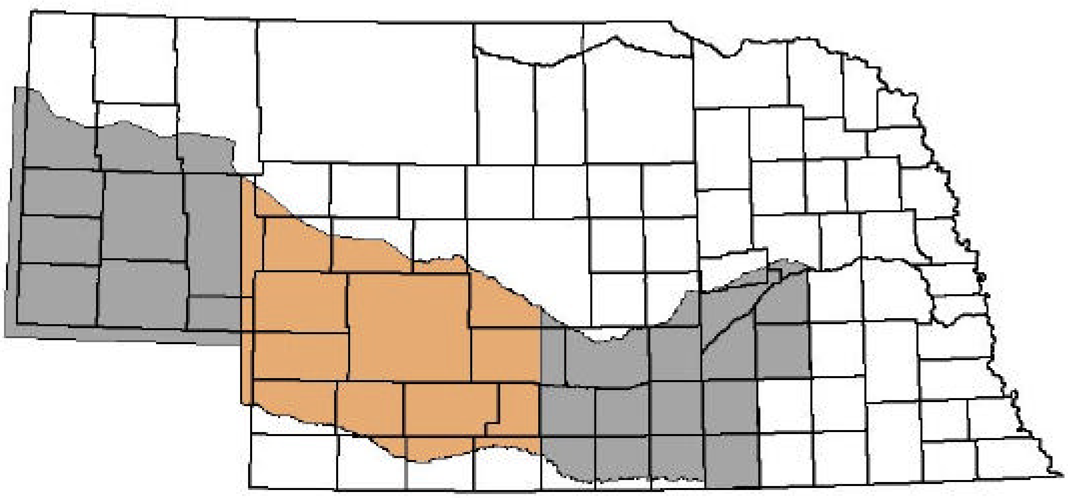
# Estimated Groundwater Discharge to Streams from the High Plains Aquifer In the Central Model Unit of the COHYST Study Area for the Period Prior to Major Groundwater Irrigation



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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 study 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 artificial hydrologic boundary that follows county lines and is sufficiently east that flow across this boundary is not likely to have a large effect on the flow of the Platte River at Columbus. The western and southwestern boundaries also are artificial hydrologic boundaries and are placed 6 miles inside Colorado and Wyoming. These boundaries are sufficiently far from Nebraska that assumptions about flow across these boundaries will have minimal impact on Nebraska. In addition, the southern boundary in Colorado nearly follows a groundwater flow line so little water probably crosses this boundary.

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.

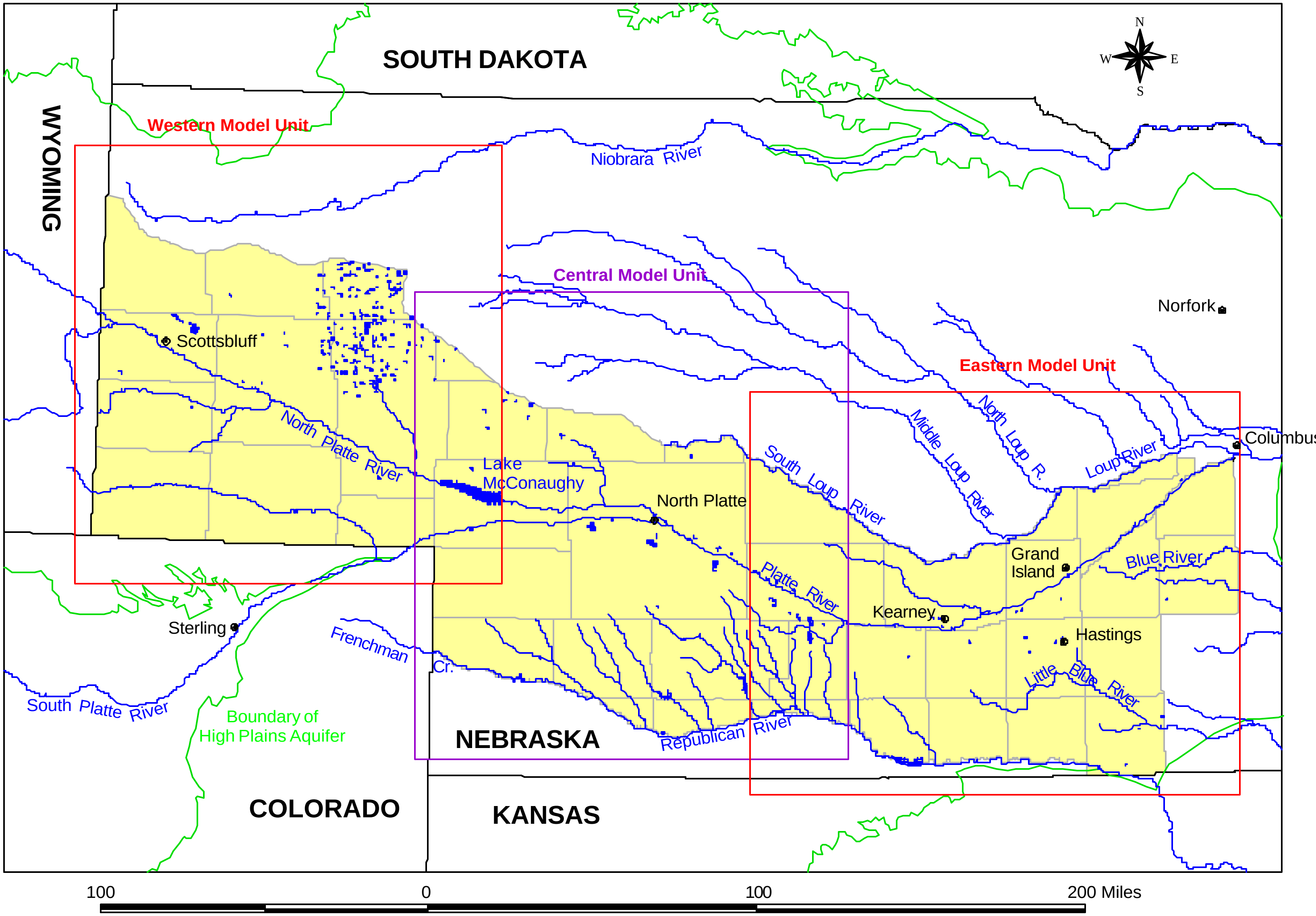


Figure 1. COHYST study area and model units.

