	25.4	millimeter per year

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

A CONCEPT OF THE SHALLOW GROUND-WATER SYSTEM ALONG THE NORTH PLATTE RIVER, SOUTH-CENTRAL WYOMING

By Marvin A. Crist

ABSTRACT

Irrigation along the North Platte River began as early as 1875. Streams are the principal source of irrigation water; however, ground water is used to supplement surface-water irrigation supplies.

During 1980 and 1981, water administrators were concerned that ground-water pumpage may have caused about 16 feet of water-level decline in an observation well. It was concluded in this study that leakage or lack of leakage to ground water from surface-water irrigation probably affects ground-water levels much more than pumpage.

This study includes a quantitative assessment of the ground-water system for an area of about 410 square miles along both sides of the North Platte River. Inflow to ground water in the study area was estimated to average 15 cubic feet per second from precipitation, 36 cubic feet per second from leakage of streams and surface-water irrigation, and 39 cubic feet per second of ground-water flow from outside the study area. Ground-water outflow from the study area was estimated to average 90 cubic feet per second assuming steady-state conditions.

An attempt to construct a ground-water-flow model for the study area indicated that more data are required. These data include measurement of inflow and outflow of streams, measurement of the distribution of stream diversions for irrigation, and seepage measurements on streams throughout the season. Additional test-hole drilling would provide data on water levels where no data are available and on saturated thickness of alluvium in the stream valleys. Analysis of test-hole data may provide a better estimate of hydraulic conductivity of the aquifers.

INTRODUCTION

This study was done in cooperation with the Wyoming State Engineer in an area of about 410 square miles along both sides of the North Platte River in southern Carbon County (fig. 1). The river valley is between the Medicine Bow Mountains, about 25 miles east of Saratoga, Wyo., and the Sierra Madre range on the south and west. Many small streams originate in the mountains and are tributary to the North Platte River in the valley.

The principal source of irrigation water is streamflow; ground water is a supplemental source. The first streamflow diversions probably occurred as early as 1875 when irrigation began in the valley (Visher, 1952, p. 6). The advent of sprinklers enabled irrigation of additional land that previously was

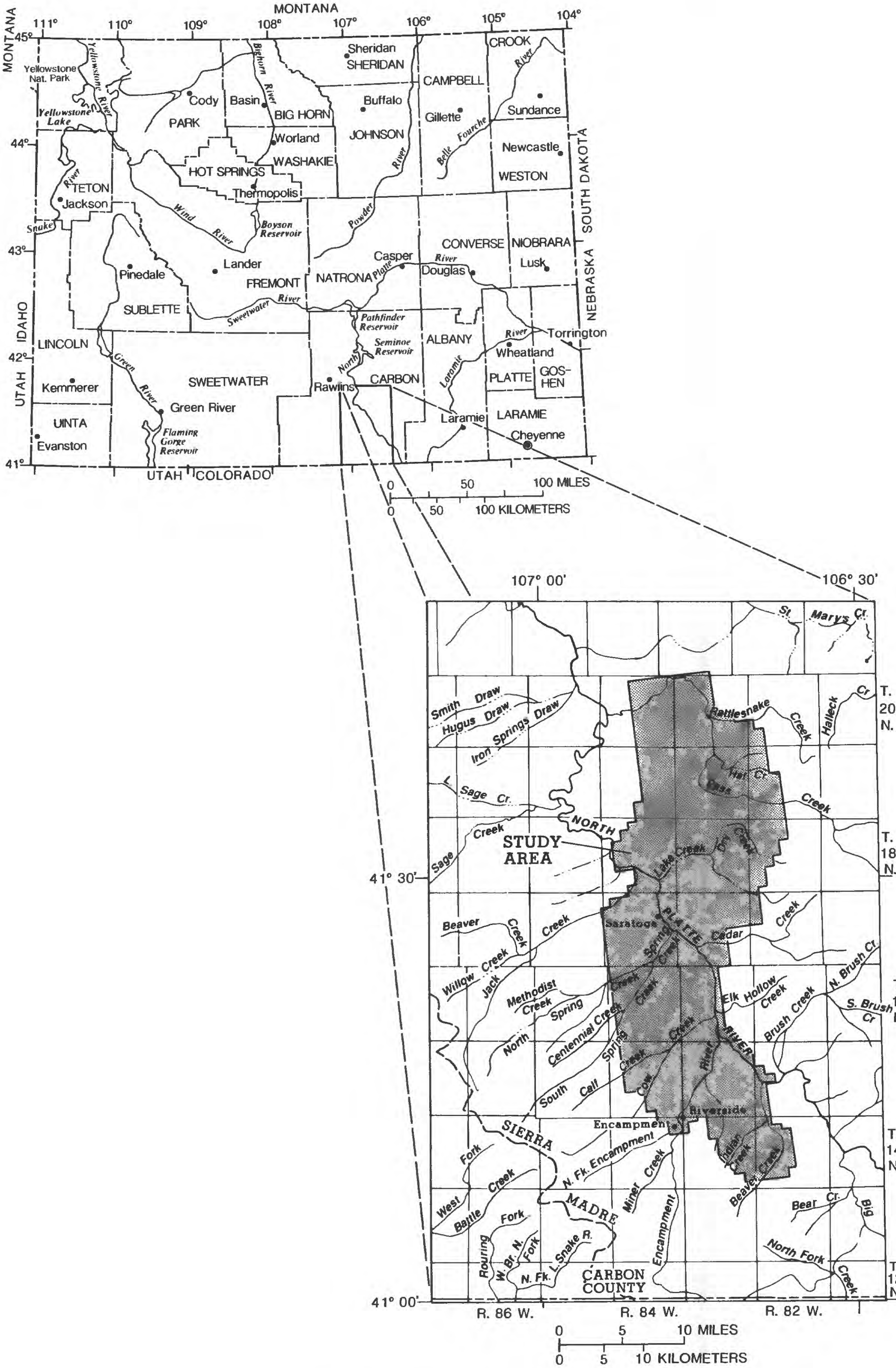

Figure 1.--Location of the study area.

not irrigated. Some of this land is now irrigated with ground water. Return flow from the irrigation moves to the nearest stream and eventually leaves the valley by way of the North Platte River.

Water administrators were concerned that ground-water development may adversely affect water levels in the Tertiary and Quaternary formations and the ground-water discharge to streams. Administrator's concerns were prompted by a hydrograph indicating 16 feet of water-level decline between July 1980 and December 1981 in an observation well completed in Tertiary rocks near Spring Creek (Lenfest, 1986, p. 12). Most of the irrigation wells are completed in the Tertiary formations; as of 1983, about 39 wells have been drilled in the study area to provide irrigation water to supplement surface-water irrigation supplies.

Purpose and Scope

The purpose of this report is to describe the concept of operation of the hydrologic system, and to describe the effect of ground-water development on ground-water levels. The report includes a quantitative assessment of ground-water movement within boundaries defined for the hydrologic system. A network of observation wells established by Lenfest (1986) was used to determine water-level changes in the aquifers. A ground-water budget was prepared. Inflow to ground water was estimated from precipitation, leakage from streams and surface-water irrigation, and water flowing into the study area through the subsurface. Outflow of ground water was estimated from pumpage by irrigation wells, streamflow gains between measurement sites, and water flowing out of the study area through the subsurface. A ground-water-flow model was used to test the quantitative movement of ground water in the study area. However, there were insufficient data for the model to be calibrated or verified.

Numbering System for Data-Collection Sites

Wells cited in this report are numbered by a method based on the U.S. Bureau of Land Management system of land subdivision in Wyoming (fig. 2). The first number indicates the township, the second the range, and the third the section in which the well is located. Lowercase letters following the section number indicate the location of the well in the section. The first letter denotes the quarter section, the second letter the quarter-quarter section, and the third letter 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. If more than one well is listed in a 10-acre tract, consecutive numbers starting with 1 follow the lowercase letters of the well number. If a section does not measure 1-mile square, it is treated as a full section with the southeast section corner serving as the reference point for the subdivision of the section.

