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

by

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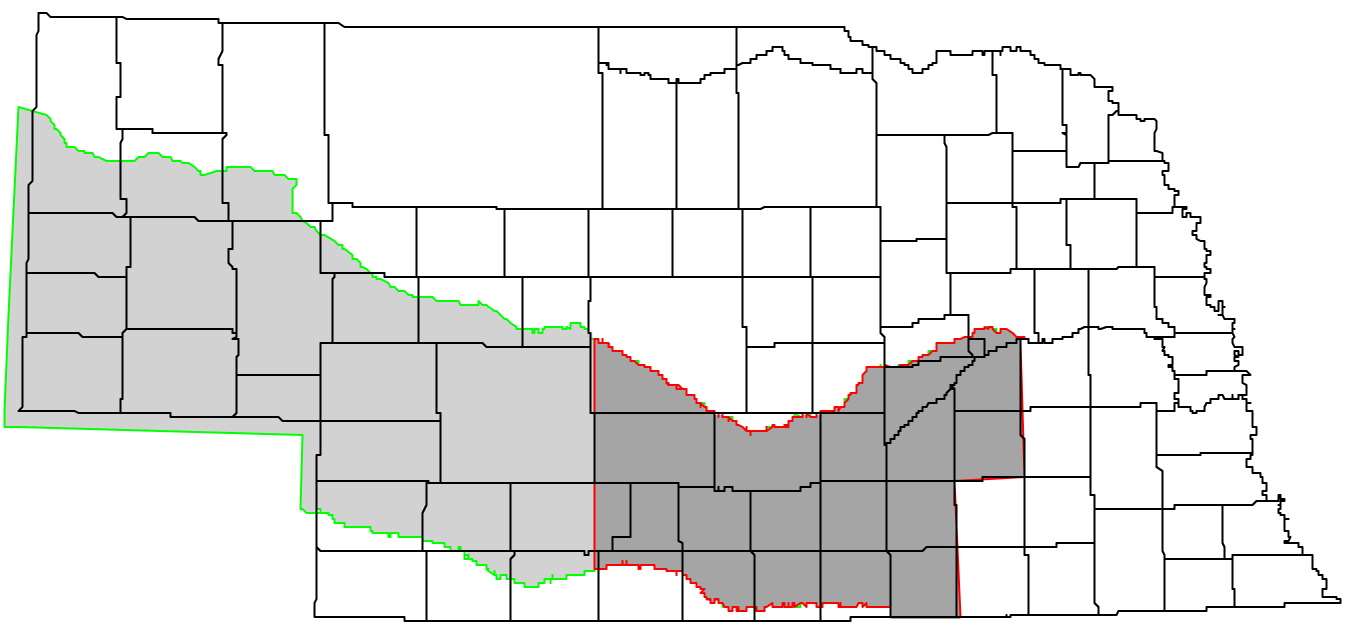

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Introduction

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 (Secretary of the Interior, Governors of Nebraska, Wyoming, and Colorado, 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 assumed to be 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 assumed to be sufficiently far from Nebraska that 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.

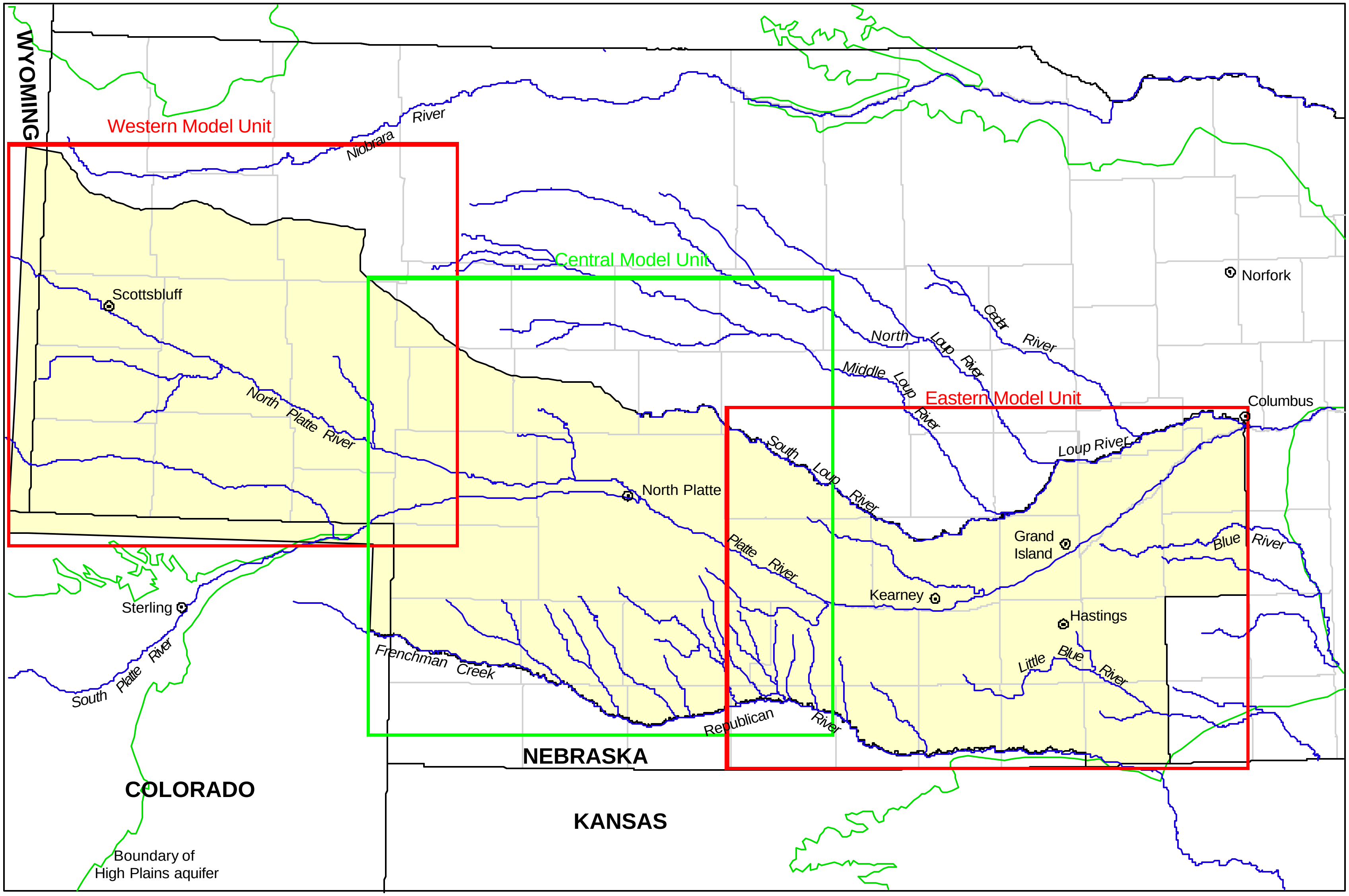

Figure 1. COHYST study area (shaded) and model units.

