HYDROLOGIC RECONNAISSANCE AND SUMMARY OF EXISTING DATA ON SURFACE AND GROUND-WATER RESOURCES IN THE MISSOURI RIVER VALLEY IN WOODBURY AND MONONA COUNTIES, IOWA, 1985

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CONVERSION FACTORS

For the use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
	Length	
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	hectare
	Volume	
gallon (gal)	3.785	liter (L)
cubic foot (ft^3)	0.02832	cubic meter (m^3)

National Geodetic Vertical Datum of 1929 (NGVD of 1929): A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

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ABSTRACT

A hydrologic reconnaissance of the Missouri River valley in western Iowa was begun in 1985. The study area is about 400 square miles of Missouri River flood plain used mainly for agricultural purposes and is located mostly in parts of Woodbury and Monona Counties, Iowa. The reconnaissance was conducted to determine the extent of hydrologic information available for the study area and to determine if the existing data base is sufficient to support an interpretive investigation to quantify the ground-water/surface-water relationships in the area. Extensive information concerning the surface-water resources of the area, particularly the Missouri River, is available. Very little information concerning the geometry, hydraulic characteristics and ground-water flow relationships in the alluvial aquifer is available. Information needs to be collected to create an adequate data base for future simulation of ground-water flow and to calibrate any estimates of flow.

INTRODUCTION

The Missouri River and its flood plain have been subjected to stream-flow regulation and channel stabilization. Among the possible changes that have occurred due to regulation and stabilization, are changes in the relationship between the Missouri River and the river valley alluvial aquifer. On March 1, 1985 the United States Army Corps of Engineers (COE) requested that the U.S. Geological Survey initiate a study of the ground-water/surface-water relationships in a part of western Iowa where changes in the river and adjacent alluvial aquifer may have occurred.

Purpose and Scope

Hydrologic changes have occurred in the Missouri River valley in western Iowa since the completion of mainstem dams upstream on the Missouri River. Missouri River channel elevations and stages at specific water discharges have decreased. These decreases may have altered the gradient between the Missouri River and the alluvial aquifer. These changes in the ground-water/surface-water relationships near the Missouri River are believed to have produced changes in water levels in wetland areas near the river channel. The wetland areas are the result of both natural river channel meanderings and recent channelization projects. The purposes of the overall investigation are to document the hydrologic conditions in the study area, to determine the physical and environmental factors that affect the ground-water/surface-water relationships in the area, and to attempt to quantify the ground-water flow relationships in the area. The results of this investigation may provide information necessary to protect and maintain hydrologic conditions in wetland areas on the alluvial plain.

The investigation is limited to a selected part of the Missouri River and the Missouri River alluvial aquifer. Data collection activities will occur mainly in Iowa because of the relatively small portion of the river valley on the Nebraska side of the navigation channel at this particular location. Data analysis and interpretation will be done for the entire river and aquifer system within the study area.

The purpose of this report is to summarize the field reconnaissance and data base search that were carried out in Fiscal Year 1985.

Location

The study area is located in extreme western Iowa and is contained in portions of Woodbury and Monona Counties (fig. 1). A relatively small portion of the river valley is located in extreme northeastern Nebraska and contained in parts of Dakota and Thurston Counties.

The study area is arbitrarly bounded on the north by latitude 42°22'30", which is about eight miles south of Sioux City, Iowa and on the south by Iowa State Highway 175. The east and west boundaries of the study area extend to the base of the bluffs at the river valley's edge (fig. 1). The study area encompasses about 400 square miles. The valley between the bluffs on the east and west consists of alluvial and eolian deposits of loess, silt, clay, sand and gravel. The land surface elevation of the valley is generally about 1050 feet above sea level and is quite flat except near the present channel of the Missouri River where terraces, sloughs, and abandoned channel meanders are numerous. Some of the wetland areas near the river are a result of abandonment of former river beds during the stabilization of the present navigation channel of the Missouri River. Most of the land within the study area is used for the production of corn and soybeans.

Previous Studies

Information documenting the parameters and hydrologic conditions that affect the flow relationships between the Missouri River and the alluvial aquifer is sparse. Ground-water/surface-water relationships are affected by the geometry of the alluvial aquifer, boundary conditions, water levels, aquifer storage, permeability and transmissivity, and the sources and amounts of recharge and discharge.

Early reports containing references to the study area are based on field reconnaissance of the area by knowledgeable persons of the time. The description by Bain (1895) and Shimek (1909) are typical of these early field reconnaissances. Other early works deal primarily with the origin and age of the Missouri River and valley.

Several other hydrologic studies in western Iowa have included maps of the bedrock surface as a part of their scope of work. Burkart (1984) and Hansen and Runkle (1984) contain maps of the bedrock surface in northwestern and west-central Iowa respectively. In general, these studies are regional in character and contain extrapolated or interpreted data in the Missouri River valley because of the lack of reliable bedrock control data in the valley.