This numbering system is a convenient method to identify other site locations. This method also is used to locate sites where streams were measured during this investigation.

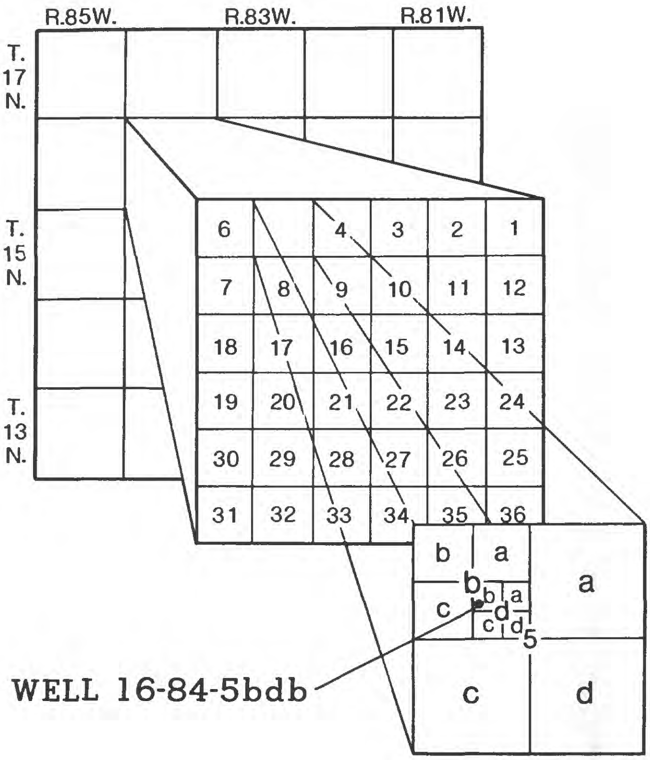

Figure 2.--Numbering system for data-collection sites.

Acknowledgments

The author thanks the residents in the area who permitted U.S. Geological Survey personnel to measure water levels in wells, and who permitted installation of digital water-level recorders. Carbon Power and Light Incorporated provided power records of irrigation wells.

SURFACE-WATER SYSTEM

The surface-water system is composed of the North Platte River and its nine principal tributaries: Beaver Creek, Encampment River, Cow Creek, Elk Hollow Creek, Cedar Creek, Spring Creek, Lake Creek, Jack Creek, and Pass Creek (fig. 3). The only part of the surface water considered in this study is that part of the streamflow that leaks into the ground-water system or that part of the streamflow that is derived from ground-water discharge.

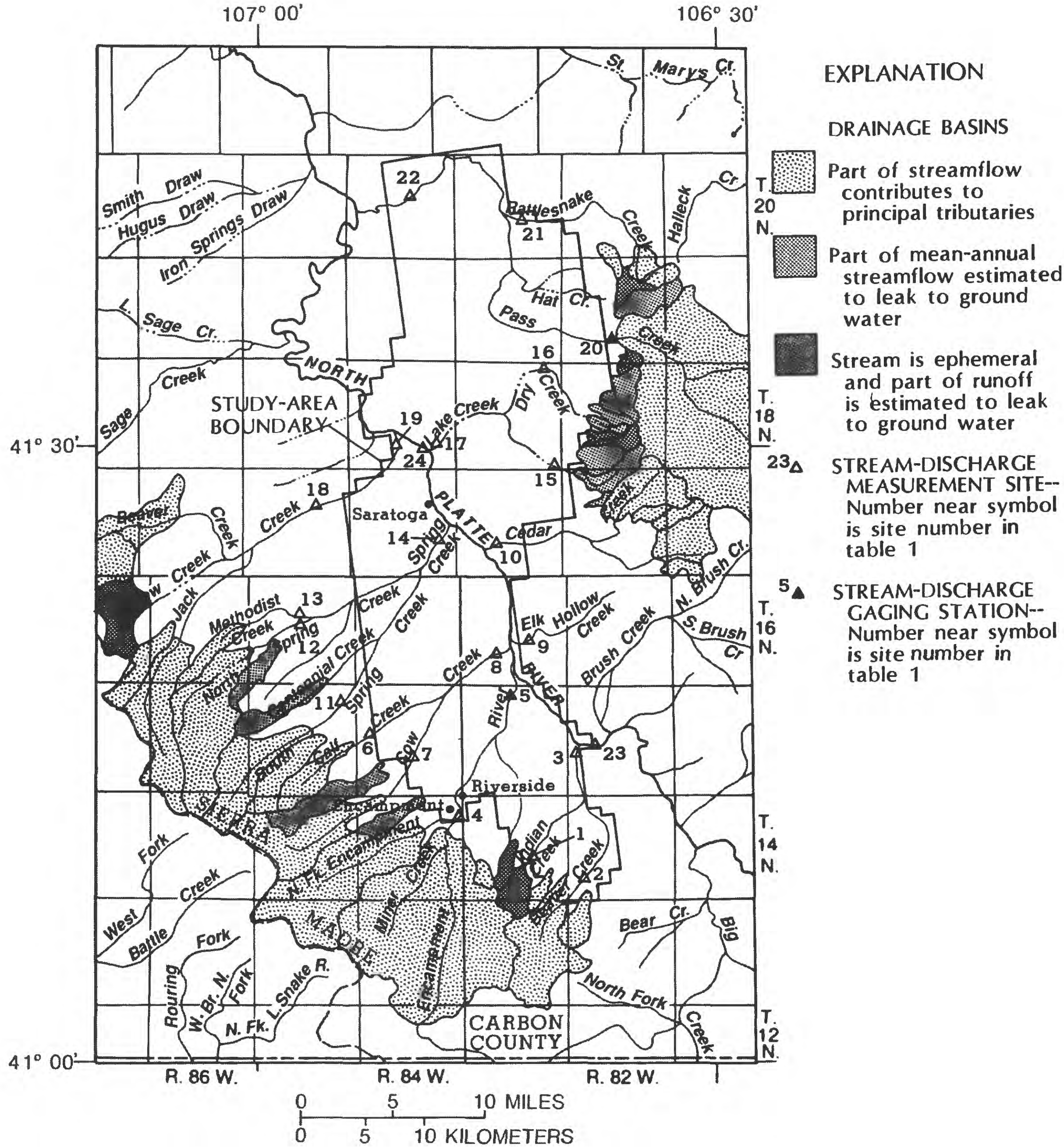

Figure 3.--Principal tributaries to the North Platte River in the study area, drainage basins outside the study area, and stream-discharge measurement sites.

A total of 52 drainage basins outside the study area were estimated to contribute water to the study area (fig. 3). Water from 27 of these basins was assumed to enter the study area as streamflow that contributes to the streamflow in the nine principal tributaries to the North Platte River within the study area. Streamflow gains and losses in the nine tributaries were estimated from one set of discharge measurements obtained during low flow in October 1981. The differences between stream-discharge measurements at adjacent sites, along each of the principal tributaries, were used to estimate the rate of ground-water discharge to streams or leakage from the streams to aquifers within the study area.

Streamflow from 13 of the 52 drainage basins was assumed to leak into the ground-water system. Perennial flow in the streams from these 13 basins disappears before reaching any of the principal tributary streams, and it was assumed that the surface water infiltrates to the ground water. Leakage to ground water from streams in the 13 basins was estimated as a percentage of the mean-annual stream discharge from each basin.

The mean-annual stream discharge from the 13 basins was calculated using the basin characteristics method described by Lowham (1976, p. 23) for perennial streams in mountainous areas. The regression equation used is:

$$Q_a = 0.0036\ A^{0.96} E^{2.57} \quad ,$$

where Q_a = the mean-annual flow, in cubic feet per second;

A = the drainage area, in square miles; and

E = the mean basin altitude, in thousands of feet above sea level.

The remaining 12 drainage basins contribute water to the study area as runoff from precipitation. The rate of leakage to ground water from the runoff was estimated as a percentage of the estimated mean-annual precipitation on the basin. Results of the stream-discharge measurements and the estimated leakage from streams to ground water are discussed later in the report.