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

System	Series	Geologic Unit	Hydrostratigraphic 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 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.
	Pleistocene	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	Undifferentiated	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 COHYST 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 Platte, South Platte, Platte, Republican, and Loup 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 Eastern Model Unit of the COHYST area (fig. 1). These estimates will be used in calibrating the flow models of the Eastern 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.

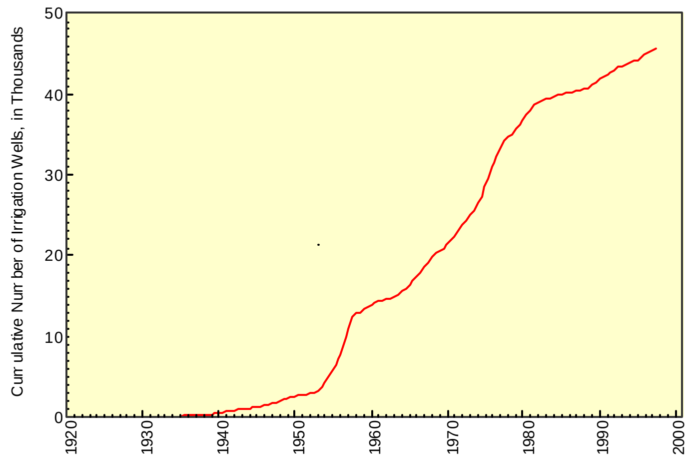

Figure 2. Irrigation well development in the Cooperative Hydrology Study area.

Streamflow-Gaging Network

Daily streamflow data were the source of information used to estimate groundwater discharge to streams for the pre-groundwater development period. All of the major streams in the Eastern Model Unit had sufficient streamflow data to make these estimates, though not always for the entire length of the stream in the study area. However, some of the smaller streams lacked adequate data.

All daily-value gaging stations on streams in Nebraska with at least 7 years of record that were within or near the Eastern Model Unit were considered for analysis (fig. 3, table 2). Note that both USGS stations and state-maintained stations are shown on figure 3, with the exception of Elm Creek Canal Diversion near Elm Creek (38500). State-run stations are designated in table 2 and figure 3 with a “NE” behind the station number. Of the 82 gaging stations considered for analysis, 52 met the record length criteria. Of the 52 stations that met initial criteria, 40 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 Eastern Model Unit.

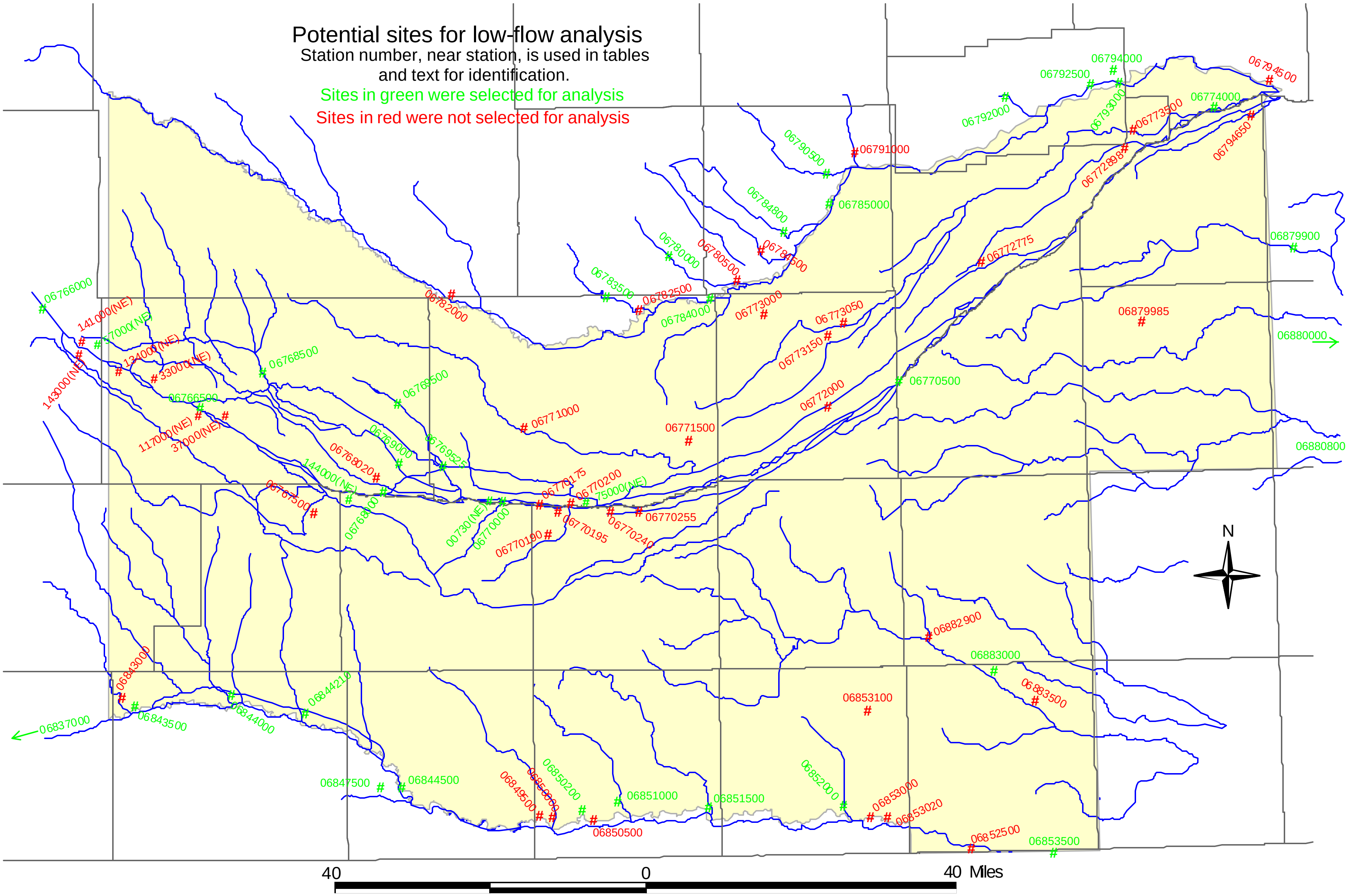

Figure 3. Streamflow stations in the Eastern Model Unit of the COHYST study area with daily streamflow values for October-November. The Nebraska DNR station for Elm Creek Canal Diversion near Elm Creek (# 38500) is not shown.

Table 2. Streamflow stations in or near the Eastern Model Unit of the COHYST study area that were considered for analysis.

