# Estimated Groundwater Discharge to Streams from the High Plains Aquifer in the Western Model Unit of the Cooperative Hydrology Study Area for the Period Prior to Major Groundwater Irrigation

by

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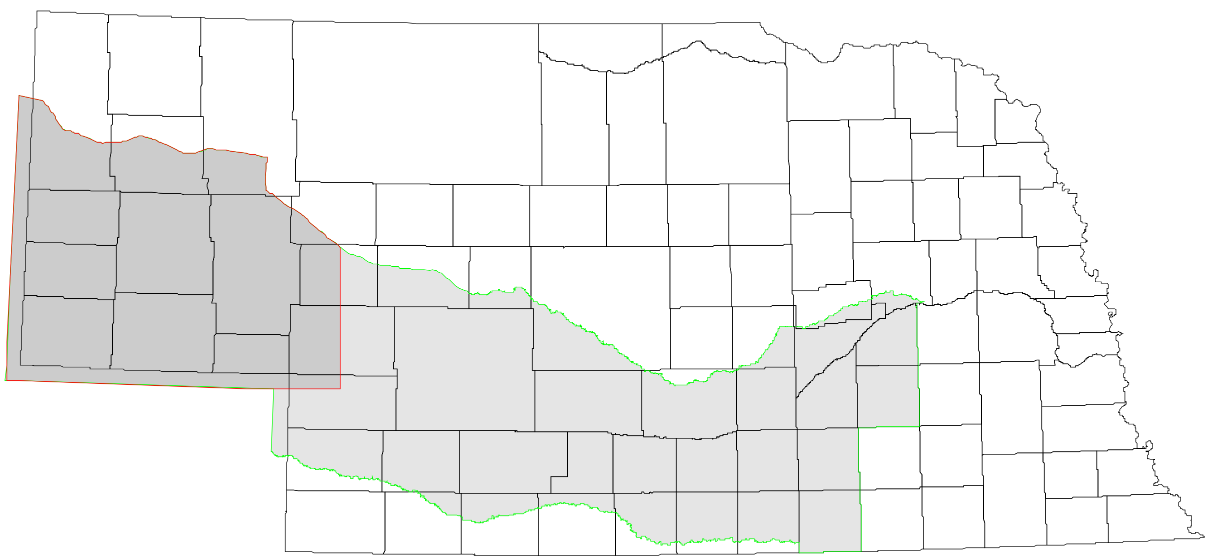

# Contents

Page



# Figures



# Tables

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## Introduction

The Cooperative Hydrology Study (COHYST) is a hydrologic study of the Platte River Basin in Nebraska upstream from Columbus, Nebraska. COHYST was started in early 1998 to develop scientifically supportable hydrologic databases, analyses, models, and other information which, when completed, will:

1. Assist Nebraska in meeting its obligations under the Three-State Cooperative Agreement (Governors of Wyoming, Colorado, and Nebraska, and the Secretary of the Interior, 1997) – for more information, see http://www.platteriver.org/;

2. Assist the Natural Resources Districts in the study area with regulation and management of groundwater;

3. Provide Nebraska with the basis for groundwater and surface-water policy; and

4. Help Nebraska analyze the hydrologic effects of proposed activities of the Three-State Cooperative Agreement.

The COHYST area (fig. 1) covers 29,300 square miles and extends from the Republican River and Frenchman Creek on the south to the Loup River, South Loup River, and a groundwater divide on the north. The eastern boundary is an arbitrary hydrologic boundary that is sufficiently east that assumptions about flow across this arbitrary boundary are likely to have minimal effect on groundwater discharge to the Platte River above Columbus. The western and southwestern boundaries also are arbitrary hydrologic boundaries in Colorado and Wyoming. These boundaries are sufficiently far from Nebraska that assumptions about flow across these arbitrary boundaries will have minimal effect on flows at the Nebraska border. In addition, the southern boundary in Colorado nearly follows a groundwater flow line, so little groundwater probably crosses this boundary.

The COHYST area is divided into three model units (fig. 1). This report covers the 11,500 square-mile Western Model Unit. Other reports cover the other model units.

The High Plains aquifer (Weeks and others, 1988) underlies nearly all of the COHYST area and consists of parts of the Brule Formation, the Arikaree Group, the Ogallala Group, and Quaternary deposits (Gutentag and others, 1984, p. 8-13; table 1 of this report). The Brule Formation is predominately a massive siltstone, but in some areas in the western part of the COHYST area, the Brule is fractured or contains sandstone or channel deposits. This part of the Brule Formation transmits large quantities of water and is included in the High Plains aquifer; the remainder of the Brule Formation transmits very little water and is excluded from the High Plains aquifer. COHYST designates that part of the Brule Formation included in the High Plains aquifer as Hydrologic Unit 8 and that part excluded as Hydrologic Unit 9.

The Arikaree Group (table 1) is predominately a fine- to very fine-grained sandstone that transmits minor quantities of water. It is an important source of water only in the western part of the COHYST area, where the Ogallala Group is absent and the Brule Formation transmits very little water. COHYST designates the Arikaree Group as Hydrologic Unit 7.

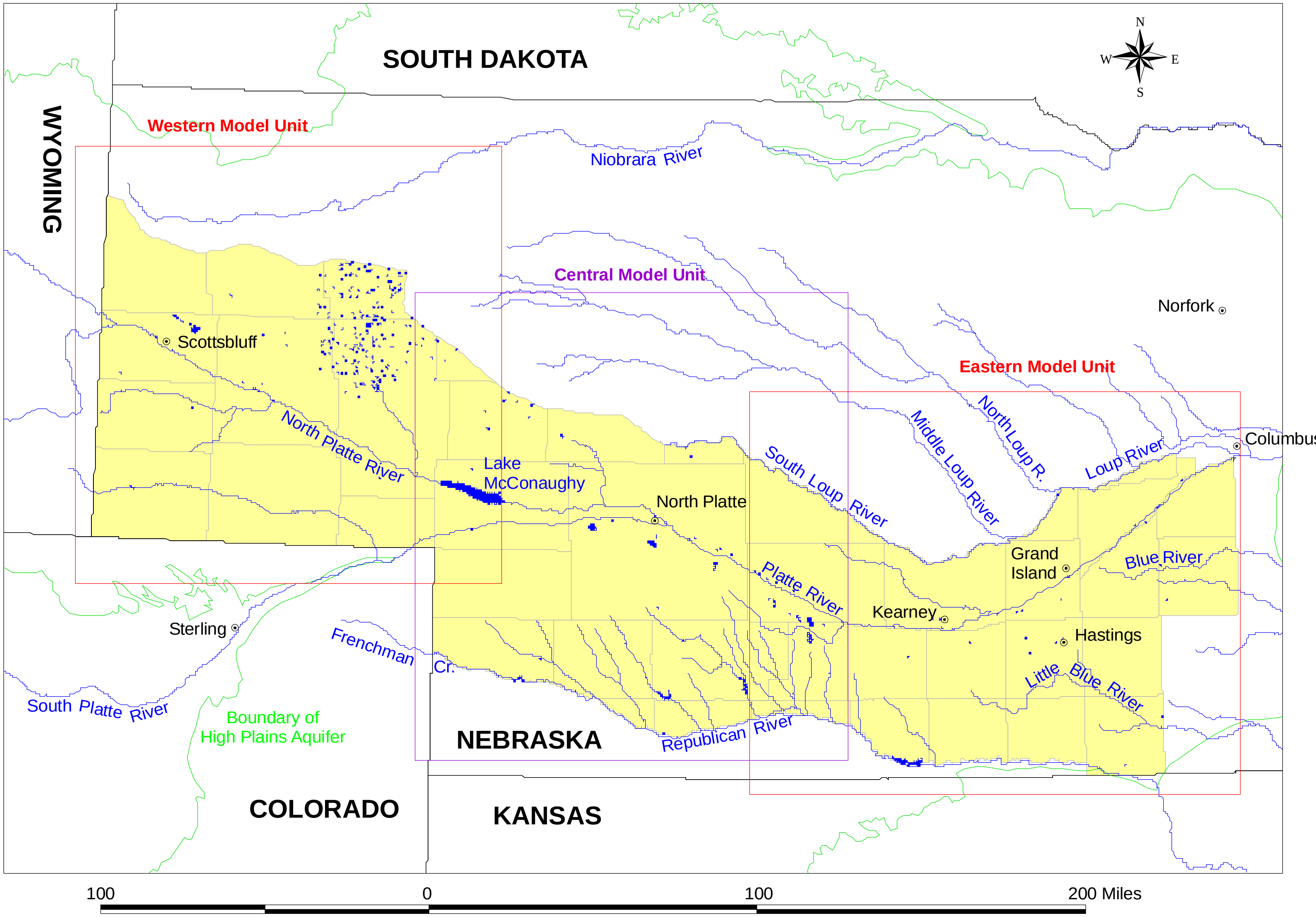


Figure 1. Cooperative Hydrology Study area (shaded) and model units.

