STREAMFLOW RECHARGE TO THE MADISON LIMESTONE AND THE CASPER FORMATION IN THE GLENROCK AREA, EAST-CENTRAL WYOMING

By David A. Peterson

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CONVERSION FACTORS

Multiply	By	To obtain
acre-foot	1,234	cubic meter
acre-foot per year	1,234	cubic meter per year
cubic foot per second	0.02832	cubic meter per second
foot	0.3048	meter
gallon per minute	3.785	liter per minute
inch	2.540	centimeter
mile	1.609	kilometer
yard	0.914	meter

Temperature in degrees Celsius (^{o}C) can be converted to degrees Fahrenheit (^{o}F) as follows:

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

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ABSTRACT

The Madison Limestone of Mississippian age has attracted considerable interest as a source for industrial water supply in Wyoming and other states. The Madison Limestone also is important in the Glenrock area because the limestone is a source of water for municipal, agricultural, and domestic uses.

Streamflow recharges the outcrops of the Madison Limestone and the Casper Formation in two of three streams measured in the Glenrock area. An average of 74 percent per year of the streamflow from Little Box Elder Creek was recharged to the Madison Limestone and the Casper Formation during water years 1975-84; the recharge averaged 775 acre-feet per year. Cottonwood Creek also recharged water to the Madison Limestone during water years 1982-84, but the volume could not be fully quantified because of incomplete data. In contrast, Box Elder Creek had approximately the same flow rate and annual volume of water downstream from the outcrop of the Madison Limestone as upstream during water years 1982-84. During 1982-84, the annual volume of water discharged from Little Box Elder Spring, which is between Little Box Elder Creek and Cottonwood Creek, was larger than the sum of the water volumes lost from those two creeks.

Samples of isotopes in ground water and ground-water level records indicated relatively recent recharge to the Madison Limestone near the outcrop. Tritium concentrations in water samples from a well completed at a depth of 75 feet in the Madison Limestone indicated a substantial proportion of modern (post-1952) water. Water levels in that well and in another well completed at a depth of 1,500 feet in the Madison Limestone varied seasonally, in response to seasonal variation in streamflow in Little Box Elder Creek. Water-quality samples from the Madison Limestone at a depth of about 6,500 feet below land surface and about 3 miles from the outcrop contained larger concentrations of dissolved solids and different proportions of the principal ions than in water samples from near the outcrop. Apparent carbon-14 ages of two samples from the deep wells were 16,200 and 19,200 years.

The streamflow, water-quality, and water-level data indicate that some of the streamflow recharge to the Madison Limestone and the Casper Formation is recharge to a local ground-water system which discharges at Little Box Elder Spring. The data also indicate recharge from the study area to the deeper, buried parts of the Madison Limestone.

INTRODUCTION

The Madison Limestone of Mississippian age is a major source of water in the Glenrock area. Uses of water from the limestone in the area include municipal, industrial, irrigation, aquatic-habitat, stock-watering, and domestic supplies. The city of Douglas obtains much of its water from a spring in the area that may be supplied by water from the Madison Limestone. The Panhandle Eastern Pipeline Corp. completed three deep wells (about 6,500 feet below land surface) in the Madison Limestone for industrial use. Knowledge of the volume of streamflow recharge to the Madison Limestone will aid water managers in making decisions regarding development of water supplies from the limestone.

Purpose and Scope

The purpose of this report is to present the available information in a way that will aid understanding of the following:

1. Recharge to the Madison Limestone by streamflow.
2. Hydraulic connection between the Madison Limestone and the overlying Casper Formation.
3. Hydraulic connection within the Madison Limestone, between the outcrop and deeper, buried parts of the formation.

Most of the information presented here was collected during previous investigations, but had not been compiled for the study area. As a supplement to the existing information, some additional data were collected during 1983-84. Sample collection and measurements of specific conductance, pH, and temperature followed procedures described by the U.S. Geological Survey (1977). The water samples were analyzed using methods described by Skougstad and others (1979).

