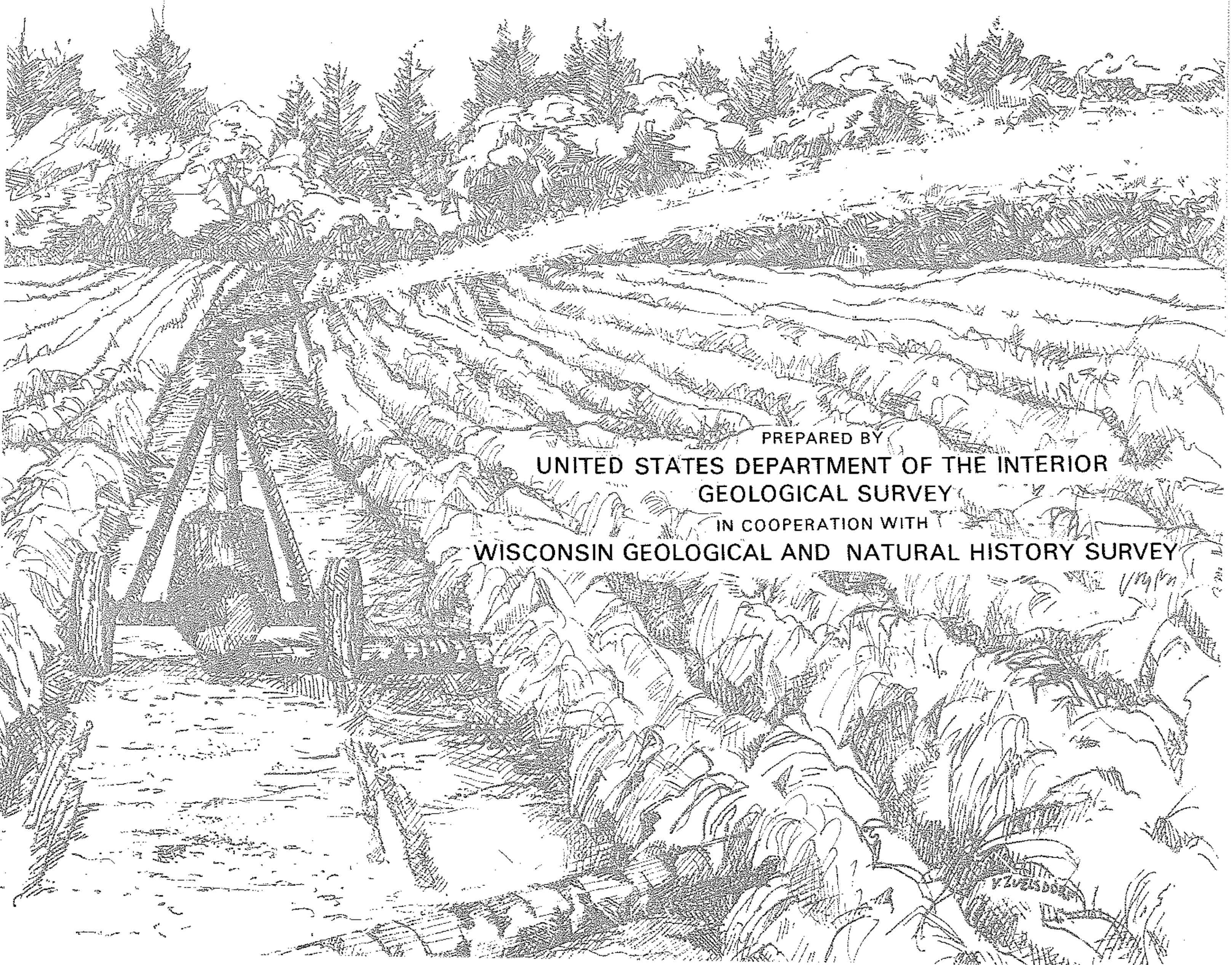
INFORMATION CIRCULAR
NUMBER 36
1978

UNIVERSITY OF WISCONSIN-EXTENSION
GEOLOGICAL AND NATURAL HISTORY SURVEY

Effects of Irrigation on Water Quality in the Sand Plain of Central Wisconsin

by
S. M. Hindall
U.S. Geological Survey



PREPARED BY
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
IN COOPERATION WITH
WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

INFORMATION CIRCULAR
NUMBER 36
1978

UWEX UNIVERSITY OF WISCONSIN-EXTENSION
GEOLOGICAL AND NATURAL HISTORY SURVEY

Effects of Irrigation on Water Quality in the Sand Plain of Central Wisconsin

by
S. M. Hindall
U.S. Geological Survey

This report is a product of the Geological and Natural History Survey Water Resources Program which includes: systematic collection, analysis, and cataloguing of basic water data; impartial research and investigation of Wisconsin's water resources and water problems; publication of technical and popular reports and maps; and public service and information. Most of the work of the Survey's Water Resources Program is accomplished through state-federal cooperative cost sharing with the U.S. Geological Survey, Water Resources Division.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
and
UNIVERSITY OF WISCONSIN–EXTENSION
GEOLOGICAL AND NATURAL HISTORY SURVEY
M. E. Ostrom, Director and State Geologist
Madison, Wisconsin
February 1978

Available from University of Wisconsin–Extension, Geological and Natural History Survey, 1815 University Avenue, Madison, Wisconsin 53706.

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

For the use of those readers who prefer to use metric units rather than English units, the conversion factors for terms used in this report are listed below.

Multiply English unit	By	To obtain metric unit
square miles (mi^2)	2.59	square kilometers (km^2)
inches (in)	2.540	centimeters (cm)
feet (ft)	.3048	meters (m)
miles (mi)	1.609	kilometers (km)
acres	.4047	hectares (ha)
pounds per acre (lb/acre)	1.121	kilogram per hectare (kg/ha)
pounds (lb)	.4536	kilograms (kg)
acre-foot (acre-ft)	1,233	cubic meters (m^3)

Effects of Irrigation on Water Quality in the Sand Plain of Central Wisconsin

S. M. Hindall

ABSTRACT

The chemical quality of the ground and surface water of the sand plain of central Wisconsin reflects the intensive farming and heavy fertilizer applications in a large portion of the area. The effect is most noticeable in and around areas of concentrated irrigation but is evident throughout the 650-square-mile part of the sand plain of central Wisconsin that was intensively studied. Total nitrogen concentrations in ground water in irrigated areas are about twice as high as in the nonirrigated areas of the study area, and four times greater than the average nitrogen concentration in ground water throughout the State of Wisconsin. Even so, the mean nitrogen concentrations measured in the ground and surface water of the study area were well within the 1972 water-quality criteria suggested by the National Academy of Sciences and National Academy of Engineering for the U.S. Environmental Protection Agency for public water supply and agriculture. There is no serious overall problem to water users in the study area at the present time.

Phosphorus and potassium also are applied during fertilization but are present in low concentrations in the ground water. Large amounts of pesticides are used in the study area to control weeds, insects, and diseases. There is little reflection of this use in the waters of the area. A single pesticide, DDT, was detected in the ground water at a single location in a heavily irrigated area. No other pesticide was found in any other ground water of the study area. DDT, DDE, diazinon, and 2,4,5-T residues were detected in the water of one stream draining the same heavily irrigated area. No pesticide residues were detected in any of the remaining streams sampled in the study area. DDT, DDD, and dieldrin were found in the bed material of all the sand-plain streams sampled, while in one stream, aldrin and chlordane also were found.

The measured mean concentration of iron in ground water ranged from 0.07 milligram per liter in an irrigated area to 12 milligrams per liter in a

nonirrigated area, with a mean of 0.78 milligram per liter for all ground water in the study area. This is about 0.5 milligram per liter more than the 0.3 milligram per liter standard set by the U.S. Public Health Service.

Chemical quality of surface water in the study area is essentially the same as that of the ground water. Areas with high concentrations of certain constituents in ground water show the same high concentrations in the surface water.

There is a distinct change in ground-water quality in the study area with depth. In irrigated areas the highest measured concentration of dissolved constituents occurs at about 30 to 35 feet below the land surface. In nonirrigated areas the highest observed concentrations were at the maximum sampling depth of about 70 feet below land surface.

In general, no distinct seasonal or general trends in ground-water quality were evident during the two-year study. However, nitrogen concentrations in one heavily irrigated area did show a 2 milligram per liter increase from 1974 to 1975, and alkalinity showed a similar overall slight increase in another irrigated area. A minor decrease in total mineralization of surface water in the study area each spring was evident due to dilution by spring melt-water runoff. Besides this small seasonal variation, no general trend in surface-water quality was evident in the study area.

Ground and surface water of the study area is generally of very good chemical quality and the effects of farming practices have not caused significant deterioration that would make the water unfit for most uses. However, high concentrations of nitrogen and the occurrence of pesticide residues in some water of the study area indicate that farming practices in the area do, in fact, affect the water quality of the study area. Data collected and compiled for this report indicate that the water quality in the study area may have stabilized by 1973. Present agricultural practices do not appear to be causing any further changes in water quality.

INTRODUCTION

The sand plain of central Wisconsin has water of generally good quality that is available in quantities adequate for large-scale irrigation. The water has an areal variation in quantity and quality that can be traced to geologic differences and farming practices.

Irrigation, fertilization, and pest control have fostered expansion of farming from a total of 4,960 acres in 1954 to 71,900 acres in 1974 in Adams, Portage, Waushara, and Wood Counties of central Wisconsin. This increase in acreage has been accompanied by changes in irrigation and farming practices along with changes in the quality of the water in the sand plain of central Wisconsin. These changes in water quality are most evident near the irrigated areas and became noticeable in the 1950's after farmers began large-scale irrigation and chemical-application programs to increase crop yields.

PURPOSE AND SCOPE

Knowledge of the relation between farming practices and chemical quality of both ground and surface water is essential to management of crop production and maintenance of the quality of the water resources.

The purpose of this report is to discuss the seasonal and long-term changes in ground- and surface-water quality resulting from applications of fertilizers and pesticides on the land surface. Changes in the hydrologic system, especially in chemical quality of the ground and surface water, resulting from past and present heavy pumpage for irrigation and fertilization were studied in detail.

Chemical-quality, streamflow, and ground-water-level data for the project were collected over a 26-month period from November 1973 through December 1975. Major emphasis of the study was placed on crop-farming practices as they affect water quality.

A 650-mi^2 area (fig. 1) in the eastern part of the sand plain of central Wisconsin was studied as part of this project. The study area includes all or parts of Tps. 19-23 N., Rs. 4-9 E., in Portage, Waushara, Wood, and Adams Counties. The study area extends from approximately Stevens Point in the north to Hancock-Big Flats-Monroe Center in the south, and from the Wisconsin River on the west to approximately the second moraine in the east.

Three small subareas within the general study area were chosen for more intensive study. Two of the subareas are intensely farmed and irrigated but the third has very little farming and no irrigation. The two irrigated subareas were studied to determine the effects of irrigation on chemical quality of ground and surface water. The third subarea, the nonirrigated area, was used as a control area to determine natural fluctuations in chemical quality of the ground and surface water. The three subareas were chosen to have hydrogeologic systems and agricultural practices representative of conditions throughout the study area. Additional factors such as depth to ground water, distance to surface drainage system, availability of background and historical data, ease of data collection, and land-owner cooperation also were considered in the choice of subareas.

Figure 1. Location of the study area in Wisconsin.

The Meehan and Bancroft subareas are heavily farmed and irrigated but the Kellner subarea has very little farming and no irrigation. Potatoes, corn, and cucumbers are the major crops of the irrigated subareas. The nonirrigated area has about equal parts of forest and pastures with a much smaller cultivated area usually in corn. All of the Bancroft subarea has been used for crop production for several years but only about 80 percent of the Meehan subarea was in crop production until the 1974 growing season. During the fall and winter of 1973-74, the remaining 95 acres were cleared, leveled, and drained for crop production.

The Kellner subarea is a small nonirrigated, lightly farmed 2.2-mi^2 drainage basin about 2 mi south and southeast of Kellner in Portage County. It includes all of the Fivemile Creek drainage basin within secs. 3, 4, 5, and 6, T. 21 N., R. 7 E. All three subareas are shown on the index map (fig. 1).

The Meehan subarea is a 1-mi^2 area and is southwest of Meehan in Portage County. It consists of all of sec. 3, T. 22 N., R. 7 E. Two drainage ditches emptying into Twomile Creek form part of the south and west boundaries of the subarea.

The Bancroft subarea is also a 1-mi^2 area just southwest of Bancroft in Portage County. It consists of the south half of section 15 and the north half of section 22 in T. 21 N., R. 8 E. Tenmile Creek Ditch No. 5 runs close to the northern edge of the subarea.

BACKGROUND AND PREVIOUS STUDIES

The highly agricultural land use results from the geologic and hydrologic character of the area. The sandy soils and high ground-water levels once supported thick, dense forest. Loggers cleared the forest and led the way for the early farmers. The crops soon depleted the nutrients in the shallow, sandy soil and, because of the lack of moisture-holding capacity of the soil, farms were abandoned. With the coming of effective fertilizers, large-capacity pumps, and efficient distribution systems, water and nutrients could be applied to crops whenever they were needed. This brought a resurgence of farming to the area. The present-day, high-intensity farming can be traced directly to the development of irrigation that was made possible by the availability of ground and surface water and the suitability of the soil for irrigation.

The study area is one of the most intensively studied areas in the State with respect to water resources. Detailed studies of the ground water and geology of Portage and Waushara Counties were made by Holt (1965) and Summers (1965), respectively. Other recent studies on the hydrology of the area were conducted by Weeks (1964a, 1964b, and 1969), Weeks and others (1965), Devaul and Green (1971), Weeks and Stangland (1971), and Novitzki (1976).

ACKNOWLEDGMENTS

This study was planned and conducted by the U.S. Geological Survey in cooperation with the University of Wisconsin-Extension, Geological and Natural History Survey. Acknowledgment is made to the irrigators and other residents in the area who provided information on their wells and gave access to their land and equipment for measurements and water-sample collection. Special acknowledgment is made to Paramont Farms Inc. and the Okray Produce Co. for permission

to install wellpoints on their land for collection of water samples. Dr. David Curwen and the personnel at the University of Wisconsin, Hancock Experiment Station, assisted in the selection of subareas for intensive study and in collecting precipitation samples for analysis.

DESCRIPTION OF THE AREA

PHYSICAL SETTING

Several factors influence the effects of irrigation development on the chemical quality of ground and surface waters. Climate, geology, topography, and soil affect the suitability of land and the availability of water for irrigation. They also influence the changes in water quality resulting from irrigation and application of chemicals in cropping practices.

Mean annual precipitation for the period 1931-60 ranged from 31.4 in at Stevens Point to 29.6 in at Hancock, with about 60 percent of it occurring during the growing season. Annual snowfall averages about 45 in.

Mean monthly temperatures in the study area range from about $-8^{\circ}C$ in January to about $22^{\circ}C$ in July.

Surface and subsurface geology of the study area are shown in figure 2. Consolidated rocks underlying the area include crystalline rocks of Precambrian age and sandstone of Cambrian age. The Precambrian rocks are relatively impermeable and form the floor of the ground-water reservoir. The sandstone overlies the Precambrian rocks in much of the southern part of the area.

Unconsolidated sediments overlie the consolidated rocks and include pitted and unpitted outwash, till, and lake deposits (all of glacial origin), and peat, alluvium, and dune sand (of postglacial origin). Glacial deposits generally are thick, as much as 300 ft, highly permeable, and form the main aquifer in the area. The more recent deposits generally are thin and limited in areal extent.

Topography in the area is closely related to glacial history and is an important control on land use. Well-drained moraines, generally too steep and rough to irrigate, occur in the eastern part of the area. Pitted outwash deposits between the end moraines also are well drained, except for kettle lakes, but generally are flat enough to irrigate. Along the western edge of the project area are large flat marshes that had to be drained to be useable by farmers. Between the end moraine and marshes there is a large, flat, well-drained area that is suited for irrigation. West of the marshes, a 6- to 7-mi wide strip of the plain is well drained by streams tributary to the Wisconsin River. Except for sand dunes in the southwest, much of this area is flat and might be suitable for irrigation if cleared of trees.

Sandy soils dominate throughout most of the study area. Deposits of sandy peat, less than 18 in thick, overlie sandy subsoils in much of the marsh area. Relatively thick deposits of peat occur in some of the marshes. All the soils allow rapid infiltration and, except for those saturated by a high water table, are low to moderately low in water-holding capacity (Beatty, 1964).

Amounts of cultivation throughout the study area differ according to the type of surficial features. Hardwood forests over most of the moraine area limit cultivation to small plots. The pitted outwash and the sand plain west of the moraine and east of the marshlands are extensively cultivated and irrigated. The marsh areas where frost hazard is relatively high have been drained only locally for cultivation. West of the marsh areas, forests containing jack pine, oak, hickory, and white pine are dominant. Numerous clearings in the forest are mainly in grass although a few are planted with hay or grain.

GROUND-WATER MOVEMENT

Paths of ground-water movement from recharge to discharge can be determined from the gradients shown on a water-table map. The general configuration of the water table in October 1965 is shown in figure 3. In 1975 the water table was very nearly the same as in 1965 and the areas of recharge, directions of movement, and places of discharge had remained essentially unchanged. Ground water flowed westward from the major ground-water divide to the Wisconsin River and eastward from the divide to the Little Wolf and Waupaca Rivers. The ground-water divide generally followed the crest of the outer moraine (figs. 2 and 3).