Table 1. Stratigraphic description of geologic and hydrologic units used in the Cooperative Hydrology Study

| System | Series | Geologic Unit | Hydrologic Unit | Description |
|---|---|---|---|---|
| Quaternary | Holocene | Valley-fill deposits | Generally Unit 2 | Gravel, sand, silt, and clay with coarser materials more common. Generally stream deposits. Upper fine material, if present, is assigned to Hydrologic Unit 1. Lower fine material, if present, is assigned to Hydrologic Unit 3. |
| | Pleistocene and Holocene | Dune sand | Generally Unit 2 unless it overlies loess or other fine grained deposits, then Unit 1 | Generally fine sand but may contain some medium and even coarse sand. May also contain some finer material. Wind-blown deposits. |
| | | Loess deposits | Unit 1 when above Unit 2, otherwise Unit 3 | Generally silt, but may contain some very fine sand and clay. Deposited as wind-blown dust. |
| | Pleisto-cene | Alluvial deposits | Generally Unit 2 | Gravel, sand, silt, and clay with coarser materials more common. Generally stream deposits. Upper fine material, if present, is assigned to Hydrologic Unit 1. Lower fine material, if present, is assigned to Hydrologic Unit 3. |
| Tertiary | Upper and middle Miocene | Ogallala Group | Units 4-6 | Heterogeneous mixture of gravel, sand, silt, and clay. Generally stream deposits but also contains wind-blown deposits. Upper fine material, if present, is assigned to Hydrologic Unit 4. Center coarse material, if present, is assigned to Hydrologic Unit 5. Lower fine material, if present, is assigned to Hydrologic Unit 6. |
| | Lower Miocene and upper Oligocene | Arikaree Group | Unit 7 | Predominately very fine to fine-grained sandstone. Fluvial deposits and wind-blown volcanic deposits. |
| | Lower Oligocene | Brule Formation of White River Group | Units 8-9 | Predominately siltstone, but may contain sandstone and channel deposits. Sometimes highly fractured with areas of fracturing difficult to predict. Upper part of Brule Formation is included in High Plains aquifer and Hydrologic Unit 8 only if fractured or contains sandstone or channel deposits, otherwise it is Hydrologic Unit 9 and is excluded from the High Plains aquifer. Wind-blown volcanic deposits with some fluvial deposits. |
| | Upper Eocene | Chadron Formation of White River Group | Unit 9; below the High Plains aquifer | Silt, siltstone, clay, and claystone. Generally forms impermeable base of High Plains aquifer. Fluvial deposits and wind-blown volcanic deposits. |
| Cretaceous | Undif-ferentiated | Undifferentiated | Unit 10; below the High Plains aquifer | Shale, chalk, limestone, siltstone, and sandstone. Except for a few minor units in the extreme western part of the COHYST area and the Dakota Sandstone in the extreme eastern part of the area, generally forms an impermeable base of High Plains aquifer. Deep marine deposits to beach deposits. |

The Ogallala Group (table 1) is predominately a fluvial deposit and consists of a heterogeneous mixture of gravel, sand, silt, and clay. The Ogallala Group typically transmits large quantities of water. The Ogallala Group is absent in some western and southeastern parts of the Cooperative Hydrology Study area. COHYST subdivides the Ogallala Group into three Hydrologic Units, upper fine material (Unit 4), center coarse material (Unit 5), and lower fine material (Unit 6). Not all Hydrologic Units are present in all areas.

Quaternary deposits (table 1) consist of Pleistocene alluvial deposits, Pleistocene and Holocene loess, Pleistocene and Holocene dune sand, and Holocene valley-fill deposits. COHYST subdivides the Quaternary deposits into three Hydrologic Units, upper fine material (Unit 1), center coarse material (Unit 2), and lower fine material (Unit 3). Not all Hydrologic Units are present in all areas. Pleistocene alluvial deposits, which typically transmit large quantities of water, are found in the eastern part of the COHYST area. Loess deposits are more common in the southern and eastern parts of the study area. Loess deposits do not transmit large quantities of water, but store and slowly release large quantities of water. Dune sand is widespread north of the North Platte and Platte Rivers and also is found between the South Platte and Republican Rivers. Dune sand will store and transmit minor quantities of water, but the saturated thickness of dune sand generally is small; much larger quantities of water usually can be developed from underlying units. The valley-fill deposits are found primarily along the North Platte, South Platte, Platte, and Republican Rivers. These deposits are a heterogeneous mixture of gravel, sand, silt, and clay and typically transmit large quantities of water. The valley-fill deposits are nearly 20 miles wide along the Platte River in the vicinity of Grand Island.

Prior to substantial agricultural development, the High Plains aquifer in the COHYST area was recharged primarily by infiltration of precipitation. Infiltration occurred either directly where the precipitation fell or after it had moved some distance and possibly had reached a stream channel. To a lesser degree, the aquifer also was recharged by infiltration of streamflow during high-flow periods. Some of the high flow originated west of the aquifer and entered the area primarily by way of the North Platte and South Platte Rivers. Because the North and South Platte River Valleys contain coarse surficial materials, tributaries to these valleys frequently lost most or all of their flow near where they entered these valleys. This water recharged the aquifer within the valleys. The North and South Platte Rivers and some of their tributaries frequently flowed during rain-free periods, indicating that the aquifer discharged groundwater into the streams during these periods.

The development of dryland agriculture in the 19th century may have enhanced recharge from precipitation to some degree in upland areas because of soil cultivation and replacement of natural grasses with crops. The development of a system of large irrigation canals in the river valleys beginning in the 1890s (Kuzelka and others, 1993) added major new components to the groundwater system. The canal systems seeped substantial amounts of water that subsequently recharged the aquifer. Canal water applied to fields also recharged the aquifer.

Prior to substantial agricultural development, the aquifer primarily discharged to streams, springs, seeps, and high water-table evapotranspiration. Discharge to springs and seeps generally occurred close to streams, and water from the springs and seeps frequently reached the streams. Evapotranspiration directly from the aquifer occurred in wetlands, where the water table was near the land surface, where springs and seeps brought water to the surface, and along streams. Direct evapotranspiration from the water table by cottonwood or similar trees occurred where the depth to water was as much as 20 to 30 feet (Robinson, 1958, p. 62). During the nongrowing season, evapotranspiration was reduced dramatically and streamflow increased by a corresponding amount. The sum of groundwater discharge to streams and evapotranspiration was reasonably constant over time where it represented discharge from a large area of the aquifer. Where the discharge was from a smaller area of aquifer, it was less constant.