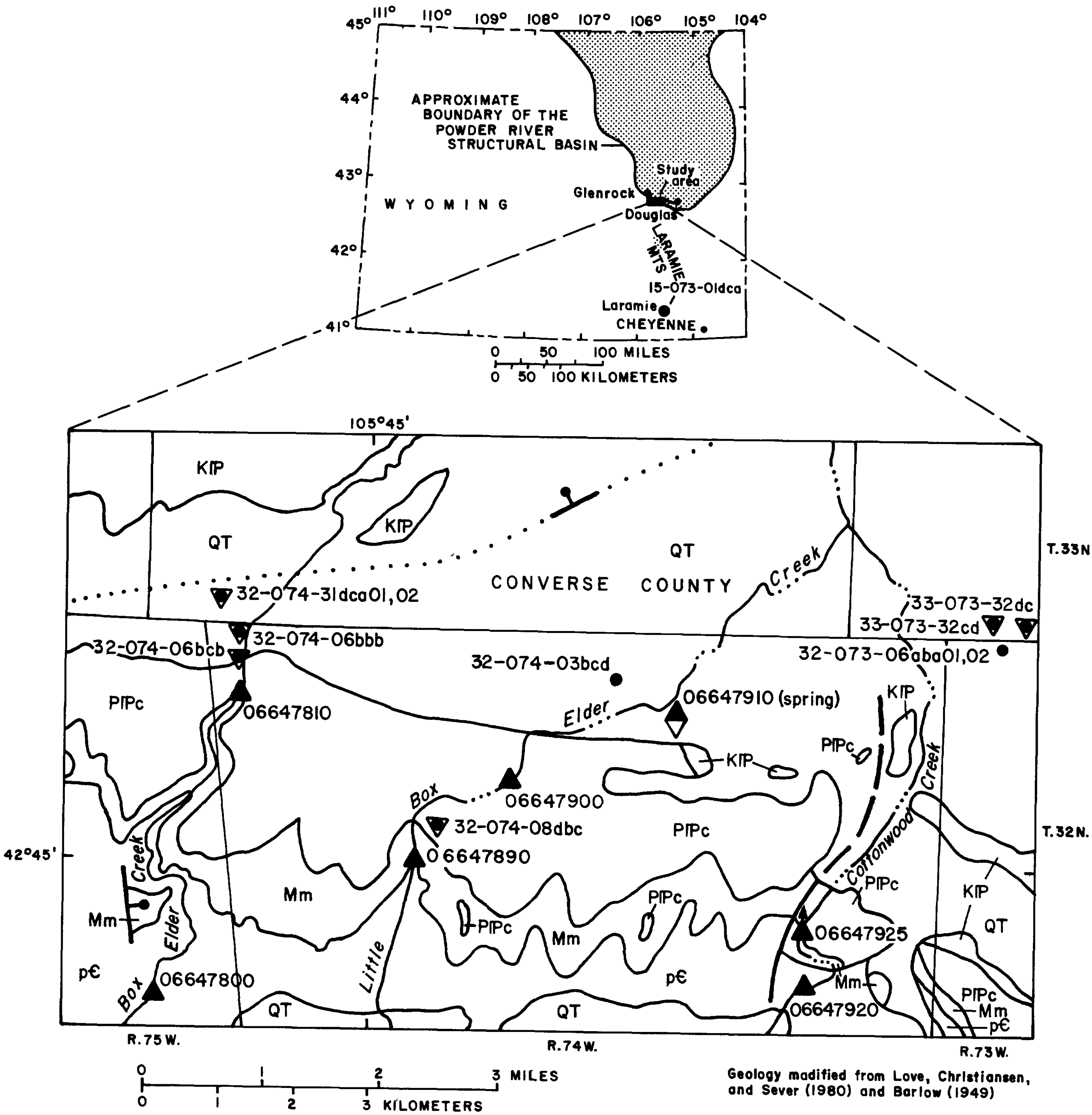
Description of Study Area

Physiography

The climate of the study area is semiarid. The weather station at Glenrock reported 15 inches of precipitation during 1982 (National Oceanic and Atmospheric Administration, 1983). The predominant vegetation is grass and sagebrush; cottonwood and box elder trees grow along the streams.

Geologic Setting

The southern margin of the study area is formed by an anticline. Streams have eroded through the anticline, crossing several formations that have been exposed by erosion of the anticline. The formations dip northward, into the Powder River structural basin (fig. 1). Precambrian rocks are exposed at the top of the anticline and the Madison Limestone (Mississippian age) and the overlying Casper Formation (Lower Permian and Upper and Middle Pennsylvanian age) are progressively exposed, in a down-dip direction (fig. 2). An east-trending, concealed fault, along the northern part of the study area, was mapped by Love and others (1980). Rejection of recharge, caused by offset of the shallow and deep parts of the formations along the fault has been postulated by Huntoon (1985), but the offset is difficult to verify because Tertiary formations blanket the area of the fault.



EXPLANATION

- QT — QUATERNARY AND TERTIARY ROCKS--Includes alluvium, upper Miocene rocks, and White River Formation of Oligocene age
- KIP — CRETACEOUS TO LOWER PERMIAN ROCKS--Includes Cody Shale, Frontier Formation, Mowry and Thermopolis Shales, Cloverly and Morrison Formations, Sundance Formation, and Goose Egg Formation
- PIPc — CASPER FORMATION--Lower Permian and Upper and Middle Pennsylvanian
- Mm — MADISON LIMESTONE--Mississippian (includes Deadwood Formation of Cambrian age)
- pЄ — PRECAMBRIAN ROCKS

- GEOLOGIC CONTACT
- FAULT--Dotted where concealed. Dashed where approximately located. Bar and ball on downthrown side
- 06647910 — STREAMFLOW- OR SPRING-DISCHARGE-GAGING STATION AND NUMBER
- 06647925 — CREST-STAGE PARTIAL-RECORD STATION AND NUMBER
- WELL AND NUMBER
- 33-073-32cd — WATER-QUALITY SAMPLING SITE

Figure 1.--Location of the study area, streamflow-gaging stations, spring-discharge-gaging station, wells, water-quality sampling sites, and generalized geology.

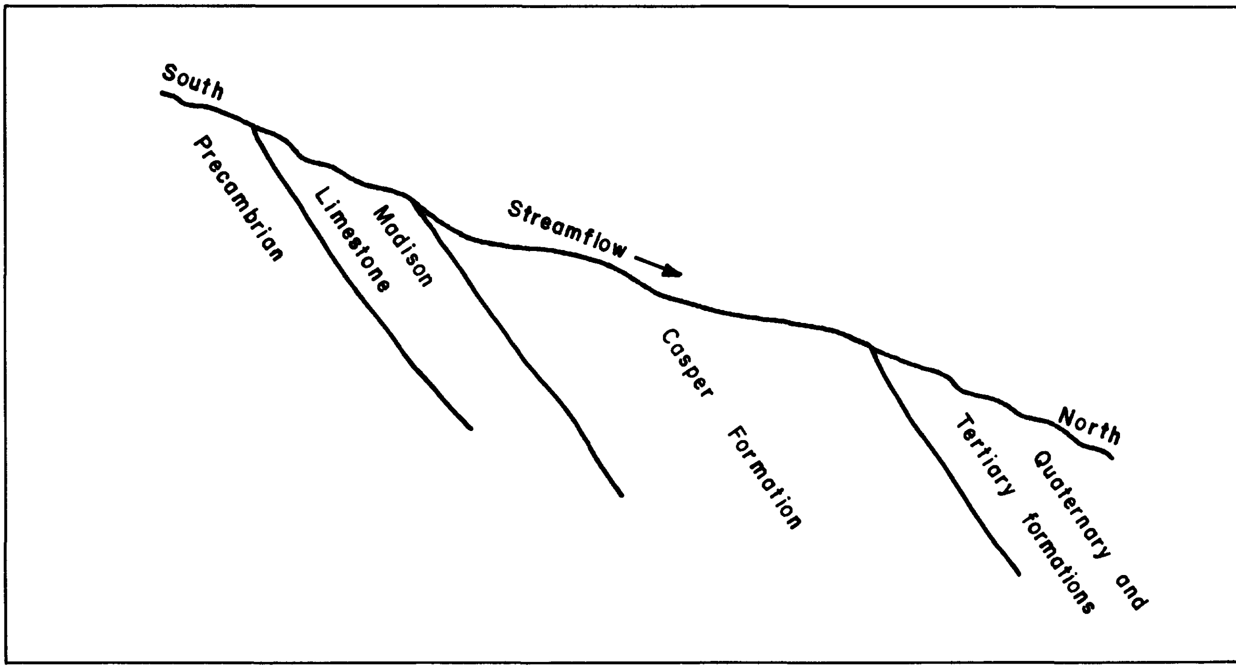


Figure 2.--Diagrammatic geologic section.

Drillers' logs of wells in the study area indicate an approximate thickness of 300 feet for the Madison Limestone and 900 feet for the overlying Casper Formation. Sinkholes and caverns are present in the Madison Limestone and the overlying Casper Formation, but are more common in the Madison Limestone. The primary permeability of the limestone and dolomite of the formations is minimal, but secondary permeability caused by the cavernous nature of the formations can be substantial. An outcrop of the Cambrian Deadwood Formation, which underlies the Madison Limestone, was mapped in the area by Barlow (1949) and has been combined with the Madison Limestone in this report.