GROUND-WATER SYSTEM

The boundary for the study area was chosen to approximate the lateral extent of the ground-water system in the Tertiary and Quaternary formations in the North Platte River valley. Exact configuration of the boundary line was constructed so that this boundary could be coincident with a ground-water-flow model. The northern boundary of the study area is considered to be Pass Creek, and the eastern and southern boundaries are generally near the edge of the Tertiary formations or where only narrow sections of Tertiary or Quaternary formations are exposed. The southern half of the western boundary was arbitrarily chosen where the Tertiary formations continue westward. The northern half of the western boundary is the edge of saturation in the Tertiary formations.

This investigation was concerned primarily with the inflow to and the outflow from the shallow ground-water system and with the water-level fluctuations in rocks of Tertiary age and younger along the North Platte River. Inflow to the ground-water system is from precipitation, leakage from streams and surface-water irrigation, and water flowing into the study area through the subsurface. Most of the water in the smaller streams within the study area is diverted for irrigation. Additional water moves into the study area as runoff from drainage basins and surface-water irrigation outside the study area. Outflow from the ground-water system is by pumpage, evapotranspiration, discharge to streams, and by water moving through the alluvium along the North Platte River.

Principal Aquifers

The principal aquifers are the North Park Formation and a separate underlying sandstone unit, both of Miocene age (pl. 1) and the alluvium of Quaternary age. Lowry and others (1973) referred to the sandstone unit as the Arikaree Formation. Montagne (1955) and other workers referred to this sandstone unit as the Browns Park Formation. The Miocene formations are fine- to medium-grained sandstone with conglomerate in the lower part and medium- to coarse-grained sandstone and conglomerate in the upper part (Lowry and others, 1973, sheet 3). A more detailed description of the North Park Formation is provided by Manlove (1942).

The North Park Formation and the underlying sandstone unit in the North Platte River valley contain water of similar chemical type. Although 5 of 6 water samples from the North Park Formation are calcium bicarbonate type water, and 3 of 6 water samples from the separate sandstone unit are sodium sulfate type, the mineral content of the water seems to vary within each formation nearly as much as between formations. A rapid comparison of the chemical analyses of the water can be shown graphically by Stiff diagrams (Stiff, 1951) which have distinctive shapes for different water composition (fig. 4). Because the North Park formation and the sandstone unit generally have similar lithology and have water of similar chemical quality, they are considered as one geohydrologic unit, hereafter referred to as the Miocene sandstone unit.

The base of the Miocene sandstone unit was contoured in part of the area (pl. 1) using information from geophysical and lithologic logs from about 40 wells including oil and gas test holes, water wells, and four test holes drilled for this investigation. In three of the four test holes, the base of the Miocene sandstone unit was identified as the contact between very fine-grained tan or greenish sandstone and dark gray to black shale. Total thickness of the formations of Miocene age (Miocene sandstone unit) in the area is about 2,800 feet (Montagne, 1955, p. 32 and 39).

Hydraulic characteristics for the Miocene sandstone unit were estimated from other studies. Lowry and others (1973, sheet 3) reported transmissivities ranging from about 4,000 to 5,000 feet squared per day. A specific yield of 12 percent is a reasonable estimate for the Miocene sandstone unit and the alluvium, and they are similar to the deposits near Wheatland, Wyo., where Weeks (1964, p. 25) determined the specific yield to be 12 percent.

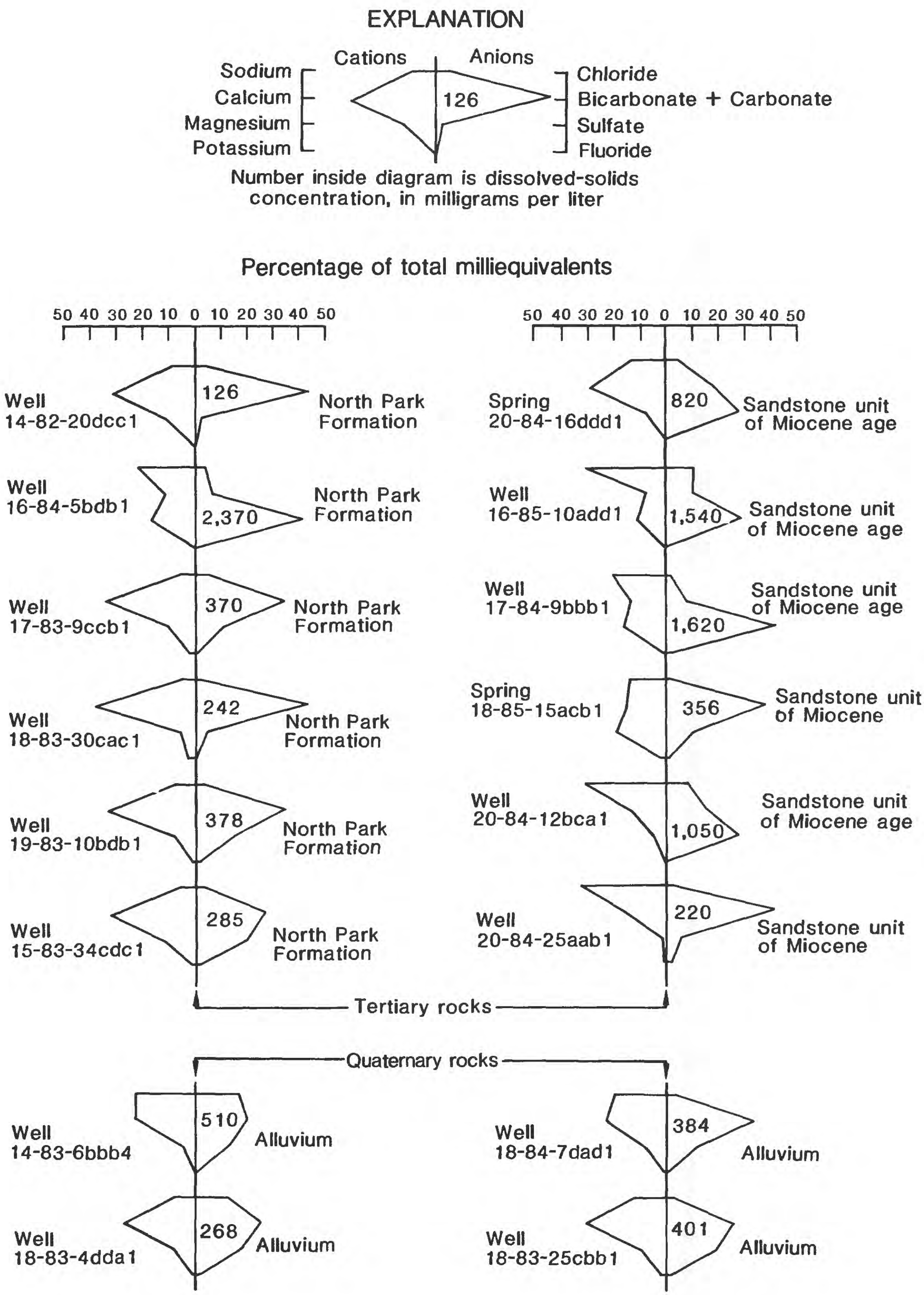

Figure 4.--Stiff diagrams of chemical analyses of water from Tertiary and Quaternary rocks. (Analyses from Lowry and others, 1973, sheet 3.)

The alluvium was mapped only in the bottom of the stream valleys and includes flood-plain deposits and some lower alluvial terraces. Lithology of the alluvium is described (Lowry and others, 1973) as principally sand, gravel, and cobbles. The hydraulic conductivity of materials in the alluvium in the North Platte River valley could range from about 3 to about 1,000 feet per day based on the hydraulic conductivity of similar alluvial materials in the Arkansas River valley in southern Colorado (Lohman, 1979, p. 53). For this study, hydraulic conductivity of the alluvium was assumed to be the same as Weeks (1964, p. 38) estimated for alluvial terrace deposits near Wheatland, Wyo. (328 feet per day). The alluvium is considered as a geohydrologic unit in hydraulic connection with the streams and the underlying Miocene sandstone unit.