The purpose of this report is to present estimates of groundwater discharge from the High Plains aquifer to streams in the Western Model Unit of the COHYST area (fig. 1). These estimates will be used in calibrating the flow models of the Western Model Unit. Ideally, the estimates for model calibration would be for the period prior to large perturbation of the hydrologic system by agricultural development. However, that is not possible because some canals were constructed as early as the 1890s and streamflow information is scarce prior to the 1930s. Sufficient information is available, however, to estimate groundwater discharge to streams prior to large-scale groundwater development for irrigation. Groundwater development for irrigation was severely limited by pump technology early in the 20th century. Droughts in the 1950s and 1970s spurred additional increases in development of the aquifer (fig. 2). Some groundwater irrigation took place prior to 1946; that date is used by COHYST as the beginning of the groundwater development period. By 1945, there were slightly more than 1,000 irrigation wells in the COHYST area. This increased to 14,000 by 1960; 37,000 by 1980; and 46,000 by 1997.

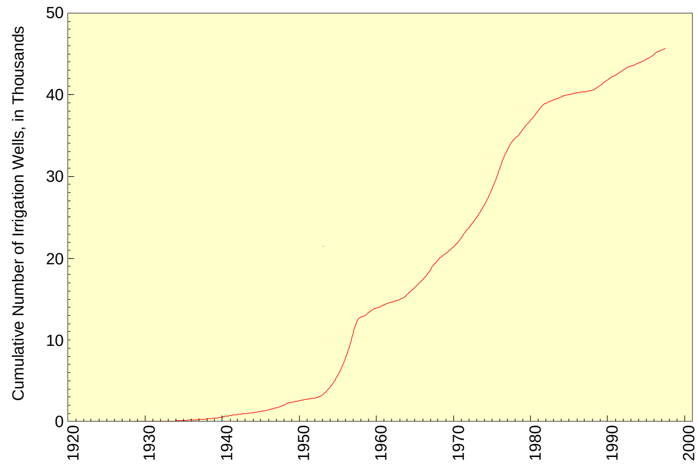


Figure 2. Irrigation well development in the Cooperative Hydrology Study area.

## Streamflow-Gaging Network

Daily stream discharge data were the source of information used to estimate groundwater discharge to streams for the pre-groundwater development period. Although the pre-groundwater development period is defined as before 1946, streamflow in the Western Model Unit was not affected substantially by groundwater development until at least the 1970s and the effect was obvious at only one stream. The reason that groundwater development has not affected the streams is not known, but may be because recharge from canal leakage and surface-water irrigation is large compared to groundwater pumpage.

All of the major streams in the Western Model Unit had sufficient discharge data to make estimates of groundwater discharge. All daily-value streamflow-gaging stations on streams in Nebraska with at least 4 years of record within or near the Western Model Unit and the Colorado station on the South Platte River at Julesburg were considered for analysis (fig. 3; table 2). There were 31 daily-value streamflow-gaging stations that met the initial criteria; 25 were used in the analysis.

## Low-Flow Analysis

Groundwater discharge to streams is best estimated using periods that are least affected by human activities. During the spring and summer, diversions, returns of diversions, runoff from irrigation, runoff from precipitation, and evapotranspiration from the woodlands and wetlands along the streams affect the natural flow of most streams in the Western Model Unit. During the winter, the ice often affects the flow of streams, and the ice effects can reduce the accuracy of streamflow estimates. During the fall, diversions, runoff, and evapotranspiration are much less and the flow of streams frequently is dominated by groundwater discharge from the aquifer. For these reasons, the period October 1 through November 30 was selected for this analysis; this period is called “fall” in this report.

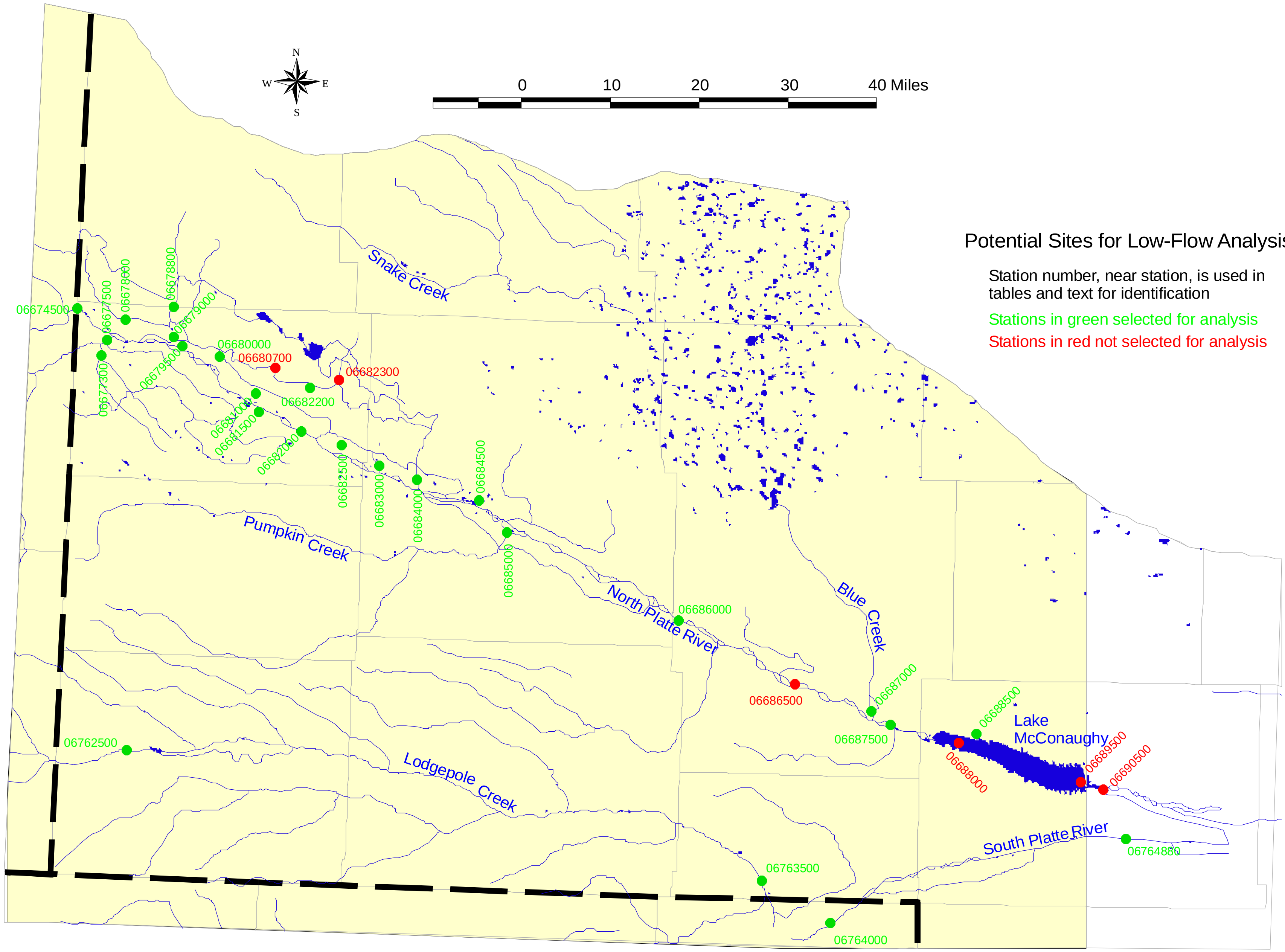


Figure 3. Streamflow-gaging stations in the Western Model Unit of the Cooperative Hydrology Study area with 4 or more years of daily streamflow discharges for October-November.

