1-1978

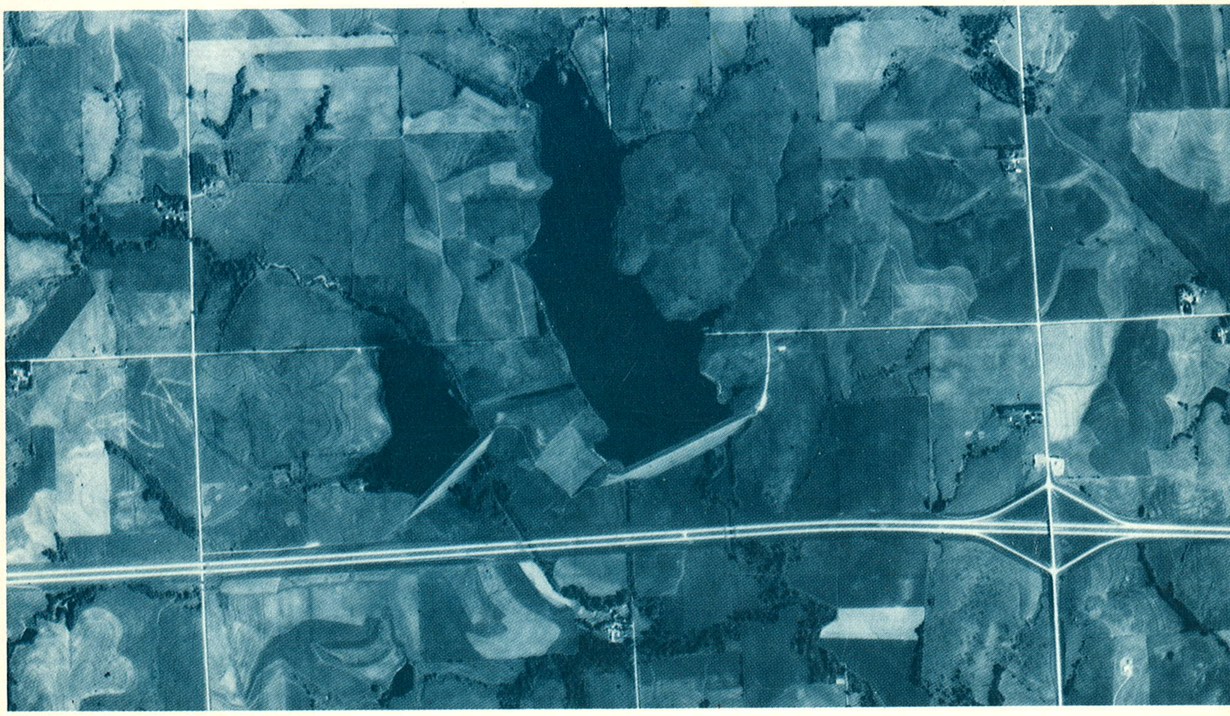
Water Resources of Seward County, Nebraska

C. F. Keech
University of Nebraska-Lincoln

Water Resources of SEWARD COUNTY, NEBRASKA

C. F. Keech

with a section on the Quality of the Water
by R. A. Engberg



NEBRASKA WATER SURVEY PAPER 46

Prepared in cooperation with the U.S. Geological Survey

Conservation and Survey Division
Institute of Agriculture and Natural Resources
The University of Nebraska–Lincoln

Water Resources of SEWARD COUNTY, NEBRASKA

C. F. Keech

with a section on the Quality of the Water
by R. A. Engberg

NEBRASKA WATER SURVEY PAPER 46

Prepared in cooperation with the U.S. Geological Survey

Conservation and Survey Division
Institute of Agriculture and Natural Resources
The University of Nebraska–Lincoln

The Conservation and Survey Division of The University of Nebraska is the agency designated by statute to investigate and interpret the geologically related natural resources of the state, to make available to the public the results of these investigations, and to assist in the development and conservation of these resouces.

The Division is authorized to enter into agreements with federal agencies to engage in cooperative surveys and investigations in the state. Publications of the Division and the cooperating agencies are available from the Conservation and Survey Division, The University of Nebraska, Lincoln, Nebraska 68588.

Publication and price are furnished upon request.

Cooperative projects with
UNITED STATES GEOLOGICAL SURVEY
William A. Radlinski, Acting Director

Water Resources Division
K. A. Mac Kichan, District Chief

January 1978

CONTENTS

Illustrations

Tables

ABSTRACT

This report describes the availability, location, quantity, source, quality, and use of groundwater and surface-water resources of Seward County, Nebraska, which includes about 572 square miles (1 480 km^2) in southeastern Nebraska.

Principal topographic features of the county are the almost level, southeastward-sloping loess plain west of the Big Blue River and the rolling drift hills developed on glacial till east of the Big Blue River. The Big Blue River flows south-southeasterly across the county and forms a dividing boundary between the plains and rolling hills. All streams except the Big Blue River, West Fork Big Blue River, and Lincoln Creek are ephemeral and flow only during and after heavy rains. The climate is subhumid; precipitation varies significantly from year to year and averages about 27 inches (690 mm) annually.

Agriculture is the principal industry. Corn, the most important crop, occupies 87 percent of the 72,600 acres (295 km^2) that were irrigated in 1972. About 65,000 acres (265 km^2) were irrigated with water pumped from 653 wells and 7,600 acres (31 km^2) were irrigated with water pumped from streams.

Water levels in wells are declining in about one-third of the county. The decline represents an estimated depletion of groundwater storage of 175,000 acre-feet (0.216 km^3) since groundwater withdrawals for irrigation began.

The most productive aquifers occur west of the Big Blue River beneath the loess plain. Saturated zones of sand and gravel of Quaternary age supply as much as 1,200 gallons per minute (0.076 m^3/s) to wells. In part of the Loess Plain area, porous saturated zones are confined by relatively impervious beds of silt and clay and the aquifer is under artesian pressure. Flowing wells occur in the valley of the West Fork Big Blue River.

The least productive aquifers occur in the Drift Hills area east of the Big Blue River, where they are thin and of limited

extent. Large-yield wells can be obtained here in only a few localities.

The Quaternary deposits rest on rocks of Cretaceous age. Only the Dakota Group (undivided) of Cretaceous age yields appreciable quantities of groundwater. Most of the water pumped from the Dakota is too highly mineralized to be used for irrigation; in some places, however, it has been applied to crops with poor to moderately successful results.

Groundwater in the sediments of Quaternary age is mostly of the calcium bicarbonate type and is highly suitable for irrigation. Locally the water is hard and contains high concentrations of iron, though generally it is potable and suitable for domestic use. Water in the Dakota aquifer contains high concentrations of chloride which, in most places, exceed the recommended federal limits for domestic use.

INTRODUCTION

Seward County includes about 572 square miles (1 480 km^2) in southeastern Nebraska (figure 1). The western two-thirds of the county is underlain by aquifers capable of supplying sufficient water for irrigation of field crops. In the eastern third of the county, the groundwater supply in most places is inadequate for irrigation; in some places, water for domestic and livestock use is not easily obtained.

The purpose of this report is to define geologic and hydrologic conditions relating to the occurrence, quantity, quality, and use of water in Seward County as an aid to the development and management of the water resources of that county.

Most of the data in this report were collected and interpreted under the cooperative program maintained by the U.S. Geological Survey and the Conservation and Survey Division, Institute of Agriculture and Natural Resources, The University of Nebraska-Lincoln.

Since 1941 the Conservation and Survey Division, in cooperation with the U.S. Geological Survey, has drilled 24 test holes to investigate the water-bearing materials in Seward County. Logs of test holes describing the materials penetrated were published in two reports (Schreurs and Keech, 1953; 1955) as part of a program for development of the Missouri River basin.

A report on the use of groundwater in Seward County (Jess, 1970) contains information on groundwater development, the use of groundwater for irrigation, and the economics of pumping water for irrigation.

An open-file report describing groundwater withdrawal and its effect on Seward County's groundwater resources through 1971 was released by the U.S. Geological Survey in August 1973. The report (Steele, 1973) contains information on well yields, pumping time, total acreage irrigated, rate of groundwater withdrawal, and water-level declines resulting from groundwater withdrawal. The study was prepared by the U.S. Geological Survey in cooperation with the Seward County Ground Water Conservation District.

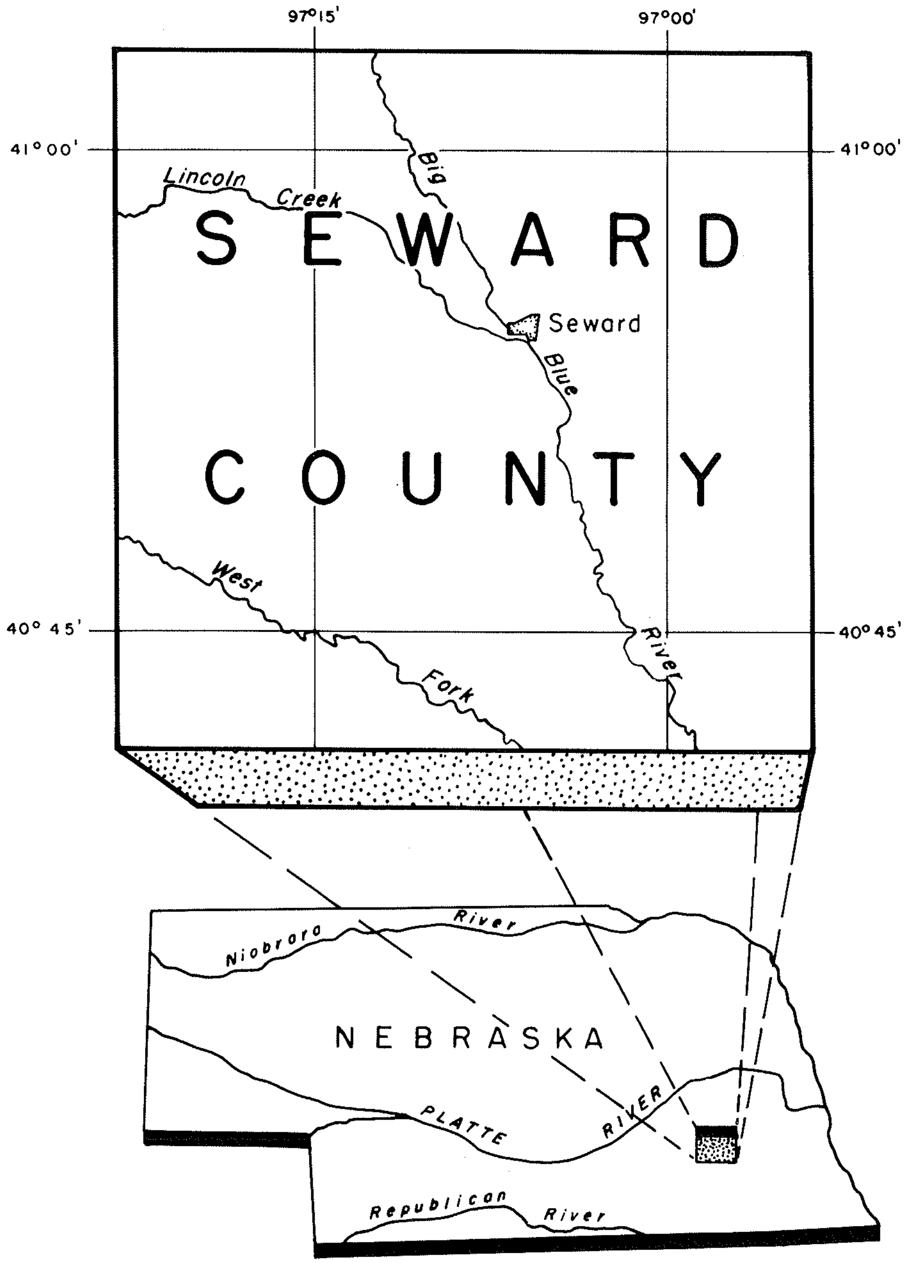


Figure 1. Location of Seward County.

METRIC CONVERSION FACTORS

To convert English units to their metric equivalents in the International System of Units (SI), follow the procedure given below:

MULTIPLY	BY	TO OBTAIN
Length		
inches (in)	25.4	millimeters (mm)
feet (ft)	3.048×10^{-1}	meters (m)
miles (mi)	1.609	kilometers (km)
Area		
acres	4 047	square meters (m^2)
square miles (mi^2)	2.590	square kilometers (km^2)
Volume		
acre-feet (acre-ft)	1 233	cubic meters (m^3)
cubic feet (ft^3)	2.832×10^{-2}	cubic meters (m^3)
gallons (gal)	3.785×10^{-3}	cubic meters (m^3)
Flow		
gallons per minute (gpm)	6.309×10^{-5}	cubic meters per second (m^3/s)
cubic feet per second (ft^3/s)	2.832×10^{-2}	cubic meters per second (m^3/s)
cubic feet per day per foot [(ft^3/day)/ft]	9.29×10^{-2}	cubic meters per day per meter [(m^3/day)/m]

SYSTEM FOR NUMBERING WELLS AND TEST HOLES

Each well and each test hole referred to in this report is located by means of a number based on the system of land subdivision employed in the U.S. Bureau of Land Management's survey of Nebraska. The figure preceding N (for "north") in the number indicates the township, the figure preceding E (for "east") or W (for "west") indicates the range, and the figure preceding the terminal letters indicates the section. The terminal letters denote location within the section. These letters are assigned in a counterclockwise direction beginning with A in the northeast quarter of each tract. As shown in figure 2, the first of these letters indicates the quarter section (160-acre tract); the second, the quarter-quarter section (40-acre tract); the third, the quarter-quarter-quarter section (10-acre tract), and the fourth, the quarter-quarter-quarter-quarter section (2.5-acre tract). For example, a well or test hole in the SE¼ SW¼ sec. 15, T. 10 N., R. 1 E., is identified by the number 10N-1E-15CD (cf. figure 2).

When additional wells are located in the same tract, they are distinguished by the sequential digit at the end of the number. For example, a second well in the SE¼ SW¼ sec. 15, T. 10 N., R. 1 E., would be assigned the number 10N-1E-15CD2.

Each test hole is identified by a field number also. It consists of three segments, the first of which is a sequential designation, the second is the letter for the rig used (either A or B), and the third is the year in which the hole was drilled. Thus, field number 18A51 indicates the eighteenth hole drilled by the A rig in 1951.

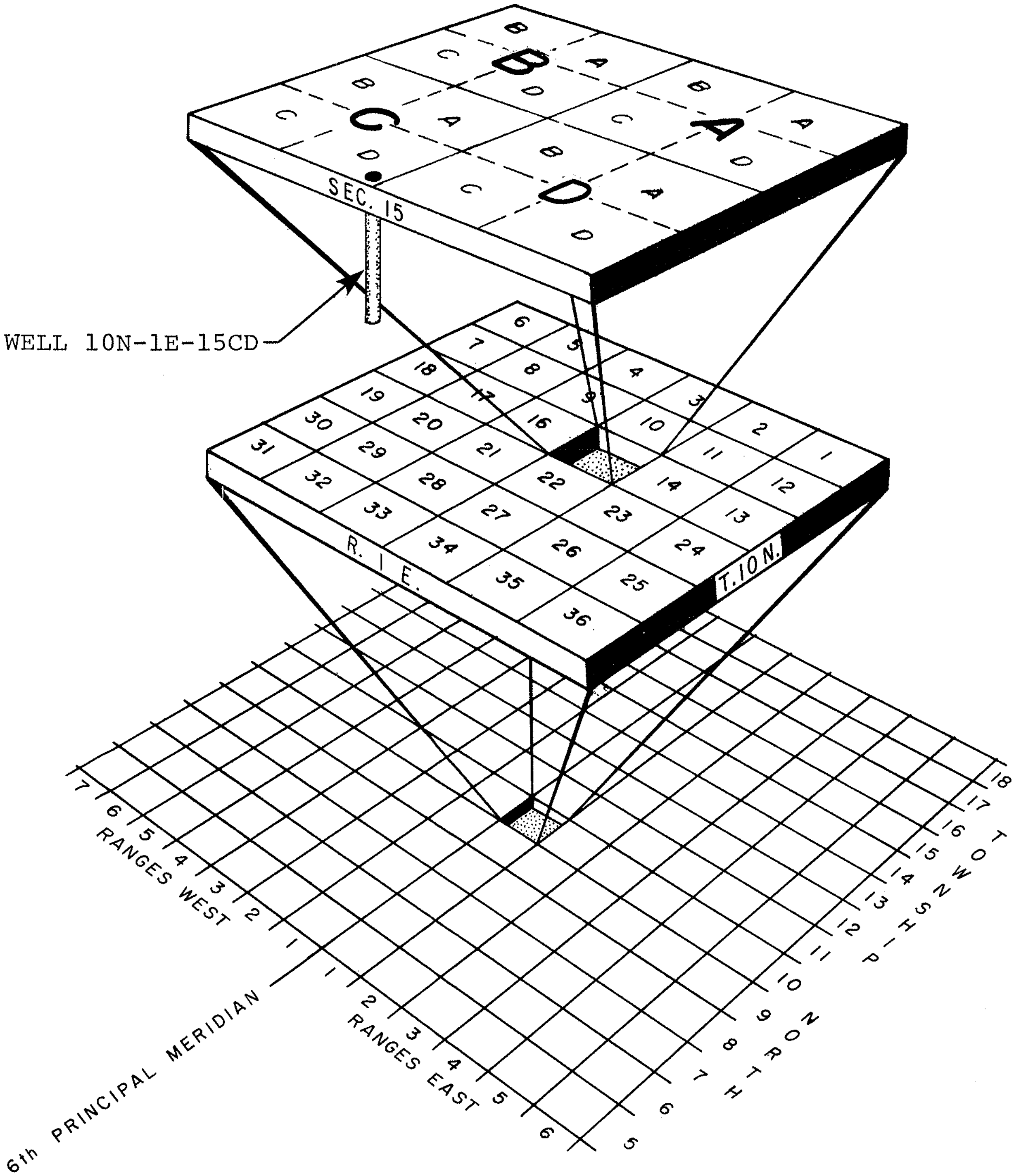


Figure 2. System for numbering wells and test holes.

TOPOGRAPHY, DRAINAGE, AND SOILS

The principal topographic features of the county are rolling hills comprised of till and related glacial deposits east of the Big Blue River valley (Drift Hills), the relatively flat plain of fluvial and aeolian deposits 60 to 90 feet (18.3 to 27.5 m) above the major stream valleys west of the Big Blue River valley (Loess Plain), and the valleys of the Big Blue River and the West Fork Big Blue River. The area covered by glacial drift, which occupies about 30 percent of the county and borders the east boundary, has been eroded to a topography of valleys, hills, and ridges. Drainage is complex and numerous gullies and laterals occur between the hills and ridges. The uplands west of the Big Blue River are part of an extensive plain that slopes southeastward about 5 feet per mile (0.95 m/km) in Seward County.

The Big Blue River flows south-southeasterly across Seward County from a point 9 miles (14.5 km) east of the northwest corner to a point 4 miles (6.4 km) west of the southeast corner; its valley is as much as 1.5 miles (2.41 km) wide. The Big Blue River drains all the area east of the river. The other half of the eastern part of the county is drained by small creeks that flow eastward to Salt Creek, a tributary of the Platte River. Lincoln Creek and the West Fork Big Blue River are tributaries of the Big Blue River and have valleys that are incised as much as 190 feet (58 m) below the plain. In their lower reaches, these valleys are about 1 mile (1.61 km) wide.

Soils in Seward County differ considerably in their capacity to absorb, retain, and transmit water to the underlying saturated zone. These differences are traceable mainly to slope, texture, and degree of loaminess. The loamy upland soils, derived from weathered loess (wind-deposited silt) or from till deposits, have a high silt or clay content. Soils developed from loess are granular and more friable than those developed from till. Such soils readily absorb water and retain soil moisture but allow percolation to the groundwater reservoir. Soils originating from till are heavier in texture. These soils do not absorb water as readily as the loessial soils, tending rather to retain moisture and to retard its penetration to the saturated zone. Because soils derived from till of the Drift Hills have a high clay content, surface runoff from them is greater than that from loamy soils. Heavy rains quickly form gullies on slopes and carry much sediment to the streams. In general, steep slopes are left in permanent pasture to help reduce erosion. Very little recharge to groundwater can occur on steep slopes because of tight soils and rapid runoff.

West of the Big Blue River a number of undrained depressions occur on the uplands. Soils in these basins are very tight. Most of the water retained after rains is lost to evaporation, and very little becomes groundwater recharge.

Bottomland soils developed on alluvium washed from adjacent uplands are similar to the upland soils but contain more humus, are more friable, and absorb and retain moisture more readily. Along the West Fork Big Blue River, much groundwater is discharged by evapotranspiration along the valley floor. Groundwater discharge by evapotranspiration along the valley of the Big Blue River is not large. The soils are formed on loess and the valley fill is colluvium and alluvium derived mainly from the loess. The silt loam soils are ideally suited to irrigation.

CLIMATE

Availability and use of water are closely associated with the climate. All water in the county originates from precipitation and most water use occurs at periods of high temperature and evaporation.

The climate of Seward County is subhumid with pronounced monthly and seasonal ranges in temperature. Average annual humidity is about 70 percent. Weather is clear about one-half of the time, cloudy a fourth of the time, and partly cloudy the other fourth. Most of the average annual precipitation of about 27 inches (690 mm) occurs during the growing season and the least occurs in winter. Spring and summer rains usually accompany local thunderstorms, whereas fall and winter precipitation results from widespread storms. Strong winds are common, though tornadoes are rare. Most tornadoes occur in rural areas, damaging farm buildings as well as power and communication lines. A tornado that struck Milford, Nebraska, on April 25, 1957, destroyed 200 homes and business establishments. Even though property damage can be severe, the loss of human life from tornadoes has been relatively small.

During the period 1930-72 annual precipitation at Seward, which is near the center of the county, ranged from 15.62 inches (395 mm) in 1934 to 39.25 (1 000 mm) in 1951 and averaged 27.13 inches (690 mm). Figure 3 shows that annual precipitation seldom is near average, having departed from average by more than 12 inches (305 mm).