Station number	Station name	Periods of fall flows through 1997 available for analysis	Remarks
06794000	Beaver Creek near Genoa, Nebraska	1940-1997	Station used, 1943-1997 data only
06853100	Beaver Creek near Rosemont, Nebraska	1967-1969	Station not used due to insufficient data
06879900	Big Blue River at Surprise, Nebraska	1964-1997	Station used
06780500	Boelus Power Canal near Boelus, Nebraska	1952-1962	Station not used, fall operation irregular
06768500	Buffalo Creek near Darr, Nebraska	1946-1968	Station used, though 7-day 5-year and 14-day 2-year are both zero
06769000	Buffalo Creek near Overton, Nebraska	1949-1957, 1996-1997	Station used
06792000	Cedar River near Fullerton, Nebraska	1940-1997	Station used, 1943-1997 data only
06851000	Center Creek at Franklin, Nebraska	1948-1955, 1968-1993	Station used
06794650	Clear Creek 1.75mi west Of Polk Co Line, Nebraska	1996-1997	Station not used due to insufficient data
06879985	Coon Branch near Benedict, Nebraska	partial 1975	Station not used due to insufficient data
06850200	Cottonwood Creek near Bloomington, Nebraska	1948-1955	Station used
06852500	Courtland Canal at Nebraska-Kansas State Line	1952-1997	Station not used, fall operation limited to 5 years
33000 (NE)	Cozad Canal Diversion near Gothenburg, Nebraska	1948, 1952-1953, 1958	Station not used, fall operation limited to 4 years
37000 (NE)	Dawson County Canal Diversion near Cozad, Nebraska	1945-1997	Station not used, fall operation limited to intermittent operations mainly in October
06770255	Downstream Drain near Newark, Nebraska	1996-1997	Station not used due to insufficient data
06773000	Dry Creek at Cairo, Nebraska	1949-1952	Station not used due to insufficient data
06852000	Elm Creek at Amboy, Nebraska	1948-1952, 1977-1997	Station used
38500 (NE)	Elm Creek Canal Diversion near Elm Creek, Nebraska	1946-1963	Station not used, fall operation limited to intermittent operations mainly in October
06769500	Elm Creek near Overton, Nebraska	1946-1957	Station used, though 7-day 5-year and 14-day 2-year are both zero
06769525	Elm Creek near Elm Creek, Nebraska	1955-1989, 1996-1997	Station used, though 7-day 5-year and 14-day 2-year are both zero
06770240	Fort Kearney Slough near Newark, Nebraska	1996-1997	Station not used due to insufficient data
57000 (NE)	Gothenburg Canal Diversion near Gothenburg, Nebraska	1945-1996	Station used, data added to Platte River at Cozad
58000 (NE)	Gothenburg Canal (in Dawson County, Nebraska)	1945-1974	Station not used, because it measures further downstream (away from the diversion) than station 57000
143000 (NE)	Jeffrey Power return to the Platte River near Brady, Nebraska	1945-1997	Station not used, fall operation limited to intermittent operations mainly in October

Station number	Station name	Periods of fall flows through 1997 available for analysis	Remarks
144000 (NE)	Johnson #2 Power return to the Platte River near Lexington, Nebraska	1941-1997	Station used, 1942-1997 data only
06882900	Pawnee Creek near Pauline, Nebraska	1962-1967	Station not used due to insufficient data
06880000	Lincoln Creek near Seward, Nebraska	1954-1993	Station used, 1954 to 1981 data only
06883500	Little Blue River at Angus, Nebraska	1950-1952	Station not used due to insufficient data
06883000	Little Blue River near Deweese, Nebraska	1953-1997	Station used
06794500	Loup River at Columbus, Nebraska	1934-1977	Station not used, since data record does not match other Loup stations
06793000	Loup River near Genoa, Nebraska	1943-1997	Station used, Loup Power diversion data added
06792500	Loup River Power Canal near Genoa, Nebraska	1937-1997	Data added to the next Loup River station downstream
06793010	Loup River Power Canal and Loup River near Genoa, Nebraska	1979-1980, 1984-1986	Station not used due to insufficient data
00730 (NE)	Kearney Power and Irrigation Diversion near Elm Creek, Nebraska	1922-1929, 1934, 1936-1990, 1992, 1994	Station used, data added to Platte River at Odessa
75000 (NE)	Kearney Power Return to the Platte River near Kearney, Nebraska	1945-1988, 1990-1991, 1996-1997	Station used
06843000	Medicine Creek at Cambridge, Nebraska	1937-1942, 1944-1956	Station not used, Medicine Creek is mostly outside of the eastern model area
06785000	Middle Loup River at St. Paul, Nebraska	1928-1997	Station used, 1943-1997 data only, November data used to mitigate effects of intermittent Farwell canal operation
06780000	Middle Loup River near Rockville, Nebraska	1955-1963, 1967-1974	Station used
06844000	Muddy Creek at Arapahoe, Nebraska	1951-1994	Station used
06783500	Mud Creek near Sweetwater, Nebraska	1946-1993	Station used, November data only
06770195	North Dry Creek 2 mi southwest of bridge south of Kearney, Nebraska	1996-1997	Station not used due to insufficient data
06770190	North Dry Creek near Kearney, Nebraska	1968-1970	Station not used due to insufficient data
06790500	North Loup River near St. Paul, Nebraska	1928-1997	Station used, data from 1943-1997 only, treated as tributary to the Middle Loup River
06784500	Oak Creek near Dannebrog, Nebraska	1949-1956	Station not used due to insufficient data
117000 (NE)	Orchard-Alfalfa Canal Diversion near Cozad, Nebraska	1946-1997	Station not used, fall operation limited to infrequent operations in October
06766000	Platte River near Brady, Nebraska	1939-1997	Station used, 1940-1997 data only

Station number	Station name	Periods of fall flows through 1997 available for analysis	Remarks
06766500	Platte River near Cozad, Nebraska	1940-1997	Station used, with Gothenburg Canal Diversion added, November data
06774000	Platte River near Duncan, Nebraska	1928-1997	Station used, 1940-1997 data only
06770500	Platte River near Grand Island, Nebraska	1934-1997	Station used, 1940-1997 data only
06770200	Platte River near Kearney, Nebraska	1982-1997	Station not used, because data record does not match other Platte stations
06770000	Platte River near Odessa, Nebraska	1938-1997	Station used, 1940-1997 data only, plus Kearney power and irrigation diversion
06768000	Platte River near Overton, Nebraska	1930-1997	Station used, 1940-1997 data only
06767500	Plum Creek near Smithfield, Nebraska	1946-1952, 1968-1974, 1996-1997	Station not used, record intermittent, most fall low-flows are zero
06773050	Prairie Creek near Ovina, Nebraska	1993, 1996-1997	Station not used due to insufficient data
06773500	Prairie Creek near Silver Creek, Nebraska	1949-1952, 1996-1997	Station not used due to insufficient data
06843500	Republican River at Cambridge, Nebraska	1945-1997	Station used, 1947-1997 data only, November data used
06853020	Republican River at Guide Rock, Nebraska	1984-1997	Station not used, because data record does not match other Republican stations
06837000	Republican River at McCook, Nebraska	1954-1997	Station not used, because data record does not match other Republican stations
06849500	Republican River below Harlan County Dam, Nebraska	1953-1997	Station not used because all flows are Harlan County Reservoir releases
06850500	Republican River near Bloomington, Nebraska	1928-1956	Station not used, because data record does not match other Republican stations
06853000	Republican River near Guide Rock, Nebraska	1984-1997	Station not used, because data record does not match other Republican stations
06853500	Republican River near Hardy, Nebraska	1932-1997	Station used, 1947-1997 data only
06844500	Republican River near Orleans, Nebraska	1947-1997	Station used, 1947-1997 data only, November data used
06847500	Sappa Creek near Stamford, Nebraska	1946-1997	Station used, though 7-day 5-year and 14-day 2-year are both zero
06772898	Silver Creek at mi 4 near Silver Creek, Nebraska	1996-1997	Station not used due to insufficient data
06773150	Silver Creek at Ovina, Nebraska	no fall flows	Station not used due to insufficient data
134000 (NE)	Six-mile Canal Diversion near Gothenburg, Nebraska	1946-1997	Station not used, fall operation limited to infrequent operations in October
06784000	South Loup River at St. Michael, Nebraska	1943-1997	Station used, 1943-1997 data only
06782500	South Loup River at Ravenna, Nebraska	1940-1957, 1967-1974	Station not used, because data record does not match other Loup stations
06782000	South Loup River near. Cumro, Nebraska	1946-1952	Station not used, because data record does not match other Loup stations
06768020	Spring Creek near Overton, Nebraska	1996-1997	Station not used due to insufficient data
141000 (NE)	Thirty-mile Canal Diversion near Brady, Nebraska	1945-1997	Station not used, fall operation limited to intermittent operations mainly in October