Table 1. Generalized section of geologic units used in the Cooperative Hydrology Study (modified from Gutentag and others, 1984).

| System | Series | Geologic Unit | Hydrologic Unit | Description |
|---|---|---|---|---|
| Quaternary | Holo-cene | 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 Central Model Unit of the COHYST area (fig. 1). These estimates will be used in calibrating the flow models of the Central 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.

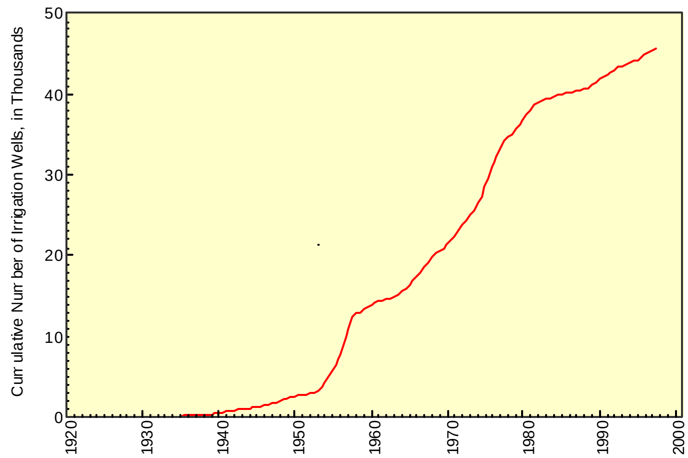


Figure 2. Irrigation well development in the Cooperative Hydrology Study area.

## Streamflow Gauging Network

Daily streamflow data were the source of information used to estimate groundwater discharge to streams for the pre-groundwater development period. Most of the major streams in the Central Model Unit had sufficient streamflow data to make this possible, with the exception being tributaries draining into Lake McConaughy in Keith County and a few streams in the eastern part of the area. All daily-value streamflow gauging stations within the Central Model Unit of the COHYST area were considered for analysis (figure 3; table 2). There were 50 daily-value streamflow stations or canal diversions that operated in the Central Model Unit at one time or another. In addition to streamflow stations, diversion and return data for two canals were used for analysis of low flows on the South Platte and Platte Rivers due to their influence on flows during the months of October and November. All other canal gages within the study area were not considered. Eight stations were not used because they had very short periods of record. Two stations were not used because they were located immediately below reservoir dams on Frenchman and Red Willow Creeks. Two sites were not used because they only gauged certain channels of the Platte River, however, gauges on the main channel at these locations (Brady and Cozad) were ultimately used. The North Platte River near Keystone, Nebraska, was not used in the analysis because it represents only water released from Lake McConaughy.

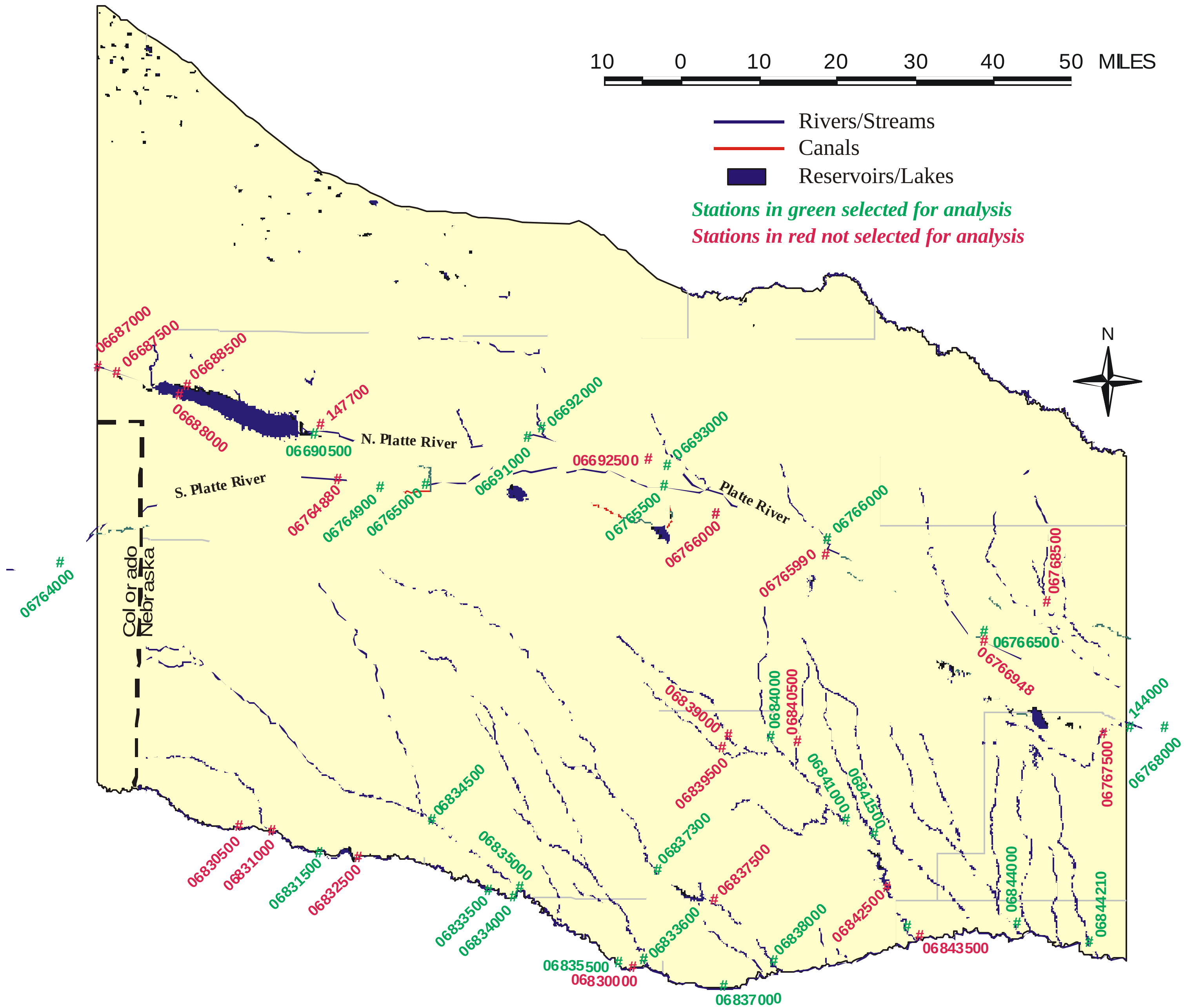


Figure 3. Gauging stations in the central COHYST modeling area of the with daily streamflow values for October-November.