Saturated Thickness

Saturated thickness of the Miocene sandstone unit (fig. 5) is shown where data were available. The thickness was determined as the difference between the altitude of the contours on the water-level surface, and the altitude of the contours on the base of the Miocene sandstone unit. The largest saturated thickness is in the northeastern part of the area near Pass Creek where it is estimated to be as much as 1,500 feet. The thickness of the alluvium along the North Platte River and major tributaries generally ranges from 10 to 20 feet (Lowry and others, 1973, sheet 3).

Ground-Water Flow

Lateral ground-water movement generally is perpendicular to the contours that represent the water-level surface (pl. 2). These contours were drawn by using water-level measurements made by Lenfest (1986). In parts of the area where no measured data were available, the altitude of the water-level surface was estimated and shown by the dashed contours. The water-level contours indicate that ground-water movement generally is from the edges of the valley toward the North Platte River.

Water-Level Fluctuations

Ground-water levels rise and fall in response to changes in storage that result from recharge and discharge. Water-level changes in four wells (figs. 6 and 7, and pl. 2) represent typical fluctuations that occurred in areas where both surface water and ground water are used for irrigation in the North Platte River valley.

Ground-water pumpage for irrigation is the probable cause of about 1 foot of water-level decline in the observation well 14-83-3cab from 1980 to 1983 (fig. 6). This well is completed in the same part of the Miocene sandstone unit as the nearby irrigation wells. In the area near the observation well, little surface water is available, so ground water is the primary source of irrigation supplies.

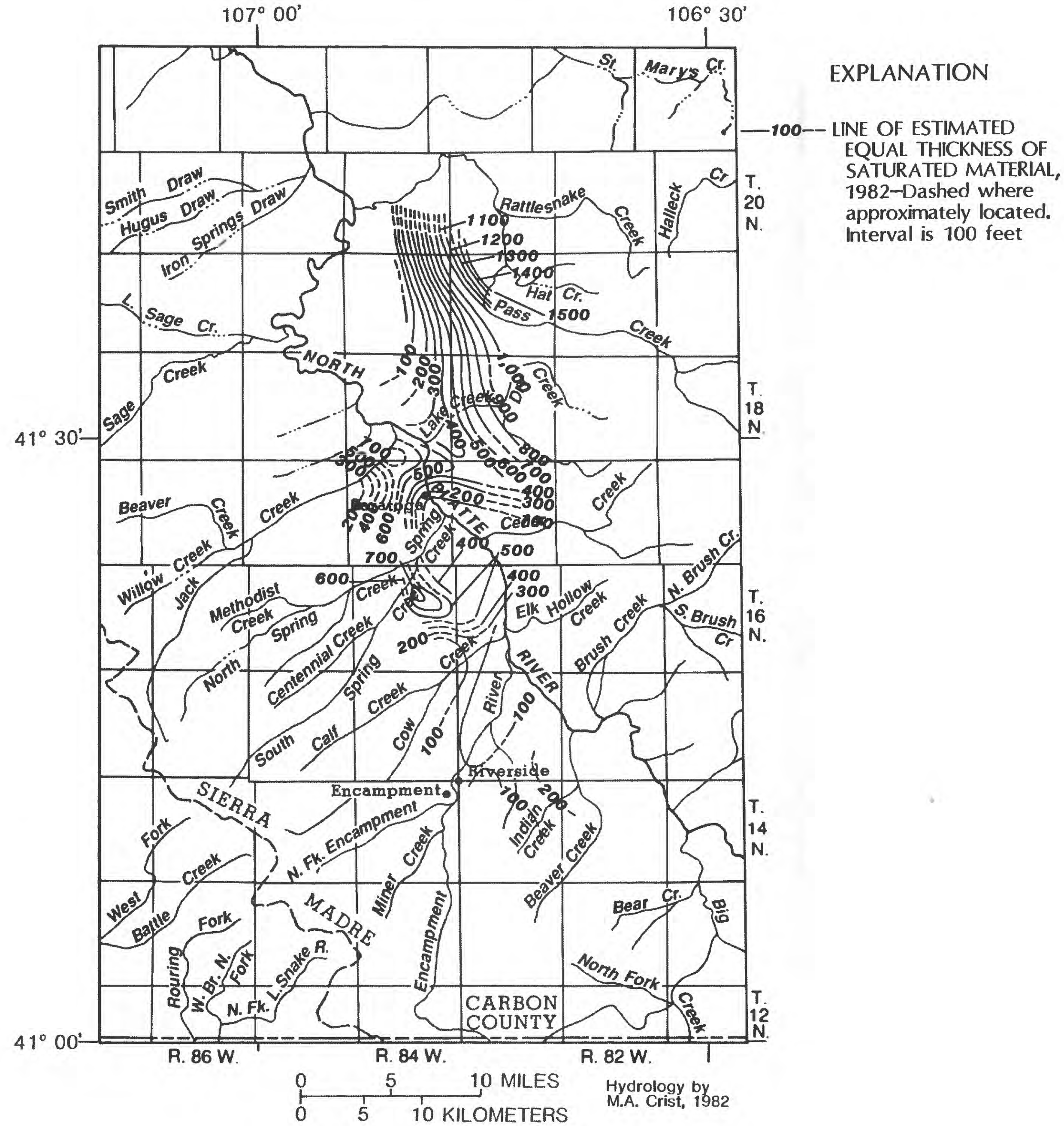

Figure 5.--Estimated saturated thickness in the Miocene sandstone unit.

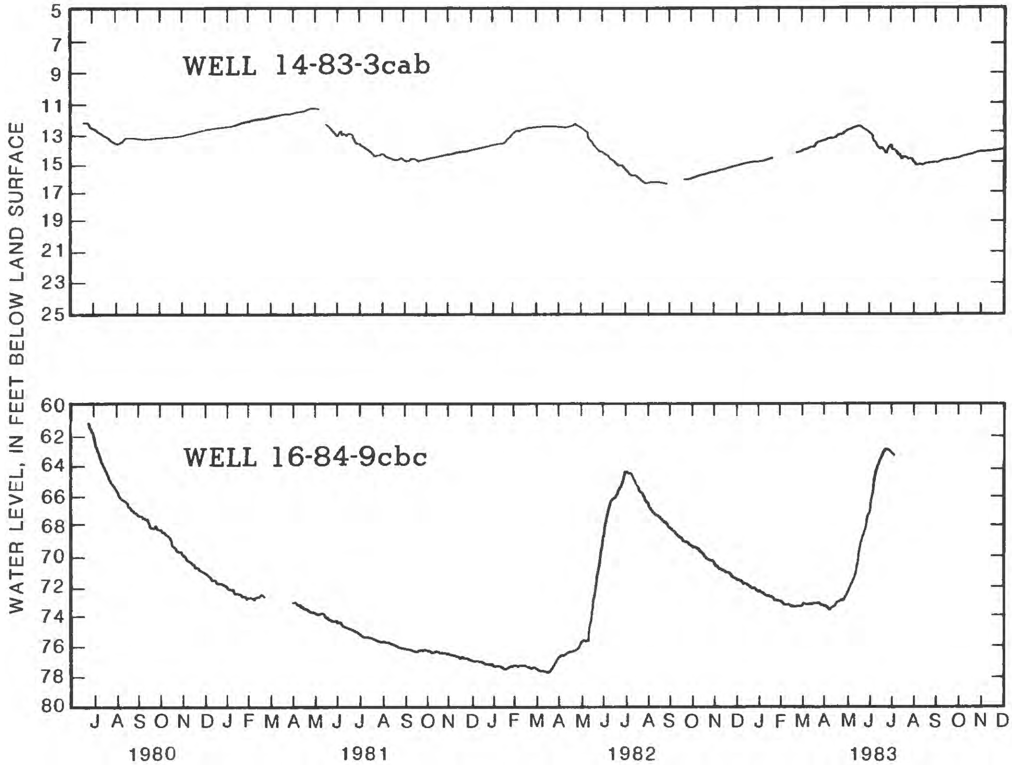

Figure 6.--Water-level fluctuation in wells in response to discharge from irrigation wells (well 14-83-3cab) and leakage from surface-water irrigation (well 16-84-9cbc).