Station number	Station name	Periods of fall flows through 1997 available for analysis	Remarks
06851500	Thompson Creek at Riverton, Nebraska	1948-1955, 1968-1997	Station used
06844210	Turkey Creek at Edison, Nebraska	1977-1997	Station used
06850000	Turkey Creek at Naponee, Nebraska	1948-1952	Station not used due to insufficient data
06784800	Turkey Creek near Dannebrog, Nebraska	1966-1969; 1978-1997	Station used
06772775	Warm Slough near Central City, Nebraska	1996-1997	Station not used due to insufficient data
06880800	West Fork Big Blue River near Dorchester, Nebraska	1958-1997	Station used
06770175	Whisky Slough 1mi east of Phelps-Kearney Co Line, Nebraska	1996-1997	Station not used due to insufficient data
06772000	Wood River near Alda, Nebraska	1953-1997	Station used, though 7-day 5-year and 14-day 2-year are both zero
06771500	Wood River near Gibbon, Nebraska	1949-1975	Station used, though 7-day 5-year and 14-day 2-year are both zero
06771000	Wood River near Riverdale, Nebraska	1946-1972	Station used, though 7-day 5-year and 14-day 2-year are both zero

During the winter, the flow of steams is often affected by ice, which can make the streamflow estimates questionable. During the fall, diversions, runoff, and evapotranspiration are much less and the flow of streams is frequently dominated by groundwater discharge from the aquifer. For these reasons, the period of October 1 through November 30 was selected for this analysis; this period is called “fall” in this report. There are some early fall diversions above Mud Creek near Sweetwater (06783500), the Middle Loup River at St. Paul (06785000), the Platte River near Cozad (06766500), the Republican River at Cambridge (06843500), and the Republican River near Orleans (06844500), but these were accounted for in the analysis.

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 has minimal effect on the results.

For each station used in the analysis, the lowest mean streamflows for 7 and 14 consecutive days for each October-November were calculated. These are called the 7- and 14-day low-flow for the fall of each particular year. By averaging streamflow for 7 or 14 days, anomalous short-term streamflow events are filtered out of the data. The 7- and 14-day fall low-flows were plotted verses time to see if they changed over time (example shown in fig. 4).

Five stations had an apparent trend in the long-term low-flows. Turkey Creek at Edison (06844210) appears to exhibit a steady increase in discharge for the entire period of record, from 1977 to 1997; Turkey Creek near Dannebrog (06784800) appears to increase in flows from 1978 to 1997. Elm Creek at Amboy (06852000) appears to have a slight decrease in flows from 1977 to 1997. However, these three stations are characterized by either a lack of early time period data or total absence thereof. A lack of substantial early data makes it unclear whether the trend indicates a long-term change or just a short-term fluctuation. Cedar River near Fullerton (06792000) appears to show a slight increase in discharge from 1980 to 1997. The discharge of Lincoln Creek near Seward (06880000) appears to increase significantly from 1981 to 1993 after a fairly consistent record from 1954 (fig. 5). Fall low-flows at other stations did not appear to change over time.

Early fall records at some stations reflect apparent irrigation withdrawals or diversions. These stations include Middle Loup River at St. Paul (06785000), Mud Creek near Sweetwater (06783500), Platte River near Cozad (06766500), Republican River at Cambridge (06843500), and the Republican River near Orleans (06844500). 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 these stations only (example shown in fig. 6).

The Platte River has a number of streamflow gaging stations on it and the stations have various periods of record. Because differences in fall low-flows between gaging stations are estimated in this analysis, comparable periods of record are desirable. Most stations on the Platte River had fall flows available for 1940-97, so this period was used in the analysis. The station at Kearney (06770200)was not used in the analysis because its period of record was not compatible with this period. The Brady gaging station (06766000) was included in the analysis even though it lies outside the primary study area, to provide an upstream station that was close to or upstream of the western boundary of the Eastern Model Unit.