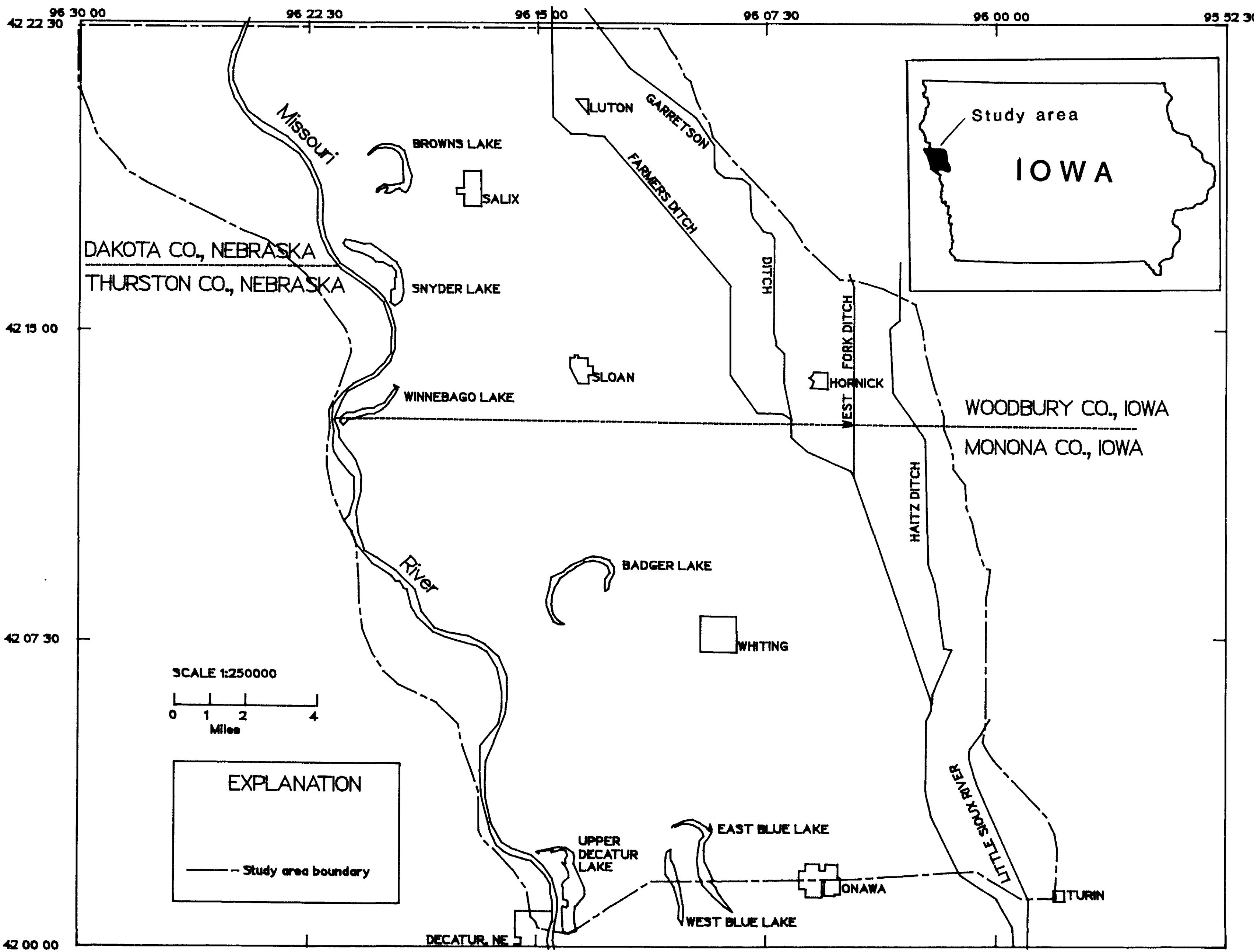

Figure 1.--Index map of study area

Hydraulic properties of the alluvial aquifer have not been documented. The abundance of relatively good quality water in the area, at times overly abundant, has resulted in the lack of exploration and mapping of the ground-water resources. To paraphrase one local resident, "we don't have an underground river here, we have an underground ocean".

The definitive work on the hydraulics and sediment characteristics of the Missouri River has been published by the U.S. Army Corps of Engineers (1981). This is being continually updated to include new data; U.S. Army Corps of Engineers (1983) and U.S. Army Corps of Engineers (1985). Detailed data on present and historical stream-flow for the Missouri River and other local streams are contained in U.S. Geological Survey (1903-60), U.S.Geological Survey (1969), U.S. Geological Survey (1973) and U.S. Geological Survey (1967-84).

Several studies concerning specific aspects of the oxbow lakes within the study area have been conducted. Ludvigson (1977), Lohnes, Dougal, and Speiran (1977), Lohnes, Dougal, Johnson, and Bachman (1977), Lohnes, Bachman, and Austin (1979), and Lohnes, Bachman, and Austin (1982) conducted a series of investigations to determine the relationships of western Iowa oxbow lakes to the water table. Observation wells were installed around the lakes to obtain near-surface geologic information and measure water levels. Much of the effort in these studies was focused on East Blue Lake (fig. 1). These studies estimated a coefficient of permeability for the surficial materials near East Blue Lake ranging from 0.085 to 126 feet per day. The locations of various sand, silt, and clay units near the lake were mapped and presented in stratigraphic cross-sections. The holes drilled for the purposes of defining surficial geology and water-level measurements were not drilled to bedrock. Potentiometric contour maps of the water table were prepared and compared to lake morphology and water-level measurements. It was determined that East Blue Lake was perched above the water table at times and that at other times the northern part of the lake was below the water table while the southern part of the lake was above the water table. Water levels in the lake ranged from 0.5 feet below the water table to 3.1 feet above the water table. The slope of the water table was estimated to be 1 to 3 feet per mile towards the southwest. Several techniques were used to estimate seepage from the lake. The annual seepage loss from the lake was estimated to be about 1700 acre-feet per year. The studies concluded that the water level in the lake paralleled the local ground-water levels. No correlation could be made between the lake water levels and the Missouri River water levels. It was also concluded that the lake water levels were dependent on both surface and subsurface recharge.

SURFACE-WATER RESOURCES

The Missouri River in the study area has been extensively studied as part of a larger investigation concerning the aggrading and degrading of the river channel below the Missouri River mainstem dam at Yankton, South Dakota (U.S. Army Corps of Engineers, 1981). Much is known about the hydraulics and the sediment-carrying capacity of the river in the study area. The changes that have occurred in the river stages, discharges, channel morphology and composition, and sediment composition in the study area are well documented. Table 1 includes a summary of the information available from five permanent surface-water data collection sites in or near the study area. Locations of these sites are shown on Figure 2. Stage/discharge relationships have been developed for these sites by the U.S. Geological Survey. Because continuous stage information which can be converted to discharge data is collected at the Sioux City site, more detailed information on the annual variations in stage/discharge are available for this site than for the Decatur, Nebraska site, where only periodic stage/discharge measurements are made. Additional stage information has been collected intermittently over the past 20 years from several oxbow lakes and at specific points along the Missouri River by the COE.

Table 1.--Information available at permanent surface-water data collection sites in and near the study area

Station No.	Station Name	Type of record	Period of record	Drainage Area (Mi**2)	Average Annual Discharge (cfs)	1982 Annual Discharge (cfs)
06486000	Missouri River at Sioux City, IA	continuous stage/discharge	10/1897 to present	314,600 (approx)	31,999	30,000
06601200	Missouri River at Decatur, NE	periodic stage/discharge	--	--	--	--
06602020	West Fork Ditch at Hornick, IA	continuous stage/discharge	4/1939 to present	403	98.8	105
06602400	Monona-Harrison Ditch nr Turin, IA	continous stage/discharge	4/1939 to present	900	219	204
06607500	Little Sioux River nr Turin, IA	continous stage/discharge	4/1939 to present	3526	1245	2177

The Corps of Engineers (1985) has reported the declines in the water surface elevations at Sioux City, Iowa and Decatur, Nebraska. At a discharge rate of 30,000 cubic feet per second (cfs) the water surface has declined by 9.1 feet between 1929 and 1984 at Sioux City. The water surface has declined 5.7 feet at Decatur at a discharge rate of 30,000 cfs between 1957 and 1984. In 1984, the water surface elvation at a discharge rate of 30,000 cfs was 41.3 feet higher at Sioux City than at Decatur. This is a slope of about 1.00 feet per river mile.

The principal Iowa surface-water drainages and their locations are shown on Figure 2. Headwaters of the major tributary streams to the Missouri River are in upland areas north and east of the study area and have drainage areas of hundreds of square miles. These streams enter the valley from the east and flow along the eastern side of the valley throughout the study area. All streams, with the exception of Sand Hill Lake Ditch, are part of the Little Sioux River drainage basin and the confluence of the Little Sioux with the Missouri River occurs about 16 miles south of the study area. Most of the natural surface-water drainages on the flood plain within the study area have been channelized and straightened. In some cases the historical channels of these streams have been abandoned but are still expressed on the land surface as sloughs and seasonally wet areas.