Table 2. Streamflow-gaging stations in or near the Western Model Unit of the Cooperative Hydrology Study area that were considered for analysis

| Station number | Station name | Periods of fall flows through 1997 available for analysis (calendar years) | Remarks |
|---|---|---|---|
| 06674500 | North Platte River at Wyoming-Nebraska State Line | 1929-97 | Station used in analysis. Only 1941-97 data used in analysis. |
| 06677300 | Kiowa Creek near Lyman, Nebraska | 1961-64 | Station used in analysis. |
| 06677500 | Horse Creek near Lyman, Nebraska | 1931-97 | Station used in analysis. |
| 06678000 | Sheep Creek near Morrill, Nebraska | 1931-90, 1992-97 | Station used in analysis. |
| 06678800 | Dutch Flats Drain near Mitchell, Nebraska | 1961-64 | Station used in analysis. Flows only because of canals and surface-water irrigation. |
| 06679000 | Dry Spottedtail Creek at Mitchell, Nebraska | 1948-82,1986-97 | Station used in analysis. |
| 06679500 | North Platte River at Mitchell, Nebraska | 1901-09, 1911, 1920-97 | Station used in analysis. Only 1941-97 data used in analysis. |
| 06680000 | Tub Springs Drain near Scottsbluff, Nebraska | 1948-82, 1986-92, 1994-97 | Station used in analysis. Flows only because of canals and surface-water irrigation. |
| 06680700 | Winters Creek at Tri-State Canal near Scottsbluff, Nebraska | 1961-64 | Not used in analysis because of short period of record. |
| 06681000 | Winters Creek near Scottsbluff, Nebraska | 1931-83, 1986-97 | Station used in analysis. Perennial only short distance above canal. |
| 06681500 | Gering Drain near Gering, Nebraska | 1931-44,1948-97 | Station used in analysis. Flows only because of canals and surface-water irrigation. |
| 06682000 | North Platte River near Minatare, Nebraska | 1917, 1923-97 | Station used in analysis. Only 1941-97 data used in analysis. |
| 06682200 | Alliance Drain near Minatare, Nebraska | 1961-64 | Station used in analysis. Flows only because of canals and surface-water irrigation. |
| 06682300 | Ninemile Drain near Minatare, Nebraska | 1961-64 | Not used in analysis because of short period of record. |
| 06682500 | Ninemile Drain near McGrew, Nebraska | 1932-97 | Station used in analysis. Flows only because of canals and surface-water irrigation. |
| 06683000 | Bayard Sugar Factory Drain near Bayard, Nebraska | 1931-82, 1986-97 | Station used in analysis. Flows only because of canals and surface-water irrigation. |
| 06684000 | Red Willow Creek near Bayard, Nebraska | 1931-82, 1986-97 | Station used in analysis. Flows only because of canals and surface-water irrigation. |
| 06684500 | North Platte River at Bridgeport, Nebraska | 1902-06, 1916-97 | Station used in analysis. Only 1941-97 data used in analysis. |
| 06685000 | Pumpkin Creek near Bridgeport, Nebraska | 1931-97 | Station used in analysis. |
| 06686000 | North Platte River at Lisco, Nebraska | 1931-97 | Station used in analysis. Only 1941-97 data used in analysis. |
| 06686500 | North Platte River at Oshkosh, Nebraska | 1928-59 | Not used because period of record inconsistent with other stations on North Platte River. |
| 06687000 | Blue Creek near Lewellen, Nebraska | 1930-97 | Station used in analysis. Only November data used. |
| 06687500 | North Platte River at Lewellen, Nebraska | 1941-97 | Station used in analysis. Only 1941-97 data used in analysis. |
| 06688000 | North Platte River at Belmar, Nebraska | 1918, 1920-25 | Not used in analysis because of short period of record. |
| 06688500 | Otter Creek near Lemoyne, Nebraska | 1932-36 | Station used in analysis. |
| 06689500 | North Platte River at Martin, Nebraska | 1933-37 | Not used in analysis because of short period of record. |
| 06690500 | North Platte River near Keystone, Nebraska | 1942-97 | Not used in analysis. Represents releases from Lake McConaughy. |
| 06762500 | Lodgepole Creek at Bushnell, Nebraska | 1931-97 | Station used in analysis. Only 1951-78 used in analysis. |
| 06763500 | Lodgepole Creek at Ralton, Nebraska | 1951-78 | Station used in analysis. Only 1951-78 used in analysis. |
| 06764000 | South Platte River at Julesburg, Colorado | 1902-97 | Station used in analysis. |
| 06764880 | South Platte River at Roscoe, Nebraska | 1982-97 | Station used in analysis. |

The North Platte River, Horse Creek (06677500– station number used in figures and tables), and the South Platte River have large drainage areas outside the COHYST area. These streams have several large reservoirs on them and these reservoirs generally store much of the streamflow in the fall, effectively reducing the drainage area to that below the most downstream reservoir. The method used in this analysis favored periods during the fall when the reservoirs were storing water.

During the fall, the streamflows are presumed to be dominated by groundwater discharge from the aquifer. The higher flows may contain some component of runoff from precipitation. By focusing only on the lowest flows, the streamflow analysis should allow an estimation of groundwater discharge to the streams. Although evapotranspiration still takes place during the fall, it is assumed to be small compared to groundwater discharge and thus to have minimal effect on the results.

The lowest mean stream discharges for 7 and 14 consecutive days for each October-November were calculated for each station used in the analysis. These are called the fall 7- and 14-day low flows for each particular year. By averaging stream discharge for 7 or 14 days, anomalous short-term discharge events are filtered out of the data. The fall 7- and 14-day low flows were plotted against time to see if they changed over time. A typical example is shown in figure 4. Lodgepole Creek (fig. 5) had a decline in fall low flows starting in the 1970s, so only flows through 1973 were used in the analysis. Fall low flows at all other stations varied but did not appear to trend upward or downward over time.

Some early fall diversions took place above one station, Blue Creek (fig. 6) near Lewellen (06687000). These diversions only occurred during some years and then often took place for only a few days or weeks. Only in a few years did these diversions extend into November. Therefore, the period November 1 through November 30 was selected for low-flow analysis for this station only.

Because differences in fall low flows between streamflow-gaging stations were important in this analysis, comparable periods of record were desirable. The North Platte River had ten streamflow-gaging stations with various periods of record, but two of the stations had only short periods of record. Most of the other eight stations on the North Platte River had fall flows available for 1941 through 1997, so this period was used in the analysis. The streamflow-gaging station at Oshkosh (06686500) was not used in the analysis because it did not operate during much of this period. Lodgepole Creek had four streamflow-gaging stations, but two stations had only a single year of data and were not considered for analysis. The common period of record (1951 through 1978) for the other two stations was used in this analysis. The South Platte River had two streamflow-gaging stations in or near the Western Model Unit. Their common period of record (1982 through 1997) was used in this analysis.

The fall 7- and 14-day low flows for the period of record used in the analysis were ranked from smallest to largest, and the probability that the fall low flow was not exceeded in any 1 year was calculated using the formula (Riggs, 1968, p. 7):

$$P\{nonexceedence\} = \frac{K}{N+1} \qquad (1)$$

where $P\{nonexceedence\}$ is the probability that the fall 7- or 14-day low flow is not exceeded in any given year;

$K$ is the rank number of the flow for that year, with the lowest 7- or 14-day low flow ranked 1 and the highest flow ranked $N$; and

$N$ is the number of years in the analysis.