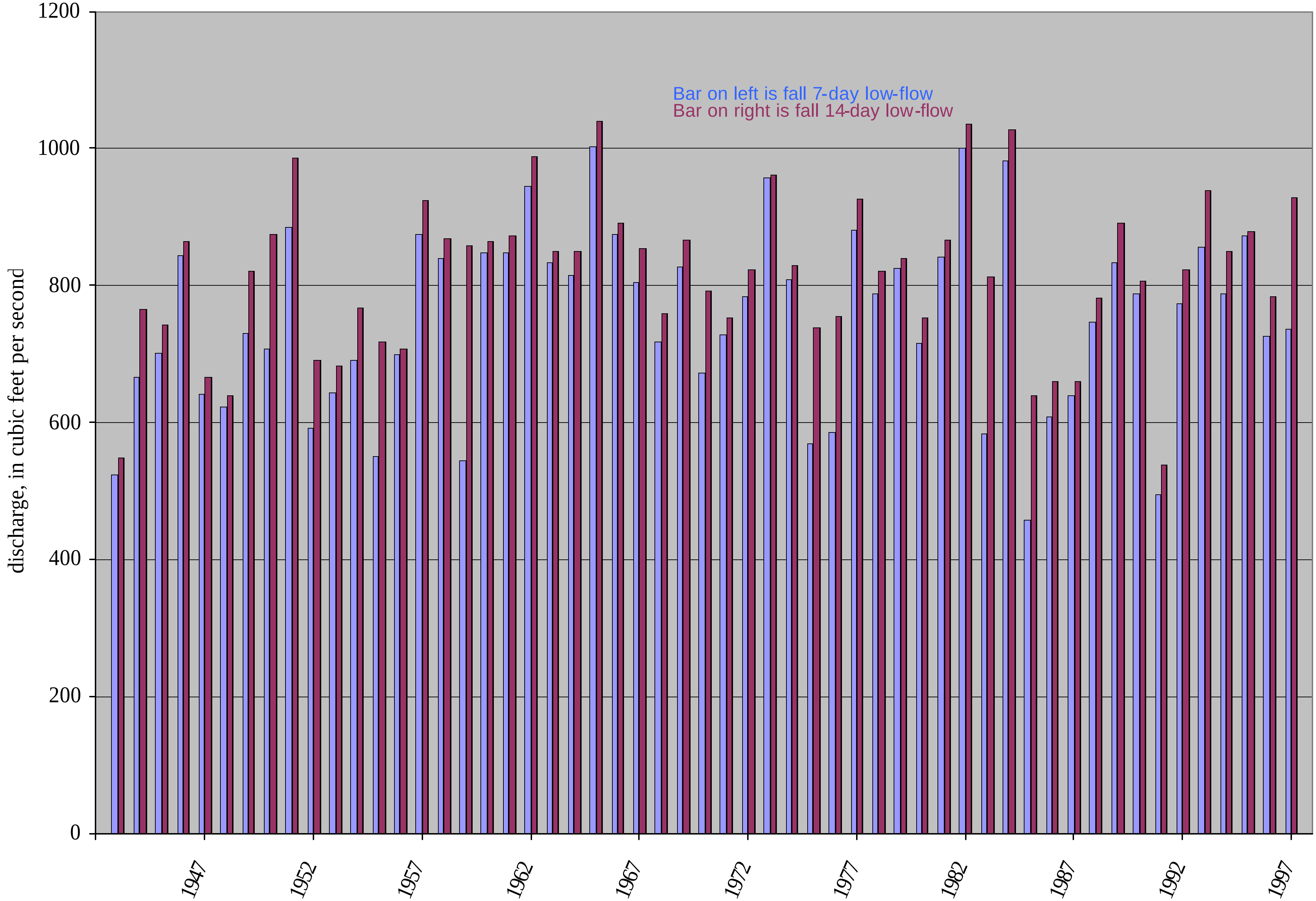

Figure 4. Fall (October-November) 7- and 14-day flows for North Loup River near St. Paul, Nebraska (06790500), for calendar years 1943 through 1997.

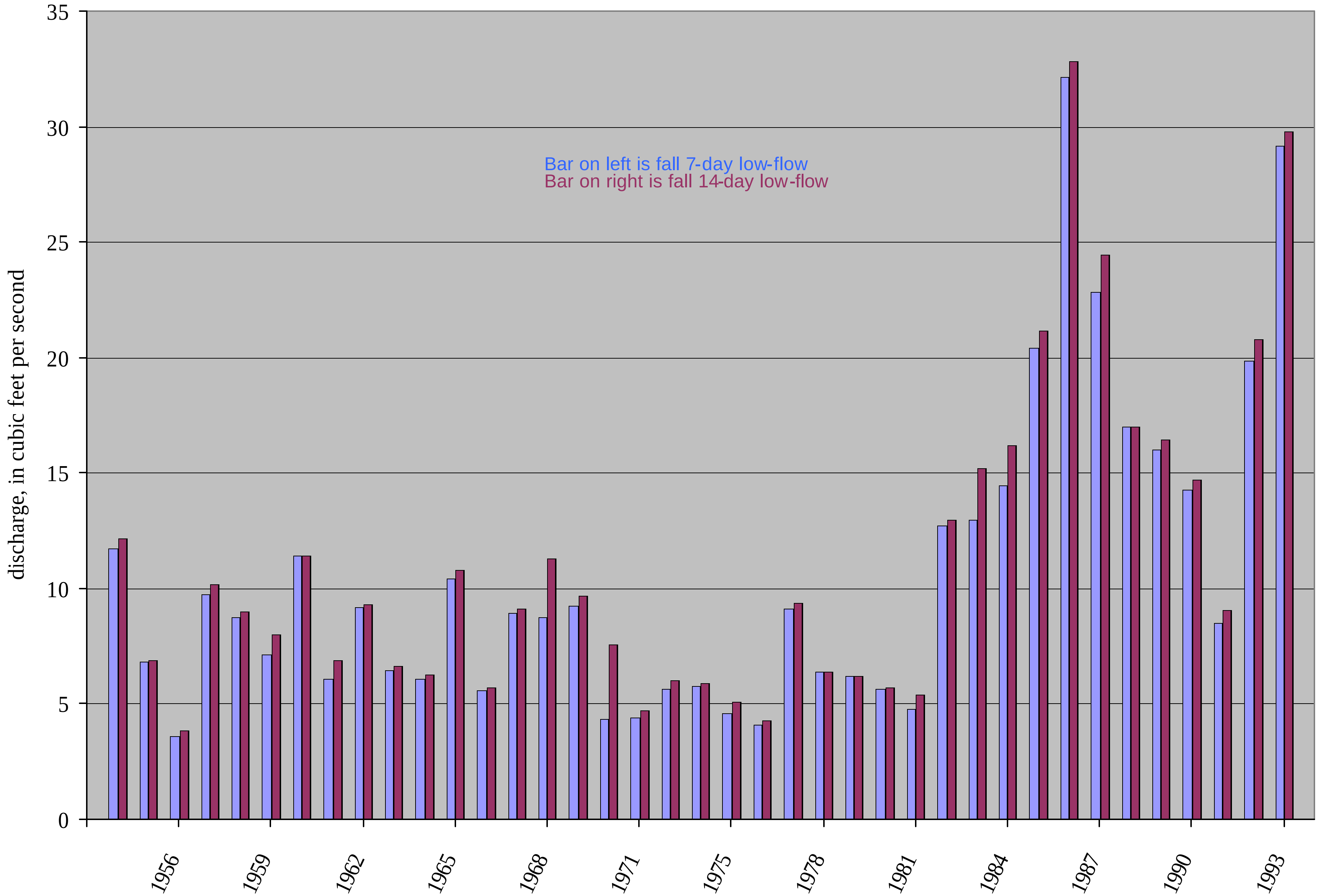

Figure 5. Fall (October-November) 7- and 14-day flows for Lincoln Creek near Seward, Nebraska (06880000), for calendar years 1954 through 1993.