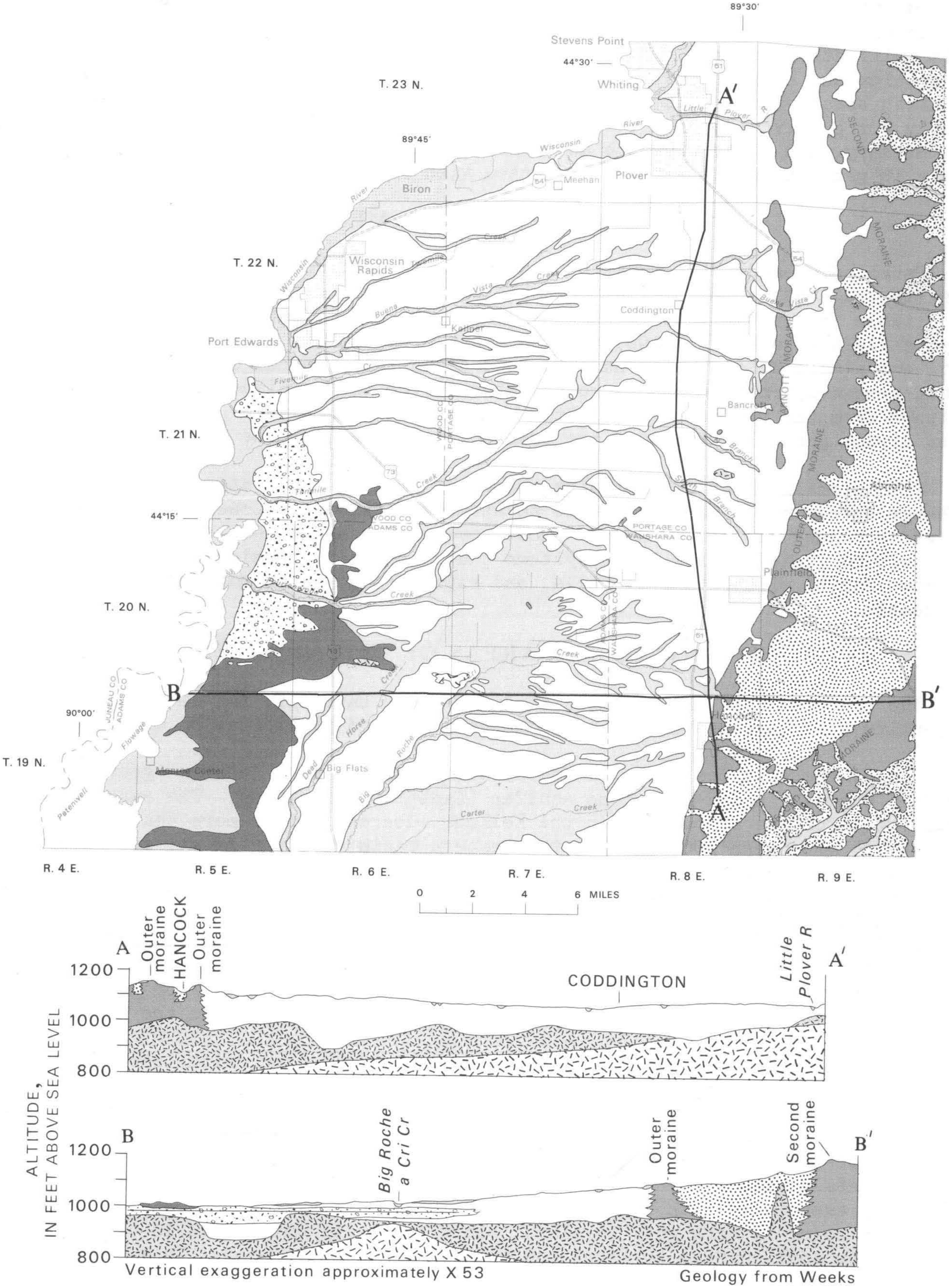
Within small areas or subbasins there are local ground-water systems where recharge moves only a short distance to streams, drainage ditches, lakes, pits, and wells, where it is discharged. Most movement is along shallow flow paths. It is within these shallow local systems that changes in chemical quality, rapid drawdown due to withdrawals by wells, and rapid ground-water movement are most noticeable.

HYDROGEOLOGY OF THE AREAS OF INTENSIVE STUDY

The hydrogeologic and climatic conditions are basically the same throughout the entire study area. Variations in temperature and precipitation are slight.

All of the subareas (figs. 1 and 2) are underlain by a sand-and-gravel aquifer (outwash) and a sandstone aquifer (Cambrian sandstone). The range of saturated thickness of outwash in the Kellner subarea is from more than 70 ft in the west to more than 100 ft along the eastern basin divide. In all subareas the outwash is a uniform, clean, medium-to-coarse sand. No marshy, organic, or clayey material was found during the test drilling in the Bancroft or Meehan subareas, but a thin layer of highly organic soils was found in the Kellner subarea. The Meehan subarea has a saturated thickness of outwash ranging from about 50 ft in the center of the area to more than 70 ft in the northwest. The saturated thickness of outwash in the Bancroft subarea increases from near zero in the southeast corner near Mosquito Bluff to more than 100 ft in the northwest.

The major soil in all three subareas is Plainfield sand, with lesser amounts of Dunning sand, Dunning sandy loam, and peat. Plainfield sand is a uniform soil about 10 in thick consisting of a brown or grayish-brown sand. This soil surface is level to very slightly undulating and, because of the loose character of the soil, drainage is excessive. The only other soil in significant amounts is the Dunning sand, found only in the Kellner subarea. This soil is closely associated with Plainfield soils and has an average depth of 6 to 12 in; its color is dark gray to almost black and it is quite high in organic matter. The soil surface is level and natural drainage is poor. In a few



Geology from Weeks and Stangland, 1971

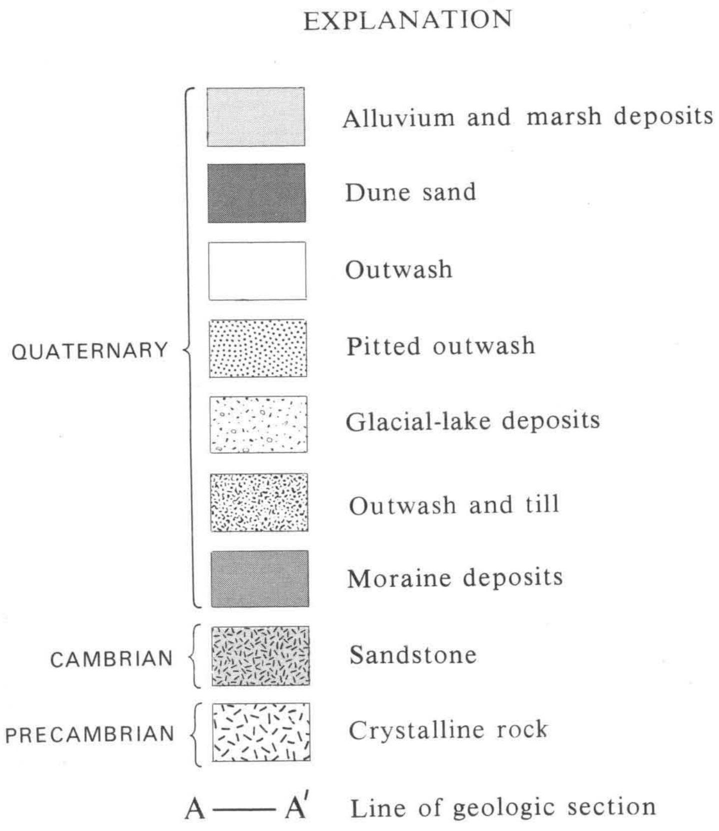
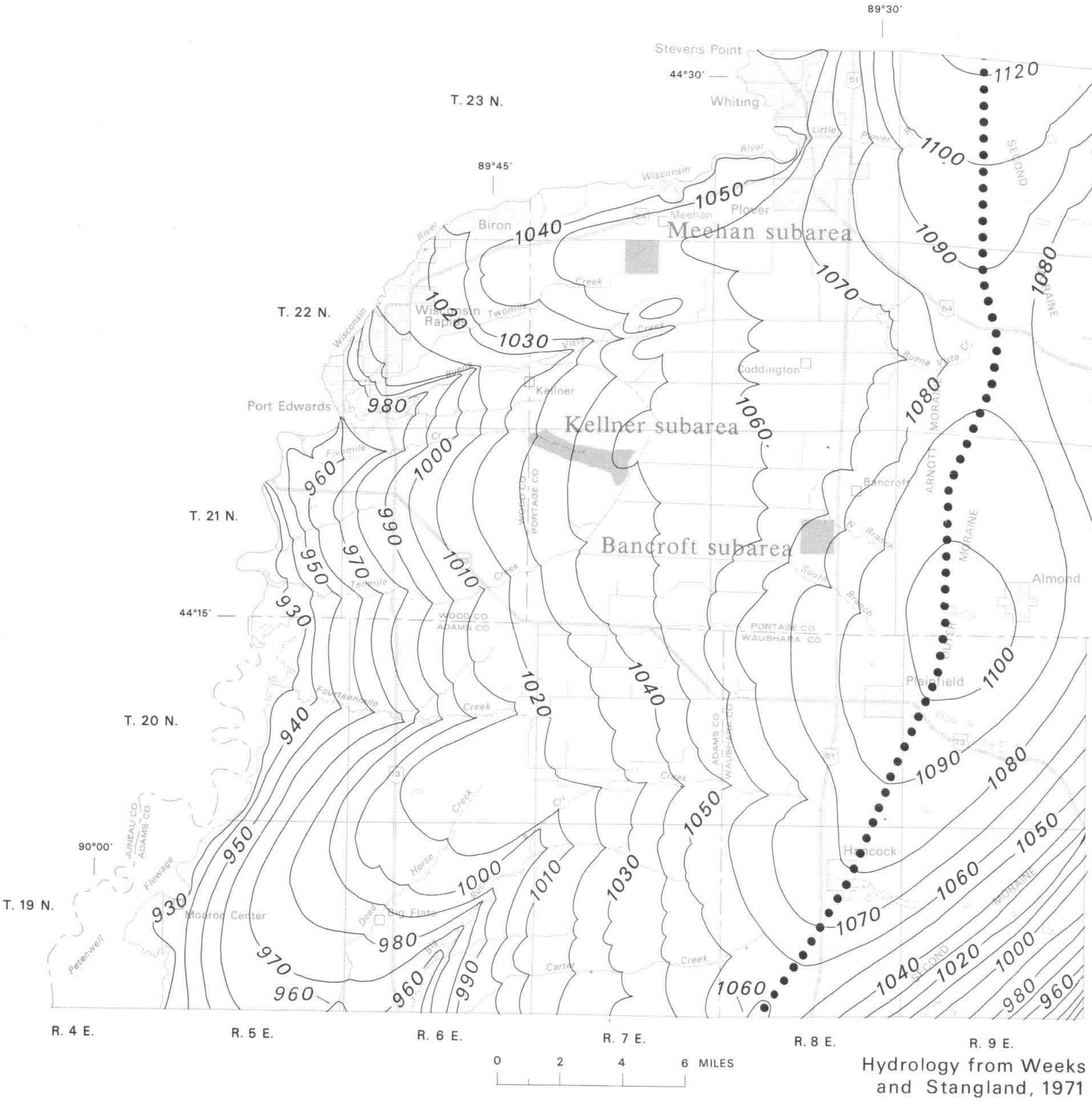


Figure 2. Surface and subsurface geology.

places the soil is loamy. Dunning sandy loam and peat, the remaining two soils, are very high in organic content. These soils are found in level, low-lying, poorly drained areas.

The topography of all three subareas is similar. All would be classified as flat with very little relief. Maximum relief is about 25 ft in the Bancroft subarea, 15 ft in the Meehan subarea, and 20 ft in the Kellner subarea. The low relief and highly permeable, sandy soil lead to a situation where overland flow is nearly nonexistent.

The amount of ground water available for use is essentially constant. Minor seasonal and year-to-year changes in storage are caused mainly by variations in precipitation and the amount of ground water pumped for irrigation. Fluctuations in ground-water elevations are a measure of the changes in amount of ground-water storage. Maximum measured fluctuation in the ground-water elevation in a single well in the sand plain of central Wisconsin was 10.4 ft. The low occurred in November 1959 and the high occurred in September 1973. Maximum fluctuation in the Kellner subarea during the 2-year data collection was about 4.2 ft or about 5 percent of the saturated thickness (fig. 4). In this subarea there was a net increase in water level of about 1.4 ft over the period



Hydrology from Weeks and Stangland, 1971

EXPLANATION

—1040— Approximate water-table contour
Contour interval 10 feet Datum is mean sea level

●●●●●●●● Ground-water divide between Wisconsin River and Wolf River basins

Figure 3. General configuration of the water table, October 1965.

of the study. In the Meehan subarea the maximum fluctuation during the 2-year data collection was about 3.7 ft or about 6 percent of the saturated thickness (fig. 4). In this subarea there was a net decline of about 1 ft over the period of study. The maximum fluctuation in the Bancroft subarea during the 2-year data collection was about 4.2 ft or about 5 percent of the saturated thickness (fig. 4). In this subarea there was a net increase in water level of about 0.2 ft over the period of study. Based on a storage coefficient of 0.2, this 0.2 ft of water-level change resulted in a 26-acre-ft increase in the amount of ground water stored in the 1-mi^2 Bancroft subarea.

Ground-water flow paths often change in response to water-level changes. Plate 1 shows the cyclic changes in direction of ground-water movement in the Kellner, Meehan, and Bancroft subareas. Water tables are shown for the spring high-water levels, the summer period of ground-water withdrawal for irrigation, and fall low-water levels for each subarea. Arrows have been superimposed over the water-table contours to show the approximate directions of local ground-water movement.

In the Kellner subarea (pl. 1), there is a general eastward migration of water-table contours up the basin as the depth to water increases from the spring high-water levels to the fall low-water levels. These three water-table maps for the Kellner subarea show the general westward movement of ground water toward the Wisconsin River. Wells in the Kellner subarea are low-capacity domestic and stock wells, none of which pump enough water to change the configuration of the water-table contours.

The general migration of water-table contours also is evident in the Meehan subarea (pl. 1). In the spring the water moves westward through the subarea toward both Twomile Creek at the south edge of the subarea and the Wisconsin River north of the subarea. Here, however, the water table is modified during the summer months by heavy ground-water pumpage from as many as seven irrigation wells. During the summer irrigation period, local cones of depression form around each pumping well. Ground water then moves toward the wells interrupting the general movement pattern described above. Because of the high hydraulic conductivity and storage coefficient of the outwash, the cones of depression around each well are areally limited and have very little effect on regional ground-water movement. In the fall the cones of depression disappear, Twomile Creek dries up in its upper reaches, and the ground water discharges to the Wisconsin River and the lower reaches of Twomile Creek.

Ground water moves generally northwestward through the Bancroft subarea (pl. 1). It is recharged throughout the subarea and discharged into North Branch Tenmile Creek and Tenmile Creek Ditch No. 5. The migration of water-table contours across the area to the southeast or up the basin toward the divide reflects water-level declines during the dry periods. The water table is altered in summer by cones of depression caused by pumpage from as many as eight irrigation wells. These cones are small and produce only local changes in the general northwestward movement of ground water.

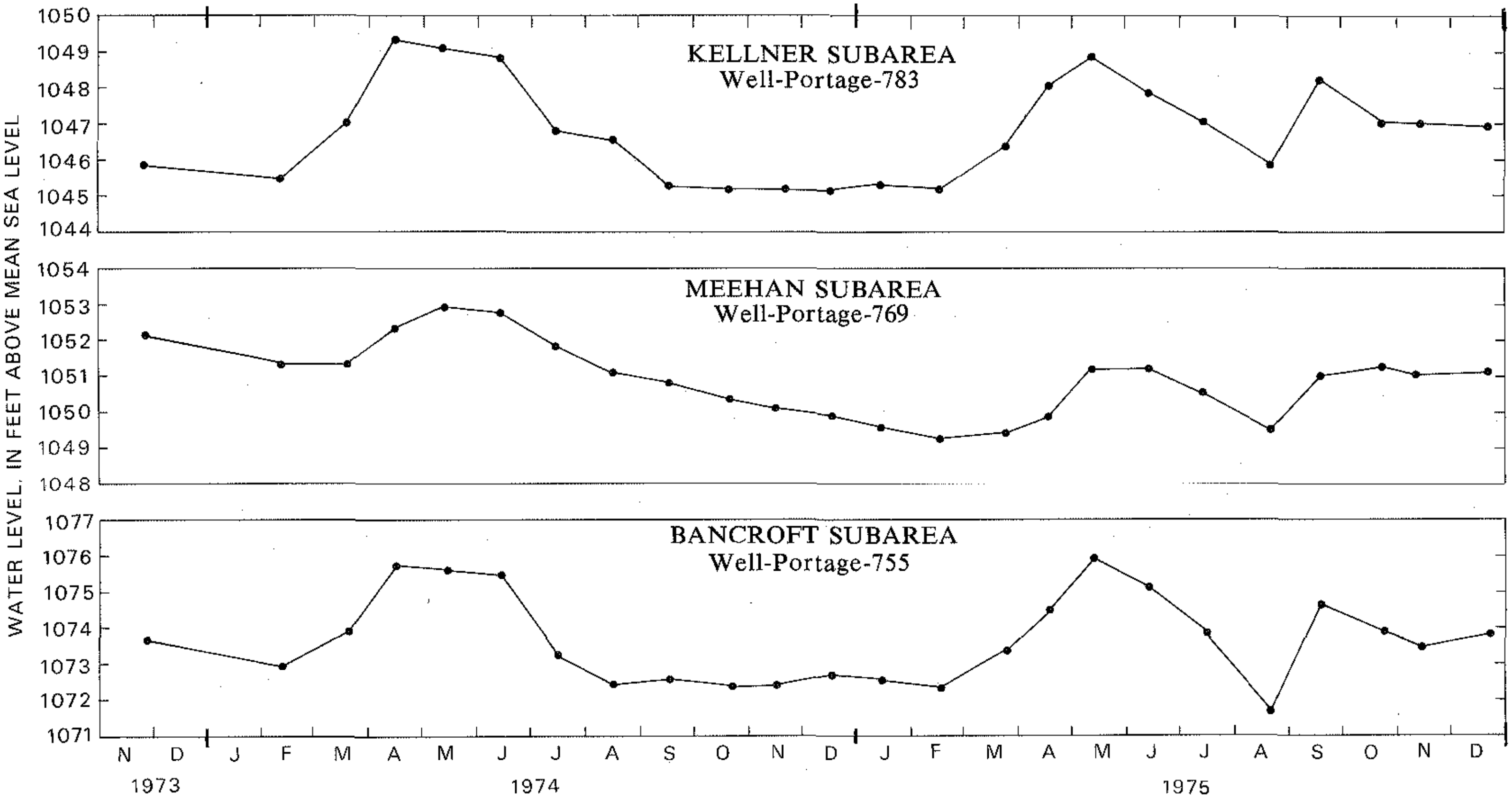


Figure 4. Representative water-level hydrographs for the Kellner, Meehan, and Bancroft subareas.

IRRIGATION PRACTICES

The resurgence of crop farming in the sand plain closely followed the development of economical irrigation procedures and equipment. Ground-water pumpage for large-scale irrigation by handset sprinkler system in the sand plain began in the late 1940's. Development, mainly from large pits excavated a few feet below the water table, was gradual until 1958. In 1958, the reverse-rotary method was first used to drill irrigation wells in the area. From then until 1966 irrigation development was rapid and most of the pits were replaced by wells. The development rate declined from 1967 to 1973, partly due to a shortage of parcels of land large enough to be irrigated economically. The price of potatoes, shortage of cannery capacity, increased costs of equipment, and restrictions on capital and loans also affected the decline. During the mid-1970's more land went into crop production and since that time the rate of ground-water pumpage for irrigation has increased more rapidly than the number of wells in use. Wells installed in the late 1960's and early 1970's have larger yields and the motor-driven and self-propelled sprinkler systems allow larger fields to be irrigated from a single well than from pre-1960 irrigation systems. By 1967 most fields in the area used for cash crops were irrigated every year.

Irrigation acreages and pumpages for Adams, Portage, Waushara, and Wood Counties for selected years in the 1949-74 period are shown in table 1. The amount of irrigation water needed depends upon the amount of precipitation during the growing season. For a year in which precipitation during the growing season approaches record lows, applications of irrigation water might reach 16 in for potatoes, 8 in for beans, and about 12 in for corn and other crops. For years in which precipitation during the growing season is above normal, applications might be only about 6 in for potatoes, about 3 in for beans, and about 5 in for corn and other crops. In a summer as wet as the wettest on record, irrigation would be almost zero (Weeks and Stangland, 1971).