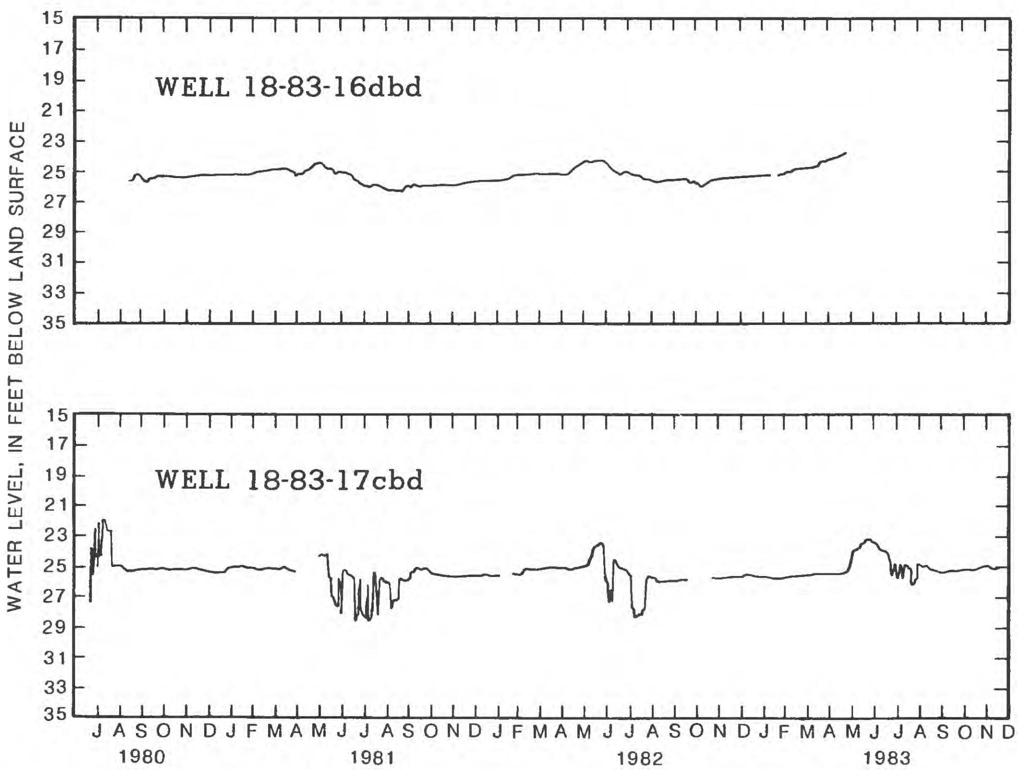

Figure 7.--Water-level fluctuation in wells near Lake Creek in response to discharge from irrigation wells and leakage from surface-water irrigation.

Annual differences in leakage from surface-water irrigation and leakage from a nearby canal (approximately 10 feet from the observation well) probably are the principal causes of more than 16 feet of water-level decline in well 16-84-9cbc (fig. 6). There was concern when the water level declined about 16 feet in this well between July 1980 and December 1981. The land near this observation well usually is irrigated with surface water, but during 1981, neither ground water nor surface water was used extensively for irrigation upgradient from the well. The only ground water used in the vicinity was about 275 acre-feet of water pumped from an irrigation well about 0.5 mile downgradient from the observation well. However, M.E. Lowry (U.S. Geological Survey, written commun., 1969) noted that the water level in well 16-84-9cbc was not affected during pumping of the irrigation well (well 16-84-8aad).

The water level declined in well 16-84-9cbc from July 1980 until irrigation began in April 1982. After surface-water irrigation started, the water level rose from April through July 1982 then declined again after irrigation stopped. Leakage from surface-water irrigation and the canal during 1982 and 1983 resulted in the water level rising each year to about the same water level measured in July 1980. Ground water was not pumped for irrigation in the area during 1982 and 1983.

The water levels in two observation wells near Lake Creek (pl. 2) (wells 18-83-16dbd and 18-83-17cbd) generally rise during May and June (fig. 7). The water-level rise in both wells probably is a result of leakage from surface-water irrigation during periods of snowmelt runoff in Lake Creek. The water level in well 18-83-17cbd also is affected by irrigation wells pumping nearby.

Thus, the hydrographs (figs. 6 and 7) of four wells with water-level fluctuations typical for wells in the study area indicate that ground-water pumpage for irrigation has had little long-term effect on ground-water levels. The water levels measured in wells 15-83-32ddd and 20-83-28bab (Ragsdale, 1982, p. 19-20) also show relatively little change since 1976. Because there is no evidence of significant water-level changes from year to year, it is assumed that long-term change in ground-water storage is negligible for most of the area. Leakage or lack of leakage from application of surface water for irrigation probably affects the seasonal water levels much more than ground-water pumpage.

Inflow

Inflow to the ground-water system includes recharge from precipitation, leakage from streams and surface-water irrigation, and ground water flowing in from outside the study area. Assuming steady-state conditions and no change in the ground-water storage, inflow should be equal to the outflow. The rate of inflow from each source was estimated using the methods in the following sections.

Areal Recharge From Precipitation

Recharge from precipitation, in areas at altitudes lower than about 7,400 feet above sea level, was assumed to be evenly distributed in time and space because in general, the topography and geology are more consistent. Most precipitation on basins above 7,400 feet runs off to streams. Leakage to ground water from these streams is discussed later. Because of similarity between the North Park Formation and the Ogallala Formation also of Miocene age, the rate of recharge from precipitation in this study was assumed to be similar to the rate of recharge to the Ogallala Formation in Laramie County estimated by Foley (1943, p. 51) to be 5 percent of the annual precipitation. Recharge from precipitation was estimated to be 5 percent of the normal-annual precipitation (9.58 inches) (U.S. Department of Commerce, 1981) at Saratoga, Wyo. or about 0.48 inch per year. Recharge from this source was estimated to average about 15 cubic feet per second.

Leakage From Streams and Surface-Water Irrigation

Within study area.--The leakage from surface-water irrigation on lands adjacent to streams is difficult to separate from the leakage directly from streams. Therefore, in this study leakage from surface-water irrigation is used as the estimate of the combined leakage from these two sources.

Surface-water irrigation was estimated because no records are maintained of the volume of water diverted from streams. Surface water applied for irrrigation was assumed to be at least as much as the consumptive irrigation requirement for crops in the area which ranges from about 13 to 20 inches per year (Trelease and others, 1970).

Because of the similarity between the soils of irrigated lands in the North Platte River valley and near Wheatland, Wyo., the percentage of surface-water irrigation that leaks downward to ground water was assumed to be similar. Weeks (1964, p. 60) estimated that leakage from surface-water irrigation ranged from 35 to 40 percent near Wheatland, Wyo. Using a consumptive irrigation requirement of about 17 inches per year (approximate midpoint of the range reported by Trelease and others, 1970) for crops grown in the North Platte valley and assuming that total water applied is 40 percent more than the consumptive requirement, total application would be about 24 inches per year and leakage would be about 7 inches per year. Leakage from surface-water irrigation on about 45,200 acres within the study area (fig. 8) was estimated to average about 36 cubic feet per second. The approximate areas and location of the lands irrigated with surface water shown in figure 8 are from a more detailed map of the irrigated acreage published by Lenfest (1986, pl. 3).

Outside study area (ground-water flow into study area).--Ground water moving into the area is derived from surface-water irrigation and precipitation. About 17,000 acres of land are irrigated with surface water outside the study area. Leakage from the irrigation moves downgradient and across the study area boundary through the subsurface. Using the same methods described in the previous section for calculating leakage from surface-water irrigation, the leakage from irrigation outside the study area was estimated to be about 13 cubic feet per second.