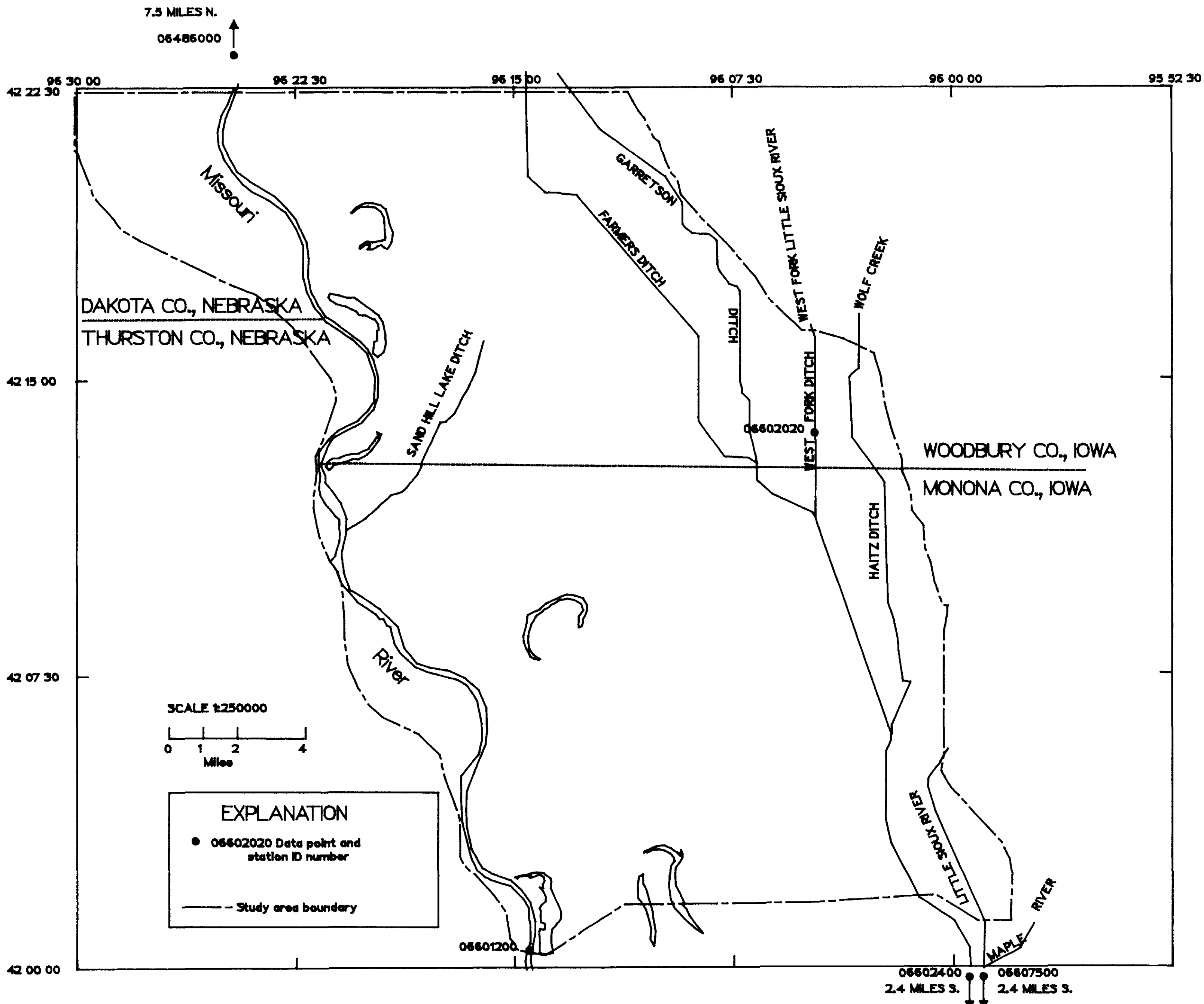

Figure 2.--Location of principal surficial drainage and surface-water data collection sites

An extensive network of small drainage ditches exists in the study area. These ditches generally occur along every road in the study area. The ditches collect surface runoff and excess water from irrigation and discharge this water to the larger channelized streams in the area. Additionally, the drainage ditches may have an impact on ground-water levels during periods of high ground-water levels.

Remnants of the Missouri River's earlier channels also are present in the form of oxbow lakes, sloughs, backwater areas adjacent to the present navigation channel, and topographically low areas on the alluvial plain. Some of these abandoned channel areas are the result of channelization and stabilization projects within the last 50 years. According to Hallberg and others (1979) East and West Blue Lake and Badger Lake (fig. 1) were formed by the shifting channel of the Missouri River between 1804 and 1852. Browns Lake was formed sometime before 1856. The U.S. Army Corps of Engineers (1981) reports that Snyder Lake, Upper Decatur Lake, and Winnebago Lake were formed during the realignment of the present navigation channel between 1957 and 1962. Many of these surface-water bodies may have closed drainage areas and rely on precipitation and ground-water flow to maintain their water levels.

GROUND-WATER RESOURCES

The alluvial aquifer of the Missouri River in the study area consists of unconsolidated sands, gravels, silts, and clays. The valley is bounded on the east and west by unconsolidated deposits of Quaternary age. The uppermost bedrock beneath the valley is composed of sandstone and shales of Cretaceous age. The Dakota Formation is a Cretaceous-age sandstone that is an important source of water for residents of northwestern Iowa and is known to outcrop in the Sioux City area (Northwest Chapter, Iowa Engineering Society, 1963). The locations of wells that have been drilled through the valley alluvium and the bedrock surface elevation at each location are shown in Figure 3. An indication of the thickness of the alluvial deposits is possible by subracting the bedrock surface elevation at the locations shown in Figure 3 from the land surface elevations at those locations. The thickness of the alluvium ranges from about 100 to 160 feet at the locations of the known bedrock surface elevations shown on Figure 3. Table 2 contains driller's logs from selected typical wells drilled in the study area.

The Missouri River alluvial aquifer is usually considered to be an unconfined aquifer, however, because of local variations in permeability, some areas and depths may exhibit semi-confined or confined aquifer characteristics. Water levels measured during the summer of 1985 in the alluvial aquifer ranged from near land surface in topographically low areas to about 20 feet below land surface in areas of higher elevation on the alluvial plain. Several flowing wells have been reported or were located during the field reconnaissance. It is not known whether they are the result of locally confined conditions in a regionally unconfined aquifer or if the well is finished in a separate aquifer with a higher potentiometric surface.