Table 2. – Stream gauging stations in the Central Model Unit of the COHYST study area with daily streamflow values for October-November.

| Station # | Station name | Periods of fall flows through 1997 available for analysis | Remarks |
|---|---|---|---|
| 06687500 | North Platte River at Lewellen, NE | 1941-97 | Not used in analysis. |
| 06688000 | North Platte River at Belmar, NE | 1918, 1920-25 | Not used in analysis. Too short of data set for analysis. |
| 06690500 | North Platte River near Keystone, NE | 1942-97 | Station used in analysis. |
| 06691000 | North Platte River near Sutherland, NE | 1936-92 | Station used in analysis. |
| 06693000 | North Platte River at North Platte, NE | 1930-97 | Station used in analysis. |
| 06764000 | South Platte River at Julesburg, CO | 1902-97 | Station used in analysis. |
| 06764880 | South Platte River at Roscoe, NE | 1982-97 | Not used in analysis. Data range does not coincide with other stations. |
| 06765000 | South Platte River at Paxton, NE | 1946-69 | Station used in analysis. |
| 06765500 | South Platte River at North Platte, NE | 1931-97 | Station used in analysis. |
| 06765990 | Platte River near Brady, NE. | 1968-91 | Not used in analysis - main channel data available. |
| 06766000 | Platte River near Brady, NE. | 1939-97 | Station used in analysis. |
| 06766498 | Platte River near Cozad, NE, south channel. | 1987-91 | Not used in analysis - total channel data available. |
| 06766500 | Platte River near Cozad, NE. | 1940-1997 | Station used in analysis. |
| 06768000 | Platte River at Overton, NE | 1939-97 | Station used in analysis. Lies beyond CMU boundary, used for reach analysis. |
| 06687000 | Blue Creek near Lewellen, NE | 1930-97 | Not used in analysis. |
| 06688500 | Otter Creek near Lemoyne, NE | 1932-36 | Not used in analysis. Too short of data set for analysis. |
| 147700 | Whitetail Creek near Keystone, NE | 1993-94 | Not used in analysis – Too short of data set for analysis. |
| 06692000 | Birdwood Creek near Hershey, NE | 1931-93 | Station used in analysis. |
| 06768500 | Buffalo Creek near Darr, NE | 1946-68 | Not used in analysis. Data set yielded 0 for average flows for time range. |
| 06830000 | Republican River near Culbertson, NE | 1935-50 | Station used in analysis. |
| 06767500 | Plum Creek near Smithfield, NE | 1946-53, 1968-75, 1996-97 | Not used in analysis due to sporadic date ranges. |
| 06837000 | Republican River near McCook, NE | 1954-97 | Station used in analysis. |
| 06843500 | Republican River near Cambridge, NE | 1945-97 | Station used in analysis. |
| 06844500 | Republican River near Orleans, NE | 1947-97 | Station used in analysis. |
| 06835500 | Frenchman Creek near Culbertson, NE | 1935-97 | Station used in analysis. |
| 06833500 | Frenchman Creek near Hamlet, NE | 1931-56 | Station used in analysis. |
| 06834000 | Frenchman Creek near Palisade, NE | 1950-97 | Station used in analysis. |

| | | **Table 2 (cont.)** | |
|---|---|---|---|
| 06831500 | Frenchman Creek near Imperial, NE | 1941-97 | Station used in analysis. |
| 06832500 | Frenchman Creek near Enders, NE | 1946-93 | Not used. Station immediately below Enders Reservoir dam. |
| 06831000 | Frenchman Creek below Champion, NE | 1934-56 | Station used in analysis. |
| 06830500 | Frenchman Creek above Champion, NE | 1932-1940 | Not used in analysis. Too short of data set for analysis. |
| 06834500 | Stinking Water Creek near Wauneta, NE | 1940-49 | Station used in analysis. |
| 06835000 | Stinking Water Creek near Palisade, NE | 1949-97 | Station used in analysis. Pre irrigation and continuous time series both calculated. |
| 06836000 | Blackwood Creek near Culbertson, NE | 1946-85 | Station used in analysis. |
| 06837300 | Red Willow Creek above Hugh Butler Lake | 1960-97 | Station used in analysis. |
| 06837500 | Red Willow Creek near McCook, NE | 1940-46,1993-94 | Not used in analysis. Too short of data set for analysis. |
| 06838000 | Red Willow Creek near Red Willow, NE | 1939-97 | Station used in analysis. Also analyzed for pre- and post- dam construction. |
| 06839000 | Medicine Creek near Maywood, NE | 1951-58 | Not used in analysis - Too short of data set for analysis. |
| 06841000 | Medicine Creek above Harry Strunk Lake | 1950-97 | Station used in analysis. |
| 06842500 | Medicine Creek below Harry Strunk Lake | 1950-1994 | Not used. Station immediately below Harry Strunk Lake dam. |
| 06843000 | Medicine Creek near Cambridge, NE | 1937-56 | Station used in analysis. |
| 06841500 | Mitchell Creek above Harry Strunk Lake | 1950-74 | Station used in analysis. |
| 06839500 | Brushy Creek near Maywood, NE | 1951-57 | Not used in analysis. Too short of data set for analysis. |
| 06844000 | Muddy Creek near Arapahoe, NE | 1951-71, 1977-94 | Station used in analysis. |
| 06839500 | Brushy Creek near Maywood, NE | 1951-57 | Not used in analysis. Too short of data set for analysis. |
| 06840000 | Fox Creek near Curtis, NE | 1977-93 | Station used in analysis. |
| 06840500 | Dry Creek near Curtis, NE | 1951-57 | Not used in analysis. Too short of data set for analysis. |
| 06844210 | Turkey Creek near Edison, NE | 1977-92 | Station used in analysis. |
| 06764900 | Korty Canal Diversion | 1946-97 | Station used for analysis. 1946-69 data used for gain/loss analysis on S. Platte River. |
| 144000 | Johnson Return | 1941-97 | Station used for analysis. 1942-97 data used. Treated as tributary to Platte River. |