Perennial streamflow from 13 of the 52 drainage basins outside the study area disappears near the point where the streams traverse from the mountainous terrain, where rocks of relatively low permeability are exposed, onto the more permeable rocks of the Miocene sandstone unit (see fig. 3). The quantity of

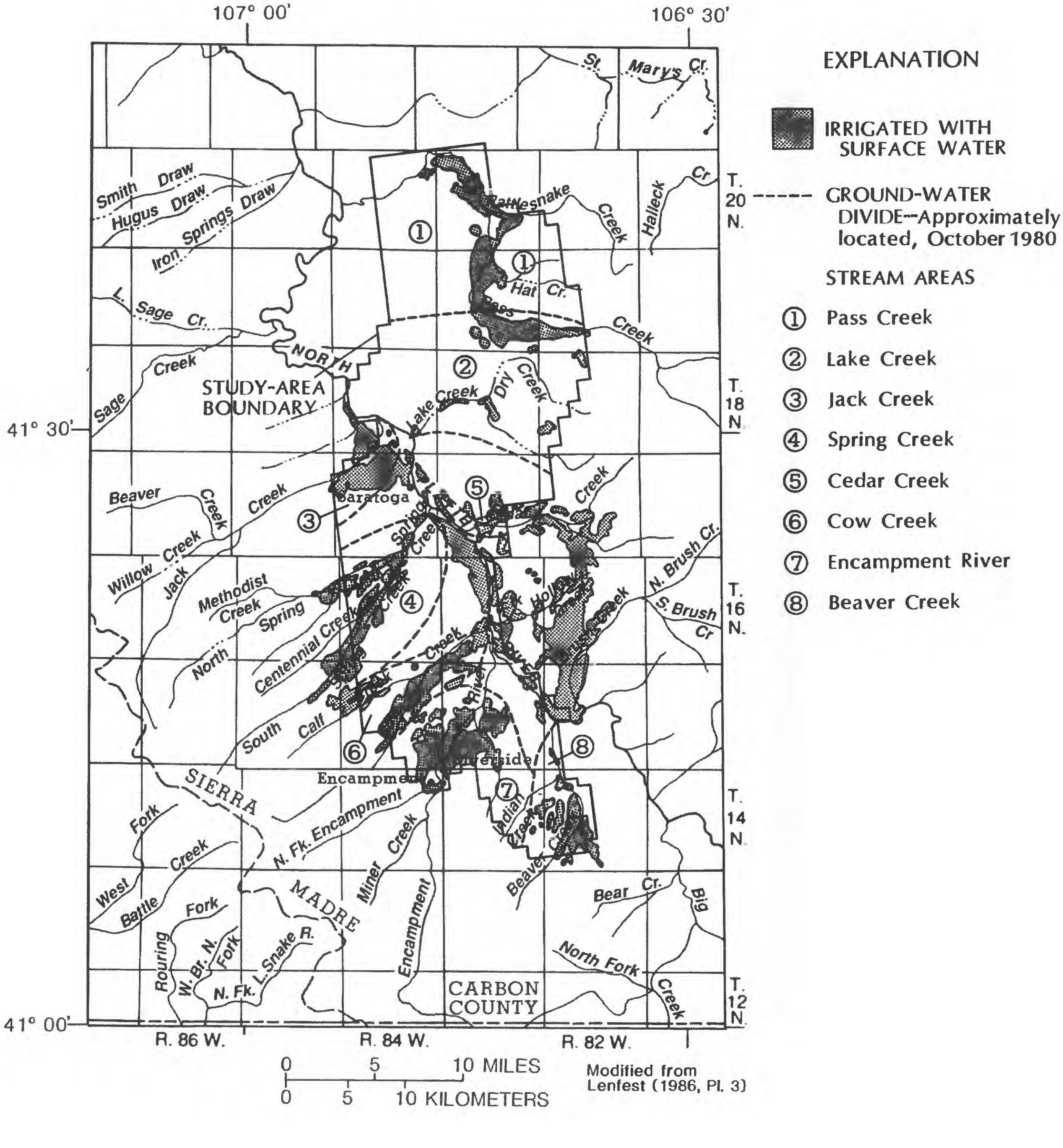

Figure 8.--Location of ground-water divides and areas irrigated with surface water.

inflow to ground water from these streams was estimated by using the basin characteristics method described (see SURFACE-WATER SYSTEM) for calculating the mean-annual discharge from each basin and assuming 40 percent reaches the ground water.

Streamflow from 12 drainage basins having an average altitude of 8,260 feet adjacent to and outside the study area occurs only in response to precipitation. Most of the precipitation falling on these basins, which have relatively steep terrain, runs off as streamflow. Part of the streamflow infiltrates and is another source of ground-water inflow. It was estimated that the mean-annual precipitation on these basins is 15 inches (J.D. Alyea, written commun., 1980) and that 40 percent of the runoff leaks to ground water in the vicinity where the runoff discharges from the basins onto rocks of the Miocene sandstone unit.

Because these 25 drainage basins have little or no surface-water irrigation, all the inflow from stream leakage is considered to be derived from precipitation. Leakage from these basins was estimated to average about 26 cubic feet per second. Combined estimated inflow from leakage of surface-water irrigation and from precipitation outside the study area totaled about 39 cubic feet per second.

Outflow

Ground-water discharge is the most convenient and most accurate quantity estimated in this study. If the ground-water system nearly duplicates steady-state conditions, then the average rate of outflow equals the average rate of inflow. These rates are assumed to be the average annual rates, although it is recognized that the rates may vary during the season. Ground water is discharged from the system through the alluvium along the North Platte River and as pumpage, evapotranspiration, and leakage to streams.

Pumpage

Pumpage for stock and domestic use was assumed to be small compared to pumpage for irrigation; therefore, only ground-water pumpage for irrigation was estimated. The estimated pumpage is listed below:

Year	Volume (acre-feet)	Source of estimate
1968	5,000	Lowry and others (1973)
1980	2,700	Lenfest (1986)
1981	4,200	Lenfest (1986)
1982	3,500	

Pumpage for 1980-82 was estimated on the basis of electric-power records.

Evapotranspiration

Although, evapotranspiration during the irrigation season is significant, the quantity of water lost from the ground-water system because of evapotranspiration is difficult to estimate without knowledge of the quantity of water used for irrigation. No records are available of the quantity of surface water diverted for irrigation or of the flow in the streams throughout the growing season.

Most areas of potential evapotranspiration losses are in irrigated areas. The consumptive irrigation requirement includes transpiration losses, therefore, it is assumed that the evapotranspiration losses are included in the 60 percent of applied irrigation water that is lost. Any error introduced by not estimating evapotranspiration separately probably is within the error of other discharge estimates.

Ground-Water Discharge To Streams

A large volume of ground water is discharged to streams during the fall and winter months after killing frost reduces evapotranspiration to a minimum and no ground water is pumped for irrigation. Any gain in streamflow in the area during the fall and winter is assumed to be ground-water discharge because there is little overland runoff from precipitation. Discharge measurements made on streams (fig. 3 and table 1) in October 1981 (L.W. Lenfest, Jr., and J.O. Ragsdale, U.S. Geological Survey, written commun., 1982) indicated that the streamflow within the study area gained about 89 cubic feet per second.

Because of the short reach of Cedar Creek and Elk Hollow Creek within the study area, it was assumed that there was negligible impact on the water budget in the study area due to a gain or loss of streamflow (table 1) in these streams.

The mean-daily discharge hydrograph for the period of record (water years 1931-70) of the North Platte River at Saratoga, Wyo. (fig. 9) is assumed to be representative of the seasonal variation of streamflow in the major streams in the valley. The slight increase in average discharge during September and October probably is the result of decreased evapotranspiration after killing frost. The average discharge rate from mid-October to mid-November is relatively stable, indicating that the streamflow is primarily ground-water discharge. The slight downward trend in the hydrograph from mid-November through January indicates there may be an irrigation-return-flow component in the measured stream discharge. However, the gains in streamflow determined from discharge measurements made in October 1981 (table 1) probably are a fair estimate of ground-water discharge because overland return flow to streams from irrigation at this time of year is virtually nonexistent.