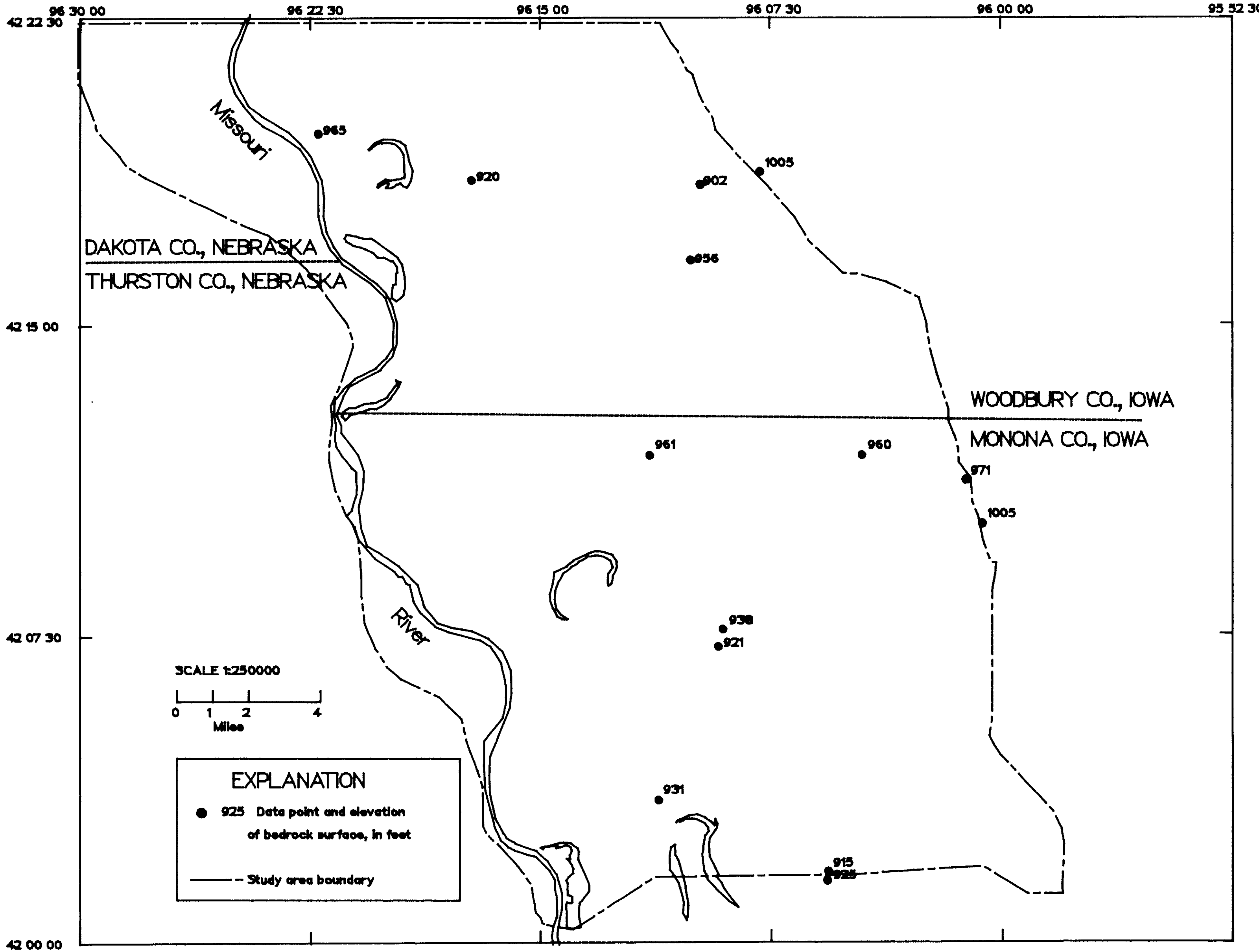

Figure 3.--Location of wells drilled to bedrock and elevation of bedrock surface in these wells

Table 2.--Selected driller's logs from area wells

Well Owner - City of Sloan
Location - Sloan, Iowa

interval	material
0-3'	top soil
3-19'	yellow clay
19-28'	fine sand and lignite
28-63'	coarse to fine sand
63-66'	lignite and wood
66-82'	medium sand and lignite
82-97'	sand and gravel

Well Owner - City of Whiting
Location - Whiting, Iowa

interval	material
0-4'	soil
4-24'	silt
24-30'	medium sand and silt
30-49'	sand, grit, and gravel
49-60'	grit and gravel with clay balls and black rocks
60-77'	silt and fine sand
77-80'	coarse sand, grit and gravel
80-93'	sand and gravel
93-100'	coarse sand and grit, some pebbles
100-106'	grit and gravel, with some cobbles
106-121'	sand, grit, and gravel with many well rounded pebbles

Well Owner - City of Onawa
Location - Onawa, Iowa

interval	material
0-5'	black loam
5-22'	sandy clay
22-32'	blue clay
32-40'	fine sand
40-57'	sand and gravel
57-64'	blue clay and fine sand
64-75'	fine sand
75-85'	sand and gravel
85-90'	coarse sand
90-100'	sand and gravel
100-104'	coarse sand
104-110'	gravel

Well Owner - City of Salix
Location - Salix, Iowa

interval	material
0-60	blue clay
60-160	course gravel
160-170	sandstone

Well Owner - Lakin Enterprises
Location - 3 mi e. and 3 mi n. of Sloan, Iowa

interval	material
0-2	black soil
2-8	brown clay
8-26	gray clay
26-40	silty sand
40-50	fine sand
50-60	course sand, gravel and fine sand
60-80	course sand and gravel
80-114	gravel and course sand few boulders at 105'
114-116	red shale

Well Owner - Farmland Foods
Location - 4 mi w. of Salix, Iowa

interval	material
0-2	fill
2-30	fine sand
30-36	gravel, course sand
35-53	course sand with clay
53-57	blue clay
57-95	gravel, course sand, pebbles
95-107	course to fine sand
107-154	gravel, course sand, pebbles, loose
154-164	sandstone

Recharge to the alluvial aquifer may be derived from a variety of sources including rainfall, melting snow and ice, and water in temporary surface storage. Figure 4 shows the annual precipitation for Sioux City and Onawa, Iowa (National Oceanic and Atmospheric Administration, 1970-84).

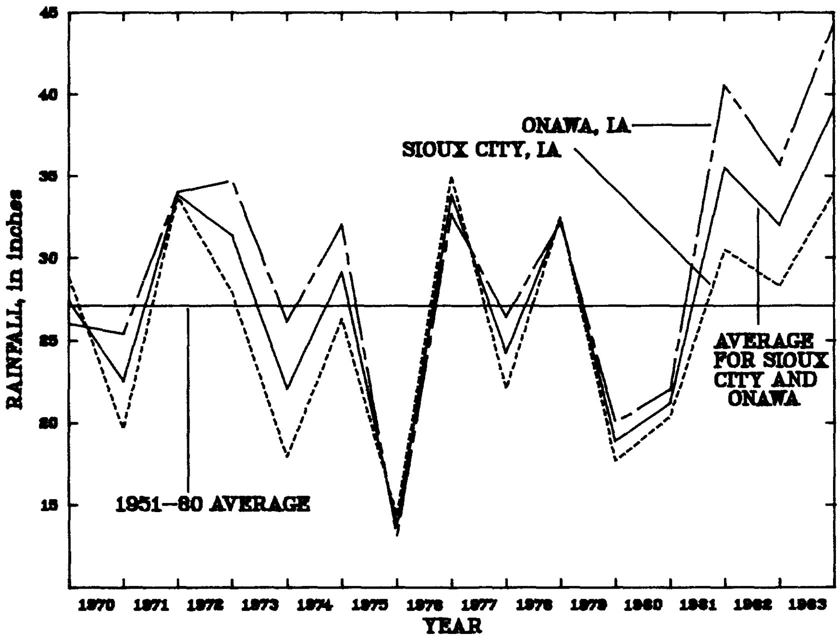

Figure 4.--Average annual precipitation data for Sioux City and Onawa, Iowa, 1970-83

Additional potential sources of water to the aquifer are dependent on water-level gradients between the aquifer and the potential source. At times or at specific locations, water from the Missouri River and other streams in the area may enter the aquifer. Because water levels may be much higher in upland areas, the upland valley sides may provide vertical and lateral flow of ground water into the alluvial aquifer. The bedrock materials beneath the aquifer may provide a source of water to the aquifer, either through direct hydraulic contact between the alluvial aquifer and the underlying Cretaceous-age aquifer or by upward leakage through a confining bed between the alluvial aquifer and the underlying aquifer. Water-level gradients between the alluvial aquifer and other local ground-water systems are not known.

Discharge from the alluvial aquifer also may take several routes. Evapotranspiration may play an important role in an overall water budget for the area because of the close proximity of the water table to the land surface and plant root zone. Some idea of potential evaporation is obtained by examining pan evaporation data obtained by the National Weather Service at Castana, Iowa, (National Oceanic and Atmospheric Administration, 1970-84) about five miles east of the study area. Evaporation data, available only during non-freezing weather, is shown on Figure 5. It should be noted that the average annual pan evaporation rate for the period of record exceeds the annual average precipitation rate for the study area (fig. 4), however actual evapotranspiration may be somewhat less than the potential evaporation as measured by pan evaporation rates.