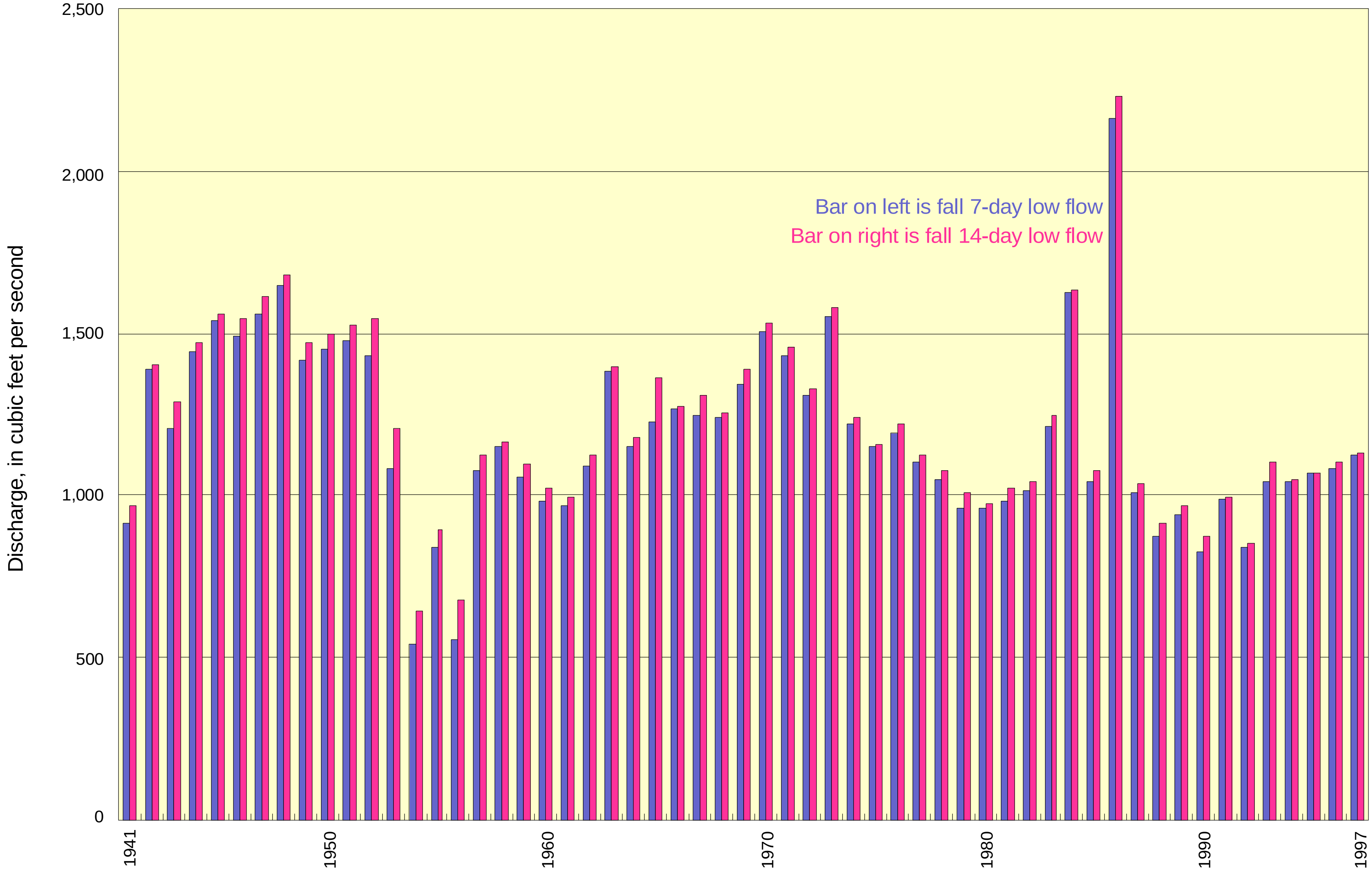


Figure 4. Fall (October-November) 7- and 14-day low flows for the North Platte River at Bridgeport, Nebraska, for calendar years 1941 through 1997.

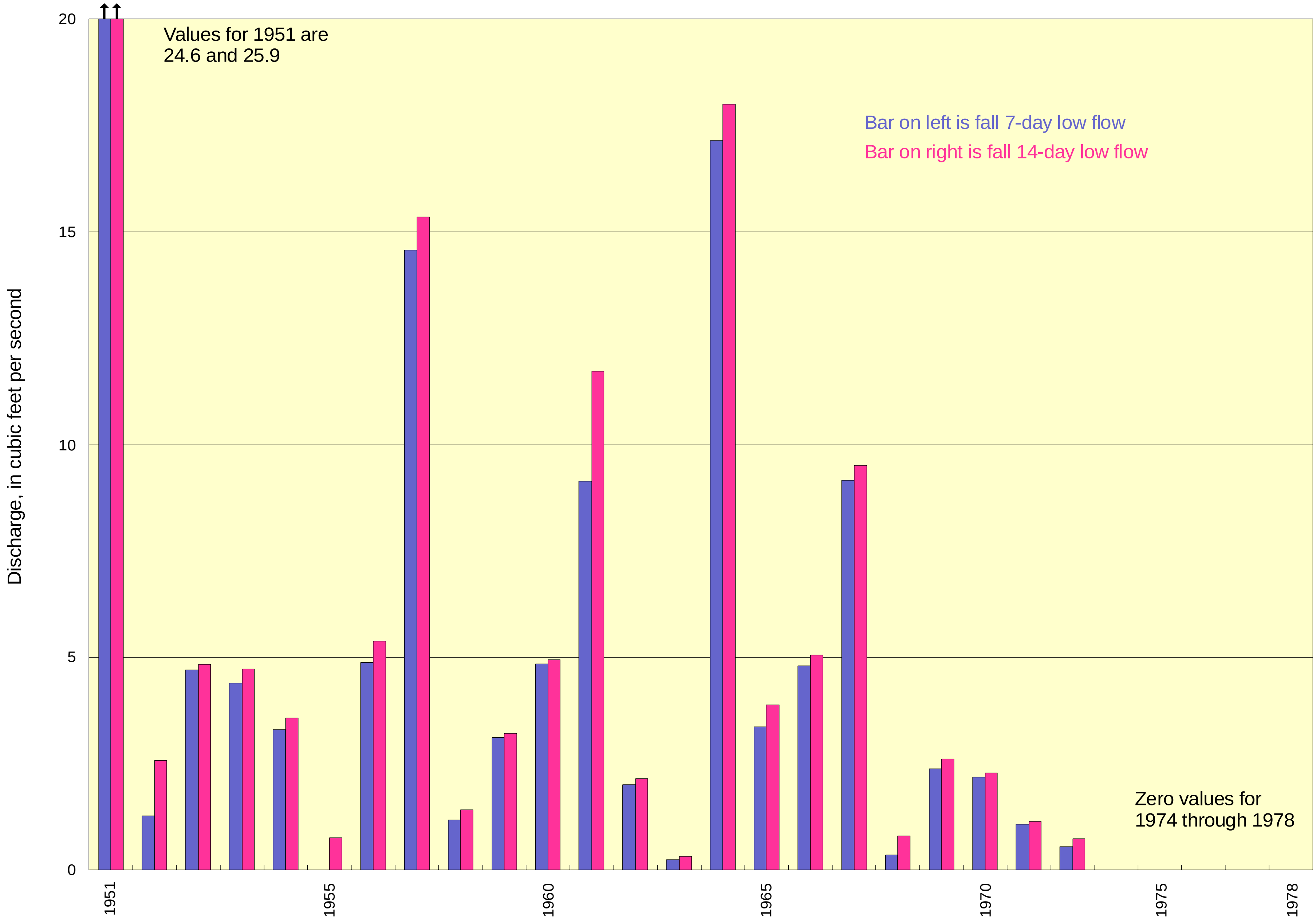


Figure 5. Fall (October-November) 7- and 14-day low flows for Lodgepole Creek at Ralton, Nebraska, for calendar years 1951 through 1978.