## Low-Flow Analysis

Groundwater discharge to streams is best estimated using periods of that are least affected by human activities. During the spring and summer, diversions, return 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 Central 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. In some instances, when diversions did occur in October or data was missing, data for the month of November only was used.

The North Platte and South Platte Rivers have large drainage areas outside the COHYST area. These systems have a number of 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 7- and 14-day fall low flows were plotted against time to see if they changed over time. Figure 4 shows an example with the South Platte River at Julesburg, CO. No discernable long-term trends are evident from this plot.

Several streams in the Republican River basin, including Stinking Water and Frenchman Creeks had a decline in fall low flows starting in the 1970s (figure 5). This decline was almost certainly due to irrigation development in the area. As a result of this decline, a separate analysis from the beginning data to 1973 was conducted to estimate groundwater discharge to these streams prior to large-scale development of the aquifer for irrigation.

The Platte River system has a number of streamflow gauging stations each having various periods of record. Because differences in fall low flows between gauging stations are used in the analysis, it is desirable to have comparable periods of record. When differences occur in periods of record, adjustments were made to develop coinciding periods of record for stations used in calculating gains/losses from groundwater. For analysis of South Platte River gains/losses, diversions to the Nebraska Public Power District’s (NPPD) South Platte Supply Canal at the Korty Diversion were incorporated to define gains between Julesburg, Paxton, and North Platte. In addition, the South Platte, North Platte, Platte and Republican Rivers along with Frenchman Creek each have multiple stations with consistent periods of record that allows for estimation of groundwater discharge to them by reach.

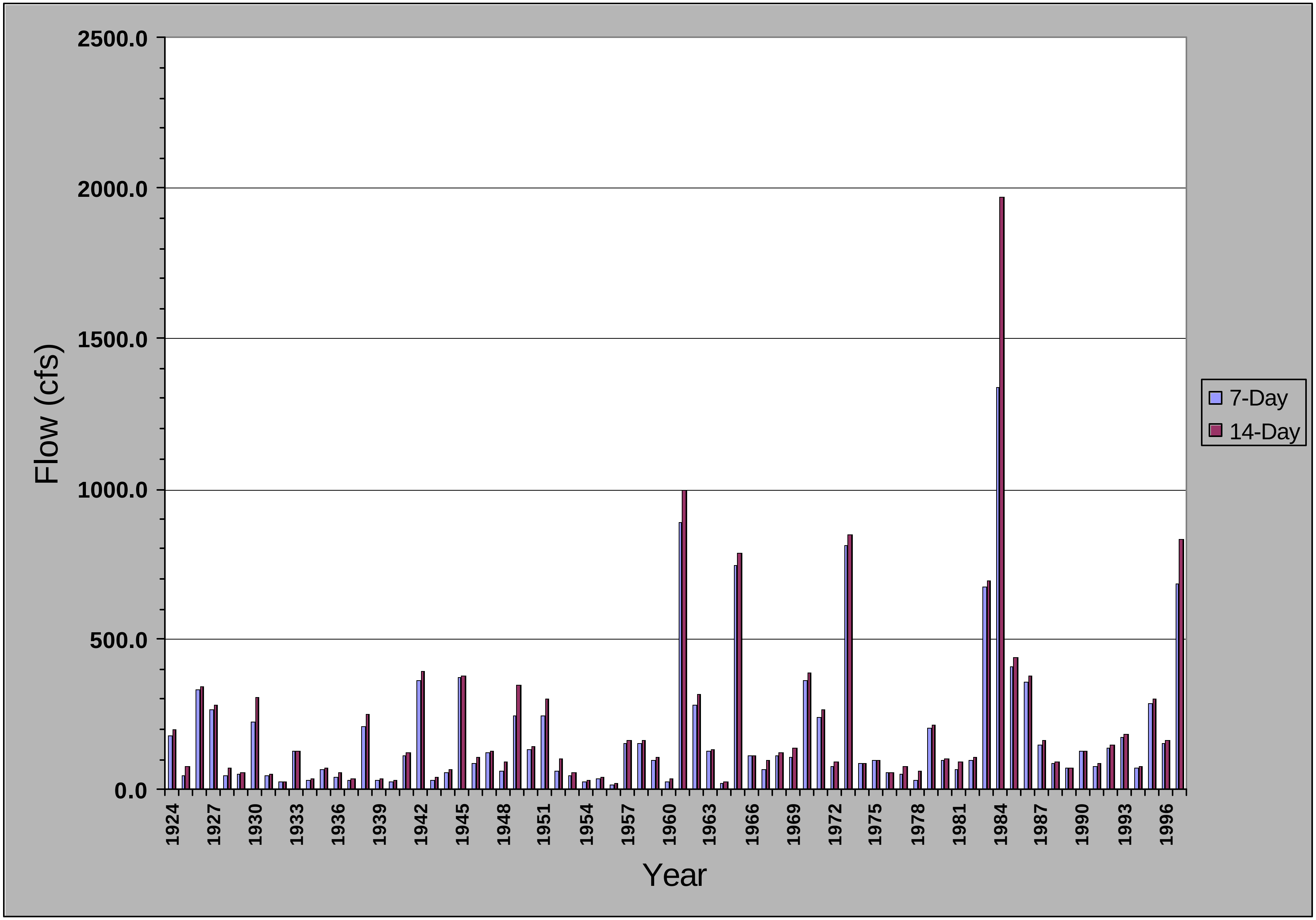


Figure 4. 7- and 14-day fall low flows for the South Platte River at Julesburg, CO (1924-97).