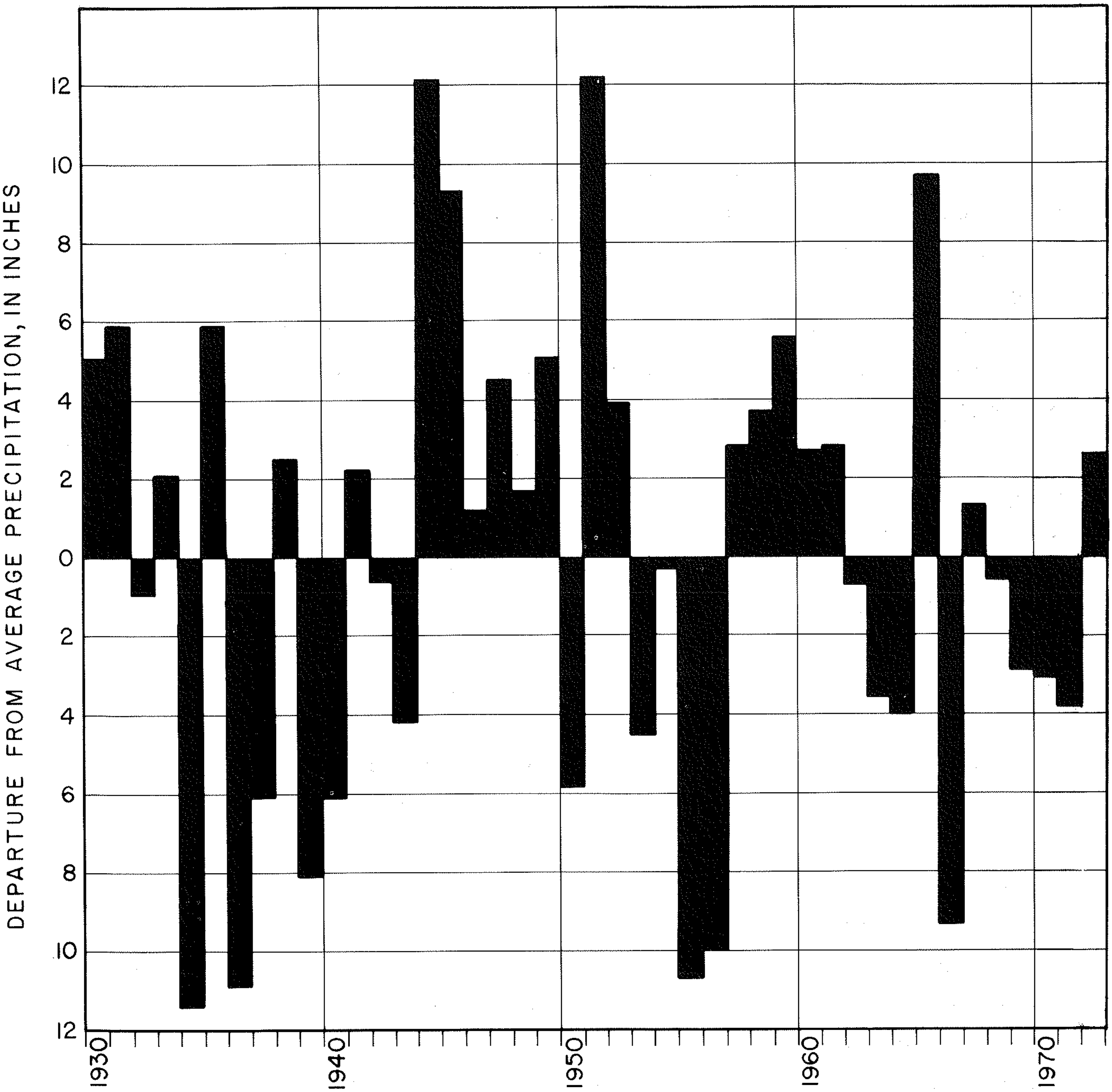


Figure 3. Departure from average precipitation at Seward, Nebraska, 1930-72.

SURFACE WATER

The Big Blue River was used for many years to develop power at Seward and Milford. The power plants had small capacity; they no longer are used for power and have fallen into disrepair.

The average annual discharge of the Big Blue River at Seward for the 18-year period of record (1953-71) was 115 ft^3/s (3.25 m^3/s). Nearly half, or 47.8 ft^3/s (1.35 m^3/s) was contributed by Lincoln Creek. Above the confluence with the Big Blue River, the West Fork Big Blue River has considerably more flow than the Big Blue River. Discharge records of the West Fork Big Blue River near the point where it leaves the county show an average annual flow of 182 ft^3/s (5.15 m^3/s) for a 13-year period of record (1958-71). (Cf. following table.)

Discharge records for three gaging stations in the Big Blue River basin

Station number 06-	Station name	Period of record (years)	Drainage area (mi^2)	Discharge			
				Maximum instantaneous (ft^3/s)	Minimum daily (ft^3/s)	Average for period (ft^3/s)	Average annual (acre-ft)
8800	Lincoln Creek near Seward	18 (1953-71)	446	10,100	1.3	47.8	34,630
8805	Big Blue River at Seward	18 (1953-71)	1,101	15,300	0[1]	115	83,320
8808	West Fork Big Blue River near Dorchester	13 (1958-71)	1,206	11,400	20	182	131,900

1. Result of pumping stream water for irrigation, July 30-31, 1955.

The total average annual discharge from the county of the Big Blue River and its tributaries is estimated to be about 250,000 acre-feet (0.310 km^3) per year, based on the average annual discharge of 257,200 acre-feet (0.315 km^3) of the Big Blue River at Crete, Nebraska, about 5 miles (8 km) downstream from the county line.

The surface-water supply is considerably overappropriated. According to records of the Nebraska Department of Water Resources, the number of claims and applications for rights to stream water in Seward County total 200 for irrigation, 28 for storage of water, and one for recreational purposes. Since only a fraction of the appropriators make use of their water rights, the total amount of water used is unknown. In drought years, when streams are near minimum discharge, the demand for irrigation water is greatest. Administrators of the water supply become hard pressed to satisfy all users because, according to Nebraska statutes, users with junior rights must reduce operations in deference to those with senior rights.

The 28 applications for water rights for storage behind small dams are for a variety of uses. Stored water results in some water loss because it is subject to evaporation. The rate of loss depends upon climatic conditions, which can change rapidly, and upon the surface area of the reservoirs, which changes slowly. Some reservoirs capture water wasted by the overapplication of groundwater to irrigated fields. A few irrigators reuse this water, which might otherwise run off to streams.

Floods are rather common along the Big Blue River and its tributaries. The most recent serious flood occurred in 1963 (Shaffer and Braun, 1967) when a considerable part of the city of Seward was inundated. According to Shaffer and Braun, valuable floodplain areas were inundated six of 20 years during 1946-65.

GEOLOGIC UNITS AND THEIR WATER-BEARING PROPERTIES

Groundwater is stored in and transmitted through openings in porous rock material. Therefore, the availability, occurrence, and quality of groundwater in Seward County depends on the lithologic characteristics, thicknesses, and areal distribution of the water-bearing and water-confining beds. Geologic formations pertinent to the water resources of Seward County are listed in table 1 in stratigraphic sequence from the Lower Cretaceous through the Holocene Series. The stratigraphic positions of the principal geologic units are shown on geologic sections presented as figures 4, 5, and 6. The geologic units shown as sand or sand and gravel are those that yield abundant supplies of fresh water to wells. The geologic units composed principally of silt and clay do not yield significant amounts of water directly to wells. Where they are saturated and are in contact with productive aquifers, they indirectly contribute water to wells.

Table 1. Generalized section of the geologic units and their water-bearing properties, Seward County

System	Series	Stratigraphic unit	Thickness (feet)	Character and distribution	Water supply
Quaternary	Holocene	Surficial terrace and floodplain deposits and soil	0 - 10±	Widespread soils; terrace and floodplain deposits of clay, silt, sand, and gravel	Significant only because it transmits recharge to the groundwater reservoir
	Pleistocene	Unconsolidated deposits, undifferentiated	0 - 450	Water-laid and windblown stratified deposits of clay, silt, sand, and gravel; stream-deposited sand and gravel containing layers of clay and silt of wind and stream origin; ice-deposited till (nonsorted, nonstratified sediment carried or deposited by a glacier); underlies much of the county	Principal source of water to wells in the county; medium- and coarse-textured deposits yield more than 1,000 gallons per minute of water where sufficiently permeable, thick, and saturated
Cretaceous	Upper Cretaceous	Carlile Shale	0 - 40	Medium- to dark-gray shale, calcareous in part; contains thin layers of limestone; occurs where the bedrock is at highest altitude in the northwestern and south-central parts of the county	Does not yield water to wells
		Greenhorn Limestone	0-25	White and gray limestone and calcareous shale; underlies about half the county; not present in the bedrock valleys	As above
		Graneros Shale	0-70	Dark-gray shale, calcareous in upper part; underlies about half the county; not present in the bedrock valleys	As above
	Lower Cretaceous	Dakota Group (undivided)	150-500	Interbedded clayey shale, sandy shale, and sandstone; underlies the entire county	Yields small to large amounts of water to a few wells in Seward County; quality of the water ranges from good to substandard

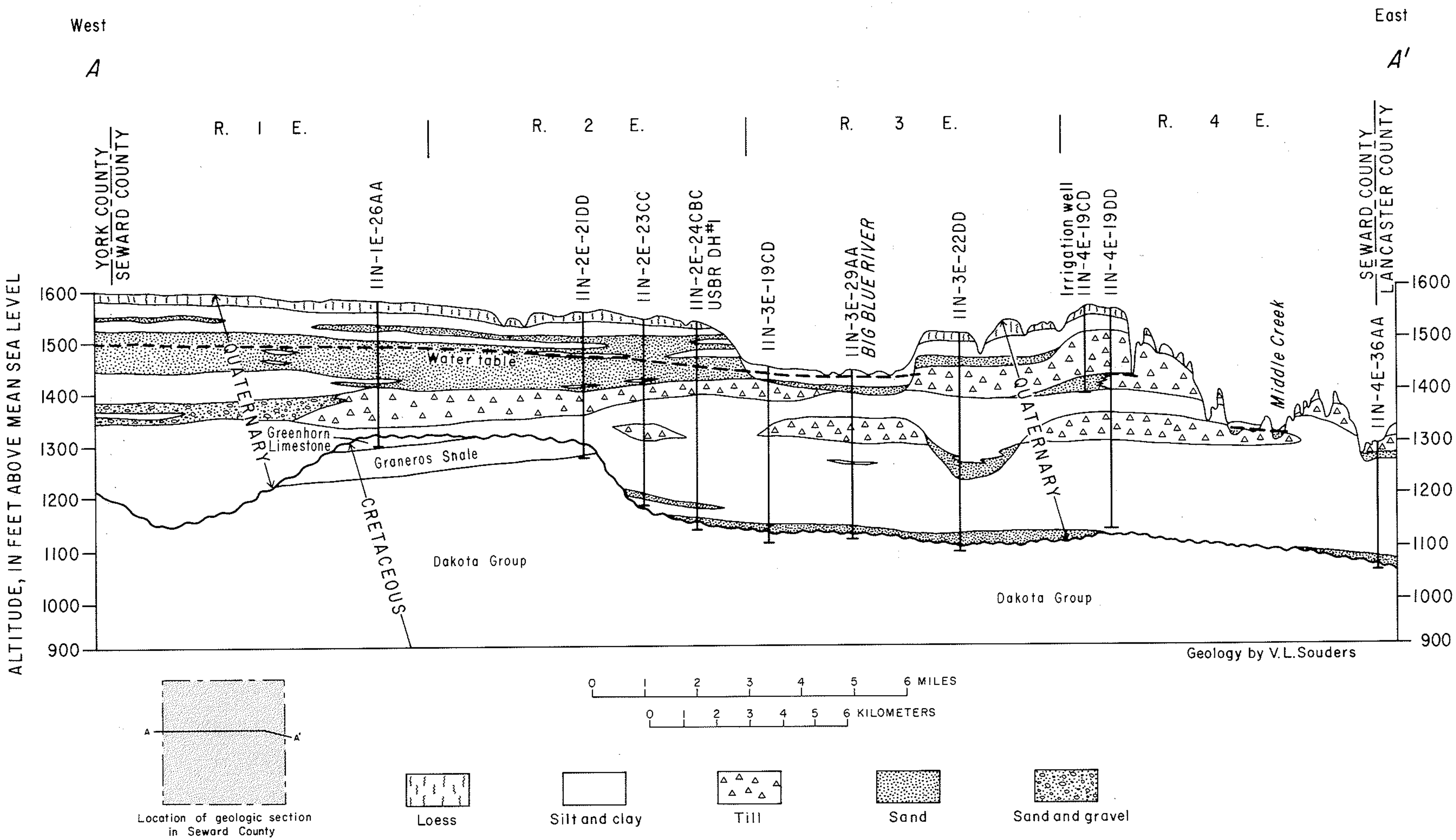


Figure 4. Geologic section line A-A'.

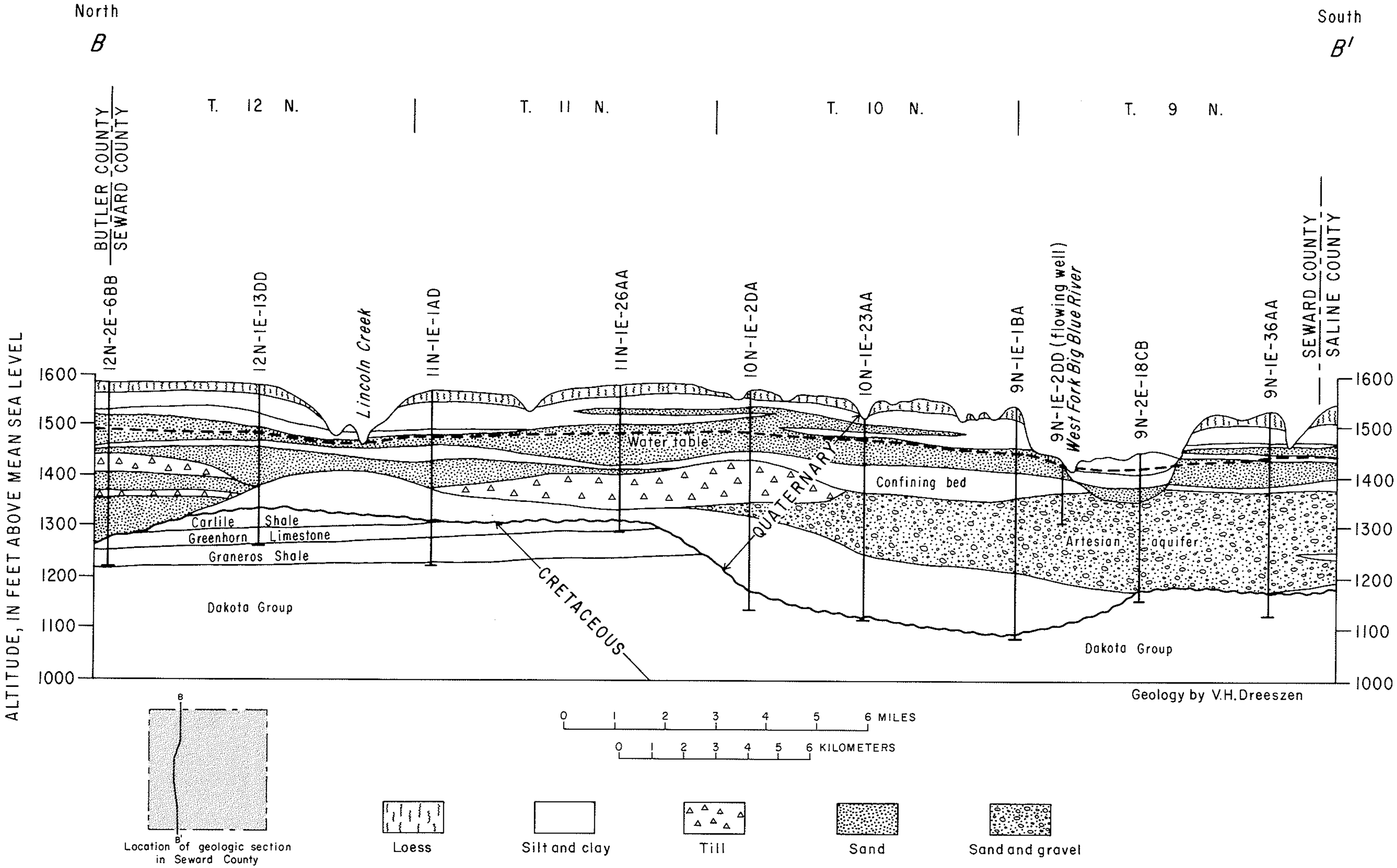


Figure 5. Geologic section line B-B'.

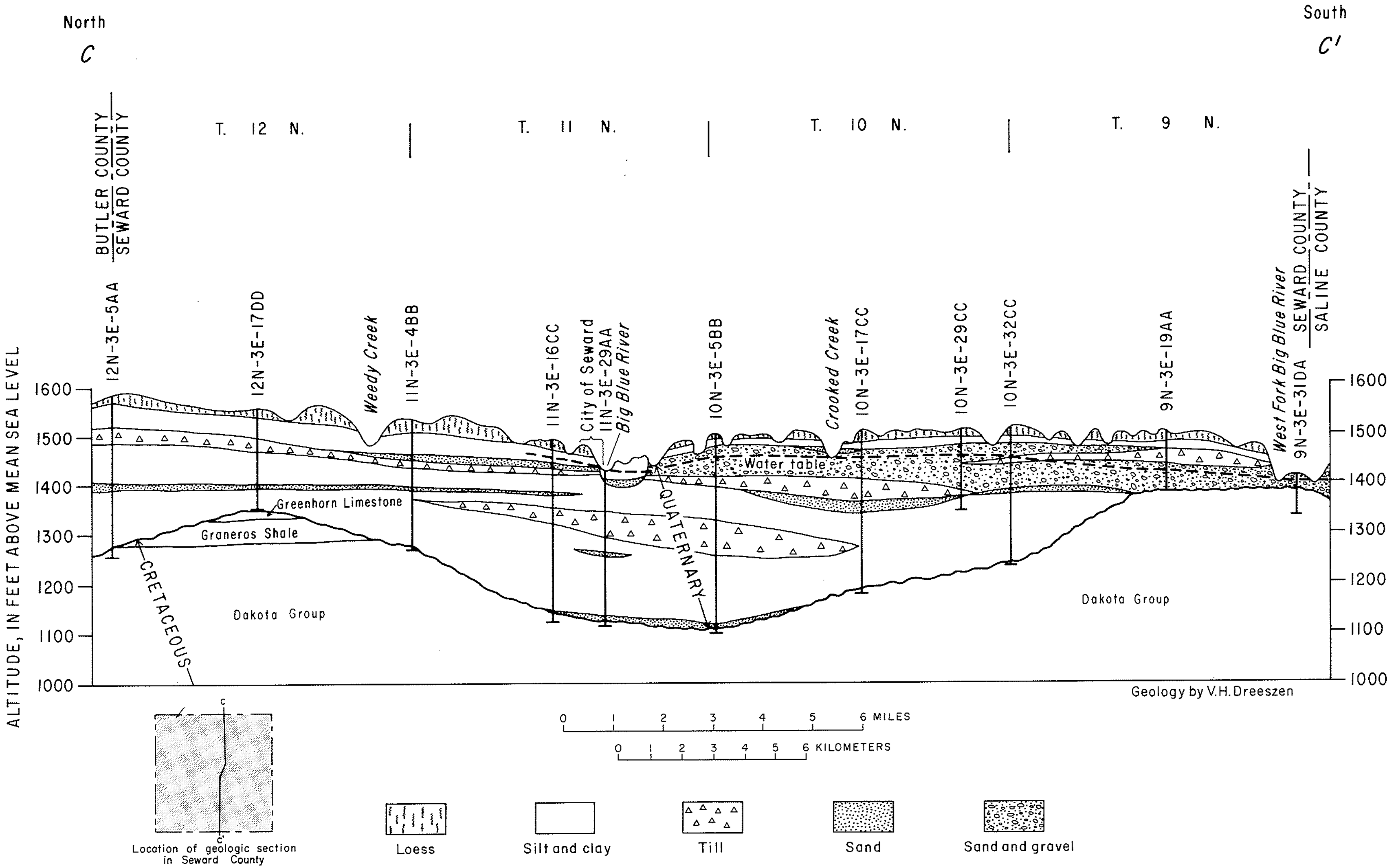


Figure 6. Geologic section line C-C'.

Quaternary deposits overlie older rocks in nearly all the county. Other geologic formations generally dip to the northwest about 5 feet per mile (0.95 m/km), although local variations in dip have been reported by Goll (1961).

Bedrock in Seward County consists of the Dakota Group, Graneros Shale, Greenhorn Limestone, and Carlile Shale--all of Cretaceous age. Only the Dakota Group is a reliable source of groundwater. The Greenhorn Limestone also may be a source of groundwater in a few places where fractures, crevasses, or solution channels occur in the formation. These may be found only by comprehensive test-hole drilling.

Rocks of Lower Cretaceous age are marine-deposited sandstone and interbedded sandstone and shale of the Dakota Group. They immediately overlie limestone and shale of Permian and Pennsylvanian age that do not yield groundwater in Seward County. Only the sandstone is capable of transmitting groundwater in significant quantity. The sandstone of the Dakota Group underlies all of Nebraska to the west of Seward County and extends to the east beyond the county boundary. Valleys that were eroded into the rocks of Cretaceous age prior to the ice age resulted in a topography of broad valleys and hills. The buried hills are composed of the Dakota Group capped by Upper Cretaceous rocks of Graneros Shale, Greenhorn Limestone, and, in places, the Carlile Shale which is the youngest Cretaceous unit in Seward County. These formations, composed of shale, clay shale, and limestone, do not contain important aquifers. However, small springs of mineralized water issue from the upper surface of the Greenhorn Limestone where it crops out along the Big Blue River near Milford.

Deposits of Quaternary age cover Cretaceous rocks in most of the county. The depositional history of the Quaternary deposits in Seward County is not fully understood. It is known, however, that such deposits are associated with continental glaciation. Water, ice, and wind transported the sediments that fill the valleys and mantle the hills of the Cretaceous surface. The processes by which the deposition probably occurred are explained by Reed and

Dreeszen (1965).

The Quaternary deposits of Seward County consist principally of unconsolidated gravel, sand, silt, clay, and till. Thicknesses range from zero to more than 450 feet (137 m). Deposits are thickest where they fill the broad buried valleys developed on the bedrock surface.

The sediment-filled, pre-Pleistocene valleys have no identification in the present topography. Because the present drainage system is not related to the ancient drainage pattern, the greatest thickness of saturated deposits does not necessarily occur beneath present-day stream valleys.

Most streams in Seward County have formed their valleys by cutting into fine-grained deposits. The valley fill washed from the uplands generally is fine material; even when saturated, it will yield only small amounts of water to wells. Highly productive aquifers occur near streams only where present stream valleys cross ancient buried channel deposits. An example of this condition occurs along the West Fork Big Blue River in the vicinity of Beaver Crossing. Fine-grained deposits that blanket the old channel deposits lie below the alluvium of the present stream and virtually insulate it from the ancient valley fill.

GROUNDWATER

Groundwater in the unconsolidated Quaternary rocks is derived from precipitation that falls as rain or snow either in Seward County or west of it. Part of the precipitation runs off the land to streams, part evaporates, and the remainder infiltrates the soil. During the growing season, most of the precipitation that enters the soil is lost to the atmosphere either by evaporation or by transpiration. However, during the nongrowing season and periodically during the growing season, some water that enters the soil infiltrates beyond the evapotranspiration zone and moves downward to the zone of saturation. Probably no more than 1.5 inches (38 mm), or about 6 percent of the total precipitation, reaches the zone of saturation during a year of average rainfall.

Because the aquifers are poorly connected hydraulically with the streams, recharge from the streams is negligible. Recharge to the groundwater takes place chiefly by precipitation and by underflow from the west. Excess irrigation water, recirculated by downward percolation, adds also to groundwater recharge. The amount is less in drought years and more in wet years. That water reaches the zone of saturation is indicated by rises of water levels in wells. Figure 7 shows the depth to water and the configuration of the water table for the fall of 1972 in the part of the county where productive aquifers occur. Water-table contours are not shown for the region underlain by glacial till because aquifers associated with the glacial till are discontinuous; therefore, no definable regional water table exists.

In general, depth to water is greatest beneath interstream areas and shallowest near streams. Throughout most of the upland, the depth to water ranges from 60 to 100 feet (18.3 to 30.5 m), whereas in the principal valleys the depth to water generally is less than 25 feet (7.6 m) below the land surface.