In the eastern part of the area present irrigation development is concentrated between the moraines, in the central part of the area between the moraines and the marshes, and in the west and north between the marshes and the Wisconsin River. Some of the marsh areas are irrigated but are subject to frost during the growing season. The extent and rate of irrigation development in the marshes probably will depend upon the frequency and severity of future frost damage and whether or not new ditches will be dug or old ones deepened.

WATER-QUALITY-SAMPLING PROGRAM

Water quality was studied over the entire study area, but the most intensive monitoring was in the three subareas. A regional network of wells and streams was sampled to get a general areal understanding of the water quality. In addition, a network was established in each of the subareas and sampled intensely to determine the effects of farming and to monitor natural variations in water quality.

Table 1.--Irrigation acreage and pumpage for Adams, Portage, Waushara, and Wood Counties

Year[1]	Adams County		Portage County		Waushara County		Wood County	
	Irrigated area (acres)	Water pumped (acre-ft)	Irrigated area (acres)	Water pumped (acre-ft)	Irrigated area (acres)	Water pumped (acre-ft)	Irrigated area (acres)	Water pumped (acre-ft)
1949	(2)	(2)	870	900	530	(2)	470	(2)
1954	290	(2)	2,800	1,800	270	(2)	1,600	(2)
1959	940	(2)	6,900	2,800	5,200	(2)	1,700	(2)
1964	3,200	(2)	17,300	(2)	13,200	(2)	1,500	(2)
1969	10,200	5,500	25,100	16,060	22,100	10,300	2,300	4,300
1974	11,000	6,800	29,200	22,400	28,300	12,000	3,400	2,600

[1] Data from Holt, 1965, and U.S. Department of Commerce, 1952, 1956, 1961, 1967, 1972, and 1977.

[2] No data available.

REGIONAL NETWORK

Data from 108 wells and 5 streams were used in the determination of the chemical quality of regional ground and surface water. Figure 5 shows the regional data network in the study area. Twenty of these wells and all of the streams were sampled once by project personnel during the project; the remaining wells were sampled by other investigators for various projects from as early as 1915. Analyses from the 108 wells showed little uniformity of measured properties, but there was a sufficient number of the same properties determined for the historical well as for project wells so that results of the historical analyses were very useful in determining areal chemical quality.

Although all substances found in water may present problems in high concentrations, the constituents that were considered potentially detrimental to human and animal consumption and crop production in this study include: nitrogen, phosphorus, potassium, iron, boron, selenium, molybdenum, lithium, insecticides, and herbicides. Major emphasis was placed on sampling for nitrogen, phosphorous, and potassium. Samples of stream-transported sediments also were collected at the surface-water-sampling sites and analyzed for nutrient, pesticide, and trace-element concentrations.

Composite samples of bulk atmospheric precipitation also were collected approximately monthly at the Hancock Experiment Station. The number of constituents analyzed depended on the volume of water collected during the month, but analyses for nitrogen and phosphorus compounds were given first priority.

Table 3 shows the constituents and characteristics analyzed in the various types of samples. The measured data and results of the analyses are published in "Water Resources Data for Wisconsin" 1975 and 1976 water year.

SUBAREA NETWORKS

More intensive sampling was done in the subareas. The completeness of analyses differed depending on the frequency of collection and whether the sample was water or stream sediments (table 3).

Ground water in the Kellner subarea was sampled at five locations (fig. 6) chosen to show quality changes in the water as it moved through the basin. At each location there was one shallow well about 14 ft deep, but at two sites there was an additional deep well, 70 ft deep, and a middepth well, about 33 ft deep.

Fivemile Creek was sampled at the western (downstream) boundary of the subarea.

In and around the Meehan subarea observation wells were installed at seven sites to get a representative sample of the ground water (fig. 7). Three of these sites had multiple wells whereas the remaining sites had only a single shallow well, about 14 ft deep. The multiple-well sites contained a shallow, middepth, and deep well. The deep wells were from 50 ft deep at one site where bedrock was found to 70 ft where bedrock was not found. The middepth wells ranged 29 ft to 35 ft deep.

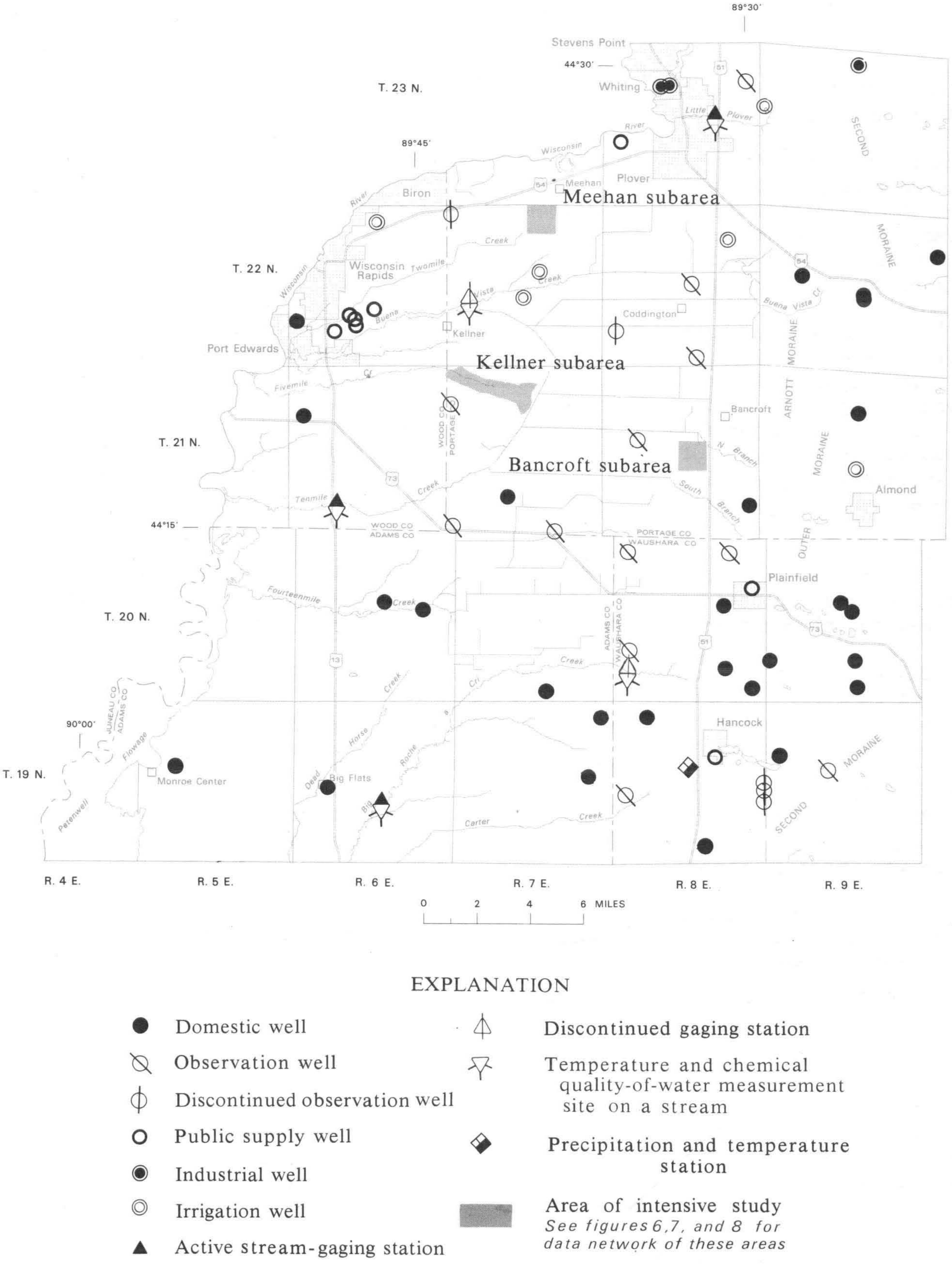
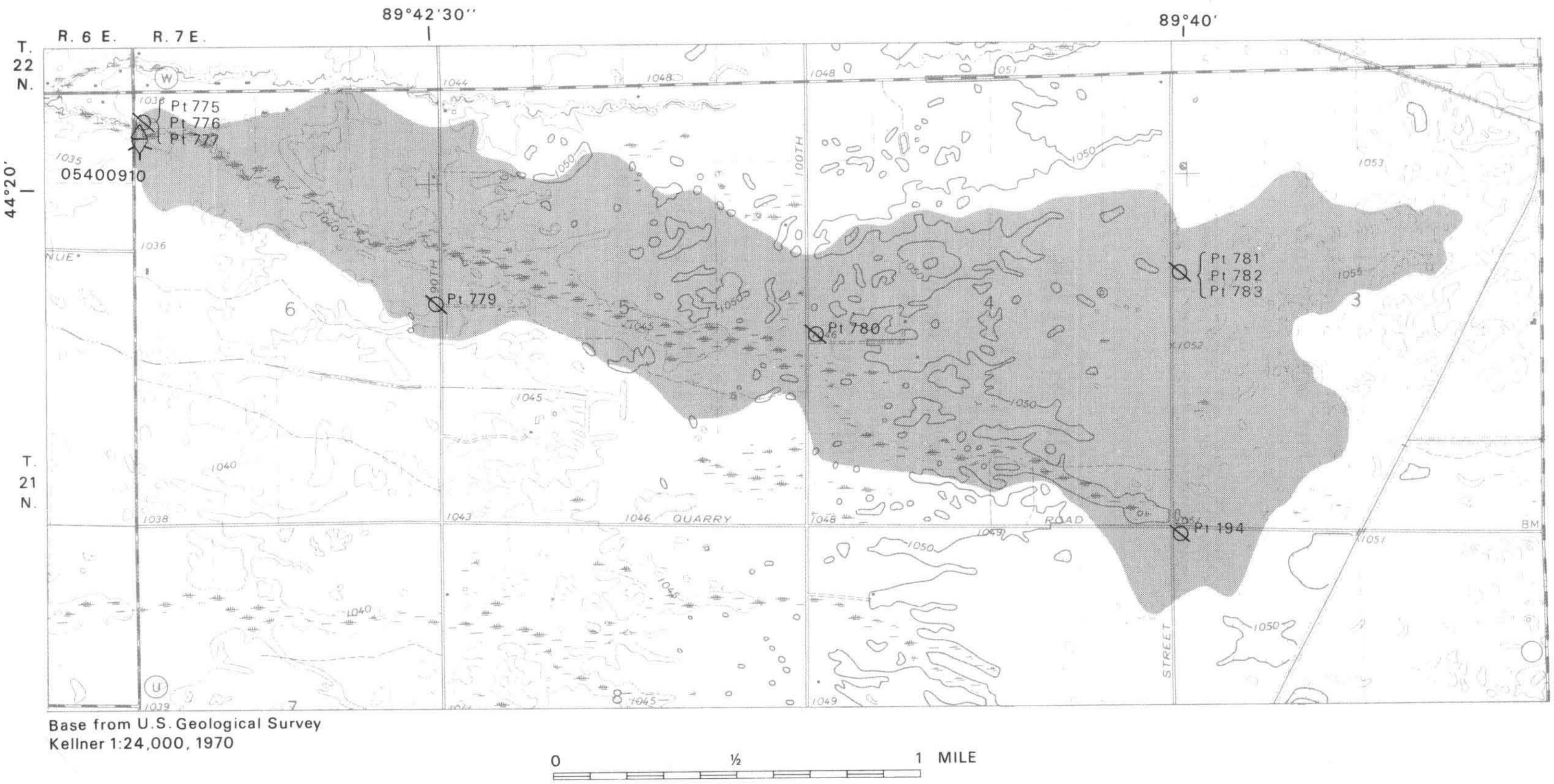


Figure 5. Study area and data network.



Base from U.S. Geological Survey
Kellner 1:24,000, 1970

CONTOUR INTERVAL 5 FEET
DATUM IS MEAN SEA LEVEL

EXPLANATION

Ø	Observation well	05400910	Gaging station, temperature and chemical quality-of-water measurement site
Pt 779	Well number	▨	Area of intensive study

Figure 6. Kellner subarea and data network.

The single surface-water site was located on a recently dug drainage ditch called Twomile Creek.

Observation wells were installed at eight locations in and around the Bancroft subarea (fig. 8) to get representative samples of the ground water. Multiple wells were installed at three locations and a single shallow well, about 14 ft deep, at each of the other five sites. The multiple-well sites had one shallow well bottoming just below the water table; one deep well, about 70 ft; and one at a depth about halfway between the shallow and deep wells, 31 ft deep.

North Branch Tenmile Creek was sampled at two sites, one upstream from the subarea and the other downstream. The downstream site was at a discontinued U.S. Geological Survey gaging station.

REGIONAL QUALITY OF WATER

Differences between chemical quality of precipitation, ground water, and surface water were found in the study area. Precipitation is the least mineralized of all water analyzed whereas ground and surface water are more highly mineralized and very similar in chemical quality.

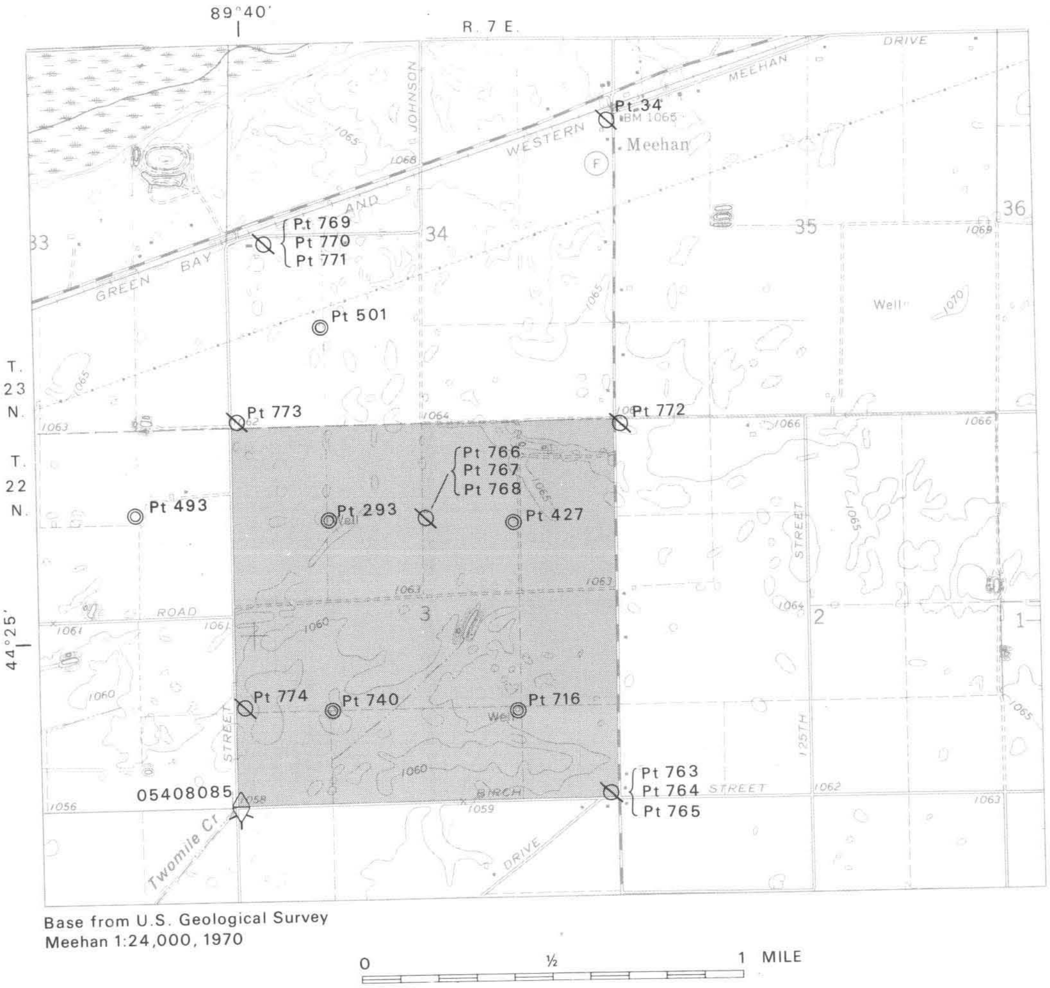
ATMOSPHERIC PRECIPITATION

Atmospheric precipitation contributes significant amounts of chemicals to the hydrologic system of the area. Two major sources of the solutes in precipitation are atmospheric gases and dust. Monthly composite samples of precipitation were collected at the Hancock Experimental Farm for chemical analysis. The number of constituents analyzed each month depended on the amount of precipitation, but the concentrations of nutrients and a few major ions were determined routinely throughout the 2-year period of data collection.

Precipitation is an important source of nutrients in ground and surface water. The average annual amount of nitrogen delivered to the land surface in solution in precipitation during 1974 and 1975 was about 14 lb/acre, and is made up about equally of nitrate nitrogen (5 lb/acre), ammonia nitrogen (5 lb/acre), and organic nitrogen (4 lb/acre). The amount of nitrite nitrogen was very small, only about 0.1 lb/acre. The average annual amounts of phosphorus and potassium contributed to the land surface was much less than that of nitrogen, being only 0.8 lb/acre and 0.5 lb/acre, respectively. About 6,000,000 lb/yr of nitrogen was received by the 650-mi^2 study area from precipitation, whereas about 1,000,000 lb/yr was received by the 72,000 irrigated acres within the study area. About 30,000,000 lb/yr (420 (lb/acre)/yr) of nitrogen is added in fertilizers to the same irrigated acres.

The amounts of nutrients in precipitation, as discussed above, are based on 1974 and 1975 precipitation records. Both years were below the 1931-60 average of 29.3 in; 1.9 in below in 1974 and 1.5 in below in 1975, therefore, average values of nutrients added to the land surface in the study area may be slightly higher than those reported here.

Concentrations of nitrogen in precipitation are relatively constant throughout the year but potassium and phosphorus have markedly higher concentrations in



Base from U.S. Geological Survey
Meehan 1:24,000, 1970

CONTOUR INTERVAL 5 FEET
DATUM IS MEAN SEA LEVEL

EXPLANATION

⊘ Observation well

◎ Irrigation well

Pt 769 Well number

05408085 Gaging station, temperature and chemical quality-of-water measurment site

▨ Area of intensive study

Figure 7. Meehan subarea and data network.