Ground-Water Flow Out of Study Area

The water-level contours (pl. 2) indicate few locations where ground-water movement is toward the study-area boundary. Ground-water discharge from the study area is assumed to occur only through the alluvium of the North Platte River. Discharge was estimated to be about 1 cubic foot per second

Table 1.-- Results of discharge measurements on major streams and their tributaries, October 1981

[E, estimated discharge; -, indicates loss]

Site no.	Stream	Measurement location	Discharge (cubic feet per second) Inflow	Outflow	Gain or loss in reach
1	Indian Creek (Beaver Creek tributary)	14-83-23bdb	0.01	---	---
2	Beaver Creek	14-82-29abb	0.65	---	---
3	Beaver Creek	15-82-19abd	---	1.60	0.94
4	Encampment River	14-83-7bba	54.9	---	---
5	Encampment River	15-83-3bbd	---	105	50
6	Calf Creek (Cow Creek tributary)	15-84-17bcd	0.30	---	---
7	Cow Creek	15-84-22aab	1.58	---	---
8	Cow Creek	16-83-28bbc	---	3.66	1.78
9	Elk Hollow Creek	16-83-21acd	---	4 E	0 E
10	Cedar Creek	17-83-28bdc	---	9.22	0 E
11	South Spring Creek (Spring Creek tributary)	15-85-1cdb	2.44	---	---
12	North Spring Creek (Spring Creek tributary)	16-85-15bcb	3.72	---	---
13	Methodist Creek (North Spring Creek tributary)	16-85-15bba	0.61	---	---
14	Spring Creek	17-84-24cac	---	10.8	4.0
15	South Fork Lake Creek (Lake Creek tributary)	18-83-36cad	0	---	---
16	Dry Creek (Lake Creek tributary)	18-83-2acc	0.13	---	---
17	Lake Creek	18-84-26dad	---	3.49	3.36
18	Jack Creek	17-85-14abb	7.24	---	---
19	Jack Creek	18-84-28abd	---	12 E	5 E
20	Pass Creek	19-82-27ccb	10.0	---	---
	Observation of flow	19-83-21ddd	---	0	-10 E
21	Rattlesnake Creek (Pass Creek tributary)	20-83-22ddd	---	0.73	0 E
22	Pass Creek	20-84-15cbd	---	7.24	6.51
23	North Platte River	15-82-20bdb	289	---	---
	All major tributaries between sites 23 and 24		138	---	---
24	North Platte River	18-84-26cdb	---	454	[1]27
		Total net gain in study area			89

[1] Gain in the North Platte River from ground water is calculated as the Outflow minus Inflow minus the contribution from all major tributaries between sites 23 and 24 (454-289-138 = 27).

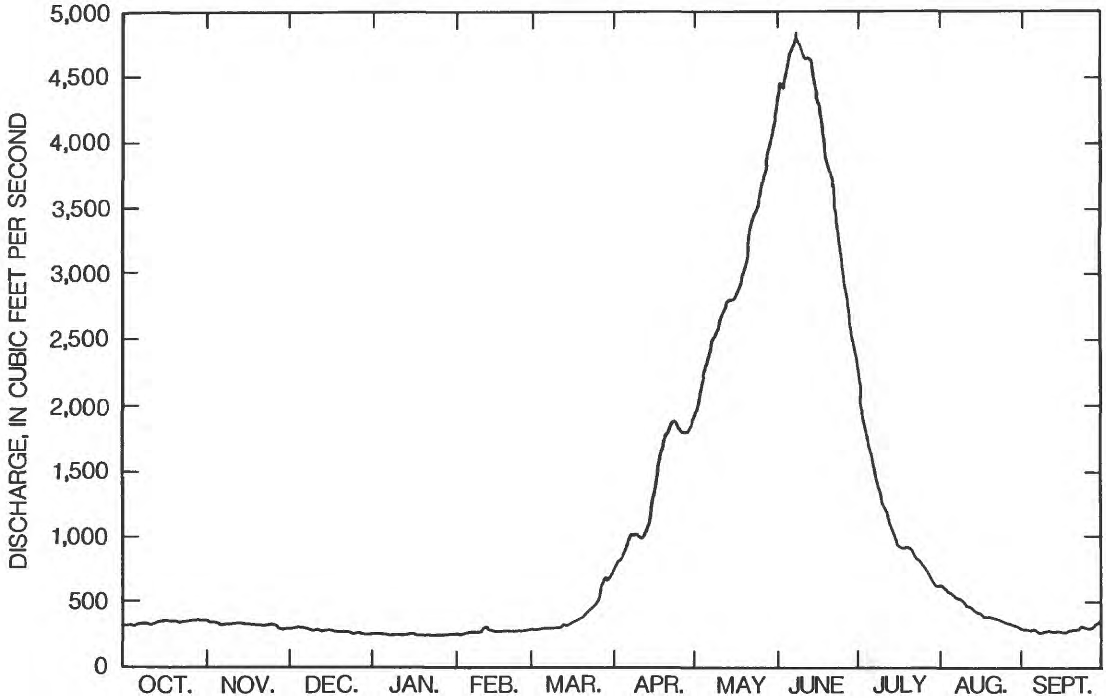

Figure 9.--Mean-daily discharge hydrograph of the North Platte River at Saratoga, Wyoming, water years 1931-70.

through alluvium about 5,000 feet wide near the study-area boundary. The water-level contours (pl. 2) are used to estimate a hydraulic gradient of 12 feet per mile; and on the basis of a few driller's logs, it was estimated that the saturated thickness is 20 feet and the hydraulic conductivity is 330 feet per day.

GROUND-WATER BUDGET

A ground-water budget was prepared for individual stream areas to test the concept of localized hydrologic systems. The areal extent of that part of the ground-water system in hydraulic connection with eight of the nine principal tributary streams was estimated by locating ground-water divides on the basis of the water-level contours (pl. 2). The ground-water divides are shown in figure 8. Using methods previously described, recharge from precipitation, leakage from streams and surface-water irrigation, and incoming ground-water flow were estimated for each stream area enclosed by the ground-water divides and the study-area boundary. The measured gain in streamflow (assumed to be the ground-water outflow) was compared to the inflow estimated for each stream area.

The Pass Creek area (fig. 8), about 93 square miles, includes about 6,600 acres irrigated with surface water. Based on the water-level contours, all ground water south of the ground-water divide between Pass Creek and Lake Creek areas moves away from the Pass Creek area. Flow in Pass Creek near the ground-water divide was nearly zero in October 1981. Therefore, flow measured downstream at site 22 (fig. 3) includes 0.73 cubic feet per second from Rattlesnake Creek plus ground-water discharge to Pass Creek between the ground-water divide and site 22.

The ground-water budget for the Pass Creek area is listed in table 2. Because the estimated outflow was nearly as large as the estimated inflow, it was concluded that Pass Creek serves as the main outlet for ground water leaving this area.

Water budgets were prepared for each of the other stream areas designated in figure 8. However, estimates for inflow and outflow for these areas were not in close agreement. Discrepancies between the estimated inflow and the measured gain in the streams may be caused partly by transbasin diversions of surface water for irrigation. In most of the stream areas, inflow to ground water was estimated to be three to four times the outflow estimated from the seepage measurements. In the Encampment River area, however, the discharge measurements showed the stream gaining about five times as much as the estimated inflow. In this stream area, the ground water probably is recharged from Beaver Creek and Cow Creek stream areas and discharged to the Encampment River. Errors also could be caused by inaccurate location of the ground-water divides which were used to define the areal extent of the local flow systems.

To minimize errors in accounting for the water in the local stream areas, where comingling may occur, a comparison was made of the estimated ground-water inflow and outflow (table 3) for the entire study area. The average rate of inflow is based on estimated average annual conditions and the average rate of outflow is based on data for October 1981 when there was no pumping for irrigation; evapotranspiration (after killing frost) is minimal so it can be considered negligible; and there is no measureable change in ground-water storage.

The reader is cautioned that these values of inflow and outflow should not be used to determine the magnitude of development that could occur. It is emphasized that the effects of pumping, such as water-level decline, are dependent on the hydraulic properties of the aquifer and the proximity of the pumping to boundaries or streams.