Station- and Well-Numbering System

Streamflow-gaging and crest-stage partial record stations have been assigned eight-digit station identification numbers. The first two digits indicate the river basin in which the station is located; for example, 06 refers to the Missouri River basin. The remaining six digits are based on position in the river basin and increase in the downstream direction.

Wells and springs are numbered by Federal system of township, range, section, quarter-quarter-quarter section, and sequence number. Quarter sections are lettered counterclockwise from the upper right. For example, well number 32-073-06aba01 is in the northeast quarter of the northwest quarter of the northeast quarter of section 6, T. 32 N., R. 73 W. (fig. 3). In this report, sequence numbers are 01 unless otherwise shown, and are listed only when necessary to distinguish multiple wells within a quarter-quarter-quarter section.

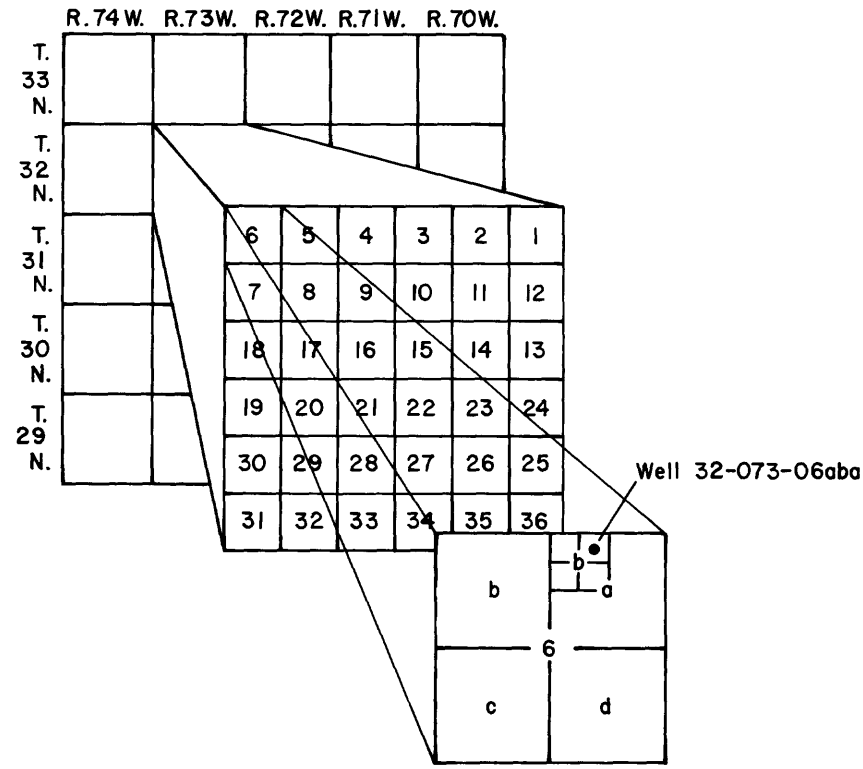


Figure 3.--Well-numbering system.

Acknowledgments

Marlin Lowry, retired U.S. Geological Survey employee, provided valuable assistance in interpreting the geology of the study area. Cooperation from landowners in the study area is also appreciated.

RECHARGE FROM STREAMFLOW

Little Box Elder Creek

Two streamflow-gaging stations were operated on Little Box Elder Creek (fig. 1), one upstream and one downstream from the outcrop of the Madison Limestone. Station 06647890, the upstream station, is on Precambrian granite just upstream from the contact with the Madison Limestone. Station 06647900, the downstream station, is about 1 mile downstream of the contact of the Madison Limestone and the Casper Formation. The streamflow data for these and other stations in this report have been published by the U.S. Geological Survey (1984).

Hydrographs for the two stations on Little Box Elder Creek (fig. 4) show that streamflow at the upper station reached the lower station only during high flow, which generally occurred during the spring. The volume of streamflow recharging the Madison Limestone between the stations was larger during years of high flow than during years of low flow (fig. 5A); the curvilinear relation of streamflow recharge to streamflow at the upstream station is shown in figure 5B. The volume of water recharged from Little Box Elder Creek to the Madison Limestone during water years 1975-84 ranged from 486 to 1,050 acre-feet per year and averaged 775 acre-feet per year; the recharge averaged 74 percent of the streamflow.

Cottonwood Creek

Two streamflow-gaging stations were operated on Cottonwood Creek. Station 06647920 is a continuous-record station one-fourth mile upstream of the contact of the Precambrian granite and the Madison Limestone. Station 06647925 is a crest-stage partial-record station at the downstream contact of the Madison Limestone and the Casper Formation.