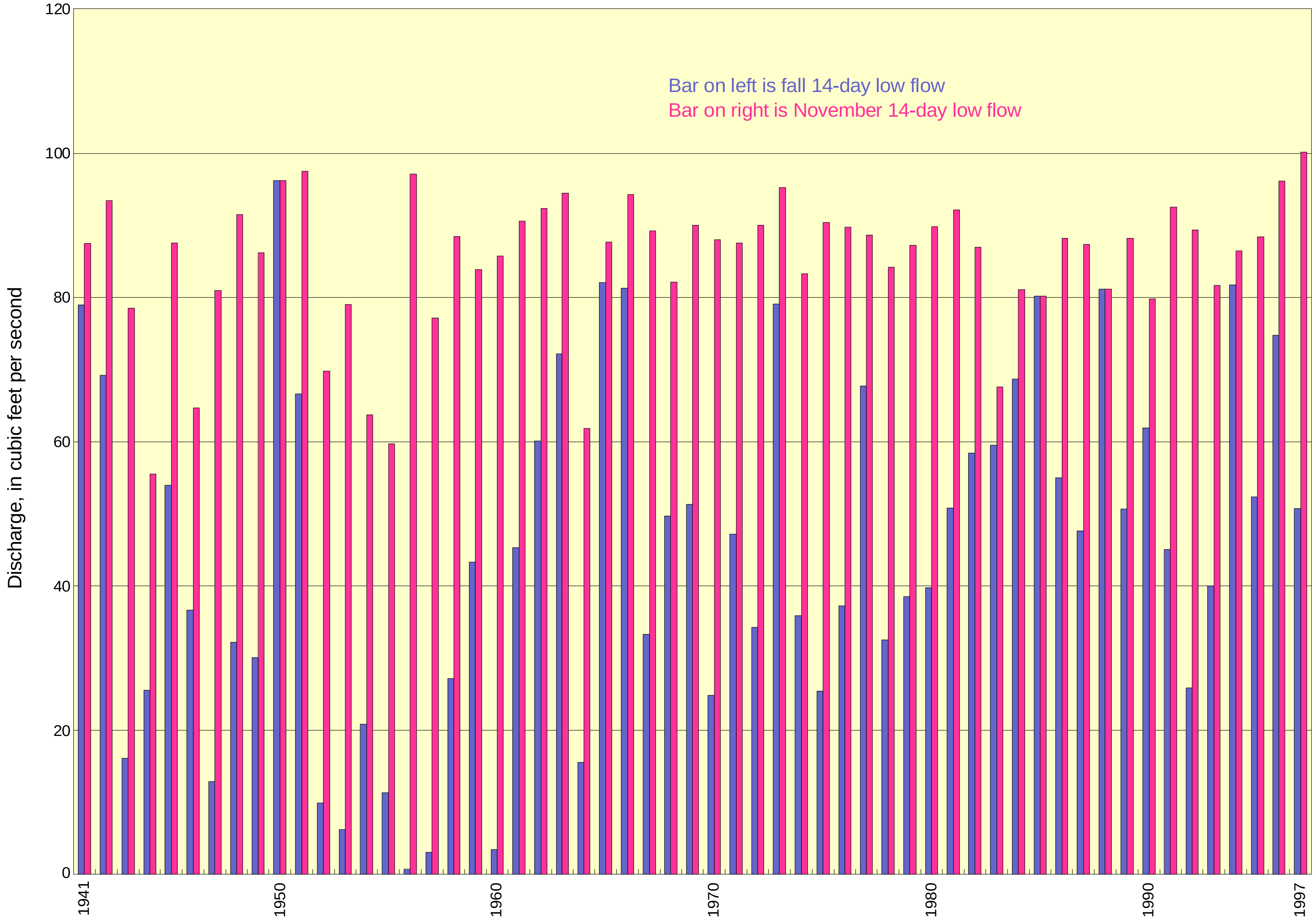


Figure 6. Fall (October-November) and November 14-day low flows for Blue Creek near Lewellen, Nebraska, for calendar years 1941 through 1997.

The recurrence interval, which is the reciprocal of the probability of nonexceedence, was calculated using the formula (Riggs, 1968):

$$T = \frac{1}{P\{nonexceedence\}} = \frac{N+1}{K} \qquad (2)$$

where $T$ is the recurrence interval, in years, and the other variables are as defined in Equation 1.

The fall 7- and 14-day low flows were plotted against the probability of nonexceedence (or recurrence interval) and smooth curves were drawn through the general trend of the points. These curves were used to estimate the fall 7-day and 14-day low flows with recurrence intervals of 5 and 2 years (fig. 7). The fall 7-day low flow with a recurrence interval of 5 years (probability of 0.2) was used as the minimum estimate of groundwater discharge passing the streamflow-gaging station (table 3). The fall 14-day low flow with a recurrence interval of 2 years (probability of 0.5) was used as the maximum. Shorter recurrence intervals were not used because these streamflows may have contained some component of runoff from precipitation. The mean estimate of groundwater discharge passing the station was defined as the arithmetic average of the minimum and maximum estimate. Smaller streams tended to have streamflow-gaging stations near their mouths, so groundwater discharge was estimated for essentially the entire stream.

The largest estimated groundwater discharge passing a streamflow-gaging station occurred at the North Platte River at Lewellen (06687500) where the estimate was 1,100 to 1,400 cubic feet per second. This was the combined groundwater discharge to the North Platte River and all its tributaries upstream of this station, but downstream of the most downstream reservoirs west of the COHYST area. Some of the estimated groundwater discharge would have come from beyond the COHYST area. The largest estimated groundwater discharge to a tributary occurred at Ninemile Drain near McGrew (06682500) where the estimate was 87 to 110 cubic feet per second.

The North Platte River had several streamflow-gaging stations so groundwater discharge to this stream could be estimated by reach. The South Platte River and Lodgepole Creek each had two stations that were used in the analysis, so groundwater discharge to these streams also could be estimated by reach, but not to the level of detail possible for the North Platte River.

For streams with multiple streamflow-gaging stations, the fall 7-day, 5-year and 14-day, 2-year low flows were computed using a consistent period of record for the upstream station, the downstream station, and where possible, any stations on contributing tributaries. For each station, the arithmetic average of the 7-day, 5-year and the 14-day, 2-year low flows was computed. The estimated mean groundwater discharge to or from the stream in the reach could have been computed as the mean low flow at the downstream station minus the mean low flows at the upstream and any tributary stations. However, the method of subtracting means would not provide a minimum and maximum estimate of groundwater gain or loss within the reach, so an alternative approach was used.

