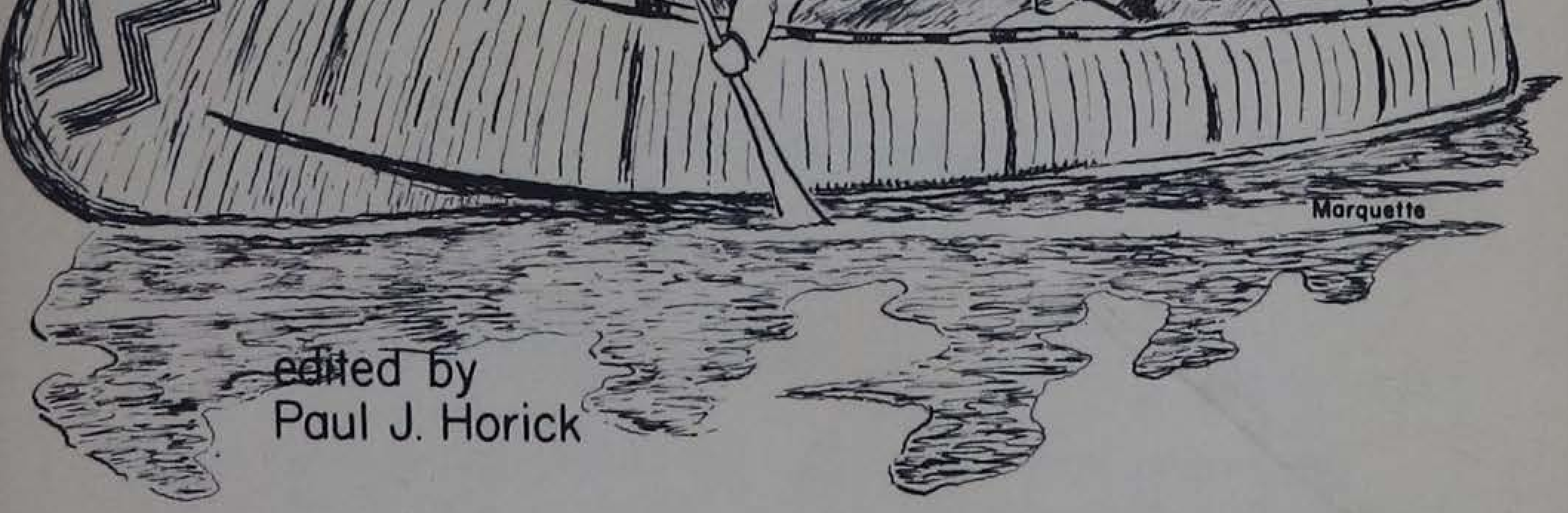
WATER RESOURCES OF IOWA

a symposium
sponsored by the
Iowa Academy of Science
1969



edited by
Paul J. Horick

Front cover

Father Marquette on the Mississippi River 1673. The famous explorer and Louis Jolliet were the first white men to use Iowa's waters.

Water Resources of Iowa

PAPERS GIVEN AT A SYMPOSIUM IN THE GEOLOGY
SECTION OF THE IOWA ACADEMY OF SCIENCE AT
THE UNIVERSITY OF NORTHERN IOWA APRIL 18, 1969

Planned and edited

by

Paul J. Horick

Ground-water geologist

Iowa Geological Survey

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Dedicated to H. Garland Hershey
State Geologist and Director of the Iowa Geological Survey
1947-1969,
Director, Office of Water Resources Research,
U. S. Department of the Interior 1969-

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Foreward

The annual volumes of the Proceedings of the Iowa Academy of Science have been printed as a hard-cover volume of several hundred pages by the State Printing Board of Iowa for many, many years. From time to time it has come to the attention of the Directors of the Academy that the traditional presentation of papers at the annual sessions and in the Proceedings could be improved, from the standpoint of interest and accessibility to interested parties. In recent years, the various section chairmen have been encouraged to plan symposia, panels, and other new approaches to enhance their section programs. This symposium on "Water Resources of Iowa" is one such effort.

This monograph is a new venture in Academy publications. Being the first of its kind, it is an attempt to present an important subject in a different way then the traditional Proceedings. It is anticipated that the monograph will be of interest to schools, colleges, conservation groups, governmental agencies, as well as Academy members, and will be available for purchase at a price well below actual printing cost.

I would like to personally acknowledge the efforts of Paul J. Horick of the Iowa Geological Survey in preparing this work for publication.

Cedar Falls
August, 1969

Robert W. Hanson
Executive Secretary
Iowa Academy of Science

PREFACE

This monograph contains eleven papers that were presented at a Water Resources Symposium held at the Eighty-First session of the Iowa Academy of Science at the University of Northern Iowa on April 18, 1969. It comprises a summary of some of the more important segments of the water resource situation in Iowa and the problems and responsibilities that have evolved in using this resource in the most beneficial way for man and protecting it for succeeding generations.

The Symposium was planned and organized with an acute awareness of our water resources problems, the need for data accumulation and research, and for regulation and management so that the water resource will be used wisely for all concerned.

Today, there is a large body of literature on water research in the nation. Many State and Federal agencies working in Iowa give high priority to water research, but most of this is of a specialized nature. There is a definite need for a publication providing an overall view of our water resources and summarizing the latest ideas and thinking. This publication is directed to the people of Iowa, and her government leaders, industrialists, engineers, hydrologists, conservationists, teachers, lawyers, economists, farmers, recreation planners and others interested in our water resources so that they may be informed.

Although the amount of information that could be presented at the Symposium was limited by the short time available, the papers in this monograph are more detailed and include illustrations. Of course, this work is not all inclusive. It does not attempt to cover every phase of the water story in Iowa. It does clearly point out the vital nature of the subject and its relation to human problems, offers some solutions, and suggests areas for further study.

I am deeply grateful to the men who contributed to the Symposium and to the Board of Directors of the Iowa Academy of Science for consenting to publish the monograph. With all humbleness, I believe this work will be a significant contribution to the water resources field and that it will be a useful reference for present and following researchers.

Acknowledgement is due to Dr. Robert W. Hanson for encouraging this publication; to Walter L. Steinhilber for counsel on the general composition of the Symposium; and to Dr. H. Garland Hershey for facilitating arrangements for the printing. Mrs. Brenda Harms patiently typed and retyped the manuscripts for the printer. Mrs. Diana Pribyl drafted many of the illustrations.

Iowa City
July, 1969

Paul J. Horick
1969 Chairman
Geology Section
Iowa Academy of Science

PAUL J. WAITE

A native of New Salem, Illinois, Mr. Waite took his education at Western State University, Macomb, at the University of Chicago, and the University of Michigan, the latter granting the M. S. degree. Presently he is with the U. S. Department of Commerce, Environmental Science Services Administration, as the State Climatologist of Iowa, located in Des Moines. He has held this position since 1959. He also teaches classes in meteorology and climatology at Drake University. He formerly served as a meteorologist with the U. S. Air Force in Florida and Korea and with the U. S. Weather Bureau in Chicago, Kansas City, and Madison, Wisconsin. He was State Climatologist of Wisconsin from 1956-1959. Mr. Waite has written several scientific papers and popular articles on Iowa and Wisconsin tornadoes, climatic change, solar radiation, and applied climatology.

IOWA PRECIPITATION

Paul J. Waite
State Climatologist of Iowa

Our precipitation, perhaps second only to temperature in importance, is the most widely measured of all our meteorological parameters. Its importance is manifest in the abundance and type of life across Iowa, in the location and growth of our cities, in the creation of our soils and landscapes, and the degree of our prosperity. The flow of our streams and springs and the ground-water levels largely depend upon precipitation. Increasingly, the importance of precipitation as an atmospheric cleanser and source for flushing the pollutants from our streams is observed. The ever increasing human requirements for water has focused the public eye upon precipitation as an available source. Iowa's changing economy is vitally linked to Iowa's precipitation and drainage pattern.

The forms of precipitation falling upon Iowa include rain, snow, hail, drizzle, ice pellets, snow grains and less common forms of falling hydrometeors. Rain constitutes nearly 90 percent of our total precipitation, snow about 10 percent; other forms normally produce only small amounts. Dew, frost and fog, even though condensation therefrom may total a few inches per year, are not included as precipitation. Mostly our precipitation falls from clouds, yet not all clouds yield precipitation. It is only when the water droplets, ice pellets or crystals become large enough to overcome the atmospheric buoyancy does precipitation fall. Only during about 10 percent of the total time that clouds persist does precipitation fall over Iowa.

The measurements of rainfall, along with other meteorological elements were first measured in 1819 at a U. S. Army fort at Council Bluffs. The first Iowa cooperative observer to measure precipitation was Professor Thomas Parvin, who began taking observations in 1839 at Muscatine, Iowa. The network slowly expanded until the Federal and State weather services were each begun in the 1870's. The Iowa Weather Division began in 1875 with sixty cooperative observers. The U. S. Signal Corps Weather Service created in 1870 had a somewhat fewer number. In 1890, when the Federal and State weather services were merged in a cooperative weather service, the number of observers totaled 62; in 1910 the number was 150. The network has grown steadily to approximately 225 published sites during the recent decades. Of these 225 sites, approximately 175 are with standard eight-inch rain gages recorded once daily. These data are printed monthly and annually in Climatological Data, Iowa (CD Iowa). The remaining 50 sites are equipped with recording rain gages.

The derived hourly data are printed monthly in Hourly Precipitation Iowa (HP). Previously, hourly precipitation records appeared in the CD Iowa for the period August 1948-September 1951, and prior to August 1948 in the Upper Mississippi and Missouri River Hydrologic Bulletins. The monthly and annual totals are printed in the annual publication of Hourly Precipitation. Hourly data are available since the creation of the network in 1939. Other precipitation data regularly printed (CD Iowa) by the U. S. Weather Bureau, cooperating with the Iowa Weather Division include snow falls and snow depths.

Iowa's 225 precipitation sites are located about 15 miles apart. Since most of the gages are of 8-inch diameter, the sampling area approaches 10^{-8} of the total Iowa area. Control and inspection of sites and observers produces a reasonably good mesoscale precipitation climatology for Iowa. Generally, microscale precipitation climatology is lacking.

Early Iowa precipitation records are useful for historical and comparative purposes, but the 1931-60 period (in accordance with the World Meteorological Organization) is used to describe Iowa's precipitation climate (Waite, 1967). Figure 1 describes the 30-year average of Iowa annual precipitation. The year by year variability is considerable. State averages since 1873 indicate that the driest Iowa year of record was 1910, averaging 19.89 inches which was with less than half that falling during 1881 when 44.16 inches was the State average (1858 may have been wetter than 1881). Since 1930 average State precipitation varied from 22.77 inches in 1955 to 42.22 inches in 1951. Complete annual State values since 1873 and the nine Iowa divisions were prepared by the U. S. Weather Bureau and Iowa Weather Division and printed in the Palimpsest, January 1969. Annual precipitation variation within Iowa varies from 74.50 inches at Muscatine in 1851 to 12.11 at Clear Lake in 1910.

The annual precipitation gradient, particularly steep in northwest Iowa, varies from near 25 inches in the northwest to 34 inches in the east-central and southeast counties. The crop season precipitation (April through September), totaling some two-thirds of the annual total, exhibits a less pronounced gradient of about 20 inches northwest to around 23 inches in most eastern and southern localities (fig. 2). The crop season and monthly variabilities of precipitation from year to year are reported in Shaw and Waite (1964). Since precipitation values do not conform to a normal distribution, other methods of describing precipitation are used. The gamma distribution parameters were used by Barger, Shaw and Dale (1959 and 1960) to determine weekly and also two- and three-weekly precipitation total probabilities. Feyerherm, Bark and Burroughs (1965) describe daily and longer period dry and wet probabilities. Waite (1966) adapted

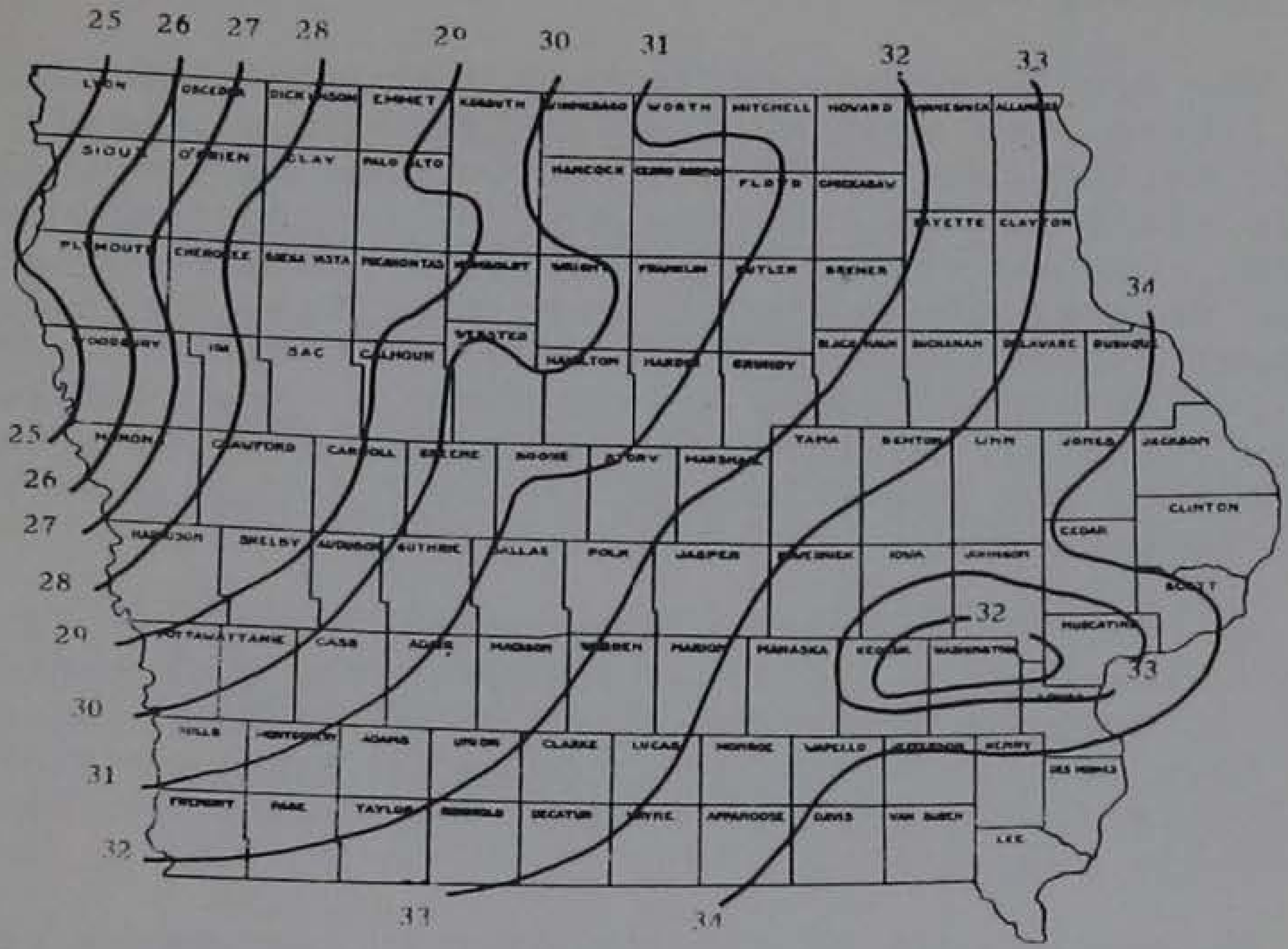

Figure 1. Normal annual precipitation.

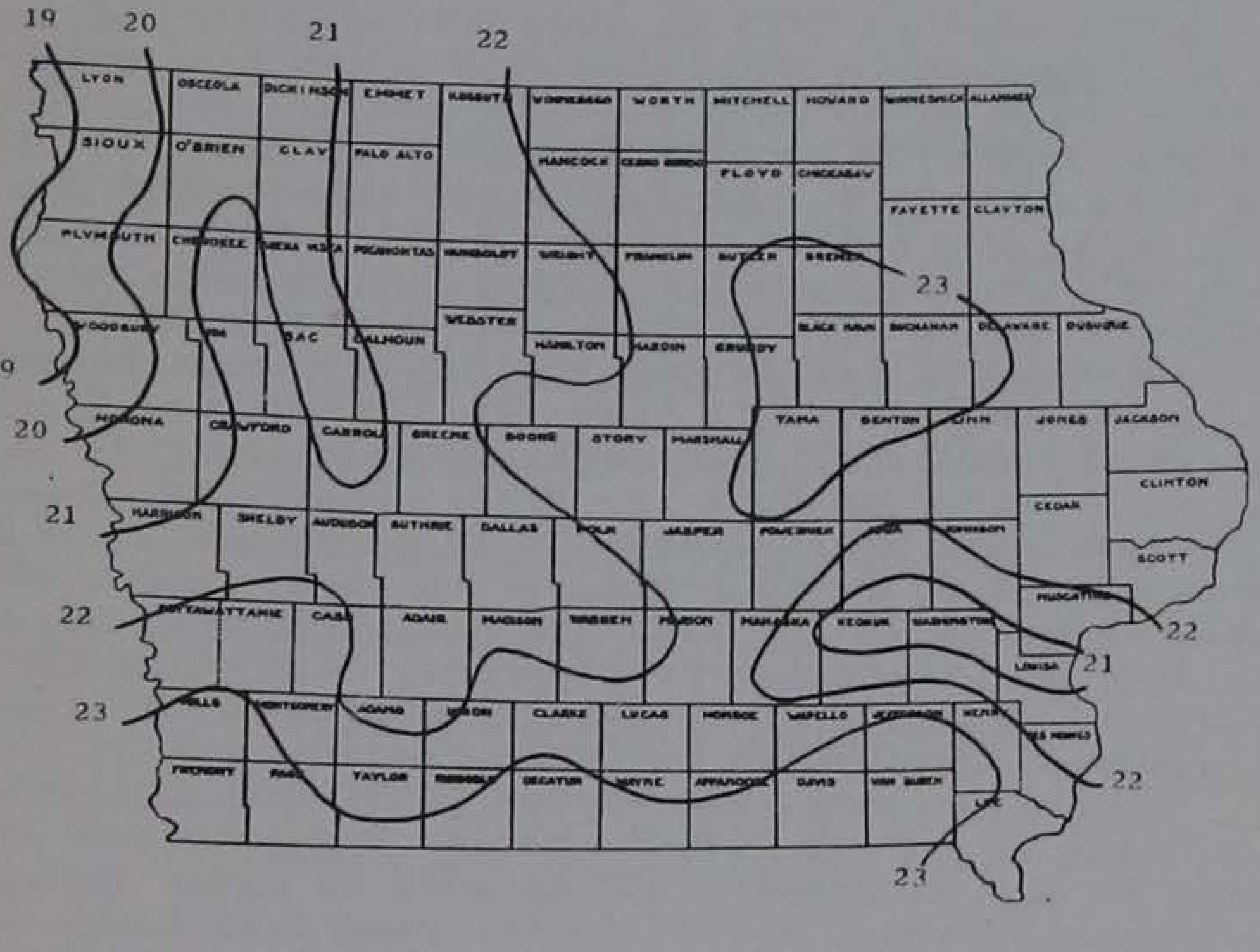

Figure 2. Normal crop season precipitation (April through September).

the latter for long range planning such as hay drying dependent upon dry days.

The cyclic annual pattern of Iowa precipitation varies from little more than an inch in February to nearly five inches during June, a direct consequence of the availability of the moisture and the proximity of the eastward moving storms. During winter the storm track is more often displaced well to the south of Iowa, migrating northward with heaviest rainfalls in May and June and diminishing during July as the storms track across Canada. A secondary, but lesser, rainfall maximum is associated with the southward movement of the prevailing storm track across Iowa in August or September.

By hour of the day, precipitation variation is relatively small. The hourly frequency peaks in the hour ending at 5 a. m. in western Iowa, but peaks about an hour later in central Iowa and two or three hours later across eastern Iowa localities (U. S. Weather Bureau, No. 82-11, No. 82-13, and No. 82-25, 1963).

On nearly half of all the days in the year a trace or more precipitation falls at all Iowa locations (fig. 3). This approximates about two-thirds of the cloudy (about 160 days) and the partly cloudy days (100 to 105 days). The preponderance of rainfall days are with small precipitation amounts. About 75 days have no more than a trace and another 40 days with measurable rainfalls of 0.01 inch or more total less than a tenth of an inch (figs. 4 and 5). Only about 20 days per year are with half an inch or more (fig. 6) of which five are with an inch to two inches and one is with two inches more. It is in the higher categories that extensive destruction such as flooding normally occur; soil erosion begins at intermediate values. The probability of six inches of rainfall in a day at any particular Iowa point has a recurrence period approaching 100 years (fig. 9). The record 24-hour rainfall at any official rain gage location is 12.99 inches, measured at Larrabee on June 24, 1891. Unofficial gages in bucket surveys have yielded amounts in excess of 17 inches. On July 16-17, 1968, 24-hour amounts to 16.20 inches at Waverly were reported in the heaviest northeast Iowa storm of record. Iowa precipitation frequencies, both point and areal may be derived from the U. S. Weather Bureau (1961) Atlas of precipitation durations and return periods (figs. 7, 8, 9 and 10). Longer periods, two to ten days, are available from the U. S. Weather Bureau (1964) similar publication. From the latter we may ascertain that as much as seven inches rainfall in a week is about a once in ten year occurrence and a nine-inch rainfall in a week has a return period of about 50 years.

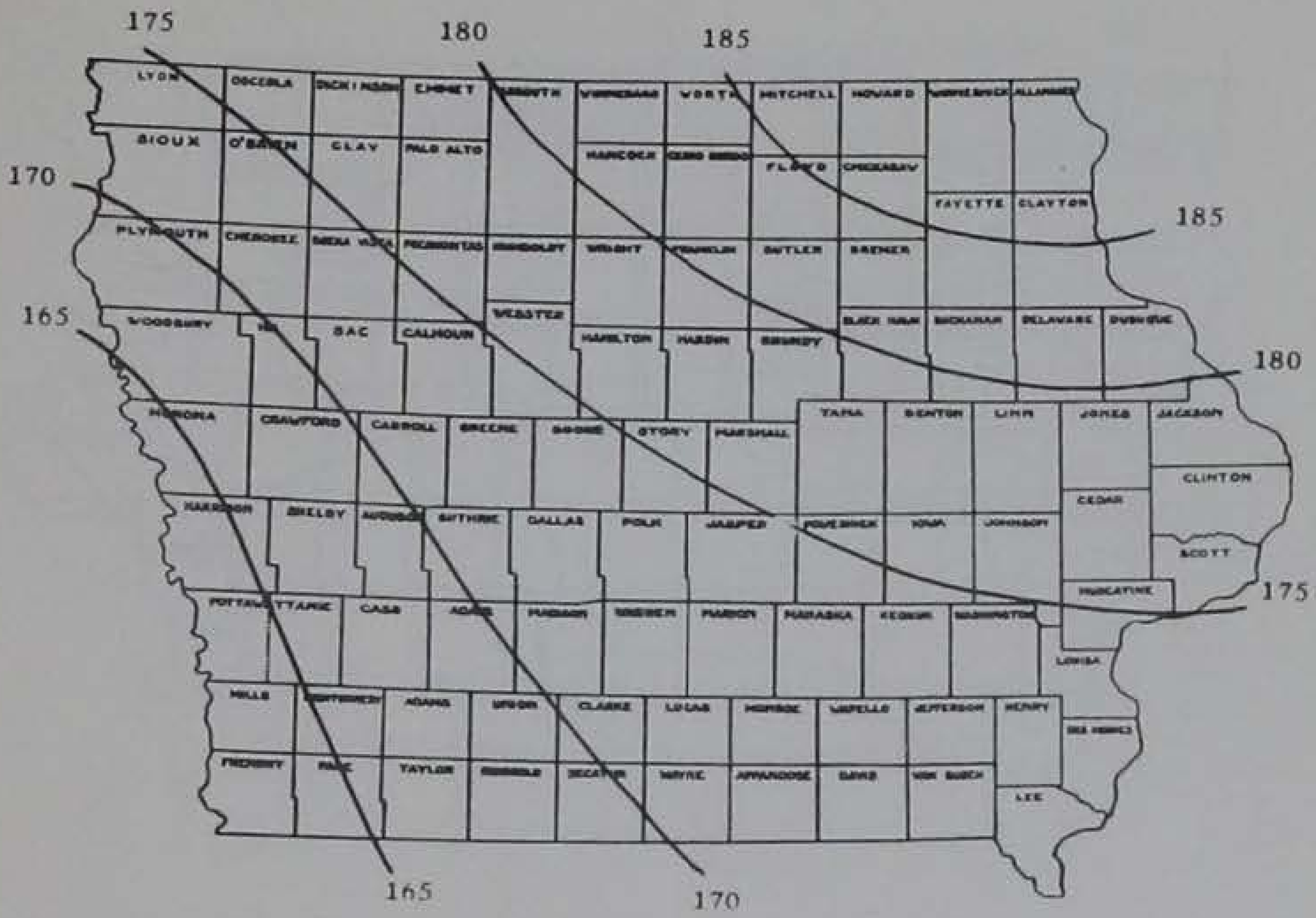

Figure 3. Mean number days per year with precipitation equal to or more than a trace per year.

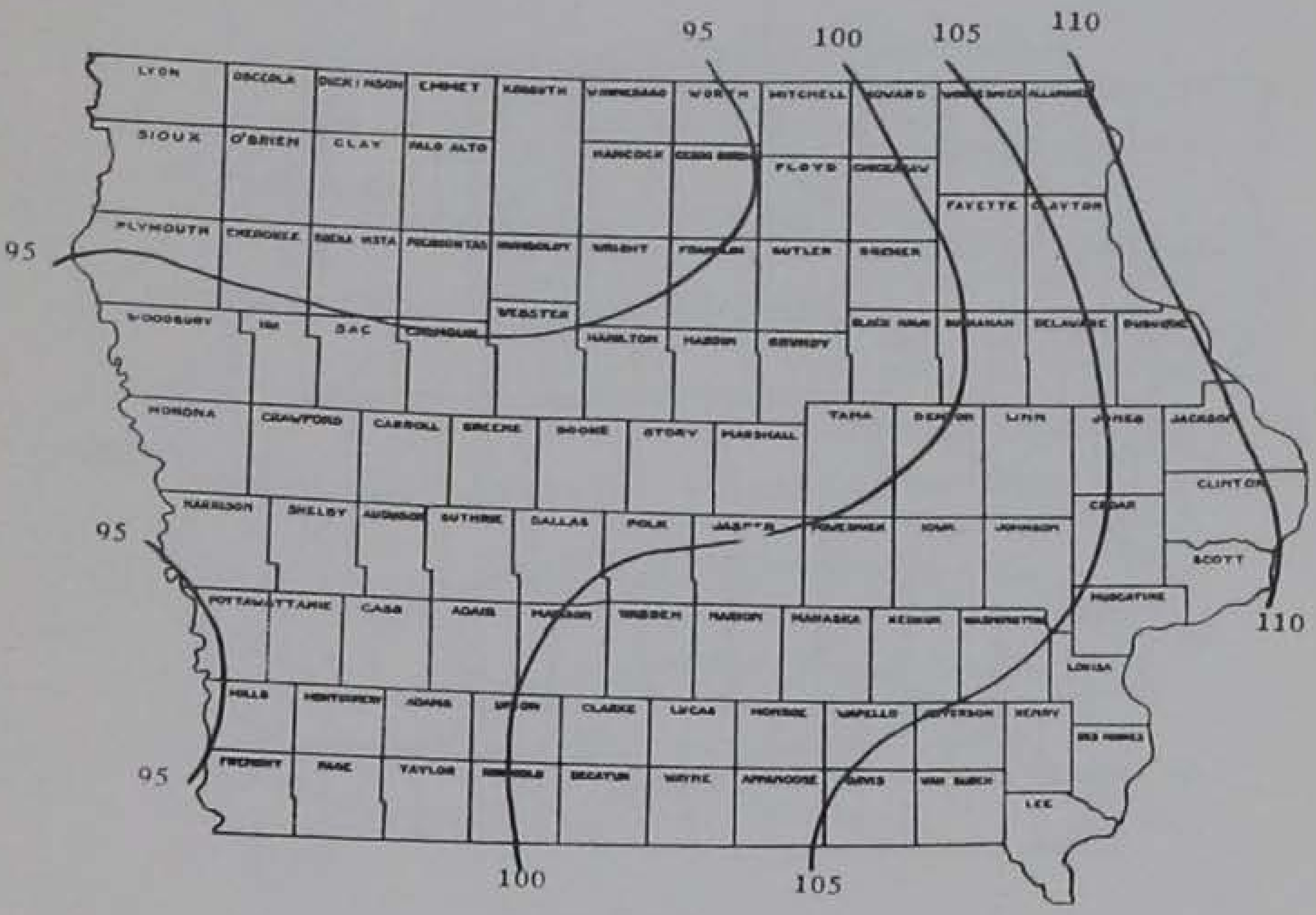

Figure 4. Mean number days per year with precipitation equal to or more than 0.01 inch per year.

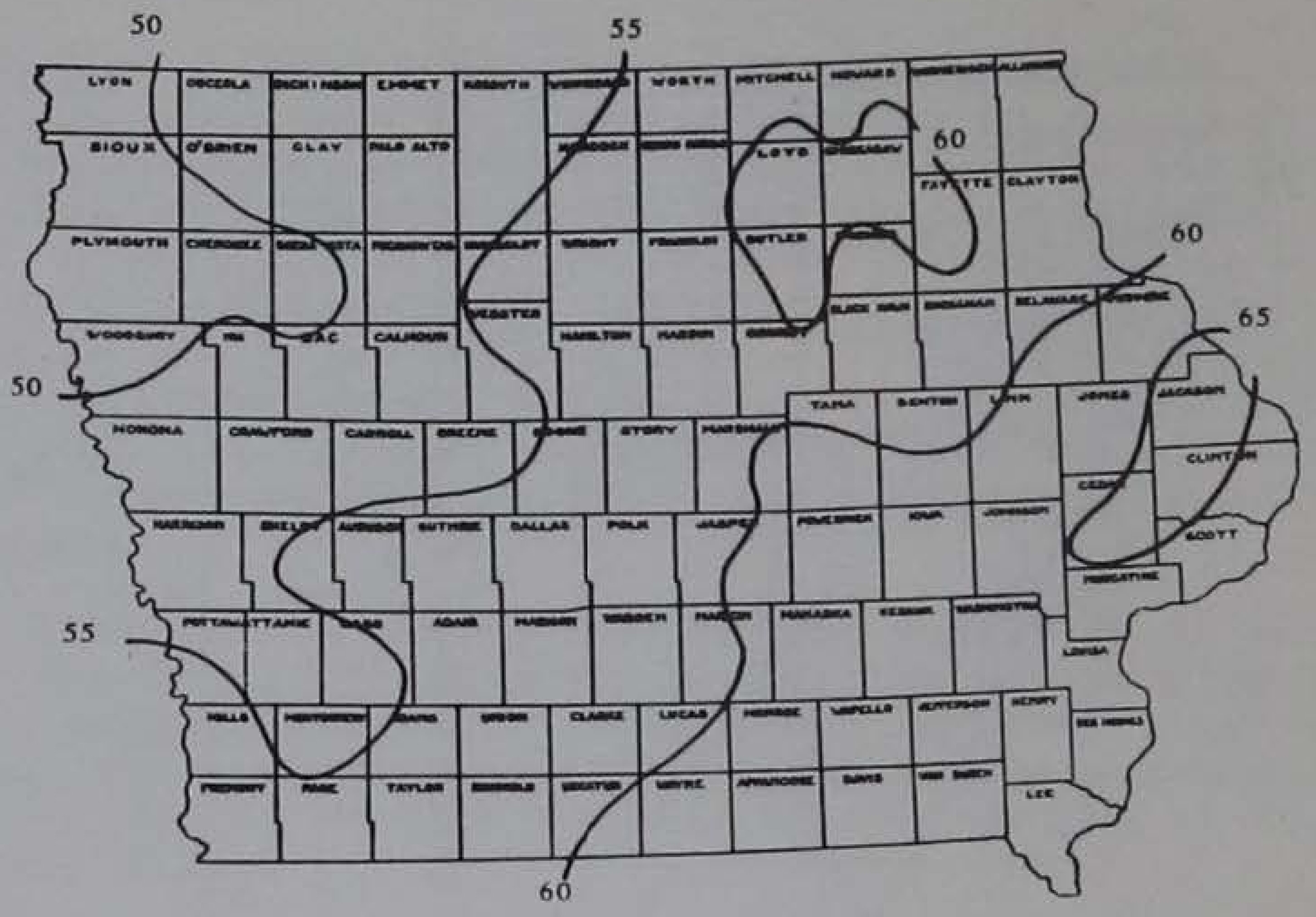

Figure 5. Mean number of days per year with precipitation equal to or greater than 0.10 inch.

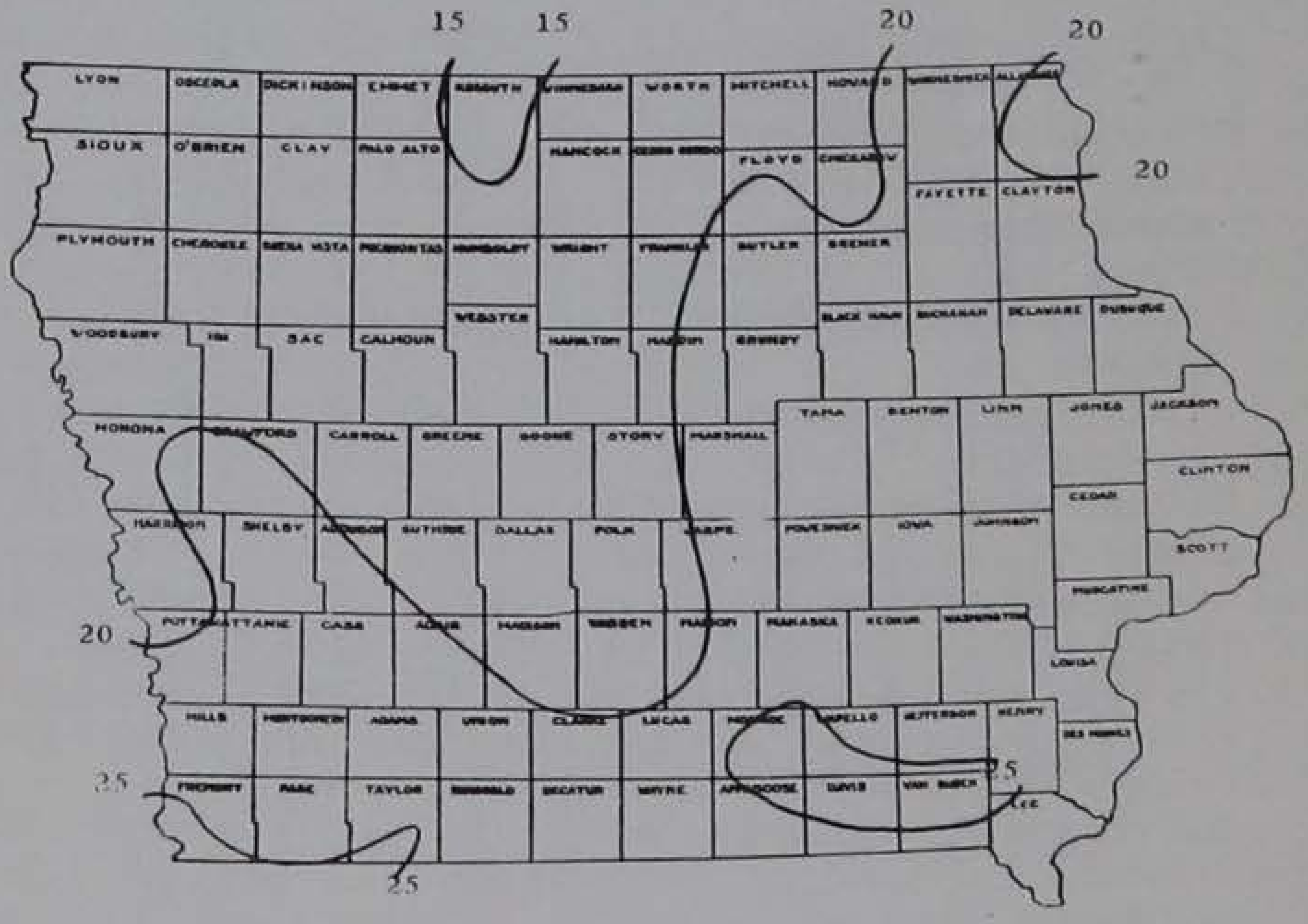

Figure 6. Mean number of days per year with precipitation equal to or greater than 0.50 inch.

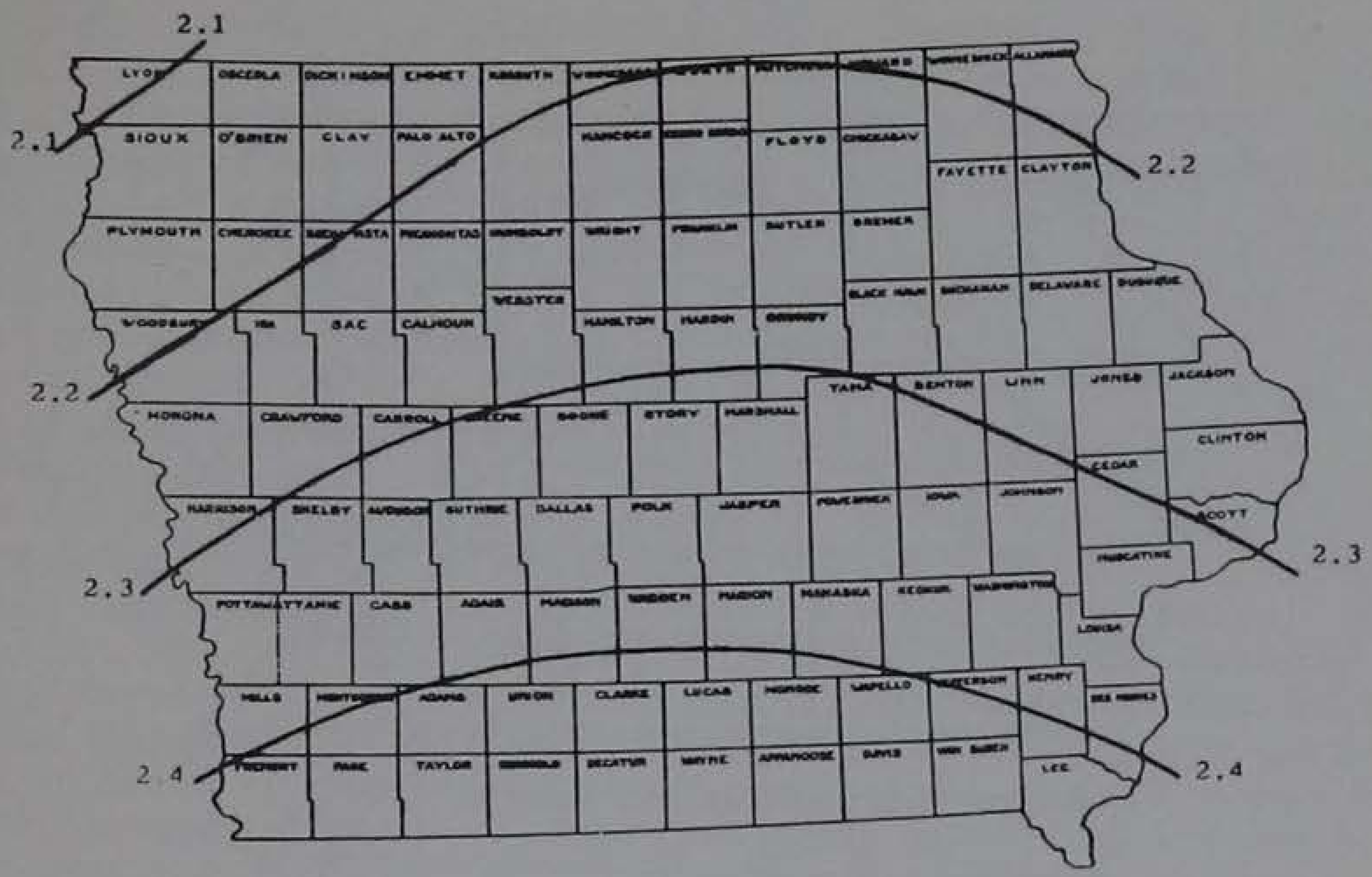

Figure 7. Rainfall frequency 2-year 6-hour rainfall (inches).