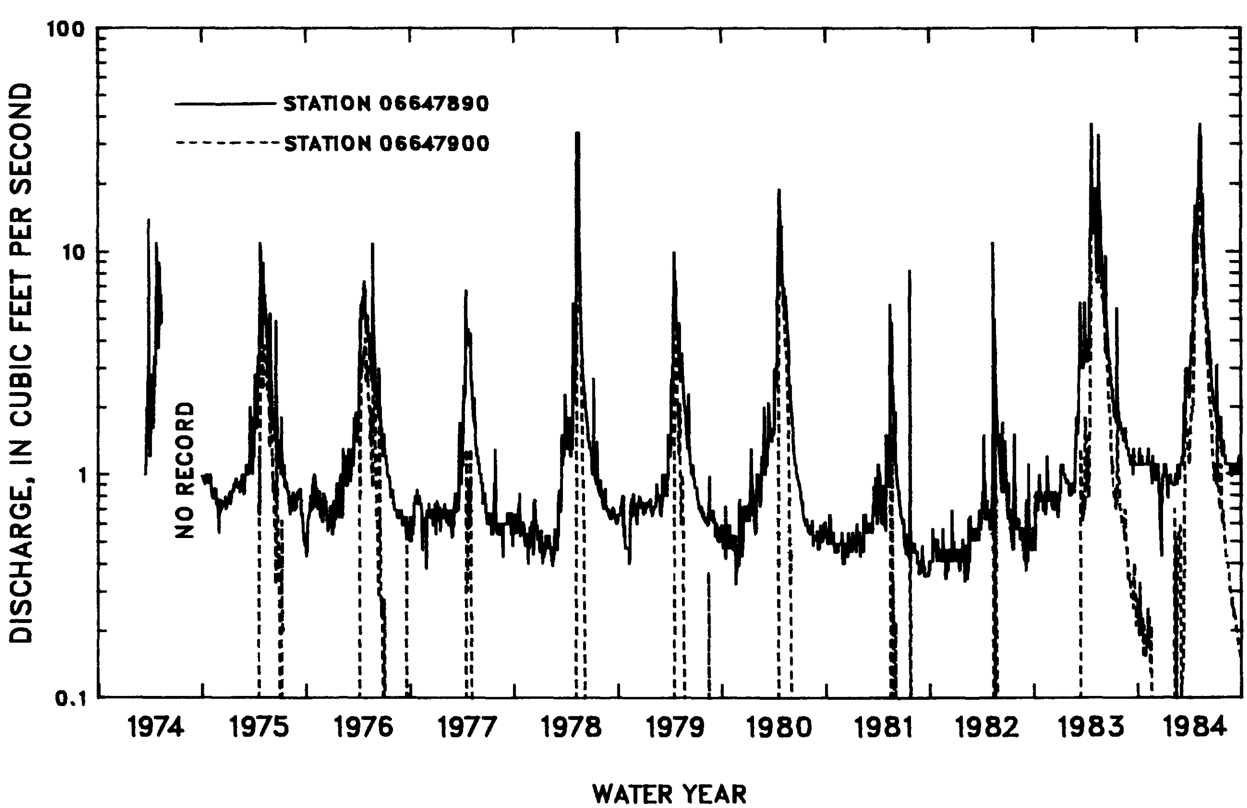


Figure 4.--Hydrographs of streamflow in Little Box Elder Creek at streamflow-gaging stations 06647890 and 06647900.

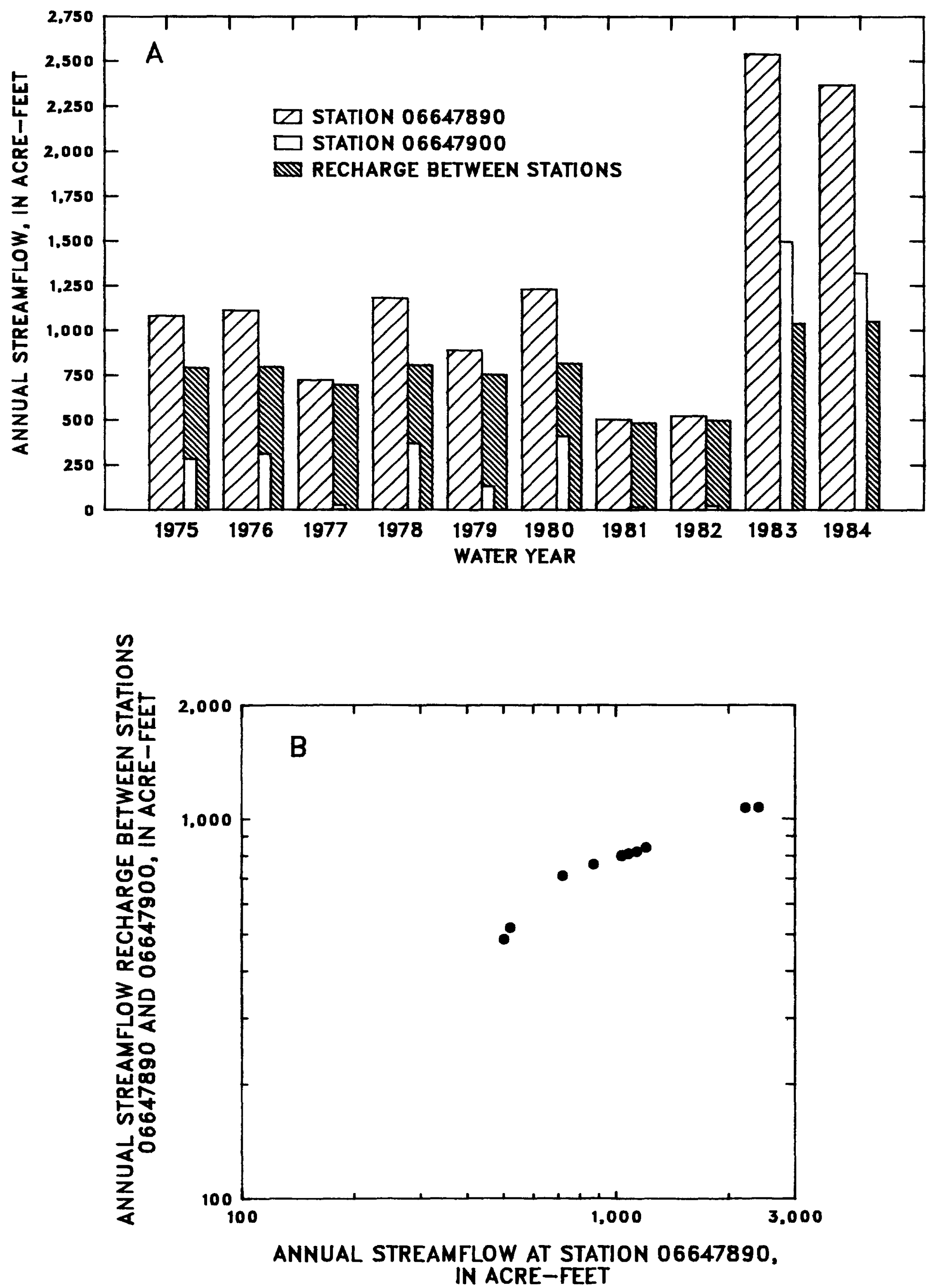


Figure 5.--A, annual streamflow in Little Box Elder Creek at streamflow-gaging stations 06647890 and 06647900; and B, relation of streamflow recharge between the stations to streamflow at the upstream station (station 06647890).

During low flow, the streamflow in Cottonwood Creek disappeared into a sinkhole in the Madison Limestone. Streamflow passed the downstream station only during maximum flows at the upstream station. The volume of streamflow at the upper station averaged 774 acre-feet per year during water years 1982-84. Recharge from Cottonwood Creek to the Madison Limestone is less than the volume passing the upstream station (average of 774 acre-feet per year), but cannot be further quantified from the partial-record data at the downstream station.

Box Elder Creek

Two streamflow-gaging stations were operated on Box Elder Creek. Station 06647800 is 3 river miles upstream from the contact of Precambrian rock and the Madison Limestone; station 06647810 is less than 1 river mile downstream from the contact of the Madison Limestone and the Casper Formation. Streamflow at the contacts generally differed from streamflow at the gaging stations by less than 10 percent (fig. 6 and Boner and others, 1976, p. 14).