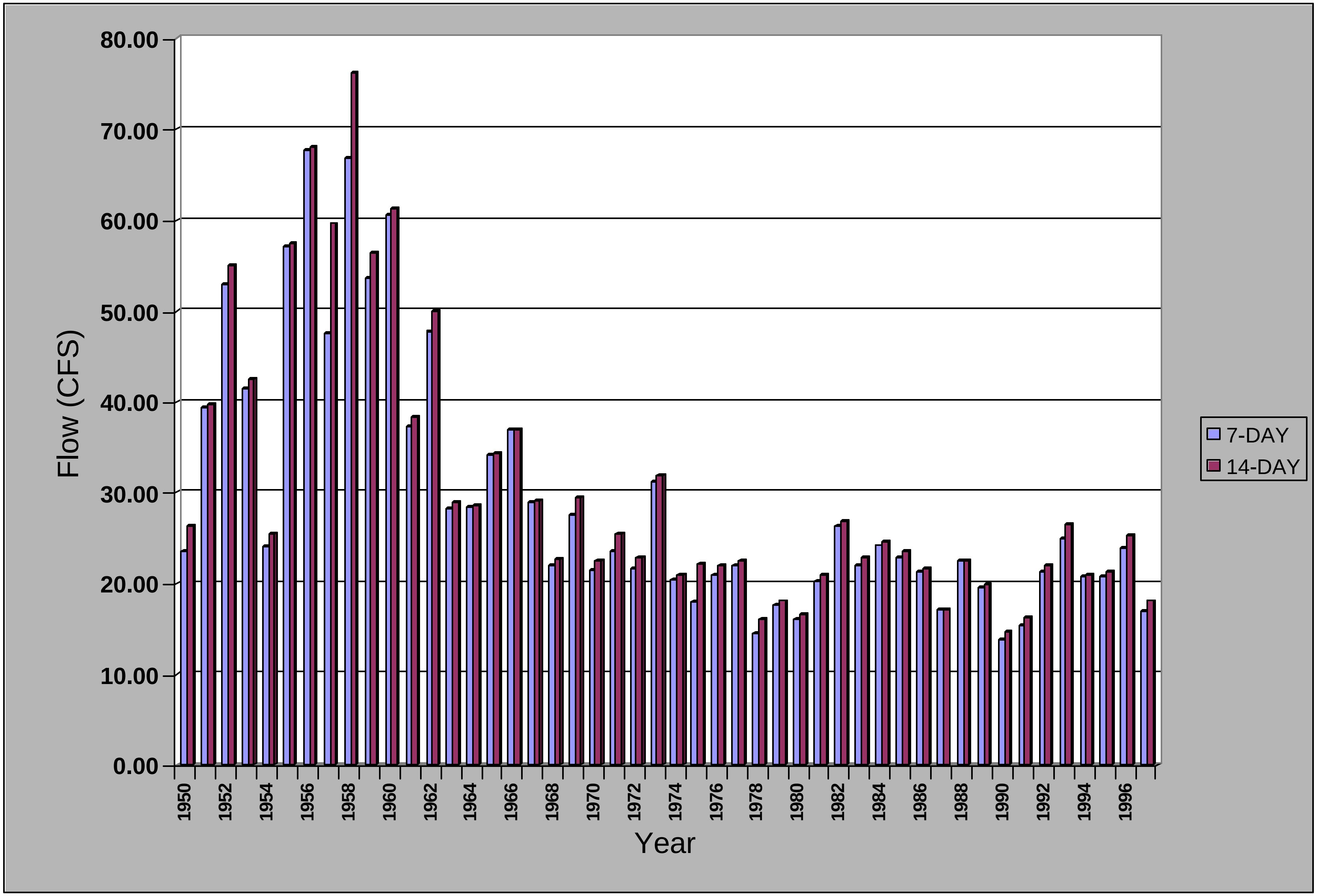


Figure 5. 7- and 14-day fall low flows for Frenchman Creek near Palisade, NE (1950-97).

The gauge at Julesburg, CO, (06764000) had the longest period of record available for any station in the Central Model Unit. However, data for this gauge as well as the North Platte gauge were trimmed to match coinciding data for diversions of the South Platte Supply Canal. For the Platte River from Brady to near the eastern model boundary, periods of record are consistent with one another. On the North Platte River, data were trimmed from the station at North Platte to match records of flow at the Sutherland gauge. Time periods for the remaining streams in the analysis are shown in Table 2.

The 7- and 14-day fall low flows for the period of record used in the analysis were ranked from smallest to largest, and the probability that the low flow was not exceeded in any one 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. N is the number of years in the analysis.

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

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

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

The fall 7- and 14-day fall 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. 6). 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-gauging 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 contain 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-gauging stations near their mouths, so groundwater discharge was estimated for essentially the entire stream.

No gauging station exists immediately on the eastern boundary of the Central Model Unit, but the largest estimated groundwater discharge passing a streamflow gauge occurs at Overton (06768000), which is approximately 15 miles east of the boundary. Here the discharge ranges from 720 to 1,040 cubic feet per second for the November-only data. At Cozad, approximately 25 miles west of the eastern model boundary, groundwater contributes an estimated 172 to 225 cubic feet per second. These are combined groundwater discharges to the river and all tributaries above this station. The largest estimated groundwater discharge to a tributary occurred at the Birdwood Creek (06692000) in Lincoln County where the estimate was 140 to 153 cubic feet per second.