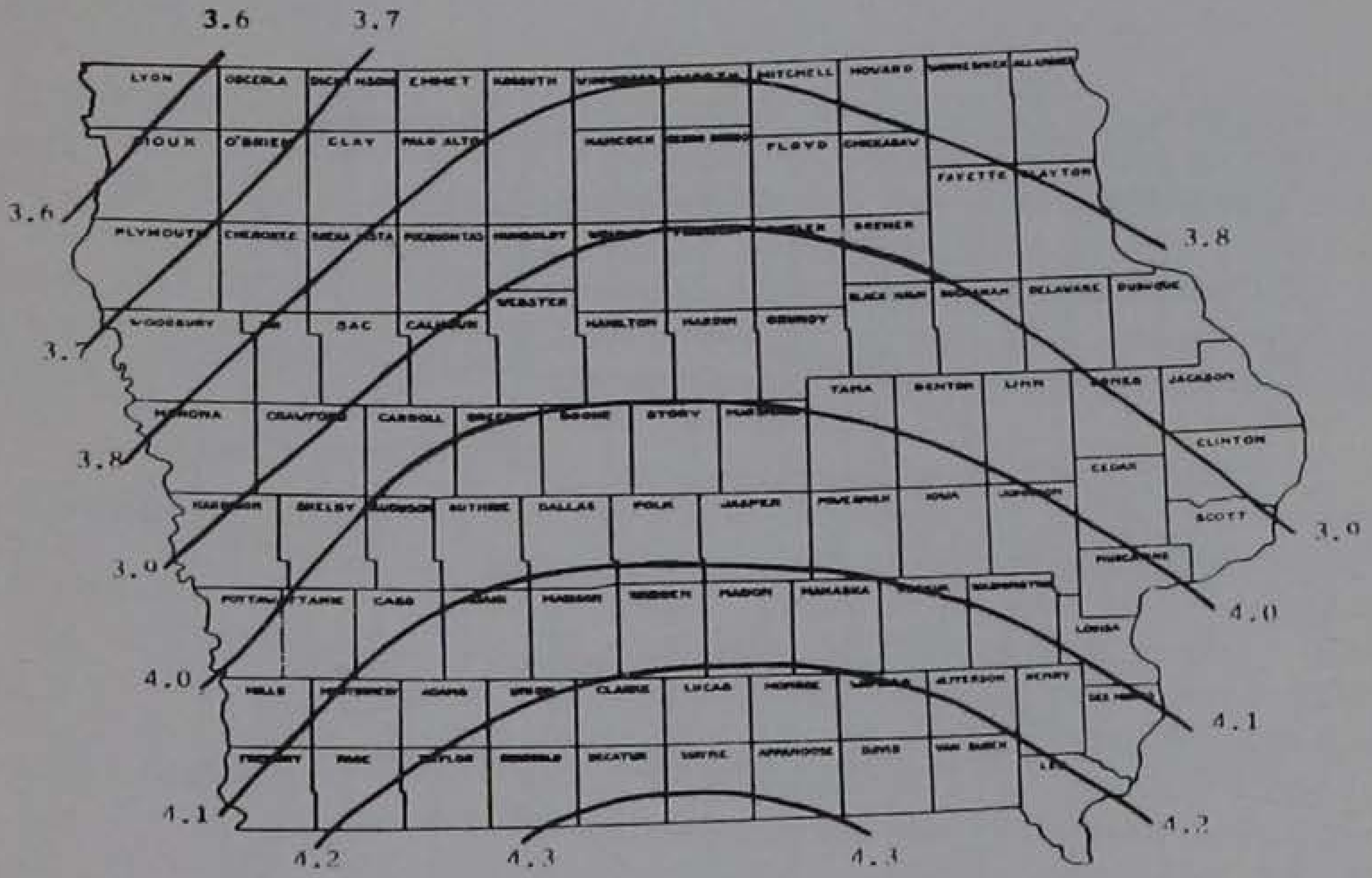

Figure 8. Rainfall frequency 5-year 24-hour rainfall (inches).

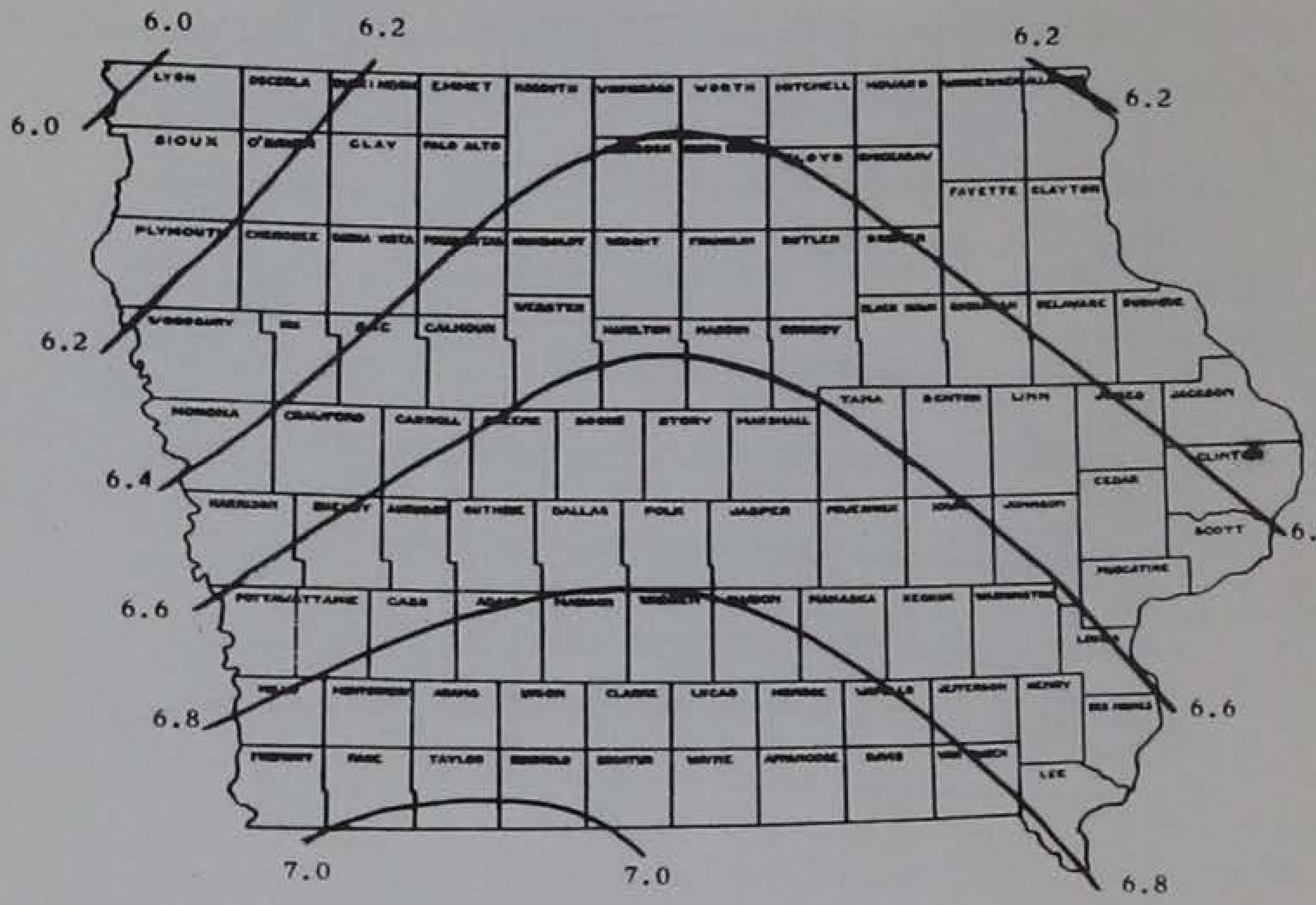

Figure 9. Rainfall frequency 100-year 24-hour rainfall (inches).

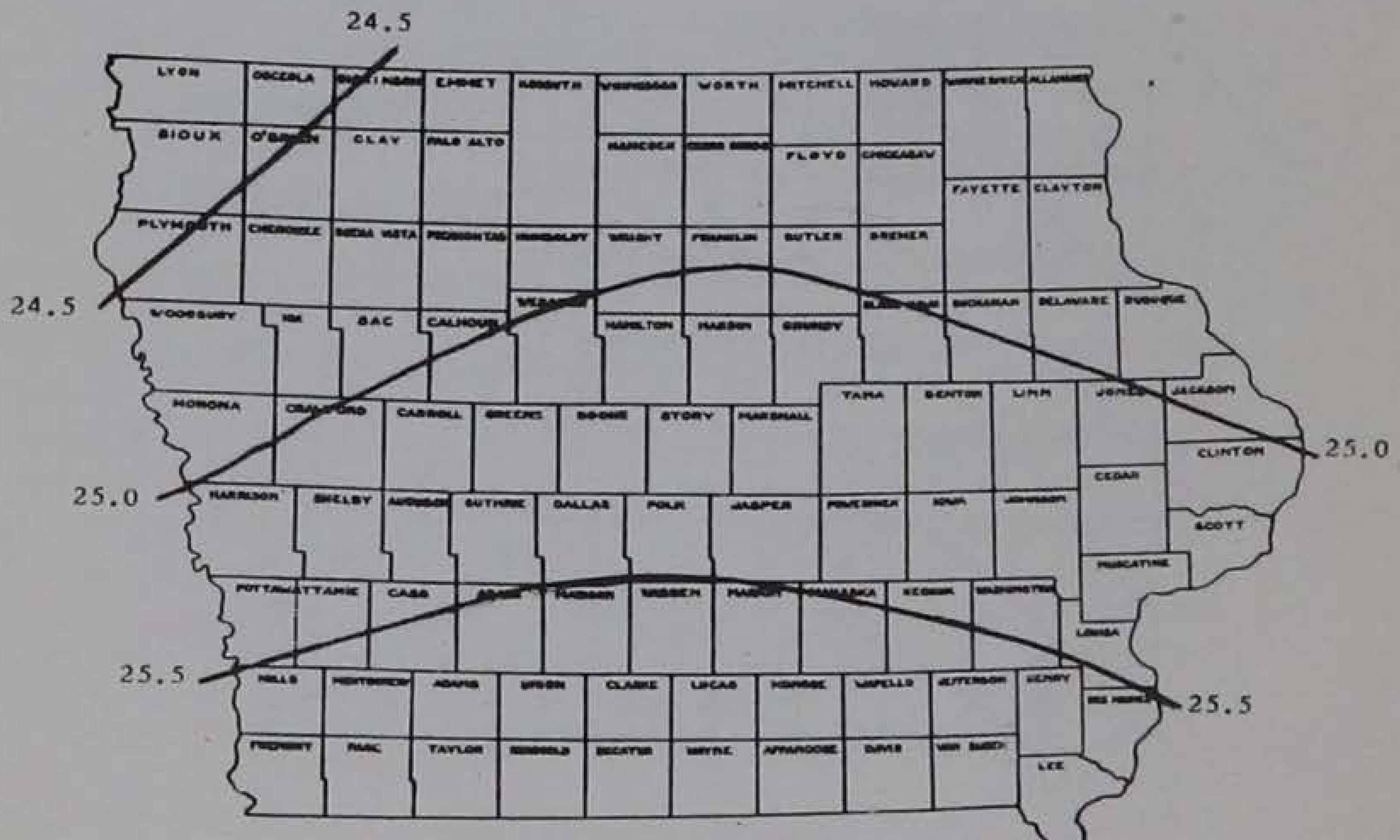

Figure 10. Rainfall frequency probable maximum 6 hour precipitation for 10 square miles (inches).

Most of Iowa's violent weather is associated with thunderstorms. The thunderstorm frequency increases with the seasonal increase in precipitation. Annually the thunderstorm days total about 40 north to 50 south occurring mostly during the warm months. Quite a large percentage of the Iowa thunderstorms are nocturnal. Thunderstorms provide most of our rainfall, hail, high winds, lightning, tornadoes and floods. The average period of rainfall in a thunderstorm cell is of the order of half an hour; the areal extent is a few miles. Supercells may exist a few hours or even several hours. The excessive rainfalls are most often associated with these intense supercells, as are the hail and severe tornadoes. Hail is observed at each Iowa point location about three times per season. A few very damaging hailstorms are reported almost every season in Iowa. Lamoureux (1952) described economic losses as related to hail. The greatest hail frequency occurs in June followed closely by July, May and April in that order. Lamoureux cites several of the worst hail storms in the State history with paths up to a hundred miles long and several miles wide. Radar has proven a most effective observational tool for locating, tracking and forecasting thunderstorm movement, and the associated rainfalls.

It is suspected that the electrical fields related to the production of the rainfalls in thunderstorms are likewise instrumental in the creation of the by-product, tornadoes, of which about 30 per year occur, mostly during April through September.

Conversely much of the light rain or drizzle falls without thunderstorm and violent weather, being associated with relatively stable precipitation producing situations such as warm front conditions. Freezing rain or freezing drizzle and consequent glazing during winter often develop with gentle upslope motion of moist warm air (warm frontal) over a subfreezing air mass, so widespread during the winters of 1935-36, 1952-53 and 1968-69.

Snowfall is of consequence to Iowans for its obstructions to travel, its insulating qualities over the soil and its flood potential in spring. Snow coupled with wind and cold in a blizzard, may be deadly to man and beast. Snowfall, averaging little more than 30 inches per year (fig. 11), has varied from a State average of 11.9 inches in 1965-66 to 59.0 inches in 1961-62. The snowfall season normally begins early in November followed by the first inch snowfall late in November or early December. Iowa normally experiences 10 to 15 days with one inch or greater snowfall per season. Snowstorms and snow cover normally end in March or early April. The average number of days with an inch or more of snow cover varies from 40 in southern counties to 90 in the northeast (fig. 12).

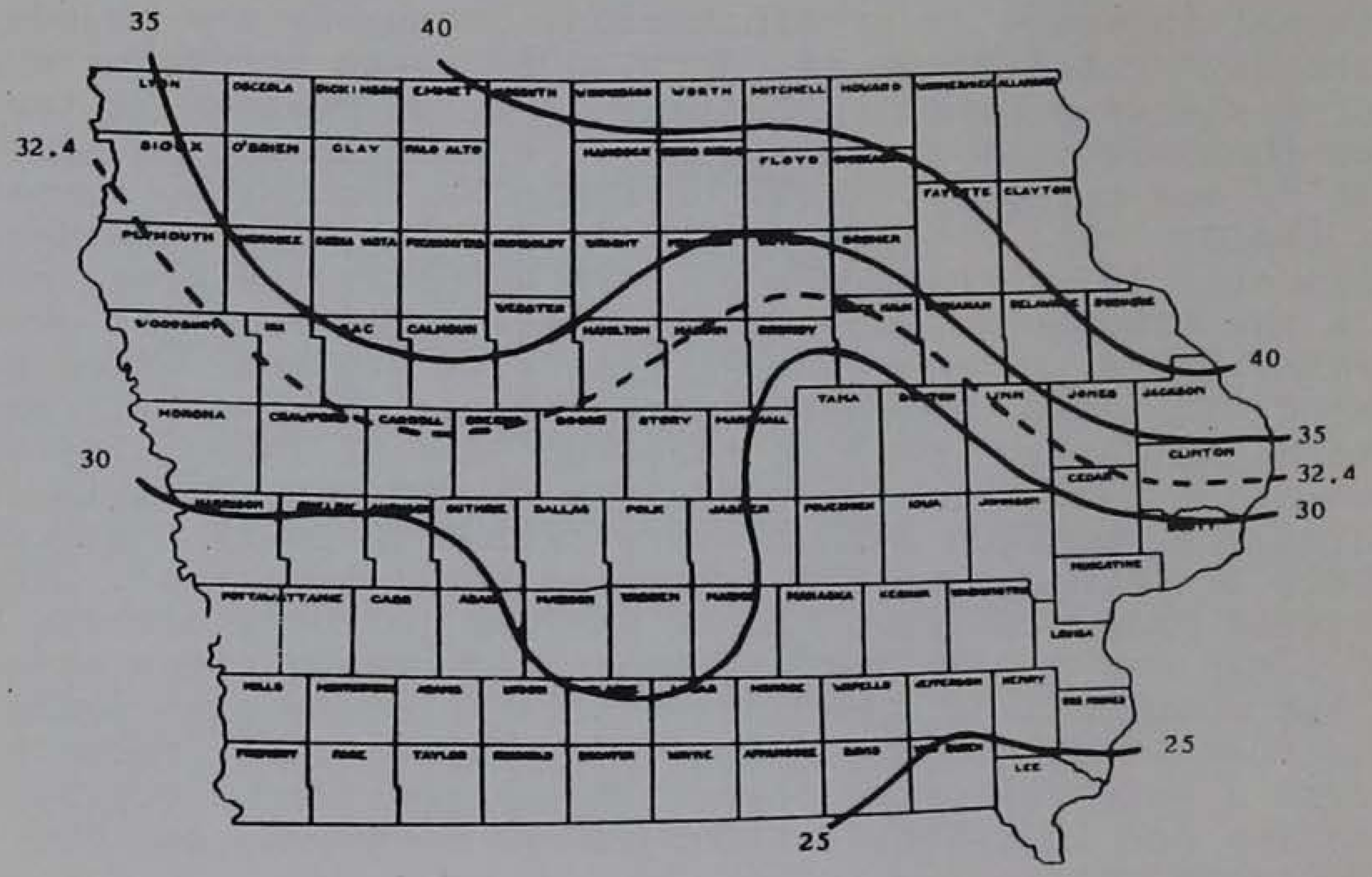

Figure 11. Average seasonal snowfall (inches).

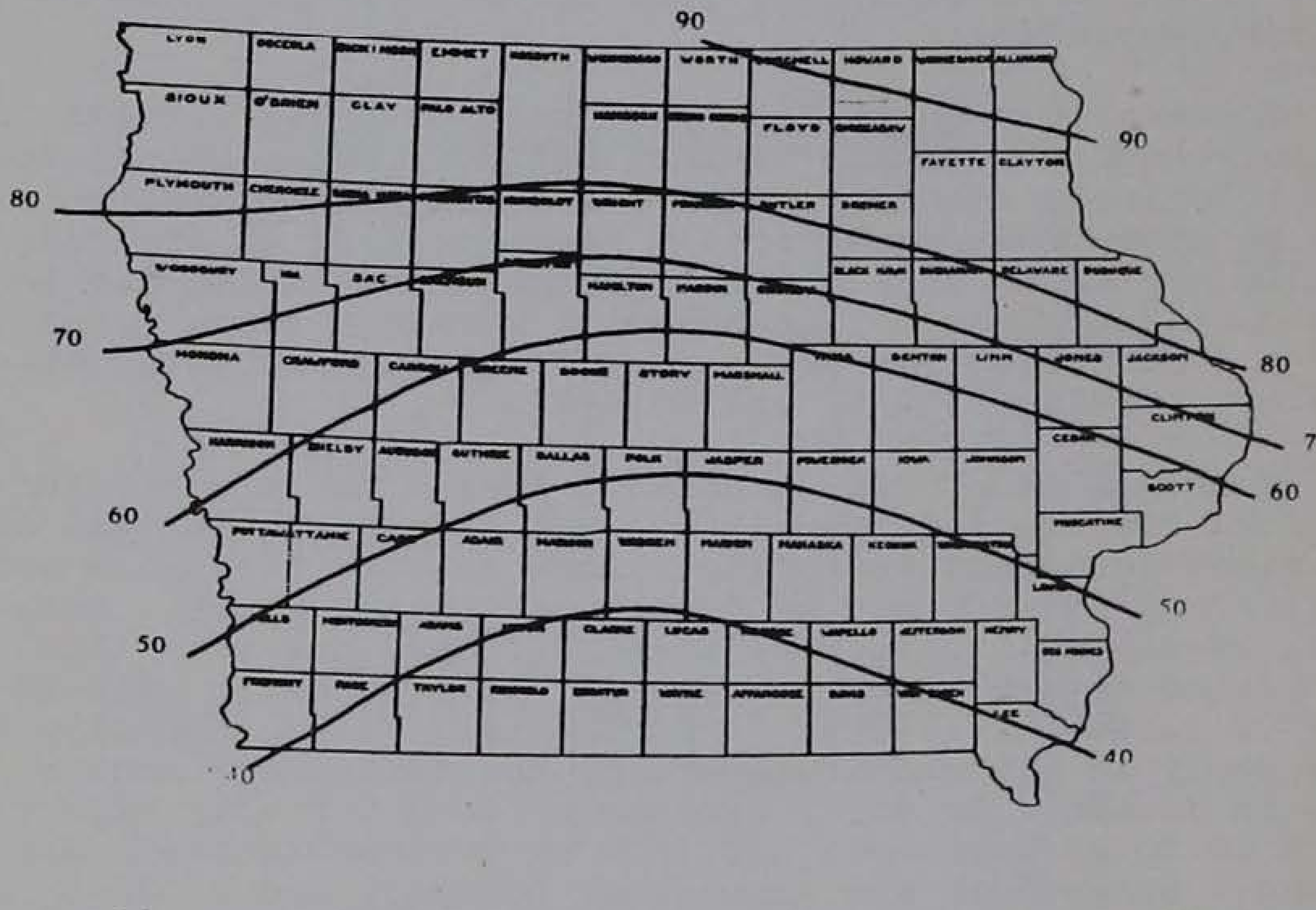

Figure 12. Average annual number of days with snow cover, 1 inch or more.

Precipitation, or more often the lack of it in the form of droughts, has been related to cyclic periods; the period most often suggested is approximately a 20- or 22-year cycle which is associated with the double sunspot cycle. The relative shortness of our Iowa record and variant dry years fit to the sunspot cycle yields are inconclusive correlation. Other cycles have been even less promising, excepting, of course, the annual cyclic rainfall pattern with all its variations. Otherwise, rainfall (and snowfall) variation since 1873 do not exhibit a consistent pattern or trend.

Without access to water, as provided by some thirty inches precipitation a year falling mostly during the crop season, life in Iowa would be impossible. Without stream flow, the changing economy requiring recreational facilities, would be without artificial lakes created on various Iowa rivers. Our precipitation variability has created both prosperity and ruin. The precipitation abundances and deficiences coupled with severe storm damages have pointed up the usefulness of precipitation control. In smaller ways, such as irrigation, building of dams and tiling fields, we have locally controlled the excesses and shortages of water. With the first successful cloud seeding in the late 1940's by V. J. Schaefer and Irving Langmuir hope was raised that precipitation control was imminent. The practicability of cloud seeding over the relatively level State of Iowa is yet debated, even though mountainous areas appear to provide about a 15 percent increase in precipitation by seeding. Perhaps, in the not to distant future, precipitation control (and storm control) will be a reality.

REFERENCES CITED

Barger, G. L., R. H. Shaw and R. F. Dale. Gamma distribution parameters from 2- and 3-week precipitation totals in North Central Region of the United States: Iowa State University, Ames, Iowa, 1959.

Feyerherm, A. M., L. D. Bark and W. C. Burroughs. Probabilities of sequences of wet and dry days in Iowa: Kansas State University, Manhattan, Kansas, 1965.

Lamoureux, C. E. Hail damage in Iowa, 1923-1948: Monthly Weather Review, v. 80, no. 3, Washington, D. C., p. 37-44, 1952.

Shaw, R. H., G. L. Barger and R. F. Dale. Precipitation probabilities in the North Central States: Bulletin 753, University of Missouri Agric. Expt. Sta., Columbia, Missouri, 1960.

Shaw, R. H. and P. J. Waite. The climate of Iowa. III. Monthly crop season and annual precipitation normals for Iowa: Iowa State University, Ames, Iowa, 1964.

U. S. Department of Commerce Weather Bureau. Rainfall frequency atlas of the United States for duration from 30 minutes to 24 hours and return periods from 1 to 100 years: Technical Paper No. 40, Washington, D. C., 1961.

____. Climatography of the United States, No. 82-11, Summary of hourly observations, Moline, Illinois, 1951-1960: Washington, D. C., 1963.

____. Climatography of the United States, No. 82-13, Summary of hourly observations, Des Moines, Iowa, 1951-1960: Washington, D. C., 1963.

____. Climatography of the United States, No. 82-25, Summary of hourly observations, Omaha, Nebraska, 1951-1960: Washington, D. C., 1963.

____. Two- to ten-day precipitation for return periods of 2 to 100 years in the contiguous United States: Technical Paper No. 49, Washington, D. C., 1964.

U. S. Weather Bureau and Iowa Weather Division. Iowa annual divisional and state averages; temperatures, precipitation and snowfalls: Palimpsest, State Historical Society of Iowa, Iowa City, Iowa, p. 61-65, January 1969.

Waite, P. J. Wet-dry day probabilities: Iowa Farm Science, v. 20, no. 11, Iowa State University, Ames, Iowa, p. 6-8, 1966.

__________. Climate of the States, Iowa, in Climatography of the United States, No. 60-13: U. S. Department of Commerce, Environmental Data Service, Washington, D. C., 1967.

SULO W. WIITALA

Mr. Wiitala is presently District Chief, Water Resources Division, U. S. Geological Survey, Iowa City, Iowa. He has held this post since 1966. He was born in Copper City, Michigan and holds the B. S. degree in Civil Engineering from Michigan Technological University. He has been with the U. S. Geological Survey in Indiana, Michigan, and Iowa since 1940 with brief stints as an instructor at the University of Illinois, Navy Pier Branch, Chicago; in structural design with International Harvester Company; as a hydraulic engineer, U. S. Army, Corps of Engineers; and in Iraq for Harza Engineering Company. Mr. Wiitala has authored several U. S. Geological Survey Water Supply Papers mostly on floods and water resources studies of urban areas. He is a member of several professional organizations including the American Society of Civil Engineers, National Society of Professional Engineers, American Geophysical Union, and the Iowa Engineering Society.

SURFACE WATER RESOURCES OF IOWA[1]

Sulo W. Wiitala
Hydrologist, Water Resources Division
U.s. Geological Survey

As an Iowan, you are a custodian of 2,125,000 gallons of surface water per year, enough water to supply you with 5,820 gallons per day. Water occurring in any basin or watercourse has been declared by the State of Iowa to be public waters and the public wealth of the people. Thus, in the quantity given above, the average annual runoff, or streamflow, of approximately 6 inches in Iowa would be distributed to the citizenry if each could take his or her share. That's a lot of water--almost 8 times the estimated 1960 per capita water use in Iowa. This does not include the flow in the Mississippi and Missouri Rivers that does not originate in Iowa.

In this presentation on the surface water resources of Iowa I shall limit my discussion to (a) average streamflow, (b) variability of streamflow, (c) firm streamflow, and (d) brief remarks on the major storage facilities built, or being built, in the State. These remarks are also limited to the interior streams of Iowa--they do not apply to the Mississippi and Missouri Rivers. My purpose is to provide a general picture of the availability of streamflow in the State.

AVERAGE STREAMFLOW

We can take streamflow as a rough measure of how much water is available to a region. So let's take a look at that average annual runoff of approximately 6 inches and make a few comparisons. The average annual runoff in the streams of the Colorado River basin and in New England amounts to about 6,500 gallons per day per-capita supply. The 6 inches of Iowa runoff are equivalent to 18 million acre-feet, or 5 1/3 cubic miles of water. The Mississippi River, North America's largest river, discharges about 133 cubic miles of water per year (Nace, 1964). Thus, Iowa, comprising about 4 1/2 percent of the land area of the Mississippi basin, contributes about 4 percent of the Mississippi's discharge into the Gulf of Mexico. The Amazon, the largest river in the world, with a flow six times that of the Mississippi, discharges the equivalent of a full year's runoff from Iowa in less than three days (Nace, 1964). Iowa's annual runoff

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[1] Publication authorized by the Director, U.S. Geological Survey.

would fill Lake Superior, North America's largest lake in 560 years and Lake Baikal, the world's largest lake, in 1180 years.

Streamflow is highly correlated to precipitation, which varies from year to year and from area to area. The average annual runoff in the State ranges from about 2 inches in extreme northwestern Iowa to more than 8 inches in eastern Iowa (fig. 1). It follows, in general, the pattern of the mean annual precipitation which ranges from less than 26 to more than 34 inches from the northwestern to the eastern and southeastern parts of the State (fig. 2).

Precipitation and streamflow also vary with time--some years are wet, some are dry, and others are in the normal range. Figure 3 shows the variation of annual runoff for the Cedar River at Cedar Rapids, the longest streamflow record in the State. Although no definite cycles are apparent, it does show that runoff tends to be above- or below-normal for periods longer than one year. The longest periods when runoff was above average were the two 6-year periods 1915-20 and 1942-47. The longest below-average period was the 7 years from 1953 to 1959. Statistics on the extremes of annual runoff are contained in table 1. The stations included in the table are predominantly those measuring the flow from basins of moderate size, and those whose records included the drought of the mid-1950's. The smallest basins are too sensitive to indicate hydrologic conditions; whereas large basins, which integrate widespread meteorologic and physical regimes, are too insensitive to be truly representative of areal conditions. Table 1 shows a range in annual runoff from 0.21 inch in 1956 for Lizard Creek near Clare to 22.72 inches in 1962 for the Maquoketa River near Manchester. This range, though not precisely defined, provides an indication of the range of annual flow within which those concerned with the water resources of the State must work.

VARIABILITY OF STREAMFLOW

Average flows are only a part of the story. Average flow, like the average annual per capita income, is a statistic that provides an indication of the magnitude of the total resource. Knowledge of average flow alone, however, is insufficient for careful planning and management. Streamflow is characteristically variable within a day, a month, a year, a decade. The nature and extent of these variations are critical to the management, use, and development of the water resources of the State.

The greatest variability in streamflow in the United States is found in the southwestern and north-central parts of the country. In Iowa, it is common for peak flows to be 10,000 and more, times the minimum flows. As an indicator of the variability of high flows, I have chosen to use the ratio of the mean annual flood to the mean discharge for the stations listed in table 1. The mean annual flood is a fairly stable statistic which is unaffected, for the most part, by the chance occurrence of a very large flood. It is the peak flow that is equaled or exceeded once on an average of about every other year (recurrence interval, 2.33 years). The values for the mean annual flood were taken from a report on the magnitude and frequency of Iowa floods by Schwob (1966). For stations listed in table 1, this ratio varied from 8.0 to 166. Inspection of all records for the State, indicates a minimum ratio of 7.15 for the Cedar River near Conesville and a maximum of 533 for Indian Creek at Council Bluffs. In general, the stations with the smaller ratios, below 20, are in the area of Wisconsin glaciation where drainage systems are not well developed. The highest ratios are for small basins in the bluff areas adjoining the Mississippi and Missouri Rivers.

As an index of the variability of low flows in table 1, I have used the ratio of the flow at the 90 percent duration level to the mean flow. The variation of this ratio, from near zero to 0.20, is much less than that for the ratio defining high flows. The highest ratios, between 0.10 and 0.20, are for basins in the northeastern part of the State where the streams are deeply incised and where the dry-weather flows are sustained at relatively high levels by ground-water inflow. Surprisingly, the Maple and West Nishnabotna Rivers draining the Kansas drift in western Iowa have relatively high ratios of 0.09 to 0.12, respectively. Elsewhere, the streams draining the Kansan drift have very low ratios.

From this brief analysis, it is obvious that Iowa streamflow is highly variable. On the average, every other year a peak flow is reached that is about 30 or more times the average flow. During 10 percent of the time, low flows are at or lower than about 3 percent of the annual flow. These are generalizations, which mask significant individual characteristics, a few of which have been pointed out in the preceding discussion.

FIRM STREAMFLOW

Now let's return to the 90-percent duration flow that was introduced into the discussion in the preceding section. Theoretically, the maximum developable supply from a river basin is equivalent to the average flow. Development of this supply would require an amount of storage sufficient

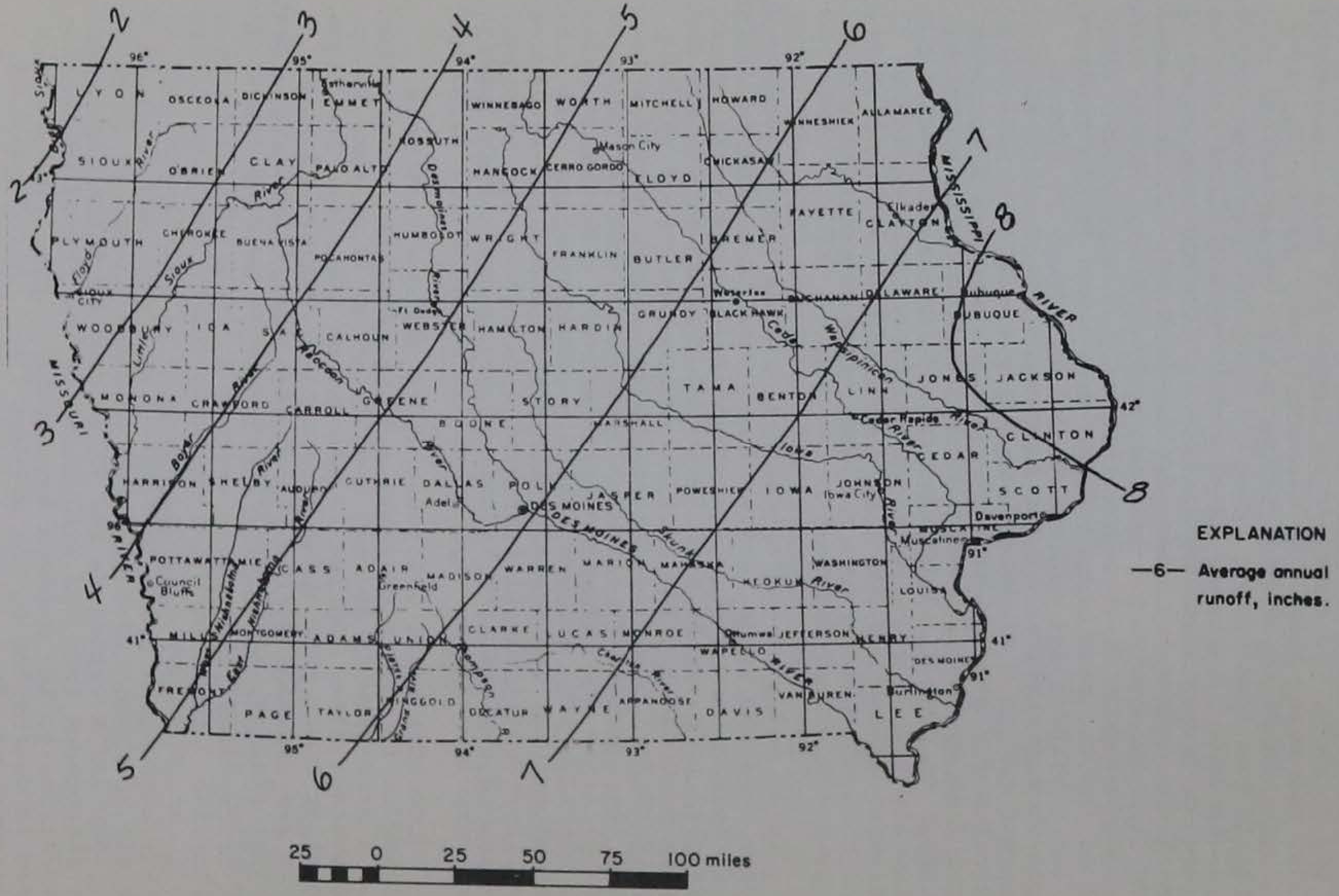

Figure 1.--Average annual runoff in Iowa.

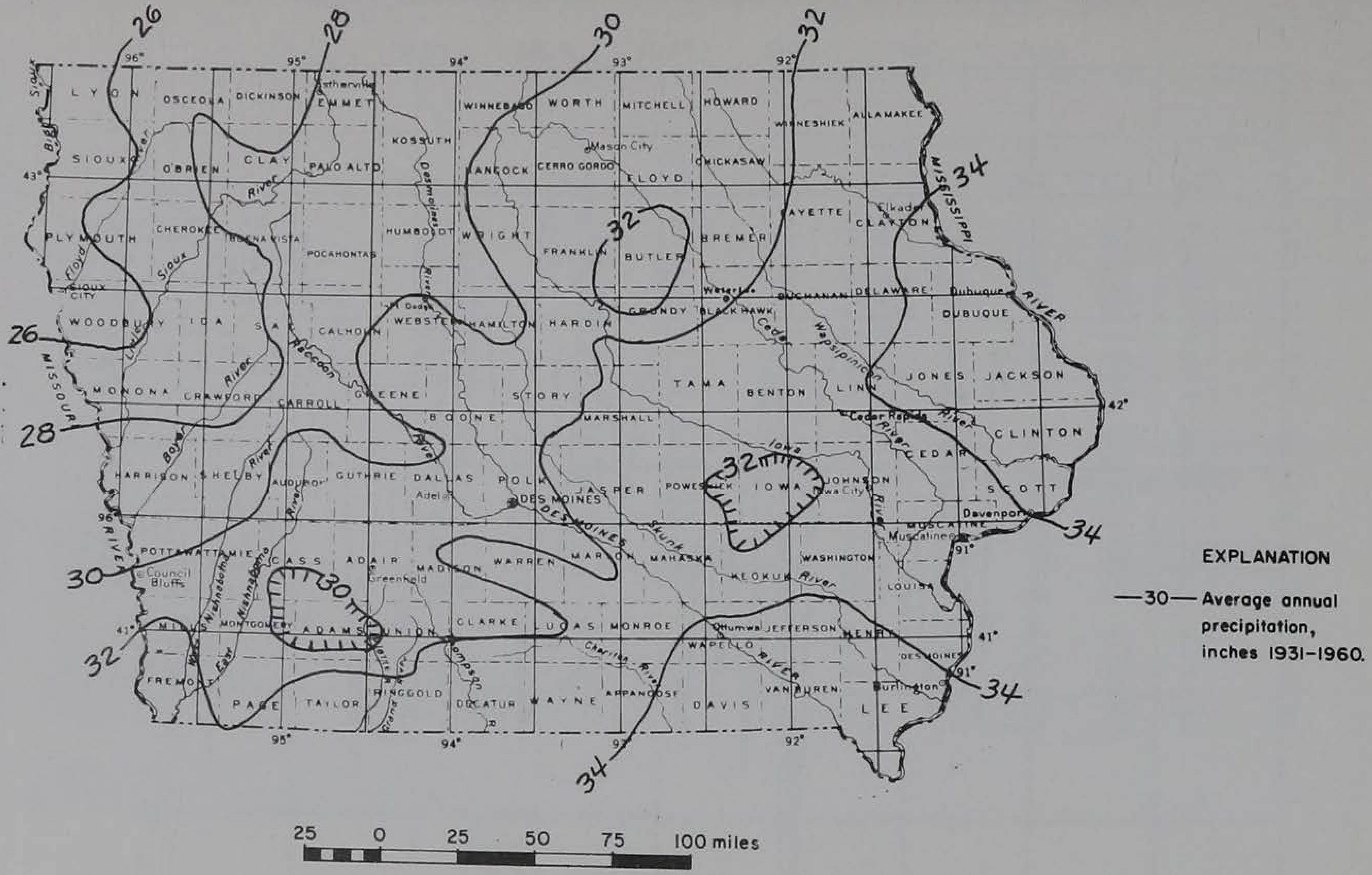

Figure 2. -Average annual precipitation in Iowa, 1931-1960.