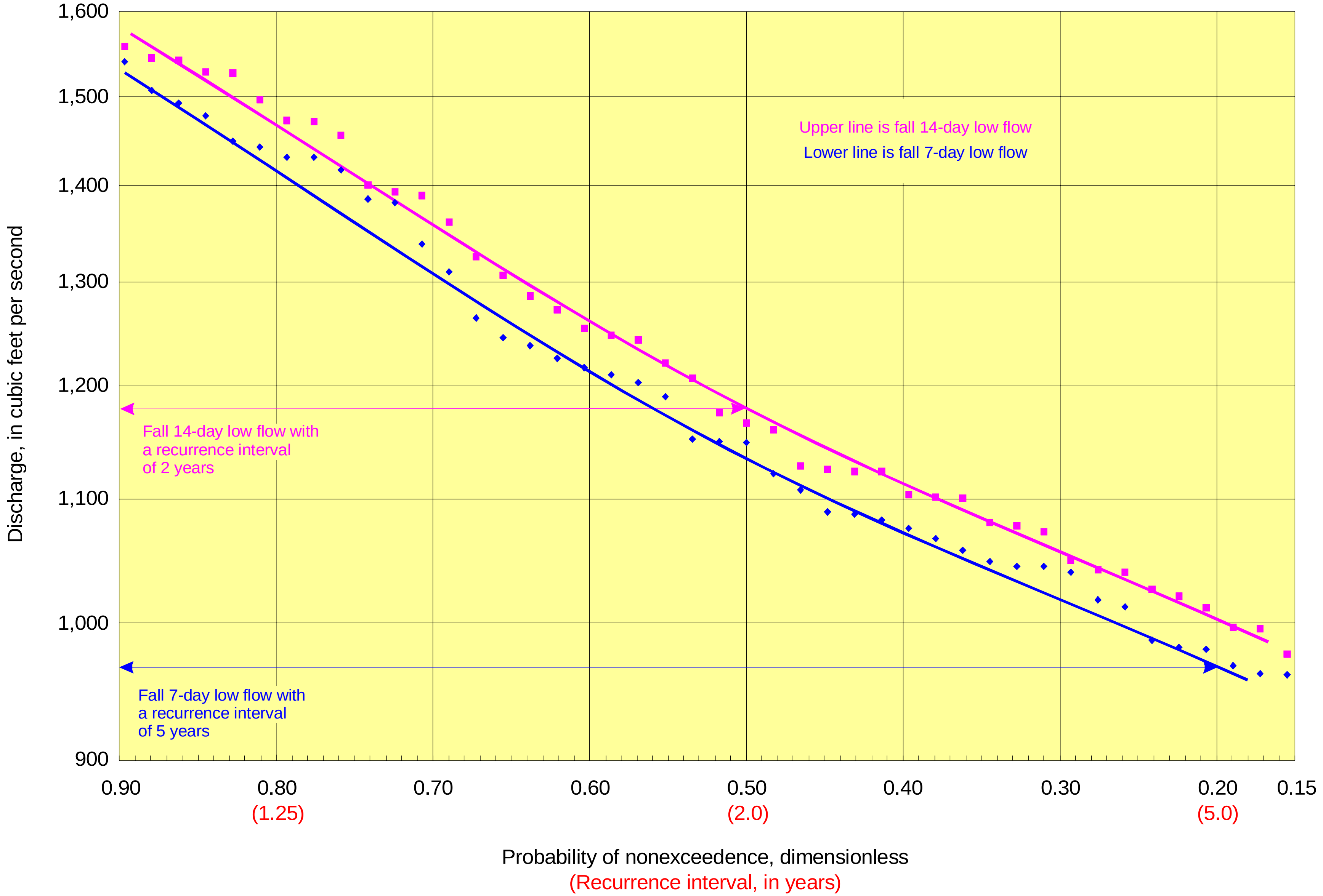


Figure 7. Frequency curves for fall (October-November) 7- and 14-day low flows for the North Platte River at Bridgeport, Nebraska, for calendar years 1941 through 1997.

## Table 3. Estimated groundwater discharge at streamflow-gaging stations

[$ft^3/s$, cubic feet per second; COHYST, Cooperative Hydrology Study]

| Station number | Station name | Period of analysis (calendar years) | Estimated groundwater discharge to streams ($ft^3/s$) | | | Remarks |
|---|---|---|---|---|---|---|
| | | | Minimum | Mean | Maximum | |
| 06674500 | North Platte River at Wyoming-Nebraska State line | 1941-97 | 260 | 300 | 330 | For reference only to compute groundwater discharge by reach. This station is near the COHYST boundary. |
| 06677300 | Kiowa Creek near Lyman, Nebraska | 1961-64 | 14 | 18 | 21 | Part of groundwater discharge is result of canal leakage and irrigation return flow. |
| 06677500 | Horse Creek near Lyman, Nebraska | 1931-97<br>1941-97 | 26<br>31 | 31<br>35 | 36<br>38 | Much of the drainage area of this stream is outside the COHYST area. Groundwater discharge includes that from Kiowa Creek. Part of groundwater discharge is result of canal leakage and irrigation return flow. |
| 06678000 | Sheep Creek near Morrill, Nebraska | 1931-97<br>1941-97 | 66<br>75 | 78<br>83 | 90<br>90 | Most of groundwater discharge probably is result of canal leakage and irrigation return flow. |
| 06678800 | Dutch Flats Drain near Mitchell, Nebraska | 1961-64 | 5 | 6 | 6 | Most of groundwater discharge probably is result of canal leakage and irrigation return flow. Estimates may be in considerable error because of short period of record. |
| 06679000 | Dry Spottedtail Creek at Mitchell, Nebraska | 1948-82,1986-97 | 19 | 21 | 23 | Most of groundwater discharge probably is result of canal leakage and irrigation return flow. |
| 06679500 | North Platte River at Mitchell, Nebraska | 1941-97 | 530 | 550 | 580 | Groundwater discharge includes that which passed State Line and that contributed by Kiowa Creek, Horse Creek, Sheep Creek, Dutch Flats Drain, and Dry Spottedtail Creek. |
| 06680000 | Tub Springs Drain near Scottsbluff, Nebraska | 1948-82, 1986-92, 1994-97 | 37 | 40 | 43 | Most of groundwater discharge probably is result of canal leakage and irrigation return flow. |
| 06681000 | Winters Creek near Scottsbluff, Nebraska | 1931-83, 1986-97 | 46 | 48 | 51 | Most of groundwater discharge probably is result of canal leakage and irrigation return flow. |
| 06681500 | Gering Drain near Gering, Nebraska | 1931-44, 1948-97 | 24 | 27 | 30 | Most of groundwater discharge probably is result of canal leakage and irrigation return flow. |
| 06682000 | North Platte River near Minatare, Nebraska | 1941-97 | 760 | 810 | 870 | Groundwater discharge includes that which passed Mitchell and that contributed by Tub Springs Drain, Winters Creek, and Gering Drain. |
| 06682200 | Alliance Drain near Minatare, Nebraska | 1961-64 | 4 | 8 | 13 | Most of groundwater discharge probably is result of canal leakage and irrigation return flow. Estimates may be in considerable error because of short period of record. |
| 06682500 | Ninemile Drain near McGrew, Nebraska | 1932-97 | 87 | 96 | 110 | Most of groundwater discharge probably is result of canal leakage and irrigation return flow. Groundwater discharge includes that contributed by Alliance Drain. |

Table 3. Estimated groundwater discharge at streamflow-gaging stations – continued

| Station number | Station name | Period of analysis (calendar years) | Estimated groundwater discharge to streams ($ft^3/s$) | | | Remarks |
|---|---|---|---|---|---|---|
| | | | Minimum | Mean | Maximum | |
| 06683000 | Bayard Sugar Factory Drain near Bayard, Nebraska | 1931-82, 1986-97 | 22 | 24 | 27 | Most of groundwater discharge probably is result of canal leakage and irrigation return flow. |
| 06684000 | Red Willow Creek near Bayard, Nebraska | 1931-82, 1986-97 | 72 | 78 | 83 | Most of groundwater discharge probably is result of canal seepage and irrigation return flow. |
| 06684500 | North Platte River at Bridgeport, Nebraska | 1941-97 | 970 | 1,100 | 1,200 | Groundwater discharge includes that which passed Minatare and that contributed by Alliance Drain, Ninemile Drain, Bayard Sugar Factory Drain, and Red Willow Creek. |
| 06685000 | Pumpkin Creek near Bridgeport, Nebraska | 1931-97<br>1941-97<br>1931-73 | 7<br>7<br>13 | 10<br>10<br>18 | 14<br>14<br>22 | Part of groundwater discharge is result of canal leakage and irrigation return flow. |
| 06686000 | North Platte River at Lisco, Nebraska | 1941-97 | 1,100 | 1,200 | 1,300 | Groundwater discharge includes that which passed Bridgeport and that contributed by Pumpkin Creek. |
| 06687000 | Blue Creek near Lewellen, Nebraska | 1930-97<br>1941-97 | 72<br>78 | 79<br>83 | 86<br>87 | Analysis is based on November data only because some storage diversions occur in October. A small part of groundwater discharge is result of canal leakage and irrigation return flow. |
| 06687500 | North Platte River at Lewellen, Nebraska | 1941-97 | 1,100 | 1,300 | 1,400 | Groundwater discharge includes that which passed Lisco and that contributed by Blue Creek. |
| 06688500 | Otter Creek near Lamoyne, Nebraska | 1932-36 | 16 | 18 | 19 | Estimates may be in considerable error because of short period and poor quality of record. |
| 06762500 | Lodgepole Creek at Bushnell, Nebraska | 1931-92<br>1931-73<br>1951-78 | 4<br>6<br>5 | 6<br>8<br>6 | 8<br>9<br>8 | Stream becomes perennial within the COHYST boundary. |
| 06763500 | Lodgepole Creek at Ralton, Nebraska | 1951-78 | 0 | 1 | 2 | Groundwater discharge includes that which passed Bushnell. |
| 06764000 | South Platte River at Julesburg, Colorado | 1902-97<br>1982-97 | 40<br>80 | 80<br>130 | 120<br>180 | For reference only to compute groundwater discharge by reach. This station is near the COHYST boundary. Groundwater discharge includes that contributed by Lodgepole Creek. |
| 06764880 | South Platte River at Roscoe, Nebraska | 1982-97 | 86 | 130 | 180 | Groundwater discharge includes that which passed Julesburg. |