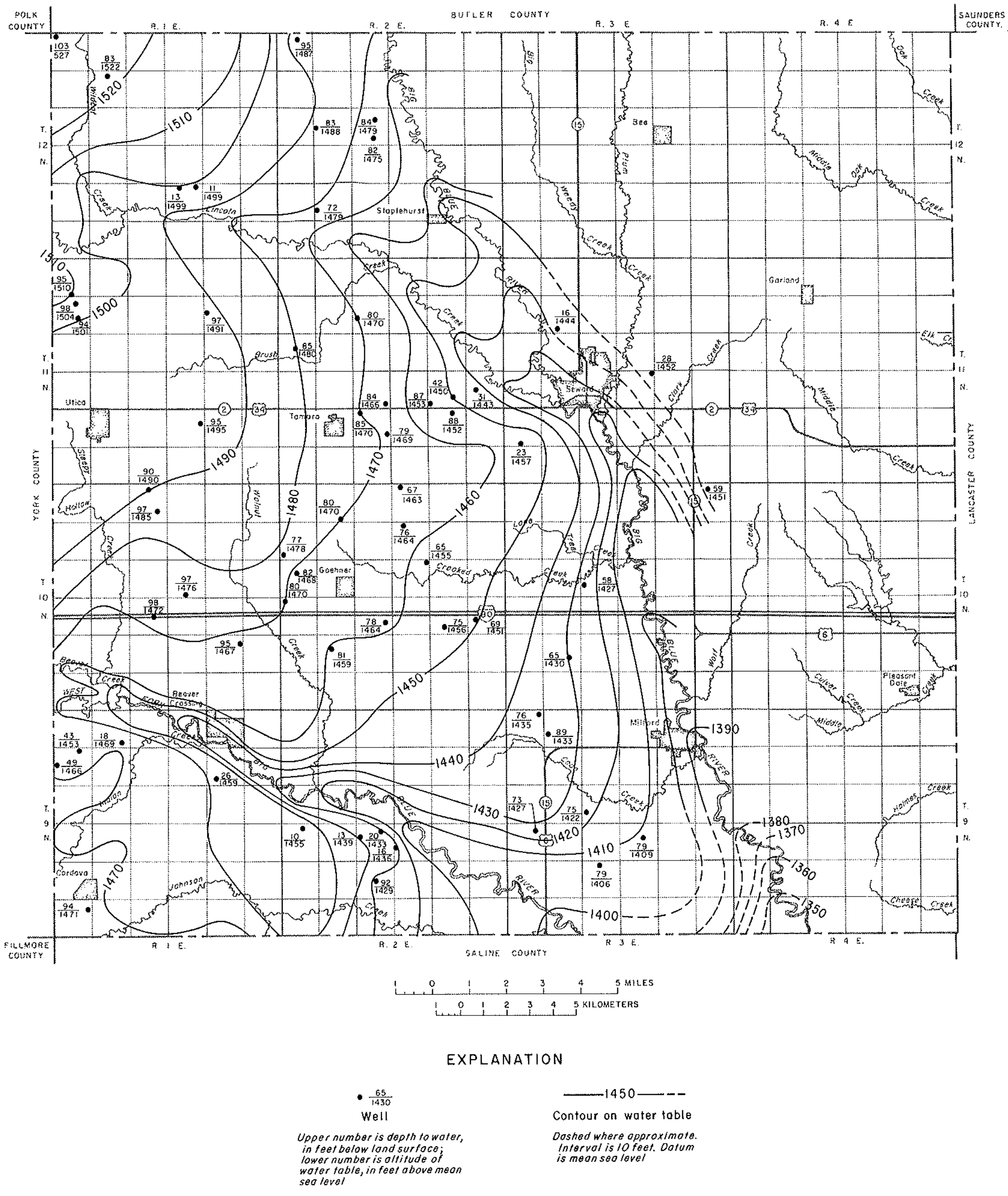


Figure 7. Configuration of the water table in Seward County, fall 1972.

The configuration of the water table is similar to but smoother than the land surface. The water table slopes toward the perennial streams, gradually becoming steeper as the valley walls steepen. Groundwater moves in the direction of the general slope of the water table; that is, toward perennial streams and other areas of discharge. The water moves very slowly, generally less than a foot (0.305 m) per day, except near wells that are being pumped. In the vicinity of pumping wells, it moves more rapidly toward discharging wells because the water-table gradient is greater near the pumping well.

Water-table conditions exist in much of the county; however, in some places water in the lower part of the Quaternary aquifer is confined (under artesian pressure). Artesian conditions occur where saturated sand and gravel is overlain by a confining layer of less permeable material, such as clay, silt, or till. The aquifer is under enough artesian pressure to produce flowing wells only along the valley of the West Fork Big Blue River.

Wells that pump from artesian aquifers have a large initial drawdown and a widespread reduction in artesian pressure. With cessation of pumping, the pressure head in the aquifer quickly recovers and water levels rise to near prepumping levels.

Interference is a problem that results when several nearby wells are pumped at the same time. Each well adversely affects the yield of other pumped wells nearby because of lowered pressure head in the aquifer. Occasionally a farmer having a well with a high yield decides to install a similar well on his farm, in the expectation of doubling his water supply. More than likely, the farmer who puts in a second well on his farm finds that his total water supply is not doubled, as he had expected, but that the yield of the old well decreases when the new well is pumped. General state regulations require 600 feet (183 m) between registered irrigation wells of different land owners (except for domestic, culinary, or stock use) and 1,000 feet (304.8 m) between irrigation and municipal wells as well as between industrial and municipal wells. Under artesian conditions, 600 feet (183 m) between irrigation wells is usually not an adequate distance to prevent considerable interference between pumping wells. The following diagram illustrates the effect of interference in pumping wells (figure 8).

Aquifers of Quaternary age

The availability of groundwater in Seward County ranges from scarce to abundant because subsurface geologic conditions and the water-bearing capabilities of the saturated deposits differ widely from place to place.

Seward County is astride two major hydrologic regions--the Loess-Drift Hills region east of the Big Blue River valley and the Loess Plains region west of the Big Blue. The dividing line between the two major regions coincides roughly with the Big Blue River valley. East of the Big Blue River valley, loess overlies glacial deposits of silt, clay, and sand that yield only small quantities of water. West of the Big Blue River valley, loess overlies extensive deposits of saturated sand and gravel that yield large quantities of water. The saturated sand and gravel or sand bodies have a combined thickness of 40 feet (12.2 m) or more and are the most productive aquifers in the county.

Loess-Drift Hills region.--The higher and flatter parts of the Drift Hills region are mantled by thin deposits of loess resting on relatively thick glacial deposits that are predominantly till (boulder clay) with thinner discontinuous zones of silt, sand, and gravel. These Quaternary deposits cover both the Cretaceous bedrock and older deposits of silt that fill the old valleys in the bedrock. A thin zone of sand and gravel occurs in places at the base of the older silt deposits.

Yields of wells within the Loess-Drift Hills region are generally small because even though the Quaternary deposits are as much as 400 feet (122 m) thick, the permeable sand and gravel aquifers are thin. Some sand and gravel deposits occur above the water table and do not yield water. Other permeable zones

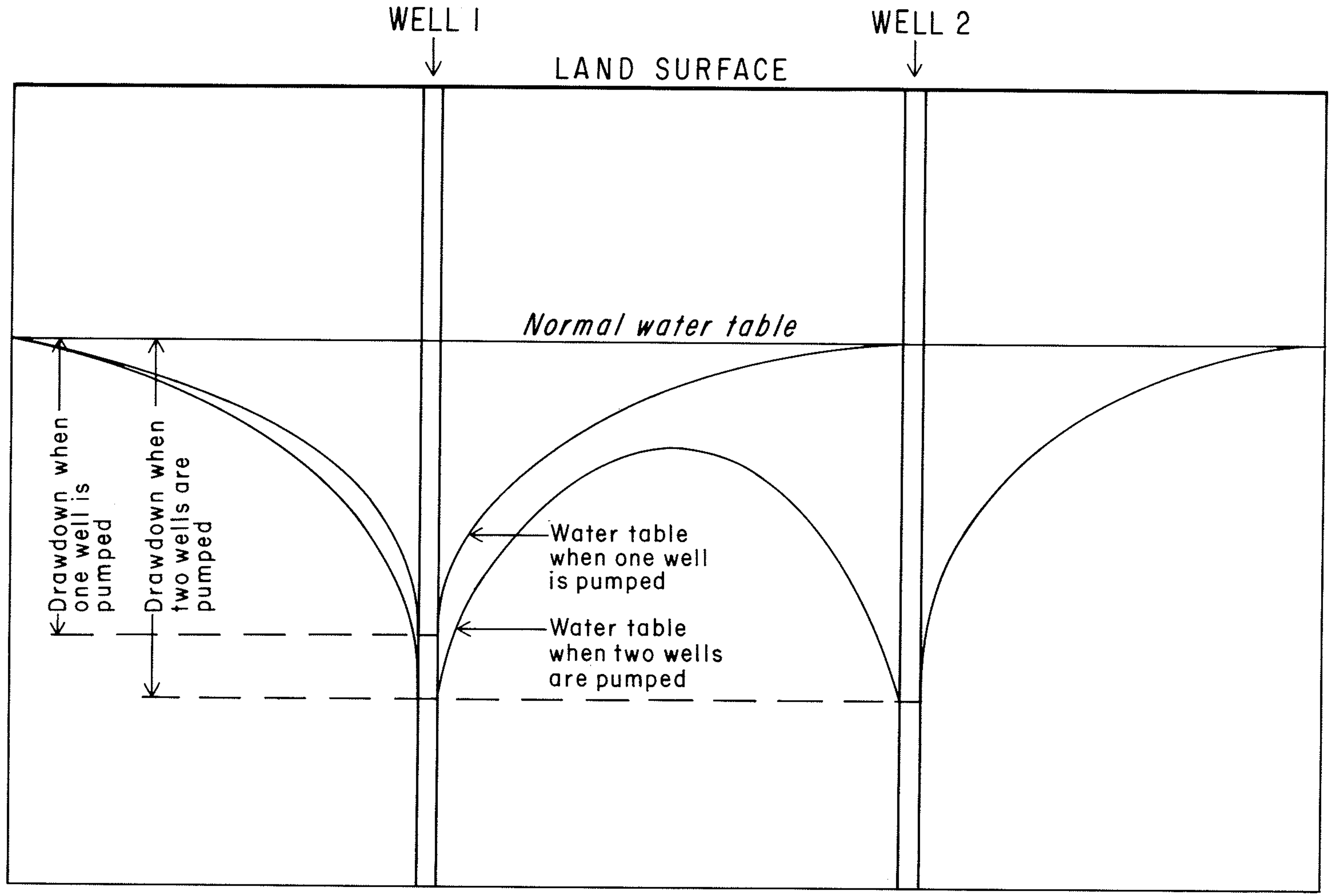


Figure 8. The effect of interference in pumping wells.

are isolated between impervious materials through which groundwater cannot move freely. Water in these zones has been virtually motionless for long periods and contains a high concentration of dissolved minerals.

The most favorable sources of groundwater in the Drift Hills region are the sands, sandy gravels, and silty sands in the alluvial and terrace deposits. These shallow alluvial deposits along the floor of ravines are recharged by surface runoff.

The next most favorable sources of groundwater in the region are saturated sand and gravel aquifers beneath broad, flat uplands. These sand and gravel aquifers are channel deposits in glacial drift and can be delineated only by drilling. In a few places, the aquifers are capable of furnishing enough water for irrigation. However, the aquifers are small and do not store large amounts of water.

The most difficult places to obtain fresh water in the Loess-Drift Hills region are areas that are deeply incised by ravines and areas where bedrock is at or near land surface, such as a 12-square-mile (31-km^2) area 3 miles (4.8 km) north of Garland. Bedrock is also near land surface at Pleasant Dale and Milford. Where there is no saturated sand or gravel above the bedrock, the only source of groundwater is sandstone of the Dakota Group.

Loess Plains region.--Two-thirds of Seward County lies west of the Big Blue River valley in the Loess Plains region. In this region the surficial loess deposits generally are underlain by sand and gravel deposits that thicken westward from the Big Blue River. The sand and gravel deposits in the western two-thirds of the region form two distinct aquifers that are separated by a zone of silt and clay.

The lower aquifer, which is not present in the eastern part of the Loess Plains region, is more permeable than the upper one and yields large water supplies in about two-thirds of the region. The upper aquifer is present under most of the region, but is less permeable than the lower one and yields smaller amounts of water.

The upper aquifer is not completely saturated in places, especially near the Big Blue River valley and in localities where large groundwater withdrawals have lowered the water table. In these areas the saturated zone is not thick enough to yield large continuous supplies. The few irrigation wells near the Big Blue River valley are not as productive as wells farther west and the yields of the former probably would be seriously reduced by a declining water table. The upper aquifer is only partly saturated near the West Fork Big Blue River; however, the lower aquifer is present in this area, has high transmissivity, and generally will sustain high-yielding wells.

Wells in the western part of the Loess Plains region are generally more productive than wells in the eastern part, and in some areas yields greater than 1,000 gpm (0.06 m^3/s) are common. Water in the lower aquifer is confined under artesian pressure great enough to produce flowing wells along the West Fork Big Blue River, but the pressure is not great enough to produce flowing wells in the uplands.

A standard procedure for obtaining wells with maximum yield and minimum drawdown is to locate permeable zones by means of test holes and to place well screens in such zones.

<u>Big Blue River valley</u>.--The Big Blue River valley includes floodplains and terraces that comprise a long, narrow transitional zone between the Loess-Drift Hills region and the Loess Plains region. The valley was scoured by erosion below the present bottomland level and has been partly filled with poorly sorted sand and gravel deposits blanketed by silt and loess. The water table in the valley is relatively shallow, ranging from less than 10 to about 25 feet (3.05 to 6.6 m) below land surface. Groundwater is more available in the valley than in the Loess-Drift Hills, although it is much less available there than in most of the Loess Plains. The aquifer underlying the valley is composed of poorly sorted sand and gravel that will not furnish adequate water for irrigation or municipal use; however, well yields generally are adequate for domestic or livestock requirements.

Artesian wells

Flowing wells occur along the valley of the West Fork Big Blue River from about 6 miles (9.7 km) below Beaver Crossing to beyond the Seward-York county line. One of the earliest irrigation developments in Nebraska was 115 acres (0.465 km^2) near Beaver Crossing, irrigated with water from nine shallow artesian wells (Barbour, 1901). The wells range in depth from 90 to 140 feet (27.5 to 42.5 m) and are developed in a sand aquifer that underlies a 50-foot (15.2-m) confining bed of clay. The wells range from 1 to 4 inches (25.5 to 102 mm) in diameter and yield from less than 10 to about 150 gpm (6.3×10^{-4} to about 9.5×10^{-3} m^3/s). Pumping in the vicinity of flowing wells diminishes or stops their flow.

The following quotation by John H. Waterman (1916) contains information about early development of groundwater under artesian pressure in the valley of the West Fork Big Blue River.

> The water of Seward County is hard. Even that of the streams and springs is hard, but is of an excellent grade. There are a number of springs of very fine water along the West Blue River. One of the largest of these springs is an "old land mark" almost in the center of the village of Beaver Crossing. It is located near where Daniel Millspaw's ranch buildings stood, and without doubt furnished many thirsty travelers, in the days of prairie schooner emigration, the first good water they had tasted after leaving the settlements.
>
> The first flowing well of the county to establish any interest or faith in the existence of flowing water in the vicinity where it exists was discovered in Dewit Eager's store in Beaver Crossing by mere accident. That such a discovery should be made within the precincts of a village store may seem strange, but Mr. Eager had a well in his store for the accomodation of his customers and the water had become impure and bad, therefore he employed Ray Virgin of Utica to sand pump the well and sink it deeper to find better water if possible. The work progressed, but the quality of the water did not improve. The well kept getting deeper and deeper; finally the bottom seemed to drop out and the water

rushed up with such force that the store cellar was half full of it before it was realized what had happened. This discovery created quite an excitement as it was made in the dry season of 1895, and several parties were soon on the anxious seat to try their luck for a well. T. J. Foster was so anxious to see the water shooting up out of the earth at his place that he could not sleep nights, and went around daytimes dreamily talking about a flowing well. In a few days he succeeded in securing the services of C. C. Evans to make him a two inch flowing well. The work on the well commenced early in the morning and flowing water was struck just a short time before night, and although the well was fully piped, flowing well construction was new business to Mr. Evans. The well was of the large size, the flow very strong and the necessary precautions to prevent an outside flow which came up around the outside of the piping, had not been taken and as a result a nice little river soon sprang into existence. Unfortunately the river was not all water, being about half quick sand which failed to run off, constantly settling in the passage way and daming the water which shortly formed a small sized lake in the midst of which was Tom's house. Tom had lost sleep over the matter of getting a well and as he shoveled sand that night to keep an opening for the water to run off and save his house from being a Noah's Ark, he might have been heard praying for one glimpse of God's token, the rainbow, and that the destruction of the earth by fire might commence while his part of it was too wet to burn. Tom Foster never swears and whether his thoughts on this occasion were solemn or otherwise he certainly had a wonderful well . . . . This well, when the stream was finally reduced to the size of an ordinary flowing well, threw water to a height of twenty-five feet, but the numerous wells which were almost immediately made in the vicinity, reduced the force of its flow to a considerable extent. However the water in most any of the numerous wells in existence today on land on a level with it will rise from ten to fifteen feet above the top of the ground. The territory upon which these wells may be procured extends over the entire width of the West Blue valley and for a distance up and down the valley of about fourteen miles.

Dakota Group aquifers

The Dakota Group underlies all of Seward County and is in direct contact with the Quaternary deposits in the bedrock valleys (figure 9). The Dakota is completely saturated and well yields range from a few gallons per minute to about 400 gpm (0.025 m^3/s). In areas where the Quaternary deposits are absent or do not furnish water to wells, the Dakota is a possible source of water. More than half of the Dakota Group is interbedded siltstone and clayey or sandy shale. Much of the sandstone in the group is fine grained and only moderately to loosely cemented. Because the deposits differ in physical characteristics from place to place, their ability to yield water and the chemical quality of the water obtained cannot be predicted without drilling a test hole. Because some of the water from the Dakota Group is of poor quality, water from this source should be analyzed for chemical quality to determine its suitability for human consumption or irrigation use. Records from wells tapping the Dakota Group in areas east and west of Seward County indicate that the mineralization of the water increases to the west and at greater depths. However, water of unsatisfactory quality has been reported from the Dakota east of the Big Blue River. If water in the upper part of the formation is of poor quality, water of better quality is not likely to occur at greater depth.

Depth to water

The depth to the static water level in wells in Seward County generally becomes shallower from west to east. As shown in figure 10, the depth to water west of the Big Blue River is greater than 75 feet (22.9 m) but less than 90 feet (27.5 m) beneath most of the upland and generally between 75 and 25 feet (22.9 and 7.6 m) beneath the surface of the land that slopes steeply toward the streams. Where the groundwater is confined

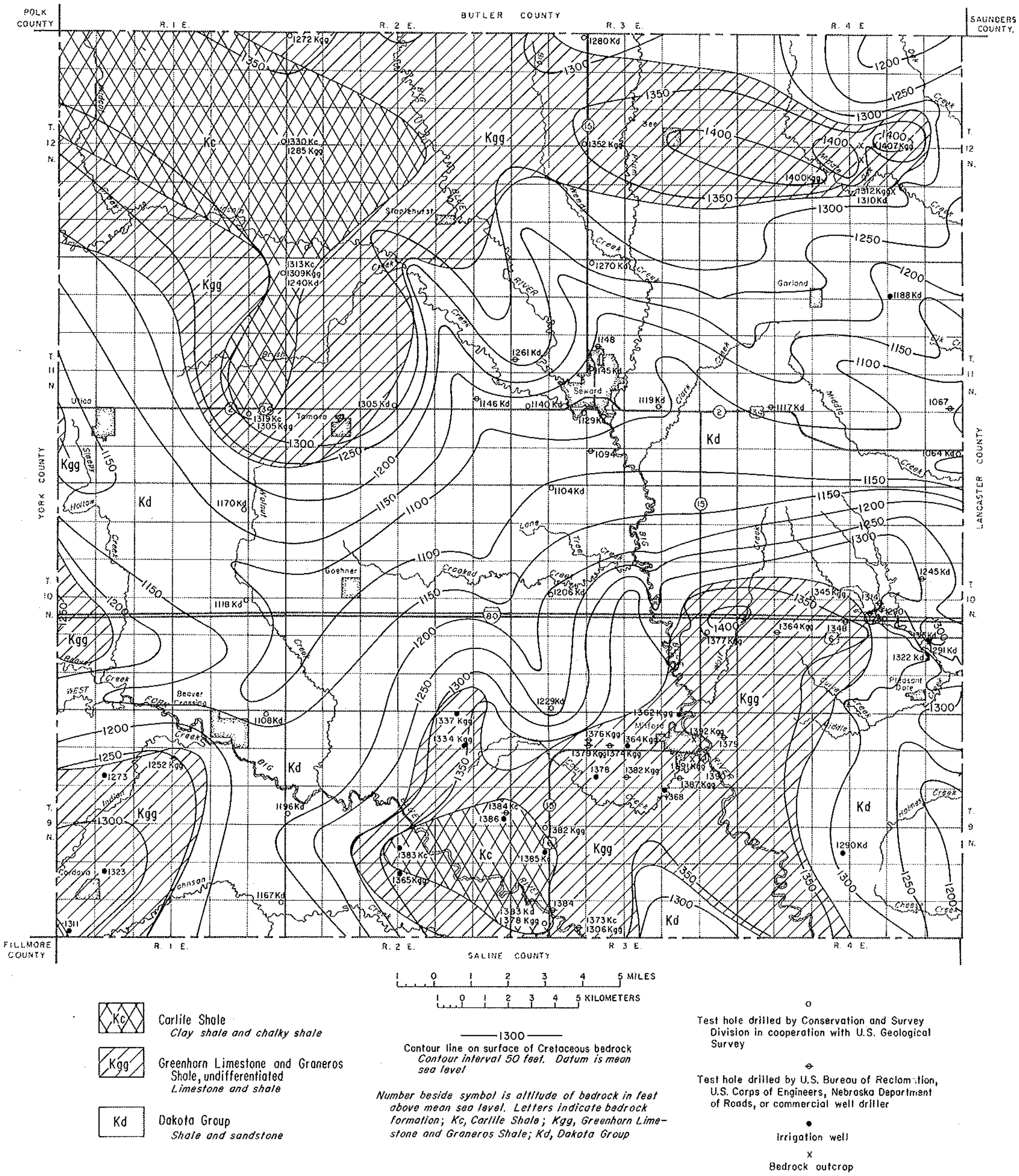


Figure 9. Distribution and configuration of Cretaceous rocks.

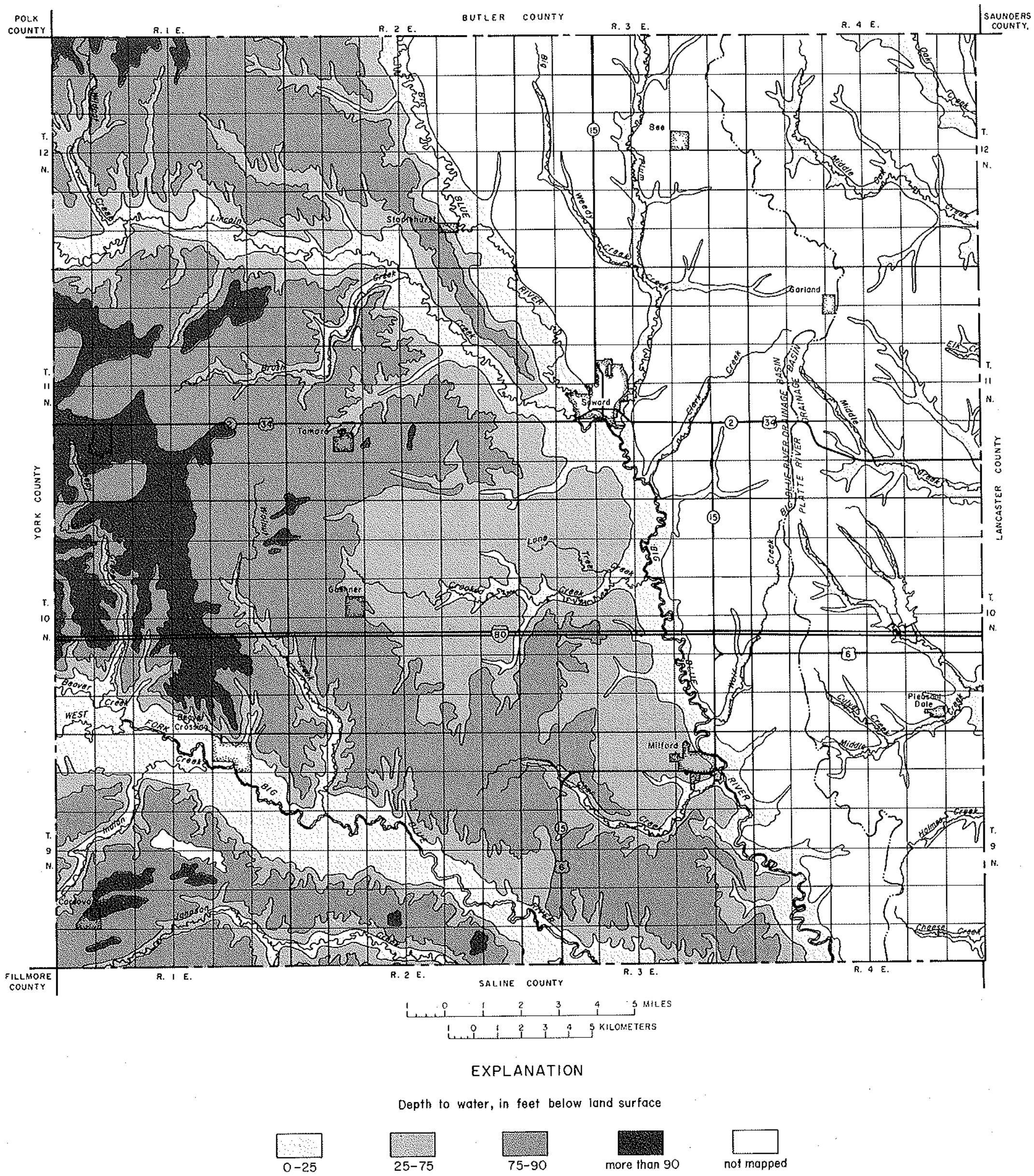


Figure 10. Depth to water below land surface in Seward County, fall 1972.

under artesian pressure, it rises above the top of the aquifer; and in low places, it may rise above land surface.