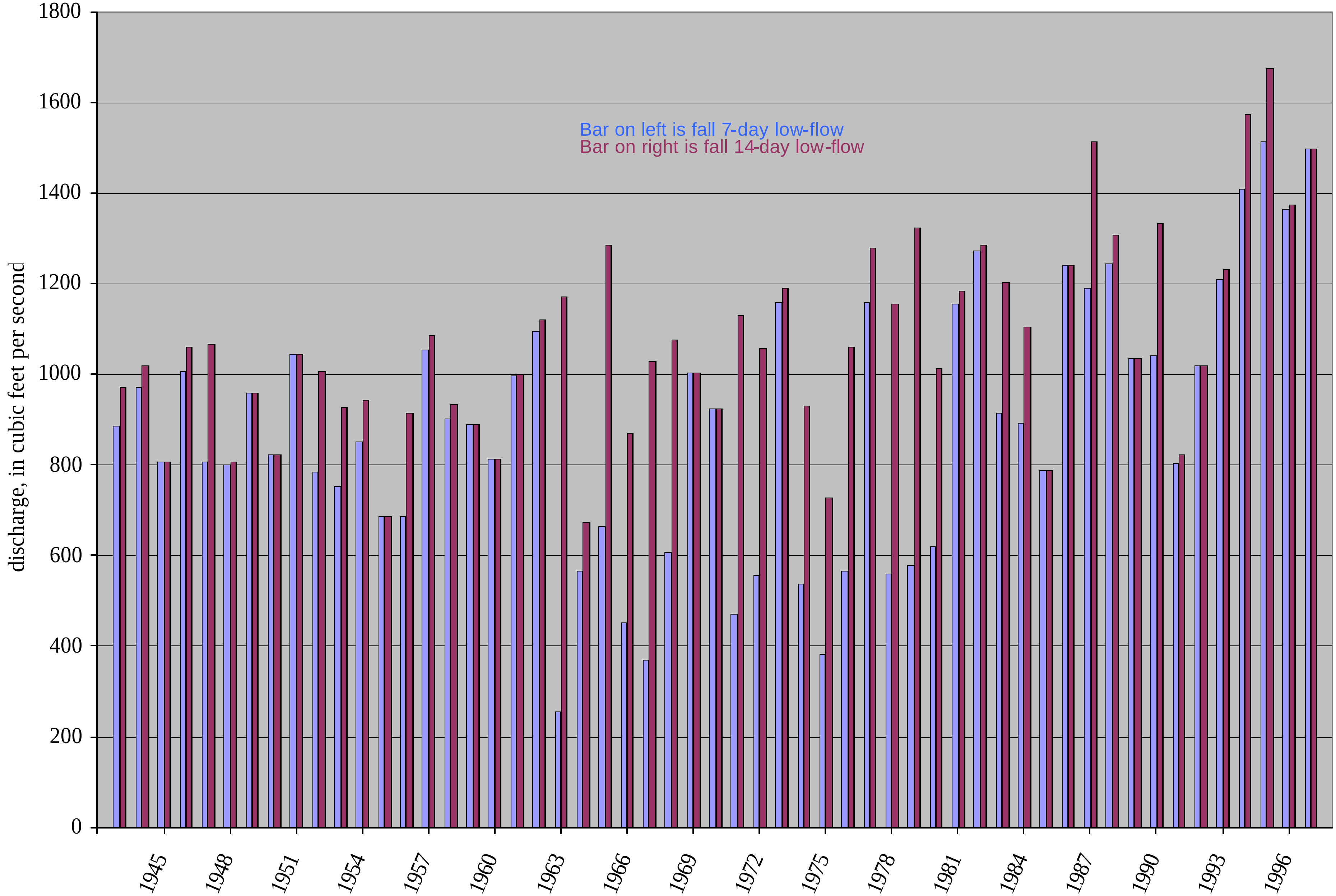

Figure 6. Fall (October-November) 7- and 14-day flows for the Middle Loup River at St. Paul, Nebraska (06785000), for calendar years 1943 through 1997.

The South Loup River, Middle Loup River, North Loup River and main Loup River each had at least two streamflow gaging stations, but four of these were omitted from the analysis. The South Loup near Cumro (06782000) contained insufficient fall data for analysis, and the South Loup at Ravenna (06782500), the Middle Loup near Rockville (06780000), and the main Loup at Columbus (06794500) did not match the period of record of the remainder of the Loup River system stations, which was from 1943-1997.

On the Republican River, the Republican River near Bloomington (06850500), Republican River at Guide Rock (06853020), and Republican River near Guide Rock (06853000) stations were omitted because they did not match the period of record of the other stations, which was from 1940-1997. The station on the Republican below Harlan County Reservoir (06849500) was excluded because the flow at that station only represents controlled reservoir releases and leakage around the dam, not discharge from groundwater.

The fall 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 fall low-flow was not exceeded in any one fall was calculated using the formula (Riggs, 1968)

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

where P{nonexceedence} is the probability that the fall 7- or 14-day low-flow is not exceeded in any one fall; K is the rank number of the fall, with the lowest 7- or 14-day low-flow ranked 1 and the highest flow ranked N; and N is the number of falls in the analysis.

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 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 7-day and 14-day fall low-flows with recurrence intervals of 2 and 5 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 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 gage occurs at the Loup River near Genoa, where the estimate is 1,300 to 1,800 cubic feet per second. This is the combined groundwater discharge to the river and all its tributaries above this station. The largest estimated groundwater discharge to a tributary occurred at Thompson Creek near Riverton (06851500) where the estimate was 17 to 20 cubic feet per second.