## Table 4. Estimated groundwater discharge by reach for North Platte River, South Platte River, and Lodgepole Creek

[$ft^3/s$, cubic feet per second; mi, mile; $ft^3/s/mi$, cubic feet per second per mile]

| Stream reach | Estimated groundwater discharge to main stem in reach ($ft^3/s$)[1] | | | Approximate distance (mi) | Estimated normalized groundwater discharge to main stem in reach ($ft^3/s/mi$)[2] | | | Remarks |
|---|---|---|---|---|---|---|---|---|
| | Minimum | Mean | Maximum | | Minimum | Mean | Maximum | |
| North Platte River (analysis based on calendar years 1941-97): | | | | | | | | |
| Model boundary to State line | 38 | 59 | 83 | 8 | 4.7 | 7.3 | 10. | Estimate based on gain per mile for next downstream reach. |
| State line to Mitchell | 71 | 110 | 160 | 15 | 4.7 | 7.3 | 10. | |
| Mitchell to Minatare | 130 | 150 | 190 | 18 | 7.1 | 8.3 | 10. | |
| Minatare to Bridgeport | 17 | 96 | 170 | 24 | 0.7 | 4.0 | 7.2 | |
| Bridgeport to Lisco | 61 | 110 | 140 | 29 | 2.1 | 3.7 | 5.0 | |
| Lisco to Lewellen | -33 | 36 | 84 | 30 | -1.1 | 1.2 | 2.8 | |
| Lewellen to model boundary | -28 | 30 | 70 | 25 | -1.1 | 1.2 | 2.8 | Estimate based on gain or loss per mile for prior upstream reach. |
| South Platte River (analysis based on calendar years 1982-97): | | | | | | | | |
| Model boundary to Julesburg | -1 | 0 | 1 | 2 | -0.5 | -0.1 | 0.6 | Estimate based on gain or loss per mile for next downstream reach. |
| Julesburg to model boundary | -17 | -4 | 20 | 33 | -0.5 | -0.1 | 0.6 | Flow at model boundary assumed equal to flow at Roscoe, 5 miles to the east. |
| Lodgepole Creek (analysis based on calendar years 1951-78): | | | | | | | | |
| Model boundary to Bushnell | 6 | 8 | 11 | 15 | 0.4 | 0.5 | 0.7 | Stream becomes perennial within model area. |
| Bushnell to Ralton | -6 | -4 | -2 | 82 | -0.1 | 0.0 | 0.0 | Stream loses water to aquifer in this reach. |
| Ralton to model boundary | 0 | 0 | 0 | 5 | -0.1 | 0.0 | 0.0 | Estimate based on loss per mile for prior upstream reach. |

[1] Estimated groundwater discharge rounded to two significant figures, but not less than 1 $ft^3/s$.

[2] Estimated normalized groundwater discharge calculated from estimated discharge before rounding and distance and thus may be different than value obtained after rounding. Normalized discharge rounded to two significant figures, but not less than 0.1 $ft^3/s$.

NOTE: Streams were subdivided based on streamflow stations shown in figure 3 and table 3. State line refers to station 06674500; Mitchell refers to station 06679500; Minatare refers to station 06682000; Bridgeport refers to station 06684500; Lisco refers to station 06686000; Lewellen refers to station 06687500; Julesburg refers to station 06764000; Bushnell refers to station 06762500; and Ralton refers to station 06763500.

In the alternative approach, the total fall gain or loss of water within the reach for each year was computed as the mean outflow minus the sum of the means of the inflows. Total gain or loss computed in this way may include some runoff from precipitation, but frequently this runoff would show up as both inflow and outflow and should not affect the analysis appreciably. The total gain or loss for each year was plotted against the probability of nonexceedence (or recurrence interval) and a smooth curve was drawn through the general trend of the points. The gain or loss with a recurrence interval of 5 years (probability of 0.2) was used as the minimum estimate of groundwater gain or loss; the gain or loss with a recurrence interval of 2 years (probability of 0.5) was used as the mean estimate; and the gain or loss with a recurrence interval of 1.25 years (probability of 0.8) was used as the maximum estimate (table 4). Positive values indicate a gaining reach and negative values indicate a losing reach. The recurrence intervals used in the reach analysis were selected so that the mean gains or losses calculated with the alternative approach were comparable to the mean groundwater discharge at the downstream station minus the sum of the mean groundwater discharges at the upstream station and tributary stations. Shorter recurrence intervals seem reasonable in the reach analysis because much of the runoff from precipitation usually would pass through upstream or tributary stations and the downstream station and would have minimal effect on the reach analysis.

The estimated minimum, mean, and maximum groundwater discharges within a reach were divided by the length of the reach to normalize the discharges (table 4). The largest estimates of normalized groundwater discharge were to the North Platte River upstream from Minatare (06682000). This seems reasonable because more canals and surface-water irrigation occurred upstream from this station than downstream. The valley narrows dramatically downstream from Lisco (06686000) and normalized discharges downstream were much smaller. The values downstream from Lisco may give a hint of what might have occurred upstream prior to operation of the large canals. Normalized discharge to the South Platte River, which has only limited surface-water irrigation, was comparable to or somewhat less than normalized discharge to the North Platte River below Lisco (06686000). Normalized discharge to Lodgepole Creek was much smaller, particularly below Bushnell (06762500).

**Summary**

The Cooperative Hydrology Study (COHYST) is a hydrologic study of the Platte River Basin to assist Nebraska and the Natural Resources Districts with management and regulation of groundwater. Groundwater-flow models will be major products of COHYST. Estimates of groundwater discharge from the High Plains aquifer to streams in the area will be used in calibrating these models. This report estimates groundwater discharge to streams in the Western Model Unit prior to large-scale development of the aquifer for irrigation.

Daily stream-discharge data during the fall (October-November) from 25 streamflow-gaging stations were used in the analysis. For individual stations, the fall 7-day low flow with a recurrence interval of 5 years was used as the minimum estimate of groundwater discharge passing the station. The fall 14-day low flow with a recurrence interval of 2 years was used as the maximum. The mean estimate was the arithmetic average of the minimum and maximum.

For streams with multiple streamflow-gaging stations, reach estimates of groundwater gain or loss were made using total fall outflow minus total inflow. The minimum estimate of groundwater gain or loss in the reach was the difference with a recurrence interval of 5 years, the mean was the difference with a recurrence interval of 2 years, and the maximum was the difference with a recurrence interval of 1.25 years. These estimates then were divided by reach length to normalize them.

The largest estimated groundwater discharge passing a streamflow-gaging station occurred at the North Platte River at Lewellen (06687500) where the estimate was 1,100 to 1,400 cubic feet per second. The largest estimated groundwater discharge to a tributary occurred at Ninemile Drain near McGrew (06682500) where the estimate was 87 to 110 cubic feet per second. The upper reaches of the North Platte River had larger estimated groundwater gains than the lower reaches.

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