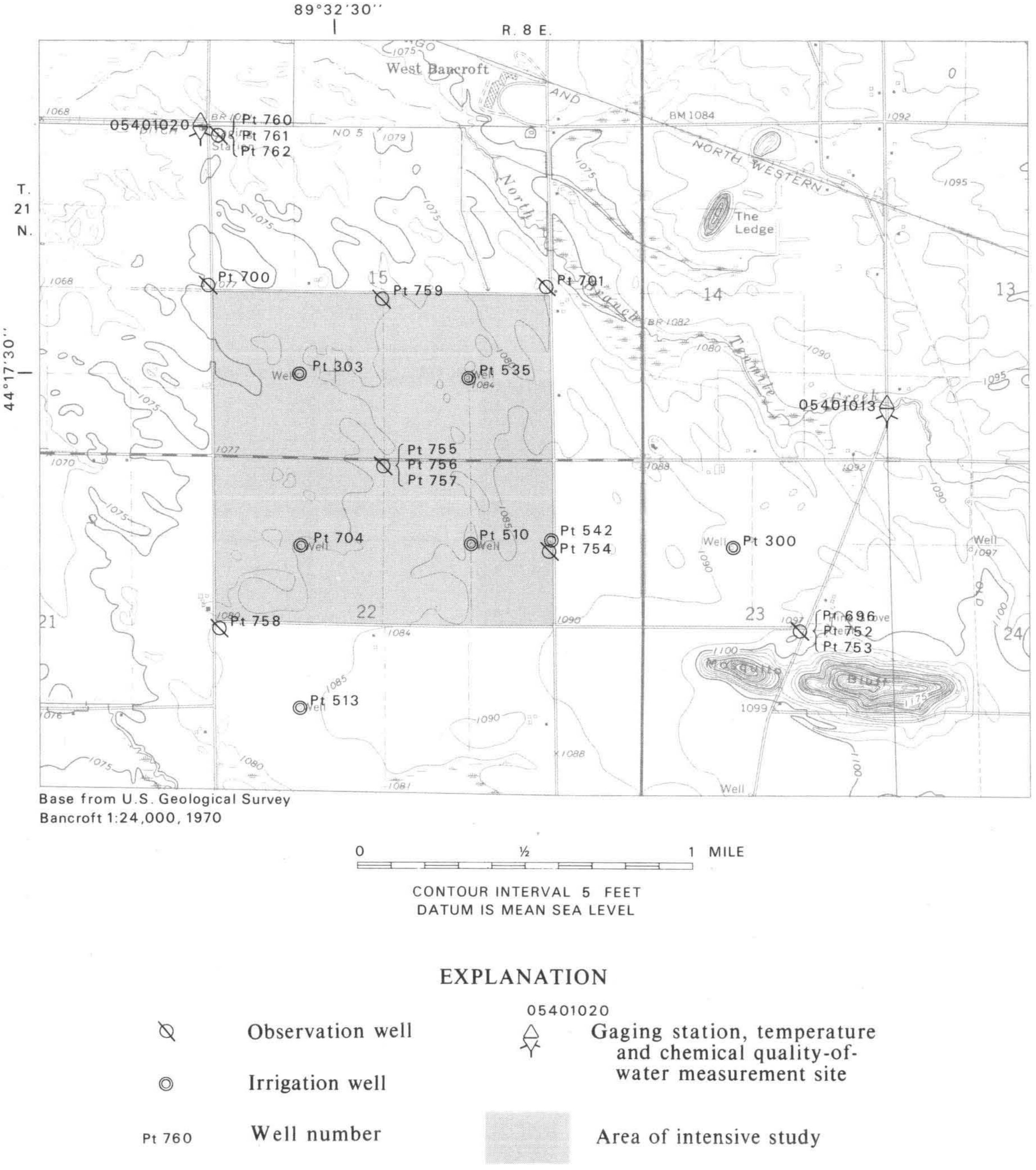


Figure 8. Bancroft subarea and data network.

the spring and early summer. The principal source of nitrogen in precipitation is gaseous nitrogen, which makes up 78 percent of the atmosphere. On the other hand, the source of phosphorus and potassium are the particulate matter carried aloft by winds. In the spring and early summer large areas of land are barren, allowing the wind to erode the soil. Some of the eroded soil is apparently carried into the atmosphere where it condenses moisture and falls with precipitation.

Concentrations of all constituents in precipitation were very low. Dissolved solids ranged from 8 to 21 mg/L, which compares to 21 to 632 mg/L for ground water. The major ions found in the precipitation were calcium, magnesium, bicarbonate, and sulfate. Their concentrations ranged from 0 to 2.9 mg/L, 0 to 2.5 mg/L, 0 to 17 mg/L, and 2.6 to 8.8 mg/L, respectively. The range in concentration of nutrients in the precipitation were 0.88 to 4.4 mg/L for total nitrogen, 0.38 to 1.4 mg/L for total nitrate nitrogen, 0.35 to 1.3 mg/L for total ammonia nitrogen, 0.12 to 1.8 mg/L for total organic nitrogen, 0.01 to 0.69 mg/L for total phosphorus, and 0.20 to 5.4 mg/L for dissolved potassium. The concentration of dissolved boron ranged from 0.0 to 0.04 mg/L.

In the one precipitation sample collected in late summer and analyzed for pesticides, small amounts of dieldrin, malathion, 2,4-D, and 2,4,5-T were detected. This one sample cannot be considered definitive evidence as to the amounts and types of pesticides in the atmosphere but it does indicate pesticides are carried into the atmosphere and come back to earth when it rains. Pesticides are applied in several ways, but two of the most widely used are aerial spraying by plane and, to a lesser extent, by irrigation sprinkler. Both methods make it easy for small amounts of pesticides to be carried into the atmosphere.

GROUND-WATER QUALITY

The regional ground-water quality of the study area is very good with no general trend toward deterioration. Some wells and areas have high iron and nitrate concentrations, but these are local problems caused by local conditions and do not adversely affect the regional quality. High concentrations of iron, as high as 23 mg/L, are natural whereas the high nitrate levels, as high as 180 mg/L, are probably man-induced.

Several generalizations can be made from the available ground-water chemical-quality data for the study area. The water is generally a calcium magnesium bicarbonate type water. Higher dissolved-solids concentrations and specific conductance are found in the eastern one-third of the area than in the western two-thirds. The eastern part of the area is covered by glacial moraines and outwash, whereas the remainder of the area is covered with either postglacial alluvium and marsh deposits or glacial outwash and lake deposits. The moraines have high dolomite or carbonate rock content and dolomite is a prime source of the calcium, magnesium, and bicarbonate ions in the ground water. Also, the water is in contact with these rocks for a relatively long period of time because ground-water-flow paths are longer in the moraines than the outwash, and the permeability of the moraines is less than that of the outwash, resulting in low ground-water-movement rates.

The western two-thirds of the area does not have either the high carbonate rock content or as long a time period from ground-water recharge to discharge.

Nitrogen concentrations range greatly throughout the study area. The highest nitrogen concentrations generally are in areas of intense agriculture and irrigation; concentrations are very low in areas with little or no farming. Areas that have soils with high organic content such as marshes and wetlands have generally low nitrate nitrogen concentrations. Denitrification is the main reason low concentrations of nitrate are found in areas with high organic content in soils. There are numerous natural sources of nitrogen in the area such as precipitation, soil material, and vegetative debris, but it is unlikely that any of these could be responsible for some of the high nitrogen concentrations measured in intensely farmed areas. They are probably due to improper septic-tank construction, large numbers of animals in feedlots, and overfertilization or improper farming practices.

Iron concentration, one of the most variable constituents in the ground water of the study area, appears to have its highest concentrations in areas associated with marshes and wetlands. The wetlands and marshes provide both a good source of iron, decaying vegetation, and an ideal environment for bacteria that reduce ferric iron to ferrous iron.

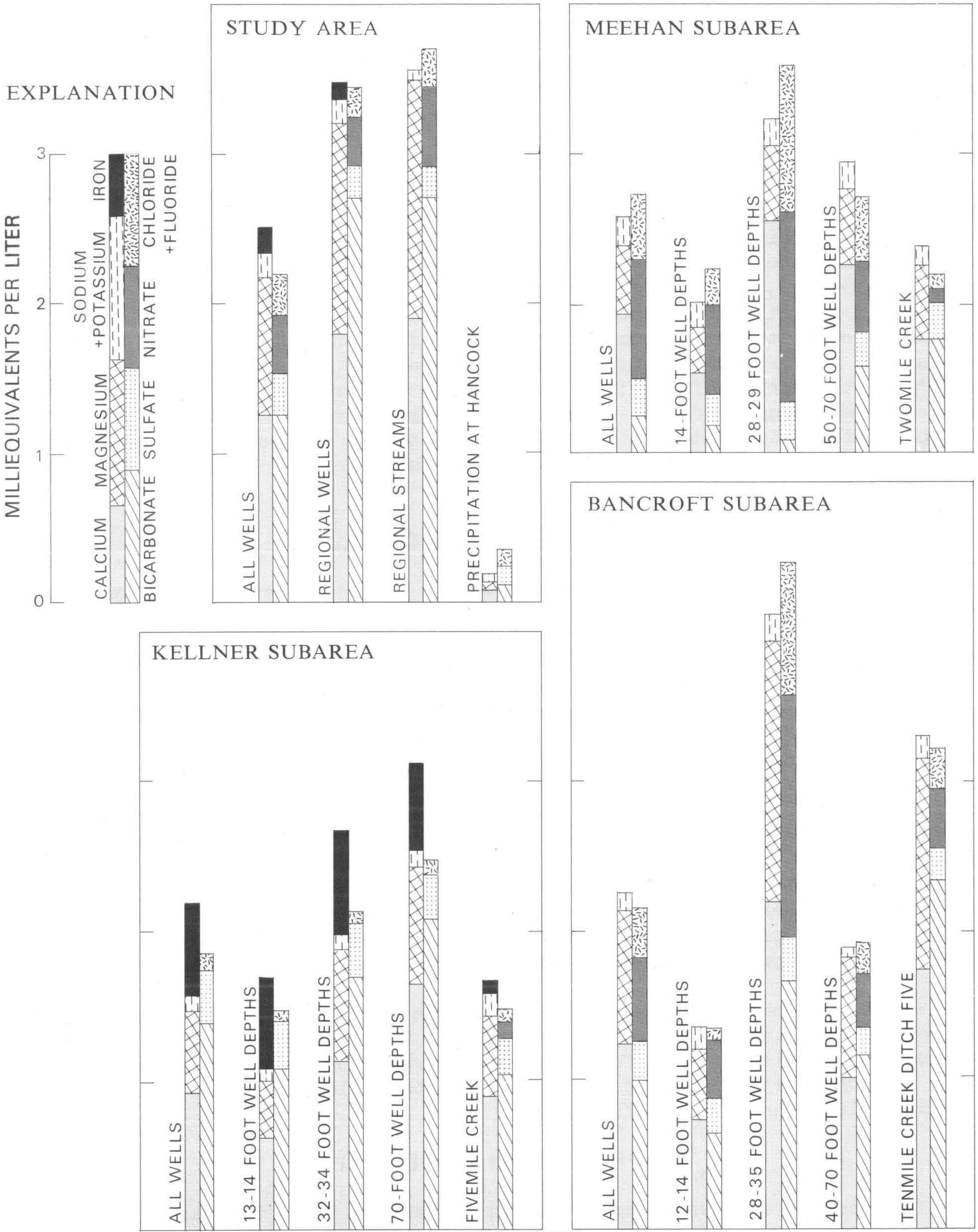
The three major ions in the ground water of the area are calcium, magnesium, and bicarbonate (fig. 9). The mean concentrations of these three constituents are 33 mg/L, 16 mg/L, and 149 mg/L, respectively or 1.65, 1.32, and 2.44 milliequivalents per liter, respectively.

Ground water in the study area is generally low in nutrients and presents no regional problem for water users. The mean concentration of measured nitrate nitrogen (total) was 4.6 mg/L, with a range of 0.02 to 32 mg/L. Mean nitrite nitrogen (total) (0.00 mg/L), ammonia nitrogen (total) (0.04 mg/L), and organic nitrogen (total) (0.17 mg/L) concentrations were very low. The two additional nutrients, phosphorus (total) and potassium (dissolved), had mean concentrations of 0.06 mg/L and 1.7 mg/L, respectively. The mean concentration of dissolved iron in the ground water of the study area was 0.78 mg/L, with a range of 0 to 23 mg/L.

Trace elements were generally found in low concentrations throughout the study area. Dissolved boron concentrations in ground water ranged from 0 to 0.19 mg/L, with a mean of 0.02 mg/L. Measurable but very small amounts, generally less than 0.003 mg/L, of arsenic, cadmium, chromium, cobalt, lead, molybdenum, selenium, and zinc were found in some ground water. In all cases, except for lead, the maximum measured concentrations were less than the Water Quality Criteria 1972 (National Academy of Sciences and National Academy of Engineering, 1974).

Although the use of pesticides is extensive throughout the sand-plain area, no pesticide residues were found in any of the regional ground-water samples. This does not mean that there are none in the ground water of the study area, but indicates that there is no areawide pesticide contamination at the present time. All the pesticides presently in use break down to harmless substances in a matter of a few days to months. Herbicides that are not very soluble in water attach themselves to the soil particles and remain there until they decompose.

Dissolved organic carbon (DOC) concentrations in ground water in the study area appear to be low, generally less than 6.5 mg/L, except in some of the marsh



Period of record November 1973 – December 1975.

Figure 9. Mean composition of ground water, surface water, and precipitation.

areas. Because there is no background DOC information in the State, there is no basis for comparison with other areas. The concentrations of DOC in the ground water of the study area range from 0.70 to 10 mg/L and the mean is 3.8 mg/L.

The chemical quality of ground water in the study area has changed only slightly in the past 60 years. To make definite statements on trends, analyses of repetitive samples from the same wells over a long period are needed. These types of data are not available for the study area, but sufficient data are available to indicate general trends in ground-water quality. Table 2 presents mean values of selected constituents and characteristics for four different periods, 1900-39, 1940-59, 1960-69, and 1970-75. The data shown in the table indicate a slight general decrease in the concentrations of major ions in the ground water of the area from the early 1900's to the 1960's. This trend appears to reverse itself with a slight increase in concentrations from the 1960's to the early 1970's. The decrease may be more artificial than real and caused by sampling different wells over different periods of time. The apparent slight increase in concentrations may be due to the increases in population, farming activity, and industrial production that the sand plain of central Wisconsin has experienced since the late 1950's and early 1960's.

SURFACE-WATER QUALITY

The chemical quality of surface water in the study area is nearly the same as the ground-water quality. Streamflow in the area is almost totally made up of ground water with very little overland flow reaching the streams. These hydrologic conditions are responsible, in a large part, for the homogeneous water-quality system found in the area (fig. 9). The surface water is basically a calcium magnesium bicarbonate type with the mean concentrations of these major ions 37 mg/L, 18 mg/L, and 161 mg/L, respectively. These values may be compared to 33 mg/L, 16 mg/L, and 149 mg/L for ground water in the same area. The mean concentration of iron was lower in surface water than ground water, 0.12 mg/L compared to 0.78 mg/L. The lower iron content is probably caused by precipitation of ferric iron as reduced (ferrous) iron in the ground water is exposed to air. Mean phosphorus concentrations were higher in surface water than in ground water, 0.09 mg/L compared to 0.04 mg/L. Total nitrogen was also higher in the surface water than ground water, 8.9 mg/L compared to 4.8 mg/L. Concentrations of nitrogen and phosphorus in the surface waters of the study area are sufficiently high to promote algae blooms (Uttormark and others, 1974).

Concentrations of other minor ions in the surface water are generally low and very nearly the same as in ground water. With the exception of the subarea streams, no pesticides were found in surface water of the study area and only very low concentrations of arsenic, boron, cobalt, lead, and zinc were detected, generally less than 0.001 mg/L.

BED-MATERIAL QUALITY

Sediment moves downstream either in suspension or as bed material. Suspended-sediment concentrations of streams in the study area are low, usually less than 10 mg/L. The majority of sediment moves as bed material through the migration of dunes downstream. The amount of bedload transport, however, was not determined as part of this project. Sediments may carry large amounts of sorbed material from areas of erosion to areas of deposition. The material that is sorbed on

Table 2.--Trends of selected ground-water-quality constituents and characteristics

{Concentrations of constituents in milligrams per liter; specific conductance in micromhos per centimeter at 25°C}

Property	Period			
	1900-39	1940-59	1960-69	1970-75
Bicarbonate	216	142	135	164
Calcium	38	34	26	36
Magnesium	22	16	13	17
Chloride	3.8	4.2	3.8	6.8
Dissolved solids	-----	185	134	186
Sodium	-----	3.3	2.4	3.3
Sulfate	-----	10	8.6	11
Iron	-----	.65	1.7	.86
Fluoride	-----	.14	.18	.15
pH, median	-----	7.4	7.4	7.5
Specific conductance	-----	349	252	323
Precipitation, in inches, at Hancock	28.8	29.5	29.8	30.2

the sediments may come from water entering the stream, overspray from fertilizer and pesticide applications, or atmospheric particulate matter.

Concentrations of sorbed materials differ from stream to stream in the study area. Total nitrogen in the bed material of the five sampled regional streams in the study area ranged from 612 to 1,170 mg/kg (milligrams per kilogram), whereas total phosphorus ranged from 16 to 36 mg/kg. Inorganic carbon concentrations in bed material ranged from 0.0 to 0.8 g/kg (grams per kilogram) and organic carbon ranged from 1.0 to 8.1 g/kg. Cadmium was found in the bed material of four streams at a concentration of 1.0 μg/g (microgram per gram) as was chromium, at concentrations of from 1 to 6 μg/g. Bed material from two streams contained arsenic concentrations of 1 and 3 μg/g. Cobalt, lead, and zinc were found in the bed material of all five streams at the following respective concentrations: 5 μg/g; 10 μg/g; and 3 to 11 μg/g. Pesticide residues were found in only the bed material of two of the five streams and limited to DDT, DDE, and DDD, and in one case, dieldrin. The levels were low, 8.1 and 1.5 μg/kg (micrograms per kilogram) for DDT, 5.3 and 1.3 μg/kg for DDE, 2.5 and 0.7 μg/kg for DDD, and 1.0 μg/kg for dieldrin. No PCB's were found in any bed material sampled. Standards have not been set concerning levels of metals and pesticides in bed material but because of the importance of the bed material to the food chain, information on concentrations is needed to identify problem areas. Levels of constituents in the bed material of study area streams are very comparable to the levels found in other streams of the State (U.S. Geological Survey, 1974, 1975, and 1976).

EFFECTS OF IRRIGATION ON WATER QUALITY

The quality of water in the subareas reflects their land use as well as their soil, sediment, rocks, and precipitation. Bancroft and Meehan subareas are heavily irrigated and water from these areas has higher concentrations of nitrate nitrogen and potassium from fertilizers than in the nonirrigated, little-farmed Kellner subarea.