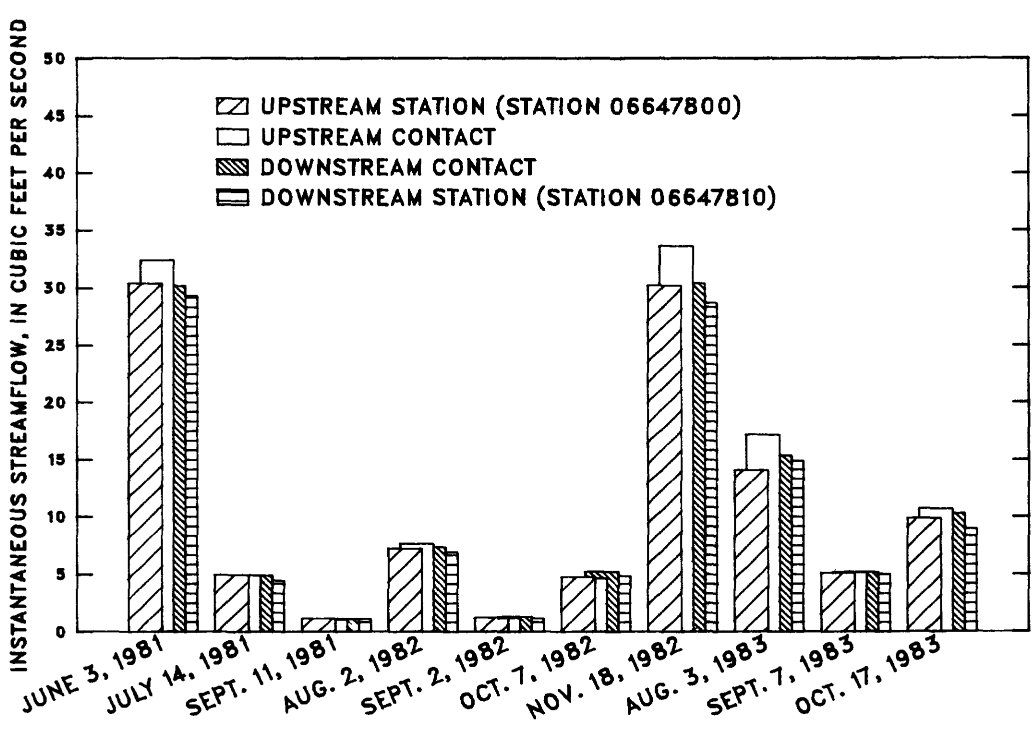


Figure 6.--Instantaneous streamflow in Box Elder Creek at the upstream and downstream streamflow-gaging stations (stations 066647800 and 06647810), and at the upstream and downstream contacts of the Madison Limestone.

Table 1.--Annual volume of streamflow or spring discharge at gaging stations

Station number	Stream or spring	Water year	Annual volume (acre-feet)
06647890	Little Box Elder Creek near Careyhurst	1975	1,080
		1976	1,110
		1977	725
		1978	1,180
		1979	890
		1980	1,230
		1981	505
		1982	525
		1983	2,540
		1984	2,370
06647900	Little Box Elder Creek at Little Box Elder Cave, near Careyhurst	1975	286
		1976	312
		1977	28
		1978	371
		1979	134
		1980	412
		1981	19
		1982	25
		1983	1,500
		1984	1,320
06647920	Cottonwood Creek near Careyhurst	1982	345
		1983	1,020
		1984	958
06647800	Box Elder Creek near Boxelder	1982	26,830
		1983	101,600
		1984	54,230
06647810	Box Elder Creek at Converse County Park, near Careyhurst	1982	27,710
		1983	101,600
		1984	55,330
06647910	Little Box Elder Spring near Careyhurst	1981	1,580
		1982	1,370
		1983	1,810
		1984	2,190

Comparison of hydrographs from the two stations on Box Elder Creek indicates that streamflow rates were nearly identical at the stations. The annual volumes of water passing the two stations also were nearly identical during water years 1982-84 (table 1); the average annual volume was 60,900 acre-feet at the upstream station, and 61,500 acre-feet at the downstream station. The difference between annual averages at the two stations was 600 acre-feet, or about 1 percent, which is well within the error associated with discharge measurements (for example, plus or minus 5 percent). Given the large secondary permeability of the formations and the recharge by Little Box Elder Creek and Cottonwood Creek, offsetting gains and losses to Box Elder Creek seem likely. One possibility is discharge to the creek from a local system offset by recharge to the regional system.

GROUND-WATER QUALITY

Principal Ions

Samples were collected from eight wells and one spring (fig. 1) for analysis of principal ions, which are calcium, magnesium, sodium, potassium, alkalinity, sulfate, chloride, fluoride, and silica. Samples were collected from locations representative of the Madison Limestone and from the Casper Formation to form a basis of comparison with water-quality samples from other locations. Water from well 32-074-08dbc was chosen as representative of water from the Madison Limestone. The well is shallow (depth of 75 feet) and is completed in the Madison Limestone above any exposures of the Casper Formation. The well chosen as representative of the Casper Formation is well 15-073-01dca, which is near Laramie, outside the study area. A location outside the study area was necessary to ensure that the water sample was representative of the Casper Formation and unaffected by water from the Madison Limestone.

As indicated by modified Stiff diagrams, calcium was the predominant cation and bicarbonate the predominant anion, based on milliequivalents per liter, in samples collected from wells 32-074-08dbc and 15-073-01dca, as well as in samples collected from four other wells and one spring (fig. 7). The four wells, which were flowing, are completed at an undocumented depth; therefore, the source of the water is unknown. However, a local resident (William Barber, oral commun., 1983) believes they are abandoned oil wells drilled during the early 1900's and completed in the Madison Limestone. A modified Stiff diagram also is shown in figure 7 for Little Box Elder Spring (station 06647910), which discharges from an outcrop of the Casper Formation. Dissolved-solids concentrations in samples collected at these sites ranged from 199 to 250 milligrams per liter (table 2).