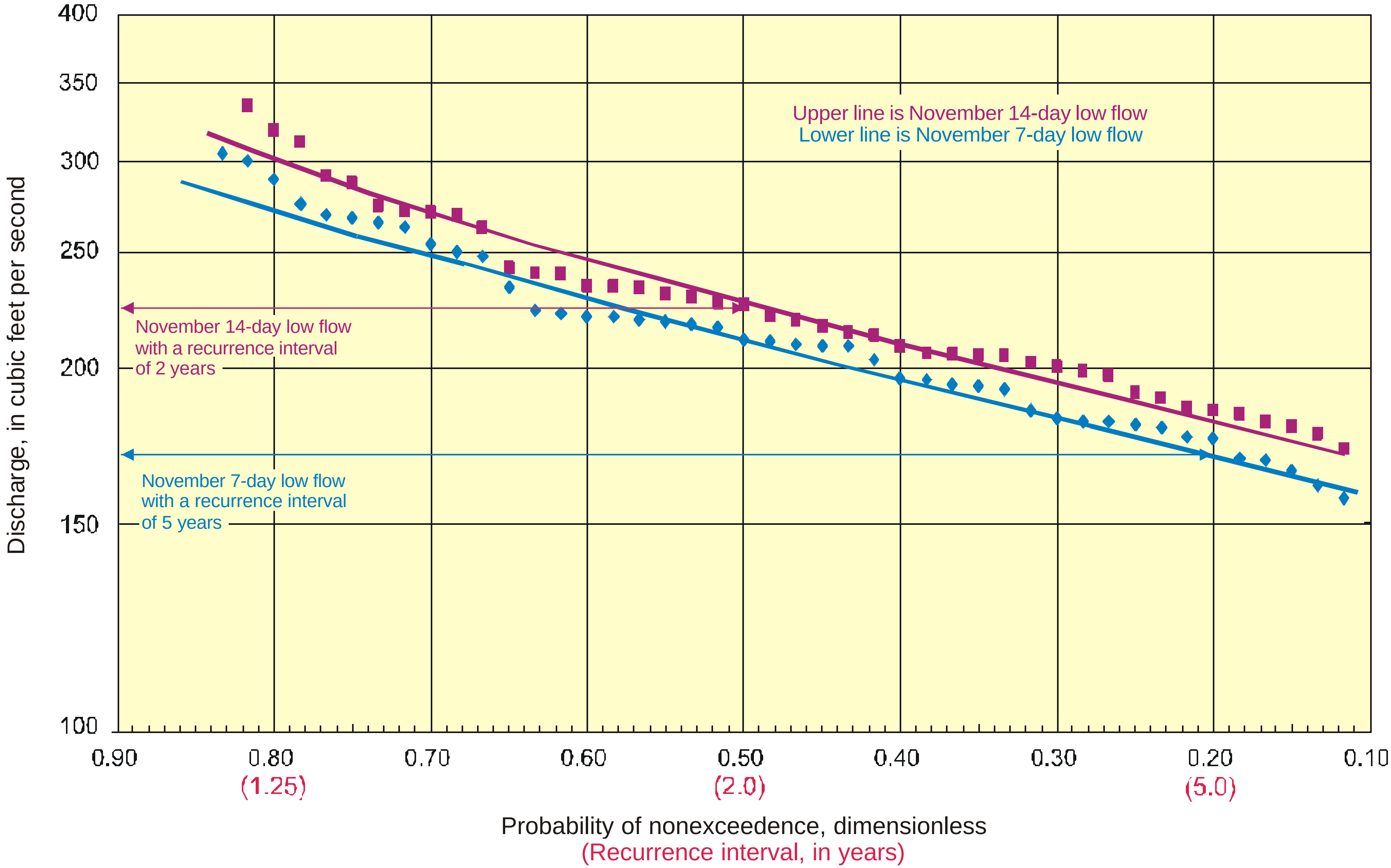


Figure 6. Frequency curves for 7- and 14-day November low flows for the Platte River at Cozad, NE, for the calendar years 1939-1997.

Table 3. Estimated groundwater discharge to streams at streamflow gauging stations.

| Station # | Station name | Period of analysis | Estimated groundwater discharge to streams ($ft^3$/sec) | | | Remarks |
|---|---|---|---|---|---|---|
| | | | Minimum | Mean | Maximum | |
| 06691000 | North Platte River at Sutherland, NE | 1936-92 | 57 | 95 | 132 | For reference only to compute groundwater discharge by reach. |
| 06693000 | North Platte River at North Platte, NE | 1930-97 | 290 | 330 | 369 | Full data range at station. |
| | | 1940-97 | 288 | 322 | 355 | Post Kingsley Dam/Lake McConaughy construction. |
| | | 1936-92 | 291 | 321 | 350 | For reference only to compute groundwater discharge by reach. |
| 06764000 | South Platte River at Julesburg, CO | 1924-97 | 72 | 122 | 171 | Westernmost gauge on S. Platte River within the CMU. |
| | | 1902-97 | 71 | 127 | 184 | Complete range of data for that gauge. |
| | | 1946-69 | 89 | 134 | 178 | For reference only to compute groundwater discharge by reach. |
| | | 1946-97 | 80 | 125 | 170 | For reference only to compute groundwater discharge by reach. |
| 06765000 | South Platte River at Paxton, NE | 1939-69 | 6 | 9 | 11 | Used for discharge by reach with diversion data at Korty Canal. |
| | | 1946-69 | 4 | 7 | 9 | For reference only to compute groundwater discharge by reach. |
| 06765500 | South Platte River at North Platte, NE | 1931-97 | 117 | 131 | 144 | Entire range of data for gauge. |
| | | 1946-69 | 116 | 123 | 130 | For reference only to compute groundwater discharge by reach. |
| | | 1946-97 | 116 | 126 | 135 | For reference only to compute groundwater discharge by reach. |
| 06693000 | Platte River near Brady, NE | 1939-97 | 112 | 113 | 143 | For reference only to compute discharge by reach. November data only. |
| 06766500 | Platte River near Cozad, NE. | 1939-97 | 172 | 199 | 225 | Easternmost gauge within the CMU with data available for analysis of discharge by reach. November data used only. |