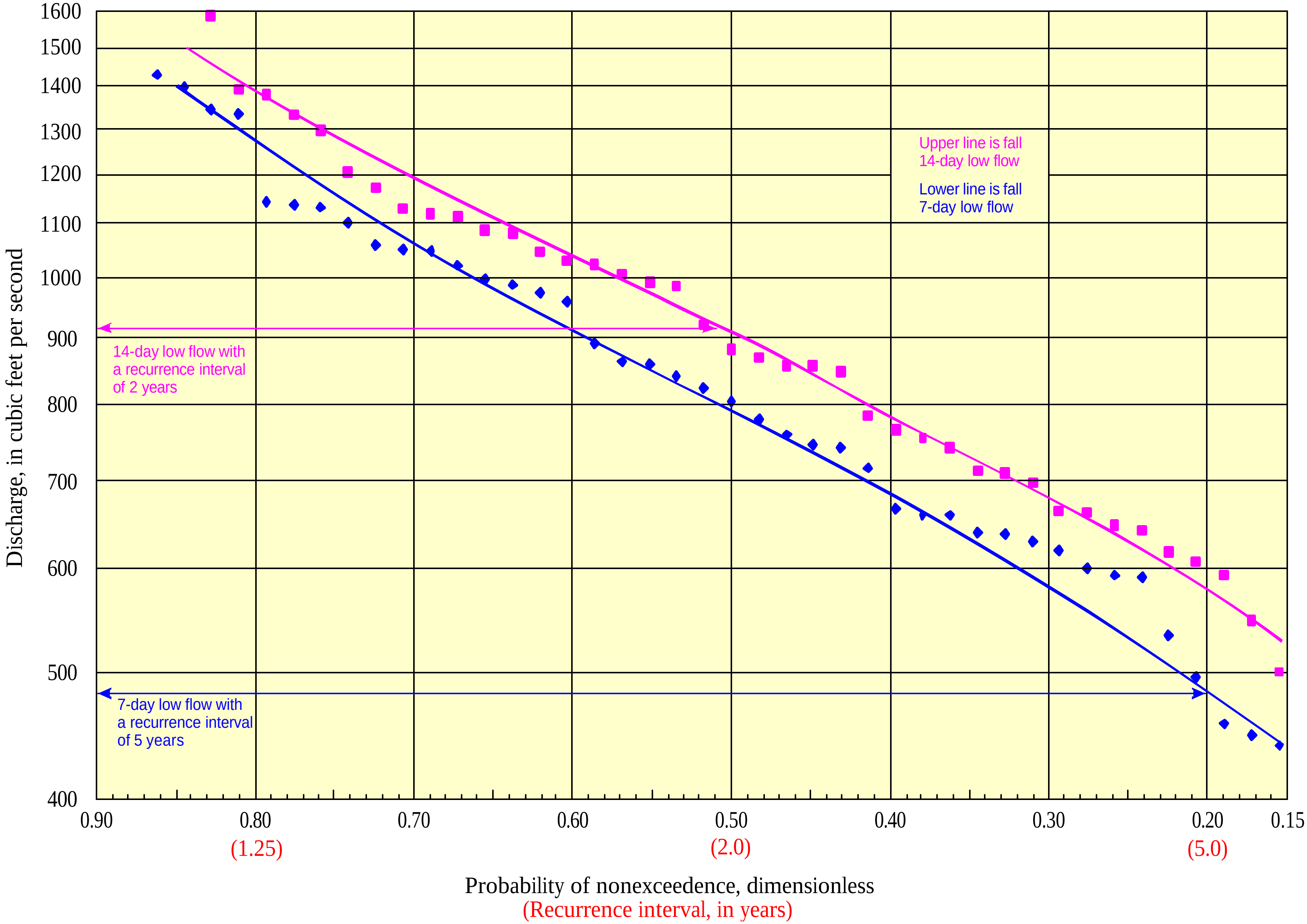

Figure 7. Frequency curves for 7- and 14-day October-November low-flows for Platte River near Overton, Nebraska (06774000), for fall 1940 through 1997.

Table 3. Estimated groundwater discharge to stations at streamflow gaging stations.

Station #	Station name	Period of analysis	Estimated groundwater discharge to streams (ft^3/sec)			Remarks
			Minimum	Mean	Maximum	
06794000	Beaver Creek near Genoa, Nebraska	1943-1997	56	61	66	The drainage area of this station is outside of the COHYST boundary. It is a tributary to the Loup River below the Genoa gaging station.
06879900	Big Blue River at Surprise, Nebraska	1964-1997	0.0	0.2	0.3	Measures all of the groundwater discharge to this branch of the Big Blue River within the COHYST boundary.
06768500	Buffalo Creek near Darr, Nebraska	1946-1968	0.0	0.0	0.0	7-day 5-year flow and 14-day 2-year flow are both zero.
06769000	Buffalo Creek near Overton, Nebraska	1949-1957, 1996-1997	0.0	0.9	1.8	Estimates may be in error due to the considerable gap in dates analyzed.
06792000	Cedar River near Fullerton, Nebraska	1943-1997	150	170	190	For reference only to compute groundwater discharge by reach. The drainage area of this station is outside of the COHYST boundary.
06851000	Center Creek at Franklin, Nebraska	1948-1955, 1968-1993	4.0	5.1	5.7	One estimate computed for entire period of record.
06850200	Cottonwood Creek near Bloomington, Nebraska	1948-1955	4.1	4.3	4.5	Tributary to the Republican River.
06852000	Elm Creek at Amboy, Nebraska	1948-1952, 1977-1997	11	12	12	Estimates may be in error due to the considerable gap in dates analyzed.
06769500	Elm Creek near Overton, Nebraska	1946-1957	0	0	0	7-day 5-year flow and 14-day 2-year flow are both zero.
06769525	Elm Creek near Elm Creek, Nebraska	1955-1989, 1996-1997	0	0	0	7-day 5-year flow and 14-day 2-year flow are both zero.
57000 (NE)	Gothenburg Canal Diversion near Gothenburg, Nebraska	1945-1996	NA	NA	NA	Data added to Platte River at Cozad prior to low-flow analysis.
144000 (NE)	Johnson #2 Power Return to the Platte River near Lexington, Nebraska	1942-1997	280	470	650	Treated as tributary to the Platte River.
06880000	Lincoln Creek near Seward, Nebraska	1954-1981	4.8	5.9	7.0	Station is outside of COHYST boundary, but no upstream station exists to measure flow on this stream.
06883000	Little Blue River near Deweese, Nebraska	1953-1997	51	56	60	Measures all of the groundwater discharge to this branch of the Little Blue River within the COHYST boundary.

Station #	Station name	Period of analysis	Estimated groundwater discharge to streams (ft^3/sec)			Remarks
			Minimum	Mean	Maximum	
06793000	Loup River near Genoa, Nebraska	1943-1997	1300	1600	1800	Loup Power diversion data added to raw data prior to low-flow analysis.
06792500	Loup River Power Canal near Genoa, Nebraska	1937-1997	NA	NA	NA	Data added to the Loup River near Genoa raw data prior to analysis.
00730 (NE)	Kearney Power and Irrigation Diversion near Elm Creek, Nebraska	1922-1929, 1934, 1936-1990, 1992, 1994	NA	NA	NA	Data added to the Platte River at Odessa raw data prior to low-flow analysis.
75000 (NE)	Kearney Power Return to the Platte River near Kearney, Nebraska	1945-1988, 1990-1991, 1996-1997	0.0	2.0	4.0	Treated as tributary to the Platte River.
06785000	Middle Loup River at St. Paul, Nebraska	1943-1997	680	840	1000	November data used to mitigate effects of Farwell Canal Diversion upstream of gage.
06780000	Middle Loup River near Rockville, Nebraska	1955-1963, 1967-1974	620	720	820	For reference only to compute groundwater discharge by reach. The drainage area of this station is outside of the COHYST boundary.
06844000	Muddy Creek at Arapahoe, Nebraska	1951-1994	3.6	4.5	5.4	Tributary to the Republican River.
06783500	Mud Creek near Sweetwater, Nebraska	1946-1993	15	18	20	November data used to mitigate effects of upstream irrigation development.
06790500	North Loup River near St. Paul, Nebraska	1943-1997	620	720	820	Treated as tributary to the Middle Loup River.
06766000	Platte River near Brady, Nebraska	1940-1997	100	120	130	For reference only to compute groundwater discharge by reach. The drainage area of this station is outside of the COHYST boundary.
06766500	Platte River near Cozad, Nebraska, plus Gothenburg Canal Diversion	1940-1997	170	195	220	Raw data from the Gothenburg Canal Diversion added prior to low-flow analysis. November data were used to minimize effects of irrigation diversions.
06774000	Platte River near Duncan, Nebraska	1940-1997	170	440	710	Groundwater discharge includes that which passed Grand Island and additional groundwater discharge.
06770500	Platte River near Grand Island, Nebraska	1940-1997	260	500	740	Groundwater discharge includes that which passed Odessa and that which was contributed by the Kearney Power Return.
06770000	Platte River near Odessa, Nebraska	1940-1997	320	560	790	Raw data from the Kearney Power and Irrigation Diversion added prior to low-flow analysis.