East of the Big Blue River, the groundwater occurs in glacial-till deposits that differ so greatly in physical characteristics that wells cannot be obtained everywhere. Because of this, the water table cannot be mapped with accuracy and is not shown. However, groundwater can usually be obtained from shallow wells in alluvium near streams and in a few places on the upland. Depth to water in the alluvium ranges from about 1 foot to 25 feet (0.305 to 7.6 m).

Hydrologic properties of water-bearing deposits

The amount of water stored in an aquifer depends upon the porosity and saturated thickness of the aquifer. The rate at which water can move through a given rock is determined by its hydraulic conductivity, which depends primarily on the nature and interconnection of pore spaces. A similar term is transmissivity, meaning the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. Transmissivity is particularly important because it is an indication of the ability of an aquifer to yield water to wells.

Nearly all groundwater used in Seward County is pumped from sand and gravel aquifers of Quaternary age. Gravel is the best water-bearing and water-yielding material in Nebraska. It is also one of the best water-yielding materials in which groundwater is stored--in technical terms, it has a high storage coefficient. Storage coefficient is the volume of water an aquifer releases or takes into storage per unit surface area of the aquifer per unit change in head. Sand ranks next to gravel as the ideal water-yielding material for an aquifer in Nebraska. However, sand conducts water less readily and generally yields a smaller portion of its water to wells.

Samples from all test holes were examined to determine their physical properties, and specific-capacity tests for many irrigation wells were analyzed. From those data, the capability of an aquifer to yield water to wells can be estimated. Based on results from an examination of samples and specific-capacity tests, the transmissivity of the aquifer was estimated by V. H. Dreeszen and mapped as shown in figure 11.

In the areas where transmissivity is less than 7,000 $(ft^3/day)/ft[(650\ m^3/day)/m]$, large yields for irrigation wells usually cannot be obtained. Moderate yields can be obtained in the areas where transmissivity is between 7,000 and 14,000 $(ft^3/day)/ft[(650$ and $1\ 300\ m^3/day/m]$; however, lowering the water table a few feet in these areas may significantly reduce well yields. Irrigation wells developed in the areas where the aquifer has a transmissivity greater than 14,000 $(ft^3/day)/ft[(1\ 300\ m^3/day)/m]$ may be expected to have large sustained yields.

Groundwater in the highly productive deposits beneath the Loess Plains is to a large degree prevented from discharging to the river by a zone of less pervious materials between the uplands and the valley. In other words, the principal aquifer has poor hydraulic connection with the Big Blue River.

This situation is unusual in Seward County because commonly water-bearing deposits are more permeable in stream valleys. In Seward County, however, fluctuation of streamflow in the Big Blue River has very little effect on the principal aquifers and the pumping of groundwater in the uplands has insignificant effect on streamflow.

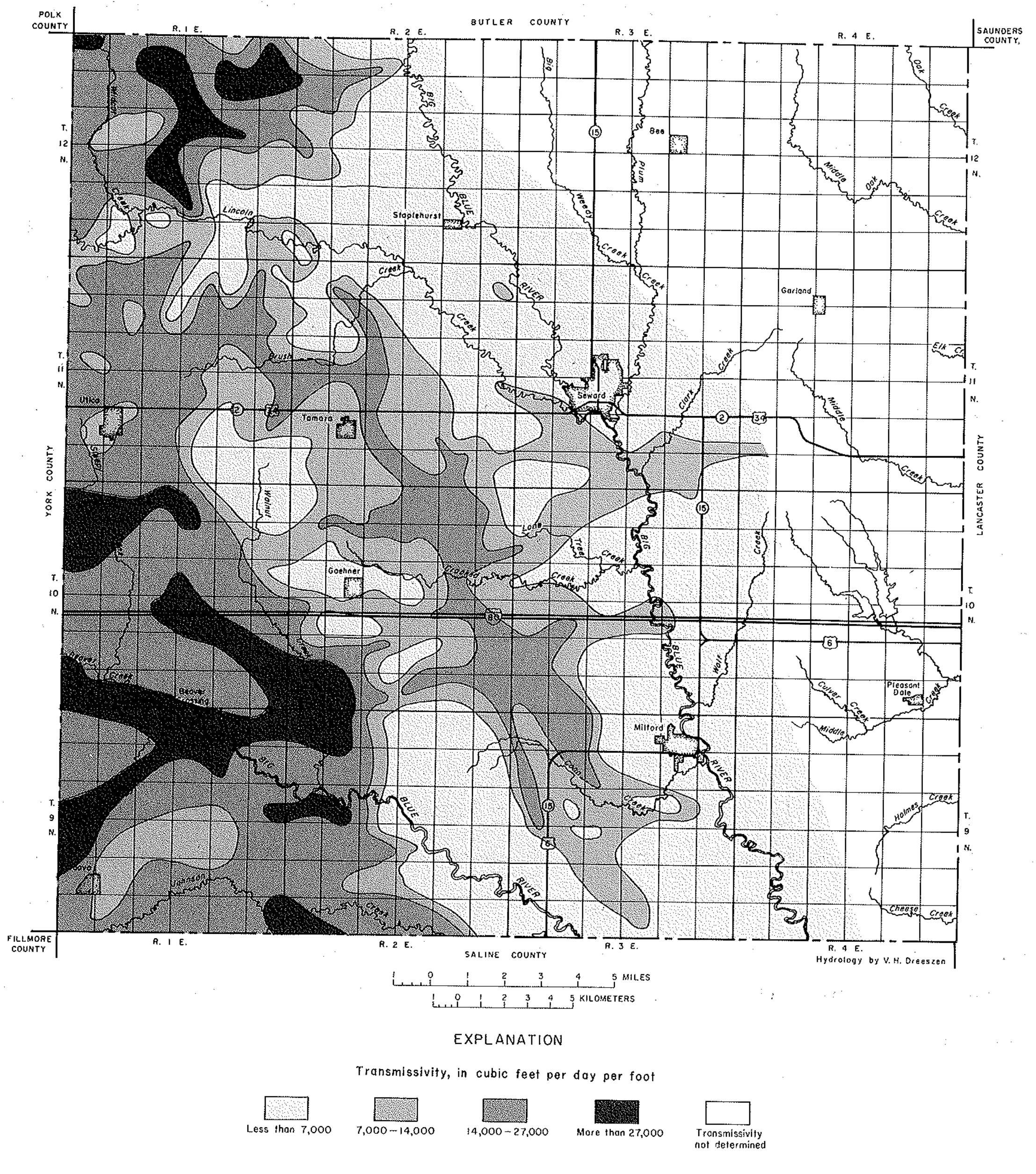


Figure 11. Estimated transmissivity of the aquifer in Quaternary deposits in Seward County.

USE OF GROUNDWATER

Domestic and livestock supplies

All domestic and most livestock water supplies in Seward County are obtained from small-diameter wells drilled only a few feet below the water table. Most wells are equipped with electrically powered jet or submersible pumps and generally yield no more than 5 gpm (0.315 l/s). Only a few windmills, which were once a common sight, still remain. Some wells in the valley of the West Fork Big Blue River yield enough water for household and livestock uses through natural flow. Wells for small water needs commonly are drilled 10 to 15 feet (3.05 to 4.55 m) below the water table and cased with 2- to 6-inch (51- to 152-m) pipe, with a few feet of screen in the sand and gravel. In a few areas the aquifers are thin or of such low permeability that even domestic or stock wells cannot be obtained from Quaternary deposits and wells must be drilled into the Dakota Group aquifer to obtain water that may be highly mineralized.

Public water supplies

All public supplies in Seward County are obtained from groundwater. Ten of the 11 villages and cities have publicly owned wells, storage reservoirs, and distribution systems. Some cities have been hard pressed to provide adequate water supplies for population growth and increasing per-capita demand for water. The cities of Seward and Milford sell water to local industries, which sale has increased the demand for water. All the wells are equipped with electrically driven turbine pumps that pump water into mains and either into an elevated tank or into a pressure tank.

All municipal water systems were inventoried during this study (cf. table 2). Because water pumped into the distribution systems

Table 2. Public water supplies

City or village	Population (1970)	Number of wells	Reservoir		Estimated consumption per day		Statistics on principal supply wells[1]				Remarks
			Capacity (gallons)	Type	Gallons per capita	Acre-feet per year	Depth of well (feet)	Diameter of well (inches)	Depth to water below land surface (feet)	Yield of well (gallons per minute)	
Beaver Crossing	400	2	30,000	Elevated tank	130	60	163	8	10	350	One well is standby; diameter 6 inches; depth 130 feet
Bee............	156	1	6,000	Pressure tank	70	12	101	8	27	360	
Cordova........	141	1	10,000	.....do......	100	158	247	12	94	300	
Garland.........	244	2	40,000	Elevated tank	70	19	405	6	315[2]	295	
Goehner........	113	1[3]	8,000	Pressure tank	85	11	135	7	117	250	
Milford........	1,846	5	278,200	Elevated tank and reservoir	100	200	122	16	70	500	Principal water supply from two wells located about 2½ miles west of Milford
							118	16	65	600	
Pleasant Dale..	258	1	20,000	Pressure tank	70	20	150	8	69	295	
Seward.........	5,294	9[4]	950,000	Elevated tank	100	590	120	12	20	350	Village also has an old well for standby; diameter 18 inches; depth 40 feet
Staplehurst....	227	1	50,000	.....do......	100	30	116	8	87	100	
Tamora.........	93[5]	.....	....	....	....	....	....	....	....	....	
Utica.........	665	3	34,000	Pressure tank	147	98	254	18	91	500	Utica has two older standby wells

1. Statistics on other supply wells in multiwell systems are similar to the principal supply well.

2. Pumping water level.

3. Supplies water to interstate highway rest area and several farm homes.

4. Water supplies for municipal and industrial needs are obtained from nine wells located about 3 miles west of the city. The wells range in depth from 115 to 120 feet. Static water levels in the wells are about 70 feet below land surface, and yields range from 225 to 350 gallons per minute.

5. Each house supplied by a private well.

is not metered, water-consumption amounts were estimated. Other public supplies, such as those for state and county institutions, were not inventoried; however, their total pumpage is very small compared to that pumped for irrigation and municipal uses.

The cities of Seward and Milford, the largest municipalities in Seward County, have experienced considerable difficulty in obtaining adequate water supplies to meet growing demands. These cities, both of which are near the Big Blue River, drilled their first wells in the valley alluvium. The alluvium near the river, however, could not supply the water needed. Eventually, both cities installed wells 2 to 3 miles (3.20 to 4.80 km) west where water supplies are adequate to meet present and projected needs. The villages of Bee, Garland, and Pleasant Dale--all located east of the Big Blue River where groundwater supplies are meager--have also experienced problems in obtaining water.

Irrigation

Precipitation in Seward County during the irrigation season averages about 17 inches (430 mm), or 12 inches (305 mm) less than the amount generally considered to be optimum for corn growth. This means that about 1 foot (305 mm) of supplemental water is needed in an average year. In dry years the irrigation-season precipitation can be less than 10 inches (255 mm), and an additional 18 inches (455 mm) of water is needed. Precipitation during the irrigation season of wet years may be as much as 28 inches (710 mm), which is ample for crop production. Water needs for irrigation thus range widely from year to year.

The need to supplement precipitation with irrigation became especially apparent during the drought of the 1930s. Farmers in Seward County, however, were not then aware of the existence of the tremendous supplies of groundwater beneath two-thirds of the county and all supplemental water supplies were pumped from the Big Blue River and its tributaries. A few irrigation wells were installed by the end of 1948, but only 15 were in use by 1952.

The years 1955-57 were very dry, and the desperate need to save crops from destruction by drought brought about a large increase in the use of groundwater for irrigation. By the end of 1957 the number of wells had increased to more than 300. Only 28 new wells were drilled in the next five years when climatic conditions were again favorable for agriculture. In 1963 another increase in the installation of irrigation wells began. Installations from 1963 through 1972 totaled 329--an average of about 33 wells annually.

Seward County had 653 registered irrigation wells on January 1, 1973 (cf. figure 12). About 65,000 acres (265 km^2) were irrigated with well water during 1972. In 1971 a total of 83,000 acre-feet (102 km^3) of groundwater, or an average of about 2.7 inches (69 mm) of water spread over the entire county, was used for irrigation (Steele, 1973). Since this is considerably more water than that returned by natural recharge, the amount of groundwater in storage was reduced by an estimated 31,000 acre-feet (0.038 km^3) (Steele, 1973).

Table 3 shows the number of hours the average well was pumped, the average area irrigated per well, the volume of water pumped, the depth of water applied to the land, and the total volume of groundwater withdrawn for irrigation during the years 1971-73.

Figure 13 shows graphically the number of wells registered with the Nebraska Department of Water Resources each year and also the cumulative number of wells from 1945 through 1972. All but 12 of the 659 irrigation wells reported on figure 13 are west of the Big Blue River.

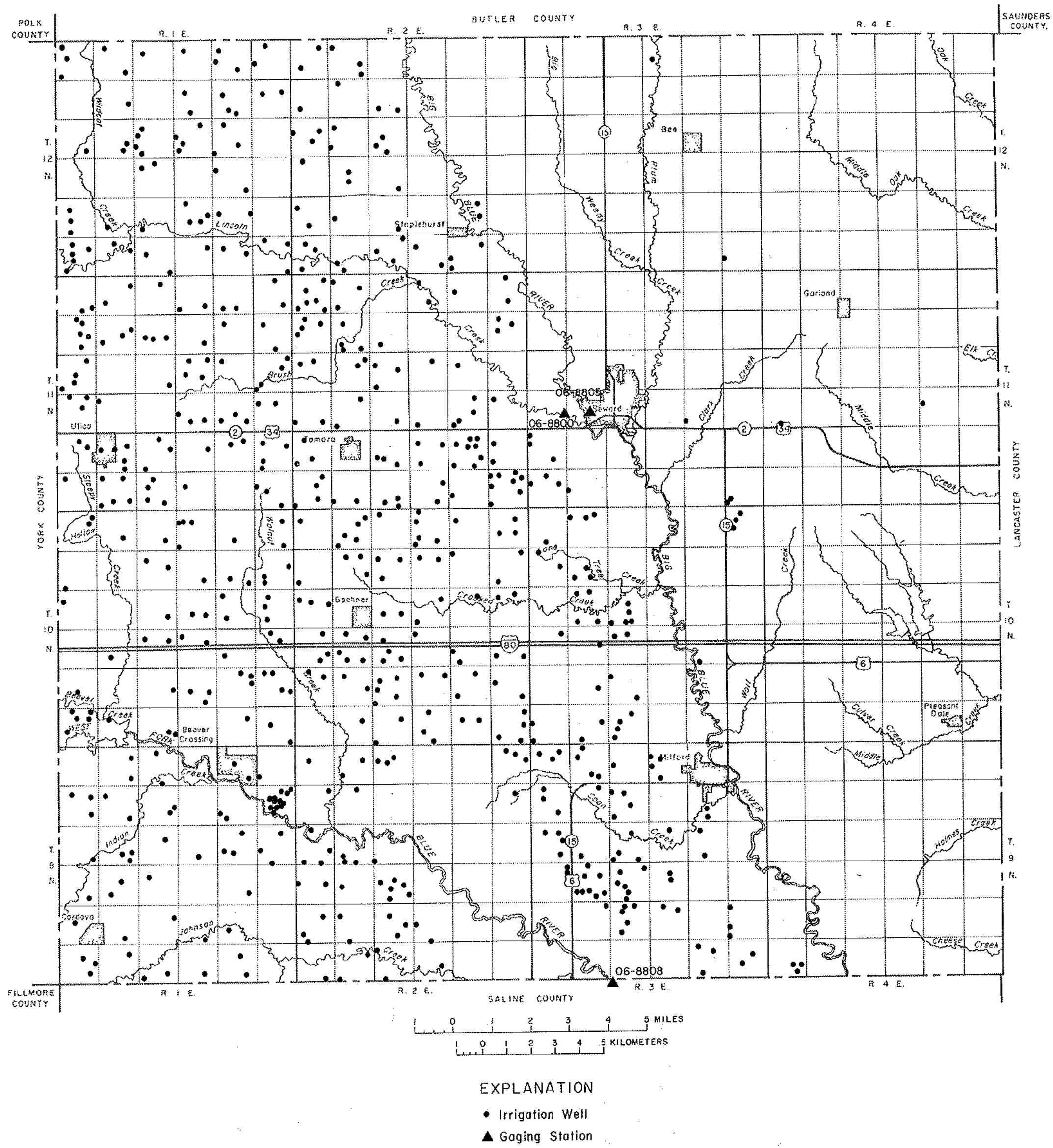
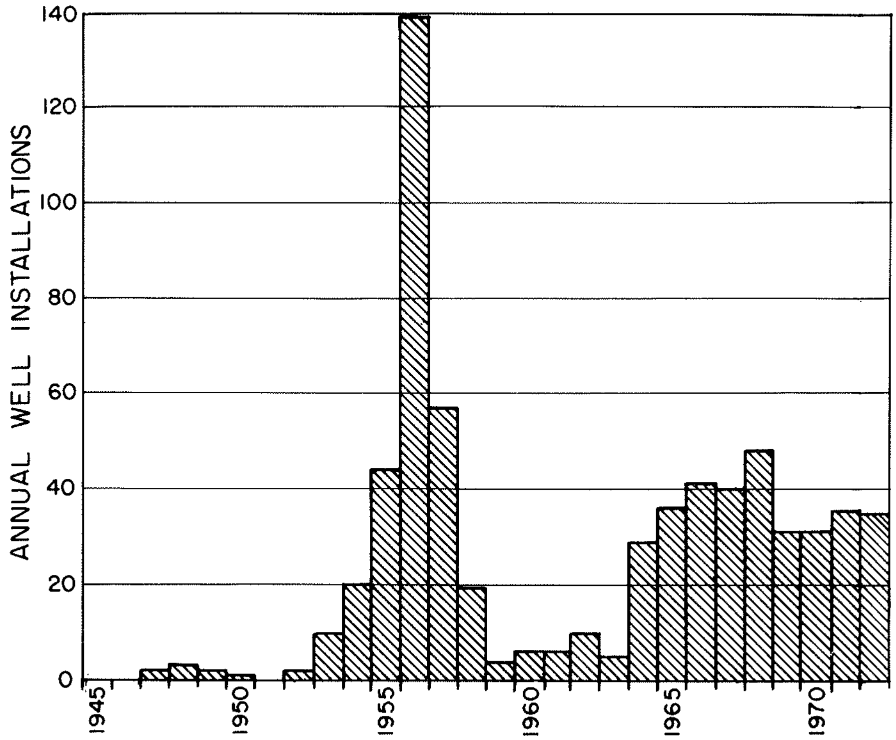


Figure 12. Location of registered irrigation wells, January 1, 1973, and location of stream-gaging stations.

Table 3. Groundwater withdrawal for irrigation in Seward County, 1971-73[1/]

Year	Average number of hours wells pumped	Average area of land irrigated per well (acres)	Total volume of water pumped per well (acre-feet)	Depth of water applied to crops (inches)	Total volume of water withdrawn (acre-feet)
1971	1,018	86	135	19	83,000
1972	700	77	93.5	14	62,000
1973	759	91	107	14.5	72,000

1. Compiled from studies by Steele, 1973.



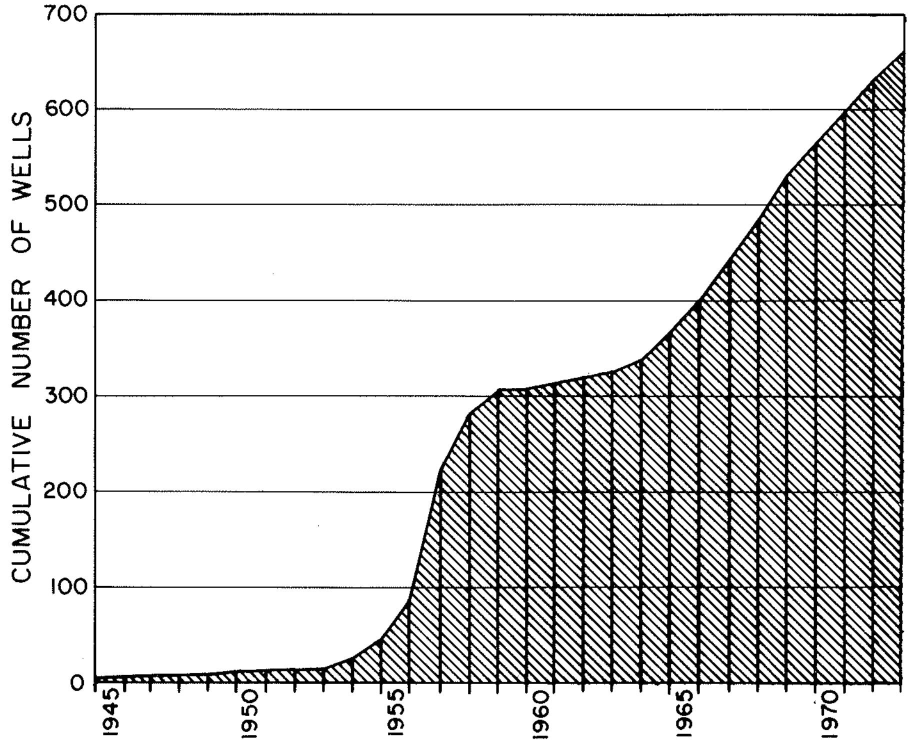


Figure 13. Annual irrigation-well registrations and cumulative number of irrigation wells, 1945-72.

In addition to the 65,000 acres (265 km^2) irrigated with groundwater, 7,600 acres (30.8 km^2) were irrigated with water pumped from streams in 1973. However, the flow of the Big Blue River diminishes in dry years to such an extent that the stream cannot adequately supply water to all the acreage in the valley developed for irrigation. Farmers with junior water rights then are required to cease diverting water in favor of those with senior water rights; as a result, some crops are damaged or lost. Unfortunately, the aquifer beneath valley lands along the river is not capable of supplying water requirements for irrigation.

Changes in water levels and groundwater storage.--Before groundwater in Seward County was pumped for irrigation, the quantity of groundwater in storage remained virtually unchanged. So did the depth to the water table as well as its general configuration. Additions (recharge) to the groundwater from precipitation that infiltrated to the water table and minor subsurface inflow from the west were balanced, over the long term, by losses (discharge) to subsurface outflow, spring discharge, evapotranspiration, and seepage into streams. But with heavy withdrawal of groundwater for irrigation, water is removed from storage more rapidly than it is replaced and groundwater levels are trending downward.