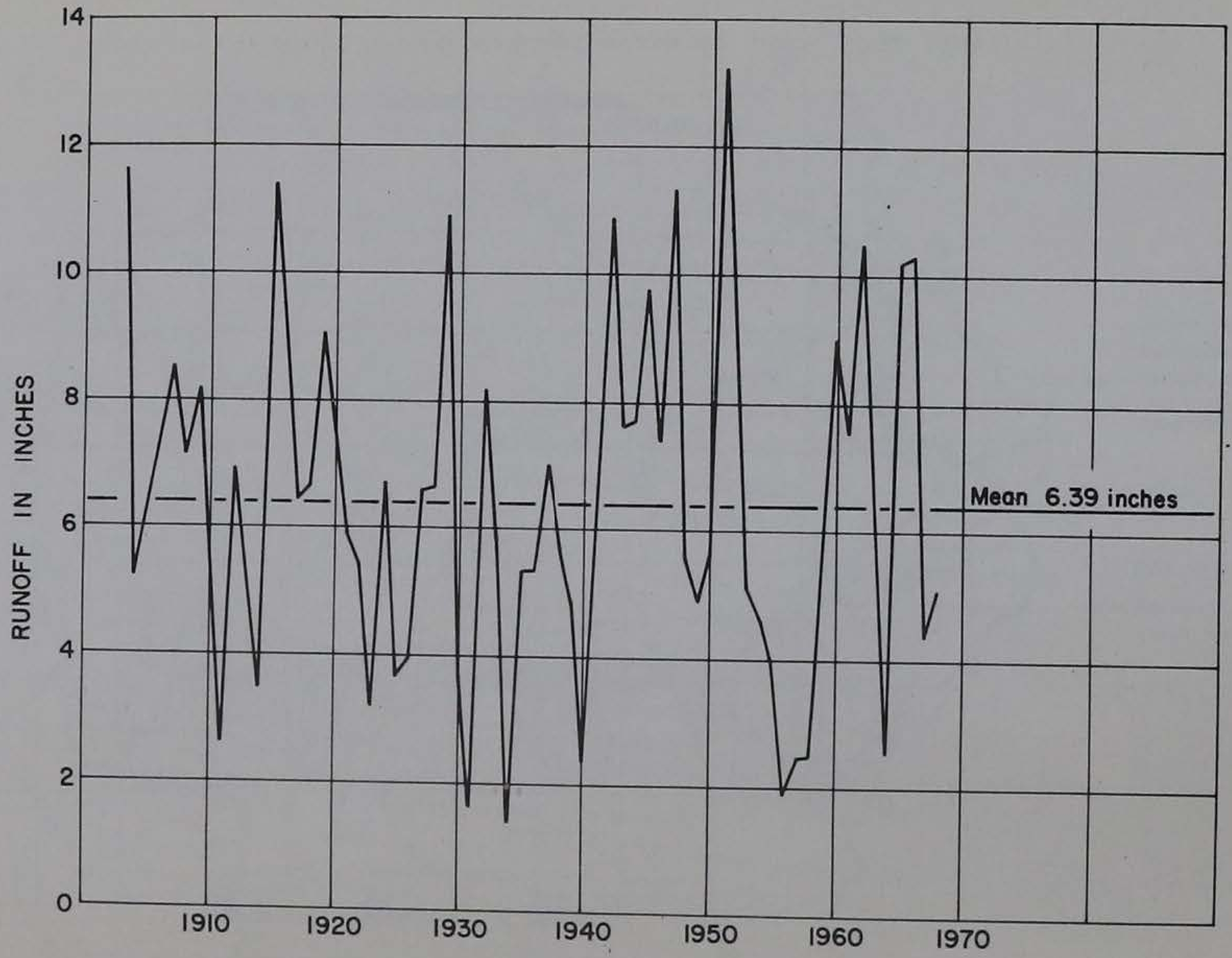

Figure 3.--Annual runoff, Cedar River at Cedar Rapids, Iowa.

Table 1.--Annual runoff and indicators of flow variability for selected Iowa streams

Map No.	Station Name	Period of Record	Drainage area sq.mi.	Mean flow cfs	Annual runoff in inches					a/ Q2.33 / Qmean	b/ Q90 / Qmean
					Mean	Max.	Year	Min.	Year		
1	Upper Iowa R. at Decorah	1951-67	511	265	7.06	13.13	1945	2.58	1958	30.5	0.20
2	Paint Cr. at Waterville	1952-67	42.8	14.9	4.75	7.24	1962	1.30	1958	166	.17
3	Maquoketa R. nr. Manchester	1933-67	305	192	8.55	22.72	1962	1.91	1934	32.1	.20
4	Bear Cr. nr. Monmouth	1957-67	61.3	39.3	8.69	17.49	1962	2.28	1958	50.9	.11
5	Wapsipinicon R. at Independence	1933-67	1,048	523	6.79	15.58	1951	.95	1934	15.6	.07
6	Iowa R. nr. Rowan	1940-67	429	181	5.70	13.94	1951	.95	1956	8.0	.08
7	English R. at Kalona	1939-67	573	326	7.60	17.61	1960	1.14	1956	17.7	.02
8	W.Fk. Cedar R. at Finchford	1945-67	846	387	6.24	18.03	1951	1.05	1956	22.4	.09
9	Winnebago R. at Mason City	1932-67	526	220	5.70	13.12	1965	.76	1934	12.8	.08
10	S. Skunk R. nr. Ames	1920-27, '32-67	315	132	5.70	12.81	1944	.24	1958	32.2	.01
11	N. Skunk R. nr Sigourney	1945-67	730	393	7.33	16.04	1960	.52	1956	16.8	.03
12	Big Cr. nr Mt. Pleasant	1955-67	106	57.2	7.33	17.39	1965	.50	1957	38.3	<.002
13	E. F. Des Moines R. nr. Burt	1951-67	462	123	3.53	9.45	1965	.54	1956	16.9	.01
14	Lizard Cr. nr. Clare	1940-67	257	91.5	4.75	12.85	1951	.21	1956	22.5	.02
15	Boone R. nr Webster City	1940-67	844	352	5.70	14.00	1951	.57	1956	10.7	.04
16	N. Raccoon R. nr Sac City	1958-67	713	238	4.48	10.41	1962	.62	1968	16.1	.05
17	E. F. Hardin Cr. nr. Churdan	1952-67	24.0	7.9	4.48	9.81	1962	.32	1956	75.3	<.01
18	Middle R. nr. Indianola	1940-67	503	242	6.52	18.31	1947	.48	1968	32.0	.03
19	South R. nr Ackworth	1940-67	460	229	6.79	17.16	1947	.52	1956	34.4	.01
20	Cedar Cr. nr. Bussey	1947-67	374	191	6.92	14.70	1960	1.08	1954	32.9	.006
21	Sugar Cr. nr. Keokuk	1922-31, '58-67	105	66.2	8.55	17.61	1929	.88	1923	33.4	<.002
22	Floyd R. at James	1934-67	882	174	2.72	10.00	1951	.29	1956	24.6	.05
23	Maple R. at Mapleton	1941-67	669	226	4.62	12.18	1951	.50	1956	39.3	.09
24	W. Nishnabotna R. at Randolph	1948-67	1,326	498	5.50	11.58	1951	1.14	1968	28.9	.12
25	Nodaway R. at Clarinda	1918-24, '36-67	762	304	5.43	11.89	1947	.67	1968	34.2	.05
26	Thompson R. at Davis City	1918-24, '41-67	701	354	6.80	14.37	1947	1.01	1956	23.1	.02

Note: Minimum annual runoff for period through 1968.
a - Q2.33 is mean annual flood; Qmean is mean flow.
b - Q90 is flow equaled or exceeded 90 percent of time; Qmean is mean flow.

to retain all of the wet-weather flow for release when the natural flow falls below the average. Most of the time, development of such storage is neither feasible nor economic. Without storage, the developable supply is much smaller due to the variability of streamflow. The 90-percent duration flow is frequently used as an index of the firm flow available without storage. It is the flow that is equaled or exceeded 90 percent of the time or, conversely, it is the flow that is lower than that which occurs 10 percent of the time. This statistic, like the mean annual flood, is a fairly stable one--sufficiently far from the minimum, which is subject to erratic variation, yet low enough to be significant.

The ratio, $\frac{Q90}{Q\ mean}$, multiplied by 100 for the stations listed in table 1 gives the percentage that low flow is of mean flow. As mentioned previously, this varies from near zero to 20 percent. To develop a specific value of assured supply, in terms of ratio to mean flow, more storage would be required in a basin having a low index of firm flow than one having a high index. The U.S. Geological Survey is currently working on a low-flow report that will contain low-flow information for all gaged locations in the State. It has been found in this work that the 90-percent duration flow is roughly equal to average 7-day annual minimum flow that occurs on an average of once in 2 years.

IMPOUNDMENTS IN IOWA

In the previous discussion, storage has been mentioned several times. As an illustration of relative storage magnitudes, let's take a look at the four major impoundments constructed, or under construction, in the State. These are the Corps of Engineers reservoirs at Coralville on the Iowa River, at Red Rock and Saylorville on the Des Moines River and at Rathbun on the Chariton River.

Total storage volume (at flood pool level) in the Coralville Reservoir is equivalent to a runoff of 3.3 inches from the basin, 52 percent of the average annual runoff of 6.31 inches. Total volume in the Red Rock Reservoir is equivalent to a runoff of 2.85 inches, 62 percent of the average annual runoff of 4.60 inches. Saylorville Reservoir will hold 1.91 inches, 48 percent of the average annual runoff of 3.99 inches for the basin. But Rathbun Reservoir, with a storage volume almost equal to Saylorville's and a drainage area less than a tenth of Saylorville's, will hold up to 18.73 inches of runoff. At the average annual flow rate of the Chariton River, it would take about 2 1/2 years to fill Rathbun Reservoir assuming that every drop of water is stored.

These reservoirs are built primarily for flood control and most of their capacity is reserved for the temporary storage of flood waters and is not available for water-supply augmentation. For Rathbun Reservoir, however, 61 percent of the total capacity is reserved for flood control and 39 percent, a volume almost equal to the average annual runoff, is available for other purposes. It is obviously a development that can be managed for multiple purposes.

CONCLUSIONS

From this broad-brush treatment of the surface water resources of Iowa, we see that the average annual runoff ranges from about 2 to 8 inches in the State. The State average is about 6 inches, an amount capable to supplying 5,820 gallons per day to every man, woman, and child. This is an impressive supply. However, it dwindles appreciably when we consider that, because of the variability of flow, only a few percent of it is available on a firm basis. The 1960 withdrawal for public water supplies alone (MacKichan and Kammerer, 1961) was equivalent to nearly 2 percent of the 5,820-gallon per capita supply. Thus, we see that, on a purely local basis, demand already approaches the firm supply. However, this does not take into consideration the vast supply available in the Mississippi and Missouri Rivers. The Mississippi River at McGregor and the Missouri River at Sioux City each have an average annual runoff equivalent to about 23,000,000 acre feet. Together, these two stations have an annual flow more than 2 1/2 times the annual runoff from Iowa. Surely no deficiencies in supply are expected for water users living within reach of these border streams.

Storage is the most obvious means by which more of a variable resource can be made available for use. All but one of the four major reservoirs in the State are designed for essentially one purpose--flood control. As population and water use increase, consideration of storage to meet the needs for water supply, waste dilution, and other purposes will surely follow.

REFERENCES CITED

MacKichan, K. A. and J. C. Kammerer, Estimated use of water in the United States: U.S. Geol. Survey Circ. 456, 26p., 1961.

Nace, Raymond L., Water of the world: Natural History, v. LXXII, p. 10-19, 1964.

Schwob, Harlan H., Magnitude and frequency of Iowa floods: Iowa Highway Research Board Bull. 28, pt. 1, 47 p., 1966.

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GROUND-WATER RESOURCES OF IOWA[1]

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INTRODUCTION

Underlying the State of Iowa is a vast rock reservoir that contains an immense quantity of water in storage. A single rock unit in the reservoir, the Jordan Sandstone, contains an estimated 80 trillion gallons of water--an amount equivalent to about 14 years of runoff from the state. The amount stored in the whole reservoir is many times more. However, water for man's many uses is recoverable from only a limited number of water-producing zones or aquifers in the reservoir. An even fewer number can produce the quantity of water required for large municipalities, thirsty industries, and large-scale irrigation. Although the aquifers are limited in number, their widespread occurrence and water-yielding characteristics make them important and vital sources of water supply throughout most of the state. During the period 1961-65, they provided 75 percent of the total water withdrawn for all purposes in the state, except water used for fuel-electric power generation (Murray, 1968).

This paper presents a general description of the physical, hydrologic, and water-yielding characteristics of the six principal aquifers in Iowa's ground-water reservoir. Principal aquifer is defined in this paper as a water-yielding zone in the reservoir that is regionally significant in meeting specific water demands. Included in this category, in addition to the highly productive aquifers, are the extensive, accessible, low-yielding aquifers, such as the glacial drift, that meet the small but widespread rural demands. Not included, and not discussed in this paper, are the water-bearing units such as the Galena Formation that have local significance only. The discussion in this paper is based on data collected under the cooperative ground-water investigations of the U.S. Geological Survey and the Iowa Geological Survey and on the references cited.

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[1] Publication authorized by the Director, U.S. Geological Survey.

HYDROGEOLOGY

The geologic framework of Iowa's ground-water reservoir is summarized in table 1 and figures 1 and 2. The bottom of the reservoir is the Precambrian crystalline complex, which occurs at a depth of about 5,200 feet in southwestern Iowa and rises to the surface in extreme northwestern Iowa and to withi 800 feet of the surface in northeastern Iowa. Overlying these basement rocks is a succession of consolidated sedimentary strata of Paleozoic age that are dominantly sandstones and dolomites in the lower part and shales, dolomites, and limestones in the upper part. These strata have been downwarped into a broad trough, known as the Iowa Basin (figs. 1 and 2). The surface of the dipping Paleozoic rocks was beveled by erosion, thus exposing older Paleozoic strata in the northeastern and northwestern parts of the state and forming the extensive recharge areas of the Paleozoic aquifers in northeastern Iowa and southern Minnesota.

Strata of Cretaceous age unconformably overlie the beveled, southeast-dipping limb of the Paleozoic basin in northwestern and parts of southwestern Iowa (fig. 1). These nearly flat-lying strata are dominantly shales and sandstones that attain a thickness of as much as 400 feet.

The surface of both the Paleozoic and Cretaceous rocks was considerably modified and dissected by pre-Pleistocene erosion. Some of the valleys that were carved into the bedrock are very broad and deep and contain appreciable alluvial deposits. Unconsolidated glacial drift and loess, averaging about 200 feet thick, mantles the bedrock, except for a small area in northeastern Iowa where the drift is largely absent, and locally where the present water courses have cut down to the consolidated rocks. Alluvial deposits of variable thickness underlie the valley floors and terraces of the present streams (fig. 3).

The six principal water-yielding rock units in the Iowa reservoir are the surficial deposits, the Dakota Sandstone of Cretaceous age, limestones and dolomites of Mississippian age, limestones and dolomites of Silurian and Devonian age, the Cambrian and Ordovician sandstones and dolomites, and the Dresbach sandstones of Cambrian age (table 1). The most consistently productive units are the Cambrian and Ordovician sandstones and dolomites. Others that are highly productive locally are the alluvium (surficial deposits), the Dresbach and Cretaceous sandstones, and limestones or dolomites of Silurian, Devonian, or Mississippian age where they directly underlie major streams.

Of the principal aquifers, the highly productive ones can be divided into two categories on the basis of their

Table I.— Geologic and hydrogeologic units in Iowa [1]

AGE		ROCK UNIT	DESCRIPTION	HYDROGEOLOGIC UNIT	WATER-BEARING CHARACTERISTICS
Cenozoic	Quaternary	Alluvium	Sand, gravel, silt and clay	Surficial aquifer	Fair to large yields
		Glacial drift (undifferentiated)	Predominantly till containing scattered irregular bodies of sand and gravel		Low yields
		Buried channel deposits	Sand, gravel, silt and clay		Small to large yields
Mesozoic	Cretaceous	Carlile Formation Graneros Formation	Shale	Aquiclude	Does not yield water
		Dakota Group	Sandstone and shale	Dakota aquifer	High to fair yields
Paleozoic	Pennsylvanian	Virgil Series Missouri Series	Shale and limestone	Aquiclude	Low yields only from limestone and sandstone
		Des Moines Series	Shale; sandstones, mostly thin		
	Mississippian	Meramec Series	Limestone, sandy	Mississippian aquifer	Fair to low yields
		Osage Series	Limestone and dolomite, cherty		
		Kinderhook Series	Limestone, oolitic, and dolomite, cherty		
	Devonian	Maple Mill Shale Sheffield Formation Lime Creek Formation	Shale; limestone in lower part	Devonian aquiclude	Does not yield water
		Cedar Valley Limestone Wapsipinicon Formation	Limestone and dolomite; contains evaporites in southern half of Iowa	Silurian-Devonian aquifer	High to fair yields
	Silurian	Niagaran Series Alexandrian Series	Dolomite, locally cherty		
	Ordovician	Maquoketa Formation	Shale and dolomite	Maquoketa aquiclude	Does not yield water, except locally in northwest Iowa
		Galena Formation	Limestone and dolomite	Minor aquifer	Low yields
		Decorah Formation Platteville Formation	Limestone and thin shales; includes sandstone in SE Iowa	Aquiclude	Generally does not yield water; fair yields locally in southeast Iowa
		St. Peter Sandstone	Sandstone	Cambrian-Ordovician aquifer	Fair yields
		Prairie du Chien Formation	Dolomite, sandy and cherty		High yields
	Cambrian	Jordan Sandstone	Sandstone		
		St. Lawrence Formation	Dolomite	Aquiclude (wedges out in northwest Iowa)	Does not yield water
		Franconia Sandstone	Sandstone and shale		
		Dresbach Group	Sandstone	Dresbach aquifer	High to low yields
Precambrian		Sioux Quartzite	Quartzite	Base of ground-water reservoir	Not known to yield water except at Manson cryptovolcanic area
		Undifferentiated	Coarse sandstones; crystalline rocks		

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[1] Stratigraphic nomenclature does not conform to U.S. Geological Survey usage.

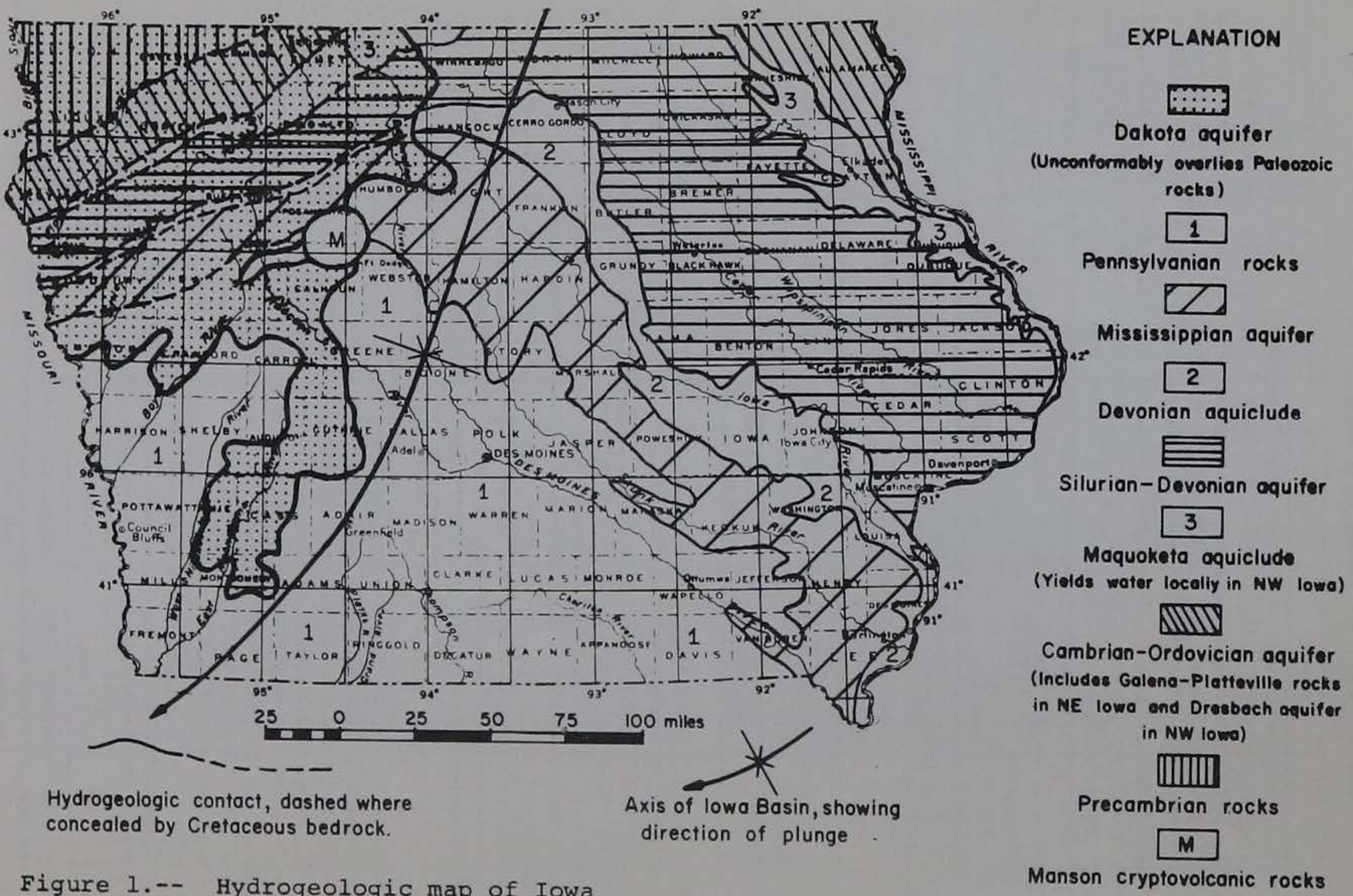


Figure 1.-- Hydrogeologic map of Iowa

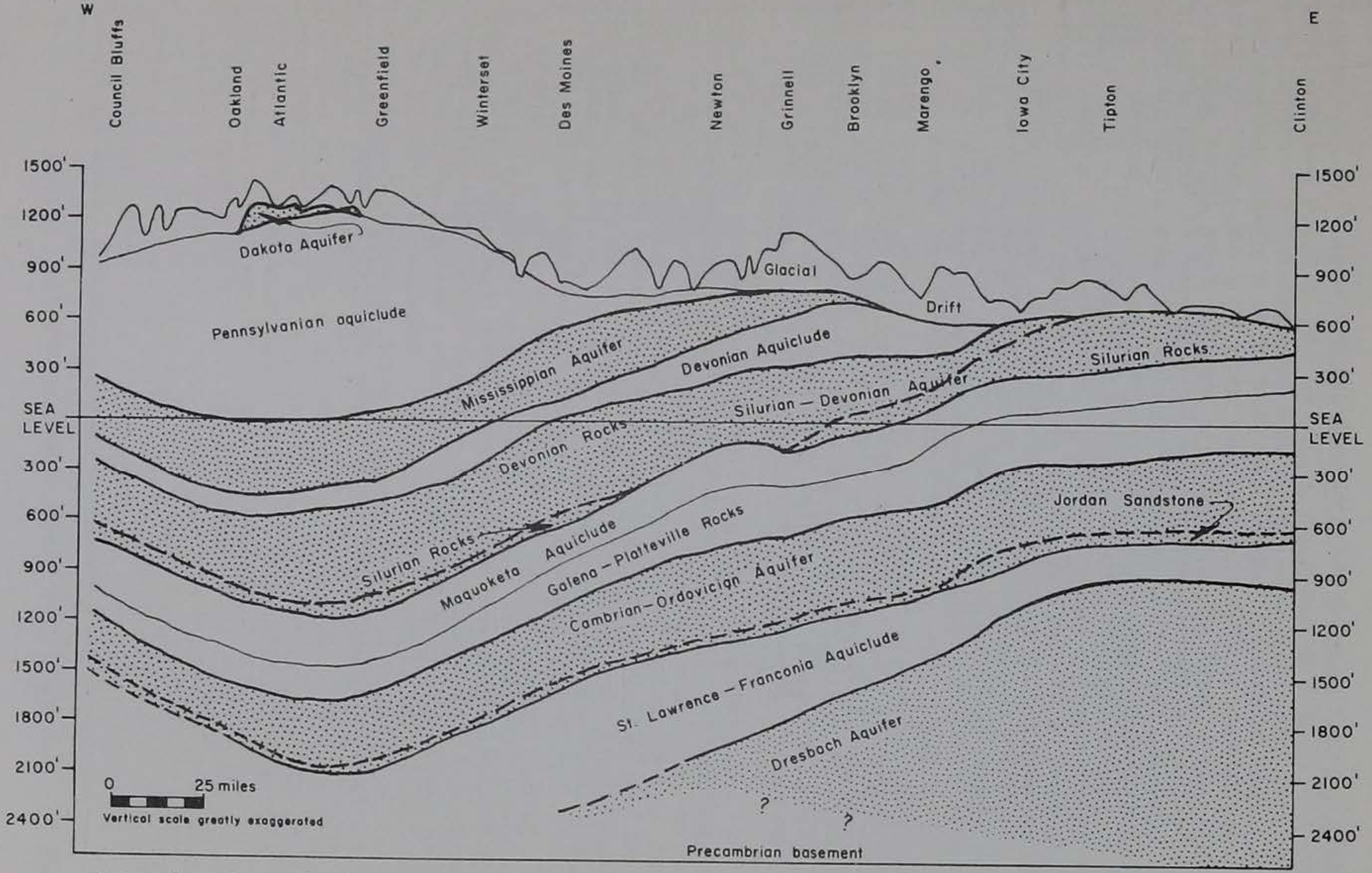


Figure 2 -- Generalized hydrogeologic section of Iowa

recharge and water-yielding characteristics. In one category are the highly productive alluvial and shallow carbonate-rock aquifers directly underlying and in hydrologic connection with principal streams. These aquifers have a close space-time relationship to the streams--so much so that, under certain conditions, most of the water withdrawn from these aquifers is induced surface water. Hence, much of the water classified as ground water in water-use surveys in Iowa could be classified properly as surface water--a concept of importance in any comprehensive plan of water development. In the other category are the deep, highly productive artesian aquifers in Iowa that are a considerable distance from recharge sources. These aquifers have a distant space-time relationship to streams in Iowa, and pumpage from them is derived from artesian storage. However, these aquifers do have an important indirect relationship to streams in Iowa, and that is the support of base flow at centers of ground-water withdrawals. For example, at Mason City[2/] the return flow of ground-water pumpage from the deep Cambrian-Ordovician aquifer adds about 12 cfs (cubic feet per second) to the Winnebago River (Hershey, Wahl, and Steinhilber, in press). This amount is particularly significant during low-flow periods; as for example, when the 10-year, 7-day natural low flow is about 7 cfs.

Interstratified with the bedrock aquifers are a number of non-water-yielding shales and dense, unfissured carbonate rocks of great areal extent (table 1 and figs. 1 and 2). These are the regional aquicludes that confine ground-water flow to the aquifers by retarding vertical movement of water in the reservoir. A few of these aquicludes, however, yield small quantities of water locally. Yields of 10 to 20 gpm (gallons per minute) are available from the Maquoketa Formation in parts of north-central Iowa, where the formation is dominantly a fissured dolomite. Similar yields are available from relatively thin limestones and sandstones that are interbedded with the thick shales of the Pennsylvanian System in parts of southwestern and south-central Iowa. The water, however, generally is highly mineralized. Occasionally yields of as much as 50 gpm of fair- to good-quality water can be produced from channel sandstones that occur locally in the Pennsylvanian.

[2/] See figure 5 for place names in text.

IOWA'S PRINCIPAL AQUIFERS

Surficial Aquifers

The surficial aquifers of Iowa comprise fluvio-glacial outwash deposits and fluvial deposits of Quaternary age (here collectively called alluvial deposits or alluvium) found along the present watercourses, outwash sands occupying buried bedrock channels, and thin discontinuous sand bodies in the glacial drift. The alluvial and buried valley deposits are important sources of moderate to large water supplies, but are restricted in occurrence to river valleys and preglacial drainage lines. The glacial drift is a source of small supplies only, but is important as a source for rural supplies because of its widespread occurrence.

Alluvial deposits underlying the flood plains and terraces of Iowa's principal rivers constitute productive aquifers that are currently and potentially important sources of water. Aquifers of appreciable areal extent occur along the Missouri and Big Sioux Rivers on Iowa's western border and the Mississippi River on the eastern border; others occur along the principal interior rivers (fig. 3). The water-bearing materials underlying these valleys consist mainly of fine to coarse sand and gravel and some interstratified clay and silt that were sorted and deposited by glacial melt waters. The coarser and more permeable deposits occur along the major valleys, where stream velocities were highest. The thickness of these alluvial deposits is from 100 to 160 feet at most places along both the Mississippi and Missouri Rivers and from 30 to 70 feet along the principal interior streams. The deposits thin out and grade into colluvium near the bluff lines. Locally, the thickness of alluvium is appreciably greater wherever present river valleys coincide with preglacial valleys. Appreciable decrease in thickness occurs in areas where local bedrock highs underlie the present valleys.

Enormous quantities of water are stored in the porous alluvial deposits of the Missouri and Mississippi valleys. The Iowa side of the Missouri River alluvium, for example, contains an estimated 6 trillion gallons in storage. The thinner and narrower alluvial aquifers along the interior streams contain smaller, but nevertheless appreciable, amounts in storage. Of more importance than storage, however, is the induced infiltration of river water that sustains the yield from these aquifers when they are developed for water supplies. Requisite conditions for induced infiltration are discussed in detail by Rorabaugh (1956) and Kazman (1948), and are summarized by Walker (1956). Sustained yields, many of them high, have been developed at some localities from the alluvial aquifers in Iowa; additional large sustained yields are available at many

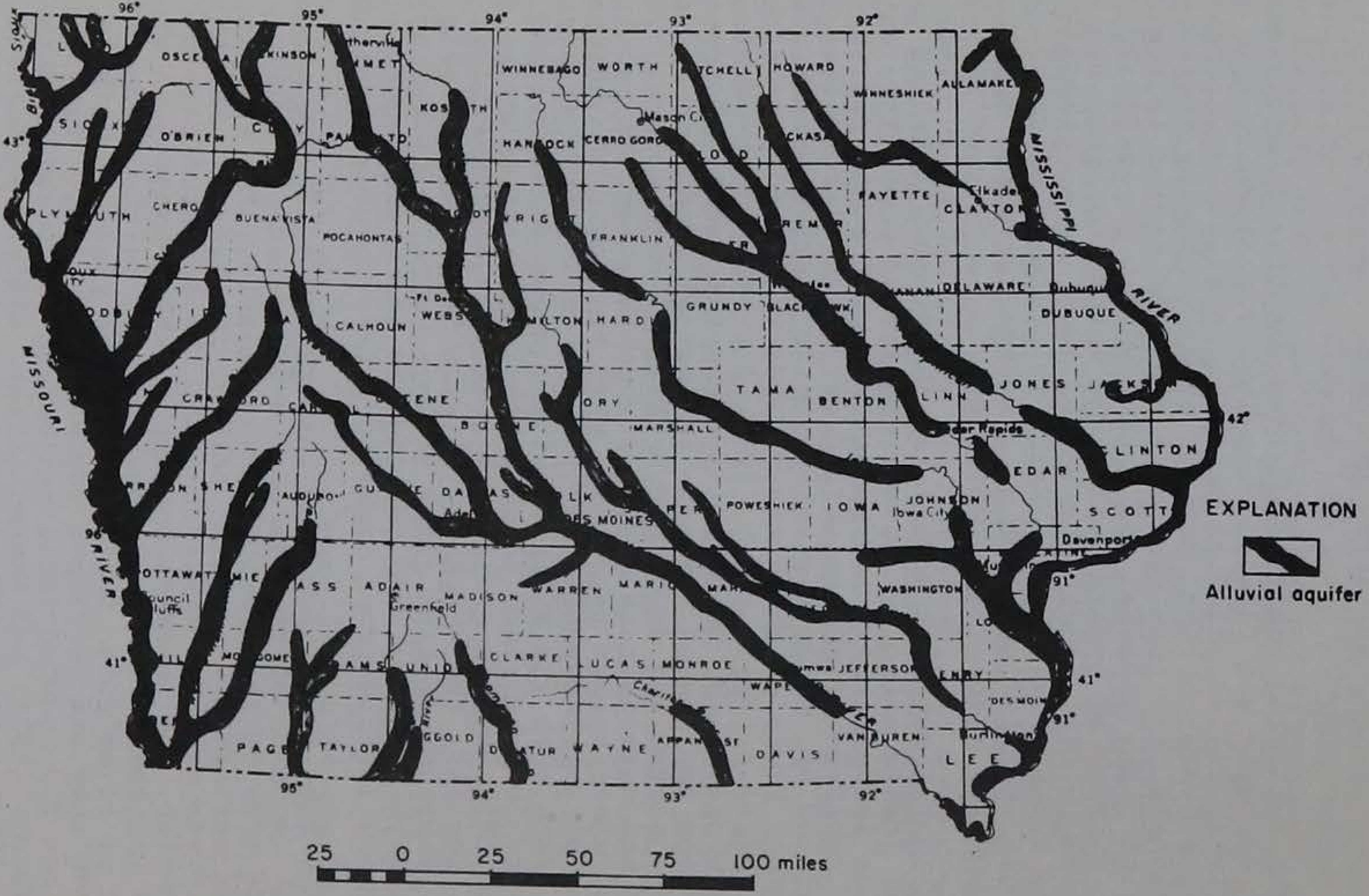


Figure 3.-- Alluvial aquifers of Iowa

other localities. A number of well fields along the Mississippi River develop more than 15 mgd (million gallons per day) each on a sustained basis for industrial and municipal uses. The municipal systems at Des Moines and Cedar Rapids produce about 20 mgd from the Raccoon River alluvium and more than 15 mgd from the Cedar River alluvium respectively.

Individual wells tapping the alluvium along the principal rivers are capable of pumping large quantities of water. In the Missouri valley numerous wells pump from 1,000 to 1,500 gpm for supplemental irrigation. Industrial, irrigation, and municipal wells in the Mississippi valley pump 1,000 to 2,000 gpm. Individual wells tapping the alluvium of the interior streams commonly yield 200 to 300 gpm, but as much as 400 to 600 gpm have been obtained along the larger streams. Much larger yields are available where the alluvial aquifers overlie gravel-filled preglacial valleys. Individual wells tapping these thick alluvial aquifers at Waterloo, Cedar Rapids, and Ames yield as much as 2,000, 1,200, and 1,100 gpm, respectively.

Buried bedrock valleys underlie the glacial drift in many parts of the state; some have been mapped (Beveridge, 1947; Twenter and Coble, 1965), and others are being mapped currently. The valleys that are filled with coarse alluvial materials provide from 10 to 100 gpm to wells at many localities. Occasional yields of 500 gpm and more are available from the aquifers where they are overlain by or are in close proximity to present-day watercourses (Twenter and Coble, 1965). The most productive of the aquifers occur in the central and eastern parts of the state.

Glacial drift is a source of water supply for numerous farms and rural homesteads throughout the state, except in the extreme northeast corner where the drift is largely absent. The drift consists principally of pebbly and sandy boulder clay containing lenticular or shoestring bodies of sorted sand and some poorly sorted sand and gravel. The drift thickness ranges from 0 to 600 feet and averages about 200 feet over the state. The producing zones are the sand bodies within or at the base of the drift. Wells may be dug, bored, or drilled and may range from 15 to 20 feet to as deep as 400 feet or more. Generally, these wells yield only a few gallons a minute, but with favorable conditions and proper well design as much as 10 to 20 gpm may be obtained. The best drift wells are in the area of the late Wisconsin drift lobe in north-central Iowa where outwash sands are abundant. However, rural residents depend heavily on the drift aquifers in western and southern Iowa where the bedrock formations may be deeply buried and yield only small supplies of poor quality water. In many places in these areas the drift sands are the only sources available for acceptable quality water at a reasonable depth. The drift aquifers are less important in northeastern Iowa because they are thinner, and the shallow bedrock aquifers yield the required supplies.

The Dakota Aquifer

Strata of Cretaceous age, principally the Dakota Sandstone (table 1), comprise the chief bedrock aquifer in northwestern Iowa and less extensively in western and southwestern Iowa. These rocks are present across most of the northwestern part of the state as far east as Kossuth, Wright, Webster, Greene, and Guthrie Counties, and as irregular remnants as far south as Montgomery and Page Counties (fig. 1). Maximum thickness of the full Cretaceous System is somewhat more than 400 feet in central Sioux and Osceola Counties, from where it thins northwestward and southeastward.

The upper part of the Cretaceous consists of a thick succession of shales representing the Carlile and Graneros Formations. These shales attain a maximum thickness of 250-300 feet in Lyon, Sioux, and Plymouth Counties and thin to the east and south. The thickness is not uniform as the surface of the shales was deeply eroded before deposition of the glacial materials. The underlying Dakota Sandstone also contains considerable shale, but has water-bearing sandstones in both the upper and lower parts. In the eastern areas commonly only one sandstone is present. Maximum thickness of the Dakota Sandstone is about 260 feet, as observed in logs of wells at Sioux City; but average thickness probably is closer to 50-75 feet. Near the boundaries of the formation the thickness may be only 10 to 20 feet or less. Usually the Dakota Sandstone is rather fine-grained and poorly cemented, which frequently causes sand-pumping troubles when wells are over-pumped. Proper well construction and aquifer development can minimize this problem.

Deposits of sandy and pebbly glacial drift of variable thickness mantle the Cretaceous rocks. Depending on the local thickness of the drift and the thickness of the Carlile and Graneros shales in the upper part of the Cretaceous, the depth to the Dakota Sandstone varies considerably. Generally, in the northwestern counties it is necessary to drill between 250 and 600 feet to penetrate the Dakota aquifer, whereas in the eastern areas the Dakota usually can be reached at between 100 and 350 feet.

The Dakota aquifer generally can be counted on to produce sufficient water for all rural and many municipal requirements. Even where the aquifer is only moderately thick, many wells have been developed to yield 50 to 100 gpm. Some municipal wells in Osceola, O'Brien, Sioux, and Cherokee Counties have been tested at 350 and 750 gpm. At Sioux City where the Dakota Sandstone is recharged by water from overlying alluvial sands and gravels, yields in excess of 1,500 gpm have been obtained. At Red Oak in southwestern Iowa, where the Dakota is thin but apparently is recharged readily, yields of up to 1,000 gpm are available locally from the aquifer.

The Mississippian Aquifer

The Mississippian aquifer consists of a thick sequence of limestones and dolomites between the overlying shales of Pennsylvanian age and the underlying Maple Mill-Sheffield shales of Devonian age (table 1). These rocks underlie that part of Iowa south of a line from Des Moines County northwestward to Hancock County and thence southwestward to Woodbury County (fig. 1).

The aquifer thickness ranges from 0 to about 600 feet with the average thickness about 350 feet. In the area where the aquifer has its main development, the average thickness probably is closer to 250 feet. In certain locations preglacial streams cut deep channels into the bedrock and removed much of the upper part of the Mississippian rocks.

The principal area for developing wells in the Mississippian aquifer is an elongated belt roughly bounded by a line extending from Des Moines County to Wright County on the northeast and by the Des Moines River on the southwest. This includes the subcrop area of the aquifer and an irregular fringe area of thin overlapping Pennsylvanian rocks immediately southwest of the subcrop area (figs. 1 and 2). In the north central part of this area the specific capacity of wells completed in the Mississippian aquifer generally is more than 1.0 gpm per ft (gallons per minute per foot) of drawdown and yields of 100 to 200 gpm are common. Exceptionally large yields have been obtained from wells intersecting large crevices or where the aquifer is recharged by infiltration from overlying glacial sands or directly by the infiltration from nearby streams. For example, wells have yielded from 500 to 900 gpm at a few localities in Wright, Hardin, and northern Story Counties. Less favorable conditions are found in the central and southeastern parts of the area owing to the scarcity of crevices in the formations. Domestic wells usually yield 5 to 10 gpm, but in many localities it is difficult to obtain as much as 2 or 3 gpm. However, some municipal wells in southeastern Iowa have been developed to yield 25 to 50 gpm.