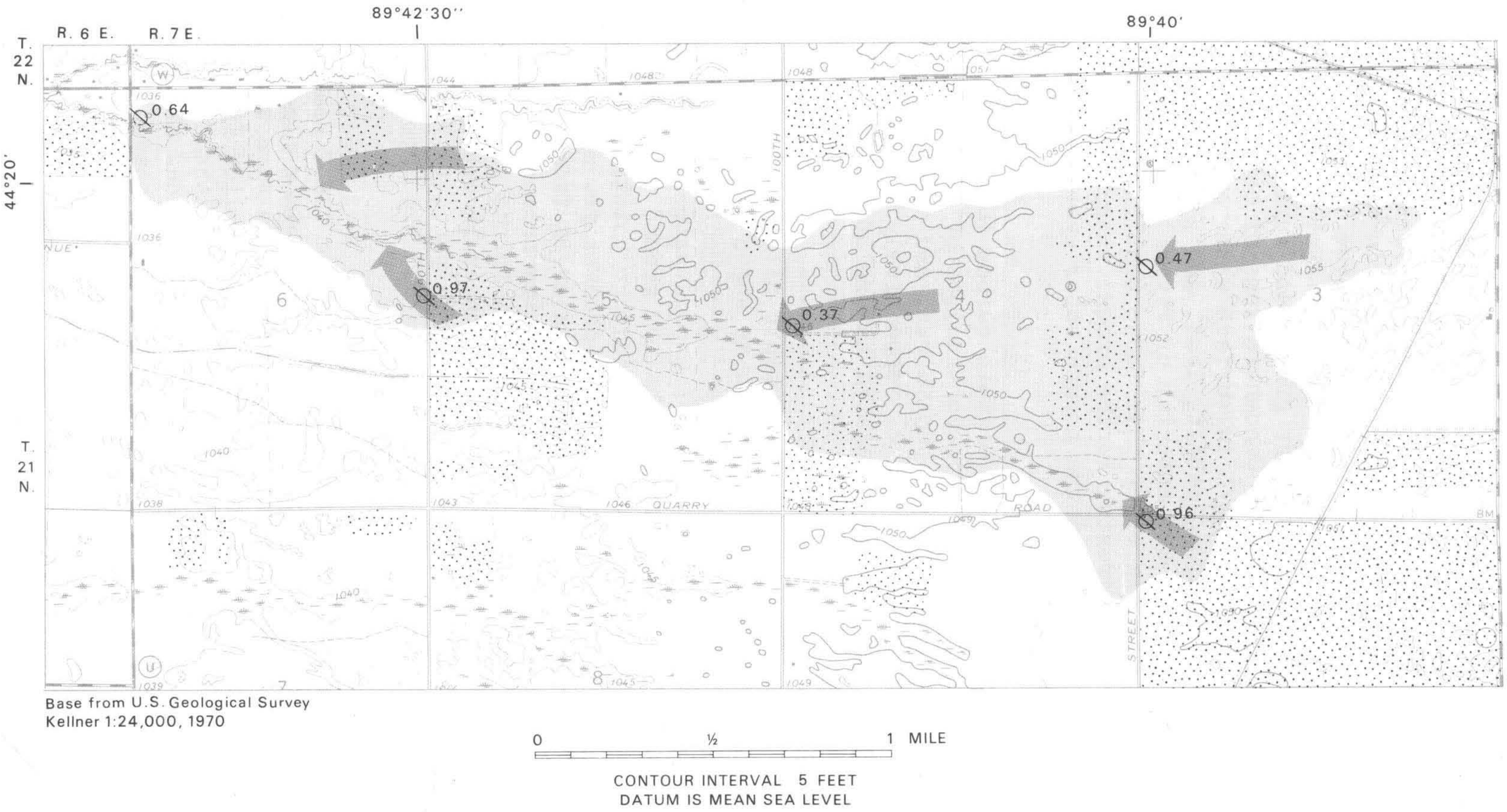
After fertilizer application, water dissolves some of the nitrogen, phosphorus, and potassium, and carries it into the soil. Much of the applied nitrogen, phosphorus, and potassium are used by the crops, but some is locked in the soil matrix, some is converted to other oxidation states by biologic activity (with some nitrogen gases returning to the atmosphere), and some remains in solution and reaches the ground-water reservoir.

WATER QUALITY IN THE KELLNER SUBAREA

The water in the nonfarmed Kellner subarea is generally a calcium magnesium bicarbonate type but with much lower concentrations of constituents than the water of the study area as a whole (fig. 9). The major differences are in organic constituents, nitrate nitrogen, total phosphorus, and iron concentrations. The relatively high concentrations of organic nitrogen (0.40 mg/L mean) and dissolved organic carbon (9.9 mg/L mean) in the ground water are attributable to the organic soils. This organic soil, local recharge, and heavy vegetation, along with lack of irrigation and large fertilizer applications, are the main causes for the low mean nitrate nitrogen concentrations of 0.06 mg/L. The organic character of the soils of the subarea promotes denitrification in the recharge water as water passes through the soil zone. High iron concentrations, 12 mg/L mean, are also common in heavily vegetated, wet swampy areas such as the Kellner subarea. The specific cause of the relatively high mean total phosphorus concentration of 0.09 mg/L found in this subarea is not readily explainable by either geology, soils, land use, or source of ground water.

In the Kellner subarea the highest measured nitrogen concentrations are either very near to, or downgradient from, cultivated or pastured areas. Figure 10 shows 2-year mean measured nitrogen concentrations of the shallow ground water, cultivated areas, noncultivated areas, and general direction of ground-water movement. The cultivated areas include cropland and pastureland; noncultivated areas are essentially forest and wetlands. The cultivated and pastured areas receive additional nitrogen through some fertilization and cattle wastes, provide less opportunity for denitrification than the more organic forested areas.

The chemical quality of the surface water in Fivemile Creek is essentially the same as that of the ground water of the Kellner subarea (fig. 9). A few minor differences do exist, however. Nitrate nitrogen concentrations are slightly higher, due to nitrification in the stream. Iron concentrations are much lower (averaging 1.4 mg/L), probably due to precipitation of ferric iron. Phosphorus concentrations are only one-third of values in the ground water, probably due to the utilization of phosphorus by aquatic vegetation and removal by precipitation.



Base from U.S. Geological Survey
Kellner 1:24,000, 1970

EXPLANATION

⦰ 0.47	Observation well *Number indicates mean concentration of total nitrogen as N, in milligrams per liter (Nov 1973–Dec 1975).*	⬅	General direction of ground-water movement
		☐	Noncultivated area
▒	Area of intensive study	⠿	Cultivated area or pasture land

Figure 10. Areal distribution of nitrogen in the Kellner subarea.

The concentrations of both pesticide residues and trace metals found in the water of the Kellner subarea were small. Pesticide residues were not found in the ground water and only one surface-water sample contained a small amount of diazinon. Residues of DDT, DDD, aldrin, chlordane, and dieldrin were all found in the bed material of Fivemile Creek. The most probable source is atmospheric particulate matter. Small amounts of arsenic, cadmium, chromium, cobalt, lead, lithium, molybdenum, and selenium were found in the ground and surface water, usually at concentrations less than 0.01 mg/L. Concentrations of boron were less than 0.02 mg/L and zinc less than 0.36 mg/L in surface water and 7.6 mg/L in ground water. Arsenic, chromium, cadmium, cobalt, lead, and zinc also were found in detectable concentrations in the bed material of Fivemile Creek. Samples were not analyzed for trace metals other than those mentioned. Concentrations of trace metals were generally greater in the ground water of the subarea than in surface water. The metals in the ground water probably precipitate when this water enters the streams.

Concentrations of nitrogen, phosphorus, and organic carbon in the bed material of Fivemile Creek are very high. Mean concentrations of nitrite plus nitrate nitrogen, ammonia plus organic nitrogen, phosphorus, and organic carbon were 67 mg/kg, 6,500 mg/kg, 520 mg/kg, and 43 mg/kg, respectively. These high levels reflect the highly organic and heavily vegetated nature of the Kellner subarea.

Concentration of all the major ions, including organic nitrogen, in the ground water of the Kellner subarea increase with depth as shown on figures 9 and 11 by the 2-year mean concentrations. The increase in concentration with depth reflects the source recharge water, direction of ground-water movement, and length of time between recharge and discharge. Shallow ground water is recharged locally and moves only a short distance to discharge points; therefore, it has a short residence time in the aquifer material, dissolves few minerals, and is low in dissolved constituents. The deeper ground water is from a more regional or areal recharge which gives a longer residence time from recharge to discharge. The aquifer material, especially the western two-thirds, is relatively homogeneous and probably not responsible for differences in chemical quality. Therefore the changes are attributable, at least in part, to residence time or how long the water has been in contact with and has had the opportunity to dissolve aquifer materials.

No discernible seasonal or general trend was evident during the 2 years that water-quality data were collected in the Kellner subarea. Minor fluctuations in nutrient concentrations of the shallow ground water from five wells in the subarea occurred (fig. 12), but they were small and random, indicating a continuous moderating effect of the organic soils. Small seasonal trends in surface-water quality were evident for Fivemile Creek. Concentrations of major ions decreased during spring runoff due to dilution effects and increased during periods of normal to low flow. Like ground water, surface-water nutrient concentrations differed randomly with no discernible trends.

WATER QUALITY IN THE MEEHAN SUBAREA

Water in the heavily farmed Meehan subarea is a calcium magnesium nitrate chloride type (fig. 9) with a low dissolved-solids concentration, generally about 100 mg/L. The mean concentrations of calcium, magnesium, and chloride in

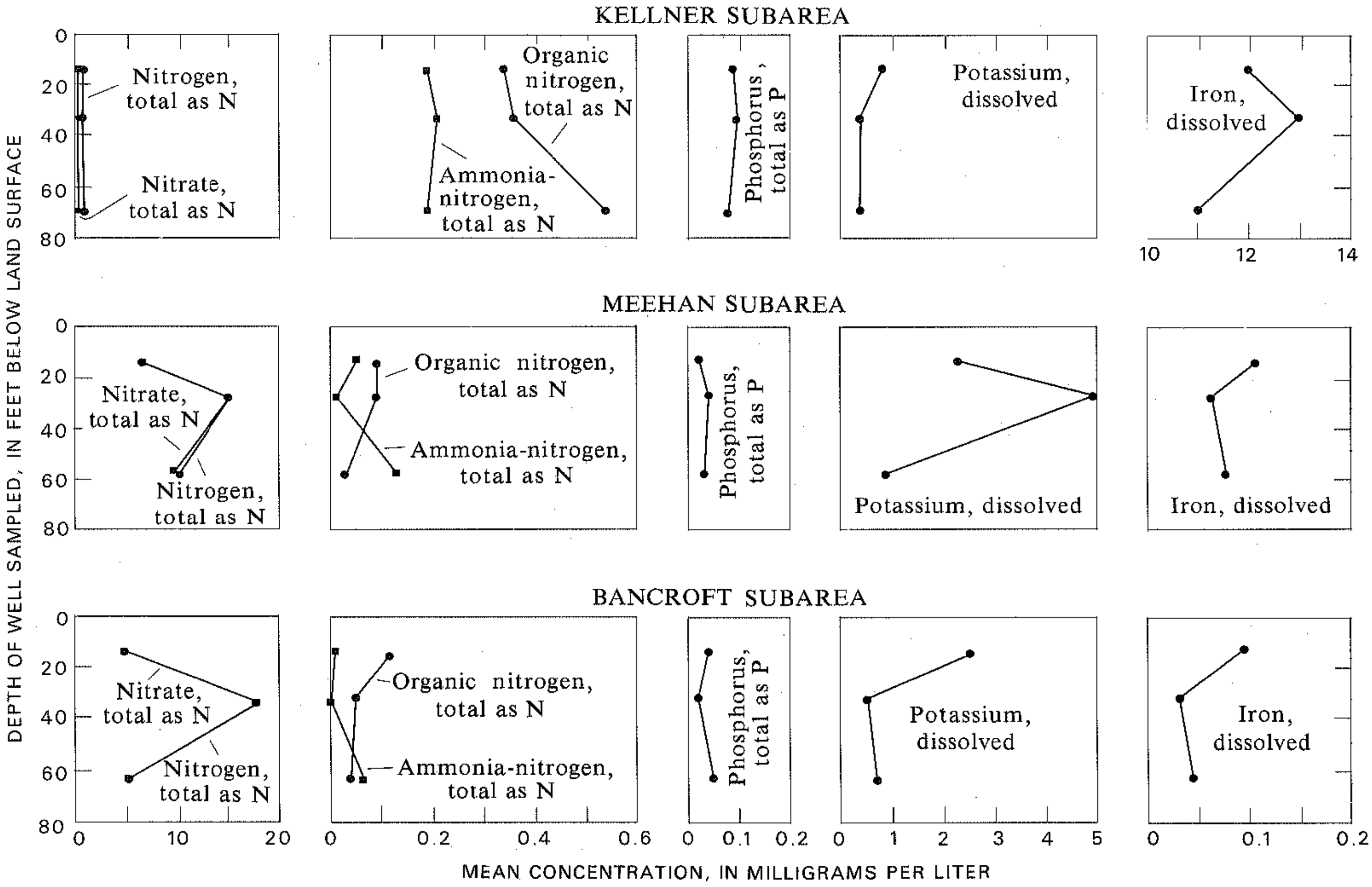


Figure 11. Differences in ground-water quality with depth in the Kellner, Meehan, and Bancroft subareas.

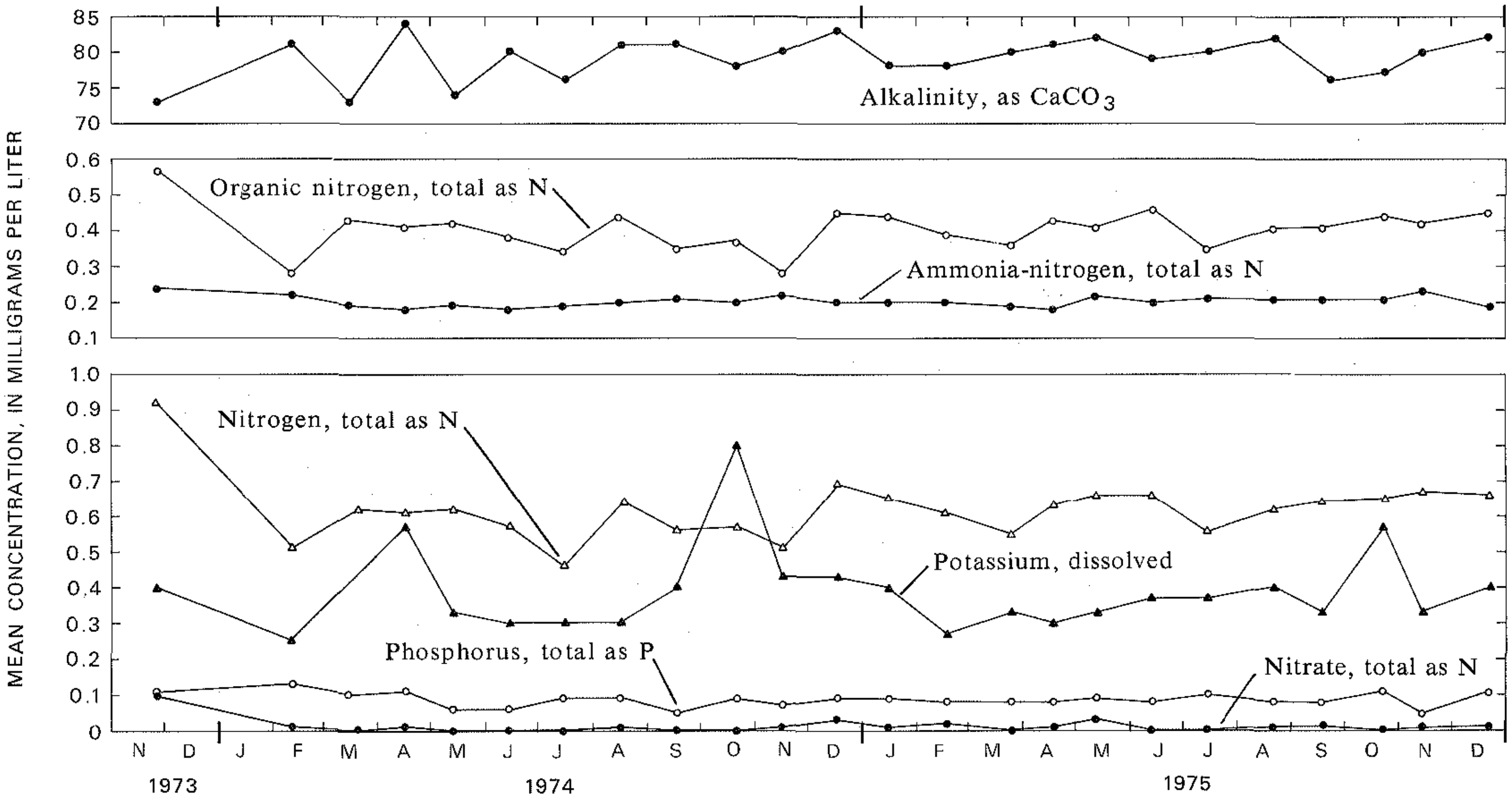


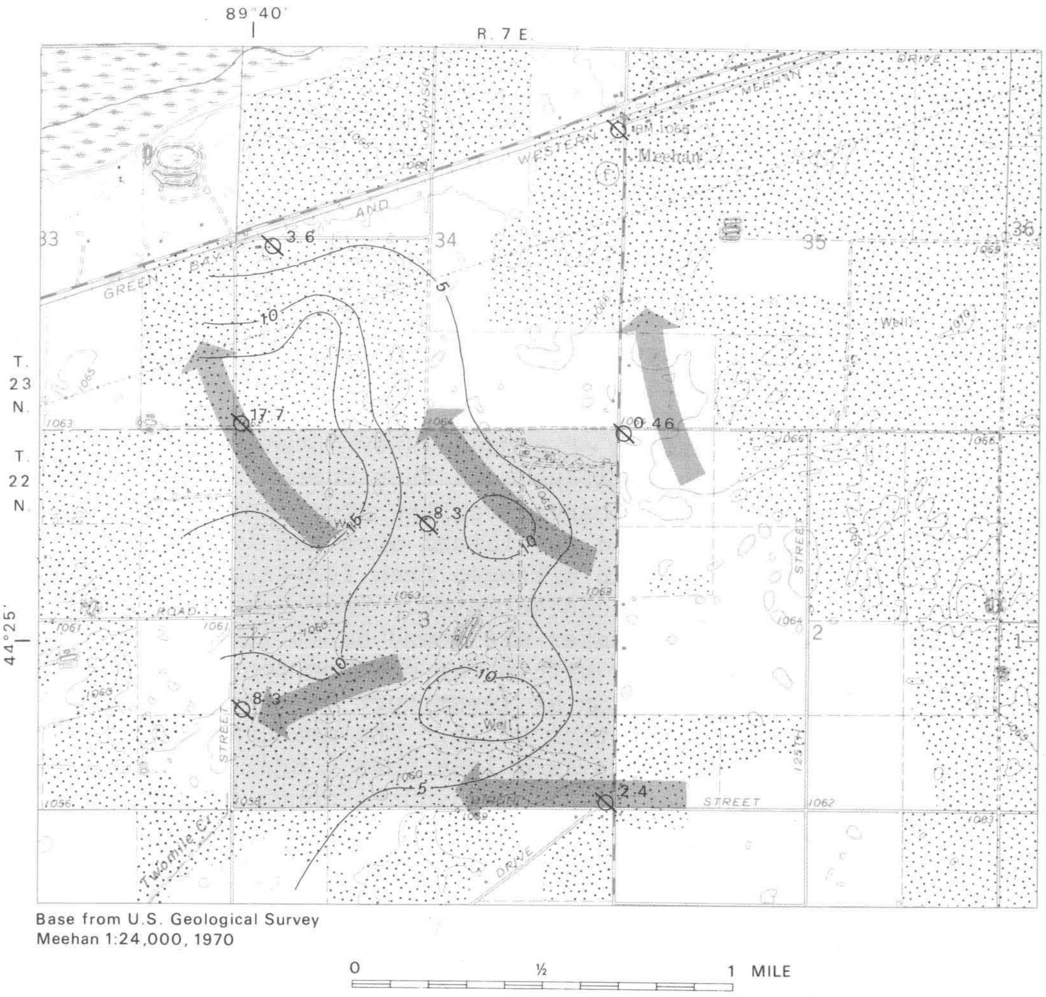
Figure 12. Variation in ground-water quality in the Kellner subarea.

the ground water were about 18 mg/L, 5.0 mg/L, and 16 mg/L, respectively. Total nitrogen concentrations ranged from 0.11 to 37 mg/L with a mean concentration of 9.2 mg/L. Nitrate nitrogen constitutes nearly all of the nitrogen in the ground water. The mean nitrate nitrogen concentration was 9.0 mg/L, with the remaining 0.2 mg/L made up of nitrite, ammonia, and organic nitrogen. The high concentrations of nitrogen in the Meehan subarea are attributed to fertilization. The mean concentration of potassium of 2.2 mg/L also probably reflects fertilization whereas the mean concentration of phosphorus of 0.03 mg/L does not. The concentrations of all the remaining minor ions in the ground water of the Meehan subarea were low.