The net change in the water table from prior to extensive development of irrigation in the early 1950s to the fall of 1972 is shown in figure 14. Figure 14 was constructed from differences in water levels between the fall 1972 water-table configuration shown in figure 7 and the configuration of the predevelopment water table (1950).

The water table in the early 1950s, when fewer than 10 irrigation wells had been installed, is considered to be predevelopment stage. Most of the wells in which water levels now are periodically measured did not exist in the early 1950s; consequently, fewer data points were available for construction of the predevelopment water table. However, because the water-table configuration of the early 1950s was virtually undisturbed, its

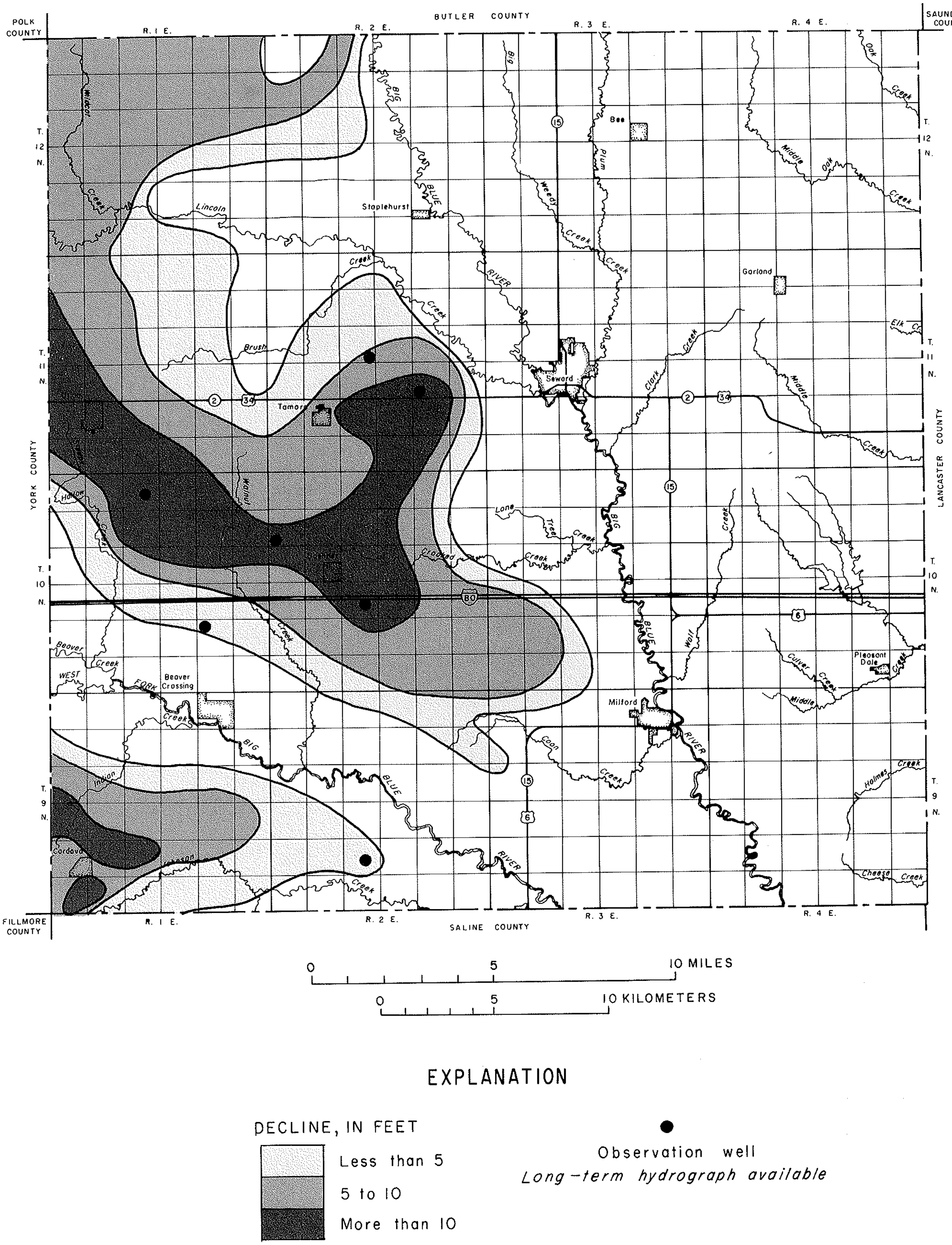


Figure 14. Net change in the water table in Seward County from predevelopment (1950) to fall 1972.

position could be defined with fewer data points than were required in 1972 after pumping had altered the water-table configuration.

Areal distribution of declines less than 5 feet (1.52 m), between 5 and 10 feet (1.52 and 3.05 m), and more than 10 feet (3.05 m) are shown. Water-level declines greater than 10 feet (3.05 m) have occurred in three areas. The largest area, in the west-central part of the county along the divide between Lincoln Creek and the West Fork Big Blue River, is about 40 square miles (104 km^2). Other small areas where water levels have declined more than 10 feet (3.05 m) are in the northwestern and southwestern parts of the county.

Water levels are declining in about 200 square miles (518 km^2) or about one-third of the area of Seward County. If the specific yield--or the volume of water removed from each cubic foot (0.005 7 m^3) of saturated sand and gravel--is one-fifth of a cubic foot (0.001 1 m^3), the decline of the water table since the beginning of the development of groundwater supplies for irrigation represents depletion of about 175,000 acre-feet (216 km^3) of stored groundwater.

The depletion cannot be estimated accurately from analyses of water-level changes in wells because groundwater in Seward County occurs under both artesian (confined) and water-table (unconfined) conditions. A decline of water levels in wells in some areas may represent the lowering of artesian pressures. Because the specific yield is much smaller under artesian conditions than under water-table conditions, a decline of artesian levels represents a much smaller water withdrawal than a comparable water-table decline.

After not changing significantly until 1955, the water table declined in a much more pronounced manner after 1963. The decline is shown by the hydrographs of A. Rolfsmeier's irrigation well 11N-2E-23CC, located about 4 miles (6.4 km) west of the city of Seward (figure 15), and by five other wells whose seasonal fluctuations are recorded in figure 16.

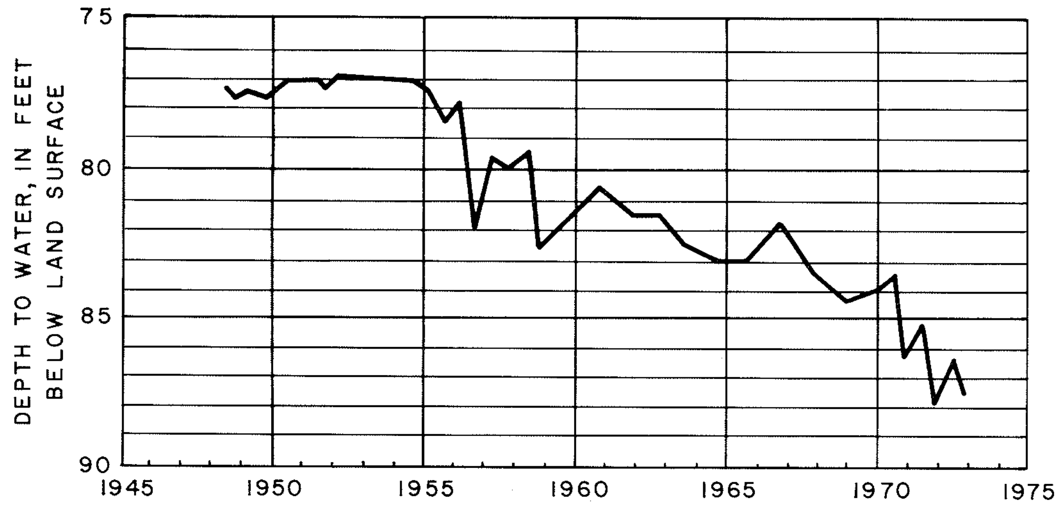


Figure 15. Hydrograph of well 11N-2E-23CC owned by A. Rolfsmeier, Seward, Nebraska.

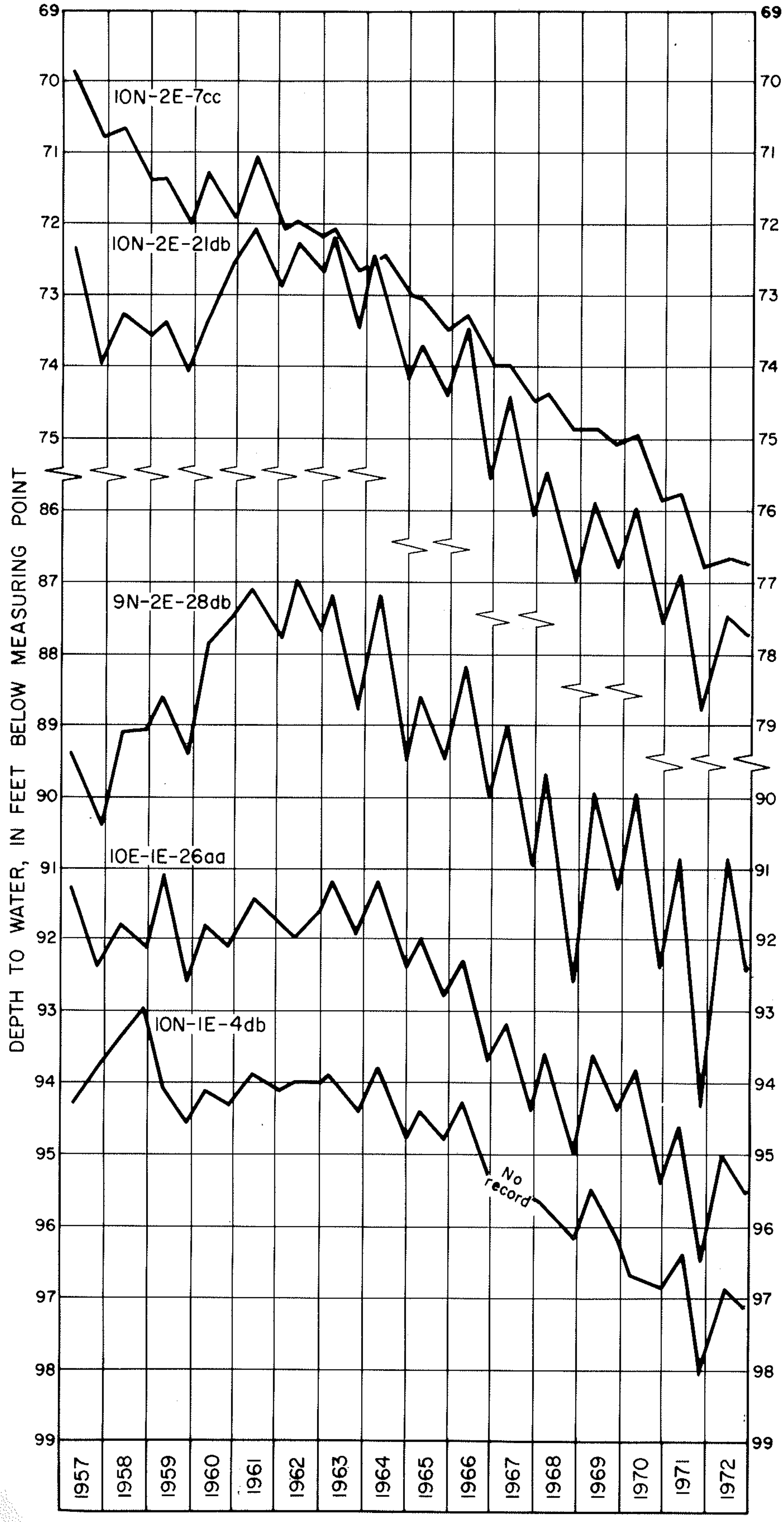


Figure 16. Fluctuations of water levels in five wells, 1957-72.

Figure 17 shows a nearly continuous record of water-level fluctuations in well 11N-2E-21DD, which was equipped with a water-level recording gage in 1958. The record shows a similar seasonal-fluctuation pattern in the water table for each year. In 1960 and 1962, when precipitation was more evenly distributed than usual and groundwater withdrawals were relatively small, the fluctuations were of smaller amplitude than in other years. A downward trend in the water table since 1966 has resulted in a net decline of about 5 feet (1.52 m) at the well site. That some decline in the water table occurred prior to installation of the recording gage in 1958 is shown by the longer record obtained a little more than 1 mile (1.61 km) east at the Rolfsmeier well (figure 15).

The impact of groundwater withdrawal on supply.--Water must be available in enormous quantities if it is to fulfill unrestricted irrigation demands. Prior to irrigation development in Seward County, the natural discharge of groundwater was in balance with the natural recharge; however, since the use of groundwater for irrigation began, the groundwater reservoir has not been in balance for any sustained period.

Since withdrawal of large amounts of water places considerable stress on a hydrologic system, large-scale irrigation development based on groundwater use cannot be accomplished without diminishing the total supply. The water discharged by wells and consumed by evapotranspiration is counterbalanced by a reduction in storage and natural discharge. The reservoir from which the water is taken is in effect bounded by time, the structure of the aquifer, and material limitations. The amount of water removed from an area is proportional to the drawdown, which in turn is proportional to the rate of pumping. Some groundwater is almost always mined when vast quantities are withdrawn for large-scale irrigation development.

After considerable time the depressed water table will extend to areas of natural discharge along the principal streams; and additional discharge by wells will be balanced, in part, by the diminution of natural discharge. If the natural discharge is

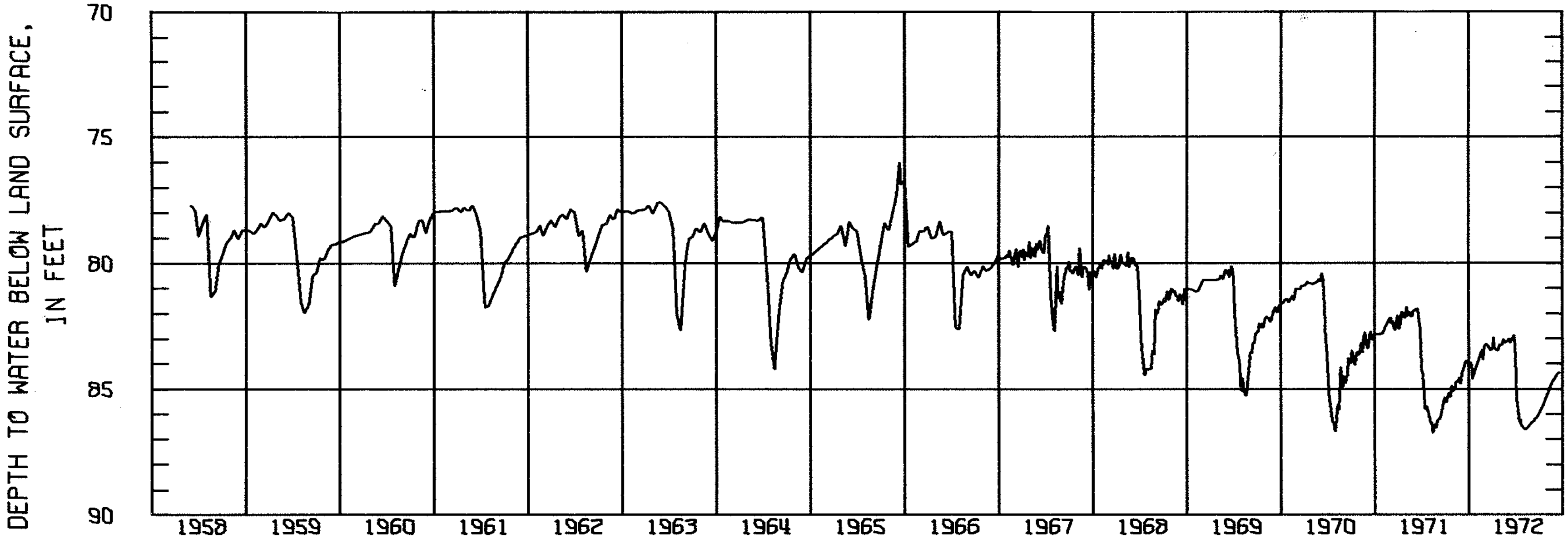


Figure 17. Water-level fluctuations in well 11N-2E-21DD, 1958-72.

being used by nonbeneficial vegetation, diminishing that use results in no economic loss. If, however, the natural discharge feeding surface streams is diminished, rights to the surface water may be impaired.

Very little water is withdrawn from storage in localities where artesian pressures prevail. Each well affects the pressure in the whole system and, in effect, obtains its water through an increase in recharge or a decrease in discharge. In Seward County, the aquifers are confined locally, meaning that they are under artesian pressure only in certain localities of limited areal extent. The aquifers are unconfined at higher elevations but yet are hydraulically connected to the unconfined groundwater reservoir. When water is withdrawn from the confined part, the pressure is lowered for the entire system and water is induced to move from the unconfined groundwater reservoir into the confined part. Pumping groundwater from areas under artesian pressure thus diminishes the total supply stored in the deposits beneath the county or beneath areas adjacent to the county.

In localities developing water from aquifers remote from areas of natural discharge, equilibrium may never be reached; and in the predictable future, virtually all the water used must necessarily be taken from storage. If pumping in such localities were at a rate that would lower the water table in ten years so drastically that further pumping would be infeasible, pumping at one-half that rate would not produce the same lowering of the water table in 100 years.

Dr. Peter W. Huntoon (1973) of the Conservation and Survey Division developed a digital model of a sizable part of the Upper Big Blue basin to predict critical conditions that may develop in the groundwater system as a result of withdrawals for irrigation. With the use of a computer, he projected the rate at which the water table could be expected to decline under different rates of irrigation development.

The water-table declines recorded in figure 18 are simulated for a point in York County, 6 miles (9.7 km) west of Utica, Nebraska. Groundwater conditions there are similar to those in western Seward County, however, and withdrawal of water from the aquifer beneath Seward County would affect its water table in like manner. The projections of figure 18 indicate that at the 1972 level of development the water table will decline at a rate of about 15 feet (4.55 m) in 32 years. However, if withdrawals were increased threefold, a 15-foot (4.5-m) decline in the water table would be reached in nine years.

Figure 18 shows four curves depicting the projected rate of decline of the water table under four sets of conditions of irrigation-well development. Each well is considered to yield a net withdrawal at a rate of 48.5 acre-feet (60 000 m^3) per year.

- Curve A projects the water-table decline to be expected at the 1972 rate of development.
- Curve B projects the water-table decline to be expected at double the 1972 rate of development, to a maximum of six wells per section.
- Curve C projects the water-table decline to be expected at double the 1972 rate of development, to a maximum of seven wells per section.
- Curve D projects the water-table decline to be expected at triple the 1972 rate of development, to a maximum of seven wells per section.

When wells near a perennial stream are pumped, the cone of depression around the well will soon reach the stream. If good hydraulic connection exists between the stream and the aquifer, the stream will become a source of supply and minimize the water-level decline. In most of Seward County, however, the transmissivity of the aquifers, except in a few places, is too small near the streams to support high-capacity wells. Only a few irrigation wells are located where stream water can be induced to sustain the withdrawal.

In the Drift Hills region, aquifers are of limited areal extent and quite thin. The few irrigation wells that have been installed in the region are withdrawing water from aquifers that are barely capable of supplying water for the present level of

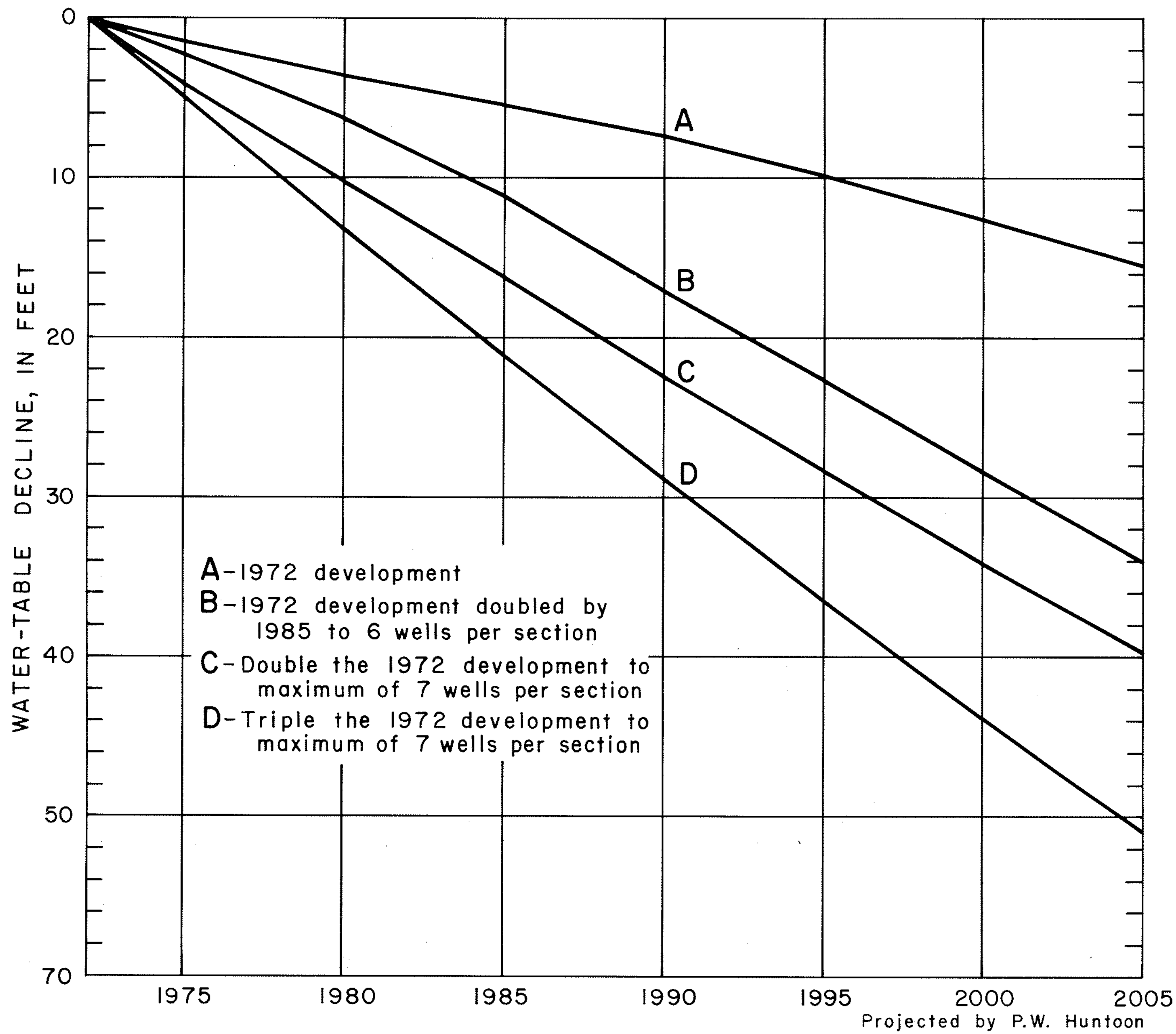


Figure 18. Comparison of projected rates of water-table declines resulting from four different management practices.

development. Water-table declines are likely to diminish yields of wells seriously in a short period. Installation of additional wells would add to the problem.

Adequacy of the basic hydrologic data for management use

Many data concerning the aquifer systems in Seward County have been collected. The size of aquifers and their capacity as sources for water supplies are well documented. These data have been obtained largely through cooperative programs carried out by the U.S. Geological Survey, The University of Nebraska's Conservation and Survey Division, and the Seward County Ground Water Conservation District.

Analysis of the data indicates that a considerable part of the groundwater withdrawn for irrigation or other uses in Seward County is removed from storage. Only a small part of the withdrawal is captured from natural discharge or is returned to the aquifer by seepage. Under present water development, little opportunity exists for increasing groundwater recharge artificially.