| Station # | Station name | Period of analysis | Estimated groundwater discharge to streams ($ft^3$/sec) | | | Remarks |
|---|---|---|---|---|---|---|
| | | | Minimum | Mean | Maximum | |
| 06768000 | Platte River near Overton, NE | 1939-97 | 720 | 880 | 1,040 | For defining discharge from Cozad to CMU eastern boundary. Nov. only. |
| 06764900 | Korty Diversion, South Platte Supply Canal | 1946-69 | 0 | 13 | 26 | Includes flow at Paxton gauging station for 1946-69 for gain/loss by stretch. |
| 06692000 | Birdwood Creek near Hershey, NE | 1931-93 | 140 | 146 | 153 | Entire range of data for gauge. |
| 06830000 | Republican River near Culbertson, NE | 1935-1950 | 32 | 59 | 86 | Entire range of data for gauge. Pre-Swanson Reservoir Construction. |
| 06837000 | Republican River near McCook, NE | 1954-97 | 73 | 84 | 94 | Entire range of data for gauge. |
| 06843500 | Republican River near Cambridge, NE | 1954-97 | 87 | 102 | 116 | 9 years of early data omitted to coincide with data at McCook gauge. |
| 06844500 | Republican River near Orleans, NE | 1954-97 | 94 | 109 | 123 | 7 years of early data omitted to coincide with data at Cambridge gauge. |
| 06834000 | Frenchman Creek near Palisade, NE | 1950-73 | 24 | 29 | 34 | Pre-Irrigation development. |
| | | 1950-97 | 19 | 21 | 23 | Entire range of data for gauge. |
| 06831500 | Frenchman Creek near Imperial, NE | 1941-73 | 47 | 52 | 56 | Pre-Irrigation development. |
| | | 1941-97 | 22 | 33 | 44 | Entire range of data for gauge. |
| 06833500 | Frenchman Creek near Hamlet, NE | 1934-49 | 73 | 79 | 85 | Pre-Enders Reservoir Dam Construction. |
| 06835500 | Frenchman Creek at Culbertson, NE | 1950-73 | 57 | 67 | 77 | Pre-Irrigation development. |
| | | 1935-97 | 34 | 45 | 57 | Entire range of data for gauge. |
| 06833500 | Frenchman Creek near Hamlet, NE | 1934-49 | 73 | 79 | 85 | Pre-Enders Reservoir Dam Construction. |
| 06835500 | Frenchman Creek at Culbertson, NE | 1950-73 | 57 | 67 | 77 | Pre-Irrigation development. |
| 06835500 | Frenchman Creek at Culbertson, NE | 1935-97 | 34 | 45 | 57 | Entire range of data for gauge. |

| Station # | Station name | Period of analysis | Estimated groundwater discharge to streams (ft$^3$/sec) | | | Remarks |
|---|---|---|---|---|---|---|
| | | | Minimum | Mean | Maximum | |
| 06831000 | Frenchman Creek at Champion, NE | 1934-49 | 26 | 30 | 34 | Pre-Enders Reservoir Dam Construction. |
| 06835000 | Stinking Water Creek near Palisade, NE | 1949-73 | 23 | 26 | 28 | Pre-Irrigation development. |
| | | 1949-97 | 18 | 20 | 23 | Entire range of data for gauge. |
| 06834500 | Stinking Water Creek near Wauneta, NE | 1940-49 | 14 | 15 | 16 | Entire range of data for gauge. |
| 06838000 | Blackwood Creek near Culbertson, NE | 1946-85 | 0.7 | 0.9 | 1 | Entire range of data for gauge. |
| 06838000 | Red Willow Creek near Red Willow, NE | 1939-97 | 6 | 7 | 9 | Entire range of data for gauge. |
| | Red Willow Creek near Red Willow, NE | 1939-60 | 14 | 17 | 20 | Pre-Red Willow Dam Construction. |
| | Red Willow Creek near Red Willow, NE | 1961-97 | 6 | 6 | 7 | Post-Red Willow Dam Construction. |
| 06837300 | Red Willow Creek NW of McCook, NE | 1960-97 | 12 | 15 | 17 | Gauge above Hugh Butler Lake. |
| 06841000 | Medicine Creek NW of Cambridge, NE | 1950-97 | 35 | 38 | 42 | Gauge above Harry Strunk Lake. |
| 06843000 | Medicine Creek at Cambridge, NE | 1937-48 | 27 | 33 | 40 | Pre-Harry Strunk Lake Dam Construction. |
| | | 1937-56 | 4 | 16 | 28 | Entire range of data for gauge. |
| 06844000 | Muddy Creek near Arapahoe, NE | 1951-71 | 1.9 | 3 | 4.4 | First set of data available. |
| | | 1977-94 | 5 | 5 | 6 | Second set of data available. |
| 06840000 | Fox Creek near Curtis, NE | 1977-93 | 4 | 4 | 5 | Later data set for gauge. 6-year span in the 1950's available. |
| 06844210 | Turkey Creek near Edison, NE | 1977-92 | 2 | 3 | 3.9 | Entire range of data for gauge. |

In the Central Model Unit, two canals, the Power Canal operated by NPPD and the Central Supply Canal operated by the Central Nebraska Public Power and Irrigation District (CNPPID) both return flows to the South Platte and Platte Rivers, respectively. The NPPD Power Canal returns to the South Platte River downstream from the ga uge at North Platte and should have minimal affect on flows there and at Brady, which is downstream from the Central Supply Canal diversion.

The Johnson Return, where water from the Central Supply Canal empties back into the Platte River, is east of the Central Model Unit boundary and therefore does not affect the easternmost gauge within the study area, but does however, influence flow at Overton, which is used in the low flow analysis.

For this analysis, November-only data were used for several gauges along the mainstem of the Platte River to lessen the influence of diversions to canals upstream from the Cozad station and diversions between Cozad and Overton. For example, the stretch from Brady to Cozad also utilized November-only data to lessen the impact of the Gothenburg, Thirty-Mile, Six-Mile, Cozad Canals and the Jeffrey Return. Records from the Nebraska Department of Natural Resources and the NPPD Historical Water Use Database indicated occasional diversions in October, especially early in the study period, but that diversion of water was virtually non-existent on these canals in November except in a few isolated instances.