Samples were collected in 1974 and 1981 from two wells completed in the Madison Limestone at about 6,200 to 6,500 feet below land surface. As shown in figure 7, the water temperature, and concentrations and proportions of principal ions in water from these two deep wells (wells 33-073-32cd and 33-073-32dc) were quite different from those in the well completed in the Madison Limestone near the outcrop (well 32-074-08dbc). The concentrations of dissolved solids in water from the two deep wells were 1,250 and 1,160 milligrams per liter; calcium and sulfate were the predominant ions. Swenson and others (1976) noted concentrations of dissolved solids in the Madison

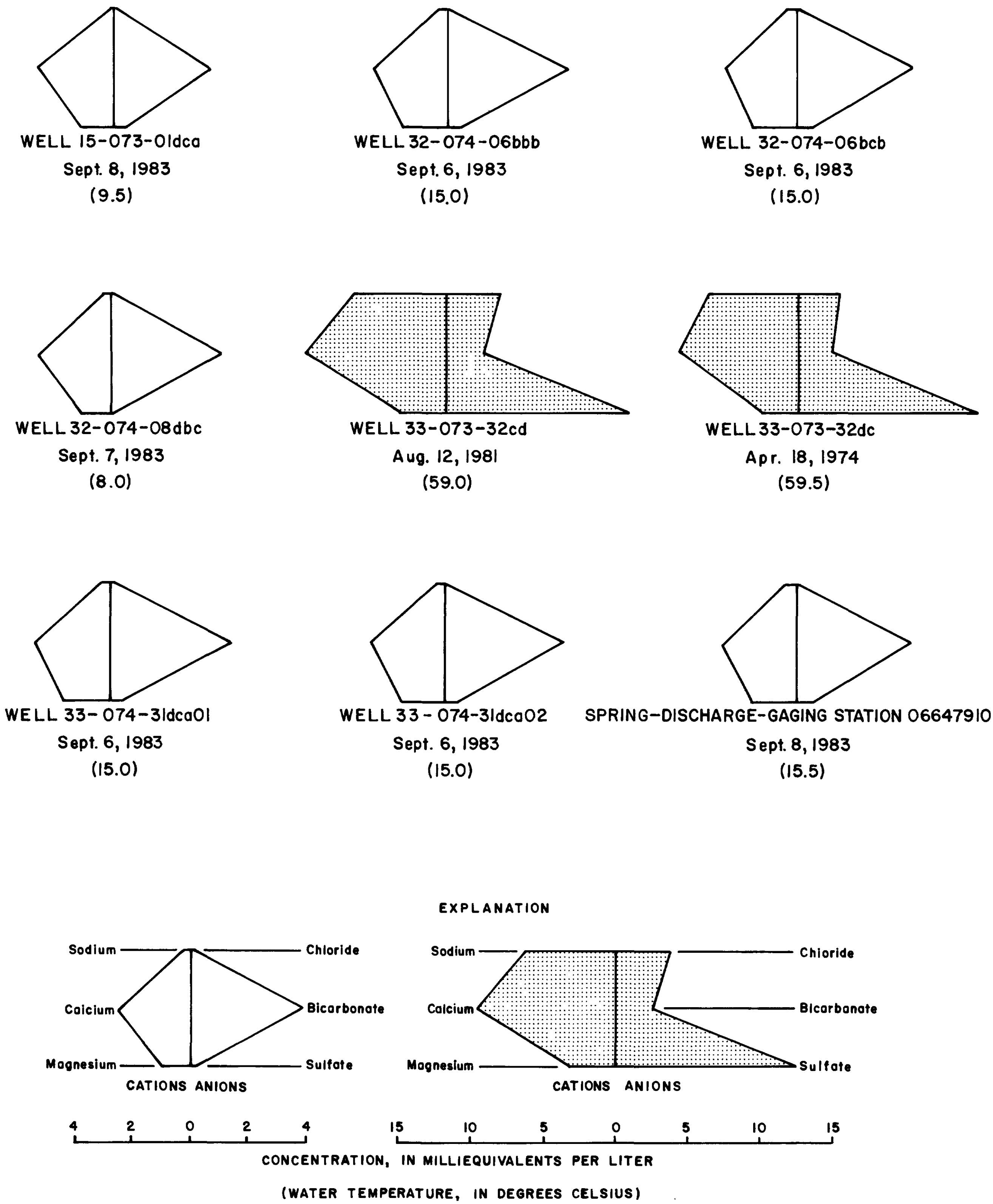


Figure 7.--Modified Stiff diagrams of principal-ion concentrations in ground-water samples.

Table 2.--Ground-water-quality data

[ft, feet; µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; mg/L, milligrams per liter; pCi/L, picocuries per liter; --, not known or not analyzed]

Station number	Date of sample	Time	Depth of well, total (ft)	Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)
15-073-01dca01	09-08-83	1800	--	400	7.9	9.5	51	13	2.4
32-074-06bbb01	09-06-83	1630	--	440	7.6	15.0	51	19	7.8
32-074-06bcb01	09-06-83	1600	--	440	7.8	15.0	50	19	7.2
32-074-08dbc01	09-07-83	1500	75	370	7.7	8.0	50	12	6.0
33-073-32cd01	08-12-81	1200	6,500+	1,620	7.1	59.0	190	39	140
33-073-32dc01	04-18-74	--	6,654	1,610	7.2	59.5	160	32	140
33-074-31dca01	09-06-83	1700	--	440	7.9	15.0	50	19	8.3
33-074-31dca02	09-06-83	1730	--	440	7.9	15.0	50	18	7.2
06647910	09-08-83	1000	--	440	7.5	15.5	51	19	8.8

Station number	Potassium, dissolved (mg/L as K)	Alkalinity, lab (mg/L as $CaCO_3$)	Sulfate, dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, dissolved, sum of constituents (mg/L)	Tritium, total (pCi/L)	Carbon-14, percent modern
15-073-01dca01	0.80	165	14	2.5	<0.1	9.4	199	--	--
32-074-06bbb01	1.9	205	15	1.4	.2	17	236	--	--
32-074-06bcb01	2.3	195	19	2.3	.3	13	231	--	--
32-074-08dbc01	2.0	184	6.2	1.4	.2	27	219	120	79.9
33-073-32cd01	21	120	620	130	1.6	39	1,250	10	--
33-073-32dc01	20	126	590	100	2.3	32	1,160	--	9.8
33-074-31dca01	1.9	205	14	1.5	.2	18	242	--	--
33-074-31dca02	2.8	200	18	2.0	.3	14	231	--	--
06647910	3.3	190	29	4.9	.3	20	250	100	81.1

Limestone increasing from less than 1,000 milligrams per liter in the study area to more than 3,000 milligrams per liter downdip in the Powder River structural basin. The concentrations of dissolved solids in samples from the two deep wells are intermediate to concentrations at the outcrop and in the basin, and are consistent with the location of the wells along a recharge path from the outcrop to the basin.

Isotopes

Concentrations of tritium (an isotope of hydrogen) indicated water circulation within the Madison Limestone and the Casper Formation near their respective outcrops. Tritium concentrations were 120 picocuries per liter in water from well 32-074-08dbc, near the outcrop of the Madison Limestone, and 100 picocuries per liter in water from Little Box Elder Spring (station 06647910). Tyler Coplen (U.S. Geological Survey, written commun., 1990) noted that a tritium concentration greater than 50 picocuries per liter indicates that the sample contains a substantial proportion of modern (post-1952) water.