The amount of groundwater in storage is large and can be withdrawn either for long or for short periods of time, depending upon the rate of withdrawal. Even though groundwater resources are large, they are not unlimited. Under present conditions, renewal cannot balance withdrawal.

The decision that needs to be made by water managers is whether to limit groundwater withdrawal or to allow unrestricted use and earlier depletion of supplies. Also, they may wish to consider whether surface water should be impounded and used to augment supplies, whether systems might be devised to import surface-water supplies, and whether a return to dryland farming would be acceptable when present groundwater supplies are depleted.

Use of water for purposes other than irrigation might be advantageous. Monetary returns from industrial use of water could, in some cases, be beneficial to the economy. Processing of agricultural products might bring greater returns from water use than irrigation. All the different approaches to water use need to be appraised.

Use of water in Seward County may in time result in deleterious effects on the quality of the resource. More detailed studies should be made of the quality of the surface water and of the groundwater to establish bases from which to determine the long-term effect of the use and reuse of the water.

QUALITY OF WATER

By R. A. Engberg

Introduction

This study of water quality includes an evaluation of the dissolved chemical constituents, sediment, and biological characteristics of the water resources of Seward County, Nebraska.

The dissolved chemical constituents in water are important because the amounts and combinations of dissolved ions in solution determine the water's suitability for most uses. In general, water that is low in dissolved solids is considered to be of good quality, whereas highly mineralized water is considered to be of poor quality. However, this is an arbitrary designation depending upon the conditions under which the water is to be used. For example, water that is of good quality for irrigation in one area may be of poor quality for irrigation in another area because of differences in soil and subsoil characteristics.

Sediment is not present in groundwater obtained from properly constructed and developed wells, but it is commonly a problem to users of surface water. Surface water used for public supply and industrial purposes may require sediment removal.

Biological characteristics of water, including bacterial content, are of concern where either groundwater or surface water is used for drinking. Biological characteristics of a water supply are related to both its dissolved chemical constituents and its sediment content. Surface water rich in nitrogen, phosphorus, and organic carbon generally is characterized by pronounced biological activity. High sediment content in water diminishes biological activity by preventing the penetration of sunlight necessary for many biological processes.

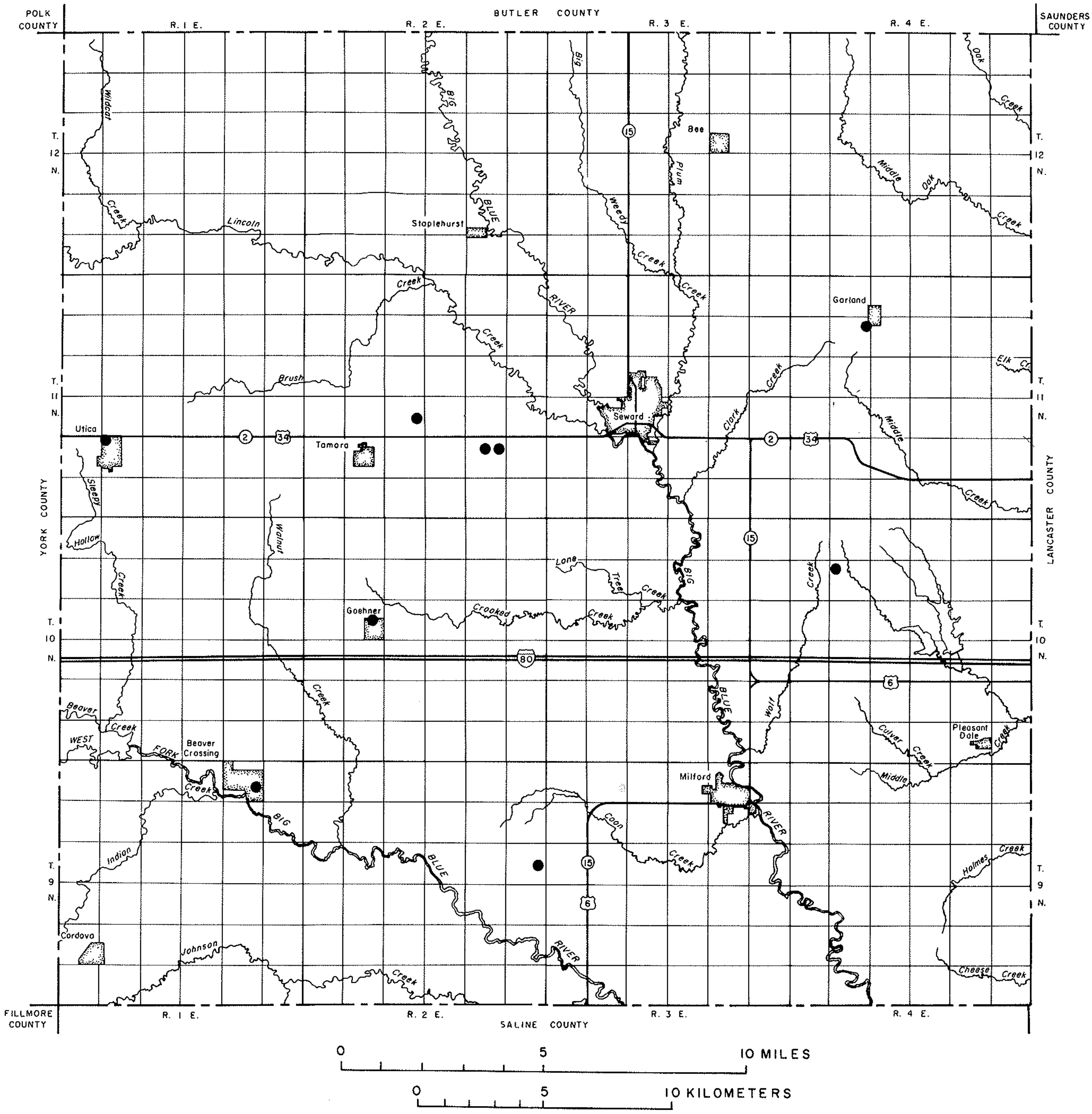
Dissolved-solids concentration, sediment content, and biologic characteristics of water depend upon several physical and chemical processes. Precipitation ordinarily contains only trace amounts of dissolved solids and gases; but as it runs off or percolates into the ground, it reacts with mineral and organic substances. The amount of material dissolved by the water depends on the chemical and physical characteristics of the soil and rocks that the water contacts and the properties of the water itself during the time of contact. Sediment content of surface water is an end product of erosional processes and depends, in part, upon the amount and duration of rainfall, velocity of runoff, and the physical characteristics of the land surface. Biologic activity in water is the result of plant and animal life processes coupled with man's use of land and water resources.

The U.S. Geological Survey has not determined sediment concentrations or biological parameters for samples of groundwater from Seward County. Cities and towns providing municipal supplies of water are required by state law to submit samples of drinking water monthly to state laboratories for bacterial analyses.

Groundwater

Dissolved chemical constituents.--Complete or partial chemical analyses of water samples from nine wells in Seward County are available from U.S. Geological Survey records. Locations of the sampled wells are shown in figure 19 and the chemical analyses of all routinely measured constituents are given in table 4. Analyses of nutrients and heavy metals were determined for some of the samples.

Water from nearly all wells in the part of Seward County west of the Big Blue River is derived from sand and gravel of Pleistocene age and valley alluvium. Seven of the nine wells sampled are located in this part of the county. One of the seven wells (9N-2E-13DADD) is drilled through sand and gravel into the consolidated Dakota Group below.



EXPLANATION

● Well sampled for chemical analysis of water

Figure 19. Location of sampled wells in Seward County.

Table 4. Chemical analyses of common constituents of groundwater from nine wells in Seward County

[Use: D, domestic; I, irrigation; PS, public supply; R, recorder]

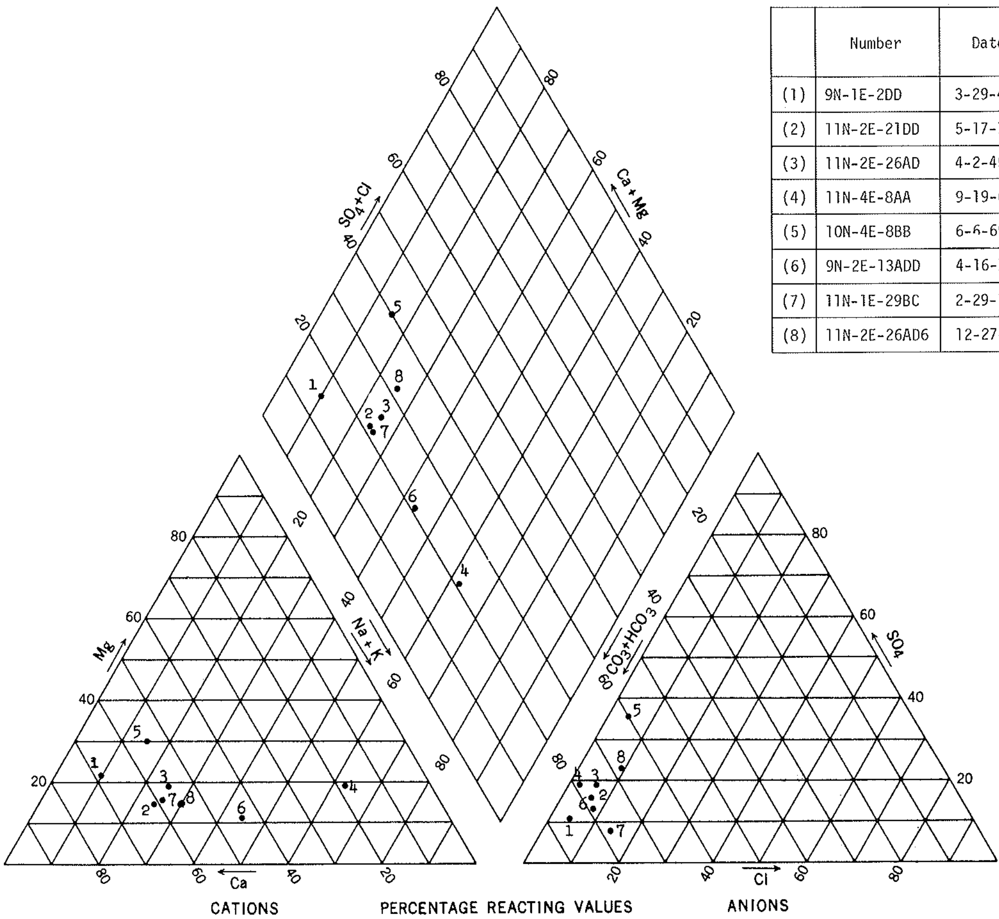
Well	Depth of well (feet)	Use	Date of collection	Silica (mg/l)	Dissolved iron (µg/l)	Manganese (µg/l)	Calcium (mg/l)	Magnesium (mg/l)	Sodium (mg/l)	Potassium (mg/l)	Bicarbonate (mg/l)	Carbonate (mg/l)	Sulfate (mg/l)	Chloride (mg/l)	Fluoride (mg/l)	Nitrate as N (mg/l)	Boron (µg/l)	Dissolved solids 180° (mg/l)	Hardness (mg/l)	Noncarbonate hardness (mg/l)	Sodium adsorption ratio	Specific conductance (micromhos per cm at 25°C)	pH
9N-1E-2DD.......	129	...	3-29-45	......	.....	.....	82	15	14	.....	306	0	31	9.0	0.2	0.0	.....	302	266	15	0.4	528	...
9N-2E-13DADD....	493	I	4-16-70	24	40	207	52	8.0	57	5.4	292	0	42	14	0.3	0.0	180	351	163	0	1.9	571	7.8
10N-2E-17DA......	90	D	3-29-45	......	.....	.....	......	.....	37	.....	230	0	60	6.0	......	3.8	.....	......	192	3	1.2	600	...
10N-4E-8BB.......	510	D	6- 6-69	49	190	30	133	44	38	8.8	441	0	210	11	0.3	0.1	100	731	511	149	0.7	1 000	7.7
11N-1E-29BC......	254	PS	2-29-72	40	30	30	71	12	30	5.7	287	0	25	11	0.4	8.0	30	372	230	0	0.9	573	6.8
			6-15-72	38	20	10	74	11	30	5.3	275	0	30	10	0.4	7.4	30	367	230	5	0.9	614	7.1
			12-27-72	38	.....	.....	68	11	28	5.0	277	0	27	8.4	......	6.0	50	348	220	0	0.8	538	7.6
			6- 1-73	......	.....	.....	......	.....	.....	.....	.....	......	......	.....	......	6.4	.....	......	......	.....	......	551	...
11N-2E-21DD......	123	R	5-27-58	33	.....	.....	69	12	27	7.5	280	0	44	4.5	0.1	2.2	40	351	222	0	0.8	541	7.2
			5-17-73	38	520	20	72	11	28	7.3	280	0	46	4.2	0.3	3.2	40	374	230	0	0.8	544	7.3
11N-2E-26AD......	115	PS	4- 2-45	......	.....	.....	64	13	33	.....	260	0	52	6.0	0.2	2.7	.....	308	213	0	1.0	522	...
11N-2E-26AD6.....	117	PS	12-15-71	36	10	0	75	12	34	6.1	252	0	80	5.5	0.4	4.8	30	394	240	30	1.0	603	6.8
			6-15-72	36	30	10	72	12	35	6.7	248	0	87	4.6	0.3	5.6	50	400	230	26	1.0	612	7.1
			12-27-72	35	.....	.....	75	12	32	6.8	251	0	68	5.8	......	5.1	90	381	240	31	0.9	593	7.2
			6- 1-73	......	.....	.....	......	.....	.....	.....	.....	......	......	.....	......	5.3	.....	......	......	.....	......	614	...
11N-4E-8AA.......	396	PS	3-29-45	......	.....	.....	50	20	103	.....	452	0	49	5.0	0.6	0.0	.....	450	207	0	3.1	766	...
			9-19-69	45	10	180	28	17	99	12	346	0	65	3.1	0.5	1.0	310	443	141	0	3.6	654	8.0

The part of Seward County east of the Big Blue River is underlain mostly by glacial till with thin deposits of sand and gravel that yield only small amounts of water. One of the two sampled wells in this area (11N-4E-8AA) derives water from a sand and gravel deposit at the base of the till and the other (10N-4E-8BB) derives water from the Dakota Group that underlies the unconsolidated deposits.

The few chemical analyses available permit only a general interpretation of the quality of groundwater in Seward County. Figure 20 is a plot of the percentage reacting values of the principal ions in solution. Percentage reacting values are based on the chemical reaction of ions (electrically charged particles) and define the relative amounts of these ions (on a percentage basis) in solution. A given amount of a positively charged ion (cation) will react with an equal amount of a negatively charged ion (anion). Water from the Pleistocene sand and gravel aquifers west of the Big Blue River is represented by numbers 1, 2, 3, 7, and 8 on the diagram. These are closely grouped on each graph. The water is of the calcium bicarbonate type; the dissolved-solids concentration is quite uniform throughout the area.

Water from the well developed in sand and gravel at the base of the till (no. 4) is of the sodium bicarbonate type. Some recharge to this aquifer probably occurs by water moving through the till. Base exchange can take place in till, thus increasing the sodium concentration of the water in the aquifer.

Well number 5 is developed in Dakota Group aquifers that are overlain by glacial till. The water is a calcium bicarbonate type but with a higher relative concentration of sulfate than is observed in water from wells developed in the Pleistocene aquifer. The percentage of constituents in the water is similar to that from many other eastern Nebraska wells developed in the upper part of the Dakota Group. Well number 6 is developed in the Dakota Group where it is overlain by sand and gravel. The water is a calcium-sodium bicarbonate type, very similar in dissolved-solids concentration to water from the wells developed in the Pleistocene sand and gravel. Movement of water from the Pleistocene into the Dakota probably occurs locally.



	Number	Date	Dissolved solids (mg/l)	Aquifer
(1)	9N-1E-2DD	3-29-45	302	Pleistocene
(2)	11N-2E-21DD	5-17-73	374	Pleistocene
(3)	11N-2E-26AD	4-2-45	308	Pleistocene
(4)	11N-4E-8AA	9-19-69	443	Pleistocene
(5)	10N-4E-8BB	6-6-69	731	Dakota Group
(6)	9N-2E-13ADD	4-16-70	351	Dakota Group
(7)	11N-1E-29BC	2-29-72	372	Pleistocene
(8)	11N-2E-26AD6	12-27-72	381	Pleistocene

Figure 20. Analysis diagram of groundwater in Seward County.

Another type of water-quality diagram is called the Stiff diagram (figure 21), which is a plot of milliequivalents per liter of the major constituents in solution. Diagrams of water of similar types have similar shapes. The five diagrams of water from Pleistocene deposits are quite similar, whereas the diagrams of water from the Dakota Group and the aquifer at the base of the Pleistocene have significantly different shapes.

An additional illustration of the similarity of water from the Pleistocene sand and gravel in western Seward County is shown in figure 22. Although similar conductivity values for water from several locations do not necessarily mean the values of chemical constituents will be similar to one another, the Stiff diagrams in figure 21 indicate that in Seward County the chemical constituents probably are similar. Conductivities of water from 35 irrigation wells sampled in 1969 range from a low of 449 micromhos per centimeter* (μmhos per cm) to a high of 764 μmhos per cm. However, the conductance value for water from 23 of the 35 wells was between 500 and 600 μmhos per cm. The average for all 35 samples was 545 μmhos per cm. Conductivity values were greater than 600 μmhos per cm for only three wells, all in the central part of the county. Percolation of water through till deposits near these wells may affect the quality of their water. Conductivity values may be multiplied by 0.7 to obtain a fairly accurate evaluation of the dissolved-solids concentration in milligrams per liter.

Few measurements of nutrients have been made on samples of groundwater from Seward County. Nutrients are substances, often chemical compounds or elements, used in metabolic processes by all living things. Although nutrients exist abundantly in nature, the nutrients specifically referred to in this report are nitrogen and phosphorus compounds. Nitrogen compounds ordinarily are introduced into groundwater from surface sources related to the activity of man and animals. Such surface sources commonly include

---

*In the International System of Units (SI), the factor for converting micromhos to siemans is 1.000 000^{00}.

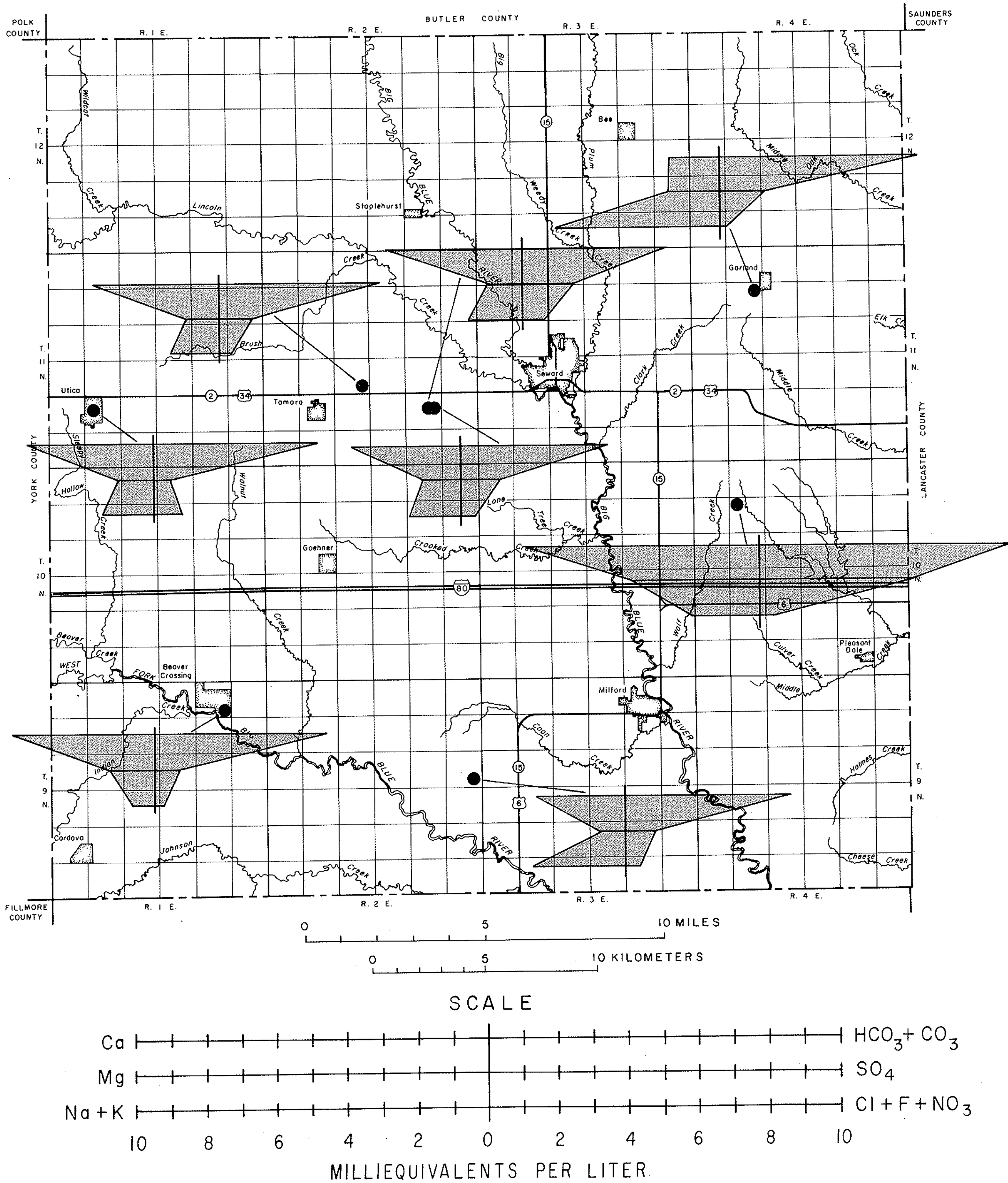
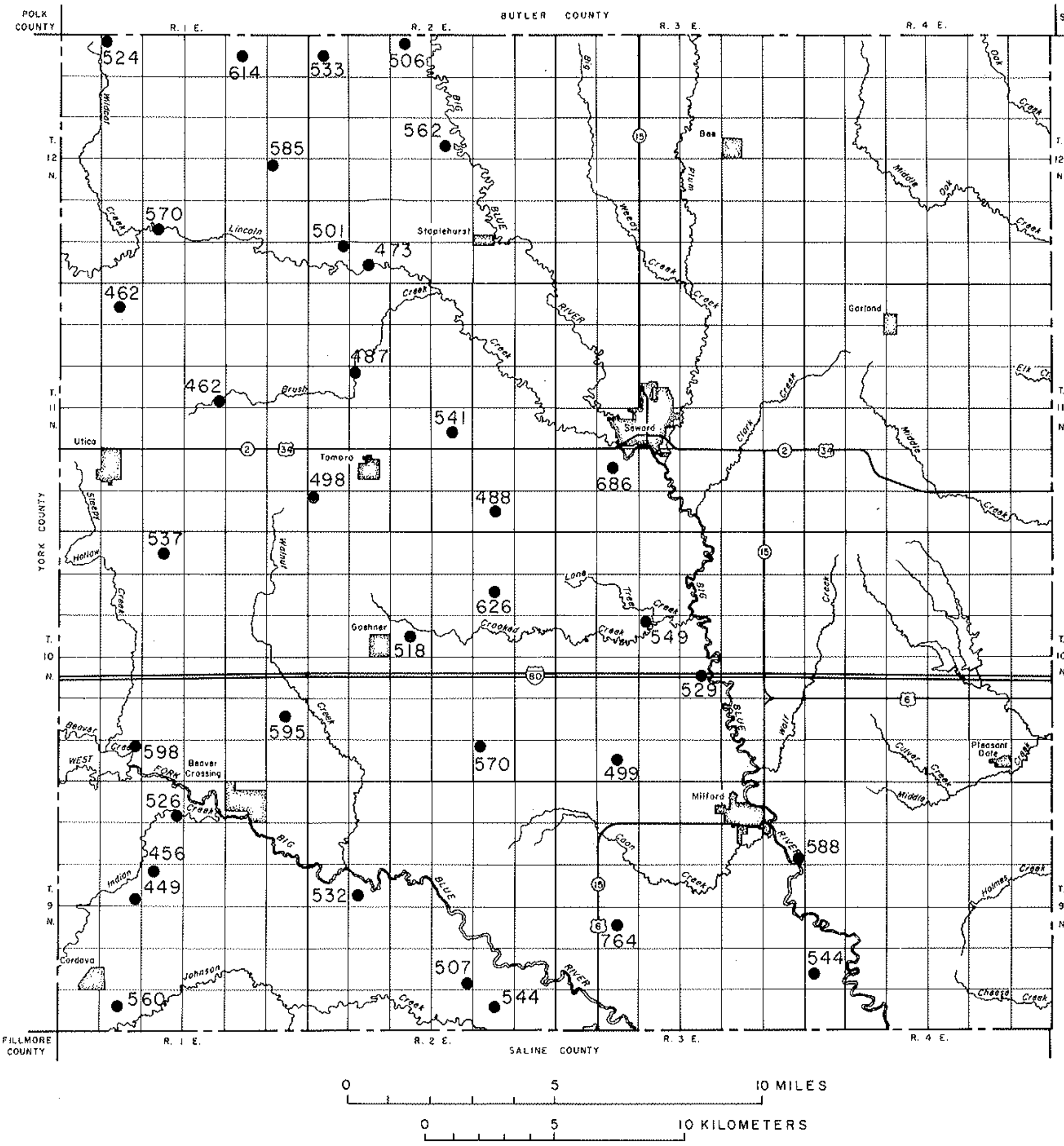


Figure 21. Stiff diagrams of groundwater samples in Seward County.