In this principal development belt, the Mississippian aquifer is overlain by glacial drift and in places by Pennsylvanian shales and usually lies 50 to 100 feet below the surface in the north-central part of the area and 100 to 400 feet below the surface in the central and southeastern parts. The aquifer has a gradual overall dip to the southwest from the main subcrop area, so that many hundreds of feet of Pennsylvanian rocks and glacial clays overlie the aquifer in south-central and southwestern Iowa (fig. 2). Yields of wells in these areas generally are low, although occasional yields of 50 gpm have been reported. The water is of such poor quality, however, that the aquifer is little used.

The Silurian-Devonian Aquifer

The Silurian-Devonian aquifer, comprising the Niagaran and Alexandrian Series of Silurian age and the Cedar Valley and Wapsipinicon Formations of Devonian age (table 1), underlies the entire state except for the northeastern and northwestern corners. The aquifer subcrops immediately beneath the glacial drift in a broad belt in northeastern Iowa and beneath the Cretaceous rocks in a narrow belt in northwestern Iowa (fig. 1). Southwest and southeast of these subcrop areas, it dips beneath the Devonian aquiclude and other younger Paleozoic rocks (fig. 2). The aquifer's thickness ranges from 0 to 650 feet and generally is between 200 and 350 feet throughout its area of occurrence.

In the northeastern subcrop area, where the aquifer is overlain only by glacial drift, the depth to the top of the aquifer ranges from 0 to about 300 feet, the greater depths generally along the southwestern part of the subcrop area. Elsewhere the aquifer is reached only after drilling through several hundreds of feet of younger consolidated rocks and glacial drift (fig. 2).

The aquifer is composed of relatively dense limestone and dolomite, whose porosity and permeability are dependent principally on secondary rock openings--fractures, joints, brecciated zones, and solution tubules. These water-bearing rocks are highly anisotropic with respect to ground-water flow--as are most carbonate rock aquifers--because the secondary rock openings are randomly oriented and are variable in size, extent, and frequency of occurrence. The anisotropic nature of the aquifer makes it difficult to determine aquifer coefficients or to predict yields from the aquifer with any assurance. However, on the basis of well records, the aquifer's porosity and permeability are known to be best developed in the northeast subcrop area. In this area, the rock openings were enlarged by solution activity by relatively rapid ground-water circulation during the long interval of pre-Pleistocene time that these rocks were exposed to erosion. Also in this area, the aquifer is overlain by glacial drift and receives recharge more readily than it does in the area where the aquifer is covered by the Devonian aquiclude.

The main area for developing wells in the Silurian-Devonian aquifer is the northeast subcrop area, a broad belt about 65-70 miles wide and 200 miles long, extending across the northeastern part of the state from Muscatine, Scott, Clinton, and Jackson Counties on the east to Howard, Mitchell, Worth, and Winnebago Cpunties at the Minnesota boundary (fig. 1). The specific capacity of wells in this area generally is at least 2.0 gpm per ft of drawdown and commonly as high as 4.0 to 6.0 gpm per ft of drawdown. Many municipal and industrial wells obtain between 150 and 400 gpm per well from the aquifer. Most domestic wells pumping from the Silurian-Devonian aquifer will deliver from 10 to 30 gpm with small to moderate drawdowns. However, in some places where the wells have failed to intersect a good crevice system, it may be difficult to obtain as much as 1 gpm per ft of drawdown. Often this situation may be remedied by acidizing and developing the wells or moving a few hundred feet to a new drilling site.

One of the best ground-water provinces in all of Iowa is a narrow strip along the Cedar River valley from Charles City to Waterloo, which is underlain by creviced limestones of Devonian age. Yields as great as 2,000 to more than 4,000 gpm have been recorded from wells at Cedar Falls and Waterloo, and somewhat less at Waverly and Charles City. The specific capacity of these wells ranges from 200 to 350 gpm per ft in the Cedar Falls-Waterloo area and from 60 to 185 gpm per ft in the Charles City-Waverly area. The aquifer in these areas receives induced recharge from the river through a thin layer of alluvial sand and thence through cavernous limestones.

The Silurian-Devonian aquifer is utilized much less in the area where it is overlain by the Devonian aquiclude. In the central and southern parts of the state, yields of 20 to 150 gpm can be obtained, but the water contains high concentrations of sulfate and total dissolved solids. The mineralization is attributed to thick evaporite deposits--gypsum and anhydrite--that occur in the Cedar Valley and Wapsipinicon Formations. In western and southwestern Iowa the aquifer is deeply buried beneath younger rocks (fig. 2). In these areas of deep burial, well developed crevice systems are proportionately fewer in the carbonate rocks. As a result, the yield of wells is smaller than in the northeastern subcrop belt. However, based on records of a few wells, yields of as much as 200 gpm of acceptable quality water might be obtained locally.

The Cambrian-Ordovician Aquifer

The Cambrian-Ordovician aquifer is widespread and consistently yields several hundred to more than one thousand gallons of water per minute to individual wells throughout the eastern three-fourths of the state. It crops out in the northeastern corner of the state and subcrops beneath the Cretaceous rocks in northwestern Iowa (fig. 1). The aquifer is present beneath younger Paleozoic rocks at progressively greater depths to the southwest and southeast. The depth to the top of the aquifer in southwestern Iowa, the deepest part of the Iowa Basin, is about 3,200 feet (fig. 2). The total thickness of the water-bearing unit ranges from 0 to 600 feet in eastern Iowa and from 0 to 400 feet in the western part of the state; the average thickness throughout its subsurface extent is generally between 400 to 500 feet.

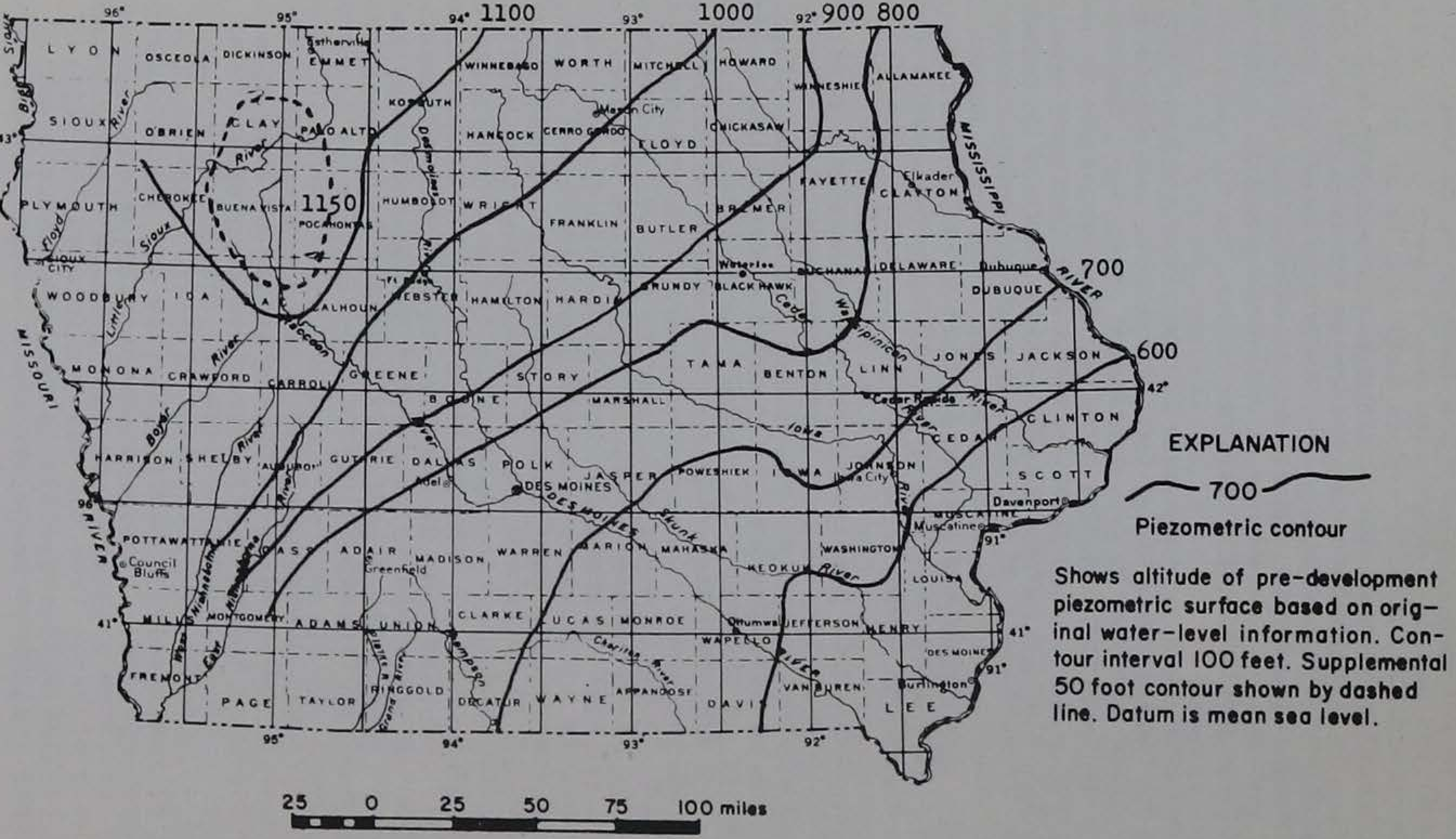
The aquifer consists of three water-bearing formations, the St. Peter Sandstone and Prairie du Chien Formation of Ordovician age and the Jordan Sandstone of Cambrian age (table 1). The St. Peter is a friable, medium-grained, almost pure quartzose sandstone that is rarely more than 50 feet thick. Although it is capable of yielding 50 gpm or more to wells in eastern Iowa, the formation generally is cased off in wells drilled to the Cambrian-Ordovician aquifer to prevent caving of the friable sandstone or to shut off poor-quality water. The Prairie du Chien Formation consists principally of dolomite but includes some sandstone beds. Its thickness is several hundred feet in the subsurface of eastern and southern Iowa, but in northwestern Iowa the formation wedges out. The formation is believed to yield significant amounts of water to wells penetrating the Cambrian-Ordovician aquifer; however, its performance generally is masked by the performance of the underlying Jordan Sandstone. The Prairie du Chien, however, is the principal water-producing unit for some wells in south-central Iowa. Also, in some unusually high capacity wells (greater than 25 gpm per ft of drawdown) finished in the Cambrian-Ordovician aquifer, most of the water is obtained from extensive crevices in the Prairie du Chien. The Jordan Sandstone is the principal water-producing unit and is penetrated by practically all wells drilled to the Cambrian-Ordovician aquifer. This formation is a medium- to coarse-grained, pure quartzose sandstone whose thickness ranges from 75 to 125 feet in southwestern Iowa. Based on a few laboratory determinations, the effective porosity of the formation is believed to be 10 to 15 percent in northeastern and northern Iowa, where the sandstone is poorly cemented and quite friable. The degree of cementation increases and the porosity commensurately decreases to the southwest.

The transmissibility of the aquifer (principally the Jordan Sandstone) has been determined by pumping tests at a few sites in eastern and northern Iowa to be between 30,000 and 40,000 gpd per ft. A storage coefficient of 2.8×10^{-4} was determined at one site and is believed to be of the correct order of magnitude for the aquifer in eastern and northern Iowa. In areas where the Jordan is between 75 and 125 feet thick and where cementation has not reduced the porosity and permeability, these aquifer coefficients are usable to predict water-level drawdowns in and near pumping wells and to calculate optimum well spacing.

Recharge to this deep artesian aquifer in Iowa is principally by subsurface inflow from the north, and discharge is by subsurface outflow to the southeast (fig. 4). The average velocity of flow through the aquifer, from recharge to discharge area, is calculated to be about 100 feet per year. The piezometric high in northwest Iowa (fig. 4) is attributed to recharge by seepage from the Dakota aquifer, which has a slightly higher pressure head than the underlying Paleozoic aquifers. Recharge is enhanced in this area by the absence of the Paleozoic aquicludes, which either wedge out or undergo facies changes to dolomites.

The aquifer is utilized extensively by municipalities and industries in the eastern three-fourths of the state. Many small communities in central and southern Iowa also utilize the aquifer because the overlying rocks do not yield enough water or the water is highly mineralized. Yields of up to 1,000 gpm are obtainable in most of the northeastern one-half of the state. Limited well data indicate that yields of only 100 to 300 gpm are available in much of the southwestern quarter of the state. Specific capacities of wells finished in the aquifer commonly range from 5 to 25 gpm per ft of drawdown in northern and eastern Iowa and from 1 to 3 gpm per ft of drawdown in southwestern Iowa. Occasional specific capacities of 30 to 80 gpm per ft of drawdown have been reported from the eastern half of the state. The yields and specific capacities of many wells have been increased 50 to 100 percent by acidizing or shooting and surging the wells. Most properly developed or stimulated wells in eastern and northern Iowa will yield over 1,000 gpm and have specific capacities of 10 gpm per ft or more.

Significant lowering of the aquifer's pressure head has occurred at a number of localities where large amounts of water are pumped from the aquifer. Loss of pressure head in the vicinity of wells pumping from the aquifer have been recorded at Ottumwa (100 feet in 70 years), Grinnell (100 feet in 80 years), and a number of other smaller communities in southeastern Iowa. The most extensive piezometric lowering has been recorded at Mason City, Cerro Gordo County, where withdrawals of water from the aquifer totaled 110 billion gallons between 1912 and 1969. During this period, water levels have declined between 140 and 200 feet at the principal



EXPLANATION

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Piezometric contour

Shows altitude of pre-development piezometric surface based on original water-level information. Contour interval 100 feet. Supplemental 50 foot contour shown by dashed line. Datum is mean sea level.

Figure 4.-- Piezometric map of Cambrian-Ordovician aquifer

centers of pumping and over 100 feet throughout the city and its immediate vicinity (Hershey, Wahl, and Steinhilber, in press). Analysis of water-level data indicates that the cone of drawdown has been practically stabilizing since about 1959, about the time that withdrawals began to stabilize at 8 to 9 mgd. Increased withdrawals in the future, however, will cause additional piezometric lowering until stability is again achieved at the new pumping rate.

The situation at Mason City is typical of pressure-head losses that will occur at most localities in the state whenever the Cambrian-Ordovician aquifer is stressed by heavy pumpage. Loss of pressure head is incurred because the withdrawal rate from the aquifer exceeds the replenishment rate at the pumping site and water is taken from artesian storage. The resultant cone of drawdown expands as more and more water is taken from storage to satisfy the withdrawals at the pumping site. If withdrawals are fairly constant, the drawdown cone will practically stabilize when enough water is diverted to the pumping site by interception of down-gradient flow (water that normally would discharge past the pumping site as underflow). Continually increasing withdrawals from the aquifer, which is the usual pumping regimen in growing communities, prevents stabilization of the drawdown cone and water levels in wells continue to decline. Remedial measures to slow down excessive water-level declines in areas where the Cambrian-Ordovician aquifer is heavily pumped are discussed by Walker (1956).

The Dresbach Aquifer

The Dresbach aquifer as here defined consists of a sequence of coarse- to fine-grained sandstones between the overlying Franconia Formation of Cambrian age and the underlying crystalline rocks or quartzites of Precambrian age (table 1). The overlying Franconia is principally a fine-grained, glauconitic sandstone, but includes much shale, dolomite and siltstone locally. These strata and the overlying St. Lawrence Formation are relatively impermeable in Iowa and are considered to be an aquiclude between the Dresbach and Cambrian-Ordovician aquifers. However, the Ironton Sandstone, the basal member of the Franconia, where present, is hydraulically connected with the Dresbach and is considered to be part of the aquifer.

The Dresbach Group is divided into three formations from the top down--the Galesville Sandstone, Eau Claire Formation, and Mount Simon Sandstone. The latter includes some sandstones that may belong to the so-called Red Clastics of Precambrian age. The combined Ironton-Galesville section is about 150-200 feet thick in eastern Iowa, but thins westward and appears to be absent in the western half of the state. The Eau Claire is principally a fine-grained sandstone in the eastern counties, but changes to a shale in central Iowa; locally it contains dolomite. This unit's thickness averages about 200 feet. The Mount Simon is practically all sandstone, althoug some thin shales may be present in the lower part. The Mount Simon sandstones are about 1,325 feet thick at Clinton, at least 325 feet thick at State Center, and 125 feet thick at Redfield. The Mount Simon may be absent in southwestern Iowa, although the Red Clastics apparently are very thick in Page County.

The top of the Dresbach lies at a depth of 50 to 75 feet below the surface at Lansing in the northeastern corner of the state and dips gradually to the south and southwest. It was reached at 675 feet at Dubuque, 1,600 feet at Clinton, 2,030 feet at Burlington, 2,980 feet at State Center, and 3,560 feet in Page County in southwestern Iowa.

The Dresbach is a significant aquifer only in a few eastern counties, where it also is one of the most productive in Iowa. High capacity wells yielding water of acceptable quality for municipal and industrial use have been developed at Lansing, Dubuque, Clinton, and Maquoketa. Some of these wells are capable of delivering 2,000 to 3,000 gpm with specific capacities of from 10 to as high as 100 gpm per ft of drawdown. Attempts were made to develop additional water supplies from the Dresbach aquifer at Mason City, State Center, Grinnell, McGregor, and Mt. Pleasant. All attempts were unsuccessful, however, because the yields generally were less than 50 gpm and/or the water was mineralized and not of acceptable quality.

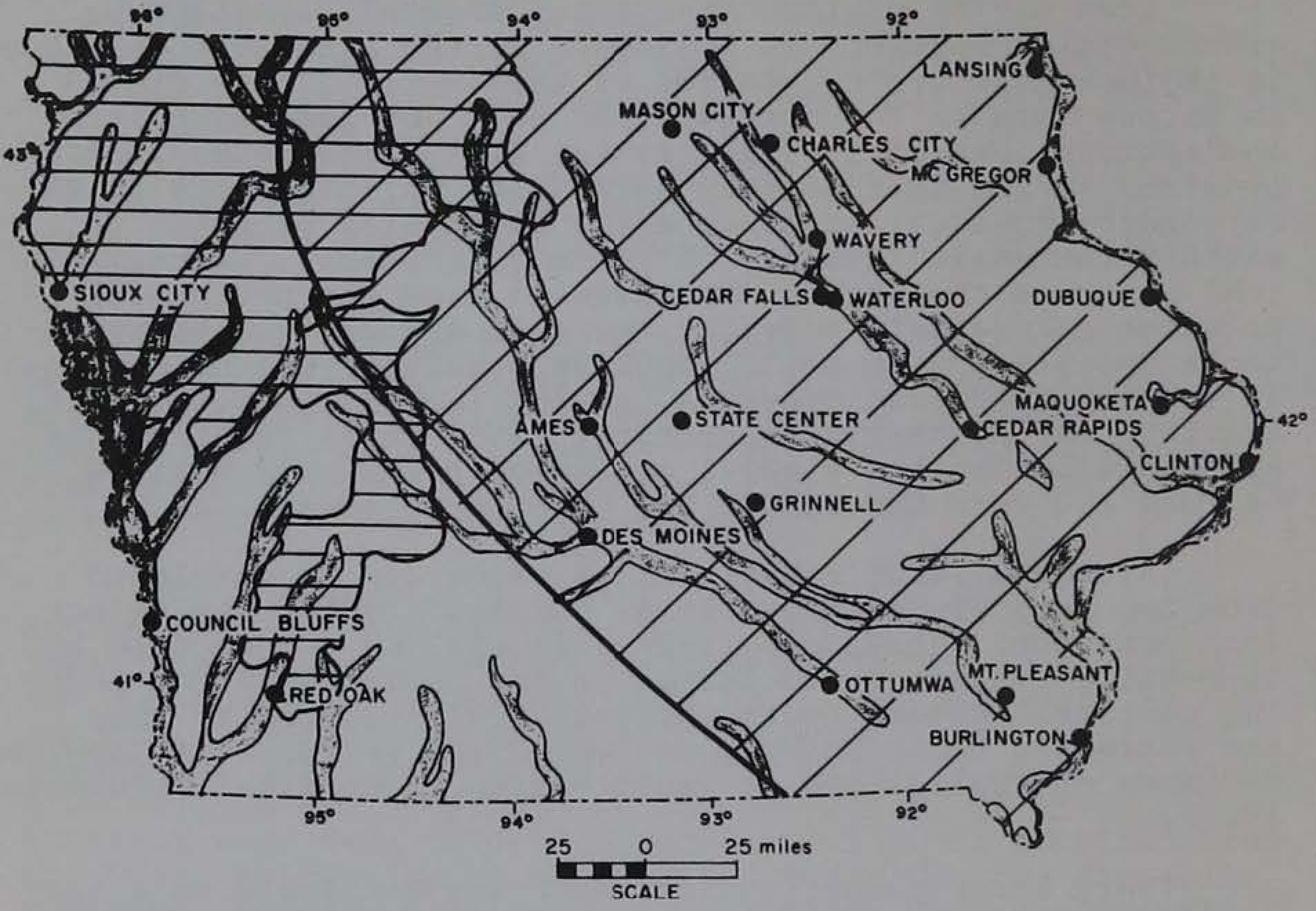
Significant pressure-head losses have occurred at Clinton, where large amounts of water are withdrawn from the Dresbach aquifer for municipal and industrial use. Pumpage from the aquifer has increased from about 1 mgd in the early 1900's to about 15 mgd in 1968. During this period, water levels have declined more than 250 feet at the major pumping centers and more than 125 feet throughout the city. Because withdrawals are continuously increasing, water levels have not stabilized as yet and the cone of drawdown continues to expand.

SUMMARY AND CONCLUSIONS

Iowa can be divided into three somewhat overlapping ground-water provinces as follows: 1) the Paleozoic province in the northeastern two-thirds of the state; 2) the Cretaceous province in the northwestern part and extending into the southwestern part of the state; and 3) the Pennsylvanian province in the southwestern part (fig. 5). Aquifers in the Paleozoic province can produce the quantities of water to satisfy increasing demands of the more populous, industrialized parts of the state. Withdrawals from the Cretaceous province can satisfy moderate regional demands and heavy demands locally. Only small supplies generally can be obtained in the Pennsylvanian province, except locally where alluvial aquifers may be fairly productive. Most rural requirements are satisfied by the glacial drift and relatively shallow bedrock aquifers throughout all three provinces.

Although large quantities of water can be developed from the deep artesian aquifers, particularly in the Paleozoic province, increased withdrawals will be accompanied by increasing pressure-head losses in the vicinity of the pumping centers. Water levels eventually will stabilize when the increased costs of pumping compel the use of other sources of water or application of conservation techniques (McGuinness, 1963).

Very large quantities of water are available on a sustained basis from the principal alluvial aquifers, which scarcely have been tapped (fig. 5). Production from these sources, if properly planned and developed, runs into the tens of millions of gallons per day. Large-scale, future ground-water development for industry and irrigation will almost certainly be located in the valleys of the principal streams because of assured supplies of good-quality water (Walker, 1956).



EXPLANATION

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PALEOZOIC GROUND-WATER PROVINCE

The upper carbonate aquifers commonly yield 50 to 300 gpm to individual wells; occasionally 300 to 500 gpm; and rarely 500 to 2000 gpm. The Cambrian–Ordovician aquifer commonly yields 500 to 1000 gpm and occasionally as much as 1500 gpm. The Dresbach aquifer in extreme east-central part generally yields 1000 to 3000 gpm.

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CRETACEOUS GROUND-WATER PROVINCE

The Dakota aquifer commonly yields 50 to 100 gpm; occasionally as much as 700 gpm; and rarely 1000 to 1500 gpm.

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PENNSYLVANIAN GROUND-WATER PROVINCE

The Pennsylvanian rocks generally yield only 10 to 20 gpm. Intermediate carbonate aquifers generally yield 50 gpm and rarely as much as 200 gpm. The deeply buried Cambro-Ordovician aquifer generally yields 100 to 200 gpm and rarely as much as 300 gpm.

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ALLUVIAL AQUIFERS

Yields of 1000 to 2000 gpm per well are available from Mississippi and Missouri River valleys. Alluvium of larger interior streams commonly yields 200 to 300 gpm and occasionally 300 to 600 gpm; yields of 1000 to 2000 gpm are available locally where buried channel aquifers underlie alluvium.

Figure 5.-- General availability of ground water in Iowa

REFERENCES CITED

1. Beveridge, T. R., Subdrift valleys of southeastern Iowa: Unpublished M.S. thesis, University of Iowa, 57 p., 3 figs., plate, 1947.

2. Hershey, H. G., K. D. Wahl, and W. L. Steinhilber, Geology and ground-water resources of Cerro Gordo County, Iowa: Iowa Geological Survey Water-Supply Bull. 10 (In press), 1970.

3. Kazman, R. G., River infiltration as a source of ground-water supply: Am. Soc. of Civil Engineers Trans., v. 113, p. 404-420, 1948.

4. McGuinness, C. L., The role of ground water in the national water situation: U.S. Geol. Survey Water-Supply Paper 1800, 1121 p., 1963.

5. Murray, C. R., Estimated use of water in the United States, 1965: U.S. Geol. Survey Circ. 556, 53 p., 14 figs., 32 tables, 1968.

6. Rorabaugh, M. I., Ground water in northeastern Louisville, Ky., with reference to induced infiltration: U.S. Geol. Survey Water-Supply Paper 1360-B, p. 101-169, 28 figs., 8 tables, 1956.

7. Twenter, F. R. and R. W. Coble, The water story in central Iowa: Iowa Geol. Survey Water Atlas No. 1, 89 p., maps, illus., 1965.

8. Walker, E. H., Reserves of ground water in Iowa: Am. Water Works Assn. Jour., v. 48, p. 499-510, 2 figs., 2 tables, 1956.

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THE CHEMICAL QUALITY OF IOWA'S WATER RESOURCES

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INTRODUCTION

This paper presents a general appraisal of the chemical quality of Iowa's water resources. Some problems--hardness, iron, fluoride, nitrate, and saline water--are considered. Data concerning the principal sources of water, the streams and lakes, the alluvial aquifers, and the major bedrock aquifers are presented in tables and on maps. Although good-quality water is available in some local areas from minor bedrock and glacial drift aquifers, the scope of this paper will not permit a discussion of these.

The better quality waters in Iowa are those containing less than 500 mg/l (milligrams per liter) of dissolved solids. These waters are almost always of the calcium bicarbonate or calcium magnesium bicarbonate type. Waters containing from 500 to 1,000 mg/l of dissolved solids are considered to be of fair quality. In some areas, ground water with concentrations of up to 1,500 mg/l is used extensively, and is considered to be acceptable. These waters usually grade from calcium or calcium magnesium to the sodium type and from bicarbonate to sulfate or sulfate chloride type in areas where the dissolved-solids content increases.

The water quality in the bedrock aquifers is shown on the following pages by a series of maps showing the distribution of the dissolved solids. The highest dissolved-solids value shown on the maps is 2,500 mg/l. Concentrations greatly exceed this value in some places, but it is not practical to show these areas on generalized maps. Areas of unusually high concentrations are mentioned in the text. The Manson area shown on some maps represents a cryptovolcanic area where crystalline Precambrian basement rocks occur near the land surface. Except for isolated patches, these crystalline rocks are not covered by any bedrock aquifers.

The interpretations made in this paper are based on several thousand chemical analyses that are in the files of the Iowa Geological Survey and the U.S. Geological Survey. The chemical analyses in these files were performed by the State Hygienic Laboratory. Where numerous analyses were available from one particular public supply, those reported in the 1964 publication, "Public Water-Supply Data," by the State Department of Health were used. Even though that publication includes only analyses of municipal supplies, it is the most recently published and complete tabulation of chemical analyses of Iowa's water.

GENERAL PROBLEMS

Some characteristics of Iowa's waters are common in almost all places and from all sources. Others are widespread, but not universal.

Nearly all of Iowa's natural waters are very hard. Hardness is a nuisance which affects the use of the water for many domestic and industrial purposes, but it can be effectively eliminated by treatment. Hardness in excess of about 100 to 150 mg/l, calculated as an equivalent amount of $CaCO_3$ is noticeable and troublesome for many uses. Hardness ranges from 150 to 400 mg/l for surface waters and from 250 to 500 mg/l for ground waters from the more commonly used aquifers. Some alluvial aquifers will yield water with a hardness of from 150 to 200 mg/l, and water from some bedrock aquifers in areas where they yield highly mineralized water often will have a hardness in excess of 1,000 mg/l.

Iron, which can be a nuisance in staining clothing and porcelain, is not a problem in water from Iowa streams and lakes. However, it does occur in amounts (more than 0.3 mg/l) which can cause problems in some places in all aquifers. Iron in troublesome amounts is commonly found in water from the alluvial aquifers, in sand aquifers beneath the glacial drift, and in near-surface bedrock aquifers.

Nitrates in excess of acceptable concentrations occur at times in most streams and have been found in many shallow wells. More than 45 mg/l of nitrates are thought to cause methemoglobinemia in infants. The source of nitrates is of organic origin and comes mainly from barnyard wastes, septic tank effluent and fertilizers.

Concentrations of nitrate are low most of the time in surface waters. However, they rise considerably and sometimes exceed 45 mg/l in streams during times of overland runoff. The nitrates are derived from material washed into the streams from the land surface. Most of this can be attributed to livestock wastes and fertilizers.

Although nitrate problems in ground waters are encountered most often in the southern part of Iowa, the occurrence of high concentrations is related more to improper well construction and location than to a particular region. Problems are encountered in almost all cases in shallow dug or bored wells which have brick, field stone or concrete or clay tile as casing or shoring material. Water in these wells is obtained from glacial drift or sand and gravel. Contaminated water enters these wells by running directly into the well from the ground surface or through the porous casing or shoring material after infiltrating only a short distance through the surficial material.

Most wells that are constructed with continuous iron or steel casing and that are situated so that surface drainage runs away from the well usually are not contaminated with nitrates. Some exceptions do exist, however. Instances of properly constructed wells yielding high nitrate concentrations are common in some alluvial aquifers. Upper layers of sand and gravel may contain unacceptable amounts whereas parts of the aquifer below an intervening clay layer contain negligible amounts of nitrate. Continued applications of fertilizer on flood plain and terrace areas may result in this problem becoming more widespread. Where clay layers do not separate the alluvial aquifers into two or more parts, nitrates may contaminate the only major source of ground water over a large area.

Other exceptions occur in wells which are drilled into limestone or dolomite, where the aquifer lies near the land surface. Joints and crevices, which are common to these rocks, can transmit water from the surface to the water-bearing zone rather rapidly. A few cases of nitrate concentrations approaching excessive levels are known, particularly in eastern Iowa.

Fluoride is added to many of Iowa's public water supplies to aid in the prevention of dental caries in children. Too much fluoride is thought to cause the mottling of tooth enamel. The U.S. Public Health Service recommends that, in Iowa, concentrations of fluoride should be between 0.8 and 1.3 mg/l and concentrations in excess of 2.0 mg/l shall be grounds for rejection of the supply. The natural concentration of fluoride exceeds this amount in some ground waters. One notable example is in the central part of the state in sections of Dallas, Polk, Boone, and Story Counties. Water from the Mississippian aquifer here generally contains 5 to 6 mg/l of fluoride and one sample had 9 mg/l. Other samples from this aquifer in surrounding areas show lower amounts, but amounts still in excess of 2.0 mg/l. Analyses from the Jordan aquifer also show fluoride in excessive amounts in an area west of the city of Des Moines and southwest of the Des Moines River downstream from the city. Several Jordan wells there yield more than 2.0 mg/l of fluoride, and some have amounts slightly more than 3.0 mg/l.

Mineralized or saline water--waters containing more than 1,000 mg/l of dissolved solids--occurs in parts of all of Iowa's major bedrock aquifers. Under present technology and economics, these waters are avoided when searching for a water supply for public or most industrial uses. These saline waters should be considered as a resource rather than a liability. The water could be utilized in some industrial processes. Cooling is one example. Presently known water desalinization processes may be employed or new ones developed in which these waters might be made potable economically.

Iowa's saline waters might be considered as a low-grade water resource, looked upon in the same light as the mining industry looks upon low-grade ore deposits. They are something to hold in reserve until our technology or our needs allow or demand that we use them.

SURFACE-WATER RESOURCES

The water in our streams is comparable, with respect to its gross chemical aspects, with the water from the better aquifers in the basin that each stream drains. However, surface waters show a wide range of dissolved-solids concentrations at any one place. The lowest concentrations occur during times of high discharge when the streams are carrying water from recent precipitation or snow melt and the highest concentrations occur during times of low discharge when the streams are carrying the base-flow contribution from ground-water inflow.

The lowest dissolved-solids concentrations are found at times of highest runoff in the spring and early summer. While the concentration of dissolved matter is lower at these times, high runoff results in material from the land surface being carried into the streams. Not only do nitrate concentrations increase, as was described before, but increased amounts of other compounds such as phosphates are evident.

The highest concentrations of dissolved solids occur most often during the period from November through February when discharge is low, the water temperatures are near freezing, and an ice cover often exists. At these times, the bicarbonate content of the water increases to as much as 500 to 600 mg/l. This results in a high alkalinity and a high calcium carbonate hardness.

Where streams are continuously monitored or samples are collected and analyzed daily, a concentration-duration curve can be constructed which is much like a flow-duration curve for stream discharge. Data of this type have rarely been collected in Iowa. Increasing demands for all types of uses are going to be made of our streams. Much more sampling and even monitoring will be needed in order to anticipate and maybe to eventually control several of the water's characteristics.

However, some streams have been sampled periodically for the past 13 years. The arithmetic means and the standard deviations of the dissolved solids and the chemical types of the water indicated by the analyses of these samples are shown for a few streams in table 1. The highest means,

Table 1.--Chemical quality of some Iowa river waters

River	Sampling Point	Water Type	Dissolved Solids		No. of Samples	Sampling Period	Drainage Area (sq. miles)
			Mean (mg/l)	Std. Dev.			
Mississippi	Clinton Clinton Co.	$Ca - HCO_3$	196	33	31	1956-69	85,600
Mississippi	Keokuk Lee Co.	$Ca - HCO_3$ $Ca \cdot Mg - HCO_3$	231	37	28	1956-69	119,000
Cedar	Cedar Rapids Linn Co.	$Ca - HCO_3$ $Ca \cdot Mg - HCO_3$ $Mg \cdot Ca - HCO_3 \cdot Cl$	309	60	30	1956-69	6,510
Iowa	Marshalltown Marshall Co.	$Ca - HCO_3$	381	74	11	1961-68	1,564
Skunk	Ames Story Co.	$Ca - HCO_3$	500	111	25	1956-68	315
Des Moines	Fort Dodge Webster Co.	$Ca - HCO_3$ $Ca \cdot Mg - HCO_3$ $Ca \cdot Mg - SO_4 \cdot HCO_3$	492	132	29	1955-68	4,190
Des Moines	Des Moines (Euclid Ave.) Polk Co.	$Ca \cdot Mg - HCO_3$ $Mg \cdot Ca - HCO_3$ $Ca - HCO_3$ $Ca - HCO_3 \cdot SO_4$	478	137	43	1956-69	6,245
Des Moines	Ottumwa Wapello Co.	$Ca - HCO_3$ $Ca \cdot Mg - HCO_3$ $Ca \cdot Mg - HCO_3 \cdot SO_4$	422	104	30	1956-68	13,374
Nodaway	Clarinda Page Co.	$Ca - HCO_3$	243	30	27	1956-68	762
Missouri	Sioux City Woodbury Co.	$Ca \cdot Na - SO_4$ $Na \cdot Ca - SO_4$ $Ca \cdot Na - HCO_3 \cdot SO_4$	507	55	14	1960-68	314,600
Missouri	Council Bluffs Pottawattamie Co.	$Ca \cdot Na - SO_4$ $Ca \cdot Mg - HCO_3$ $Na \cdot Ca - SO_4$	488	66	28	1956-68	322,800

which are just slightly more than 500 mg/l, are from the interior streams which drain the central part of the state and from the Missouri River. The lowest means of the dissolved solids are less than 250 mg/l. They are from samples of the Mississippi and Nodaway Rivers. The Nodaway River is believed to be typical of streams in southwestern Iowa whose base flow is derived from surficial materials and not from more mineralized bedrock aquifers. The major type of river water is calcium bicarbonate with the exception of that from the Missouri River. The first type listed in table 1 for each stream has the most frequent occurrence; and where several are listed, the last one was found in only one or two samples.

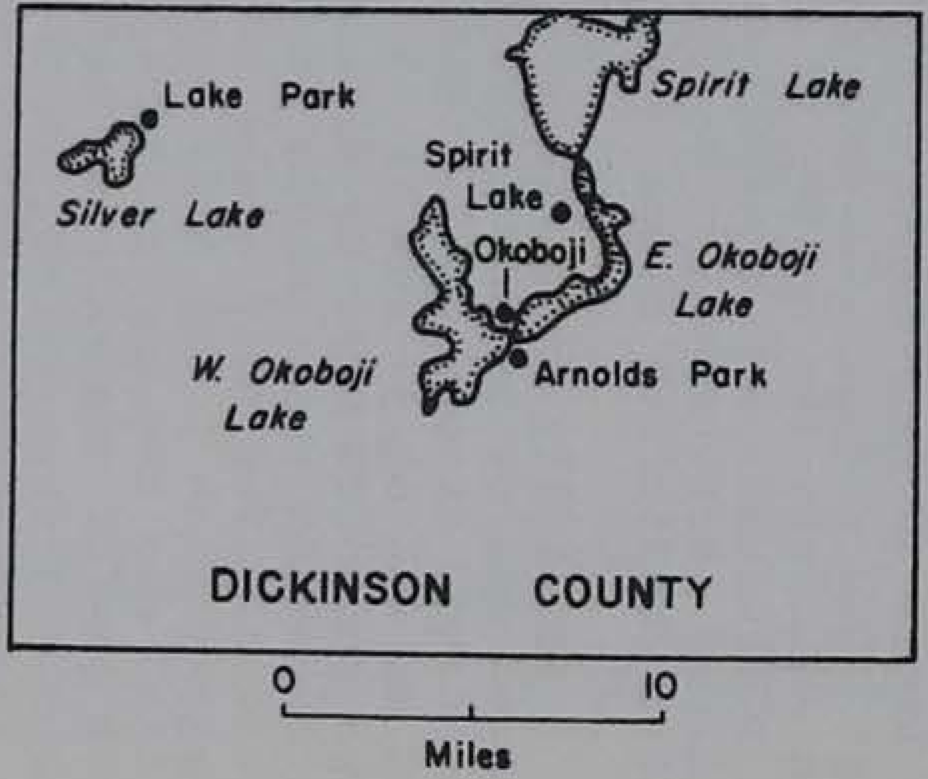
Lakes and reservoirs constitute another surface-water source. Natural lakes in northern Iowa are commonly used as a source for a public supply, and several reservoirs have been constructed in southern Iowa where appreciable ground-water sources are hard to find and the natural flows in streams are not dependable. During the summer of 1964, Bachmann (1965) samples 61 lakes and reservoirs and reported seven parameters for each. With the exception of one bog lake and a few lakes whose waters contained high sulfates, he found them to be what he called typical hard-water lakes. The higher average specific conductances and sulfate concentrations Bachmann listed were from lakes in northwestern Iowa. Considerable variation can be found in the lake waters in that part of the state. Complete mineral analyses are available from three lakes in Dickinson County--West Okoboji, Spirit, and Silver Lakes (table 2). These lakes are not more than 10 miles apart, but the analyses show a considerable difference in chemical composition of their waters. Three samples were collected from each lake during the drought period of 1956-57 and may not be typical. However, additional samples from Spirit Lake indicate that the three 1956-57 analyses from that lake, at least, are typical. Hence, the others from that period are probably typical also.

The dissolved-solids content of Silver Lake is twice that of Spirit Lake and more than two and one-half times that of West Okoboji Lake. The sulfate concentrations in Silver Lake is five times that in Spirit Lake, and ten times that in West Okoboji. Spirit and West Okoboji Lakes' waters are of the calcium bicarbonate type; that from Silver Lake is calcium sulfate.