Station #	Station name	Period of analysis	Estimated groundwater discharge to streams (ft^3/sec)			Remarks
			Minimum	Mean	Maximum	
06768000	Platte River near Overton, Nebraska	1940-1997	490	700	910	Groundwater discharge includes that which passed Cozad and that which was contributed by the Johnson #2 Power Return to the Platte River.
06853500	Republican River near Hardy, Nebraska	1947-1997	45	70	100	Groundwater discharge includes that which passed Orleans and that which was contributed by Elm Creek, Thompson Creek, Center Creek, and Cottonwood Creek.
06843500	Republican River at Cambridge, Nebraska	1947-1997	90	110	130	For reference only to compute groundwater discharge by reach. The drainage area of this station is outside of the COHYST boundary.
06844500	Republican River near Orleans, Nebraska	1947-1997	100	120	130	Groundwater discharge includes that which passed Cambridge and that which was contributed by Turkey Creek and Muddy Creek. November data used to mitigate effects of canal diversions upstream.
06847500	Sappa Creek near Stamford, Nebraska	1946-1997	0.0	0.0	0.0	7-day 5-year flow and 14-day 2-year flow are both zero.
06784000	South Loup River at St. Michael, Nebraska	1943-1997	110	130	150	Groundwater discharge includes that which comes downstream from the drainage area in the Sand Hills and that which is contributed by Mud Creek.
06851500	Thompson Creek at Riverton, Nebraska	1948-1955, 1968-1997	17	19	20	Tributary to the Republican River, upper drainage area overlies the margin of the High Plains aquifer. Estimates may be in error due to the non-continuous period of record.
06844210	Turkey Creek at Edison, Nebraska	1977-1997	2.4	3.6	4.8	Tributary to the Republican River.
06784800	Turkey Creek near Dannebrog, Nebraska	1966-1969; 1978-1997	4.0	6.0	8.0	For reference only to compute groundwater discharge by reach. The drainage area of this station is outside of the COHYST boundary. Estimates may be in error due to gap in record.
06880800	West Fork of the Big Blue River near Dorchester, Nebraska	1958-1997	38	49	60	Measures all of the groundwater discharge to this branch of the Big Blue River within the COHYST boundary.
06772000	Wood River near Alda, Nebraska	1953-1997	0.0	0.0	0.0	7-day 5-year flow and 14-day 2-year flow are both zero.
06771500	Wood River near Gibbon, Nebraska	1949-1975	0.0	0.0	0.0	7-day 5-year flow and 14-day 2-year flow are both zero.

Some of the estimated groundwater discharge likely comes from outside of the COHYST study area. This is especially true when considering that many tributaries and branches of the Loup River system originate in or near the eastern part of the Nebraska Sand Hills. Of the streams analyzed in this report, it is likely that all of the Platte River (except the Platte River at Brady) and tributaries to the Platte River, as well as all the tributaries to the Republican River, represent groundwater discharge originating solely from within the Eastern Modeling Unit of the COHYST study area.

The Platte River, the Republican River, and the Loup River (parts of the South, Middle, and North) each had several streamflow gaging stations on them so groundwater discharge to these streams could be estimated by reach. For streams with more than one streamflow gaging 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 intervening tributaries. For each station, the arithmetic average of the 7-day, 5-year and the 14-day, 2-year fall low-flows was computed. The estimated mean groundwater discharge to or from the stream in the reach could have been computed as the average low-flow at the downstream station minus the average low-flows at the upstream and tributary stations. However, this method did 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 appreciably affect the analysis. 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 alternate 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 would usually pass through upstream or tributary stations and the downstream station and would have minimal effect on the reach analysis.

In order to account for canals when analyzing streams by reach, canals that returned to a river were treated as tributaries, therefore, 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 and the Kearney 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 diversions were added to the next downstream gaging station data prior to performing the low-flow analysis. This was done for the Gothenburg Canal Diversion, which was added to the Platte River at Cozad; for the Kearney Irrigation and Power Diversion, which was added to the Platte River at Odessa gaging station data; and for the Loup River Power Canal near Genoa, which was added to the Loup River at Genoa gaging station data.

The estimated minimum, mean, and maximum groundwater discharge within a reach was divided by the length of the reach to normalize the discharge. The largest estimates of normalized

Table 4. Estimated groundwater discharge to streams by reach for the Platte River, Republican River, and Loup River.

River Reach	Estimated groundwater discharge to main stem in reach (ft^3/s)			Approximate distance (miles)	Estimated normalized groundwater discharge to main stem in reach ($ft^3/s/mi$)			Remarks
	Minimum	Mean	Maximum		Minimum	Mean	Maximum	
Platte River, Brady to Cozad	60	100	180	25	2.0	4.0	7.0	Mean indicates gaining reach.
Platte River, Cozad to Overton	-100	20	200	27	-4.0	1.0	7.0	Mean indicates gaining reach.
Platte River, Overton to Odessa	-80	-20	50	15	-5.0	-1.0	3.0	Mean indicates losing reach.
Platte River, Odessa to Grand Island	-750	-150	300	56	-13	-3.0	5.0	Mean indicates losing reach.
Platte River, Grand Island to Duncan	-80	20	260	55	-1.0	0.0	5.0	Mean indicates neutral reach.
Republican River, Cambridge to Orleans	-20	0.0	40	43	-0.4	0.0	0.9	Mean indicates neutral reach.
Republican River, Orleans to Hardy	-50	0.0	240	102	-0.5	0.0	2.4	Mean indicates neutral reach.
Mud Creek / South Loup River, Sweetwater to St. Michael	130	160	180	16	8.0	10	11	Mud Creek and the South Loup are treated as the same feature for the upper reach estimate. Mean indicates gaining reach.
South Loup River at St. Michael to Middle Loup River at St. Paul	40	810	1100	23	2.0	35	50	South Loup River and Middle Loup River converge in this reach, thus are treated as a continuous feature. Mean indicates gaining reach.
Middle Loup River at St. Paul to Loup River at Genoa	-180	-50	70	45	-4.0	-1.0	2.0	Middle Loup River and North Loup River converge in this reach to form the main Loup River. Mean indicates losing reach.

groundwater discharge are to the South Loup River at St. Michael to the Middle Loup River at St. Paul. High discharge to this reach seems reasonable because the upper reaches of the South Loup River drain the eastern margin of the Sand Hills, which are a fairly constant source of groundwater discharge. The largest normalized losses to groundwater occur on the Platte River between Overton and Odessa. Large losses occur through this area, and to a lesser extent downstream of this area, probably due to local geology. In general, normalized gains and losses on the Platte and the Loup River system trend from gaining in the upper reaches to losing in the lower reaches. On the Republican River, normalized gains and losses indicate the upper reach loses slightly, whereas the lower reach gains slightly. The largest estimated groundwater discharge to a tributary occurred at Thompson Creek near Riverton (06851500) where the estimate was 17 to 20 cubic feet per second.

Summary

The Cooperative Hydrology Study 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 used to calibrate these models. This report estimates groundwater discharge to streams in the Eastern Model Unit prior to large-scale development of the aquifer for irrigation.

Daily stream discharge data during the fall (October-November) from 40 streamflow-gaging stations were used in the analysis. For individual stations, the 7-day fall low-flow with a recurrence interval of 5 years was used as the minimum estimate of groundwater discharge passing the station and the 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 more than one station on them, 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 normalized by dividing them by reach length.

The largest estimated groundwater discharge passing a streamflow gaging station occurred at the Loup River near Genoa (06793000) where the estimate was 1,300 to 1,800 cubic feet per second. The largest estimated groundwater discharge to a tributary occurred at Thompson Creek near Riverton (06851500) where the estimate was 17 to 20 cubic feet per second. In general, the Loup and Platte Rivers tended to gain more in the upper reaches than in the lower reaches, and the Republican River tended to gain more in the lower reaches than in the upper reaches.

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