The two samples from the deep wells completed in the Madison Limestone (wells 33-073-32cd and 33-073-32dc) had apparent carbon-14 ages of 16,200 and 19,200 years. The apparent ages were calculated from the equation

$$t = t_{1/2} 1.44 \ln(Ao/A) \quad (1)$$

where t = apparent carbon-14 age, in years;

$t_{1/2}$ = the half-life of carbon-14 (5,730 years);

Ao = initial activity of carbon-14; and

A = activity of carbon-14 at time t.

The apparent carbon-14 ages need to be adjusted for several factors such as dead carbon (Back and others, 1983); therefore, the ages given above are not absolute. The presence of tritium in water from well 33-073-32cd may be the result of contamination of that sample.

The isotope data in the study area are consistent with recharge from the outcrop to the regional Madison Limestone in the Powder River structural basin. In a regional study of the Madison Limestone, Busby and others (1983, p. 20 and 82-86) described a flow path northward from the study area into the basin. Busby and others (1983, p. 118) hypothesized that the Madison Limestone is permeable on a regional scale based on apparent carbon-14 ages of less than 40,000 years. In this study, the two carbon-14 ages of less than 20,000 years from samples of the deep wells are intermediate to isotopic ages at the outcrop and in the basin, similar to the pattern observed for dissolved-solids concentrations and consistent with the flow path described by Busby and others (1983).

GROUND-WATER LEVELS

A potentiometric-surface map of the Madison Limestone shows that hydraulic heads decline from the study area into the Powder River structural basin (Swenson and others, 1976). By convention, ground-water flow would be perpendicular to the potentiometric contours, in a north to northeast direction.

Wells

Ground-water levels or flow rates were measured in five wells completed in the Madison Limestone. Two wells (wells 32-074-08dbc and 32-074-03bcd) were equipped with continuous recorders. Well 32-074-08dbc is completed at 75 feet below the land surface and is about 200 yards from Little Box Elder Creek. Well 32-074-03bcd is completed at about 1,500 feet below the land surface and is about 0.25 mile from Little Box Elder Creek.

Seasonal variations in the water level in the two wells (fig. 8) corresponded to seasonal variations in streamflow and indicate recharge from Little Box Elder Creek. The highest water level during 1981-83 in well 32-74-08dbc was recorded within a few days of the maximum streamflow in Little Box Elder Creek. The highest water level in well 32-074-03bcd lagged maximum streamflow in Little Box Elder Creek by 1 to 9 weeks during the 7 years that the highest water level was recorded.

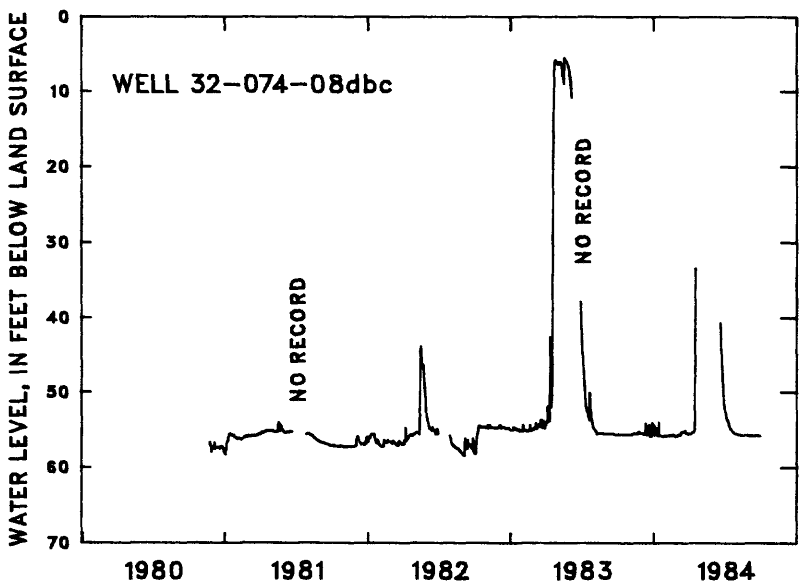
Discharges or water levels or both also were measured in three deep wells completed in the Madison Limestone at about 6,200 to 6,500 feet below land surface. During 1983-84, well 33-073-32cd discharged 34.1 to 51.4 gallons per minute and well 33-073-32dc discharged 22.9 to 34.7 gallons per minute (table 3). Flow from the two wells indicates hydraulic connection between the wells and a source of recharge. Water-level measurements from a dual completed well (32-073-06aba01 and 02) also are listed in table 3. The two perforated intervals in the well are separated by a packer; the upper perforated interval (01) is in the Casper Formation, and the lower interval (02) is in the Madison Limestone. Water levels in both formations were less than 35 feet below land surface.

Little Box Elder Spring

Little Box Elder Spring discharges inside a shelter, in which station 06647910 is operated. The Casper Formation is exposed at the land surface in the area of the spring.

The discharge of the spring varied seasonally, with maximum discharges during March to June (fig. 9). The spring discharged an average of 1,740 acre-feet per year during water years 1981-84; annual volumes ranged from 1,370 to 2,190 acre-feet (table 1).

The sources of water discharged by Little Box Elder Spring have not been determined, but possible contributions include streamflow losses from Little Box Elder Creek and Cottonwood Creek. During water years 1982-84, when data from all three water bodies were available, the average annual discharge of the spring (1,790 acre-feet) exceeded the sum of average annual losses from