The natural lakes are essentially windows in the ground-water table, and the lakes waters' chemical characteristics are similar to those of the ground water in their respective areas. High concentrations of dissolved solids and sulfates also occur in the water of the bedrock and alluvial aquifers in this area, and the concentrations in the lake water

Table 2. --Quality of water in three lakes in Dickinson County

Lake	Town Supply	Dissolved Solids (mg/l)		Sulfate (mg/l)		Number of Samples	Sampling Period
		Mean	Std. Dev.	Mean	Std. Dev.		
W. Okoboji	Arnolds Park	266	8.4	29.6	4.0	3	1956-57
W. Okoboji	Okoboji	273	7.3	28.8	7.2	3	1956-57
Spirit	Spirit Lake	333	2.5	58.9	4.3	3	1956-57
Spirit	Spirit Lake	340	26.0	61.1	7.5	30	1956-68
Silver	Lake Park	696	47.0	290	28.2	3	1956-57



result from the inflow of ground water which contains large amounts of sulfate.

GROUND-WATER RESOURCES

Alluvial Aquifers

Unconsolidated alluvial aquifers are present along most major stream courses in Iowa. These sands and gravels offer a source of good-to-fair quality water in many areas where the underlying bedrock aquifers contain highly mineralized water. The quality of the water from the alluvial aquifers is quite variable. It is difficult to delineate areas where dissolved solids fall within a particular range. Often there will be as much of a variation within one well field as there is from several locations along any particular valley. The quality depends a great deal on the thickness of the aquifer, the depths of the wells, the underlying aquifer or aquiclude, and whether the water is coming from storage, induced infiltration, or from local precipitation. The climatic conditions often have much to do with the quality.

Generally, water containing less than 500 mg/l of dissolved solids can be found in the alluvial aquifers (fig. 1). The water at one well field may range from 300 to 700 or 400 to 800 mg/l; but in the areas shown on the map as having less than 500 mg/l of dissolved solids, a lower value can be obtained even though some water with higher values is present. The only areas having dissolved solids generally greater than 1,000 mg/l are in the northwest along the Little Sioux and the Little Rock Rivers. All alluvial waters in Iowa are of the calcium bicarbonate or calcium mangesium bicarbonate type except in the reaches where the dissolved-solids concentrations are more than 1,000 mg/l. These waters are of the calcium sulfate type.

Bedrock Aquifers

The major bedrock aquifers in Iowa are the Dakota Sandstone, Mississippian limestones and dolomites, Silurian-Devonian limestones and dolomites, and the Jordan Sandstone and associated dolomites.

The Dakota Sandstone of Cretaceous age is the major bedrock aquifer in western and northwestern Iowa. It covers more than 20 percent of the state, but its dissolved-solids concentration is below 500 mg/l in less than 5 percent of

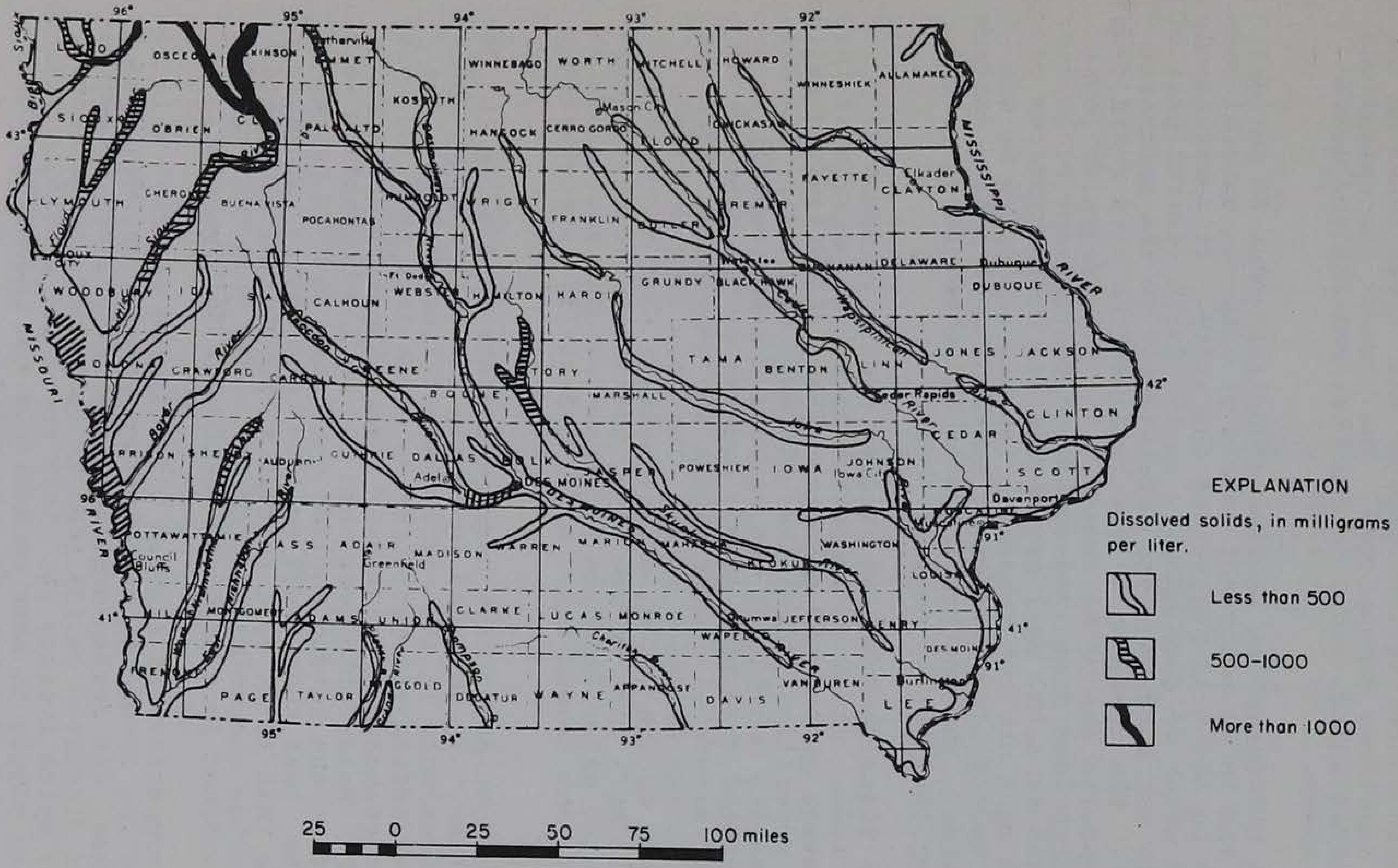


Figure 1. --Dissolved-solids concentrations of the water from the alluvial aquifers

Iowa and below 1,000 mg/l in about 12 percent. Figure 2 represents water from the upper part of the Dakota Sandstone. Waters with concentrations greater than those shown on the map are sometimes encountered. The highest concentrations of dissolved solids occur in the west-central and northwestern areas.

The Mississippian aquifer underlies about 60 percent of Iowa and is an important source of water to several communities in about 10 percent of the state. It consistently provides water of good quality in the north central part of the state and somewhat less consistently in the southeast (fig. 3). The 2,500 mg/l line outlines the area where evaporite deposits are often found in the Mississippian rocks. In southern Iowa dissolved-solids concentrations of greater than 3,000 to 4,000 mg/l are common and concentrations of up to 8,000 mg/l are not unusual. The Mississippian is one aquifer that yields some water containing excessive amounts of fluoride. This occurs in parts of Boone, Dallas, Polk, and Story Counties in central Iowa.

The Silurian-Devonian aquifer occurs in about 85 percent of Iowa. It is an important source of water over the northeastern quarter of the state where the dissolved-solids content generally is less than 500 mg/l (fig. 4). The dissolved-solids content of the water increases rapidly in a southwestward direction mainly because of the presence of evaporite minerals, mostly gypsum and anhydrite, which are present in the Devonian rocks. The area of evaporite occurrence in the Devonian is generally that enclosed by the 2,500 mg/l line on the map. The dissolved-solids content of the water from the Silurian-Devonian aquifer in the evaporite may exceed 8,000 mg/l, especially in southeastern Iowa.

The most productive bedrock aquifer in Iowa is the Jordan aquifer. It is found in nearly the entire state and is used extensively in the eastern two-thirds of Iowa. The dissolved-solids concentration is often less than 300 mg/l in the northeast and increases toward the west and south (fig. 5). Water with less than 500 mg/l of dissolved solids is found in the Jordan aquifer over more than 20 percent of the state, less than 1,000 mg/l in more than 35 percent, and less than 1,500 mg/l in over 60 percent of the state. The fluoride concentrations of the water from this aquifer were described in a previous section of this paper.

A comparison of figures 3 and 4 with figure 5 will reveal why the Jordan is an important aquifer in Iowa. In a large area, the Jordan contains water with lower concentrations of dissolved solids than is contained in the bedrock aquifers which overlie it. This fortunate situation affords a potable supply to many communities and industries where other sources of water are unsuitable.

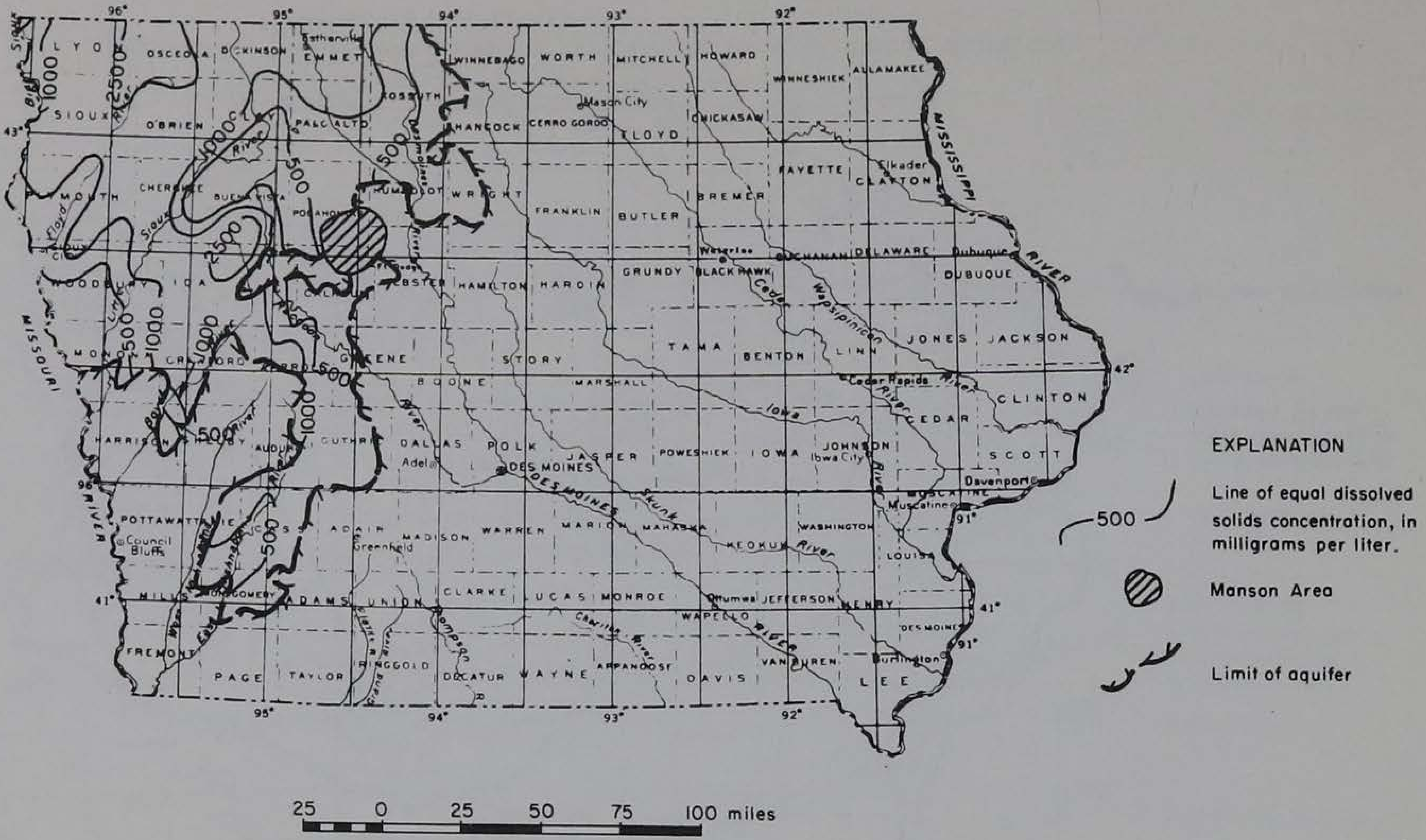


Figure 2. --Dissolved-solids concentrations of water from the Dakota aquifer

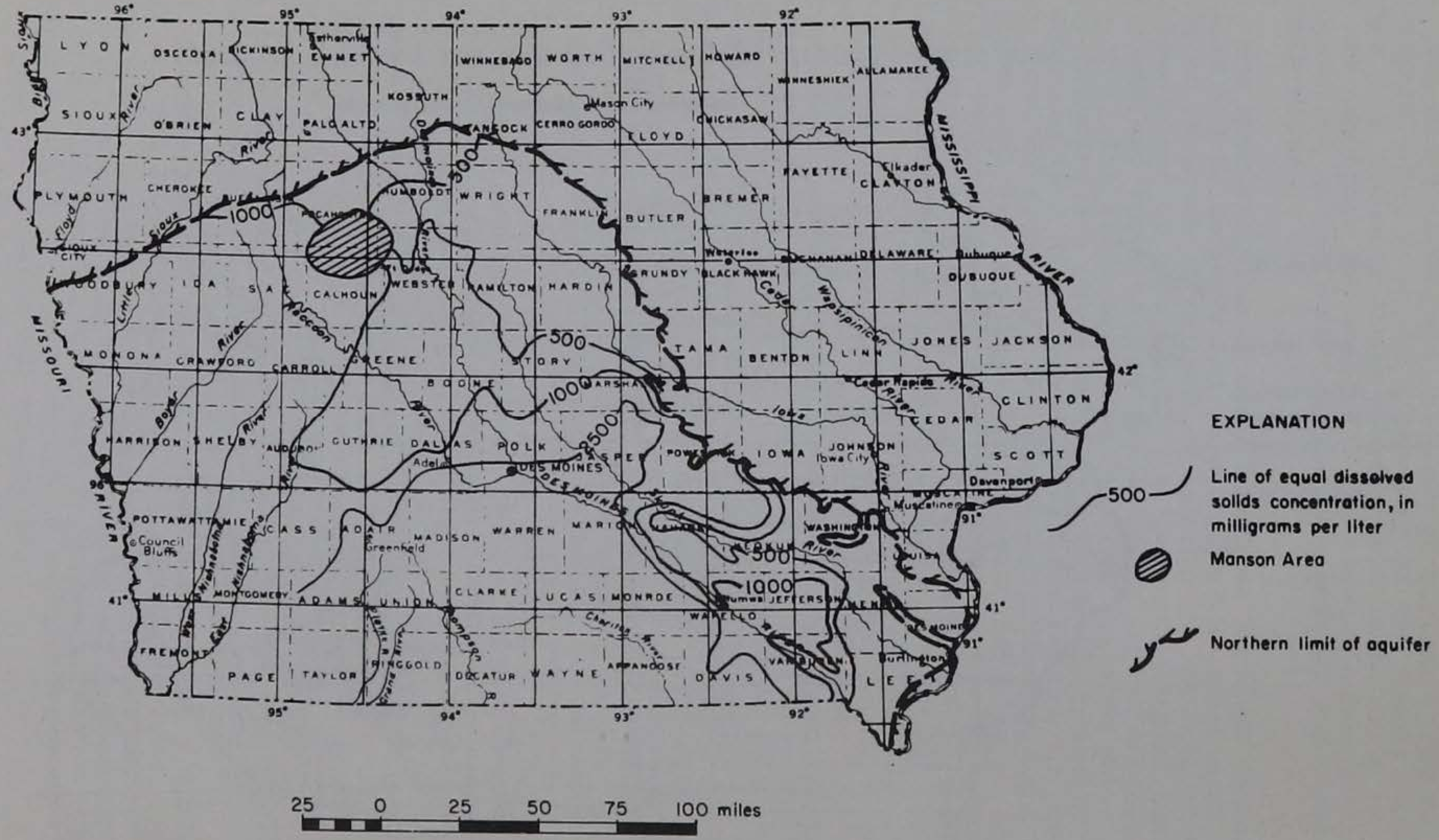


Figure 3. --Dissolved-solids concentrations of water from the Mississippian aquifer

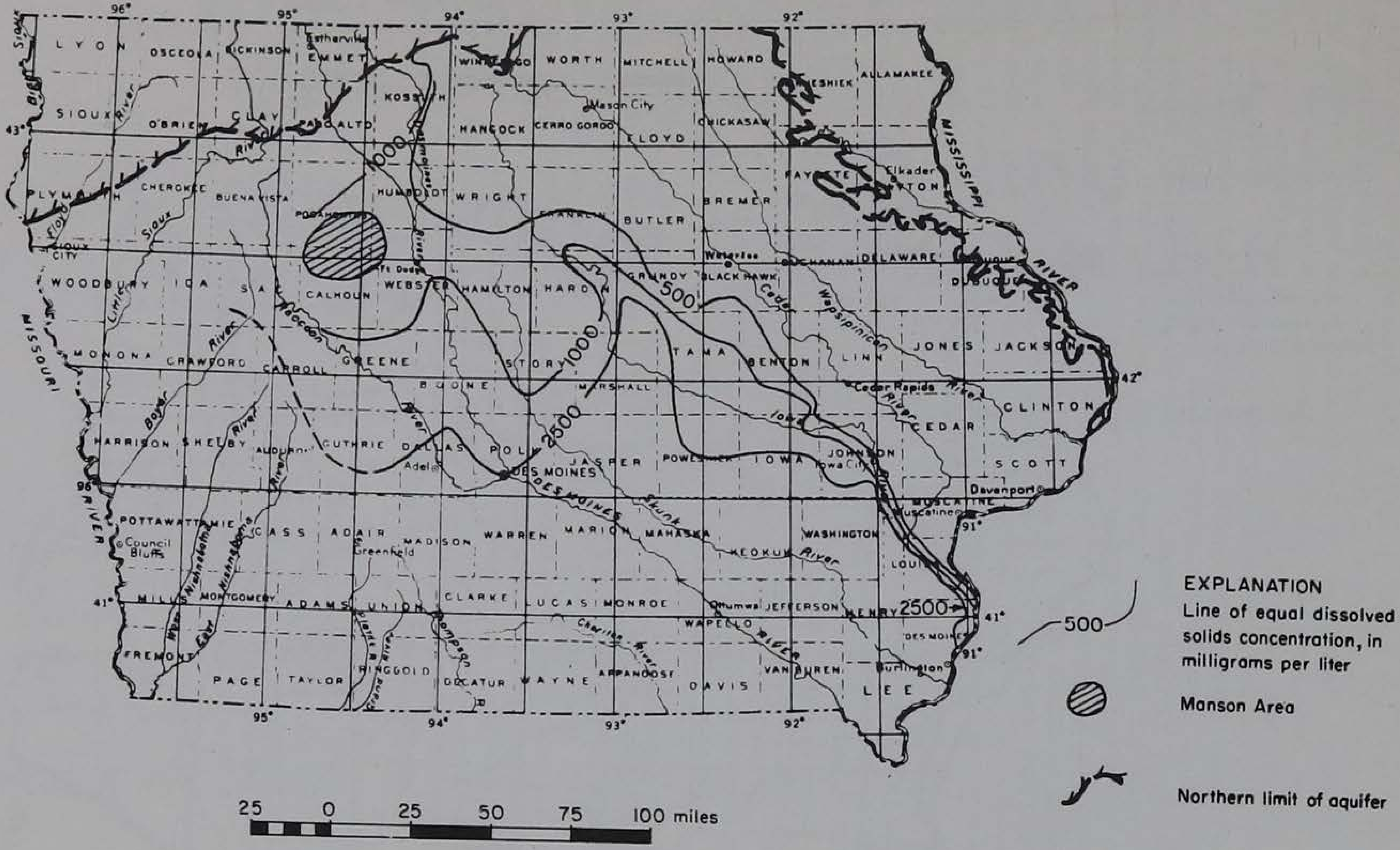


Figure 4. --Dissolved-solids concentrations of water from the Silurian-Devonian aquifer

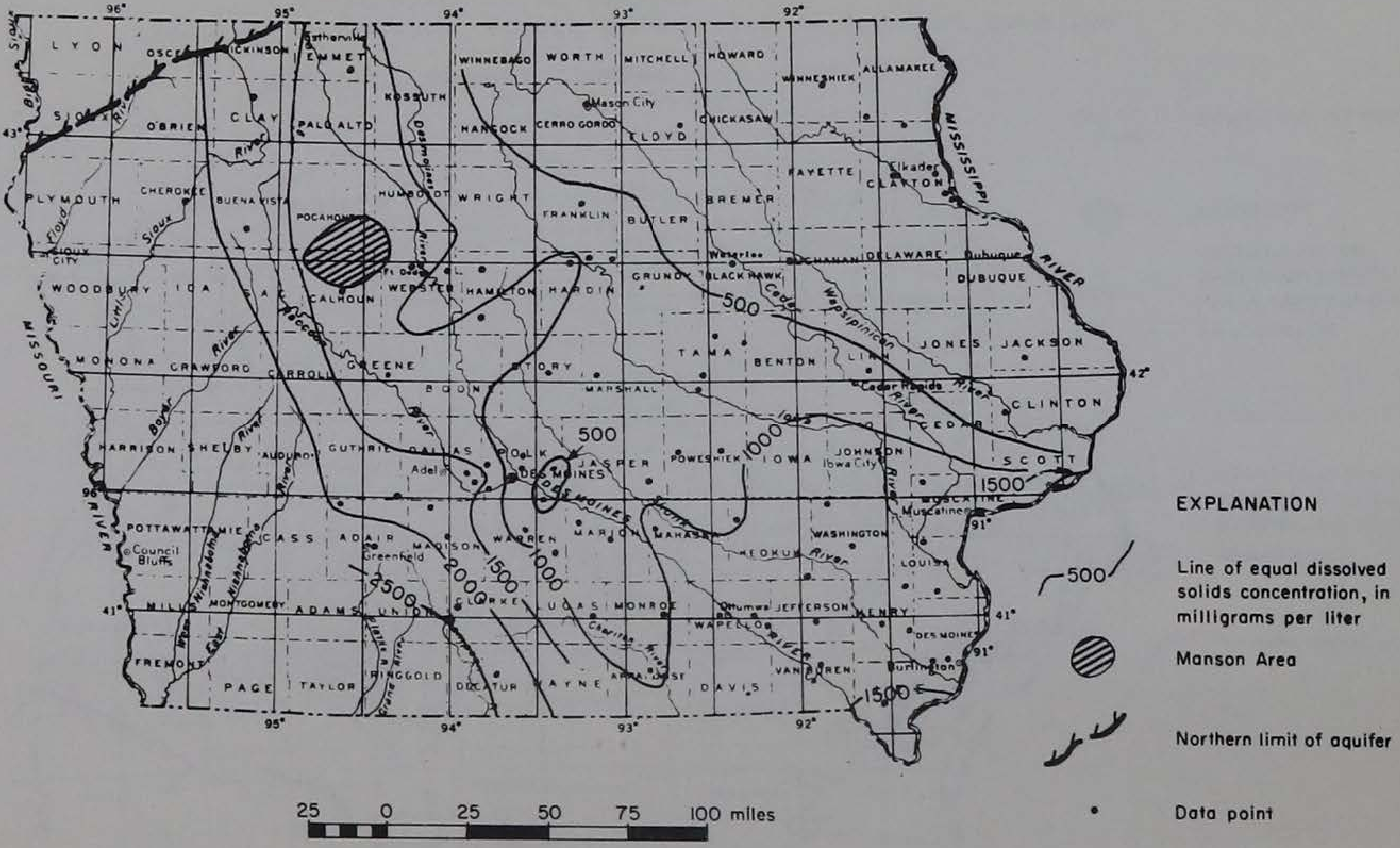


Figure 5. --Dissolved-solids concentrations of water from the Jordan aquifer

A problem does exist in these areas, however, in that a well must pass through the saline water in the upper aquifers in order to reach the potable supply in the Jordan. The saline water must be completely excluded from these wells by placing well casing through the saline water zones and then completely filling the drill hole around the casing with cement. Some Jordan wells were not constructed this way in the past, and many have been abandoned because they produced saline water. Unfortunate as it was that money was wasted in drilling these wells, a more serious problem has developed. Saline water from these aquifers is flowing through these well bores and into other aquifers which contain potable water, thus the potable source is being contaminated. Improper construction is not the only reason this is taking place. The saline water, being very corrosive, can cause the well casing to be eaten away or to disintegrate allowing free passage of the saline water into wells that were once properly constructed.

Such a situation is suspected of being responsible for one municipal well in a community in Des Moines County yielding water which is becoming more saline with time. Another similar well is also used for the town's water supply. This first well should be repaired or plugged before the second well becomes contaminated. Another case similar to this has occurred, but fortunately the problem was discovered and the leaking well was repaired before much damage was done.

Abandoned wells exist in Iowa where situations like these could be taking place today. The contamination has not been discovered because the aquifers being contaminated are not being used in the vicinity of these old wells. However, the aquifers could be ruined for future use in these localities. Small leaks of saline water into these wells may seem insignificant, but they have been leaking into the potable aquifers for many years; and a little water with 8,000 mg/l of dissolved solids can contaminate a large amount of otherwise potable water.

Figure 6 is a summary of figures 3, 4, and 5 and shows the minimum dissolved-solids content available from bedrock aquifers in the state. The better quality water consistently occurs in north-central, northeastern, and eastern Iowa. The water in all the bedrock aquifers is much more mineralized in the southern, southwestern, and western parts of Iowa.

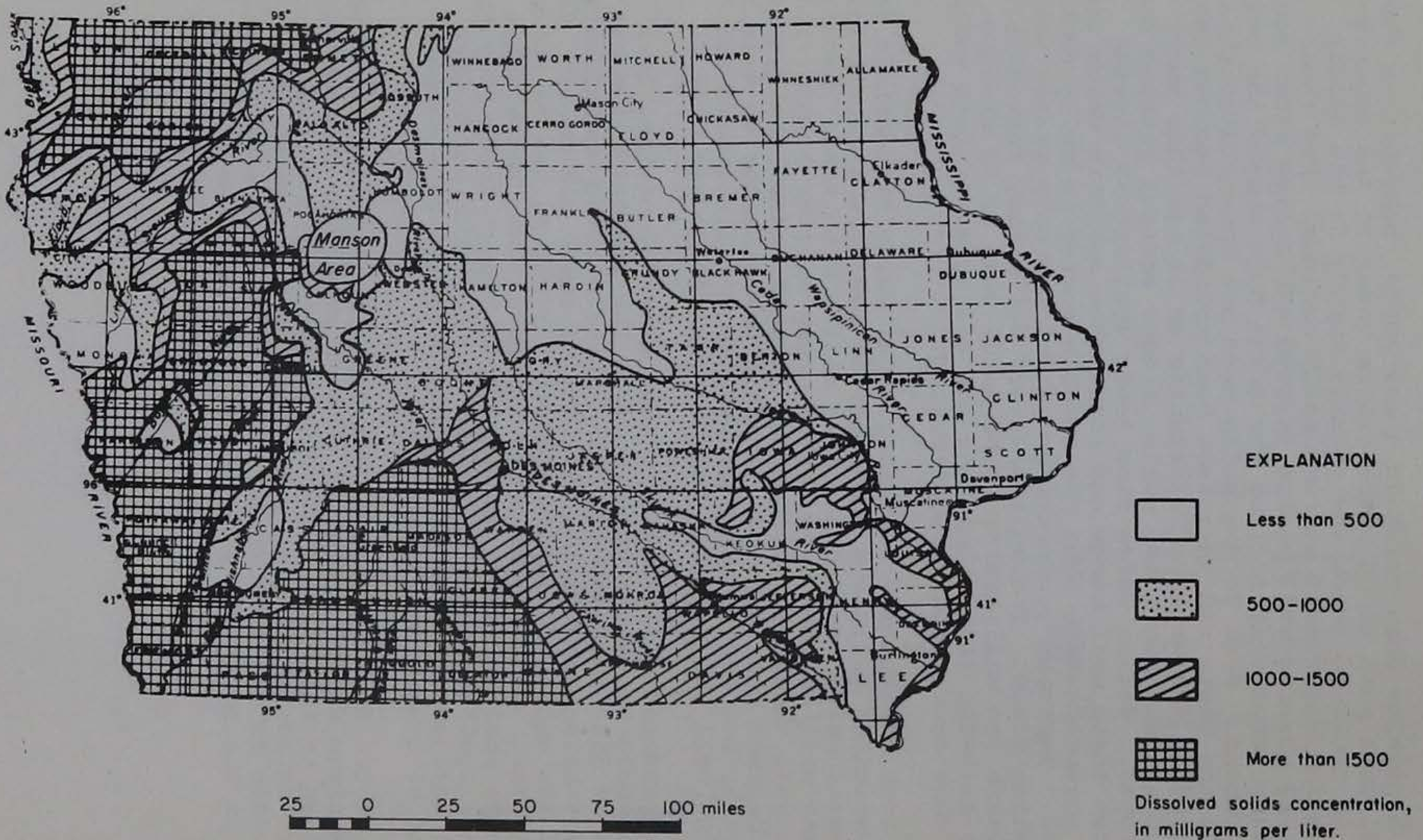


Figure 6. --Areas where water with the minimum dissolved-solids content is available from bedrock aquifers

SUMMARY

Water of good quality is available from one or more sources throughout most of Iowa. Hardness and iron are nuisances in many places, but can be treated. Nitrate problems exist in some shallow ground-water supplies and in some streams at times of high runoff. Fluoride concentrations in excess of recommended concentrations are known to occur only in part of two aquifers.

Iowa's streams usually contain water with less than 500 mg/l of dissolved solids. When the dissolved-solids content exceeds this amount, it is most generally the result of a higher bicarbonate content which occurs during times of low discharge in the winter months.

Alluvial aquifers occupying the valleys of the major streams generally yield water of good quality. A large part of Iowa is underlain by one or more bedrock aquifers that contain good or fair quality water; although poor quality water does occur in all aquifers. The better waters from the bedrock aquifers generally are found in the northeastern one-half of Iowa and in smaller areas in the western and northwestern parts of the state.

REFERENCES CITED

Bachmann, R. W., Some chemical characteristics of Iowa lakes and reservoirs: Iowa Acad. Sci., v. 72, p.238-243, 1965.

State Department of Health (Iowa), Iowa public water supply data: State of Iowa, 78 p., 1964.

LOUIS F. GIESEKE

Mr. Gieseke, Deputy Iowa Water Commissioner, is employed by the Iowa Natural Resources Council located at Des Moines, Iowa. He has been with this organization since 1958. He is a graduate of the University of Minnesota holding a B. S. degree in Agricultural Engineering. He was previously employed as an irrigation engineer in Minnesota and by the U. S. Department of the Interior, Bureau of Reclamation at Durango, Colorado, as a hydraulic engineer . In his present capacity, Mr. Gieseke conducts water permit hearings across the State. He reviews applications and listens to testimony in various categories of water use and makes decisions on whether an application will be approved or rejected. In the Water Commissioner's office he has access to a large file of information on water use permits and withdrawal rates in Iowa. Mr. Gieseke is a knowledgable, conscientious, and helpful public servant assigned to protect our water resources and assure they will be given the most beneficial use.

WATER USE IN IOWA

Louis F. Gieseke
Deputy Water Commissioner
Iowa Natural Resources Council

It is estimated that man's use of water in Iowa was initiated about 10,000 years ago by the American Indian. White man's use apparently was initiated by Father Marquette and Louis Joliet in 1673. Their first use of Iowa water was for navigation near the mouth of the Iowa River. The earliest settlements in Iowa developed on the banks of her many creeks and rivers which were used as sources of water, sources of power, as trade routes, for waste disposal and various other purposes. Today, certain waterways continue to be important as water supplies and most continue to be used for waste disposal purposes.

The first water power development in Iowa was a U. S. Army sawmill on the Yellow River in the 1830's. By 1879 there were 712 flour and grist mills in Iowa. It is estimated that only about 18 of these mills still remain today. The use of Iowa's streams for hydroelectric power was important during Iowa's early history but has almost vanished from the scene. There are 11 dams in the state licensed for hydroelectric power and still used for that purpose. Nine dams are licensed for electric generation other than hydroeletric and are used to store water primarily for cooling purposes. Three dams are licensed for industrial or manufacturing purposes.

As of March 31, 1969, 5,216 applications for water permits had been received at the Water Commissioner's office since its inception in 1957. About 1,650 of these were for use of water relating to highway construction, 710 were for industrial use, 865 were for irrigation, 195 were for municipal use, 890 were for storage and 49 were for recreational use. About 800 applications for renewal or modification of existing permits have been received.

On March 31, 1969, there were 2,255 water permits in force, excluding highway permits. There were 649 for irrigation, 37 for recreation, 472 for industrial use, 199 for municipal use, 897 for storage and 1 drainage well. Excluding storage, which is from natural runoff, these permits authorize the use of water from 1,585 sources consisting of 701 wells, 530 streams and 354 reservoirs. Three hundred and four of the permits originally granted for purposes other than highway construction are no longer in force. Highway construction water permits normally are granted for a period of one year.

A maximum annual amount of about 2,000,000 acre-feet of water is authorized for industrial use; about 93,000 acre-feet for irrigation; about 142,000 acre-feet for municipal use; about 8,200 acre-feet for recreational use; and about 87,000 acre-feet for storage. Most of the industrial water is obtained from streams, while wells supply the largest portion of the water for irrigation and municipal use. The source of water for recreational use is divided quite evenly between streams and wells. Surface reservoirs are the primary sources for industrial uses because the use of water in the production of road building materials is included in the industrial classification. About 66 percent of the irrigation water is obtained from wells.

By far the largest use of water in Iowa is for the growing of crops. Including pasture land there are about 30,000,000 acres of crop land in Iowa. Assuming an annual evapo-transpiration use of 21 inches, 52,500,000 acre-feet of water are consumed by plants each year. This is a total of 17,100 billion gallons or about 95 billion gallons per day for the 6-month growing season. It is estimated by the U. S. Geological Survey that all other off-channel uses in the United States require about 1,600 gallons per day per person. This represents a daily use of about 4.64 billion gallons in Iowa. The use by evaporation and transpiration is approximately 20 times the total amount used for all other off-channel purposes. Almost all the water used by the crops in Iowa is supplied directly by rainfall, but irrigation has been increasing and will increase more in the future and must be taken into account.

In 1949 about 7,500 acres of land were irrigated in Iowa. In 1956 this had increased to about 27,000 acres. As of March 31, 1969 irrigation of 93,200 acres was authorized. A maximum annual quantity of 99,300 acre-feet of water was authorized for this use by the 649 valid irrigation permits. Wells are the primary source in 362 permits, streams in 237 and reservoirs in 50. The amount of water authorized from each source is not in proportion to the number of permits. That is, wells are authorized by 56 percent of the irrigation permits but supply 66 percent of the water. Streams are the source for 36 percent, but supply 28 percent of the water. Reservoirs are the source for 8 percent of the irrigation permits and supply 6 percent of the water.

The protected flow concept and its enforcement apparently has discouraged some of the stream irrigators who did not renew their permits because they were not allowed to irrigate during certain droughts. Their reasoning is that since they are not allowed to withdraw water at the time their crops need it the most there is no good reason for maintaining an irrigation system. Of the 79 irrigation permits that have terminated, 51 authorized streams, 24 authorized wells and 4 authorized reservoirs as their source.

Irrigation is practiced in almost every county in the state, but the greatest concentration of projects occurs on the Missouri River flood plain. About 40 percent or 247 of all the irrigation permits in Iowa are in the six counties bordering the Missouri River downstream from Sioux City. Eighty-four permits or 14 percent, are in Monona County alone. About 80 of the 84 permits in Monona County authorized wells as the primary source.

Reports of water used and personal interviews indicate that less than one-half of Iowa's irrigators actually irrigate during any certain year. They normally apply 4 to 8 inches of water during the growing season and average about 6 inches. However, as much as 22 inches have been applied to certain specialty crops such as sod and certain nursery crops. Irrigation in Iowa generally is supplemental irrigation and is used to prevent crop failures during drought periods and to increase yields and improve product quality on certain crops.

One of the most important uses of water in Iowa is for municipalities. There are 944 incorporated cities and towns in Iowa with a total 1960 population of 1,909,361 persons, and 751 of these communities have public water supply systems serving about 1,877,000 persons. There are 449 cities and towns with populations over 500. All but one of these have public water supply systems. One unincorporated area with an estimated population of 500 also has a public water supply. There are 193 incorporated towns with populations of less than 500 that do not have public water supplies. About 32,000 people or about 1.8 percent of the population living in incorporated communities are not served by public water systems. Forty-six unincorporated communities are served by public or quasi-public water supply systems. There are numerous privately owned water systems supplying water to incorporated and unincorporated areas throughout the state.

Streams are the source of water for 9 municipalities, 21 use impounding reservoirs, 6 use natural lakes, and 715 use wells. The 6 natural-lake supplies are in northern Iowa with 5 of them being in Dickinson County. The 21 communities using impounding reservoirs are all located in the south central part of the state.

As of March 31, 1969, 199 municipal water permits have been granted. About 93 percent or 186 of these permits authorize wells as the primary source; 8 authorize streams. A municipality is not required to make application for a water permit until its use of water is increased by 100 thousand gallons or 3 percent, whichever is greater, per day more than its highest per day beneficial use prior to May 16, 1957. Municipalities that change sources of water must also make application for a water permit. Industrial users of water, having their own water supply within corporate limits, are also nonregulated until their water use exceeds 3 percent more than the highest per day beneficial use prior to May 16, 1957. Information relating to these nonregulated uses generally is not available. Experience has shown that complete water use information throughout the state is desirable for administering Iowa's water law and for comprehensive planning purposes. The value of the information presently available would be greatly enhanced by the addition of comparable information relating to nonregulated uses.

The United States Resources Council states in its November 1968 report entitled "The Nation's Water Resources", that the national average of total water withdrawn by public water supply systems within the conterminous United States in 1965 was about 157 gallons per capita per day. The average per capita use of water for municipal purposes in Iowa is considerably lower than it purportedly is for the nation. It appears that the average use of water per capita per day in Iowa's towns and cities is about 100 gallons, varying from about 30 in small towns without public water supply systems to about 135 in larger cities having large industries and high water-use demands.

Generally, the large cities of the nation have high per capita uses. For example, Chicago reports an average daily per capita use of more than 250 gallons of water. Iowa has no large cities of comparable size and water demand. The per capita use is also much higher in cities where extensive lawn irrigation is practiced.

The population in many Iowa cities and the per capita use of water have increased and are expected to continue to increase. In Des Moines the population increased from about 126,000 in 1920 to about 250,000 in 1968. The daily per capita use of water increased from 68.5 gallons to 121.38 gallons during the same period. Both figures just about doubled in the last 48 years and the total use of water in Des Moines has increased almost fourfold.

A maximum annual withdrawal of about 2,000,000 acre-feet is authorized by the 472 industrial water permits in Iowa. Reservoirs comprise the largest number of sources for industrial permits because the production of highway construction material such as sand, gravel, and limestone is included in that category. Many of the pits and quarries involved must be dewatered or serve as the source for processing water and are classified as reservoirs. The industrial permits include 245 reservoirs, 128 wells and 99 streams. Streams provide 79 percent of the water used under industrial permits, reservoirs provide 14 percent and wells provide 7 percent.

The 472 industrial permits include 26 authorizing the use of water for electric generation plants. Although large quantities of water are used for this purpose, most of it is used for cooling and the water is returned to the stream within a few minutes after it is withdrawn. The quality of the water is unchanged except for a slight rise in temperature.

The largest single off-channel use of water in Iowa is an electric generating plant. Its maximum withdrawal rate, 630 cubic feet per second, is larger than the discharge of most Iowa streams. This plant has a maximum annual use of 460,300 acre-feet. The water is used for cooling and is returned to the river shortly after withdrawal.