In the Meehan subarea nitrogen concentration increases from the southeast to the northwest (fig. 13). This gradient of the 2-year mean nitrogen concentration in the shallow ground water is controlled and shaped by the direction of ground-water movement. The pattern of ground-water movement during nonirrigation periods influences the nitrogen gradient more than during irrigation periods. The ground water that enters the subarea from the south and east is from a nonirrigated, lightly cultivated and fertilized area and is low in nitrogen. Recharge within the subarea picks up nitrogen from fertilizers, carrying it downgradient where it becomes more concentrated. Therefore, the highest nitrogen concentrations in ground water are found as it leaves the subarea. Ground-water pumpage for irrigation within the subarea concentrates nitrogen around the irrigation wells when, for at least part of the year, local ground-water movement is toward the irrigation wells. The measured nitrogen concentrations in the Meehan subarea range from less than 1 mg/L in the northeast to more than 17 mg/L in the northwest. All the values shown in figure 13 are averages of monthly sampling; therefore, for individual months, the pattern may be significantly different.

The chemical quality of the water in Twomile Creek is very much like that of the ground water (fig. 9). The surface water is the calcium magnesium bicarbonate type whereas the ground water is the calcium magnesium nitrate chloride type. Bicarbonate has replaced nitrate as the major anion. The higher nitrate nitrogen concentration of the ground water is lowered as the ground water discharges to surface water and nitrate nitrogen is used in the growth of algae and macrophytes. The availability of carbon dioxide from the atmosphere is the major cause for the increase in bicarbonate in Twomile Creek. The low concentrations of nitrogen, phosphorus, and carbon in the bed material of Twomile Creek reflect the growth of stream vegetation and the nonorganic character of the soils. The mean concentration of nitrate plus nitrite in the bed material was 13 mg/kg and the concentration of ammonia plus organic nitrogen was 590 mg/kg. The mean phosphorus concentration in bed material was 95 mg/kg. Inorganic and organic carbon concentrations were 1.5 mg/kg and 4.8 mg/kg, respectively.

Pesticide residues were found in both the ground and surface water of the Meehan subarea. Small amounts of DDT and DDE were found in the ground water whereas DDT, DDE, diazinon, and 2,4,5-T were found in Twomile Creek. Concentrations of all the observed residues in water of the Meehan subarea were generally less than 0.01 µg/L. The bed material of Twomile Creek contained DDT, DDD, and dieldrin, at concentrations less than 2 µg/kg. Pesticide application to control weeds, insects, and diseases in this and surrounding heavily irrigated



Base from U.S. Geological Survey
Meehan 1:24,000, 1970

CONTOUR INTERVAL 5 FEET
DATUM IS MEAN SEA LEVEL

EXPLANATION

—10— Line of equal concentration of total nitrogen as N
In milligrams per liter

▨ Area of intensive study

⁚ Cultivated area

☐ Noncultivated area

⊘8.3 Observation well
Number indicates mean concentration of total nitrogen as N, in milligrams per liter (Nov 1973—Dec 1975).

⇦ General direction of ground-water movement

Figure 13. Areal distribution of nitrogen in the Meehan subarea.

areas is the main source of pesticide residues in the water. Fallout of atmospheric dust from distant sources is probably a minor source of pesticides. The use of DDT and its derivatives have been discontinued, but because of their very long life, they are the most common residue in the waters. Pesticides currently being used have very short lives and are rare in the ground and surface waters of the Meehan subarea.

Small amounts of arsenic, cadmium, chromium, cobalt, lead, zinc, molybdenum, lithium, selenium, and boron were detected in the ground and surface water of the Meehan subarea, whereas arsenic, cadmium, chromium, cobalt, lead, and zinc were found at detectable levels in the bed material of Twomile Creek. Samples were not analyzed for other trace metals. Mean concentrations of metals were generally greater in the ground water than in surface water because they precipitate as the ground water becomes oxygenated upon entering the stream. Concentrations of metals in the ground water were less than 0.01 mg/L except for zinc and boron, which were less than 6.0 mg/L and 0.55 mg/L, respectively.

Continued application of fertilizers over a long period has had a measurable effect on the ground- and surface-water quality of the Meehan subarea. Various amounts of nitrogen, phosphorus, and potassium were applied to the land surface throughout the 2-year period of the project (fig. 14). Potassium generally is added in the fall and early spring and lesser amounts during the growing season. About 180 lb of potassium were added to each acre in the Meehan subarea in 1974, based on estimates made by farmers, whereas only about 100 lb/acre were applied in 1975. Phosphorus was applied at a rate of about 95 lb/acre in the early spring of 1974 and about 45 lb/acre was applied during the summer of 1975. Nitrogen generally is applied only during the growing season when crops can use it immediately. Each acre in the subarea received about 360 lb/acre of nitrogen in 1974 and about 200 lb/acre in 1975.

The ground water around the 30-ft level is the most highly mineralized water found in the subarea (figs. 9 and 11) and it is from this zone that most of the water is withdrawn for irrigation in this subarea. The higher concentrations at this level reflect the effects of fertilization, infiltration, pumpage, and aeration. During the summer irrigation season when large amounts of fertilizers and chemicals are available for leaching, irrigation pumpage creates a recirculation of the ground water (Weeks and Stangland, 1971). This recirculation moves the nutrients down through the aquifer causing a build up of nutrients in the ground water. For the remainder of the year, when the fertilizers and chemicals are not as readily available for leaching, precipitation tends to flush the nutrients out of the upper part of the aquifer to either the streams or the lower part of the aquifer. Aeration in both the irrigation and infiltration processes also affects the concentration of nutrients found in the ground water of the upper part of the aquifer.

Seasonal or general trends in nutrient concentrations in the shallow ground water from six wells in the Meehan subarea were not clearly evident during the 2 years of data collection (fig. 15). Except for nitrate nitrogen, which had some random scatter, the concentrations of the nutrients stayed relatively constant. Concentrations of alkalinity, as calcium carbonate, increased from about 10 mg/L average in 1974 to about 13 mg/L in 1975. Twomile Creek declined in concentration of major ions during spring runoff due to dilution by snowmelt.

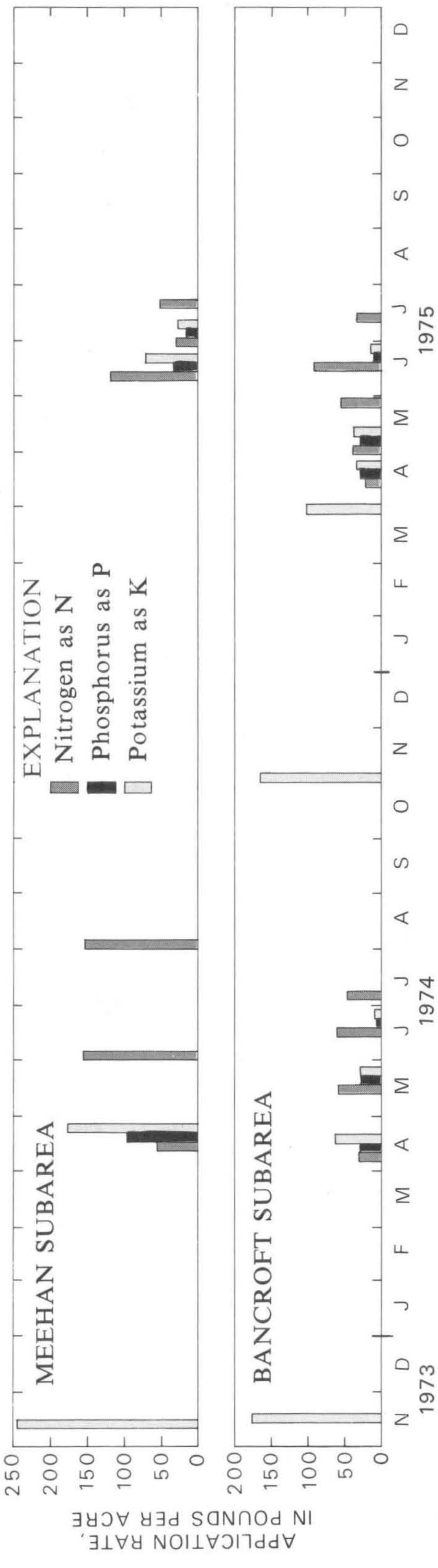


Figure 14. Fertilizer application in the Meehan and Bancroft subareas.

The minor ions and nutrients, except for nitrate nitrogen, remained relatively constant through the year, with only random scatter. Nitrate nitrogen increased slightly during the spring runoff.

WATER QUALITY IN THE BANCROFT SUBAREA

The water in the Bancroft subarea is a calcium magnesium bicarbonate nitrate type with dissolved-solids concentration generally less than 200 mg/L (fig. 9). The mean concentrations of calcium, magnesium, and bicarbonate in the ground water were 25 mg/L, 11 mg/L, and 62 mg/L, respectively. Nitrate nitrogen concentrations in the ground water ranged from 0 to 41 mg/L with a mean concentration of 7.6 mg/L. Chloride, present in appreciable quantities in some samples, had a mean concentration of 11 mg/L. Generally, low concentrations of both phosphorus and potassium were observed. The mean concentration of phosphorus in ground water was 0.04 mg/L and for potassium, 1.6 mg/L. Dissolved organic carbon had a mean concentration in ground water of 3.4 mg/L. The remaining minor ion concentrations in ground water were low.

The relatively high levels of nitrate nitrogen in the ground water and the lack of significant natural sources of nitrogen in the Bancroft subarea indicate that farming practices and fertilization are the primary sources.

The areal distribution of 2-year mean nitrogen concentrations in the shallow ground water of the Bancroft subarea is influenced by ground-water withdrawal during irrigation periods (fig. 16). The general direction of ground-water movement in the subarea is toward the west, as shown on plate 1 but, due to ground-water pumping during certain periods of the year, this westerly movement is interrupted and the ground water moves toward the pumping wells locally within the subarea.

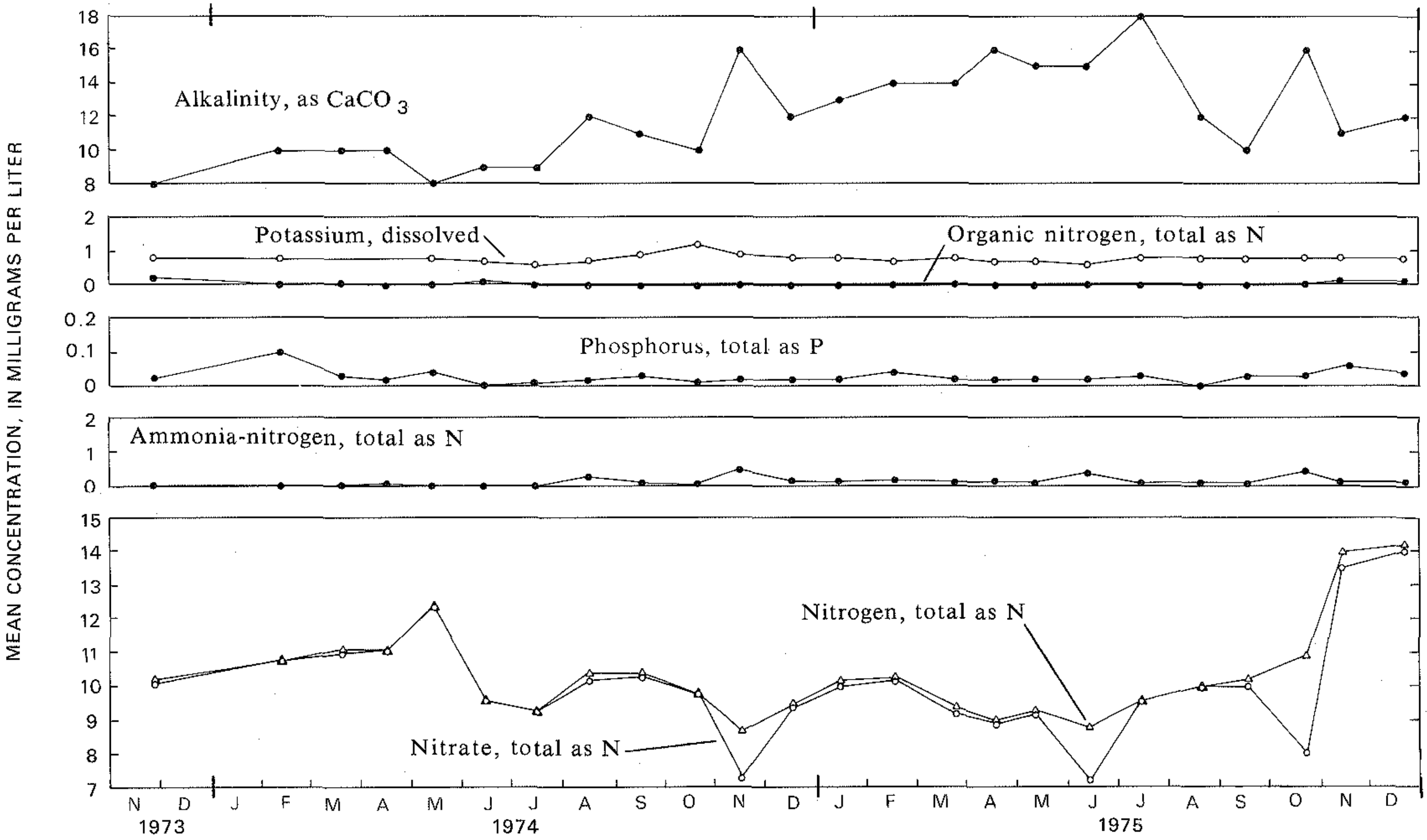


Figure 15. Variation in ground-water quality in the Meehen subarea.

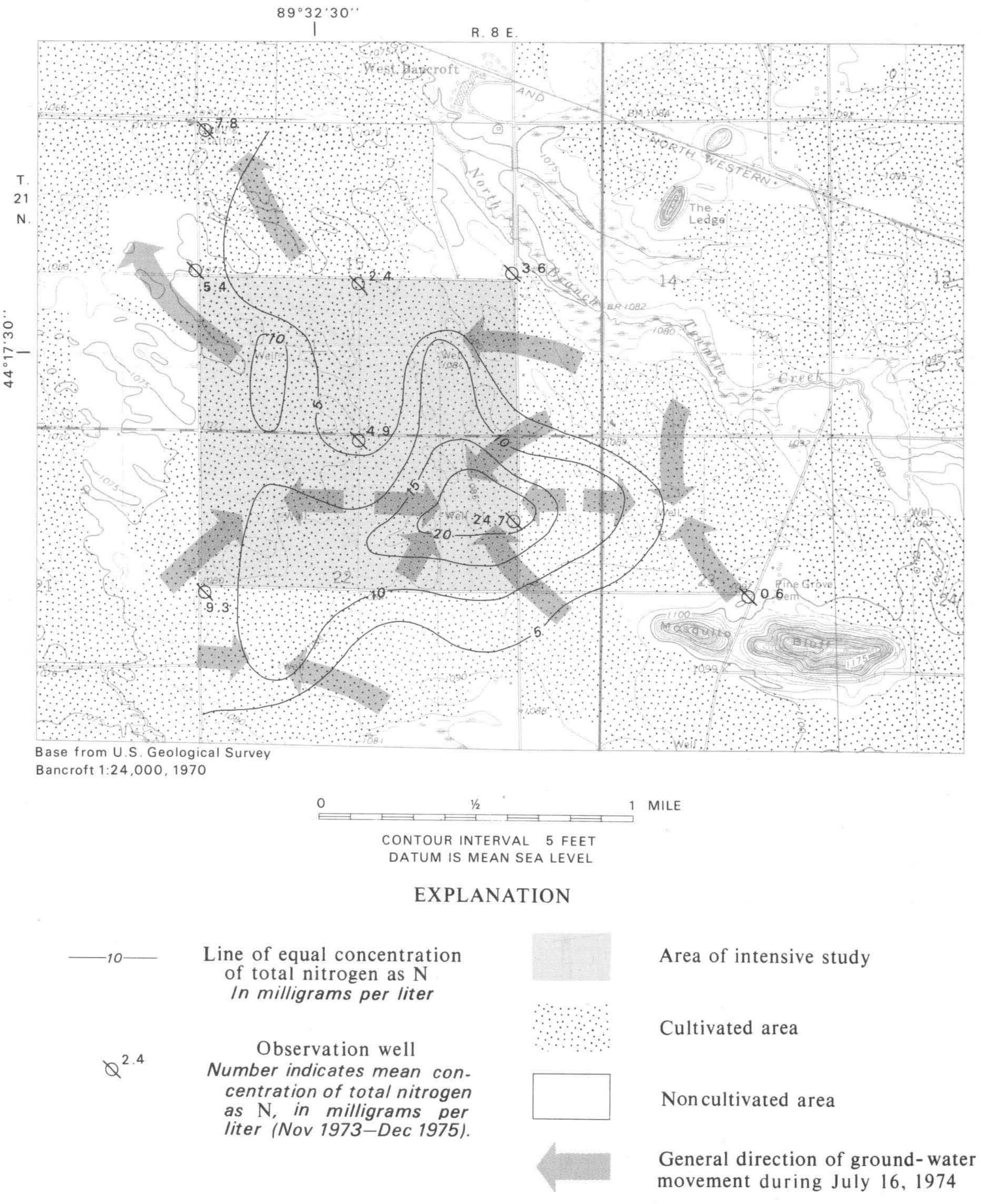


Figure 16. Areal distribution of nitrogen in the Bancroft subarea.

Ground water with low concentrations of nitrogen moves into the subarea from the noncultivated areas. As the water moves into and through the subarea, it is supplemented by ground water high in nitrogen from fields with heavy fertilizer application. Nitrate concentrations progressively increase down the ground-water gradient. The highest nitrogen concentrations were in an observation well very near two closely spaced and intensely pumped irrigation wells and along the western side of the subarea. Figure 16 shows nitrogen concentrations increase from low concentrations in the east to high concentrations around irrigation wells and then to slightly lower nitrogen concentrations along the western subarea boundary. The nitrogen concentration varies from less than 1 mg/L in the recharge area in the east to greater than 20 mg/L around the two heavily pumped irrigation wells, to between 5 and 10 mg/L in the northwest where ground water leaves the subarea. The values shown in figure 16 are averages of monthly samples.