For streams with multiple streamflow-gauging station on them, 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.

In the alternate 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.

When power canals (canals with flow year around for hydroelectric generation) were considered, canals that returned to the river were treated as tributaries, and the canal flows were subtracted from the net balance of mean flows for that reach. This was performed for the Johnson #2 power return to the Platte River. Where canals diverted water from a river through most or all of the fall time period for several years, those canal flows were added to the nearest downstream gauging station data prior to performing the low-flow analysis. This was performed for the South Platte Supply Canal at the Korty Diversion which was added to flow to the Paxton gauging station.

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).

Table 4. Estimated groundwater discharge to streams by reach for the Frenchman Creek, North Platte, South Platte, and Platte River

| River/Reach | | | | Gain/loss per mile ($ft^3$/sec) | | | | Remarks |
|---|---|---|---|---|---|---|---|---|
| | Min. | Mean | Max. | Distance | Min. | Mean | Max. | |
| N. Platte River, Sutherland to North Platte | 69 | 88 | 119 | 20.7 | 3.3 | 4.3 | 5.8 | November data only. |
| Platte River, Brady to Cozad | 55 | 70 | 119 | 23.7 | 2.3 | 2.9 | 5.0 | November data only. |
| Platte River, Cozad to Overton | -133 | 45 | 131 | 26.8 | -2.4 | 1.7 | 8.6 | Johnson Return accounted for in analysis. |
| S. Platte River, Julesburg to Paxton | -42 | -10 | 14 | 45.1 | -0.9 | 0.2 | 0.3 | Korty Diversion data accounted for in analysis. |
| S. Platte River, Paxton to North Platte | 121 | 128 | 147 | 33.3 | 3.6 | 3.9 | 4.4 | November data only |
| Frenchman Creek, Champion to Hamlet | 51 | 59 | 63 | 37.1 | 1.4 | 1.6 | 1.7 | Pre- Enders Dam Construction. |
| Frenchman Creek, Palisade to Culbertson | 15 | 18 | 27 | 24.6 | 0.6 | 0.7 | 1.1 | Pre-Irrigation development. |
| Republican River, McCook to Cambridge | -48 | -38 | -2 | 33 | -1 | -0.1 | 1.1 | Red Willow and Medicine Creeks accounted for as tributaries. November only data for gauges, all fall data for tributaries to reduce canal effects. |
| Republican River, Cambridge to Orleans | -13 | 7 | 20 | 52 | -0.3 | 0.1 | 0.4 | Muddy Creek accounted for as a tributary. November data only for gauges, all fall data for tributaries to reduce canal effects. |

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.

Positive values in tables 3 and 4 indicate a gaining reach and negative values indicate a losing reach. The Platte River between Cozad (06766500) and Overton (06768000) shows a range from -133 to 131 feet$^3$/second, indicating that historically the river had both gaining and losing conditions. The stretch between the Sutherland (06691000) and North Platte (06693000) on the North Platte River shows a gain along the entire stretch with a range of 69 to 119 cubic feet per second or 3.3 to 5.8 cubic feet per second per mile. Data from 1954-1997 on Republican River gauges within the study area allowed for section gain and loss also. Between the gauge at McCook, NE (06837000) and Cambridge, NE (06843500), low-flow analysis reveals a losing stretch, with losses ranging from -48 to -2 cubic feet per second which normalizes to -0.97 to -0.40 cubic feet per second per mile. Further analysis reveals this condition to change downstream from Cambridge as results show a range indicating both gaining and losing conditions between the upstream gauge and the Orleans, NE gauge (06844500). Although outside of the Central Model Unit, the gauge at Orleans was the only gauge with an applicable data set within proximity of the study area boundaries. The low flow in this stretch ranged from –13 to 20 cubic feet per second that normalizes to –0.22 to 0.17 cubic feet per second per mile. Analysis of these stretches included the Red Willow and Medicine Creeks as tributaries for the McCook-Cambridge reach and Turkey and Medicine Creeks for the Cambridge-Orleans reach. November data were used for the stream gauges to help reduce the effect of canal diversion from the river. Canal diversion data from the Nebraska Department of Natural Resources indicated that October diversions did occur sporadically throughout the time period on the Bartley, Cambridge, Culbertson, Red Willow, and Meeker-Driftwood canals, but November diversions were very rare. Analysis of Frenchman Creek indicated gain along the stretches between Champion to Hamlet and Palisade to Culbertson in the 1-3 cubic feet per second per mile range. Data for the stretch from Champion to Hamlet was from years prior to the construction of Enders Reservoir Dam and prior to major development of irrigation utilizing groundwater for Palisade to Culbertson. Use of this data will hopefully best reveal predevelopment conditions.

## Summary

The Cooperative Hydrology Study is a hydrologic study of the Platte River Basin to assist Nebraska and 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 to calibrate these models. This report estimates groundwater discharge to streams in the Central Model Unit prior to large-scale development of the aquifer for irrigation.

Daily stream discharge data during the fall (October-November) from 31 streamflow-gauging 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 and 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 gauging 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 were then divided by reach length to normalize them.

The largest estimated groundwater discharge passing a streamflow-gauging station occurred at the Platte River at Overton (06768000) where the estimate was 720 to 1,040 cubic feet per second. The largest estimated groundwater discharge to a tributary occurred at Birdwood Creek near Sutherland (06692000) when the estimate was 140 to 153 cubic feet per second. Low flow conditions ranged from losing to gaining for reaches of the Platte River, Republican River, and Frenchman Creek. One reach of the Republican River was determined to have losing conditions (McCook to Cambridge). All remaining estimates showed gaining conditions. The South Platte River showed much higher gaining conditions on the downstream reaches than from the western boundary to Paxton. Flows from Paxton to North Platte are likely due to increased seepage from the NPPD Power Canal and Sutherland Reservoir which are documented to leak an average of 222 cubic feet per second.

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