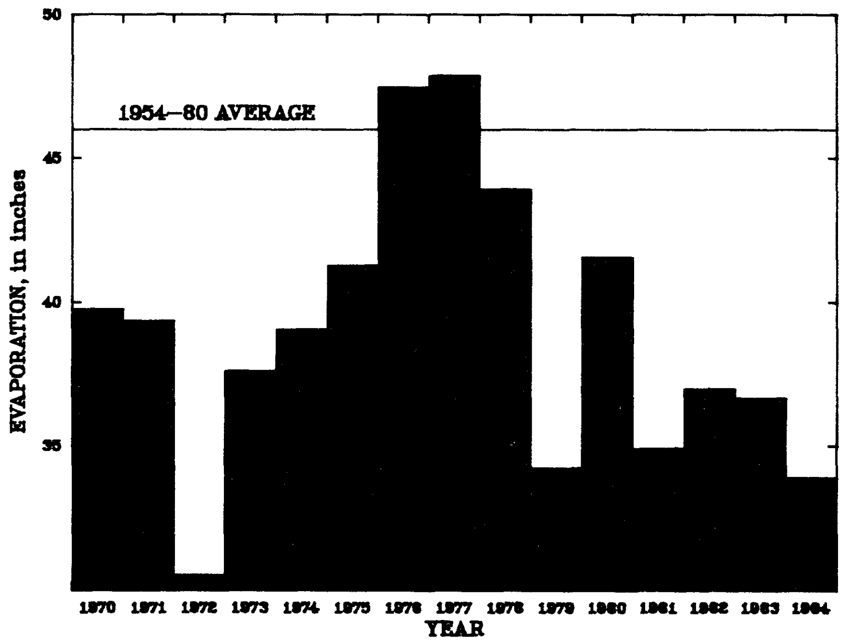

Figure 5.--Annual pan evaporation at Castana, Iowa, 1970-84

The other natural avenues of discharge are dependent on water-level gradients. The alluvial aquifer may provide water to the Missouri River and other local streams during times of base flow. No estimates of the ground-water discharge to area streams are available. The alluvial aquifer may also transmit water vertically and laterally to other ground-water systems.

Pumpage is another way water may be discharged from the aquifer. The Iowa Department of Water, Air and Waste Management (written commun., 1985) reports the present annual permitted withdrawal from the alluvial aquifer in the study area is 38,621.3 million gallons per year or about 118,470 acre-feet per year. In general, most water users obtain water from the alluvial aquifer, however some withdrawals are made from deeper Cretaceous sources. Table 3 lists the towns within the study area and their sources of water. Rural water use consists of domestic, livestock watering, and irrigation uses. Irrigation is by far the largest withdrawal use of water from the alluvial aquifer. About 74,500 acres within the study area are under permit for irrigation. Permitted irrigation users are required to report their annual pumpage to the Iowa Department of Water, Air and Waste Management.

Table 3.--Public water supplies in the study area

Town	Public Supply	Aquifer	1980 Pumpage (gallons)
Hornick	Yes	Alluvium	17,084,000
Luton	No	--------	-----
Onawa	Yes	Alluvium	160,080,000
Salix	Yes	Alluvium	21,115,000
Sloan	Yes	Alluvium	36,063,000
Turin	No	--------	-----
Whiting	Yes	Alluvium	34,794,000

The locations of irrigation and industrial wells field located in the spring of 1985 are shown in Figure 6. The field reconnaissance indicated about 120 irrigation wells in the Woodbury County, Iowa part of the study area, with about 55 connected to center-pivot sprinkler systems. The Monona County part of the study area contained 288 irrigation wells, with 136 connected to center pivots. The Nebraska side of the valley was not inventoried during 1985. Active wells that were not equipped with center-pivot sprinklers were used for flood irrigation or the transfer of the sprinkler apparatus from another site. Some wells appeared to have been abandoned for a number of years. Area residents report that the center pivot sprinklers are used at least once each year, in order to maintain the equipment, even if the crops do not need supplemental water.

Very little information about the hydraulic characteristics of the aquifer is documented. Reports from local well drillers indicate that the aquifer may be able to supply up to 5000 gallons per minute to a properly constructed well. Owners of irrigation wells report drawdowns ranging from 10 to 40 feet when pumping about 1100 gallons per minute. Recovery to pre-pumping water levels is reported to be nearly instantaneous. It should be noted that most measurements concerning aquifer performance are made in wells that are open only to a part of the saturated thickness of the aquifer.

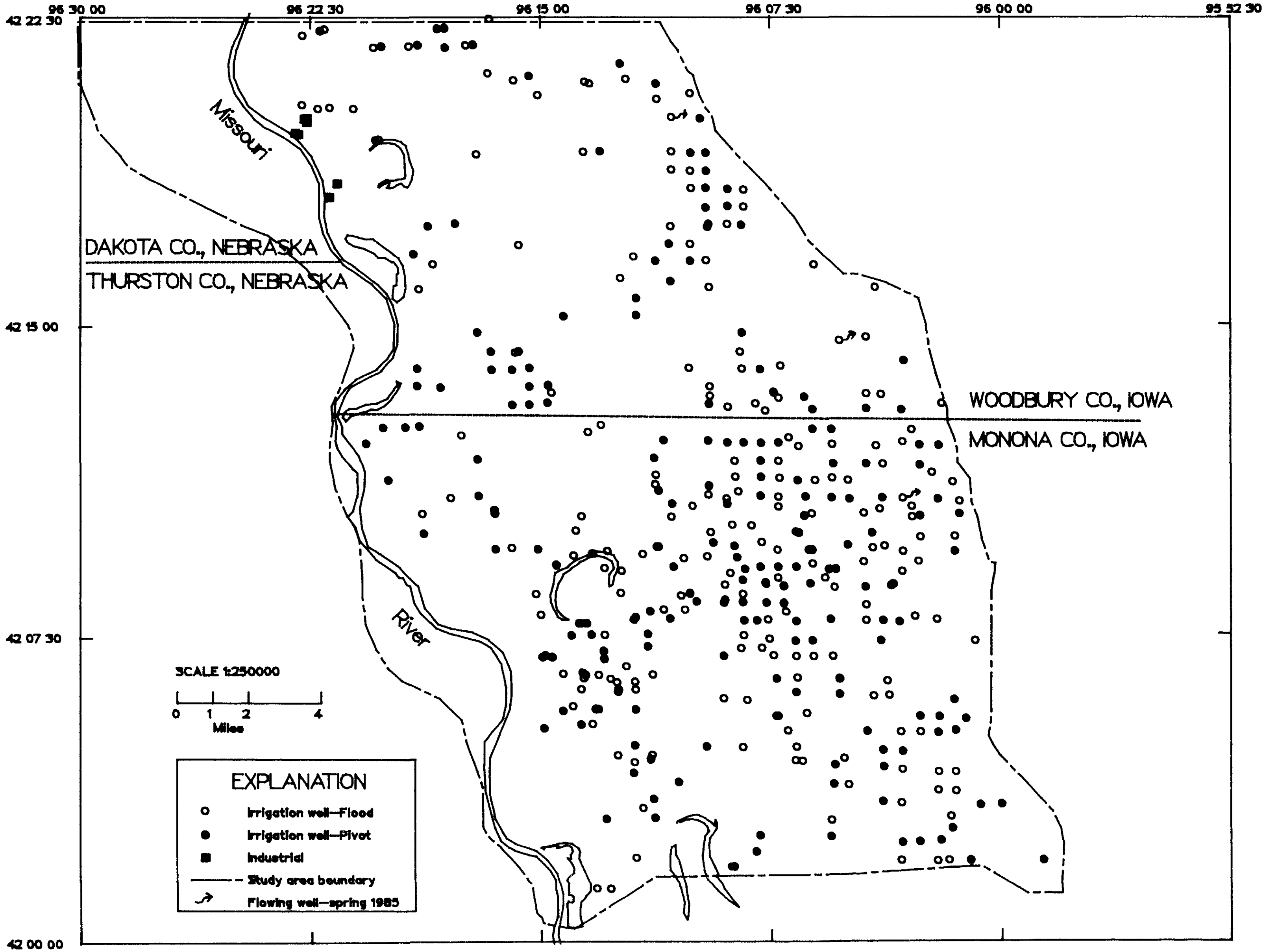

Figure 6.--Irrigation and industrial well locations

GROUND-WATER/SURFACE-WATER RELATIONSHIPS

Water-level measurements in observation wells and stages in oxbow lakes and the Missouri River have been obtained by the COE to determine hydrologic relationships between the Missouri River and two wetland areas (fig. 7). Data collection began at the Synder-Winnebago oxbow lakes area in October 1966 and near the Upper-Decatur oxbow lake in March 1979. Measurements which have been made intermittently since the starting dates are usually dependent upon access to many of the sites. Some of the observation wells are no longer measured because of access limitations or because the well has been destroyed.