EXPLANATION

● 544

Irrigation well

Number is specific conductance in µmhos/cm

Figure 22. Specific conductance of water from irrigation wells in Seward County.

fertilizers, septic tanks, barnyards, and feedlots. Nitrate is the end product of the oxidation of all nitrogen compounds. The leaves and roots of plants and the bodies of animals and insects in soils are oxidized and the small amounts of nitrate produced are tightly held in the soil-plant system. Nitrate is the form of nitrogen to be expected in water under unconfined conditions. Only trace amounts of other forms of nitrogen have been observed in the groundwater of Seward County (cf. table 5).

Phosphorus compounds in groundwater may originate from the rocks through which water percolates or from human-related activities. However, phosphorus compounds are easily adsorbed by fine-grained sediments. Water from wells developed in the Dakota Group contained a maximum of 0.07 mg/l, a relatively low amount reflecting the thick sections of fine-grained sediments overlying the aquifer. Larger amounts of phosphorus (maximum of 0.34 mg/l) occur in water from Pleistocene aquifers west of the Big Blue River where the likelihood of phosphorus being derived from human-related activities is greater.

Trace-constituent concentrations in samples of groundwater from Seward County are given in table 6. For the purposes of this report, the term trace constituent includes those chemical substances generally occurring in quantities less than 1 000 micrograms per liter (μg/l) which are not considered part of a routine chemical analysis. Many trace constituents are harmful to humans and/or animals. These are discussed later in relation to standards issued by the U.S. Public Health Service.

Seward County is primarily an agricultural area. The principal use of groundwater there is for irrigation. Along with being applied to such physical characteristics of the soil as permeability, slope, drainage, and water-holding capacity, suitability of water for irrigation is usually based on a combination of two criteria: the salinity hazard, represented by conductivity of the water; and the alkali hazard, represented by the sodium-adsorption ratio (SAR) of the water. The SAR is related to the amount of sodium adsorbed by the soil from applied irrigation water.

Table 5. Nutrients in groundwater from nine wells in Seward County
[Results in milligrams per liter]

Well	Date of collection	Nitrate as N[1]	Nitrate as N	Ammonia as N	Organic nitrogen as N	Kjeldahl nitrogen as N	Orthophosphate as PO_4	Dissolved phosphorus as P	Total phosphorus as P
9N-1E-2DD....	3-29-45	0.0	......	......	....	....	....	....	....
9N-2E-13DADD.	4-16-70	0.0	......	......	....	....	0.00	0.07	....
10N-2E-17DA...	3-29-45	3.8	......	......	....	....	....	....	....
10N-4E-8BB....	6- 6-69	0.1	......	......	....	....	0.04	....	....
11N-1E-29BC...	2-29-72	8.0	......	......	....	....	....	0.27	....
	6-15-72	7.4	......	......	....	....	....	0.33	....
	12-27-72	6.0	......	......	....	....	....	0.30	....
	6- 1-73	6.4	0.00	0.01	0.00	0.01	....	....	0.21
11N-2E-21DD...	5-27-58	2.2	......	......	....	....	....	....	....
	5-17-73	3.2	0.00	0.04	0.03	0.07	....	0.00	0.23
11N-2E-26AD...	4- 2-45	2.7	......	......	....	....	....	....	....
11N-2E-26AD6..	12-15-71	4.8	......	......	....	....	....	0.34	....
	6-15-72	5.6	......	......	....	....	....	0.32	....
	12-27-72	5.1	......	......	....	....	....	0.29	....
	6- 1-73	5.3	0.00	0.01	0.00	0.00	....	....	0.28
11N-4E-8AA....	3-29-45	0.0	......	......	....	....	....	....	....
	9-16-69	1.0	......	......	....	....	0.08	....	....

1. Repeated from table 4.

Table 6. Trace constituents in groundwater from nine wells in Seward County
[All concentrations are in micrograms per liter]

Well	Date of collection	Aluminum	Arsenic	Barium	Beryllium	Cadmium	Chromium	Cobalt	Copper	Lead	Lithium	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Vanadium	Zinc
9N-1E-2DD...	3-29-45	...	...	....	....	....	.....	....	....	....	.....	....	....	.....	...	....	......	...	.....
9N-2E-13DADD	4-16-70	100	1	<5	0	<5	<5	<5	<5	<5	19	....	6	<5	14	<5	470	...	1 350
10N-2E-17DA..	3-29-45	...	....	....	....	....	.....	....	....	....	.....	....	....	.....	....	....	......	...	.....
10N-4E-8BB...	6- 6-69	200	...	....	....	....	.....	....	10	....	10	....	....	.....	....	....	920	...	.....
11N-1E-29BC..	2-29-72	...	...	....	....	....	.....	....	20	....	.....	....	....	.....	....	....	......	...	80
	6-15-72	...	...	....	....	....	.....	....	20	....	.....	....	....	.....	....	....	......	...	10
	12-27-72	...	...	....	....	....	.....	....	....	....	.....	....	....	.....	....	....	......	...	.....
	6- 1-73	0	2	300	0	0	0	0	50	0	10	0.2	1	1	6	1	300	8.2	20
11N-2E-21DD..	5-27-58	...	...	....	....	....	.....	....	....	....	.....	....	....	.....	....	....	......	...	.....
	5-17-73	10	5	200	0	0	0	0	1	0	20	0.0	1	13	20	0	280	7.3	140
11N-2E-26AD..	4- 2-45	...	...	....	....	....	.....	....	....	....	.....	....	....	.....	....	....	......	...	.....
11N-2E-26AD6.	12-15-71	...	...	....	....	....	.....	....	10	....	.....	....	....	.....	....	....	......	...	20
	6-15-72	...	...	....	....	....	.....	....	9	....	.....	....	....	.....	....	....	......	...	10
	12-27-72	...	...	....	....	....	.....	....	....	....	.....	....	....	.....	....	....	......	...	.....
	6- 1-73	0	1	300	0	1	0	0	6	0	20	0.3	1	0	27	0	340	2.6	10
11N-4E-8AA...	3-29-45	....	...	....	....	....	.....	....	....	....	.....	....	....	.....	....	....	......	...	.....
	9-16-69	50	...	....	....	....	.....	....	10	....	90	....	....	.....	....	....	540		10

Generally, water having conductivity of 750 μmhos or less is suitable for application to soils in which a moderate amount of leaching occurs. Fine-grained, poorly drained soils in time may become alkaline if water with low to medium salinity is applied. The salinity hazard appears to be minimal in the irrigated part of Seward County. The highest conductivity observed in water from the 35 samples from Seward County irrigation wells was 764 μmhos, which is only slightly above the suitability range (750 μmhos) for moderately well drained soils. According to Elder (1969), the soils in western Seward County are quite favorable for irrigation in respect to drainage, water-holding capacity, permeability, depth to root zone, and slope characteristics.

The SAR is used to predict the alkali hazard involved in the use of irrigation water. The formula for calculating SAR--in which concentrations of sodium (Na), calcium (Ca), and magnesium (Mg) are expressed in equivalents per million--is as follows:

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$$

Water having a value of less than 10 SAR units can be used for almost any crop, with little danger of alkali formation. Although SAR values were not determined for water from the 35 irrigation wells on which conductivity values were reported, the highest SAR observed in water from the six wells developed in the Pleistocene sand and gravel was 1.2. This value is probably representative of the water in the irrigated part of the county.

The most recent standards for quality of water used for public supply, published by the U.S. Public Health Service (1962), placed limits on some constituents. These limits are applicable to Nebraska groundwater used for public supply because Nebraska has no separate standards for groundwater.

If more suitable supplies are available, water should not be used as public supply when it contains substances in concentrations exceeding the values shown on the following page:

Substance	Concentration, in mg/l
Alkyl benzene sulfonate...........	0.5
Arsenic..........................	0.01
Chloride.........................	250
Copper...........................	1
Carbon chloroform extract.........	0.2
Cyanide..........................	0.01
Fluoride.........................	Based on temperature
Iron.............................	0.3
Manganese........................	0.05
Nitrate..........................	45
Phenols..........................	0.001
Sulfate..........................	250
Dissolved-solids concentration.....	500
Zinc.............................	5

Limits for many of these constituents are based primarily on aesthetic considerations. Excessive amounts of chloride, sulfate, and dissolved solids may impart an undesirable taste to the water and may have a cathartic effect on users, although normally individuals become accustomed to the water in a short time. Copper and zinc impart a metallic taste to water when concentrations exceed the indicated limits. Iron and manganese also impart a bad taste to water and are responsible for rust and stains on plumbing fixtures and laundry. Often iron and manganese are treated collectively in terms of recommended maximums.

Included in the following list are substances whose presence in excess of the limits set by the U.S. Public Health Service (1962), expressed on the next page as concentrations, are grounds for rejection of a water supply.

Substance	Concentration, in μg/l
Arsenic...........................	50
Barium............................	1 000
Cadmium...........................	10
Chromium (hexavalent).............	50
Lead..............................	50
Selenium..........................	10
Silver............................	50

The listed standards are for public supply; they are not required for domestic wells. For the health of the individuals concerned, however, the same general precautions should be observed by those using private water supplies. In the case of nitrate, for example, concentrations greater than 45 mg/l have been known to cause serious health problems for infants, including a few infant deaths.

Recommended concentration limits were exceeded for only three substances in the samples collected from Seward County. The recommended limit for iron was exceeded in water from the Pleistocene aquifer in well 11N-2E-21DD, which is not used for public or domestic purposes. Although manganese exceeded the recommended limit in both wells producing water from the Dakota aquifer, the combined amounts of iron and manganese do not exceed the combined recommended maximums.

Selenium concentrations exceeded the maximum limit in water from three wells. The selenium limit of 10 μg/l established by the U.S. Public Health Service in 1962 was below the lower detection limit of all except the most precise methods then existing for determining selenium concentrations. Advances in quantitative analysis procedures for selenium have since made possible the detection of smaller concentrations of selenium. The toxicity to humans and animals of large quantities of selenium has been known for many years, but evidence concerning the beneficial effects of small quantities of selenium was just beginning to be published in 1962. Recent studies indicate that selenium concentrations slightly exceeding the U.S. Public Health Service limit, such as those observed in water from Seward County, probably are not harmful (Engberg, 1973).

Surface water

Water flowing in a stream is derived from two principal sources--overland runoff and groundwater discharge. Overland runoff includes storm runoff and discharge from such sources as return flow from irrigation, sewage effluent, and feedlot drainage. At low flow, little overland runoff reaches the stream and the flow consists mostly of groundwater discharge. During high-flow periods, however, overland runoff contributes most of the discharge.

Water quality fluctuates with variations in discharge. In general, an inverse relationship exists between discharge and water quality. Water discharge approaching base flow usually results in higher mineralization of a stream because the groundwater component usually is more highly mineralized than the overland-runoff component. Periods of low flow are significant when the chemical quality of the water is the major concern of the user, because during those periods the quality normally is poorest. Thus, if the water's chemical quality is satisfactory under low-flow conditions, it will usually be satisfactory during medium to high flow. If clarity of water is the major consideration of the user, periods of high-flow discharge are critically important because normally sediment concentrations are greatest and clarity is poorest when discharge is high.

Dissolved chemical constituents.--Analyses of the chemical quality of samples of surface water from six sites in Seward County were made by the U.S. Geological Survey (figure 23). Data concerning the sampling period, number of samples, maximum and minimum water discharges, and specific conductance for the period

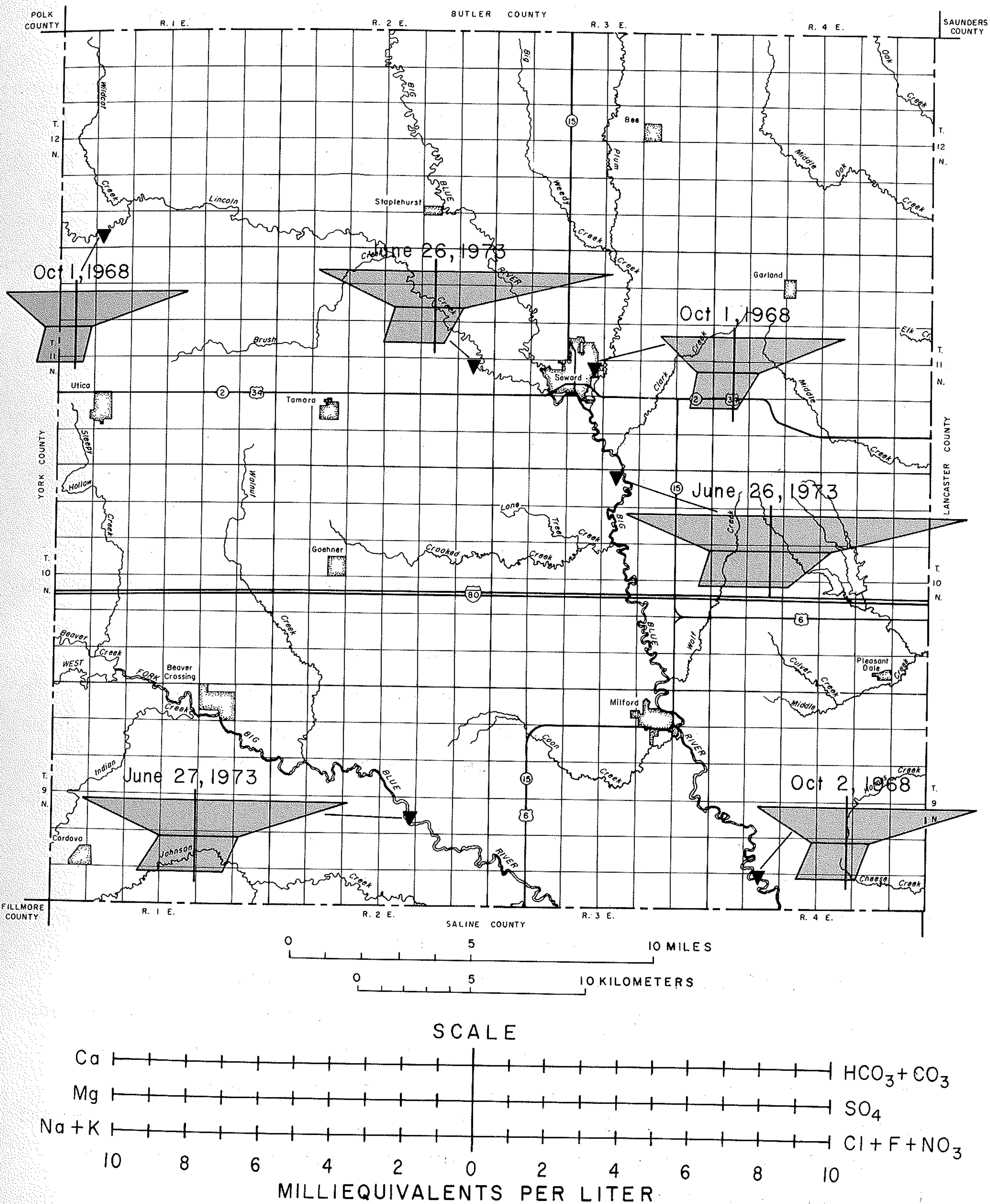


Figure 23. Location of surface-water sampling sites in Seward County and Stiff diagrams showing representative quality of the water at low flow.

of sample are given in table 7. More than 100 samples were collected from the West Fork Big Blue River near Dorchester and from Lincoln Creek near Seward during a wide range of river stages. Only a few samples were collected from three of the stations, but considerable variation of chemical quality was observed even though variations of water discharge were small. No samples were taken during high flow at these three stations.

Figures 24 and 25 show the relationship of specific conductance to discharge for all samples collected from the West Fork Big Blue River near Dorchester and from Lincoln Creek near Seward. The inverse relationship of conductance to discharge is definite on both graphs.

Table 8 is a comparison of the quality of water at low flow and at high flow for the West Fork Big Blue River near Dorchester and for Lincoln Creek near Seward. The samples were obtained during a period of about three weeks. Samples at high flow were obtained following a storm when the stream was near peak discharge for the storm period.

Concentrations of most major constituents such as calcium, sodium, bicarbonate, sulfate, and chloride decreased sharply with increased water discharge. Concentrations of potassium and nitrate did not decrease as might have been expected; in some samples, they actually increased slightly at high flow. Potassium and nitrate, the primary constituents of fertilizer, are readily carried in solution with runoff from fields during heavy rainfall. This probably accounts for the high concentrations of these constituents in the stream at high flow.

The Stiff diagrams of figure 21 represent average water quality of the streams under low-flow conditions. Ratios of the major constituents were very nearly the same at all sampling locations and were nearly identical to those of water from Pleistocene aquifers. This indicates that under low-flow conditions most of the water is derived from groundwater discharge from Pleistocene aquifers.

Table 7. Maximum and minimum observed specific conductance and discharge for six surface-water stations in Seward County

[Frequency: I, intermittently; M, monthly]

Station number 06-	Station name	Sampling period	Fre-quency	Total samples	Water discharge (ft^3/s)				Specific conductance (micro-mhos per cm at 25° C)			
					Maxi-mum	Date	Mini-mum	Date	Maxi-mum	Date	Mini-mum	Date
8799.95	Lincoln Creek nr. Utica..........	May 1968- Oct. 1968	I	5	24	8-19-68	1.1	10 -1-68	538	6-13-68	152	8-19-68
8800	Lincoln Creek nr. Seward.........	June 1963- Sept. 1970 Feb. 1973- present	M	116	4,510	6-16-67	1.3	6-25-70	603	12-21-64	51	6-16-67
8805.1	Plum Creek at Seward........	May 1968- Oct. 1968	I	6	21	8-12-68	0.04	10- 1-68	791	5- 9-68	154	8-12-68
8805.2	Big Blue River below Seward..	Feb. 1973- present	M	12	650	2-26-73	26	6-26-73	853	12-18-73	213	2-26-73
8805.5	Big Blue River near Milford..	May 1968- Oct. 1968	I	4	108	8-20-68	15	10- 2-68	558	5- 9-68	200	8-20-68
8808	West Fork Big Blue River nr. Dorchester...	June 1963- Sept. 1970 Feb. 1973- present	M	123	3,400	6-13-67	38	7-11-66	625	5-18-70	78	6-12-67

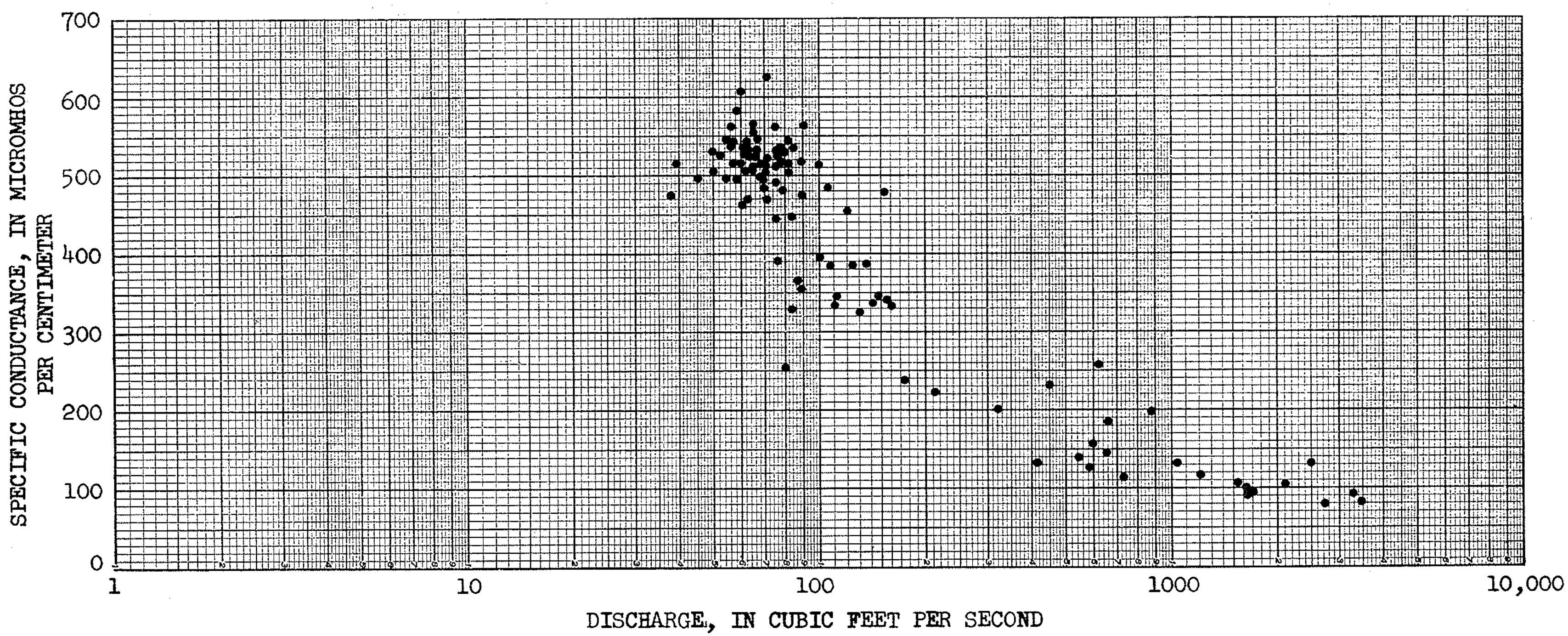


Figure 24. Relationship of specific conductance to discharge, West Fork Big Blue River near Dorchester, Nebraska.