In the Bancroft subarea, nitrogen concentrations in the shallow ground water from eight wells had a net increase of about 1 mg/L per year (fig. 17) during the 2 years of data collection. There was also a net rise in the water table over this period. Therefore, the amount of nitrogen stored in the ground-water reservoir increased.

Nitrogen in various amounts enters and leaves the Bancroft subarea by many different paths (fig. 18). The major paths by which nitrogen can enter the system are ground-water flow, surface-water flow, precipitation, and fertilizer application. Some atmospheric nitrogen is added to the subarea system by nitrogen fixation by microorganisms. Nitrogen may leave the system in ground-water flow or surface-water flow, be removed by crop and vegetation, and lost as a gas. Surface-water flow is negligible in the Bancroft subarea, and does not enter into the nitrogen balance.

If more nitrogen enters the subarea than leaves the subarea, it must be stored within the area, either in the ground water, locked in the soil or aquifer structure, or in plant growth. The change in storage for this budget is assumed to be entirely in ground-water storage. Very little nonagricultural vegetation exists in the subarea, consequently this is not an important factor in the storage term. Additional nitrogen could be locked in the soil structure but determination of this was beyond the scope of the project.

The nitrogen budget for the Bancroft subarea can be written as follows:

$$\text{Nitrogen}_{\text{In}} = \text{Nitrogen}_{\text{Out}} \pm \text{Change in storage} \pm \text{Residual}$$

The residual term is a "catchall" containing the unmeasured inputs and outputs, such as free nitrogen and ammonia gases, noncrop vegetative growth, and unmeasured changes in storage. The equation is expanded to the form:

$$\text{GW N}_{\text{In}} + \text{Precip N}_{\text{In}} + \text{Fertilizers N}_{\text{In}} =$$

$$\text{GW N}_{\text{Out}} + \text{Crops N}_{\text{Out}} \pm \text{GW N}_{\text{Storage}} \pm \text{Residual}$$

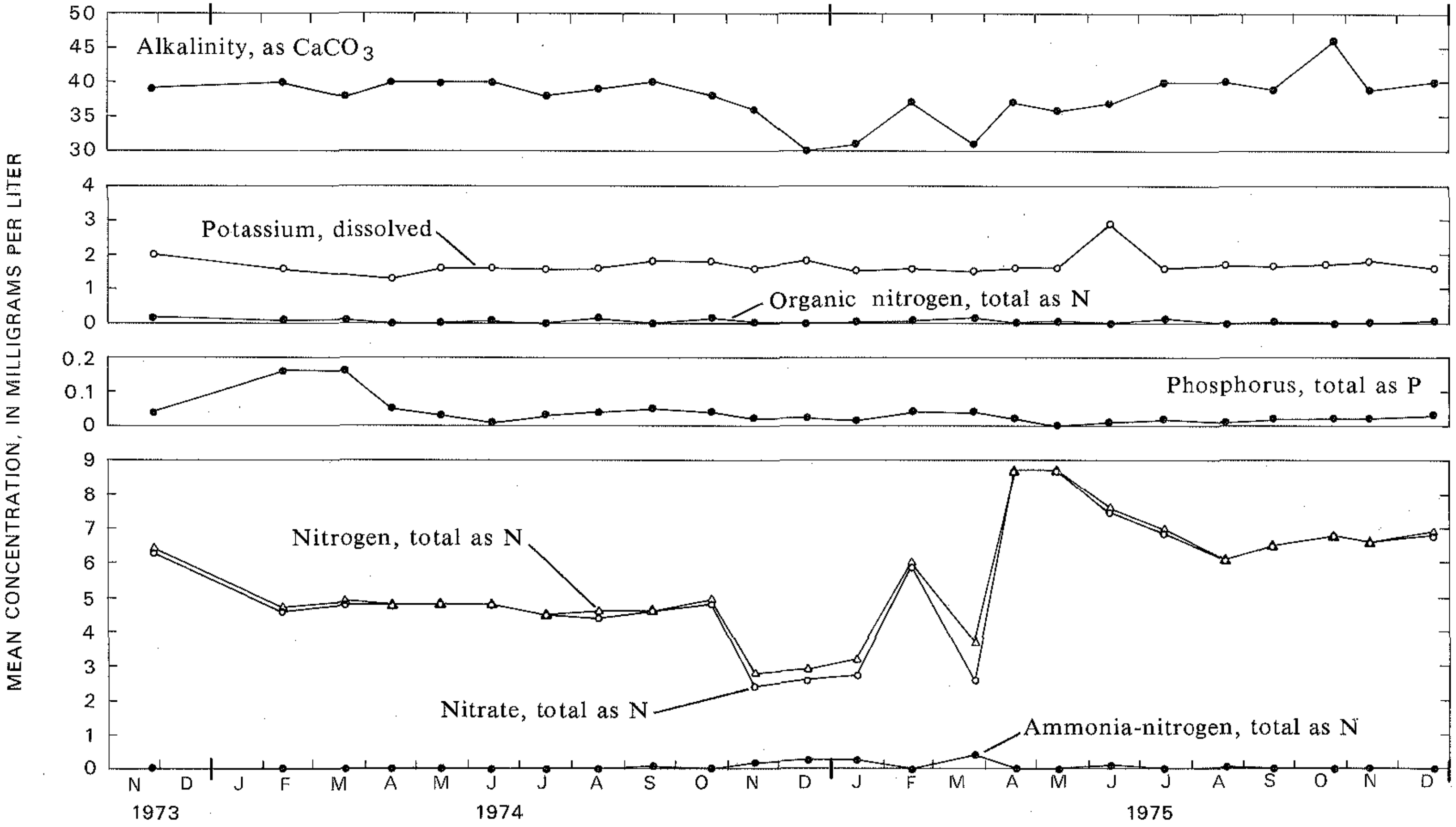


Figure 17. Variation in ground-water quality in the Bancroft subarea.

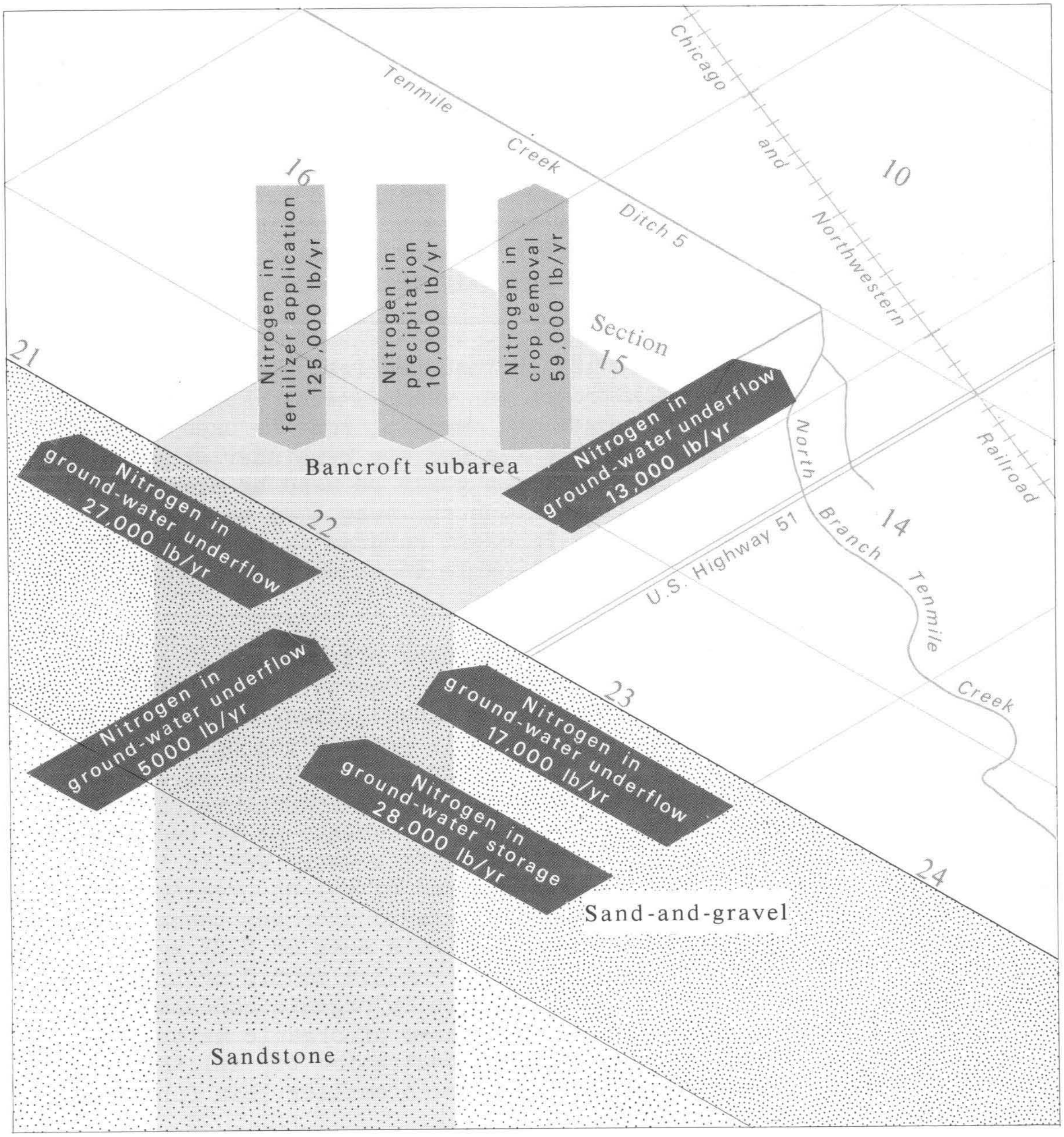


Figure 18. **Generalized** total **nitrogen** budget for Bancroft subarea for the 2-year period of study.

Nitrogen entering and leaving the Bancroft subarea was calculated for the 2-year period of study and is shown in figure 18. An average of about 125,000 lb of nitrogen fertilizer was applied to the subarea each year of the study, based on estimates made by farmers. About another 10,000 lb of nitrogen is added annually in the 28 in of annual precipitation that fell during the project. As stated earlier, ground-water storage in the Bancroft subarea increased annually by about 26 acre-ft. This amounts to a 28,000 lb/yr increase in the amount of nitrogen stored in the ground water within the subarea. Ground water flows through the Bancroft subarea from the southeast to the northwest (pl. 1) carrying nitrogen into and out of the subarea. The amount of flow is calculated using Darcy's Law and by knowing the nitrogen concentrations at the subarea boundaries (fig. 16) the approximate amount of nitrogen entering and leaving the subarea in ground-water flow can be calculated. It amounted to approximately 22,000 lb entering and 40,000 lb leaving the Bancroft subarea annually during the project. About 59,000 lb of nitrogen was removed annually from the subarea in the harvested crops.

When the values shown in figure 18 are inserted into the formula above, it leaves a residual of 30,000 lb of nitrogen per year excess. Much of this residual may be lost as gaseous nitrogen and ammonia; some is used in growth of the nonagricultural vegetation in the subarea and the remainder stored in the soil and soil moisture. This stored nitrogen could be used by plants, be converted to gaseous form, or go into solution and seep down to the ground-water reservoir. The nitrogen budget for the Bancroft subarea is only approximate, but the values presented are probably applicable to other irrigated areas as well.

The chemical quality of water in Tenmile Creek Ditch No. 5 is similar to the ground-water quality of the Bancroft subarea. Concentrations of all the major ions were similar to those of the ground water. Bicarbonate was one notable exception, with concentrations in Tenmile Creek Ditch No. 5 more than twice those of ground water (a mean surface-water concentration of 143 mg/L). This shows the effect that biological activity and the atmosphere, and more specifically carbon dioxide, has on ground-water discharge as it becomes surface water. Another difference between ground and surface water was in the level of organics. Significantly more organic nitrogen and dissolved organic carbon were found in surface water than in ground water. Organic nitrogen concentrations ranged from a mean of 0.09 mg/L in ground water to a mean of 0.51 mg/L in surface water, whereas dissolved organic carbon ranged from 3.4 to 5.0 mg/L for ground and surface water, respectively. This difference in organic concentration illustrates how vegetation, plant debris, and decay of organic matter can affect the quality of surface water. The range in concentration for all the measured constituents in Tenmile Creek Ditch No. 5 were much smaller than for the ground water.

Low concentrations of organic constituents and nutrients were found in the bed material of Tenmile Creek Ditch No. 5. The mean concentration of inorganic and organic carbon in bed material were 0.12 and 2.1 g/kg, respectively, and the mean phosphorus concentration was 83 mg/kg. Mean nitrogen concentrations in the bed material of Tenmile Creek Ditch No. 5 ranged from 13 mg/kg nitrate plus nitrate nitrogen to 300 mg/kg ammonia plus organic nitrogen. The low level of organic carbon in the bed material shows the lack of sources of organic material in the Bancroft subarea.

Pesticide residues were not found in either the ground or surface waters of the Bancroft subarea, but the bed material of Tenmile Creek Ditch No. 5 contained some dieldrin, DDT, and DDD. The measured concentrations of these three residues were usually less than about 0.2 μg/kg. The DDT and DDD in the bed material are residues from past years. The source of the three pesticides in the bed material is probably dust from areas where the pesticides had been used. Because of the short lives of the modern pesticides and lack of any samples collected during periods of application, none of the presently used pesticides were detected in the analyses.

Small amounts of arsenic, boron, cadmium, chromium, cobalt, lead, selenium, and zinc were found in the waters of the Bancroft subarea, whereas arsenic, cadmium, chromium, cobalt, lead, and zinc were detected in the bed material of Tenmile Creek Ditch No. 5. Molybdenum or lithium were not found in either the ground or surface water of the subarea. The concentrations of all metals, except boron and zinc, were generally less than 0.005 mg/L. The maximum concentrations of boron and zinc in ground water were 1.7 mg/L and 0.68 mg/L, and for surface water 0.22 mg/L and 0.02 mg/L, respectively. Generally, concentrations of metals in the ground water were greater than in surface water because they precipitate as the ground water becomes oxygenated upon entering the stream.

Fertilizers, mainly nitrogen, phosphorus, and potassium, are applied regularly to the land surface in the Bancroft subarea. Figure 14 shows the types, approximate amounts, and times of application. Nitrogen generally is applied during the growing season and, in 1974, about 200 lb of nitrogen was applied to each acre in the Bancroft subarea, based on estimates made by farmers. In 1975 this figure was about 220 lb/acre total. Phosphorus generally was applied in the spring and early summer with a total of about 60 lb/acre applied in both 1974 and 1975. Potassium usually is applied year round. About 270 lb of potassium was applied to each acre of the subarea during 1974 but only about 180 lb/acre was applied in 1975. These large amounts of fertilizer and the large amount of water it takes to produce cucumbers and potatoes help to explain the high nitrogen levels found in the ground water of the subarea.

Concentrations of various constituents in ground water changes with depth in the Bancroft subarea (fig. 9). The shallow ground water from 12 to 14 ft below land surface has very low concentrations of constituents. The middepth ground water, generally 28 to 35 ft below land surface, had concentrations of the major ions of calcium, magnesium, chloride, nitrate, and bicarbonate that ranged from 3 to 10 times those of the shallow ground water. The water from the 40- to 70-ft zone is very nearly the same as the shallow ground water. Chloride changes most with a concentration increase from 2.0 mg/L for the shallow ground water to 31 mg/L for the middepth. Organic nitrogen, ammonia, nitrite nitrogen, phosphorus, potassium, iron, and dissolved organic carbon decreased in mean concentrations from shallow to middepth (fig. 11).

The causes of this change in water quality with depth are similar to those in the Meehan subarea. They reflect the effects of fertilization, infiltration, pumpage, and aeration. During the summer irrigation season when large amounts of fertilizers and chemicals are available for leaching, irrigation pumpage creates a recirculation of the ground water (Weeks and Stangland, 1971). This recirculation moves the nutrients down through the aquifer causing a build up of nutrients in the ground water. For the remainder of the year when the fertilizers

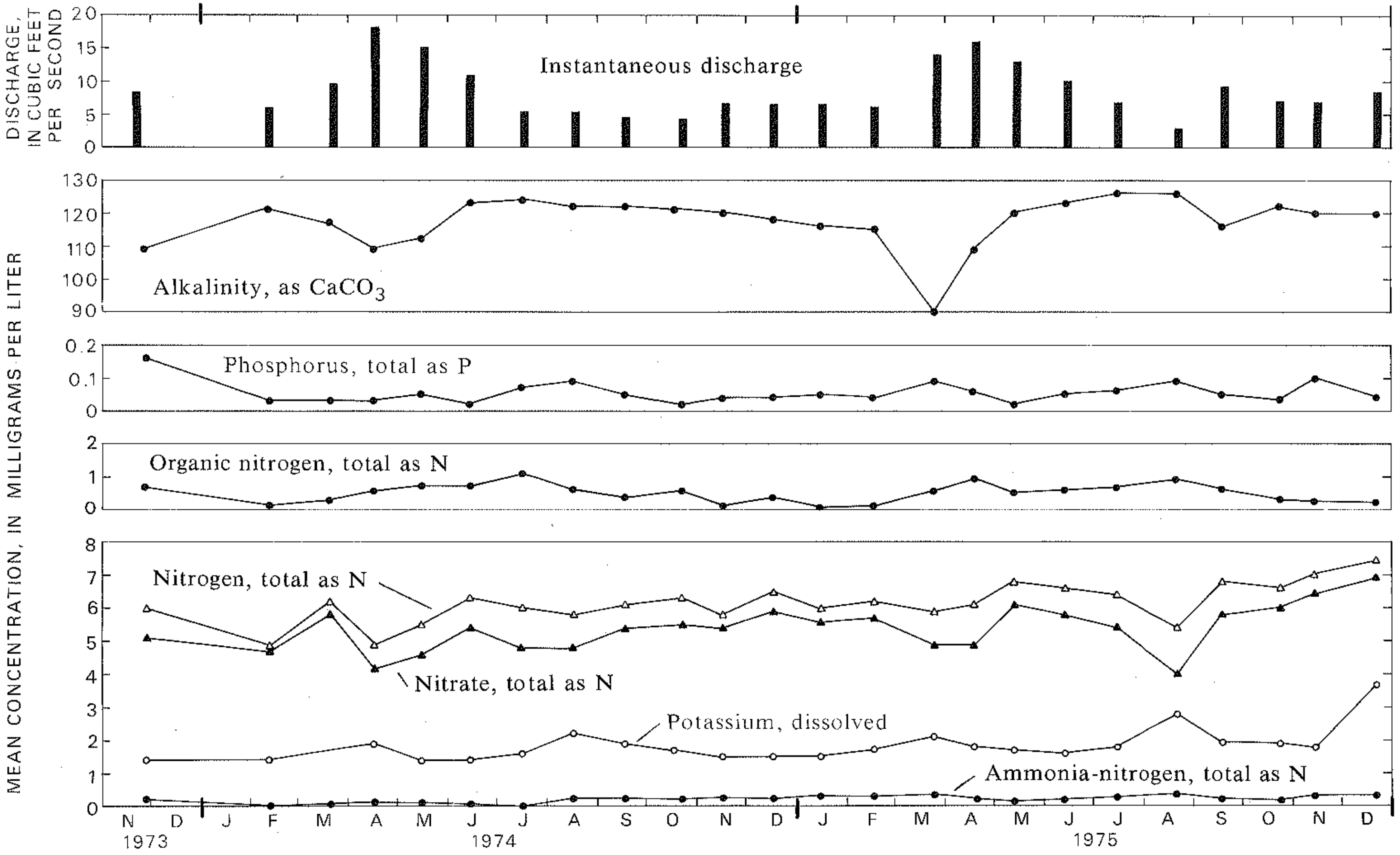


Figure 19. **Variation in the surface-water quality and discharge of Tenmile Creek Ditch No. 5 near Bancroft.**

and chemicals are not as readily available for leaching, precipitation tends to flush the nutrients out of the upper portion of the aquifer to either the streams or the lower portion of the aquifer. Aeration in both the irrigation and infiltration processes also affects the concentration of nutrients found in the ground water of the upper portion of the aquifer.