Hydrographs of the data collected from these two areas provide a graphical means of comparing water-level relationships and trends at each area. Figure 8 shows the historical elevation of the water-levels in observation well, S-2 (fig. 7), and the Missouri River stage at Sioux City, Iowa. Well S-2 is about 0.8 miles east of Snyder Lake. The river stage elevations near Snyder Lake may be quite different because of the difference in water-surface elevation between Sioux City and the Snyder Lake area. Actual measurements of river stage near Snyder Lake need to be made to determine the gradient between the river and aquifer at this location. Measurements also need to be made frequently to determine the magnitude and duration of gradient changes.

More detailed information on ground-water/surface-water relationships is available in the Upper-Decatur Oxbow Lake area. Figure 9 is a hydrograph of well T-3 (fig. 7) and the Missouri River stage at Decatur, Nebraska (fig. 2).

Data collected during 1981 from the Upper-Decatur Oxbow Lake area are illustrated in Figure 10, which shows the water levels in wells T-3 and T-4 (fig. 7) and stages of the oxbow lake and Missouri River. The Upper-Decatur oxbow lake is separated from the navigation channel of the Missouri River by a narrow strip of land several hundred feet wide. Well T-3 is an observation well adjacent to the oxbow lake and on the east bank of the lake. Well T-4 is located about 0.5 miles east of the oxbow lake. Notice that the oxbow lake stage was the highest water level measured during the summer months.

The magnitude of water-level changes in the central part of the river valley during this time period are not known. Water-level measurements were begun in 1985 in several irrigation wells throughout the study area. The location of these wells is shown in Figure 7. Measurements made from May to August 1985 in these wells indicate a decline of about 4 to 5 feet during the summer months of 1985. Rainfall during this period was below normal and irrigation use was considerable.