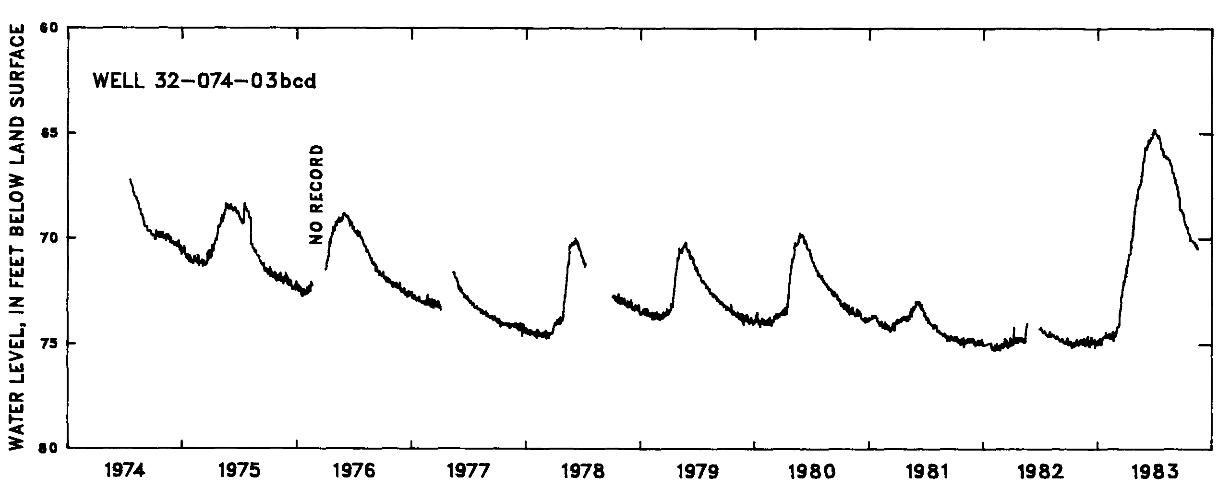


Figure 8.--Hydrographs of water levels in well 32-074-08dbc and 32-074-03bcd.

Table 3.--Discharge and water-level measurements from selected wells

[--, not measured]

Date	Discharge (gallons per minute)		Water level (feet below land surface)	
	Well 33-073-32cd	Well 33-073-32dc	Well 32-073-06aba01 Casper Formation	Well 32-073-06aba02 Madison Limestone
March 28, 1983	--	--	19.03	--
April 7, 1983	--	--	18.61	--
May 10, 1983	40.4	22.9	14.69	32.03
June 6, 1983	34.1	24.2	13.92	30.43
July 25, 1983	37.2	26.7	11.41	29.09
Sept. 21, 1984	51.4	34.7	8.38	29.64

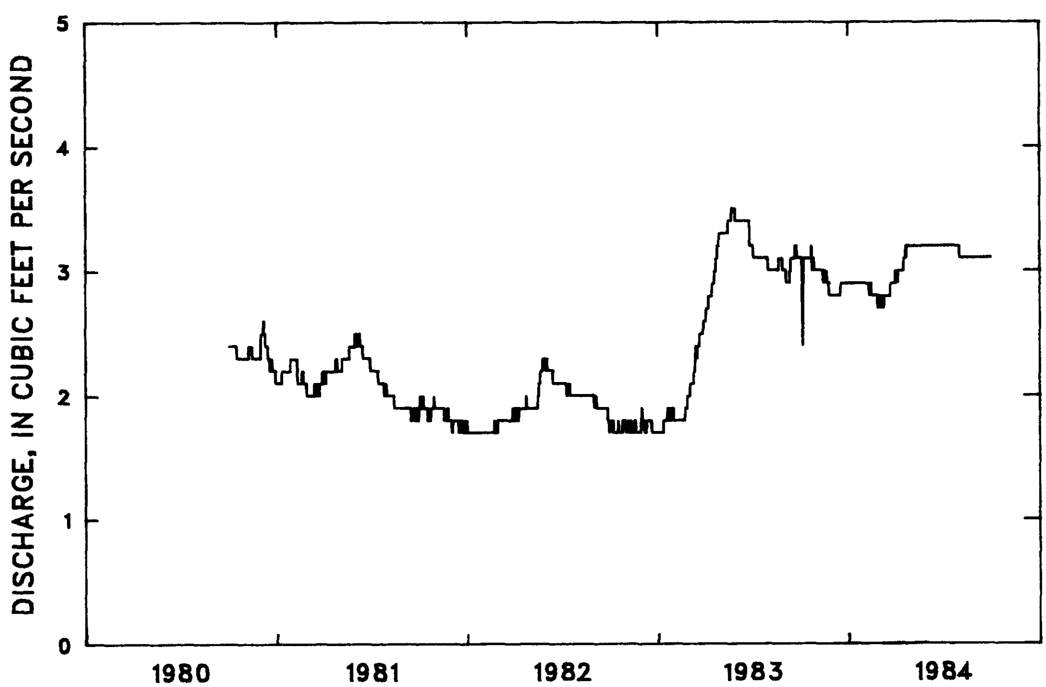


Figure 9.--Hydrograph of discharge from Little Box Elder spring.

Little Box Elder Creek (863 acre-feet) and from Cottonwood Creek (less than 774 acre-feet). This indicates contributions to the spring discharge from other sources, such as precipitation or ground-water discharge from the Casper Formation. Recharge to the spring from the creeks would indicate hydraulic connection between the Madison Limestone and the Casper Formation near the outcrops.

SUMMARY AND CONCLUSIONS

Records of streamflow from paired streamflow-gaging stations upstream and downstream from the outcrop of the Madison Limestone indicated substantial recharge to the Madison Limestone from Little Box Elder Creek and Cottonwood Creek. Recharge from the two creeks contributes, at least partially, to a local ground-water system which discharges at Little Box Elder Spring. The volume of water lost from the creeks during water years 1982-84 was less than the volume of water discharged from the spring, indicating additional contributions to the spring flow from other sources, such as precipitation or ground water from the Casper Formation. Recharge to the spring from the two creeks indicates hydraulic connection between the Madison Limestone and the Casper Formation near the outcrops. Data from the third creek in the study area, Box Elder Creek, indicated little or no net gain or loss of streamflow between the paired gaging stations. Given the large secondary permeability of the formations and recharge by two other creeks in the area, hydraulic connection of Box Elder Creek with the local or regional ground-water systems seems likely, but such connections apparently are offsetting.

Water movement within the Madison Limestone and the Casper Formation near their respective outcrops also can be inferred from water-quality data and water-level fluctuations. Tritium concentrations from well 32-074-08dbc (Madison Limestone) and Little Box Elder Spring (Casper Formation) indicated presence of modern (post-1952) water and relatively recent recharge. Records of ground-water levels in two wells (75 and about 1,500 feet deep) completed in the Madison Limestone showed seasonal fluctuations in response to seasonal fluctuations in streamflow.

Water-quality and water-level data indicate recharge from the outcrop to the deeper, buried parts of the Madison Limestone in the Powder River structural basin. Concentrations of dissolved solids and carbon-14 ages from samples of two wells completed in the Madison Limestone at about 6,200 to 6,500 feet below land surface are consistent with increases along a flow path from the outcrop to the basin as described by Swenson and others (1976) and Busby and others (1983, p. 20 and 82-86). The flow from those two wells ranged from 22.9 to 51.4 gallons per minute, also indicating hydraulic connection with a source of recharge and consistent with the potentiometric surface shown by Swenson and others (1976). The quantity of streamflow recharge to the deeper, buried parts of the Madison Limestone, in relation to that recharged to the local system near the outcrop, is not known.

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