The largest single consumptive water use in Iowa will also be an electric generation plant. The planned nuclear generation plant on the Cedar River near Palo, Iowa will be a 550-megawatt plant. It is scheduled for completion during December, 1973 and will have a continuous consumption of water of 16.5 to 20 cubic feet per second. This is larger than the normal flow in most creeks and some of the rivers in Iowa. It is reported that nuclear plants generally require about 40 percent more cooling water than conventional plants. It has been estimated that the nation's demand for electric power is doubling every six to ten years and that about 50 percent of all future expansion is planned as atom-driven plants.

Iowa water law states that the Water Commissioner and the Natural Resources Council shall have the authority to issue a permit for beneficial use of water in a watercourse provided the established average minimum flow is preserved. Therefore, protected minimum stream flows had to be established before permits authorizing consumptive uses from watercourses could be granted. Protected flows have been established for every major stream and most of the minor streams in Iowa. The protected flows are based primarily on the material presented in Iowa Natural Resources Council Bulletin No. 9, "Low-Flow Characteristics of Iowa Streams", published in 1958. This publication is the result of a cooperative effort of the Iowa Natural Resources Council and the U. S. Geological Survey. The work was done at the District Office, U. S. Geological Survey, Iowa City, Iowa, under administrative direction of V. R. Bennion, District Engineer. Harlan H. Schwob, Hydraulic Engineer, U. S. Geological Survey, was the principal author. This bulletin lists data on low-flows at 84 stream gaging stations in Iowa. It lists the minimum flow for the period of record for 1-, 7-, 30-, 60-, 120-, and 183-day periods. Discharges for selected duration percentages from 1 to 99 for the base period 1934 to 1953, and for the period of record are also listed. The same duration percentages for the months of July and August and the 6-month growing season April 1 to September 30, for the 1934-53 base period are also shown. The recurrence interval in years for selected periods and magnitudes of flow are listed for the 1934-53 base period.

The protected flows are designed to provide adequate protection to the supply of water for ordinary household, poultry, livestock, and domestic animal uses, for fish and wildlife, for recreational and aesthetic uses of the stream, for pollution control and dilution of wastes, and for other uses of a public nature. All consumptive and depleting uses of water from streams are restricted so that water may not be withdrawn from the stream if the flow therein is less than the protected flow. This procedure apparently has been well accepted throughout Iowa and has not resulted in any serious problems.

The protected flow for each river basin in Iowa is established at the most downstream gaging station in the basin. It is then projected upstream to the other major gages on the stream by means of a correlation using comparable yield curves. The protected flows are calculated for other points on a stream as needed. As more stream flow information becomes available, the computed comparable flows at upstream points may be changed slightly, from year to year. Most of the basin protected flows are based on 30 to 40 years of record and only one has changed because of additional information since the program was started. That was at a station with only 8 years of record at the time Bulletin No. 9 was prepared. The protected flows at many upstream points are based on much shorter records and occasionally do change slightly as additional stream flow records become available. Bulletin No. 9 is presently being updated by the U. S. Geological Survey, Iowa City, Iowa in cooperation with the Iowa Natural Resources Council. At least 10 years of new data will be added to existing records.

The regulation of withdrawals of water from watercourses during periods of low flow is one of the most important functions of the Water Commissioner's Office and is probably the most unusual feature in the Iowa water law. It is also the least understood feature in the law and is the one we have the most questions about. It is based on the protected flows just discussed. When the flow in a stream drops to the protected flow, parties making withdrawals therefrom for consumptive uses are advised that their withdrawals must cease until the flow recovers to a flow greater than the protected flow.

Low-flow regulation - an unfortunate abbreviation because it is not the flow that is being regulated, but the withdrawal - actually begins during November of the preceding year upon receipt of the report of subsoil moisture throughout Iowa from the Iowa State University. The "plant available" moisture in the top 5 feet of soil is plotted on a map, giving some guidance as to what may be expected for base flow the following spring and summer. The fall forecast, of course, can be completely changed by the rainfall situation the following spring and summer. Updated reports of the subsoil situation are received periodically during the spring and summer months.

Monthly reports of the flow at the 110 stream gaging stations in Iowa are received from the three U. S. Geological Survey subdistrict offices in Iowa. The previous month's measurements are normally received the first or second week of each month. Measurements of flows of less than 200 percent of the protected flow made during the critical summer months are reported promptly by telephone to the Water Commissioner's Office. During periods of low flow, additional measurements are made at about 450 low-flow partial-record stations throughout the state. The ten years of records that have been accumulated for the low-flow partial-record stations have been used to establish protected flows on many smaller streams.

Generalized reports of state-wide rainfall are received from the U. S. Weather Bureau each week throughout most of the year. These weekly reports show the rainfall distribution for the previous week and list the precipitation departure for the last week, the last two weeks and the last four weeks for the nine reporting districts in Iowa. The Weather Bureau's monthly report lists the rainfall received, the normal rainfall, and the departure; all for the current month; and the departure since January 1 for each of the 9 districts.

Two publications relating to low-flow characteristics of Iowa streams during the summer months were published during 1966. The Iowa Water Resources Research Institute published "Recession Characteristics of Iowa Streams, Part I - Temporal and Areal Distribution of Recession Constants", Joseph W. Howe, Principal Investigator. The Water Resources Division, Iowa City District Office, U. S. Geological Survey, U. S. Department of Interior, in cooperation with the Iowa Natural Resources Council published "Summer Base-Flow Recession Curves for Iowa Streams". This report was authored by Carroll W. Saboe, Hydraulic Engineer. In general, both of these publications are designed for use in predicting the time at which the base flow of Iowa streams will reach a particular magnitude such as the protected flow. These reports have proved to be useful tools and should be more useful each year as their use is established. With these additional two publications we now have fairly reliable data for predicting the occurrence of flows near the protected flow on Iowa streams. It is hoped that in the near future it will be possible to predict the occurrence of low flows a few weeks before they occur, so advance notice can be given to the water users who will be affected.

All permittees making withdrawals of water for consumptive uses from a stream are contacted within a day or two after the report of a low-flow is received. The permittees are questioned in relation to their plans for withdrawing water for the rest of the season and advised of the low-flow condition. The total withdrawal rate of all permittees who plan withdrawals of water for the current season from that particular reach of the stream is determined, and added to the protected flow to establish a cut-off flow. Each permittee is then advised of the cut-off flow and how to ascertain whether or not the flow in the stream is above the cut-off flow. It is then the permittee's responsibility to ascertain that the protected flow is not violated. Under certain conditions the permittee is required to read a staff gage each day before any withdrawals are made and to furnish a written record of these readings to the Office of the Water Commissioner.

The use of water in Iowa has been increasing each year and it is anticipated that it will continue to increase along with Iowa's population, industrial development and economic growth. There have been and will be occasional local shortages of water, but no major state-wide shortage is anticipated in the foreseeable future.

HARLAN H. SCHWOB

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MAXIMUM FLOODS IN IOWA[1]

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The word "flood" can evoke several questions in the minds of thoughtful individuals. Questions as: (1) how big do floods get and is there a limiting size? (2) how often do floods occur, especially those of great size? (3) how much damage will the great floods do? and (4) how may they be controlled or what actions may be taken to protect life and property? A thorough discussion of even one of these questions would be impossible in a short paper such as this. It is my purpose, therefore, to discuss briefly only the first of these questions; that concerned with the magnitude (but not the limiting size) of floods, and to show how Iowa's experience compares with that of other states in the Midwest. To do this I propose to make comparisons of flood magnitudes with size of drainage area and to list the ratio of flood discharge to that of the mean annual flood. Also included are brief descriptions of the precipitation causing the flood events in Iowa discussed in this paper.

DEFINITIONS

For the purpose of this paper the highest peak discharge in each year will be considered the annual flood. This in spite of the fact that in some years the peak may not overflow the banks and thus may not fit the common definition of a flood. However, by use of this definition we have a flood event for each year of record and, therefore, a sample of the flood population that can be analyzed by statistical methods (Dalrymple, 1960). One of the products of such an analysis is the mean of the annual flood discharges (MAF)--a useful tool in the study of flood magnitudes. The U. S. Geological Survey defines a MAF as a graphically determined mean with a recurrence interval of 2.33 years. The mean so determined is an estimate of the mean of the annual floods that would be determined by arithmetical methods from a very long record--perhaps 1,000 years or more. Also, it is approximately the flow equivalent to a bankful stage on many streams. By using graphical methods the MAF discharge can be determined with fair accuracy from a short record of 10 or more years of peak discharges. Regional studies have shown that the MAF can be correlated with drainage area and other parameters to produce an estimate of its discharge for ungaged areas. A cooperative

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[1] Publication authorized by the Director, U. S. Geological Survey

study with the Iowa Highway Research Board (Schwob, 1966) has defined the MAF and other flood statistics for the State of Iowa at both gaged and ungaged sites. U. S. Geological Survey Water Supply Papers covering flood magnitudes and frequencies furnish the statistics for areas adjacent to Iowa, also on a regional basis.

If frequency studies have been made they can furnish an estimate of the rarity of some floods. However, most flood records are too short to permit reliable frequency estimates for the rarer floods--often, frequency estimates not exceeding the 50-year level are a practical limit. In Iowa the 50-year flood discharge has a ratio of 3.10 to that of the MAF except in a small area of northwest Iowa. In this area the ratio is 4.50. In the selected midwest states the ratio at the 50-year level in some locations is as high as 9.

FLOOD RECORDS

Before we look for the answers to our questions, it is desirable to examine the flood records available in Iowa. At present there are 116 complete-record gaging stations within the borders of the state. The drainage area for these stations range from 1.33 to over 14,000 square miles. Additionally, as a cooperative project with the Iowa Highway Research Board, flood records are being collected at 134 crest-stage gages which have drainage areas ranging from 0.33 to 252 square miles. A few discontinued gaging stations also provide flood discharge data as do a considerable number of peak discharge measurements obtained at miscellaneous sites. The longest flood record in the state is the 66-year record of the Cedar River at Cedar Rapids. Data on maximum known floods for Iowa and for selected midwest states are shown in tables 1 and 2. These data have been taken from publications of the U. S. Geological Survey (see references) and its cooperating agencies. For Iowa, only those data are listed that are necessary to define the flood experience curve to be shown later. For other midwest states only floods with ratios to the MAF greater than those experienced in Iowa on drainage areas of comparable size are tabulated. No flood ratios meeting this requirement were found for Minnesota, Wisconsin, Illinois, or Missouri. In both tables floods at gaging stations and at miscellaneous sites have been included without differentiation. The items in table 1 are listed in descending order of ratios whereas in table 2 the data are listed by state.

PRECIPITATION

All floods listed in table 1 resulted from rains having intensities that were greater than those indicated for a 100-year frequency (Hershfield, 1961) but were less than the

Table 1. Maximum known floods in Iowa in ratio to the mean annual flood

	Stream	Drainage area sq. mi.	Flood discharge cfs	Ratio to MAF[1]	Date
1.	Floyd R. at Alton	265	45,500	36	6-7,8-53
2.	Big Devil Cr. nr. Ft. Madison	152	80,000	29	6-10-05
3.	Big Sugar Cr. nr. Viele	109	60,000	28	6-10-05
4.	Pine Cr. nr. Winthrop	28.3	24,200	20	7-17-68
5.	Floyd R. at James	882	71,500	17	6-8-53
6.	Wayman Cr. at Garber	6.98	15,500	17	5-31-58
7.	Dawson Cr. nr. Sibley	4.35	4,290	15	6-7-53
8.	Union Park Cr. at Dubuque	1.07	3,000	11	7-9-19
9.	Des Moines R. nr. Tracy	12,479	155,000	4.3	6-14-47

[1] The mean annual flood used is that from Bulletin 28, Iowa Highway Research Board

Table 2. Maximum known floods in North Dakota, South Dakota, Nebraska, and Kansas with ratios greater than Iowa experience for comparable size of drainage area.

Stream and State	Drainage area sq. mi.	Flood discharge cfs	Ratio to MAF	Date
Turtle R. at Manvel, N. Dak.	556	28,000	26	4-17-50
Redwater Cr. above Belle Fourche, S. Dak.	920	16,400	22	6-16-62
Castle Cr. nr. Rochford, S. Dak.	32.6	8,500	121	7-28-55
Claghorn Canyon at Rapid City, S. Dak.	6.96	2,920	122	7-13-62
South Canyon at Rapid City, S. Dak.	6.06	2,960	141	7-13-62
Deep Cr. nr. Glen, Nebr.	10.9	3,050	25	8-15-53
Cottonwood Cr. nr. Dunlap, Nebr.	82.2	28,100	72	7-28-51
Plum Cr. Trib. at Farnum, Nebr.	19.8	4,300	29	6-22-47
Buffalo Cr. nr. Darr, Nebr.	63	9,000	36	6-22-47
Elm Cr. nr. Overton, Nebr.	31	8,000	44	6-22-47
Wood R. nr. Riverdale, Nebr.	379	20,000	37	6-22-47
North Loop R. nr. St. Paul, Nebr.	1,270	90,000	24	6-6-1896
Republican R. at Stratton, Nebr.	4,800	200,000	25	5-31-35
Republican R. at Trenton,Nebr.	5,000	200,000	24	5-31-35
Dry Cr. nr. Curtis, Nebr.	20	25,900	30	6-21-47
Medicine Cr. at Cambridge, Nebr.	680	120,000	26	6-22-47
Union Cr. Trib. nr. Madison, Nebr.	2.5	2,560	21	6-2-50
E. Fk. Maple Cr. nr. Howells, Nebr.	67.1	22,000	29	6-11-44
Indian Cr. north of Max, Nebr.	72.6	13,300	95	7-31-62
Indian Cr. nr. Max. Nebr.	81.8	27,000	180	7-31-62
W.Fk. Big Blue R. trib. at McCool Jct., Nebr.	17.2	15,200	42	7-9-50
W.Fk. Big Blue trib. nr. York Nebr.	6.9	23,000	104	7-9-50
S.Fk. Solomon R. at Alton, Kans.	1,720	91,900	24	7-12-51
Solomon R. at Niles, Kans.	6,770	178,000	23	7-14-51
Prairie Dog Cr. at Dellvale, Kans.	663	65,500	24	5-28-53
Saline R. trib. at Collyer, Kans.	2.5	3,220	27	8-18-61
Gypsum Cr. nr. Kipp, Kans.	250	64,500	43	7- -51

probably maximum precipitation (Riedel, et al, 1956). One possible exception is the 1947 flood on the Des Moines River at Tracy that has a drainage area of 12,500 square miles. Estimates of precipitation maximums are unavailable for drainage areas of this size; however, the 1947 rainfall in the basin probably did not equal the maximum probable. The relative frequency of precipitation causing the floods listed in table 2 was not determined.

The nine major floods listed in table 1 were caused by six storms. Floods numbered 1, 5, and 7 were caused by excessive precipitation on June 7, 1953, over northwest Iowa. The precipitation resulted from two storms centers over the area and produced as much as 10.8 and 11 inches in a period of about 14 hours. Amounts in excess of 7 inches were general over much of the area.

Floods numbered 2 and 3 resulted from a storm on June 9, 10, 1905 in southeastern Iowa. Precipitation totals of 12.1 and 10.25 inches in 12 hours were recorded at Bonaparte, Iowa, and La Harpe, Illinois, respectively. In the Devils Creek basin near Fort Madison the amounts varied from 7 to 10 inches.

Flood number 4 resulted from a storm on July 16, 17, 1968, in the Waterloo and Independence general areas. Precipitation as much as 16 inches in 24 hours fell in one area whereas as much as 14 inches in 24 hours fell on the Pine Creek basin.

Flood number 7 resulted from heavy rainfall over the Wayman Creek basin near Garber in northeast Iowa on May 31, 1958. No rain gages were in the area of maximum precipitation; however,it was estimated to be about 6 inches in 3 hours.

Flood number 8 resulted from rains on July 9, 1919, in Dubuque with totals as much as 3.87 inches in five hours. Of this amount, 2.23 inches fell in a period of 1 hour.

Flood number 9, in June 1947, resulted from widespread rain over a period of several weeks in the Des Moines River basin. The flood on June 14 at Tracy, in the lower Des Moines River basin, is the greatest of record in Iowa for a drainage area of this size.

COMPARISONS OF FLOOD MAGNITUDES

Data in tables 1 and 2 have been used to prepare figure 1 which shows the enveloping curve for Iowa floods. Also shown are the data from the selected midwest states.

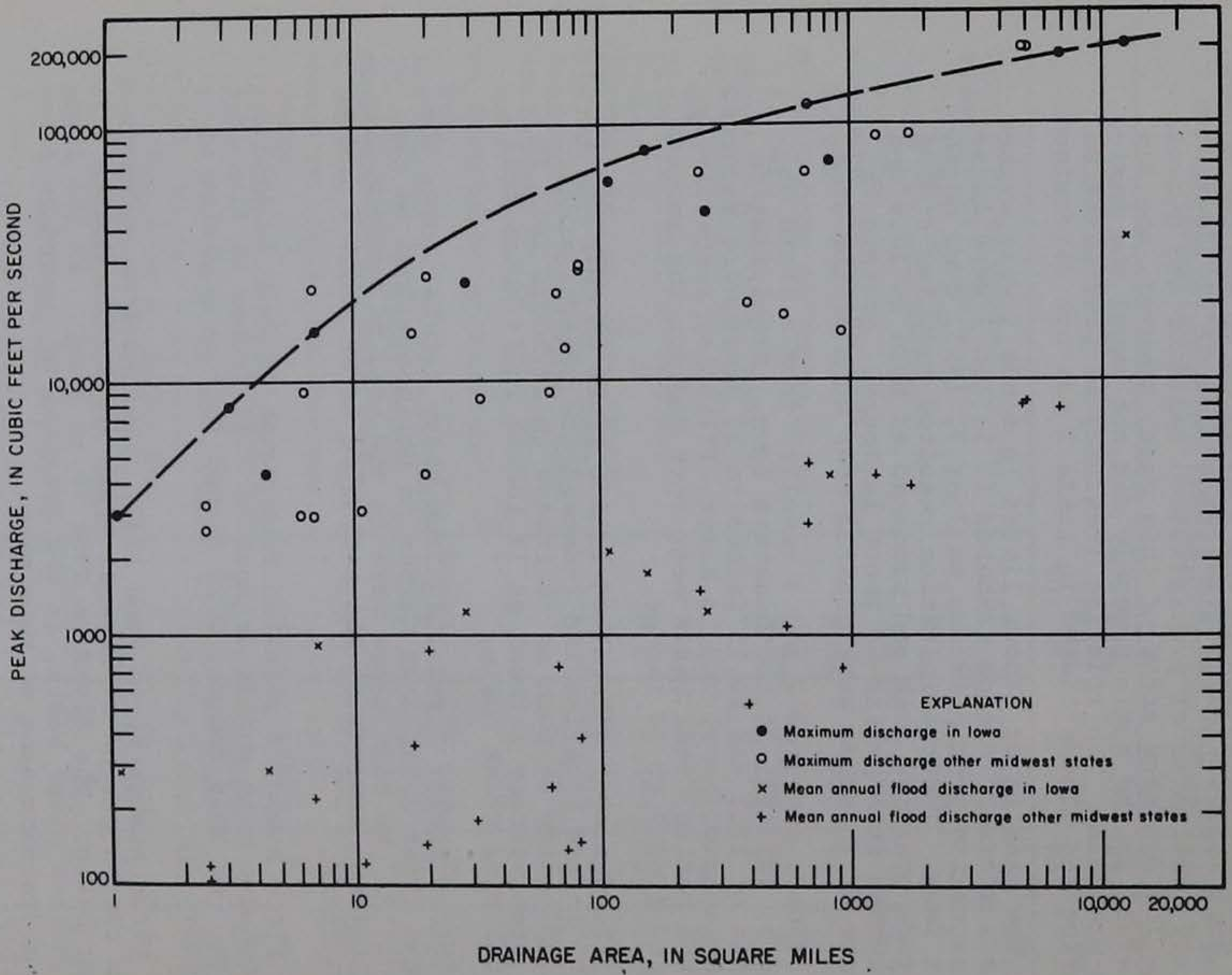

Figure 1.--Relation of peak and mean annual flood discharge to drainage area in Iowa and other midwest states.

It should be noted that the Iowa data do not include the record of the border streams.

Flood discharges are frequently compared on the basis of size of drainage area. These comparisons are generally made by using logarithmic graph paper to plot either (1) the peak discharge against drainage area, or (2) the discharge per square mile against drainage area. Figure 1 shows a type (1) plot. The dashed curve points out the highest values from Iowa and the states listed in the 2 tables. Sometimes curves used in this type of plot are straight lines enveloping all but a few points. Also shown on the plot are the mean annual flood values for items listed in tables 1 and 2. Three MAF values for drainage areas less than 40 square miles in South Dakota were less than 100 cfs (cubic feet per second) and are not shown.

DISCUSSION

Figure 1 shows the magnitude of the flood discharge without regard to frequency or to possible undetermined physiographic influences on flood magnitudes. The graph also shows that the mean annual flood in Iowa and other states varies greatly even for drainage areas of approximately the same size. Within areas smaller than a state, the ratio of a flood to the MAF is an indication of the rarity of the flood--the larger the ratio, the rarer the flood. However, because of the variation of the MAF discharge, this may not hold true for areas as large as several states. Thus, the ratios in table 1 when compared to the larger ratios in table 2, may not indicate less rare floods.

Because of the relatively short record of streamflow in Iowa and adjacent states, it is not possible to compute the frequency of the extreme events that are shown in figure 1. Statistical studies made of short flood records furnish an estimate of the 50-year flood within a state or region, but are not adequate to estimate the frequency of the rare floods shown in tables 1 and 2. Floods exceeding the estimate of the 50-year flood are common--in the period from 1940 to 1968 there were floods exceeding the 50-year flood discharge at one or more places in Iowa in 20 of the 29 years. The flood records at 182 sites were used in flood frequency studies in Iowa--94 of these records included floods greater than the 50-year flood. However, these do not represent 94 storms since floods caused by a single meteorologic event may be measured by more than one gaging station or miscellaneous measurement.

Tables 1 and 2 show the date of each flood peak listed. It should be noted that all are late spring or summer floods, not affected by snow melt. Also, it should be noted that in

Iowa they are not all ancient history--one flood peak helping to define the enveloping curve on figure 1 occurred in July 1968.

Finally, floods that are of much lower magnitude than the floods discussed in this paper have caused widespread suffering and property destruction. Snow-melt floods are included in this category.

REFERENCES

Dalrymple, Tate. Flood-frequency analyses: U. S. Geol. Survey Water Supply Paper 1543-A, 80 p., 1960.

Hershfield, D. M. Rainfall frequency atlas of the United States for durations of 30 minutes to 24 hours and return periods from 1 to 100 years: U. S. Dept. of Commerce, Weather Bureau Tech. Paper no. 40, 115 p., 1961.

Matthai, H. F. Magnitude and frequency of floods in the United States, Part 6-B, Missouri River basin below Sioux City, Iowa: U. S. Geol. Survey Water Supply Paper 1680, 491 p., 1968.

Peterson, J. L. Magnitude and frequency of floods in the United States, Part 6-A, Missouri River basin above Sioux City, Iowa: U. S. Geol. Survey Water Supply Paper 1679, 471 p., 1966.

Reidel, J. T., J. F. Appleby and R. W. Schloemer. Seasonal variation of the probable maximum precipitation east of the 105th meridian for areas from 10 to 1,000 square miles and durations of 6, 12, 24, and 48 hours: U. S. Dept. of Commerce Weather Bureau Hydrometeorological Report no.33, 58 p. 1956.

Schwob, Harlan. Magnitude and frequency of Iowa floods: Iowa Highway Research Board Bulletin 28, in 2 parts, 423 p., 1966.

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POLLUTION PROBLEMS IN IOWA

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and
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The three major sources of pollutants to the water resources of Iowa are agricultural, industrial and municipal in origin. It is common practise to attribute practically all of the water pollution problems to industrial waste but this allegation is unfounded and not supported by the facts in the Iowa environment. Also, the "fish kill" is a very poor yardstick with which to measure the condition of Iowa streams. A much better evaluation can be assessed using the recently adopted Iowa Water Quality Standards. The fish kill is far too drastic a limit and requires enormous deterioration of water quality from normal status of surface water in Iowa and certainly does not permit the analysis of trends which can eventually lead to an increased incidence of fish kills.

Iowa has approximately 15,000 miles of flowing streams and fish kills have occurred on only about 300 miles. Measured by this yardstick, we are operating at the 98% acceptance level and the number of fish kills occurring annually are actually decreasing. This is primarily due to the fact that waste treatment facilities are covering municipal and classical industrial waste sources to a quite adequate extent. In the past, practically all fish kills were traced to overloaded or poorly operated municipal waste treatment plants or to dumpage of toxic industrial wastes into our streams. The majority of the industrial waste produced fish kills were accidental spills and good engineering has greatly reduced the incidence of this type fish kill. Practically all of the urban population of Iowa is served by municipal waste treatment to an adequate extent as recently stated by the Federal Water Pollution Control Administration. In fact, Iowa ranks at the top with respect to urban waste treatment facilities. Most of the municipal treatment facilities on internal streams have secondary treatment which removes 85-95% of the organic load but towns and cities on our two large border streams usually are treated by primary facilities removing about 35% of the initial organic loading. Primary treatment plants are designed to take out the floatable and settleable solids producing an effluent which has little if any visible detrimental effect on the receiving stream.

It has been quite common practise for many years that industries existing within municipal borders make every attempt to pass their industrial waste through the city treatment facilities rather than discharge to streams directly. All industries, of course, have not done this and it is the current vigorous policy of the Iowa Water Pollution Control Commission to sponsor and order where required municipal treatment of industrial waste. If this is not feasible, it is current policy to require industries to provide the equivalent of at least primary treatment. In any event, industries are being required to provide whatever level of treatment necessary to protect the quality of the receiving stream as measured by the Iowa Water Quality Standards currently in effect.

Compared to the quality of surface water in other states having comparable economic development, the quality of surface water and ground water in Iowa stands at a high level. The Water Quality Standards for the State of Iowa have been set at levels which very adequately protect the streams so that all of the necessary uses can be met. We do not have streams classified essentially for waste disposal and navigation but all of our streams are subject to standards which adequately provide usage for public water supply, aquatic life propagation and growth, recreation, industrial and agricultural purposes. It is the intent of the Iowa Water Pollution Control Commission to maintain this high quality and we feel that economic growth in all its phases is compatible with this goal if surveillance, adequate planning and a spirit of cooperation and understanding is applied by all participating groups in our society.

A great deal has been written on industrial and municipal waste contribution to pollution of Iowa streams and much has been achieved regarding control of these wastes but far too little has been researched, evaluated and controls planned or accomplished with respect to the very significant water pollutants originating from the use of farm chemicals and modern agricultural practises. The remainder of this paper will attempt to judiciously establish the sources and significance of agricultural wastes in the total quality panorama and present some factual data collected over a two decade period of fairly comprehensive study as a part of statewide monitoring programs carried on by the State Hygienic Laboratory at the University of Iowa. These research projects have been in conjunction with various state agencies such as the Iowa State Department of Health, the Iowa State Conservation Commission, the Iowa Geological Survey, etc, and have been funded in part by these agencies usually on a contractual basis.

There are over 150,000 individual farmsteads in the State of Iowa, raising cattle, hogs, sheep, and poultry having a population equivalent (PE) far exceeding the human population of our state. The excreta from these animals produce enormous amounts of carbonaceous and nitrogeneous wastes of which large portions eventually reach the water courses of our state. These wastes usually get into our streams following excessive run-off from either rain or snow melt. This excessive leaching of the soil surface carries soluble materials and organic compounds adsorbed on or absorbed in soil particles that move into the streams as siltation. This phenomenon cleanses the soil surface of broad areas of our state depending upon the characteristics of the rain or melting and is not restricted just to feedlots or barnyards. Considering the broad areas over which significant rainfall occurs in our state, it is not difficult to see that enormous amounts of organic materials can reach our streams in very short periods of time. Especially is this true during the time when the earth is frozen and the rain is unable to percolate downward to ground-water aquifers.

One might postulate that the large amount of water carrying these organic materials into the streams would dilute out the concentration of oxygen demanding materials and that no adverse conditions would occur. This is not true, as a considerable number of fish kills have actually been caused by the rapid influx of agricultural organic material into our streams at levels sufficient to deplete the dissolved oxygen in the water resulting in the death of large numbers of fish due primarily to oxygen deficient conditions. This phenomenon occurs frequently during winter thaws when the receiving streams are still ice covered making oxygen replenishment by atmospheric contact quite impossible. Severe winter fish kills have occurred on central Iowa streams and the analytical evidence gathered during our investigations tightly supports this theory.

Susceptibility to oxygen depletion by agricultural organic runoff is heightened by the fact that most of the water flowing in central Iowa streams during wintertime conditions prior to run-off comes from ground water seeping into the river bed. It is a well known fact that most ground-water aquifers in Iowa are very low in dissolved oxygen content and therefore the rivers are in their poorest condition to accept the oxygen demanding agricultural organics.

1/ The Encyclopedia Britannica Yearbook 1969 farm livestock census lists Iowa as having approximately 7.1 million cattle, 13.7 million hogs and pigs, 947,000 sheep and lambs, 17 million chickens, and 218,000 turkeys. Horses were not listed, but the horse population in Iowa is sizeable and probably increasing.-Ed.

The biological oxygen demand (BOD-organic load) of Iowa streams will average approximately 5-10 parts per million (ppm). This low BOD level can justifiably be considered as the normal organic loading of the streams coming from human and industrial imput. Our records show that it is not at all uncommon for the BOD during runoff to reach levels of 25-30 in rivers like the Iowa, Des Moines and the Cedar. We have on record one situation where a small feeder stream showed 350 parts per million of BOD in the early stages of soil leaching run-off. The fact that we have had frequent agriculturally produced fish kills indicates that the organic materials discharged to the streams during this run-off condition exerts its oxygen demand with great rapidity. Coupled with the fact that the organic loading can come from the leaching of many thousands of acres of agricultural land, it is not difficult to see the importance of this situation. In our opinion, the early stages of this runoff phenomenon carries the highest amount of organic loading and it is during this early period when this sharp oxygen demand is imposed on the stream that the sudden lowering of available oxygen results in the death of fish. Most limnologist (aquatic biologists) feel that 4 parts per million of dissolved oxygen is a legitimate lower limit for warm water fish species and that 3 parts per million of dissolved oxygen for any significant period of time will result in fish kill of significant magnitude. Several cases studied intimately on the Iowa river in the Iowa City area have recorded dissolved oxygens as low as 1 part per million in the river upstream from the Coralville reservoir. This condition occurs frequently and fish kills of significance are recorded almost every year, usually in late January or February at the time of the first major winter thaw run-off. Careful and immediate investigation of these reported fish kills have not developed any evidence indicating that they were produced by municipal or industrial wastes.

Decaying plants produce significant amounts of soluble and insoluble carbohydrate materials which add their organic oxygen demanding load to that normally coming from the common use of animal excreta as broadly distributed fertilizer. These are the materials that are leaching into the stream and in their various stages of microbiological degradation they exert rapid oxygen demand, producing oxygen deficiency and subsequent fish kills.

Nitrogeneous materials are also of great import in water quality although under normal circumstances they are not of significant import with respect to fish kills. Plant protein, animal manures used as fertilizers, chemical fertilizers containing ammonium and nitrate compounds contribute the major sources of nitrogen from agricultural sources. These materials reach the stream in a similar manner during run-off periods but their oxygen demand is usually much slower and they are not normally causative agents of severe and sharp oxygen deficiency conditions. Nitrogen exists in water in a variety of states or conditions with the two most important being the nitrate and ammonium ion states. The condition in which nitrogen exists at any given time is a function of oxygen levels, temperature, species of bacteria and the age of the nitrogeneous material itself. Ammonium ion is one of the reduced states of nitrogen and is in position to take up oxygen from the water supply under the proper conditions. As ammonium ion itself, it is a toxicant to many aquatic organisms and the Iowa Water Pollution Control Commission has a maximum permissible level of ammonium ion of 2 parts per million as nitrogen. Iowa streams are usually well below this level and fish kills attributable to ammonium ion have to our knowledge occurred only as the result of accidental agricultural or industrial spills. The toxicology of ammonium ion to aquatic life is highly complex but it should be recorded here that the records of the State Hygienic Laboratory over more than twenty years indicate that the ammonium ion concentration in central Iowa streams is increasing, especially during the last three or four years. While practically all municipal sewage treatment plants release ammonium ion, the levels in Iowa streams recorded during non-run-off periods is usually less than 1 part per million. A large number of values exceeding 4.0 parts per million have been recorded in several Iowa streams this spring and only fortunate circumstances of temperature and oxygen levels prevented damage to aquatic life. Most of the nitrogeneous material was organically bound but these high levels of ammonium ion are alarming to those of us who realize the damage which can be caused to aquatic life when the proper natural circumstances coincide with these high ammonium levels in our streams.

Elevated concentrations of ammonium ion in surface waters cause difficulties other than strictly aquatic and it has been extremely difficult to produce an adequate grade of distilled water here at the University and severe and costly problems with respect to operation of our steam generation plant have occurred.[2] Extensive chlorine demand in surface water plants around the state also results from increased nitrogeneous loadings of our streams.

The nitrogeneous materials, especially nitrate ion, serve as nutrients for the growth of biological organisms such as algae which eventually degrade in the stream producing adverse conditions from sudden oxygen demand and taste and odor contributing metabolites. The eutrophication of Iowa surface

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2/ The University of Iowa, Iowa City, obtains the bulk of its water from the Iowa River. -Ed.

waters is a well demonstrated fact. One central Iowa stream serving as the raw water source for a large municipality has recorded nitrate ion levels as high as 43 parts per million with considerable frequency during the last couple of years. The nitrate level in this stream 15 to 20 years ago averaged in the neighborhood of 10-15 parts per million showing the increase in nitrogeneous nutrients which has occurred over this time period. Again, this phenomena of increasing nitrogeneous content in Iowa streams is much greater in the smaller internal streams, while the large dilution of water from non-agricultural areas supplying the Mississippi and the Missouri has prevented significant increase of both organic and nitrogeneous materials in these border streams. If this trend continues, it is quite likely that we will be facing the problem of nitrate content in streams to be treated for public water supply which exceed safe limits for nitrate content. Nitrate ion content over 45 parts per million produces infant cyanosis or blue babies when this water is used for preparation of infant formula. This is a serious disease and in the past has resulted in the death of several Iowa infants.

It is highly infeasible to remove soluble nitrate ion from public water supplies and we should all be aware of the serious implications which this trend of rising nitrate ion in surface water portends.

Approximately 18-22% of water supplies submitted to the State Hygienic Laboratory from private and rural water supplies contain nitrate ion concentrations above 45 parts per million. (See Table 1). This figure does not represent an extensive increase over the percentages which our laboratory has recorded for many years and it would be very easy to develop complacency over this lack of increase of nitrate ion in farm wells. Let us analyze this situation for a moment recognizing some of the economic and educational factors involved. Recent years have seen a reduction in the number of farmsteads having shallow, dug or bored wells and as the economic status of the Iowa farmer has improved we have noticed an increasing number of drilled and deeper well samples being submitted to our laboratory. It is significant to note that the percentage of high nitrate specimens has remained at the 18-22% level even though the specimens submitted are from types of wells normally not subject to nitrate contamination. Also, we have recorded nitrate ion concentrations in some Iowa wells as high as 3,200 parts per million which grossly exceeds the magnitude of extremely high nitrate concentrations recorded in the early 1940s. It would be very easy to say that these high nitrates are primarily produced by the use of nitrogeneous fertilizers, but a careful evaluation of the location of the well, its construction and the possible usage of nitrogeneous chemicals will be necessary before such a conclusion is valid.

TABLE 1

PERCENT OF TOTAL NITRATES OVER 45 ppm

	1965	1966	1967	1968	1969
Jan		16.8	16.5	15.6	14.7
Feb		20.8	15.6	18.1	16.7
March		16.3	16.3	15.5	22.6
April	15.2	20.8	16.4	14.6	
May	11.0	22.8	17.3	18.5	
June	15.5	21.2	20.1	13.4	
July	15.1	17.2	18.2	14.9	
Aug	22.0	17.3	15.9	22.9	
Sept	20.1	25.4	13.6	19.3	
Oct	22.1	15.4	16.5	18.9	
Nov	16.8	16.5	13.7	17.5	
Dec	20.6	14.0	12.8	18.8	
Annual	16.5	20.9	16.4	17.4	18.8

12,000 - 15,000 nitrate analysis performed annually on private well specimens.

Based on the increase noted in nitrate and ammonium concentrations in surface waters and the greater numbers of drilled wells yielding ground water high in nitrates, it appears very logical to postulate that nitrogeneous farm chemicals are reaching both our streams and underground aquifers in increasing concentrations. In our opinion, the high nitrates in well water supplies is due to surface run-off getting into the well due to improper location or construction, rather than percolation of these materials downward through the soil to the subterranean aquifer. Good judgment must still be used in choosing the location of the well so that it is not in the path of farm land drainage. It is still good practise to be deeply concerned about the caliber of construction so that the well is given all the protection possible with respect to drainage carrying contaminating materials. A resource as important as the farm water supply, often serving both the family and livestock, certainly deserves all necessary attention so that it is not accidentally and irreparabley damaged. Many materials commonly used around a farm can contaminate a well and its aquifer so that cleanup and restoration is practically impossible.

Many fertilizers contain significant percentages of phosphate (PO_4) ion and these materials being largely soluble find ready entrance to surface water streams during soil leaching run-off. While they are not toxic to aquatic life, they serve as nutrients for algae and stimulate their growth resulting in oxygen depletion and taste and odor problems. Our research into the phosphate problem has been quite scanty and it can only be said that the phosphates are undoubtedly increasing in concentrations as their environmental association in quite similar to the nitrogeneous materials. Again, our research does show that the phosphate content of internal smaller streams in Iowa exceeds considerably the levels of phosphate in our two large border streams.

Animal excreta used for fertilizers can be considered as a farm chemical produced on the farm. Its contribution to the bacterial loading of Iowa streams is delineated to a considerable extent. We know that the coliform bacteria content in Iowa surface waters is at its highest level in the early stages of run-off. These high bacterial levels far exceed the water quality standards established by the Iowa Water Pollution Control Commission and all scientists and engineers involved in water quality recognize that these bacterial levels are of agricultural origin. Many bacterial organisms pathogenic to man are transmitted by the fecal material of livestock and the contribution of agricultural bacterial pollutants is probably the major water quality deficiency in Iowa streams. Hydrologic conditions in our state are such that the highest agriculturally produced bacterial levels occur simultaneously with the time of greatest recreational demand. Building municipal and industrial sewage plants is not going to significantly alter this condition. Improvement in the bacterialogical levels of our streams is only going to come when agriculture makes the necessary effort to correct this condition.

It is significant to note here that the recent stream monitoring has indicated that high nitrogen and phosphate levels occur in the face of lesser rises in bacteriological pollution. This tends to indicate that greater amounts of commercial chemical fertilizers are being used rather than livestock excreta. This change in farming practise has tended to reduce the bacteriological loadings on our streams and in this respect is a step in the right direction.

The use of pesticides as farm chemicals has occupied the limelight more than any other class of materials. They have been responsible for highly significant advances in agricultural efficiency and have produced vastly improved food products benefiting the consumer with respect to cost and quality. They are in many cases highly toxic to humans and other animals but if used properly as directed their contribution to the environment is tolerable consistent with their benefits. The State Hygienic Laboratory in conjunction with the Iowa State Conservation Commission has been involved in environmental pesticide research for approximately 15 years. The gamet of environmental involvement has been covered over this period encompassing monitoring of milk, dairy products, surface and ground water, air, soil and food products. The Iowa State Conservation Commission has been much interested in the amounts of various pesticides reaching the aquatic and wildlife environment and has provided financial aid to the laboratory so that these projects can be carried out. An extensive amount of data on the environmental conditions with respect to pesticides have been gathered and three areas of water quality will be discussed in this paper.

Chlorinated hydrocarbons are extremely durable in the environment even carrying over from one application season to the next, while the organophosphates deteriorate very rapidly in the presence of water and sunlight. The data herein presented will be restricted to primarily the chlorinated hydrocarbon phase of the problem which does not necessarily mean that we consider them the most important. Organophosphates are highly toxic to human beings and their use as farm chemicals with potential toxic effect on the applicators make them extremely important from an individual standpoint. Organophosphates are far less toxic to fish and aquatic life however and a considerable portion of our research disregarded these materials for that very reason.