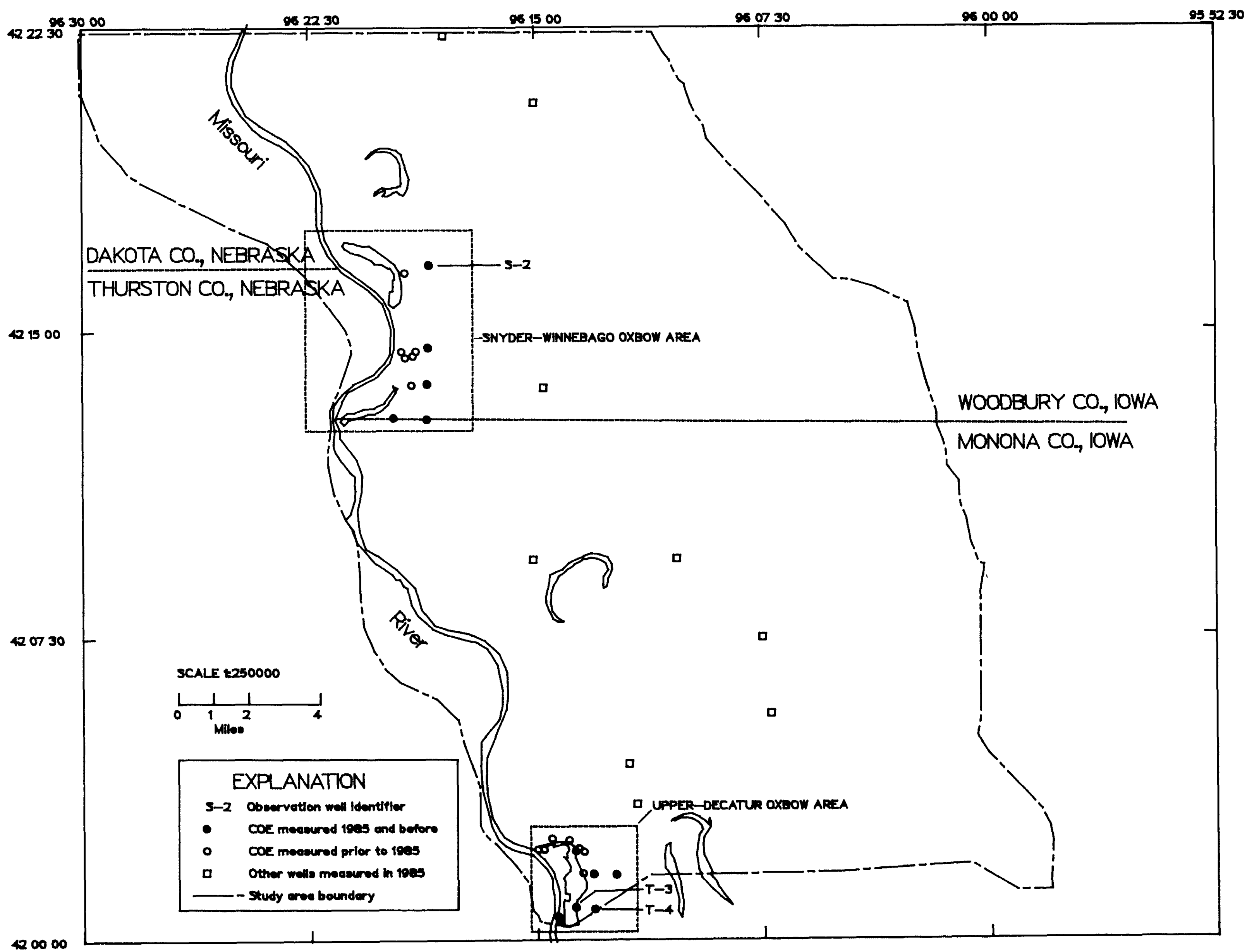

Figure 7.--Ground-water level measurement locations

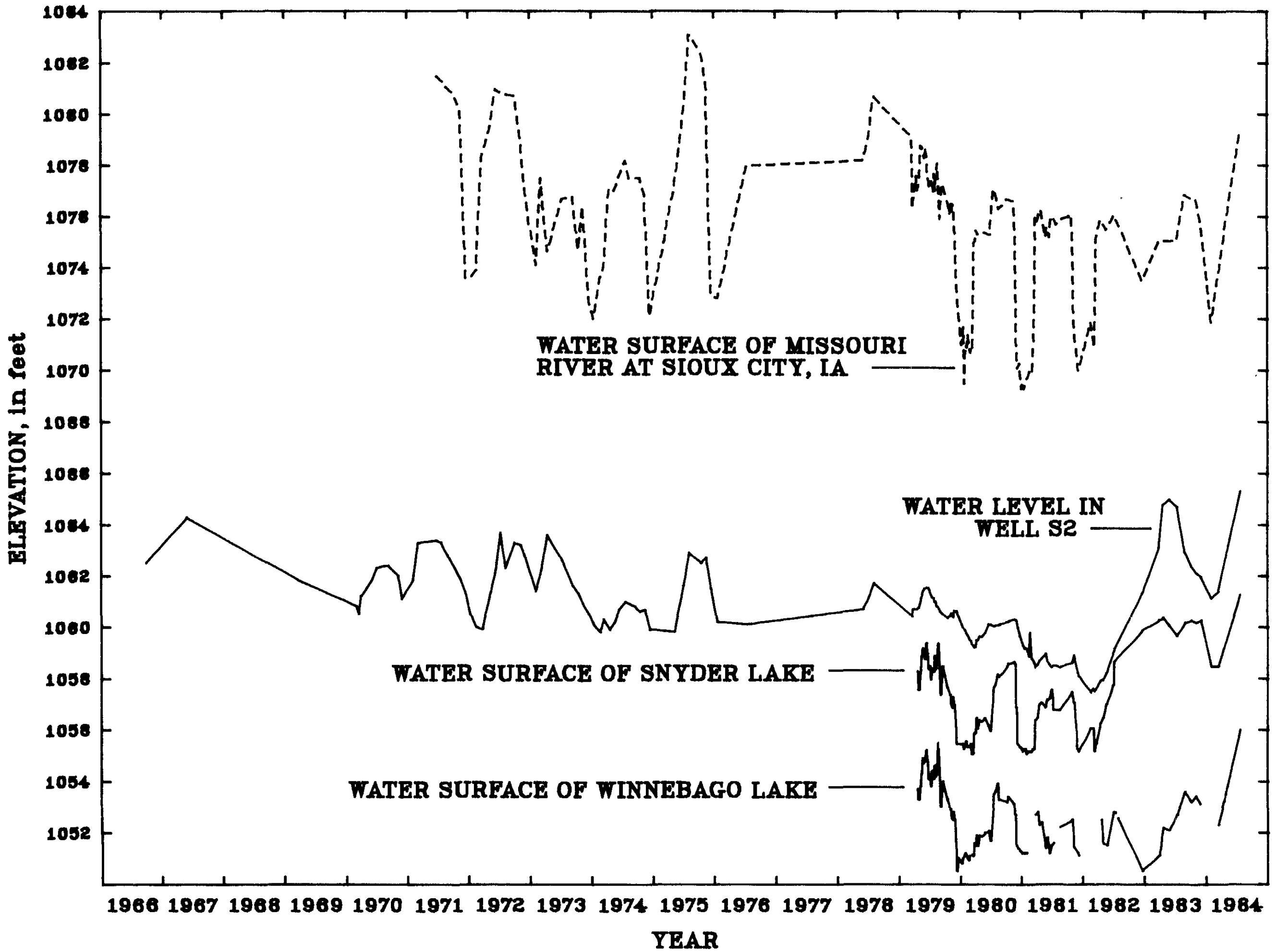

Figure 8.--Elevation of ground-water levels and oxbow lake surface near Snyder-Winnebago oxbow area and Missouri River water surface at Sioux City, Iowa, 1966-84

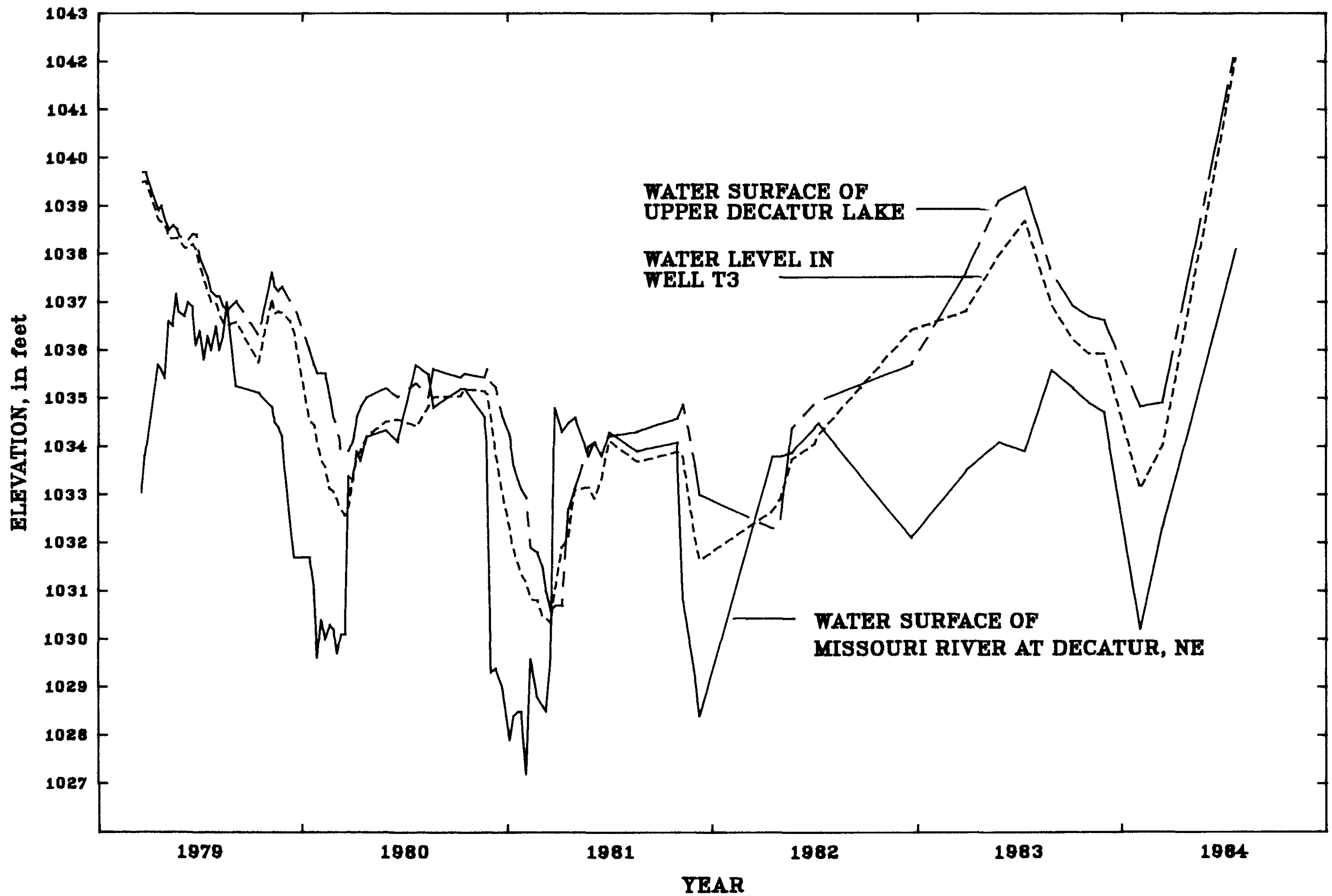

Figure 9.--Elevation of ground-water levels, oxbow lake surface, and Missouri River water surface near Upper-Decatur Oxbow Lake area, 1979-84