An attempt to construct a mathematical ground-water-flow model for the study area indicated that more measured data are required. All streamflow entering and leaving the study area needs to be measured. To make better estimates of leakage from irrigation, measurements of the volume of irrigation water diverted from streams, the time interval that water is diverted, the acreage to which the water is applied, and seepage measurements on the streams throughout the season are needed. These data would help to estimate evapotranspiration during the growing season. Water levels are needed in areas where no data are available. An inventory of pumpage on a monthly basis would be helpful to determine seasonal stress on the system. Additional drilling is needed to determine the thickness of alluvium in the stream valleys and the aquifer saturated thickness. Analysis of drill cuttings may provide a better estimate of hydraulic conductivity of the aquifers.

Table 2.-- Estimated ground-water inflow and outflow for the Pass Creek area

	Cubic feet per second
Inflow (Based on average annual conditions)	
Areal recharge from precipitation	3.3
Leakage from surface-water irrigation	5.1
Ground-water flow into study area	0.4
Total	8.8
Outflow (Based on data for October 1981)	
Ground water discharged to Pass Creek (7.24 - 0.73 from Rattlesnake Creek)	6.51
Ground-water flow out of study area (assumed negligible)	0
Evapotranspiration (assumed negligible)	0
Total	6.51

Table 3.-- Estimated ground-water inflow and outflow for the study area

	Cubic feet per second
Inflow (Based on average annual conditions)	
Areal recharge from precipitation	15
Leakage from streams and surface-water irrigation	
Within study area	36
Outside study area (Ground-water flow into study area)	39
Total	90
Outflow (Based on data for October 1981)	
Ground-water discharge to streams	89
Ground-water flow out of study area through North Platte River alluvium	1
Total	90

SUMMARY AND CONCLUSIONS

The study area includes about 410 square miles that extends along both sides of the North Platte River in southern Carbon County. Many small streams originate in the nearby mountains and are tributary to the North Platte River. Irrigation has been practiced in the area since 1875. Streams are the principal source of irrigation water and irrigation wells are used to supplement surface-water irrigation supplies.

The purpose of this report is to describe the concept of operation of the hydrologic system and to describe the effect of ground-water development on ground-water levels. The report includes a quantitative assessment of ground-water movement within boundaries defined for the hydrologic system.

Fifty-two drainage basins outside of the study area contribute water to the study area. Nine principal tributaries to the North Platte River collect water from 27 of these basins. Perennial streamflow from 13 drainage basins disappears before reaching the principal tributaries. Leakage to ground water from streams in these basins was estimated as 40 percent of the mean-annual stream discharge from each basin. Streamflow (runoff) from 12 drainage basins occurs only in response to precipitation. Leakage to ground water from these 12 basins is estimated as 40 percent of the runoff from the basins.

This investigation primarily was concerned with the inflow, outflow, and ground-water-level fluctuations in rocks of Tertiary age and younger. The principal aquifers are the Miocene sandstone unit and the alluvium. In this report, the North Park Formation and a separate underlying sandstone unit are considered one geohydrologic unit and referred to as the Miocene sandstone unit. The alluvium is also considered a geohydrologic unit that is hydraulically connected to the streams and the underlying Miocene sandstone unit.

Generally ground-water movement in the aquifers, as indicated by the configuration of the water-level-contour map, is from the edge of the valley toward the North Platte River. Most of the ground water discharged from the study area leaves the valley as streamflow.

Leakage or lack of leakage from surface-water irrigation probably affects ground-water levels much more than pumpage. In an area east of Encampment, Wyo., where little surface water is available, ground-water pumpage for irrigation was the probable cause of about 1 foot of water-level decline from 1980 to 1983 in an observation well completed in the same part of the Miocene sandstone unit as nearby irrigation wells. It was concluded from this study that the 16 feet of water-level decline measured in an observation well near Spring Creek could be attributed to lack of leakage from surface-water irrigation and a nearby irrigation ditch. Because there is no evidence of substantial water-level changes from year to year, it is assumed that long-term change in ground-water storage is negligible for most of the area.

It was estimated that the average rate of ground-water inflow and outflow is 90 cubic feet per second. This estimate was prepared by assuming steady-state conditions and on the basis of data for October 1981, when there was no pumping for irrigation, evapotranspiration was minimal, and there was no measureable change in ground-water storage. Inflow to ground water in the study area was estimated to average about 15 cubic feet per second from precipitation, about 36 cubic feet per second from streams and surface-water irrigation, and about 39 cubic feet per second from ground-water flow into the study area. Outflow of ground water from the study area was estimated to average about 89 cubic feet per second to streams and about 1 cubic foot per second through the alluvium along the North Platte River.

An attempt to construct a mathematical model of the ground-water system in the study area indicated that more data are required. These data include measurement of inflow and outflow of streams, measurement of the distribution of stream diversions for irrigation, and seepage measurements on streams throughout the season. Additional test-hole drilling would provide data on water levels where no data are available and on saturated thickness of alluvium in the stream valleys. Test-hole drilling also may provide an improved estimate of hydraulic conductivity of the aquifers.

REFERENCES CITED

Foley, F.C., 1943, Progress report on the geology and ground-water resources of the Cheyenne area, Wyoming: U.S. Geological Survey Open-File Report (unnumbered), 96 p.

Houston, R.S., and Ebbett, B.E., 1977, Geologic map of the Sierra Madre and western Medicine Bow Mountains, southeastern Wyoming: U.S. Geological Survey Miscellaneous Field Studies Map MF-827, scale 1:125,000.

Houston, R.S., and others, 1968, A regional study of rocks of Precambrian age in that part of the Medicine Bow Mountains lying in southeastern Wyoming--with a chapter on the relationship between Precambrian and Laramide structure: Geological Survey of Wyoming Memo No. 1, 167 p.

Lenfest, L.W., Jr., 1986, Ground-water levels and irrigation water use in Saratoga valley, Wyoming, 1980-81: U.S. Geological Survey Water-Resources Investigations Report 84-4040, 24 p.

Lohman, S.W., 1979, Ground-water hydraulics: U.S. Geological Survey Professional Paper 708, 70 p.

Lowham, H.W., 1976, Techniques for estimating flow characteristics of Wyoming streams: U.S. Geological Survey Water-Resources Investigations 76-112, 83 p.

Lowry, M.E., Rucker, S.J., IV, and Wahl, K.L., 1973, Water resources of the Laramie, Shirley, Hanna Basins and adjacent areas, southeastern Wyoming: U.S. Geological Survey Hydrologic Investigations Atlas HA-471, 4 sheets.

Manlove, C.F., 1942, Geology of the Saratoga anticline: Unpublished report, U.S. Geological Survey, Cheyenne, Wyo., 12 p.

Montagne, J.M., de la, 1955, Stratigraphy and structure of the Pick Ranch area, Carbon County, Wyoming: University of Wyoming, unpublished Doctor of Philosophy thesis, 140 p.

Ragsdale, J.O., 1982, Ground-water levels in Wyoming, 1971 through part of 1980: U.S. Geological Survey Open-File Report 82-859, 200 p.

Stiff, H.A., 1951, The interpretation of chemical water analysis by means of patterns: Journal of Petroleum Technology, v. 3, no. 10, p. 15-17.

Trelease, F.J., Swartz, T.J., Rechard, P.A., and Burman, R.D., 1970, Consumptive use of irrigation water in Wyoming: Wyoming State Engineer's Office, Wyoming Water Planning Report No. 5, 83 p.

U.S. Department of Commerce, 1981, Climatological data annual summary, Wyoming, National Oceanic and Atmospheric Administration: U.S. Government Printing Office.

Visher, F.N., 1952, Reconnaissance of the Pass Creek Flats area, Carbon County, Wyoming: U.S. Geological Survey Circular 188, 19 p.

Weeks, E.P., 1964, Hydrologic conditions in Wheatland Flats area, Platte County, Wyoming: U.S. Geological Survey Water-Supply Paper 1783, 79 p.

Weitz, J.L., and Love, J.D., 1952, Geologic map of Carbon County, Wyoming: The Geological Survey of Wyoming, scale 1:158,400, 1 sheet.

☆U.S. GOVERNMENT PRINTING OFFICE:1990-775-868