Farmers and licensed pesticides applicators often mix their compounds in close proximity to the farm well for convenience. This has resulted in a considerable number of rural well owners requesting our laboratory for services regarding the possible contamination of their private water supply. Since 1966 we have had approximately 150 such requests wherein it was suspected that pesticide had in one manner or another reached the well itself. Table 2 shows the area from which these specimens came, the probable mode of entry into the well and the pesticide concentration found. Without going into the toxicities of the concentrations delineated, it can be seen that the contamination of private well supplies with pesticides contemplated for use on the farm is a real rather than an imaginary problem. The analysis of pesticides, even when we know the probable compound involved, is a lengthy and costly proposition which limits the actual number of tests that can be economically performed. Many of the materials are carried in solvents which themselves are damaging to the well supply and are extremely resistant to removal by simply pumping out the well. In fact, some of the materials are essentially irremovable and their entrance into the well results in its abandonment. This is a severe financial blow to a farmer and is invariably the result of negligence or at least unawareness of the significance and possibility of contamination. Scientists and physicians are not at all certain what the maximum safe permissible concentrations are for many of the commonly used agricultural pesticides so that no one wants to make the decision regarding the acceptability of detectable levels in well water. This often leaves the farmer very confused regarding his course of action once we have detected measurable concentrations of toxic pesticides in his well water. Obviously, the best protection is to restrict pesticide solution mixing anywhere near the well.

Because we were interested in the mode of entry of surface applied pesticides from a normal agricultural situation, the State Hygienic Laboratory set up a controlled experiment near Iowa City in the spring of 1967.

Two farms were selected, No. 1 in northeast Johnson County which was using only aldrin, and No. 2 in southeast Johnson County which was using aldrin on part of its land and diazinon on part. Drawings illustrating the farm layouts and drainages are shown in figs. 1 and 2. Aldrin was used in the fields indicated at a rate of 2 pounds actual aldrin per acre and diazinon at a rate of 2 pounds actual diazinon per acre.

The run-off water from farm No. 1 finally drained into Rapid Creek which empties into the Iowa River just north of Iowa City.

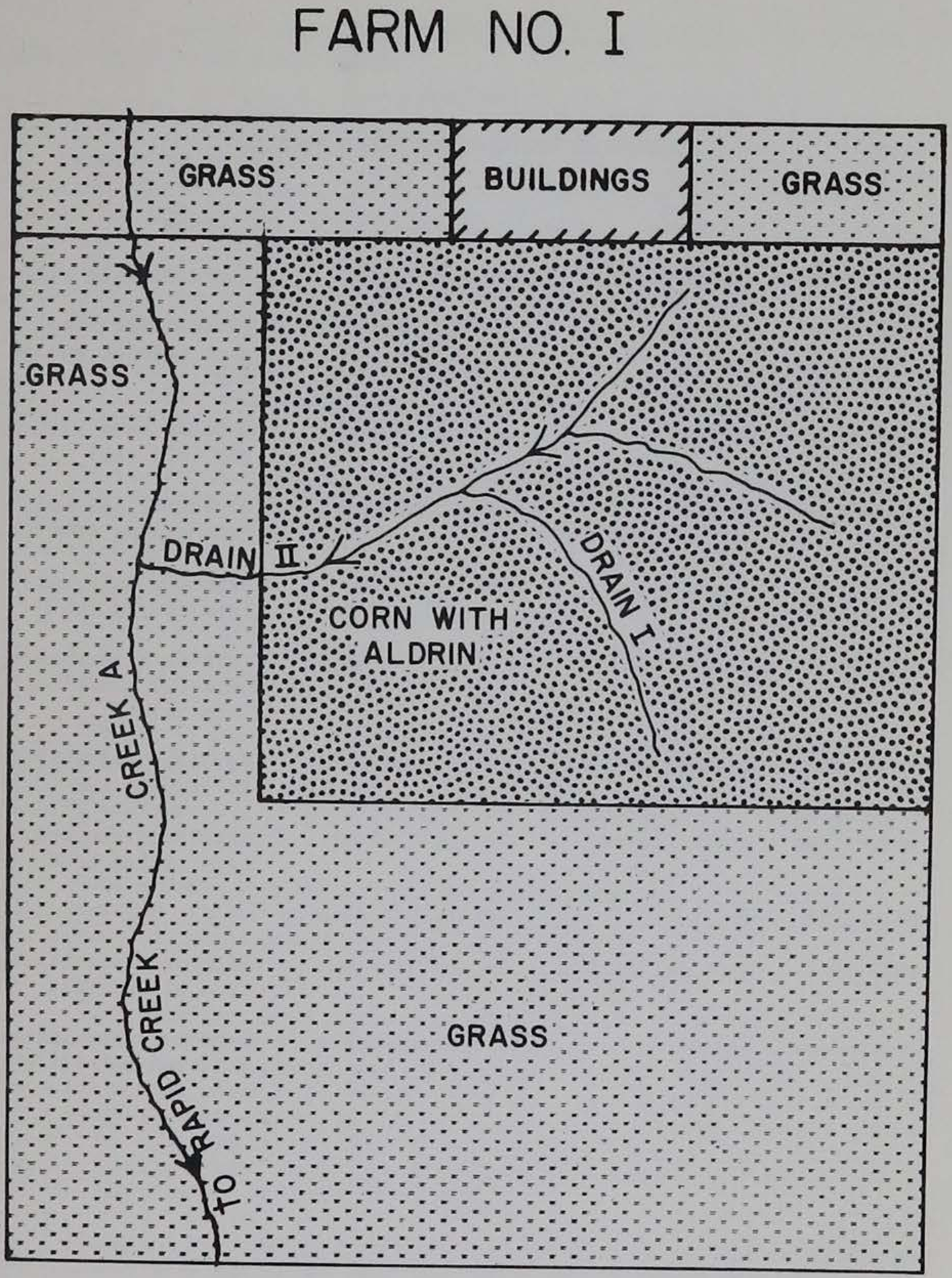


Figure 1. Layout of Farm No. 1 in northeast Johnson County using only aldrin pesticide.

TABLE 2

PESTICIDE PROBLEMS IN PRIVATE WELLS

	Area	Found	Cause
June 1966	Ridgeway	10 ppm 2,4-D	Siphoned into well
June 1966	Wapello	.09 ppb dieldrin	Flushed into well when washing equipment
June 1966	Altoona	.07 ppb aldrin	Spilled near well & ran into well
June 1967	Ossian	15 ppb atrazine	Siphoned into well from mixing tank
July 1967	Clarence	10 ppb 2,4-D	Siphoned into well from mixing tank
Feb 1968	Keota	5 ppb chlordane	Termite exterminator injected chlordane into soil
March 1968	Shenandoah	5 ppb cyprex	Spilled down well during mixing
March 1968	Belle Plaine	20 ppb treflan	Siphoned into well from mixing tank
Sept 1968	Salix	10 ppb atrazine	?
Sept 1968	West Burlington	16 ppb treflan	Siphoned into well from mixing tank
March 1969	Keota	1 ppb chlordane	Termite exterminator injected chlordane into soil

The run-off water from farm No. 2 runs into the Cedar River in Muscatine County.

On May 1, 1967 all the drainage sites selected which had water flowing in them were sampled. These are labeled as creeks or rivers in the drawings and tables. The other natural surface drainage paths which contained no flowing water at this time are labeled drains.

Insecticides had not been applied on these farms for the 1967 season at this time, and there had been no rainfall for several days prior to this.

Table 3 shows the locations where samples were collected. No pesticides were detected at or above the 0.01 part per billion concentration level.

Within the two week period following this sampling all the fields marked were planted with corn with the insecticide listed on the drawings and in all fields the herbicide atrazine was added.

From May 1st to June 7th there was no rainfall which caused any surface run-off. On the morning of June 7th there was a four inch rainfall, county wide, which began at about midnight and continued until noon.

Table 4 lists the points sampled on June 7, the time sampled, estimated rainfall at this time, and amounts of pesticides found in the water. There was water flowing in all the drainages at this time and the creeks were either bank full or overflowing.

The water in the creeks sampled normally is slow flowing and fairly clear; however, all the water samples taken on June 7th were quite turbid and contained suspended soil particles.

The samples were collected in gallon glass jugs and the solids allowed to settle for 24 hours. The water (which was still somewhat turbid) was decanted off and analyzed. Traces of heptachlor and heptachlor epoxide were found in several of the samples but since these were much lower in concentration than the dieldrin and aldrin and since their source is unknown (carry-over form previous years or draining from other land) they were omitted from Table 4.

Aldrin is slowly converted to dieldrin in the presence of oxygen and sunlight and by micro organisms. All the samples which contained aldrin also contained greater amounts of dieldrin. Evidently the month which the aldrin was on the soil was sufficient for the majority of it to be converted to dieldrin.

FARM NO. 2

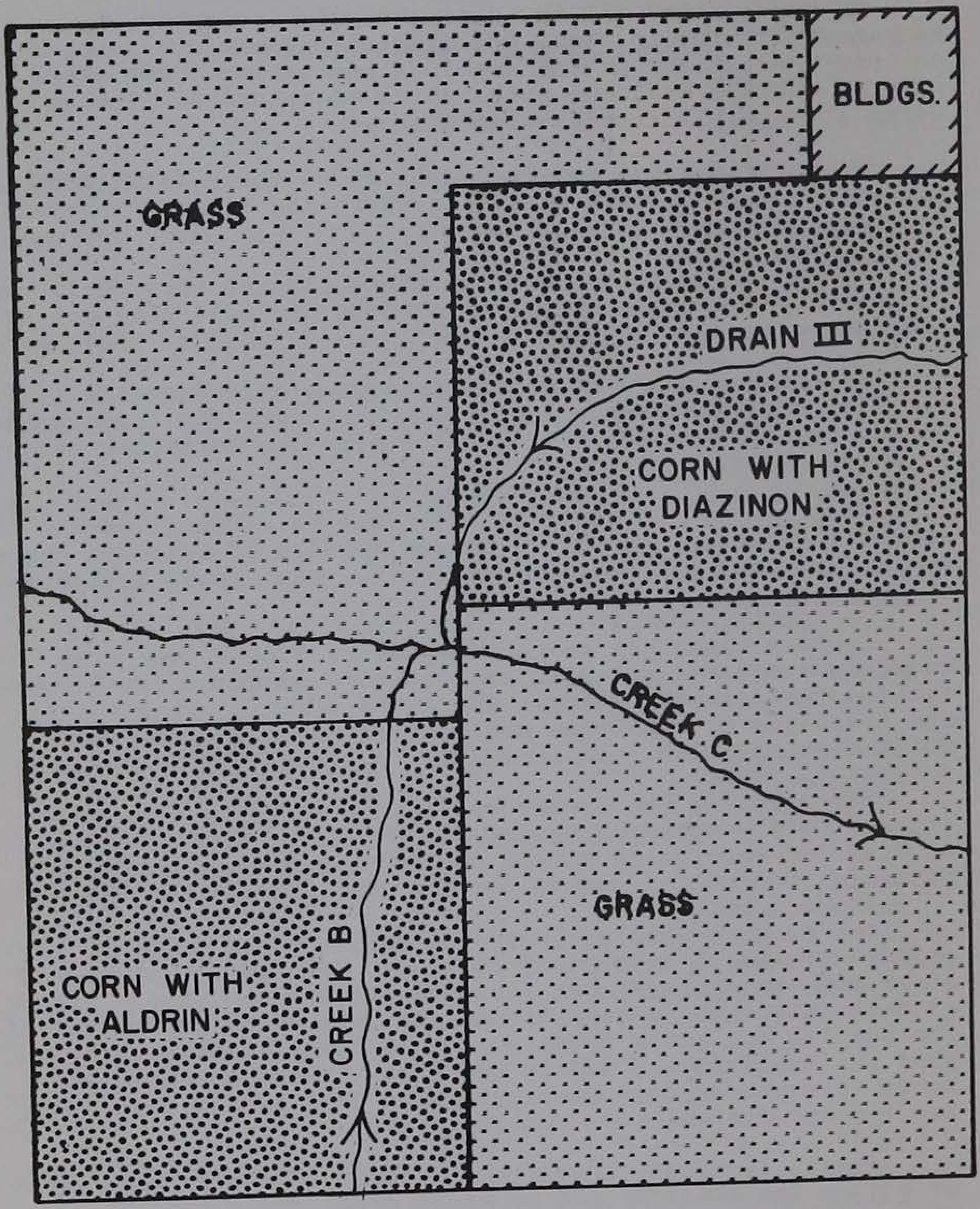


Figure 2. Layout of Farm No. 2 in southeast Johnson County using aldrin pesticide on part of its land and diazinon on another part.

The results are quite consistent in table 4, the samples which are taken closest to the source of the insecticides containing the largest amounts. The only exception being creek B on farm No. 2. The low aldrin - dieldrin content of this sample cannot be explained.

No diazinon was found in the surface run-off from farm No. 2 even though it was applied to one of the fields. Diazinon is an organo phosphorous insecticide which is readily hydrolized by water. Unlike aldrin it is not converted to other compounds which are readily detected. Apparently the majority of the diazinon which was applied to farm number 2 was degraded during the month it was on the soil.

After the water was decanted off, the solids which had settled during a 24 hour period were dried and analyzed for aldrin and dieldrin content. The amount of solids present and insecticide concentrations in them are listed in table 5.

Because of the relatively small amounts of solids in the samples taken and the somewhat inexact method of separating them from the water the percent solids in table 5 is probably only an approximation of the solids being carried by the streams.

From the amount of solids and the concentration of aldrin and dieldrin on the solids it can be seen that the total amount of insecticides carried by these solids is about equal to the amount carried by the water.

Even though the concentration of pesticides is much greater in the solids than in the water, the weight of the water is so much greater than that of the solids that the total amounts of pesticides carried by the solids and by water were about equal in samples described in this report. Possibly some of the insecticides in the water were carried by soil particles which were small enough that they did not settle out in 24 hours.

The data in this report make it clear that pesticide concentration in surface water due to agricultural run-off is much higher in the small streams which are directly fed by the run-off water.

A significant portion of the pesticides are adsorbed on solid soil particles which will settle out on the bottom of the streams and rivers. There the pesticide may be partially desorbed and taken into the water slowly over a long period of time. It will also be slowly degraded to less toxic products over a period of time.

TABLE 3

Samples Collected May 1, 1967

Farm 1	Farm 2
Creek A	Creek B
Rapid Creek	Creek C
Iowa River (Iowa City)	

TABLE 4

Samples Collected June 7, 1967
Pesticides in Water

	Parts Per Billion				
Farm 1	Dieldrin	Aldrin	Diazinon	Time	Inches of Rainfall
Drain 1	0.10	0.02		9:30AM	3
Drain 2	0.20	0.06		9:30AM	3
Creek A	0.19	0.06		10:00AM	3
Rapid Creek	0.11	0.04		8:45AM	2.5
Iowa River	0.01	*		10:30AM	3.5
Farm 2					
Drain 3	*	*	*	12 noon	4
Creek B	0.08	0.01	*	12 noon	4
Creek C	0.13	0.06	*	12 noon	4

*None detected

TABLE 5

Samples Collected June 7, 1967
Pesticides in Solids

	Parts Per Billion			
Farm 1	Dieldrin	Aldrin	Diazinon	% Solids
Drain 1	143	97		0.22
Drain 2	170	120		0.19
Creek A	150	131		0.24
Rapid Creek	63	29		0.16
Iowa River	28	15		0.05
Farm 2				
Drain 3	*	*	*	0.28
Creek B	142	137	*	0.10
Creek C	18	2	*	0.27

*None detected

A study of ground-water wells on Muscatine Island in 1965 showed definite evidence that these wells, producing from sandy soil and alluvium, were contaminated by pesticides applied during agricultural practise in that area. DDT, DDE and Dieldrin were used in specific locations and were shown to subsequently occur in the well water on the farms studied. Concentrations as high as 58 parts per trillion of DDT and 7 parts per trillion Dieldrin were shown to have occurred under the conditions studied. While these levels are in themselves relatively low for human consumption, they do clearly indicate the vulnerability of farm wells to pollution in certain soil conditions by percolation and/or surface water run-in. Again, the logical warning not to apply toxic chemicals in the immediate area adjacent to a farm water supply seems highly pertinent.

Pesticide concentrations in major streams are shown by representative data in table 6 and table 7. These data are a part of the information gleaned by our routine river pesticide sampling program which currently involves sampling points at 10 points at 10 different locations on critical Iowa streams. The earlier data indicates the lack of sensitivity in pesticide methodology occurring in 1965 when we were able to determine DDT and its degradation products in the neighborhood of 100 parts per trillion or 0.1 parts per billion. Three years later in 1968 table 7 shows actual quantitation in the parts per trillion (ppt) range and indicates that we are now able to delineate pesticide concentrations even at the low levels existing currently in our major streams. The concentrations shown in table 6 indicate the extremely low levels of common chlorinated hydrocarbons in Iowa surface waters and in our opinion do not serve as cause for any alarm with respect to usage for either public water supply or other uses. The chemist has improved his ability to detect to such a gross extent, that we can almost be accused of creating a problem where none exists. The values we are able to report with accuracy and precision now would have been reported as zero or absent using the methodology which was current as little as five years ago. There is no epidemiological data indicating that concentrations which we are finding in Iowa streams is detrimental to any of their uses.

The past year has seen our laboratory involved in studies of heavy metal concentrations in streams, bottom sludges and in aquatic life residing in these streams. We have found levels of chromium, zinc, copper and other heavy metals throughout this aquatic environment in concentrations higher than we anticipated. Some of these metals are now being incorporated as trace metal nutrients in livestock feeds and this fact is of considerable interest to us. We wonder if agricultural practises as well as industrial metal containing discharges are contributing to this reservoir of potentially toxic metals. Fish aggregate some of these metals to a large

TABLE 6

Survey of Chlorinated Hydrocarbon Pesticide Levels in Selected Iowa Rivers
1965

Sampling points:

Mississippi River:	Dubuque - Davenport
Cedar River:	Cedar Rapids
Iowa River:	Iowa City
Raccoon River:	Des Moines
Missouri River::	Council Bluffs

Results to date:

	Feb	Mar	April	May	June	July	Aug	Sept
Dubuque:	*	*	–	*	*	*	*	*
Davenport:	*	*	–	*	*	*	*	–
Cedar Rapids:	*	*	–	*	*	*	*	*
Iowa City:	*	**	–	DDT 0.4 ppb DDE 0.1 ppb	*	*	*	Inc.
Des Moines:	*	–	*	*	*	*	Inc.	Inc.
Council Bluffs:	*	*	–	*	*	*	*	*

*	No pesticides found in concentrations as high as 0.1 ppb
**	No pesticides found in concentrations as high as 0.3 ppb
Inc.	Received but not completed

TABLE 7

PESTICIDE IN IOWA RIVERS 1968

(Parts Per Billion)

SOURCE	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER
Mississippi River Dubuque	Dieldrin 0.003	DDE 0.005	DDE 0.002	DDT 0.005	ND	ND	ND
Davenport	ND	ND	DDE 0.003	ND	DDT 0.004	Dieldrin 0.004	ND
Missouri River Council Bluffs	ND	ND	ND	Dieldrin 0.002	ND	ND	DDT 0.004
Raccoon River Des Moines	Dieldrin 0.003 DDT 0.006	DDT 0.005	Dieldrin 0.004 DDT 0.004	-----	DDT 0.005	DDT 0.004	Dieldrin 0.005
Cedar River Cedar Rapids	Dieldrin 0.004 DDT 0.012	DDT 0.010	Dieldrin 0.005 DDE 0.004	ND	Dieldrin 0.010	DDE 0.012	ND
Iowa River Iowa City	Dieldrin 0.006	Dieldrin 0.004	Dieldrin 0.008 DDT 0.012	Dieldrin 0.006	ND	Dieldrin 0.007	ND

ND= Not detected

extent in their skeletons and it is of import when considering their propagation and growth characteristics. The State Hygienic Laboratory anticipates increased study of the heavy metal problem in order to delineate the source of these elements and their signigicance. Extension of these studies to drinking water supplies of both surface and ground-water origin is already in progress.

A very important aspect of stream pollution which often goes unrecognized is siltation. Iowa soils due to their peculiar structure and the practise of high percentage cultivation are especially subject to erosion. Iowa streams carry a vast silt load which precipitates out and tends to cover natural bottom habitats with clay, mud and silt. This cover renders the bottom inhospitable to the natural fish food organisms and creates a hostile environment for natural fish species even though the water quality itself is good.

A constant stream degradation results and until we reverse the trend with erosion control we can look forward to an expanding loss of fishable streams in Iowa. This is a perfect example of a non-toxic pollutant whose physical effect is just as lethal as sewage or toxic chemicals. The Iowa Water Pollution Control Commission has prohibited discharge of lime softening plant sludge into streams because of a similar damaging effect yet we continue to pour agricultural land siltation into our streams in vast tonnages every year. The ecological balance of nature conveys no group privilege.

We have talked at considerable length on the real and probable contribution of waste materials by agriculture to the aqueous environment. Because the contributors on the individual farmsteads are so numerous and scattered all over our state, the control of these waste discharges presents an enormously complex problem. While much has been done by soil conservation groups in retaining water where it falls, we must do a far better job in this respect in the future. Simple percolation downward through the soil adsorbs or absorbs the majority of the surface contaminating materials so that the hazard to the subterranean ground-water supply normally is not a significant factor. It is the soil surface leaching with rapid runoff into the streams of Iowa that is the prime problem with respect to agricultural pollution. It is utterly unrealistic to ask the Iowa farmer to reduce his usage of ertilizers, pesticides and other soil conditioners, as the demands for quantity and quality placed upon him by the American consumer could not be met with agricultural practises in force a decade ago. We must learn to live with the usage of these chemicals.

The manufacturing chemist is working diligently to design farm chemicals which will serve their intended purpose and then degrade or decay into materials having no adverse environmental effects. He also is attempting to design these materials so that they bond or fasten themselves onto soil particles with slow, graded release as needed in the agricultural process. However, trying and getting the job done are often two different things. The monitoring trends presented in this paper indicate that we have not as yet reached as acceptable point in product development with respect to holding applied farm chemicals at the point of application. They are reaching our streams and our ground-water supplies. In my opinion, the best hope for success lies in the field of improved soil conservation designed to retain the moisture where it falls and force it into the ground-water environment. Obviously, total success in this respect would produce streams with insufficient flow to provide dilution water for municipal and industrial waste assimilation and other important needs for minimum surface-water flow.

It is apparent that cooperation of all segments of this problem is necessary to an adequate solution. The farmer, scientist, engineer, hydrologist, soil conservationist and the general public are going to have to adapt their individual operation to the common good rather than placing group special privilege first. Water resources are limited and we cannot demand high water quality on one hand expecting total cooperation from other segments while insisting upon exceptions for ourselves. The surveillance of the water environment across this state is a monumental task requiring trained scientists and engineers with expensive and sophisticated equipment. Programs within the State Hygienic Laboratory and the other mentioned agencies have developed over the past 20 years must be supported and expanded if we are to find the answers to these important and perplexing environmental problems. The nucleus of an adequate water pollution control program currently exists and given the financial support from our legislature we can be sufficient to the need.

RICHARD G. BULLARD

Mr. Bullard, a native of Maxwell, Iowa holds the B. S. degree in Civil Engineering from Iowa State University. He is presently State Water Commissioner of Iowa, a post he has held since 1957. He is a registered professional engineer in Iowa and Missouri. His experience as an engineer before becoming Iowa Water Commissioner includes a year with Stone & Webster Engineering Company on the Bagnell Dam at Warsaw, Missouri, 14 years with the Soil Conservation Service of Iowa, six years on flood surveys and flood control planning with the city of Kansas City, Missouri, and five years as acting director of the Iowa Natural Resources Council. The water commissioner processes applications for water permits and conducts hearings as required. He has a thorough understanding of Iowa water laws and serves in a quasi-judicial capacity in interpretation of the law and in granting permits. Mr. Bullard is a member of the Iowa Engineering Society, the Soil Conservation Society of America, and the American Society of Civil Engineers.

IOWA WATER LAWS

Richard G. Bullard
Water Commissioner
Iowa Natural Resources Council

The State of Iowa has a number of laws concerned with the management, protection, control and utilization of its water resources. These laws have been passed over a long period of time as the understanding of various problems dictated a need for legislative action. Some of this legislation has pioneered in areas of necessary public protection and Iowans can be proud of the foresight of their lawmakers.

This paper is not intended to be a legal treatise. It would be most inappropriate for the writer, an engineer, to attempt to comment on the legal aspects of the multitude of statutes loosely grouped in the classification "Iowa Water Laws". As an employee of the Iowa Natural Resources Council, the most all-inclusive state agency dealing with water, for 17 years, and as the State Water Commissioner, acting in a quasi-judicial position in administering the Iowa Water Rights Law since its passage in 1957, I will attempt to briefly cover the broad field and then deal more specifically with the duties of the Council as outlined in Chapter 455A of the Iowa Code.

The source of all water in Iowa is precipitation. In recent years scientific advancement has indicated the possibility of changing the amount, type, distribution or time of precipitation by weather modification. The legal aspects of such alterations are many, and although some thought has been given concerning legislation to regulate weather modification, Iowa does not have laws concerning such activities.

One of the earliest problems in the water field that required legislative action was drainage. General and specific laws covering drainage activities have been passed by the Iowa legislature over a period of many years. A book entitled "Iowa Drainage Laws" was published by the Iowa Highway Research Board in 1957. It contained 870 pages, thus illustrating the multicipity and complexity of laws in this field. There is no state agency with the duty or authority to coordinate, assist or supervise the vast number of local and county boards, commissions, voluntary or legal organizations and agencies legally authorized to carry out some drainage functions. Attempts in recent years for the very desirable modernization and simplification of the laws covering drainage activities have been unsuccessful. There is definite need for legislative action to provide a state agency to supervise and coordinate drainage and associated flood control and levee activities.

Adequate laws protecting the purity of public water supplies are very ably administered by the State Department of Health and local boards of health.

The State Department of Health has a commendable record of encouraging installation of adequate sewage and waste treatment facilities in Iowa over a long period of years. In 1965 the Iowa legislature strengthened the pollution control laws by the creation of the Iowa Water Pollution Control Commission. This commission, using the Public Health Engineering staff of the State Department of Health, has speeded up the installation of municipal and industrial waste treatment facilities, and is attacking other sources of water pollution such as runoff from feedlots. Pollution caused by runoff from agricultural lands and by solid waste disposal is also being studied.

The State Soil Conservation Committee, since its creation in 1939, has assisted in the formation of the 100 county-wide Soil Conservation Districts (Pottawattamie County has two districts) covering the entire state. These districts, created by a vote of the people and governed by an elected board, have, with the assistance of Federal agencies, primarily the Soil Conservation Service and Agricultural Conservation Program, been instrumental in getting landowners to install many practices that significantly effect water resources. Soil conservation measures reduce sediment loads that fill reservoirs and stream channels and make the water less desirable for other uses. These measures also reduce the rate of water runoff and conserve water for later use by storage in surface reservoirs or in the ground due to increased infiltration.

The State Conservation Commission by law administers the large state-owned bodies of water including natural lakes and meandered streams. As a part of its program of providing recreational facilities for residents of the state, the commission has constructed and manages a number of artificial lakes and duck marshes. It supervises the activities of the legally constituted county conservation boards that develop recreational programs, many of them water based, at the county level.

The Iowa Geological Survey is legally constituted as the state agency responsible for the collection, interpretation, and reporting of basic geologic and hydrologic data. The Survey works cooperatively with the Water Resources Division, U. S. Geological Survey, in obtaining both stream flow and ground-water data. Soil and rock cutting samples from more than 21,000 wells are available in the Survey files plus a very large number of driller's written well logs. This probably constitutes one of the best inventories of the underground geologic framework and aquifer conditions available in any state. This information has been obtained mostly from cooperating well drillers on a completely voluntary basis. Laws regulating well drilling have been considered but Iowa has no legislation in this area as yet.

The broad field of Iowa Water Laws would also include: the public utility regulation laws insofar as they affect water service; eminent domain laws authorizing condemnation for water supplies, sewer systems, water power generation, flood control works and related water resources interests; authorization for cities and towns to provide water and sewage services, to construct, operate and maintain flood control systems and to create water recreational areas, and to finance these improvements by various means; and laws authorizing formation of benefited water districts and sanitary districts within counties.

The foregoing maze of laws authorizing various activities in the field of water was no doubt paramount in the thinking of the legislature when it states"-- it is hereby declared to be the policy of the state to correlate and vest the powers of the state in a single agency, the Iowa Natural Resources Council, with the duty and authority to establish and enforce an appropriate comprehensive state-wide program for the control, utilization and protection of the surface and groundwater resources of the state." (Chapter 455A.2 Iowa Code 1966)

The present functions of the Iowa Natural Resources Council are the product of an evolutionary development involving the work and study of a series of legislative committees and the capable assistance of the water agencies at various levels of government. In 1947, the Iowa legislature appointed the Interim Flood Control Committee. One of the stated purposes of this Committee was to study Iowa's need for laws on the control and use of water, and to submit drafts of any recommended legislation pertaining to this area. A primary aspect of the report submitted by this Committee was a recommendation that a State Water Control and Resources Council be established. The Committee further recommended that a function of the new Council be to study the problem of the preservation of ground water in the state, and to correlate the action of the federal, state, and local governments in all activities relating to flood control and water supplies.

In 1949 the Iowa legislature established the Iowa Natural Resources Council and assigned to it duties in accord with the recommendations of the Interim Flood Control Committee. In addition, the Council was given the authority to establish and enforce a comprehensive state-wide plan for the control of water and the protection of the water resources of the state.

The nine members of the Natural Resources Council are appointed by the governor for overlapping six year terms. Selection for memberships is made from the electors of the state at large solely with regard to their qualifications and fitness to discharge the duties of office and without regard to their political affiliation. Thus far this procedure for selection has resulted in an administrative agency operating around a core of persons highly qualified in water resource development and management. The Council is required to "meet at the seat of government on the first Monday in the months of January, April, July and October" and by custom normally has a two day meeting each month. The work of Council, under procedures established by it, is performed by a full-time staff.

By 1955 the competition for water in certain areas of the state had become so potentially serious that the legislature saw fit to create an Iowa Study Committee on Water Rights and Drainage Laws.

The primary purpose of this Committee was to present a comprehensive report which would include a consideration of all water problems or potential problems, existing legislation, court decisions, and any federal laws which would provide assistance in the area.

After several public meetings and careful study, the committee drafted a bill in the form of an amendment to the 1949 legislation which created the Natural Resources Council. This proposed water rights law was submitted along with the Committee's report in 1956. Following, as it did, several years of serious water shortage, the idea of regulating the state water resources in the public interest so appealed to the Iowa legislature that the bill swept through both houses of the 57th General Assembly without a dissenting vote. The legislature was sufficiently impressed by the importance of the new law that it made it effective immediately upon publication and the law went into effect May 16, 1957.

Statutory provisions pertaining to comprehensive planning of water resources were clarified by amendments to Chapter 455A in 1965 at which time a new flood-plain regulation section was added.

The functions of the Council as established by law, therefore, are roughly divided into four categories - (1) comprehensive planning, (2) regulation, (3) flood-plain management and (4) water use.

During the years 1952 to 1958 inventory reports of water resources and problems in the various river basins in the state were made by the staff of the Council. These reports showed in general terms the amount of water being used, the amount available, the potential water shortages in certain areas of the state, the flood problems, and other water related data essential for long range, comprehensive planning. These reports were published as Bulletins No. 1 through 8. Regulatory functions demanded the time of the limited staff during the following years and a state-wide comprehensive water resources plan has not been developed. Staff members in recent years have been a part of committees composed of state and federal officials engaged in preparing comprehensive long-range plans for the Missouri and for the Upper Mississippi River Basins.

Section 455A.33 of the Iowa Code under the title - powers of the council - states, "It shall be unlawful to suffer or permit any structure, dam, obstruction, deposit or excavation to be erected, used, or maintained in or on any floodway or flood plains, which will adversely affect the efficiency of or unduly restrict the capacity of the floodway, adversely affect the control, development, protection, allocation, or utilization of the water resources of the state, or adversely affect or interfere with the state comprehensive plan for water resources, or an approved local water resources plan, and the same are declared to be and to constitute public nuisances, provided, however, that this provision shall not apply to dams constructed and operated under the authority of Chapter 469 as amended."

The reference to Chapter 469 of the Code concerns the mill dam law. Construction and operation of mill dams was very important to the economy of the state during its early history. Their importance has diminished in later years and at the present time only 21 are being used for manufacturing or power purposes. Regulation of mill dams was transferred from the Executive Council of the state to the Iowa Natural Resources Council by the legislation which established the Resources Council by 1949.

The regulatory functions assigned to the Council by Section 455A.33 have required an increased amount of time each year. Projects reviewed include channel changes, road bridges and grades, levees, water impoundment structures, and buildings on the flood plains of the state. During 1968 orders were issued by the Council authorizing 323 different projects. Each project requires individual inspection and study and each order contains conditions designed to assure that public and private interests will be protected.

Review of flood control-projects proposed by the U. S. Army Corps of Engineers, are by law, and as designated by the Governor, reviewed by the Iowa Natural Resources Council prior to authorization and installation. Many of these projects such as the large dams at Coralville, Red Rock, Rathburn and Saylorville, and the levees along the Mississippi, Missouri and Little Sioux Rivers, are very important in water control.

Regulation of use of the flood plain, the third general function of the Council, is a relatively new concept in flood damage prevention. Historically, man has tried to reduce the flood damages through the exercise of control over the river in time of flood. Dams and reservoirs, levees, dikes, flood walls, and channel improvements have been constructed at great cost, principally by federal, state, and local governments. The steady increase in flood hazards and damages despite the expenditure of billions of dollars in tax funds has led to a new approach to the reduction of these hazards and damages - the exercise of control over the land lying adjacent to the river through the planned management and development of flood hazard areas.

Regulation of flood-plain use can be carried out by a variety of means - encroachment lines, zoning ordinances, subdivision regulations, and modifications or additions to building codes. Park and open space developments, evacuations, urban renewal, flood proofing, tax reduction, and warning signs are other methods which may be helpful, particularly in special localized areas.

Flood-plain regulation involves the establishment of legal tools with which to control the extent and type of development which will be allowed to take place on the flood plains. There are two basic objectives of such regulation. The first is to assure the retention of an adequate floodway for the river, floodway being defined as the channel and those portions of the adjoining flood plains which are reasonably required to carry and discharge flood flows without unduly raising upstream water surface elevations. The second objective of regulation is to encourage sound land use consistent with the flood hazard and the community land use needs.

Zoning is the legal tool used by cities, towns and counties to control and direct the use and development of land and property. The zoning ordinance is used to implement and enforce the comprehensive plan which has no legal status. Flood-plain zoning is not a special type of ordinance but merely another set of provisions which can be incorporated into the comprehensive zoning ordinance so that flood damage can be minimized.

These considerations led the 1965 Iowa legislature to enact the new flood-plain regulation Act. Under the Act, the Council may establish and enforce regulations for the orderly development and wise use of the flood plains of any river or stream within the State, and alter, change, or revoke the same. The Council shall determine the characteristics of floods which reasonably may be expected to occur and may by order establish encroachment limits, protection methods, and minimum protection levels appropriate to the flooding characteristics of the stream and to reasonable use of the flood plains. The Council may cooperate with and assist local units of government in the establishment of encroachment limits, flood-plain regulations and zoning ordinances relating to flood-plain areas within the local units' jurisdiction.

At the request of local communities and on approval by the Iowa Natural Resources Council, the Corps of Engineers has completed flood-plain information studies in eight flood-hazard areas in Iowa. Five additional studies are in progress or have been initiated. From these studies, which show the areas inundated by various magnitudes of floods, the Council determines permissable limits of encroachment to guide the Council and local communities in preserving adequate floodway area and in promoting sound flood-plain use consistent with the flood hazard. The Council has completed encroachment studies at four locations and six additional studies are underway. Such a study by the Council in 1960 was used by Iowa City in adopting regulations governing the use of the floodway and flood plains as a part of its comprehensive zoning ordinances approved in 1962.

The fourth general function of the Council is administrating the water rights law. This is believed to be the first comprehensive water rights law adopted in the 31 eastern more-humid states. It is administered by a water commissioner and deputy water commissioners, employed by and acting under policies and procedures formulated by the Council.

One of the important aspects of the Iowa law is that it regulates both surface and underground waters and they are treated as a single resource. The interconnection between surface water and ground water is well known in Iowa. Sometimes this interconnection is apparent almost immediately. Sometimes there is a delay of days, weeks, months or years before a change in one affects the other. All decisions on applications for regulated uses of water take into account the effect the use will have on the entire water resource.

Other important features of the Iowa law include:

1. A public hearing, conducted following legal notice as prescribed by law, is required on each application for a permit to use water.

2. The permit is granted, or the application denied, by the Water Commissioner or a deputy on the basis of hearing which he conducts and other available information.

3. Determinations of the Water Commissioner must be appealed to the Council within 30 days of filing of the determination and a decision on this appeal made on the basis of another hearing by the Council prior to appeal to the Courts.

4. No permit may be granted for more than 10 years.

5. Priorities, as such, are not established.

6. Minimum flows in streams are protected against withdrawals for consumptive uses.

Iowa law requires that a permit be secured for any use of water in excess of 5,000 gallons a day, with a few exceptions.

A permit is also required for the diversion of water or any material from the surface directly into any underground watercourse or basin. Such diversions existing when the law was passed do not require a permit if waste or pollution is not created. The present policy is to deny requests for such permits unless it can be conclusively shown that there is no danger of pollution. The reason for this is the danger of contaminating or polluting the underground water supplies on which about 85 percent of Iowans depend for their drinking water.

Provisions for the initial step of the administrative appeal to the Iowa Natural Resources Council prior to litigation in the courts has proven very beneficial. Although several determinations of the Water Commissioner have been appealed to the Council, there have been no cases tried in court during the twelve years of operation of our law, thus saving time and money for all concerned.

The Iowa Attorney's General and their staffs have worked very closely with the Iowa Natural Resources Council and have helped to develop procedures that could be followed covering the various phases of the law. Cooperation of water users throughout the state has been excellent and has assisted materially in the progress that has been made in administering the Iowa law.

Correlative to the water rights law is the oil and gas law. Early in 1963 a deposit of commercially acceptable crude oil was located in southeastern Iowa, the first such discovery in our state. The legislature, meeting that year, passed legislation regulating development of this new resource and assigned administration of the new law to the Iowa Natural Resources Council through the Office of the State Geologist.

A permit must be obtained from the State Geologist for the drilling of each well for oil or gas. A $50 fee is required and a bond must be furnished by each operator to assure compliance with the rules and regulations and proper completion of the well. The rules and regulations are designed to insure suitable protection of water and oil and gas resources and to provide that adequate well information is obtained and submitted to the State Geologist. More than 100 wells have been licensed to date. Several of these wells extend into the basement complex at depths exceeding 3,000 feet. Most of the wells have been drilled to explore geologic conditions at depths of 2,000 feet or less in an attempt to locate formations suitable for underground storage of natural gas.

Generally, these are the laws concerned with water in Iowa. An excellent monograph published by the Agricultural Law Center, College of Law, University of Iowa in 1966 entitled "A Decade of Experience Under the Iowa Water Permit System" by Professor N. William Hines is recommended reading for those interested in more detailed legal treatment of the water rights law.

The administration of each of the laws mentioned is the responsibility of the second branch of government, the executive. The laws in many instances have been supplemented by rules and regulations required for efficient administration.

When conflicts arise, the third branch of our system of government, the judiciary, resolves these conflicts through interpretation of the statutes and rules involved and the application of constitutional precepts to the case at hand.