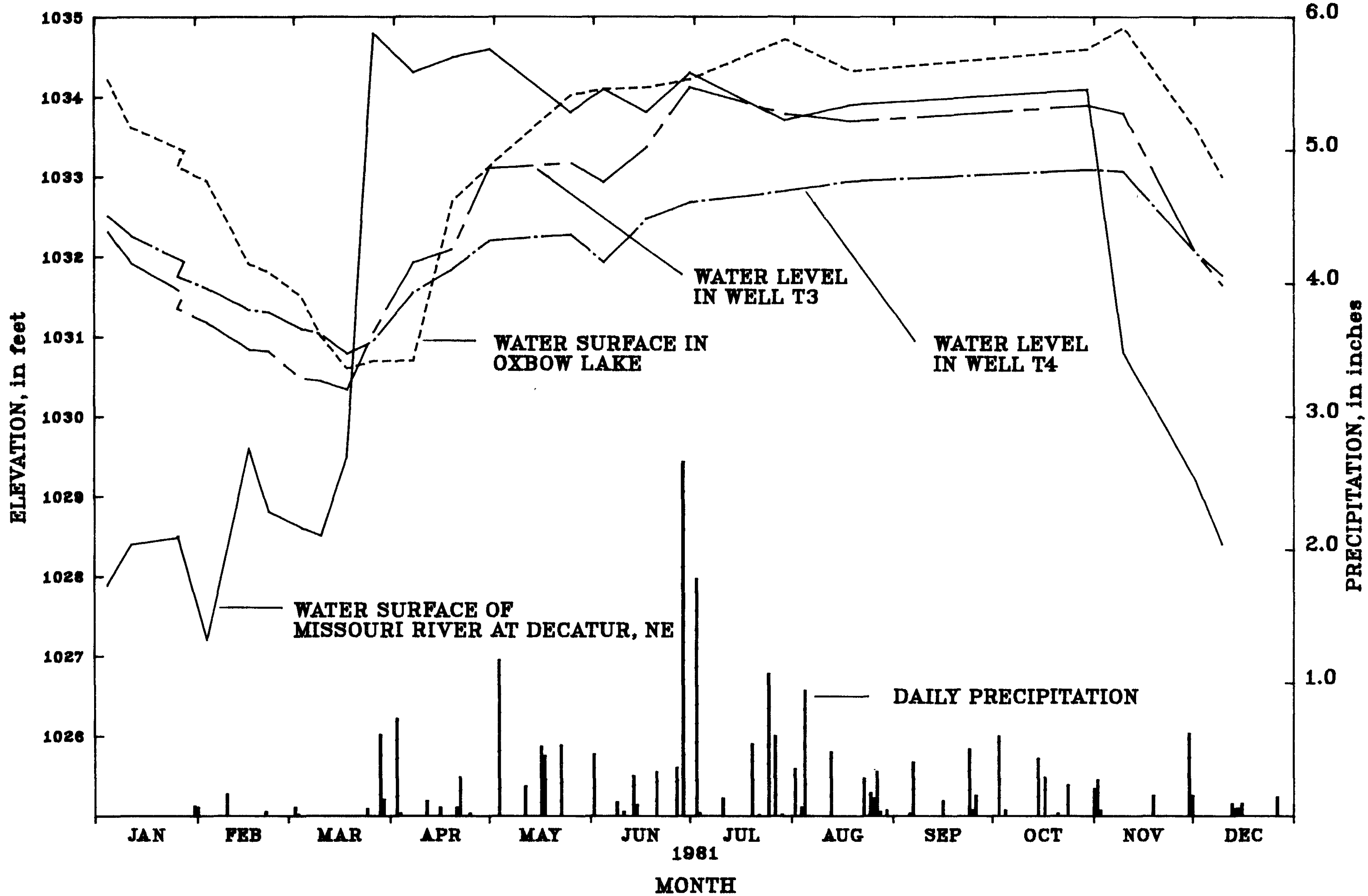

Figure 10.—Elevation of ground-water levels and river and lake water surfaces near Upper-Decatur Oxbow Lake area in 1981

SUMMARY

The Missouri River and the alluvial aquifer associated with it provide abundant water to municipal, domestic, industrial, and irrigation users throughout the study area. Most of the water used in the area is obtained from the alluvial aquifer.

Accurate and detailed surface-water data exists, which if properly supplemented, could provide adequate data input for the surface-water component of a ground-water/surface-water relationship study. Additional data collection needs to be done in some areas to quantitatively determine discharge and recharge rates. Supplemental stage data is also needed in places to determine water-level gradients.

The ground-water component of a ground-water/surface-water relationship study in this area needs a much more detailed and extensive data base than currently exists. The relative ease in obtaining large quantities of relatively good quality water has resulted in little exploratory knowledge about the variability in aquifer characteristics. The information that is available is mostly in the form of generalities that may not be sufficient to provide acceptable estimates of quantitative flow relationships in the area.

The accuracy of any quantitative estimates of flow relationships in the study area depends on the amount and quality of information available for the entire surface-water and ground-water system in the area. It is not known if calibration of these quantitative flow estimates in terms of accurate water-level predictions at specific locations is possible. However, the regional implications of the relationship between the river and the aquifer between a range of hydrologic conditions could be of use to water managers.

REFERENCES

Bain, H.F.,1895, Geology of Woodbury County, Iowa, Iowa Geological Survey Annual Report, Vol. 5, pp 241-300

Burkart, M.R., 1984, Availability and quality of water from the Dakota aquifer, Northwest Iowa, U.S. Geological Survey Water-Supply Paper 2215, 65 p.

Northwest Chapter, Iowa Engineering Society, 1963, Water resources in Sioux City and vicinity, 40 p.

Hallberg, G.R., Harbaugh, J.M., and Witinok, P.M., 1979, Changes in the channel area of the Missouri River in Iowa, 1879-1976, Iowa Geological Survey Special Report Series Number 1, prepared for the Iowa Conservation Commission, 32 p.

Hansen, R.E., and Runkle, D.L., 1984, Bedrock topography of west-central Iowa: U.S. Geological Survey Open-File Report 84-731

Lohnes, R.A., Dougal, M.D., and Speiran, G.K., 1977, Water management, water quality and alluvial-glacial morphology study of selected Iowa oxbow and shallow glacial-remnant lakes as they may be impacted by dredging, Initial report to Iowa Conservation Commission, 45 p.

Lohnes, R.A., Dougal, M.D., Johnson, M., and Bachman, R., 1977, Water management, water quality and alluvial morphology of selected Iowa oxbow lakes, Final report to Iowa Conservation Commission, 87 p.

Lohnes, R.A., Bachman, R.W., and Austin, T.A., 1979, Water management, water quality and engineering geology study of selected oxbow lakes as they may impacted by dredging--Phase II, Iowa State Water Resources Research Institute, 99 p.

Lohnes, R.A., Bachmann, R.W., and Austin, T.A., 1982, Influence of lake restoration measures on water quality and water quantity in Blue Lake, Iowa, Phase III report to Iowa Conservation Commission, 49 p.

Ludvigson, G.A., 1977, Hydrogeology of Blue Lake, Monona County, Iowa, Iowa Geological Survey Report of Investigations, 8 p.

National Oceanic and Atmospheric Administration, 1970-84, Monthly reports for Iowa, 1970-84 from Environmental Data Service, Asheville, North Carolina, 27 p.

Shimek, B., 1909, Geology of Harrison and Monona Counties, Iowa, Iowa Geological Survey Annual Report, Vol. 20, pp 273-485

U.S. Army Corps of Engineers, 1981, Volume IV supporting technical report Missouri River Degradation; Review report for water and related land resources management study, Omaha District, U.S. Army Corps of Engineers

U.S. Army Corps of Engineers, 1983, Investigation of channel degradation-1983 update, Omaha District, U.S. Army Corps of Engineers

U.S. Army Corps of Engineers, 1985, Investigation of channel degradation-1985 update, Omaha District, U.S. Army Corps of Engineers

U.S. Geological Survey, 1903-60, Surface-water supply of the United States, part 6, Missouri River Basin, 1903-60: U.S. Geological Survey Water Supply Papers (published annually)

U.S. Geological Survey, 1969, Surface-water supply of the United States; 1961-65, part 6, Missouri River Basin: U.S. Geological Survey Water Supply Paper 1918, Vol. 3, 751 p

U.S. Geological Survey, 1973, Surface-water supply of the United States; 1966-70, part 6, Missouri River Basin: U.S. Geological Survey Water Supply Paper 2118, Vol. 3, 710 p

U.S. Geological Survey, 1967-84, Water resources data for Iowa, 1966-83: U.S. Geological Survey Water-Data Reports IA-66-1 to IA-83-1 (published annually)