Seasonal fluctuations in the chemical quality of the waters of the Bancroft subarea were not evident, but nitrate nitrogen concentrations in both ground and surface water increased slightly during the 2 years of data collection. Figures 17 and 19 show the fluctuation in water quality. The only constituent in the ground water of the subarea that changed significantly was nitrate nitrogen. Ten percent more nitrogen was applied in 1975 than in 1974. Except for 1 month, 1975 had a very dry growing season (fig. 20), requiring much irrigation. This increased irrigation recirculated ground water to the land surface and back again instead of allowing discharge to Tenmile Creek Ditch No. 5. This closed recirculation tends to build up dissolved constituents. In this case, one of the most readily available soluble materials is nitrogen found in fertilizers.

Generally the water quality of Tenmile Creek Ditch No. 5 had little trend or seasonal variation except nitrate nitrogen, which increased slightly during the latter part of 1975. This increase probably was caused by the increased nitrate nitrogen in the ground water that discharges to the ditch.

The weak correlation between precipitation (fig. 20) and streamflow (fig. 19) appears to have little influence on the chemical quality of either ground or surface water of the Bancroft subarea. The concentrations of major ions decreased during the early high-runoff months, but even this decrease was slight and could not be attributed directly to precipitation. Snowmelt and early spring precipitation increase streamflow and raise ground-water levels, but the late spring, summer, and early fall precipitation have little effect on streamflow or ground-water levels.

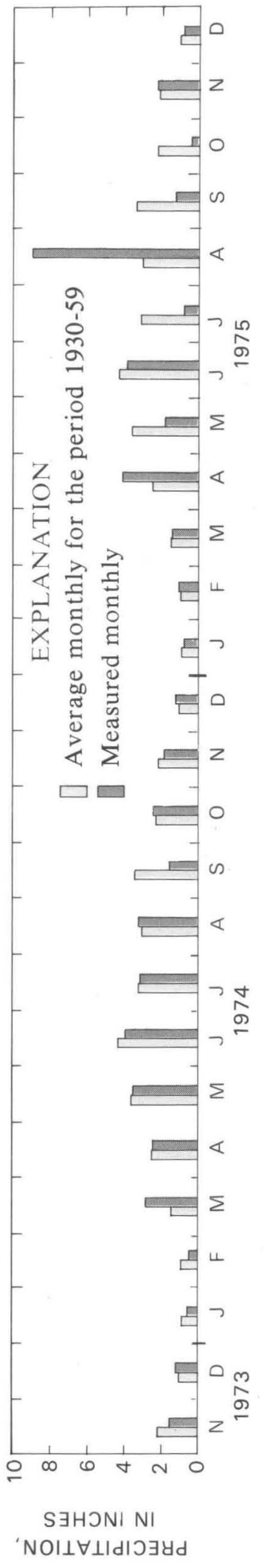


Figure 20. Precipitation at the Hancock Experimental Farm.

SUMMARY AND CONCLUSIONS

Agricultural irrigation has affected the quality of both ground and surface waters in the sand plain of central Wisconsin. This effect is most noticeable in and around areas of intensive farming and irrigation, but because of the homogeneity of the hydrologic system it is also evident throughout the area. Deterioration in water quality, although evident, has not yet reached the point where the use of water needs to be limited in order to conform with current water-quality standards. The most noticeable changes in water quality that can be attributed to irrigation are the higher concentrations of nitrogen relative to those found in nonirrigated areas, and the occurrence of pesticide residues in ground and surface waters of the sand plain of central Wisconsin. Lesser changes also have occurred in concentrations of other constituents, but they cannot be easily related to irrigation. At the present time no significant change in water quality appears to be taking place. During the period of data collection for this project, 1973-75, minor variations in concentrations of a few constituents were observed but no readily apparent seasonal or general trends were evident. Drastic changes from present conditions in the type of farming, types of crops grown, amounts of water pumped, and types and rates of chemicals applied to the land surface in the sand plain of central Wisconsin could result in further changes in the water quality of the area.

Water quality of the study area is generally very good. It is chiefly a calcium magnesium bicarbonate type with a mean measured dissolved-solids concentration about 140 mg/L. Iron presents the only significant water-quality problem in the study area and only in ground water that is used for domestic purposes. The mean measured concentration of iron in ground and surface water of the area are 0.78 and 0.12 mg/L, respectively. Maximum allowable concentrations for iron are 0.3 mg/L for domestic use and 5.0 mg/L for irrigation use (National Academy of Sciences and National Academy of Engineering, 1974). High iron concentrations occur randomly, but are found more commonly in wet marsh areas or areas with high organic soil content.

Changes in water quality were most evident in areas of intensive farming and irrigation, but noticeable changes have also taken place throughout the study area. The mean total nitrogen concentration for ground water in the study area is 4.8 mg/L, whereas those for the irrigated Meehan and Bancroft subareas are 9.2 mg/L and 7.7 mg/L, respectively. These values are considerably higher than the mean nitrate nitrogen concentration of ground water throughout the State (about 3 mg/L). No major natural source of nitrogen exists in the area, so at least some of the higher nitrogen content of ground water must be due to intensive agricultural practices. In irrigated areas, the high nitrogen concentrations are most certainly derived from nitrogen fertilizers. Mean concentrations of both phosphorus and potassium in the waters of the study area are low and do not appear to reflect the heavy fertilizer application. The mean concentration of phosphorus was 0.06 mg/L for ground water and 0.09 mg/L for surface water. Mean potassium concentrations were 1.7 mg/L and 0.80 mg/L for ground and surface water respectively.

Small amounts of pesticide residues were detected in the waters of the study area, especially in the water and bed material of streams draining areas of intensive farming. The most persistent and widespread residues occurring were DDT and its derivatives DDE and DDD. DDT and DDD are no longer in use, but because of their persistence, residues are still commonly found. Modern pesticides are being used extensively in the irrigated areas but they have a very short life. The presence of some of these pesticides was detected, but concentrations were low and occurrences random. Due to the short life of modern pesticides, they present very little problem to the water of the sand plain of central Wisconsin.

Data indicate that trace elements, mainly heavy metals, do not occur in sufficiently high concentration to present a deterrent for present use. Boron, selenium, lithium, and molybdenum, all potentially harmful to crops, occur in concentrations below the limits set for irrigation and domestic water by the U.S. Federal Water Pollution Control Administration (1968), the U.S. Public Health Service (1962), and the U.S. Salinity Laboratory (1954). Concentrations of other trace elements were similarly low.

Present volumes of ground-water pumpage for irrigation have little effect on water quality in the sand plain of central Wisconsin. The effects of pumping on water quality are not a serious problem although more water recirculation due to possible increases in pumpage may cause an appreciable build up of nitrogen in the water system in the future.

SELECTED REFERENCES

Beatty, M. T., 1964, Soils of central Wisconsin, in Vegetable and fruit potential for production and processing in central Wisconsin: Wisconsin Univ. Ext. Service, Coll. Agr., p. 22-25, table 22.

Binning, L. K., Powell, R. D., Libby, J. L., and Wade, E. K., 1976, Potatoes, chemical recommendation: Wisconsin Univ. Ext. Service, Coll. Agr. and Life Sciences, A 2352, 4 p.

Curwen, D., and Powell, R. D., 1975, Snap beans--green and wax: Wisconsin Univ. Ext. Service, Coll. Agr. and Life Sciences, A 2328, 4 p.

_______1975, Pickling cucumber production: Wisconsin Univ. Ext. Service, Coll. Agr. and Life Sciences, A 1587, 4 p.

Devaul, R. W., and Green, J. H., 1971, Water resources of Wisconsin--central Wisconsin River basin: U.S. Geol. Survey Hydrol. Inv. Atlas HA-367.

Eccles, L. A., Hughes, J. L., and Malcolm, R. L., 1973, Dissolved organic carbon (DOC), a definitive parameter in organic ground water contamination, in Proc. Inst. Environmental Science, Anaheim, California, 1975: p. 340-346.

Gritton, E. T., Oplinger, E. S., and Powell, R. D., 1975, Peas: Wisconsin Univ. Ext. Service, Coll. Agr. and Life Sciences, A 2346, 4 p.

Hem, J. D., 1970, Study and interpretation of the chemical characteristics of natural water, second edition: U.S. Geol. Survey Water-Supply Paper 1473, 363 p.

Holt, C. L. R., Jr., 1965, Ground-water resources of Portage County, Wisconsin: U.S. Geol. Survey Water-Supply Paper 1796, 77 p.

Leenheer, J. A., and Malcolm, R. L., 1973, Chemical and microbial transformations of an industrial organic waste during subsurface waste disposal, in Proc. Inst. Environmental Science, Anaheim, California, 1975: p. 12.

Malcolm, R. L., and Leenheer, J. A., 1973, The usefulness of organic carbon parameters in water quality investigations, in Proc. Inst. Environmental Science, Anaheim, California, 1975: p. 336-340.

National Academy of Sciences and National Academy of Engineering, 1974, Water quality criteria 1972: U.S. Environmental Protection Agency, Ecological Research Ser., EPA R3-73-033, 594 p.

Novitzki, R. P., 1976, Recycling ground water in Waushara County, Wisconsin--resource management for cold-water fish hatcheries: U.S. Geol. Survey Water-Resources Inv. 76-20, 60 p.

Schoenemann, J. A., Libby, J. L., Wade, E. K., and Powell, R. D., 1975, Potatoes: Wisconsin Univ. Ext. Service, Coll. Agr. and Life Sciences, A 2257, 4 p.

Summers, W. K., 1965, Geology and ground-water resources of Waushara County, Wisconsin: U.S. Geol. Survey Water-Supply Paper 1809-B, 32 p.

U.S. Department of Commerce, 1952, 1950 U.S. census of agriculture: U.S. Dept. Commerce, Bureau Census, v. 1, pt. 7, 284 p.

_______1956, 1954 U.S. census of agriculture: U.S. Dept. Commerce, Bureau Census, v. 1, pt. 7, 252 p.

_______1961, 1959 U.S. census of agriculture: U.S. Dept. Commerce, Bureau Census, v. 1, pt. 14, 211 p.

_______1967, 1964 U.S. census of agriculture: U.S. Dept. Commerce, Bureau Census, v. 1, p. 14, 367 p.

_______1972, 1969 U.S. census of agriculture: U.S. Dept. Commerce, Bureau Census, sec. 1, v. 1, pt. 14, 576 p.

_______1977, 1974 U.S. census of agriculture: U.S. Dept. Commerce, Bureau Census (in preparation).

U.S. Federal Water Pollution Control Administration, 1968, Report of the committee on water quality criteria: Washington, D.C., 234 p.

U.S. Geological Survey, 1974, Water resources data for Wisconsin, 1973: U.S. Geol. Survey Ann. Rept., 258 p.

_______1975, Water resources data for Wisconsin, 1974: U.S. Geol. Survey Ann. Rept., 347 p.

_______1976, Water resources data for Wisconsin, 1975: U.S. Geol. Survey Ann. Rept., 380 p.

U.S. Public Health Service, 1962, Drinking water standards, 1962: U.S. Public Health Service Pub. 956, 61 p.

U.S. Salinity Laboratory staff, 1954, Diagnosis, and improvement of saline and alkali soils: U.S. Dept. Agr. Handb. 60, 160 p.

Uttormark, P. D., Chapin, J. D., and Green, K. M., 1974, Estimating nutrient loadings of lakes from non-point sources: Wisconsin Univ., Madison, Water Resources Center, U.S. Environmental Protection Agency Rept. EPA-660/3-74-020, 112 p.

Weeks, E. P., 1964a, Use of water-level recession curves to determine the hydraulic properties of glacial outwash in Portage County, Wisconsin: U.S. Geol. Survey Prof. Paper 501-B, p. B181-B184.

_______1964b, Field methods for determining vertical permeability and aquifer anisotropy: U.S. Geol. Survey Prof. Paper 501-D, D193-D198.

_______1969, Determining the ratio of horizontal to vertical permeability by aquifer-test analysis: Water Resources Research, v. 5, no. 1, p. 196-214.

Weeks, E. P., Ericson, D. W., and Holt, C. L. R., Jr., 1965, Hydrology of the Little Plover River basin, Portage County, Wisconsin, and the effects of water resource development: U.S. Geol. Survey Water-Supply Paper 1811, 78 p.

Weeks, E. P., and Stangland, H. G., 1971, Effects of irrigation on streamflow in the central sand plain of Wisconsin: U.S. Geol. Survey open-file rept., 113 p.

Wisconsin Statistical Reporting Service, 1967, Wisconsin weather: Madison, Wis., 31 p.

Table 3.--Sampling frequency and analytical schedule

	Frequency of sample collection									
	Ground water			Surface water			Bed material		Precipitation	
	Area wells	Subarea wells		Area streams	Subarea streams		Area streams	Subarea streams	Area stations	Subarea stations
	Once	Seasonal	Monthly	Once	Seasonal	Monthly	Once	Seasonal	Monthly	Occasionally
Specific conductance	X	X	X	X	X	X			X	
Temperature	X	X	X	X	X	X			X	
pH	X	X	X	X	X	X			X	
Carbon dioxide	X	X	X	X	X	X			X	
Alkalinity, total	X	X	X	X	X	X			X	
Bicarbonate	X	X	X	X	X	X			X	
Carbonate	X	X	X	X	X	X			X	
Nitrogen:										
Total	X	X	X	X	X	X			X	
Total organic	X	X	X	X	X	X			X	
Dissolved organic	X	X		X	X					X
Dissolved ammonia	X	X		X	X					X
Total ammonia	X	X	X	X	X	X			X	
Dissolved nitrite	X	X		X	X					X
Total nitrite	X	X	X	X	X	X			X	
Dissolved nitrate	X	X		X	X					X
Total nitrate	X	X	X	X	X	X			X	
Dissolved Kjeldahl	X	X		X	X					X
Total Kjeldahl	X	X	X	X	X	X	X	X	X	
Total nitrate plus nitrite	X	X	X	X	X	X	X	X	X	
Dissolved nitrate										X
Dissolved nitrate plus nitrite	X	X		X	X				X	

Table 3.--Sampling frequency and analytical schedule--Continued

	Frequency of sample collection									
	Ground water			Surface water			Bed material		Precipitation	
	Area wells	Subarea wells		Area streams	Subarea streams		Area streams	Subarea streams	Area stations	Subarea stations
	Once	Seasonal	Monthly	Once	Seasonal	Monthly	Once	Seasonal	Monthly	Occasionally
Phosphate, dissolved ortho	X	X		X	X					
Phosphorus:										
Total	X	X	X	X	X	X	X	X	X	
Dissolved	X	X		X	X					X
Dissolved ortho	X	X		X	X					X
Total ortho	X	X		X	X					
Carbon:										
Dissolved organic	X	X		X	X					X
Inorganic, total							X	X		
Organic, total							X	X		
Calcium, dissolved	X	X		X	X					X
Magnesium, dissolved	X	X		X	X					X
Sodium, dissolved	X	X		X	X					X
Sodium adsorption ratio	X	X		X	X					X
Dissolved solids, residue on evaporation	X	X		X	X					X
Hardness, Ca-Mg	X	X		X	X					X
Potassium, dissolved	X	X	X	X	X	X			X	
Chloride, dissolved	X	X		X	X					X
Sulfate, dissolved	X	X		X	X					X
Fluoride, total	X	X		X	X					X
Silica, total	X	X		X	X					X

Table 3.--Sampling frequency and analytical schedule--Continued

	Frequency of sample collection									
	Ground water			Surface water			Bed material		Precipitation	
	Area wells	Subarea wells		Area streams	Subarea streams		Area streams	Subarea streams	Area stations	Subarea stations
	Once	Seasonal	Monthly	Once	Seasonal	Monthly	Once	Seasonal	Monthly	Occasionally
Arsenic:										
Dissolved	X	X		X	X					
Total							X	X		
Boron, dissolved	X	X		X	X					X
Cadmium:										
Dissolved	X	X		X	X					
Total							X	X		
Chromium:										
Dissolved, hexavalent	X	X		X	X					
Total							X	X		
Cobalt:										
Dissolved	X	X		X	X					
Total							X	X		
Iron, dissolved	X	X	X	X	X	X			X	
Lead:										
Dissolved	X	X		X	X					
Total							X	X		
Manganese, dissolved	X	X		X	X					X
Mercury, dissolved	X	X		X	X					
Molybdenum, dissolved	X	X		X	X					
Dieldrin, total	X	X		X	X		X	X		X
Endrin, total	X	X		X	X		X	X		X
Heptachlor, total	X	X		X	X		X	X		X

Table 3.--Sampling frequency and analytical schedule--Continued

	Frequency of sample collection										
	Ground water			Surface water			Bed material		Precipitation	
	Area wells	Subarea wells		Area streams	Subarea streams		Area streams	Subarea streams	Area stations	Subarea stations
	Once	Seasonal	Monthly	Once	Seasonal	Monthly	Once	Seasonal	Monthly	Occasionally
Heptachlor epoxide, total	X	X		X	X		X	X		X
Lindane, total	X	X		X	X		X	X		X
Toxaphene, total	X	X		X	X		X	X		X
2, 4-D, total	X	X		X	X		X	X		X
2, 4, 5-T, total	X	X		X	X		X	X		X
Silvex, total	X	X		X	X		X	X		X
Ethion, total	X	X		X	X		X	X		X
Methyl parathion, total	X	X		X	X		X	X		X
Methyl trithion, total	X	X		X	X		X	X		X
Trithion, total	X	X		X	X		X	X		X
Zinc:										
Dissolved	X	X		X	X					
Total							X	X		
Lithium, dissolved	X	X		X	X					
Selenium, dissolved	X	X		X	X					
Aldrin, total	X	X		X	X		X	X		X
DDD, total	X	X		X	X		X	X		X
DDE, total	X	X		X	X		X	X		X
DDT, total	X	X		X	X		X	X		X
Parathion, total	X	X		X	X		X	X		X
Diazinon, total	X	X		X	X		X	X		X
Chlordane, total	X	X		X	X		X	X		X
PCB, total	X	X		X	X		X	X		X
Malathion, total	X	X		X	X		X	X		X