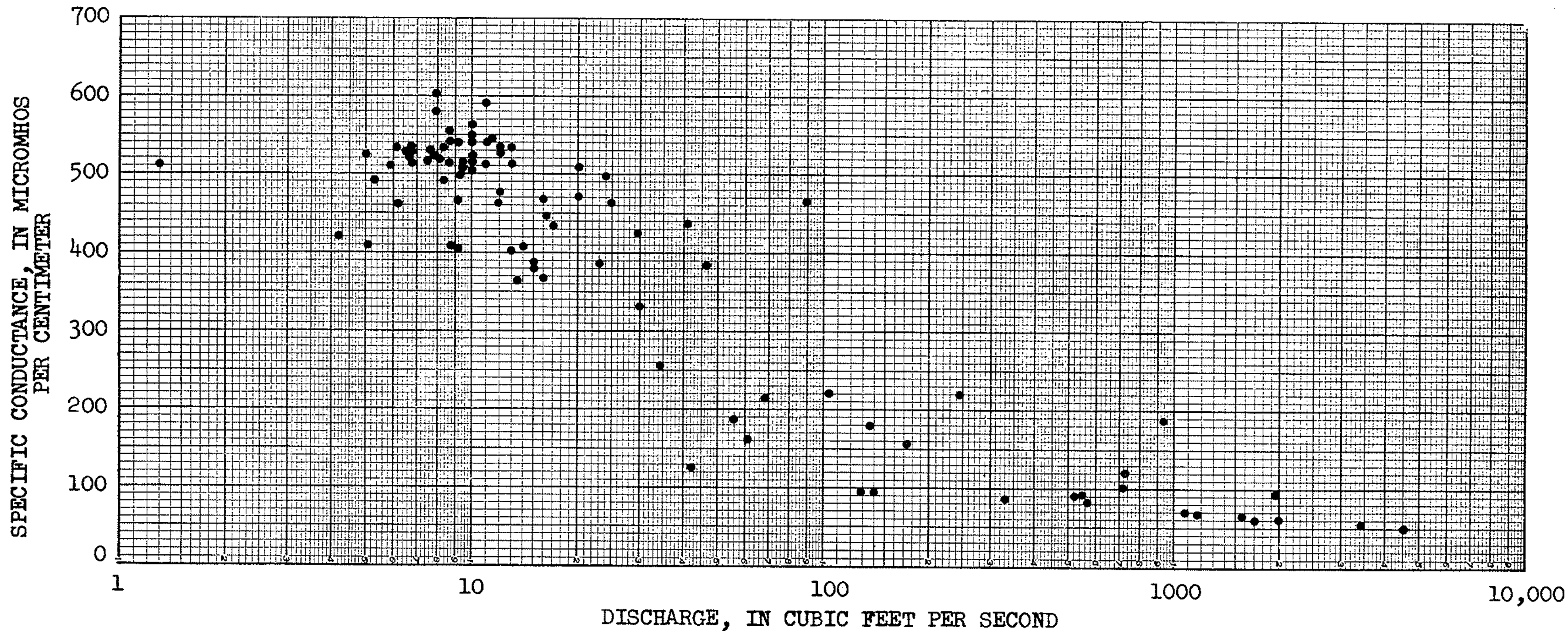


Figure 25. Relationship of specific conductance to discharge, Lincoln Creek near Seward, Nebraska.

Table 8. Comparison of water-quality paramaters during high-flow and low-flow conditions at two stations

[Constituents in milligrams per liter unless otherwise indicated]

Station number 06-	Station name	Date of collection	Water discharge (ft^3/s)	Specific conductance (micromhos per cm at 25°C)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (µg/l)
8800	Lincoln Creek nr. Seward......	5-24-67	6.9	532	69	12	29	8.2	306	26	5.4	0.4	5.1	0.04
		6-16-67	4,510	51	4.2	1.7	0.6	8.0	14	4.8	1.2	0.2	4.6	0.02
8808	West Fork Big Blue River nr. Dorchester......	5-24-67	52	524	62	11	36	8.0	251	41	20	0.4	2.9	0.06
		6-13-67	3,400	83	6.3	1.6	2.0	8.6	27	7.0	1.2	0.2	4.6	0.04

Sediment.--Sediment load in streams is mostly from overland runoff. As velocities increase with higher discharge, however, stream banks are eroded and stream-bed material is scoured and transported.

The amount of sediment carried into a stream by storm runoff varies with the time of year, the type of ground cover, and the slope of the land. Runoff from storms following spring thaws may carry heavy sediment loads since vegetation has not developed enough to stabilize the soil. Runoff from land having permanent vegetative cover generally carries less sediment than runoff from cultivated fields.

Sediment samples were collected monthly from June 1963 to September 1967 at the West Fork Big Blue River near Dorchester and from June 1963 to September 1970 at Lincoln Creek near Seward. Sediment analysis included both the determination of the concentration and particle size of suspended sediment and the determination of the particle size of bed material. Figures 26 and 27 show suspended-sediment concentrations plotted against discharge for all samples collected at the two stations mentioned above. Sediment concentrations appeared to be almost independent of stream discharges below 10 ft^3/s (2.832 m^3/s) at the Lincoln Creek station and at discharges below 100 ft^3/s (28.32 m^3/s) at Dorchester. At higher flows than these, there appeared to be some correlation of sediment concentration with stream discharge, even though data points are widely scattered. Much of the sediment load is transported by streams during high-flow conditions.

Particle-size data indicated that at least 75 percent by weight of the sediment carried by streams in Seward County is of clay size, 0.004 millimeters or less. The rest of the sediment is mostly silt. The amount of sand carried by the streams usually is very small.

Biological parameters of water quality.--The degree of stream pollution can be determined by measuring certain biological parameters. Monthly measurements were made in 1975 on

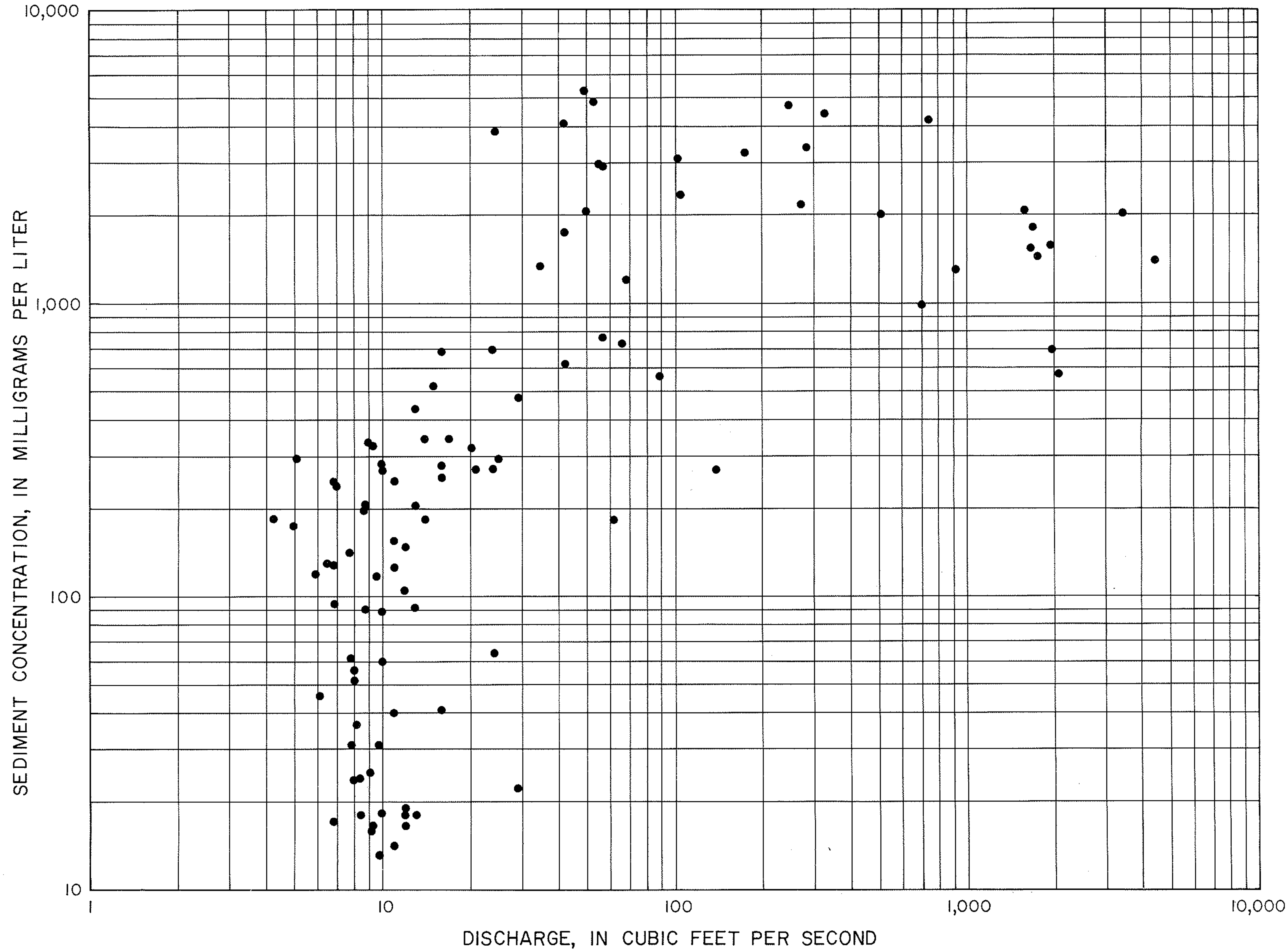


Figure 26. Relationship of sediment concentration to discharge, Lincoln Creek near Seward, Nebraska.

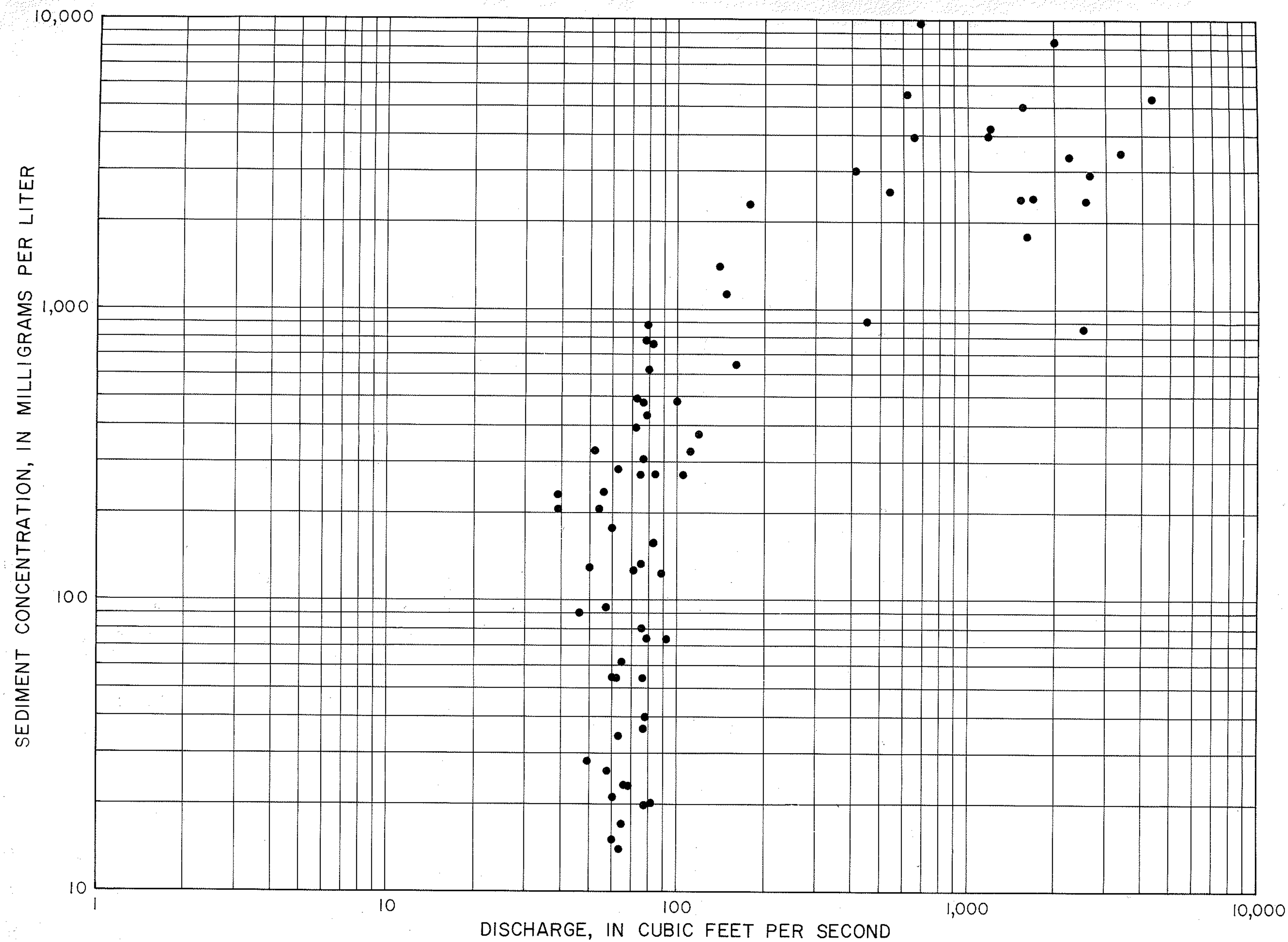


Figure 27. Relationship of sediment concentration to discharge, West Fork Big Blue River near Dorchester, Nebraska.

samples collected at three locations in Seward County. These monthly sampling procedures were started in February 1973. The sites were Lincoln Creek near Seward, Big Blue River below Seward, and the West Fork Big Blue River near Dorchester. Measured parameters given in table 9 include dissolved oxygen (DO), biochemical oxygen demand (BOD), fecal coliform (FC), and fecal streptococcus (FS).

DO is essential for maintaining aquatic life. Normally DO should be greater than 5 mg/l to maintain fish life in a warm-water stream (Federal Water Pollution Control Administration's Water Quality Criteria, 1968). DO concentrations below 5 mg/l can be tolerated by most species of fish for a few hours but traumatic effects occur as the period lengthens. In uncontaminated streams, DO varies with temperature and, to some extent, with variations in salinity and atmospheric pressure. In winter months when oxygen solubility increases with decreasing temperature, DO concentrations are normally higher. In summer, photosynthesis activity of vegetation in the stream adds oxygen during daylight hours, partially offsetting effects of diurnal temperature variations. Curves plotted to reflect diurnal variations in DO usually differ from stream to stream.

Observed DO concentrations at Lincoln Creek near Seward and at the West Fork Big Blue River near Dorchester are within acceptable limits. However, during summer months DO levels have, at times, fallen below 5.0 mg/l at the Big Blue River station below Seward. The station is approximately 2 miles (3.22 km) below the outfall of the sewage-treatment plant at Seward. DO in the stream is consumed in the decomposition of the treated sewage effluent. Fish life could be severely affected in this region, particularly between the outfall and the point downstream where DO concentrations remain above 5.0 mg/l.

BOD is closely related to DO. Organic matter carried by a stream, whether derived from natural or man-made sources, is decomposed by microorganisms in the water. In this process, microorganisms acquire DO from the stream, thereby decreasing the DO concentration of the stream. The DO required for decomposition of organic material is called the BOD.

Table 9. Biological parameters measured in samples from Seward County streams

[FC, fecal coliform; FS, fecal streptococcus; DO, dissolved oxygen; BOD, biochemical oxygen demand]

Station number 06-	Station name	Date of collection	Time	Water temperature (°C)	Water discharge (ft^3/s)	FC (colonies/100 ml)	FS (colonies/100 ml)	FC/FS ratio	DO (mg/l)	BOD (mg/l)
8800	Lincoln Creek nr. Seward................	2-26-73	1440	0.5	50	210	4,280	0.05	11.6	4.9
		4-26-73	1000	10	22	593	750	0.79	9.2	2.6
		5-23-73	1120	17.5	20	500	810	0.62	7.7	3.3
		6-26-73	1115	24	12	560	1,150	0.49	7.8	6.6
		7-26-73	1100	21	19	2,400	1,650	1.4	7.5	4.4
		8-29-73	1115	24	11	700	900	0.78	6.4	3.8
		9-20-73	1100	15	12	1,530	1,900	0.80	8.4	2.3
		10-30-73	1430	11	19	300	1,800	0.17	9.2	2.0
		11-27-73	1100	4.5	36	26,000	50,000	0.52	10.0	7.4
		12-18-73	1130	0.5	10	70	150	0.47	9.5	1.3
		1-29-74	1100	0.5	26	240	560	0.43	10.2	.....
		2-22-74	1145	1	91	280	260	1.1	9.4	8.3
8805.2	Big Blue River below Seward..............	2-26-73	1200	0.5	650	1,190	19,200	0.06	11.0	6.9
		4-25-73	1050	13.5	79	460	1,180	0.39	7.0	5.6
		5-25-73	1020	18	41	1,060	340	3.1	6.0	5.1
		6-26-73	0940	24.5	29	2,900	1,200	2.4	4.6	9.6
		7-26-73	0945	21.5	114	4,700	7,800	0.60	6.8	10.5
		8-29-73	1015	25	18	3,400	500	6.8	4.0	3.0
		9-20-73	0945	15	34	10,000	1,800	5.6	7.8	13.3
		10-30-73	1530	9.5	51	900	1,400	0.64	9.2	2.0
		11-27-73	1010	4	192	11,700	10,000	1.2	10.2	4.8
		12-18-73	1030	1	50	1,980	560	3.5	9.2	.....
		1-29-74	1000	1	74	4,400	4,400	1.0	10.6	.....
		2-22-74	1320	3	427	1,200	1,100	1.1	9.8	19
8808	West Fork Big Blue nr. Dorchester........	2-27-73	1350	3	115	429	2,920	0.15	11.3	3.0
		4-25-73	1300	12.5	117	330	2,050	0.16	8.4	2.3
		5-24-73	1010	16.5	105	590	420	1.4	8.5	4.3
		6-27-73	0940	21	80	2,600	1,850	1.4	8.4	7.0
		7-27-73	0945	24	240	55,000	35,000	1.6	7.5	2.6
		8-30-73	0945	24	80	1,600	2,200	0.73	7.1	3.2
		9-21-73	0900	18.5	165	6,900	1,450	4.8	8.7	2.0
		10-31-73	1015	4.5	106	460	700	0.18	10.2	1.8
		11-28-73	1015	3	174	3,200	9,200	0.35	8.7	5.6
		12-12-73	1225	3	92	1,000	7,900	0.13	9.6	.....
		1-28-74	1015	1	86	1,500	1,300	1.1	10.2	.....
		2-14-74	1145	2	378	1,670	70,000	0.02	10.7	11

BOD concentrations usually are fairly low at the Lincoln Creek and Dorchester stations, generally running higher at the station on the Big Blue River below Seward. Treated sewage carried by the Big Blue River below Seward exerts a higher BOD than does the organic material in the other streams that drain predominately rural areas. Though the West Fork Big Blue River carries effluent from the Hastings, Nebraska, sewage-treatment plant, the distance is so great from the outfall to the Dorchester station that DO recovery ordinarily has taken place by the time the stream reaches Dorchester.

FC and FS bacteria occur in the digestive tracts of warm-blooded animals. In water, these bacterial organisms are not necessarily toxic themselves, but they do indicate that certain toxic microorganisms may be present. FC bacteria predominate in human waste, while FS bacteria predominate in most animal waste. A ratio of FC concentration to FS concentration in a sample from a stream may indicate the principal source of pollution. A high ratio, 4 or greater, may indicate largely human pollution such as sewage; while a low ratio, 0.7 or less, may indicate that feedlot runoff or a similar source is responsible for the bacteria. Ratios between 4 and 0.7 usually indicate a combination of sources.

FC and FS concentrations in water vary considerably with time because they are affected by changes in source, amount of contamination, temperature, storm runoff, and water discharge. Because the station at the Big Blue River below Seward is below the outfall of the Seward sewage-treatment plant, higher FC/FS ratios generally are observed at this station than at the other two that drain largely rural areas. When the overland runoff component of streamflow increases, the FC/FS ratio usually decreases as field, feedlot, and barnyard runoff containing a higher proportion of FS enters a stream.

High stream discharge disturbs bed deposits where both FC and FS have settled, generally increasing concentrations of both. The July 27, 1973, sample from the West Fork Big Blue River near Dorchester probably is representative of the latter condition. Changes in temperature also affect the survival rate of bacteria.

The data for all three stations indicate that FC and FS concentrations are lower in winter months when water temperatures are lower. However, even when temperatures are low, other changes in stream characteristics (such as discharge) often cause variations in bacterial concentrations.

CONCLUSION

The amount of water stored under water-table conditions in a groundwater reservoir, known technically as an unconfined aquifer, is controlled by the rates of recharge and discharge. To estimate the sustained yield of wells in such an aquifer, it is essential to evaluate these factors. It is also essential to separate natural factors from any artificial factors introduced by humans. For example, when water levels decline, it is important to know how much of the lowering is the result of natural factors and how much is attributable to withdrawals of water from wells.

In the area of Seward County west of the Big Blue River, the 1975 rate of groundwater withdrawal is diminishing the total supply and the water table is declining about 0.5 foot (0.152 m) per year. If development increases, the rate of decline will increase correspondingly. The groundwater stored in sand and gravel aquifers generally is adequate for several decades of withdrawals at the present rate; however, eventually the supply of water in the reservoir will be greatly diminished if withdrawals continue at the present rate and recharge is not increased.

Aquifers east of the Big Blue River are discontinuous, thin, and barely capable of supplying water for the 1973 rate of withdrawal. Increased withdrawals are likely to diminish yields rapidly.

Groundwater in sand and gravel aquifers of Quaternary age, typically low in dissolved solids, is of the calcium bicarbonate type. although such water is hard, it is of satisfactory quality for domestic use, irrigation use, and many industrial uses. Water in the sandstone of the Dakota Group is a calcium-sodium bicarbonate type with high concentrations of iron, magnesium, and sulfate. It is unsuitable for irrigation, domestic, or industrial uses, being used for livestock and domestic supply only where no other water supplies are available.

Water in the streams generally is suitable for irrigation use.

REFERENCES

Barbour, E. H. 1901. A few remarkable artesian wells and the uses to which they are put. Scientific American 85:21.

Condra, G. E., and Reed, E. C. 1959. The geological section of Nebraska. Revised edition. Conservation and Survey Division, University of Nebraska: Geological Survey Bulletin 14A. 82 pp.

Elder, J. A. 1969. Soils of Nebraska. Conservation and Survey Division, University of Nebraska: Resource Report 2. 60 pp.

Engberg, R. A. 1973. Selenium in Nebraska's groundwater and streams. Conservation and Survey Division, University of Nebraska: Nebraska Water Survey Paper 35. 42 pp.

Goll, C. L. 1961. The geology of Seward County, Nebraska. Unpublished M.S. thesis. University of Nebraska. 110 pp.

Huntoon, P. W. 1973. A digital model of the Upper Big Blue Watershed. Nebraska Water Resources Research Institute, University of Nebraska: Technical Paper II. 70 pp.

Jess, J. M. 1970. Use of ground water for irrigation, Seward County, Nebraska. Conservation and Survey Division, University of Nebraska: Nebraska Water Survey Paper 25. 24 pp.

Reed, E. C., and Dreeszen, V. H. 1965. Revision of the classification of the Pleistocene deposits in Nebraska. Conservation and Survey Division, University of Nebraska: Geological Survey Bulletin 23. 65 pp.

Schreurs, R. L., and Keech, C. F. 1953. Logs of test holes, Seward County, Nebraska. Conservation and Survey Division, University of Nebraska, and U.S. Geological Survey: Open-file report. 19 pp.

_____. 1955. Supplement to logs of test holes, Seward County, Nebraska. Conservation and Survey Division, University of Nebraska, and U.S. Geological Survey: Open-file report. 13 pp.

Shaffer, F. B., and Braun, K. J. 1967. Floods in Seward quadrangle, southeastern Nebraska. U.S. Geological Survey: Hydrologic Investigations Atlas HA-258. Single sheet.

Nebraska Crop and Livestock Reporting Service. 1973. Nebraska agricultural statistics: 1971. Nebraska Department of Agriculture: Annual report 1971. 176 pp.

Steele, E. K., Jr. 1973. Use of ground water for irrigation in Seward County, Nebraska, in 1971. U.S. Geological Survey: Open-file report 7308. 28 pp.

U.S. Department of Health, Education, and Welfare. 1972. Public Health Service drinking water standards, 1962. Public Health Service publication 956. 61 pp.

U.S. Department of the Interior. 1968. Water quality criteria. Federal Water Pollution Control Administration (now named Environmental Protection Agency): Report of the National Technical Advisory Committee to the Secretary of the Interior. 234 pp.

Waterman, J. H. 1916. General history of Seward County, Nebraska. Beaver Crossing, Nebraska: John H. Waterman. 291 pp.