Many of the statutes mentioned, including the water use and permit system, the floodway encroachment - flood-plain regulation provisions and the water pollution control law, have never been tested in the Iowa courts on any basis; also the constitutionality of such regulation generally, the adequacy of the particular statute, or the reasonableness and necessity of a particular administrative act or order have never been tested in the courts. Although scholars may theorize at length regarding the progressive trends in technical and judicial thinking in such matters, and arguments favoring the constitutionality and adequacy of such laws often can be buttressed with impressive facts reflecting the changing situation and needs, the final and only opinion that really matters is that of the court of last resort finding the particular law constitutional, adequately drawn and properly administered. This is not to say that these theories, opinions, facts, and authoritative writings are of no value. Judicial decisions are often influenced or based on the same considerations first enunciated by experts totally concerned with problems in the area in question. The construction placed upon a statute by the administering agency and the apparent successful administration of a statute of considerable public importance, over a substantial period of time, is also considered by the courts. Once enacted by the legislature, a particular statute normally is presumed to be constitutional and is administered as enacted until overturned by the courts.

No doubt additional laws will be required for the control of water. Change is inevitable and as our civilization becomes more complex, water, one of the most important resources and definitely a limited one, will require more complex management. On the basis of the past actions, we in Iowa can look to the future confident that enlightened legislators, able administrators, and just courts will provide legal means so that our water resources may continue to be used with the greatest service to the people of Iowa.

H. GARLAND HERSHEY

Dr. Hershey is the Director of the Office of Water Resources Research, U. S. Department of the Interior, Washington, D. C. From 1947 to 1969 he was State Geologist and Director of the Iowa Geological Survey. He was born in Quarryville, Pennsylvania and received the A. B. and Ph. D. degrees from John Hopkins University. He was a geologist with the B. & O. Railroad and an assistant with the Maryland Geological Survey before coming to Iowa in 1936. In Iowa he was quickly absorbed in ground-water work and under his guidance in the ensuing years the Iowa Geological Survey became one of the best repositories of basic data in the upper Midwest. In his early years here he served as a lecturer in the University of Iowa Geology Department. He also held the position of District Geologist for the U. S. Geological Survey from the 1944 to 1955. Dr. Hershey has served on many important state and national committees on problems of flood control, water resources policy, water conservation, and water use, including the President's Advisory Committee on Water Resources Policy and the U. S. National Committee for the International Hydrological Decade. He was Chairman of the Iowa Natural Resources Council from 1949 to 1969. Dr. Hershey is a member and officer of many professional organizations. He has published a number of reports and maps on mineral resources, ground water, stratigraphy, and dam sites of Iowa.

MANAGEMENT OF IOWA'S WATER RESOURCES

H. Garland Hershey
Director, Office of Water Resources Research
U. S. Department of Interior

INTRODUCTION

Iowa has one of the most comprehensive mechanisms in the United States for the overall management of surface- and ground-water resources. The laws involving water management, particularly those enacted in recent years, were especially tailored to fit the State of Iowa after comprehensive studies had been made to identify the State needs. These laws are working very well, not only because they were soundly drawn, but because of the highly competent staffs chosen to administer them in the various departments.

Management of Iowa's water and water-related land resources is principally in the hands of five state departments and two federal agencies. They are the Iowa Natural Resources Council, the Iowa Water Pollution Control Commission, the State Department of Health, the State Conservation Commission, and the State Soil Conservation Committee, the Corps of Engineers, U. S. Department of the Army and the Soil Conservation Service, U. S. Department of Agriculture.

At lower levels of government in Iowa numerous entities are legally involved in water management to varying degrees. They include cities and towns; levee, drainage, and sanitary districts, soil conservation districts and others.

If we admit research, and the collection and synthesis of basic data as part of water management--and, of course, I think we must--then the Iowa State Water Resources Research Institute, the Iowa State University, the University of Iowa, the State Hygienic Laboratory, the U. S. Weather Bureau, the U. S. and Iowa Geological Surveys, and others also play significant roles.

How these governmental agencies function and the parts they play in the management of Iowa's waters are discussed by Bullard elsewhere in this volume. A rather full discussion of the laws involving them will soon appear in reports of the Type 1 studies of comprehensive long-range planning committees for the Missouri and Upper Mississippi River Basins. Therefore, no attempt will be made here to explore this area of our consideration except to point out that the major duties and responsibilities of coordinating the management of our waters on a statewide basis have been placed in the hands of the Iowa Natural Resources Council and the Iowa Water Pollution Control Commission while the other agencies play important but less extensive roles.

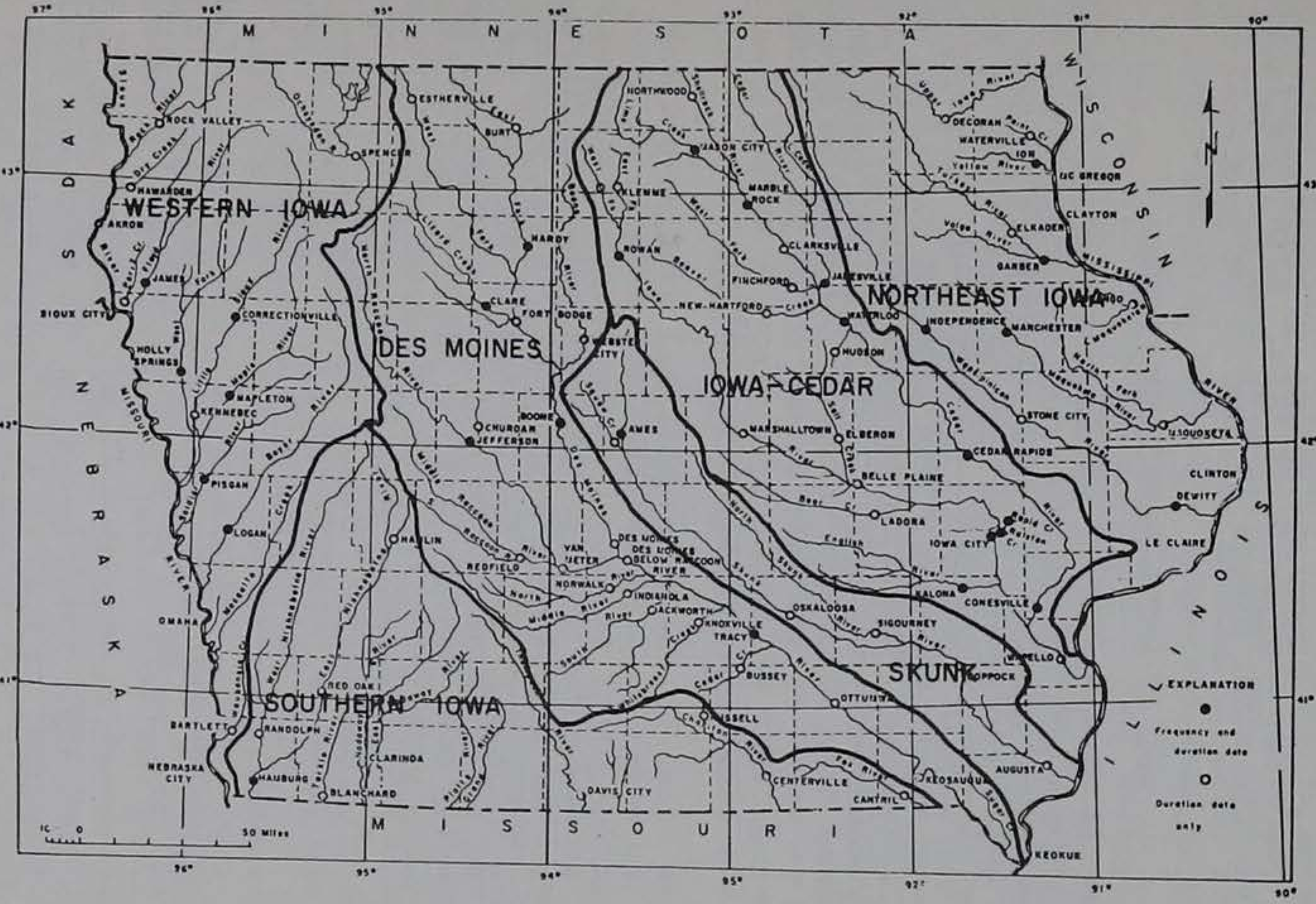
Although Iowa's laws and procedures for water management are reasonably adequate today, some problems remain. Improvements are offered by certain sections of companion bills (SF 17 and HF 17) now before the 63rd Iowa General Assembly. These bills would establish, prescribe the boundaries of, and provide for administration and support of six conservancy districts, which together would include the entire territory of the State of Iowa. In effect the conservancy districts are river basins or combinations of river basins in Iowa as shown on figure 1.

The districts are envisioned to coordinate the work of individual drainage and soil conservation districts, and to facilitate putting into effect the comprehensive statewide water resources plan being developed by the Iowa Natural Resources Council as prescribed by law.

The bills provide for and require full coordination and communication not only between the district boards and local agencies but between the boards and the Iowa Natural Resources Council as well. These are certainly among the most attractive and beneficial aspects of the proposed legislation. The study committee and drafters of the bills should be commended if only for their conception of the administrative framework that would coordinate and streamline water management from the grass roots to the highest state government levels. The concepts of the committee would solve numerous present problems and would vastly improve our present very loose coordination as well as provide a feasible mechanism for communication through the various levels of government.

At present Iowa has a sufficient supply of good water over most of the State. Not only is it plentiful now but it will be plentiful for many decades in the future--if managed properly. This does not mean, however, that there is an ample supply suitable for most uses in all areas of the state. In some areas the quantity is limited, in others the quality is poor, and in still others increases in present heavy pumping from wells will impose additional problems. Nevertheless, except perhaps in a few small areas, it now appears that adequate supplies of acceptable water are or can be made available throughout the state for the foreseeable future and on an economically feasible basis if sound management policies are followed.

It is not possible to include in such a short report as this must be, all of the aspects of water management when it is remembered that the subject includes coordinated management in the following major areas: Public water supply, pollution control, water-based recreation, soil conservation, and run-off retardation, drainage and levees, flood control, lake and river (meandered streams) conservation, channel changes, road bridges and grades, water impoundment structures



Prepared by Iowa Natural Resources Council

Figure 1. Map of proposed conservancy districts in Iowa

and buildings on the flood plains, heat exchange, drilling for oil and gas production and storage, and a variety of ground-water areas.

The aim of this report therefore is only to outline very briefly some of the recent advances, concepts, and problems of water resources management in Iowa. With this in mind, it meshes with the other papers in this volume.

WHY IS WATER MANAGEMENT NEEDED

Water is the most vital manageable resource upon which man depends for the maintenance and expansion of social organization. The failure of local governments to take cognizance of this fact in the more arid western lands of the Nation during time of population and water-use increase has required some costly remedies. The greatest practical benefit of sound management, based on adequate basic information, is the money that is saved in the long run. The question is often raised "Can we afford to spend the money we now spend and plan to spend in the near future on water resources?" The answer is that we cannot afford not to do so. The alternatives are almost invariably more costly.

It is vital to recognize that all available water is a part of the total supply, and that the effects of developing either surface water or ground water must be considered in relation to the total supply. This imposes some constraints, but it also has significant advantages. Water management is intimately associated with and dependent upon many factors. It requires a knowledge of the available sources of supply, their quantity and quality, and the alternatives of treatment of these supplies within the financial capabilities of the users. It is dependent upon parametric and stochastic forecasting of population, social and economic trends. Legal aspects are often of prime importance. "How much water is available for use?" often means "How much money is available for the treatment and to get the water from the source to the point of use?" Thus, dollars are a consideration and above all, total management of our water resources, if it is to be successful, must be based on solid hydrologic information.

Conservation management of water does not mean leaving things as they are. Water moves, on and below the surface. For most purposes, it must be intercepted and used--or lost. The problem boils down to how much can be used without upsetting the balance of supply and demand, and without infringing on the rights of others.

The use of water in the United States has been rising steadily for several decades as shown in figure 2. In the past 15 years the withdrawal of ground water alone has doubled as indicated in table 1. (Murray, 1968). There is every reason to believe that it will continue to grow in future decades -- in the cities and towns, in business and industry, and on the farms. Projections indicate that by the year 2000 an estimated 100 million people will join the present 200 million in the United States. By A.D. 2000 the quantity of water used in central Iowa will have increased 130 percent from 1960, (Twenter and Coble, 1965, p.15) although the population will have increased only 55 percent.

Although all of Iowa may not be in the average -- increase population class, we still must expect appreciable population increase here. At the same time we should expect additional industrial expansion (new industry) in Iowa along with an increase in production by present industry. More important, with a 50-percent increase in national population will come a commensurate increase in the demand for food and fiber, which may really be Iowa's place in the sun. Clearly, under these conditions, water will have to play an increasingly important role for irrigation alone if our food production is to be materially increased.

MANAGEMENT PROBLEM AREAS

Water Supply

As already suggested, ground water and surface water are so intimately related that for proper solution of the over-all problems of planned management, it is necessary to have all the facts regarding both sources. For example, consider a stream flowing in an alluvial valley and water being withdrawn from both the stream and the alluvium. During periods of high runoff when stream levels are high, the alluvial aquifers normally are recharged. Conversely, when stream levels drop, the ground-water discharge provides the base flow of the stream. From this it is obvious that withdrawal from either source can and does have an effect upon the other source.

It is vital in present-day long-range planning for development and management to be certain that the surface- and ground-water forecasts are evaluated with the "oneness" of water always in mind. Use of forecasts prepared without this fundamental concept can lead to serious repercussions, particularly during periods of drought or periods of maximum use from one or both sources.

Another example of ground-surface water relationships highlights other management possibilities and problems. It has been estimated that, on the average, approximately one-third to two-fifths of the streamflow in the United States is water that has come from ground-water reserves. The average daily discharge of Iowa's rivers and streams is 15,600 million

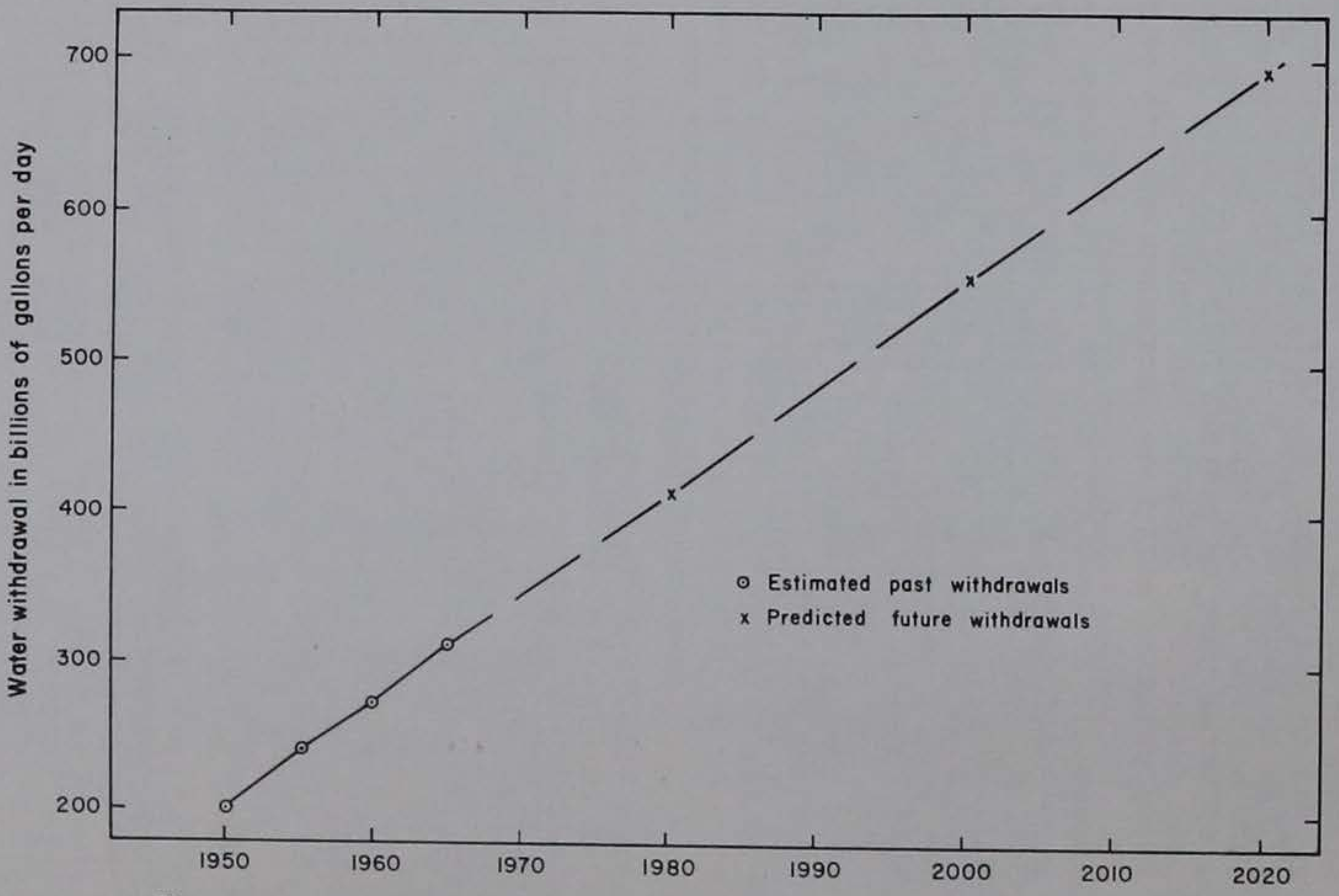


Figure 2. Water withdrawal in the United States, 1950–2020 (Adapted from Murray, 1968)

Table 1. — Water used in Iowa, 1965

(Partial figures may not add to totals because of independent rounding)

Use	Population served							Water delivered				Water consumed (mgd)
								Industrial and commercial uses			Domestic use and losses (mgd)	
	Ground water (thousands)	Surface water (thousands)	All water (thousands)	Ground water (mgd)[a]	Surface water (mgd)	All water (mgd)	Per capita (gpd)[b]	Air conditioning (mgd)	Except air conditioning (mgd)	All uses (mgd)		
Public supplies	1,470	402	1,870	150	47	200	104	1.2	56	57	140	19
Rural uses												
Domestic				41	.3	41						7.0 160
Livestock				130	20	150						150
Irrigation (87,000 acres)				47	26	73						73
Self-supplied industries												
Thermoelectric power					1,500[c]							21
Other uses				130	55	180						19
Hydroelectric power						95,000						
Summary[d]			2,758	500	1,600	2,100	770					290
United States			196,411	61,000	250,000	310,000	1,600					78,000

a Million gallons per day

b Gallons per day

c Mostly used for condenser cooling

d Does not include water withdrawn for hydroelectric power

(Adapted after Murray 1968)

gallons. If one-third of that amount is ground water, we are losing an average 5,200 million gallons a day from underground reserves. We would not want to and could not conserve all of this water, but some of it could be conserved and perhaps stream flow stability improved through better management.

It is ground water that keeps streams flowing in dry times, during many winter months, and augments stream flows except during flood or high precipitation and melt-water runoff periods. Why, then, should we not replenish our aquifers or even store water underground from the surplus available from surface-water floods? We can utilize our underground reservoirs in much the same manner as we do surface reservoirs, applying similar technological competence for planning and managing the underground facility.

Replenishment has been tried by various methods of spreading and by recharge wells and has been successful in some cases, but much more research and experimentation needs to be done to know how successful it might be on a large scale in Iowa. If areas along streams where recharge possibilities are favorable could be set aside to allow flood waters to cover them, a two-fold purpose might be served in shaving flood peaks and increasing aquifer recharge.

In Iowa, as throughout the nation, there is a growing tendency for large water users to concentrate in relatively constricted areas within or near cities and towns. This poses numerous problems in all phases of water management, especially potentiality of local over-pumpage of groundwater reserves. Obviously, decentralization would be a possibility for alleviating these problems. However, economics and total availability of water in the immediate area are the controlling factors at the present time and will continue to prevail until such time as the cost of water becomes prohibitive within any one water-use complex. Prudent over-all management can be an important factor in lessening the problems involved.

It may be necessary to set priorities for water use. However, it would not be feasible or desirable to set rigid state-wide priorities. Priorities for a city or town with large industrial and manufacturing development need to be different from a nonindustrialized municipality or a dominantly agricultural area. Within a single river basin all three of these situations may occur and acceptable management may require a complex system of priorities in time and space to protect low-flows in streams, overpumping from wells, and consequently to manage the total supply for the greatest common good and the most economic benefits.

As an example of the foregoing, consider cities and towns located along the Mississippi and Missouri Rivers and the major tributaries of these rivers. Water is available to the cities and industries on or near these rivers from multiple sources, i.e., (1) directly from the river (with added treatment cost), (2) from high yielding alluvial sands and gravels under the river flood-plains, and (3) from bedrock aquifers at intermediate or greater depth. In such instances the principle of conjunctive use can be applied.

In the past most of the municipalities as well as the industries along these rivers used the intermediate or deeper ground waters as a source of supply. Davenport and Council Bluffs are notable exceptions in that they have always used river water.

In 1956 the City of Dubuque changed from the available deep aquifer to Mississippi River alluvium, thus making more water at a shallower pumping level available for present and future industrial use within and near the city. Later when the deep wells again began to flow at the surface, the deeper water was used to prevent waste and was advantageously blended with the alluvial water in the treatment process. Water from the deep aquifer now comprises about 30 percent of the total supply.

At present Clinton is studying the possibilities of future development of the river or the alluvial supplies. If a change of source of municipal supply should materialize, present industrial users off the flood plain would benefit and the way would be opened for additional industries to develop closer to the city, because of the resulting rise of the piezometric surface of the deep bedrock aquifer in the surrounding area.

As a further step in modern management near the same city, a major industry, located on the flood plain and now using deep wells as its major source, is looking toward the alluvium as an alternate source of supply or to augment its present supply without additional draft on deeper aquifers.

All of the deep wells in the Clinton area do or will ultimately interfere with each other to an increasing degree as heavy pumping continues. On the other hand, the amount of water held in storage in the alluvial aquifer in this area is so great and recharge to it so frequent (if not continuous) that serious interference problems are not expected to occur in the shallow wells, even with relatively close spacing. Water taken directly or indirectly from the Mississippi River would have an insignificant effect on the regimen of the stream.

The objective of the foregoing practices is to manage the available total water supply in such a way that requirements of the municipal-industrial complex be met as efficiently as possible. As water problems become acute in localities of concentrated withdrawals, the principle of conjunctive use will become an important management tool.

A most interesting question--semantic at the moment--is involved in this area of management. Obviously it cost hundreds of thousands of dollars to change from a deep well to a shallow well or a river supply. Other deep well owners in the area are being materially benefited by such a move. The question is: Should the benefited well owners be requested or required to share the costs of the operation from the benefits that they receive?

What management problems do we face, however, when only one source of water supply is available? For surface waters within the State we think this problem has been largely solved by the Iowa Natural Resources Council policy of protecting low flows. A similar solution is not discernably available for ground waters primarily because the problems are more varied and complex and because we have less basic data on which to found satisfactory solutions. Basically the problem resolves itself into management of ground-water levels. When a well is pumped, the water level in the well is lowered. This causes the water table level in unconfined aquifers or the piezometric (pressure-indicating) surface in artesian aquifers surrounding the well also to decline. Thus, a cone of drawdown is formed as pumping continues and the diameter and depth of the cone increases with higher pumping rates and with time. Most commonly the area of the drawdown cone spreads beyond the property lines of the well owner. If adjacent property owners have no wells in the same aquifer, no apparent damage is done, and perhaps, this phase of the problem needs no futher consideration. However, if contiguous or other nearby property owners have one or more wells tapping the same aquifer, serious interference problems may occur when the cones of drawdown intersect. The resultant cone of depression or the drawdown at any point in the area is the algebraic sum of the several cones of depression. Furthermore, if a new well is installed by another property owner within the radius of influence of the pumping wells, he, too, is effected to a greater or lesser degree. Usually this means lifting water from a considerably greater depth which may require larger pumps and certainly higher pumping costs.

In areas of heavy ground-water withdrawal, particularly industrialized cities and towns, the area affected by the total cone of depression commonly is not small. In Mason City after more than 30 years of pumping, the appreciable cone of drawdown (more than one foot) in 1942 had a 20-mile radius from the apex of pumping. This is estimated to mean a drawdown of 83 feet one-half mile from the pumping center, 63 feet at one mile, 53 feet at two miles, and 42 feet at three miles. Effective drawdown at the apex of the cone has increased at an average rate of about four feet a year since 1942 (i.e., a total of more than 100 feet) and the cone of drawdown has increased commensurately in radius and depth (Hershey, Wahl, and Steinhilber, 1969). This phenomen is known to exist to varying degrees in numerous other cities and towns in Iowa using ground water as a source of supply. Unless pumping is reduced, water levels in these areas will continue to decline indefinitely although theoretically at a decreasing rate. If the municipalities increase in population, expand industrially and utilize the principal aquifer to meet the resulting increased demand, the water levels will drop more rapidly.

Some may ask--Is this bad? At Mason City the principal aquifer (Jordan Sandstone) is more than 900 feet below present pumping levels and theoretically pumping levels could be lowered to the top of the aquifer. Unfortunately, we do not know the hydraulics well enough to evaluate what will happen to the flow pattern and the loosely consolidated formations with high water velocities and high pressures that will result from such severe pumping regimens.

How can we manage to resolve these compound and complex problems when they arise and make more water available for beneficial use and at lower cost? Proper well spacing has been widely practiced and controlled or staggered pumping schedules can help prevent excessive drawdown of ground-water levels or heads. Numerous other suggestions have been made including decentralization (already mentioned), compacts among the users, a modified form of unitization (as practiced by the oil industry), area authority, districtization on a water use basis, and finally recharge under rigid controls. Several of these are similar, none is fully satisfactory. It is a vexing problem, but solutions are being sought and ultimately will be found--hopefully through research with more basic data.

Flood Insurance and Flood Damage Reimbursement

Flood insurance is now obtainable under the law, but it is too early to evaluate the feasibility of this controversial mechanism. Flood insurance, like other state and federal reimbursement in any form for flood damages, is not truly a management function. In fact it mitigates against flood-plain management except in a relatively few instances, e.g., manufacturers who must be contiguous to water transportation, sewage disposal plants, flood control works, and the like.

Flood-Plain Management and Flood-Plain Zoning

One of the most interesting and, perhaps, one of the most important advancements in water management in Iowa in the past few years is the increasing public knowledge and acceptance of flood-plain management and flood-plain zoning. Iowa has shown strong leadership in this advance in planned management. Iowa City already has a flood-plain zoning ordinance in force which was arrived at after study and cooperation with the Iowa Natural Resources Council, the Corps of Engineers and others. Several other cities, notably Davenport and Cedar Rapids, are nearing completion of final plans for a flood-plain zoning ordinance on Duck Creek and Prairie Creek respectively. Numerous other cities and towns are in various stages of preparing formal flood-plain management facilities. A few counties have shown an interest in the possibilities of county-wide flood-plain zoning.

In Iowa the aim of flood-plain zoning is to give the local governing body adequate control of the valley in order to prevent undue encroachment on the channel, but at the same time to permit land owners to make reasonable use of their river-bottom lands. The benefits are numerous. One major benefit, for example, is that land owners and developers are deterred from placing structures on or in the floodway that will suffer damage or be destroyed by floods.

Flood-plain zoning procedures in Iowa are following a uniform general plan but each project has different characteristics that must be given special treatment. A full discussion cannot be given here, but a very brief commentary follows:

> After rigorous study, a decision is made on what size flood is to be protected against, i.e., the design flood. (For Iowa City, a river flow having a 2-percent chance of occurrence in any one year was adopted as a reasonable figure upon which to base land use and channel capacity.) After this decision has been reached, the Natural Resources Council prepares a flood-plain map showing the limits required to convey the design flood. This zone may not be encroached upon by filling with any material or by building any structure that would cause an obstruction to the conveyance of the design flood. Only open-space uses are permitted, e.g., truck gardens, parks, golf courses and the like. The flood-plain map, with topographic contours also shows the location of an "inundation limit" or zone outside the "conveyance or encroachment zone." Within the inundation limit, structures are permitted, but no floors or basements may be lower than the water level of the design flood. Thus

the land in this zone may be put to any use permitted in the adjacent zoning district provided the land is filled to the level of the inundation limit. (For more detail see Howe, 1963 and Cooper, 1968.)

Disposal of Wastes

Waste disposal is a major water management problem. The Federal Water Pollution Control Act literally demands cleaning up our streams. Almost automatically this makes underground disposal of wastes look inviting and there will be increased pressures to attempt to take this alternative. Some authorities are recommending and accomplishing the disposal of wastes underground through wells.

This is short-sighted thinking for Iowa, where 90 percent of our people rely on ground waters for their source of domestic supply; and where business, industry, and agriculture also rely heavily upon underground sources for usable water. Neither should our aquifers containing mineralized water be hastily considered for disposal sites.

Demineralization of water is becoming progressively less expensive. A new breakthrough or a cheaper source of power could suddenly place large supplies from presently unusable sources of ground water within our grasp. Why, then, permit increasing pollution hazards through disposal wells?

However, it should be noted that demineralization also poses additional disposal problems. At the present time for each gallon of desalted water produced, we have a gallon of more highly mineralized water that must be disposed of in some manner. Although this ratio most likely will be improved, the disposal problem will be more difficult because of the more concentrated nature of the waste product.

In summary on underground waste disposal, the present Iowa law and official policy virtually prohibits introducing deleterious materials into wells for waste disposal. The law and policy are working very well and it is recommended that they not be tampered with.

Return Wells

A tempting solution to another vexing problem in water management is that of returning used ground water to the original or to another aquifer. Obviously this would materially help sustain higher ground-water levels, help eliminate present disposal problems and have still other advantages. However, returning water underground is fraught with hazards that threaten underground reserves. Some of these are obvious--other are less so.

It has already been stressed that polluted materials should not be permitted to be disposed of underground. In addition, some ground waters pumped to the surface undergo rapid chemical changes that--in Iowa--make them undesirable to return underground.

Unescapable, however, is the fact that large volumes of ground water are used for cooling alone, much of which is retained in a closed system but after use is then discharged--ultimately to a nearby stream. At first glance it appears that it is a shameful waste not to return this water to its original source. However, there are disadvantages that could or would result.

One of the most important of these is that the temperature of the water is raised and if returned nearby, would increase the ground-water temperature and reduce the efficiency of the cooling operation. This might be offset by removing and using the heat from the water during the cold months of the year. Moreover, the possibility of leaks, breaks in the system, well deterioration and other incidents that could result in aquifer contamination must be recognized.

Until now the Iowa policy has been in opposition to return wells except under very special circumstances. This policy should be examined periodically, and perhaps additional carefully controlled experimental work done, particularly in areas of heavy ground-water use.

It is recommended that the management of return-well programs he made the responsibility of the local governmental entity with periodic checks by state officials. This method of operation would reduce the chances of widespread contamination in the aquifer if the return-well system should break down.

Discharging ground water used for cooling to waste is only part of the story. Most of the ground water used by municipalities and industry is not consumed and it, too, is discharged to the streams. In most cases treated effluent is beneficial to the receiving stream, particularly during low fl periods. In fact, the discharged water in some instances has periodically comprised almost the only flow in the stream during long dry periods. Obviously there is opportunity to manage suitable effluents so that they can be utilized to better advantage. It has already been suggested that they be re-used directly for irrigation or for surface spreading to recharge shallow sand and gravel aquifers.

Furthermore, under mutually acceptable contractual agreements, discharged cooling water from one industry might be used by another that does not require a low temperature water for its purposes. It is even conceivable, under rigid control of course, that industrial cooling effluents could be discharg into a municipal supply prior to treatment. This could also apply to ground water used for heating, a mechanism not yet utilized in Iowa, but practiced elsewhere. In any event, increased demand for water, particularly in industry-congested municipal areas will require more attention by management for better and more reuse of available water supplies. There are a host of potentials available.

GROUND WATER MANAGEMENT REQUIREMENTS

The pressures that have been intensifying in recent years to plan for water development, use, and management have been heavily directed toward surface water. Ground water has not been neglected, but requirements regarding it have not been as complete or as voluminous as for surface water nor are required data as obviously or easily gathered. However, the day is not far off when more detailed attention will be given to ground water, and pressures will be applied to all of those in the water resources endeavor for more intensive efforts. Some near-future requirements relating to ground-water management but involving other disciplines as well, seem apparent.

In certain areas more test drilling is needed, not only in relation to our shallow aquifers but in connection with our deeper ones as well. Such test drilling should not follow the common test drilling programs of the past where: 1. no location maps were made, 2. no land-surface elevations determined and 3. only the barest of essentials on the water-yielding potential of the tested areas were preserved.

Many pumping tests yield only a small portion of the total information that could be obtained with minor changes in procedure. The latest and most sophisticated formulas require that certain procedural specifications be met. Adherence to these specifications usually does not cost more money; primarily it is a matter of planning that can pay big dividends.

Regarding water quality, more numerous chemical analyses should be made than we are now making, not only from newly developed sources but especially to monitor quality changes in established supplies. Analyses for monitoring need not always require that all elements be determined. One or two constituents could be sufficient to determine if there is any change in the mineral content.

From present trends, particularly in the pollution field, it appears that there will soon be a demand for better located and more ruggedly constructed wells to withstand better the pressure, corrosion, and other forces which tend to cause wells to fail. These wells will be as fully developed and as fully stimulated as the cost-to-benefit ratio will allow, with the most economical operation and production that is possible This will apply to both alluvial and rock wells, whether they be municipal, industrial, agricultural or private. A badly located, poorly constructed, leaky, or polluted private well can be just as dangerous as a municipal or industrial well in the same condition.

It appears that the time is near to require that at least some wells be plugged when they are abandoned or essentially useless, or when it can be clearly demonstrated that they are in such condition that they are hazardous to other wells or to one or more important aquifers. Particular targets in this regard are the deeper wells that penetrate severa water-bearing zones, at least one of which contributes highly contaminated, or highly mineralized water to the well, or is "taking" water from the major aquifer involved, because of different hydrostatic heads.

At the present time Iowa has a good program for collecting and processing ground-water data for general use. However, except for a few localities in the state we have only the very roughest approximation of how much ground water is available for use and how much we are pumping. For good management, more precise data are necessary. If management must wait to gather the required basic data until it is needed it will be too late. The time to collect and process ground-water data for a wide variety of uses is now.

To get more precise estimates of proved ground-water reserves and withdrawals may require continuous water level and pumpage figures on high-production municipal, industrial and agricultural wells. Better instrumentation and methods need to be devised to accomplish this in the most feasible manner.

SUMMARY

Iowa has plenty of good water. Not only is it plentiful now but it will be plentiful for many decades in the future if properly managed. The facilities for managing this vital resource are largely at hand through laws, policies and procedures now operable; and in Iowa, unlike most other states, they apply to both surface and ground waters. And it is recognized that all of the water available (i.e., surface and underground) must be considered in prudent management of the total supply.

Flood-plain zoning is permissible in Iowa and acceptance of it is growing. The aim is to give the local governing body adequate control of the stream valley to prevent undue encroachment on the floodway, but at the same time to permit landowners to make reasonable use of their river-bottom lands while protecting them from losses.

Disposal of wastes underground is prohibited and at present it is the policy of the state to discourage any waters to be diverted underground. The primary reason for this is that about 90 percent of the people of the state rely on ground water as their source of domestic supply.

Priority of use has not been set in Iowa except that private-domestic and a few other uses are not regulated. In areas where large water users concentrate in restricted areas, protected low flows are established for streams on a formula basis. Where more than one water source is available (surface or underground) there is a growing tendency to look to the principle of conjunctive use for economic and other reasons. Where the only source of supply is a single aquifer, the problem is more difficult and requires special management practices.

Water management coordination and communication is very good at state department level. This does not extend downward to the same degree through local levels to the "grass roots." Attention needs to be given to better communication and better coordination throughout all levels of water management in the State.

In the past, management requirements for ground water have not been as sophisticated or voluminous as for surface water. Soon more detailed attention must be given to ground water. Some of the near future requirements relating to ground-water management but involving other disciplines as well include:

1. More test drilling in certain areas for stratigraphic purposes.
2. Pumping tests to determine the quantities of water available from specific aquifers.
3. Chemical analysis especially to monitor changes in established supplies which could identify leakage, pollution, and other deleterious results of well deterioration.
4. Better located and more ruggedly constructed wells to withstand better the possibilities of contamination and the pressures, corrosion and other forces which cause wells to fail.
5. Plugging abandoned wells, particularly deeper multi-aquifer wells in which at least one aquifer contributes poor quality water to the well or "takes" water from the principal aquifer.
6. More precise estimates of proved ground-water reserves.

Iowa has one of the most comprehensive mechanisms for the management of her surface and ground waters in the Unitec States. The shortcomings of the management system are known. They are minor and can be eliminated by proper planning and the continuance of the support that the administrative and legislative arms of state government have given this vital water resources program in the past.

Water is our most valuable manageable natural resource. Unguided management commonly leads to errors that require very costly remedial measures. But management founded upon research and systematic basic data collection and interpretation invariably saves dollars and makes more and better water available to the user.

REFERENCES CITED

Cooper, J. F. The Iowa flood plain management program. In Dougal, M. D., Flood plain management, Iowa's experience: Iowa State University Press, p. 219-232, 1969.

Hershey, H. G., K. D. Wahl and W. L. Steinhilber. Geology and ground-water resources of Cerro Gordo County, Iowa: Iowa Geol. Survey, Water-Supply Bull. 10, (in press 1970).

Howe, J. W. Modern flood plain zoning ordinance adopted by Iowa City: Civil Engineering, p. 38-39, April 1963.

Murray, C. R. Estimated use of water in the United States, 1965: U.S. Geol. Survey Circ. 556, 53 p., 1968.

Twenter, F. R. and R. W. Coble. The water story in central Iowa: Iowa Geol. Survey, Water Atlas 1, 89 p., 1965.

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SOME ECONOMIC CONSIDERATIONS IN PLANNING FOR IOWA'S FUTURE NEEDS FOR WATER

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Until recent years, Iowa's growth and development has been limited more by excesses of water than by deficits. With relatively few exceptions, water has been regarded as abundantly plentiful for beneficial uses in the "Ricardian" sense of a free gift of nature. In past decades, Iowa has been concerned with planning of water from a disposal point of view, since planning of beneficial uses of a plentiful resource is redundant and even superfluous.

Presently, however, Iowa is in a transitional stage of water use and development wherein water deficits for beneficial purposes are sharing responsibilities for the State's growth and development along with the earlier concerns of excesses of water with their adverse consequences. During this transitional stage, as is usually the case, our institutions, uses and even concerns relating to water, lag behind adjustments required for meeting Iowa's future needs for water. With the increasing demands for water as an essential ingredient of the states growth and development, attention and effort must necessarily shift to the planning of water as a scarce rather than an abundant surplus resource.

The need for water resources planning for beneficial uses is becoming increasingly obvious. Future needs for water in a growing and developing Iowa economy, will expand the demand for water around 5 percent per year through 1980, with even greater increases in prospect beyond 1980.

As water becomes more scarce in meeting the expanding needs of industry, agriculture and services, the science of economics has an increasingly important role to play in water resources planning. Since economics is primarily concerned with decision making processes in allocating scarce means for achieving competing ends in a manner that will maximize net benefits for the decision maker and his clientele, water, being scarce and its use claims being competitive, comes within the purview of economic analysis. I should hasten to add, however, that the usefulness of economic analysis in planning the use, allocation and development of water in meeting Iowa's future water needs is limited by the physical and technological data available to the economist. Economic analyses will yield results no better than the physical and technological coefficients with which the economist works and the results can be even less useful unless the economist adapts his theories, models and tools of analysis to the unique and complicated problems associated with water use.

This means that economics must become a member of the team alongside geology, climatology, hydrology, soils, engineering and other disciplines in identifying and evaluating alternative courses of action with the associated consequences in the planning process. This means a multidisciplinary approach to the understanding and solution of Iowa's future water problems.

The purpose of this paper is to explore with you some of the major economic considerations which appear essential in the planning process for meeting Iowa's future water needs.

In pursuing this purpose, I address my remarks to three major questions. First, how can Iowa gain access to sufficient water supplies to meet its growing needs in the years ahead? Second, how may water be allocated among competing uses and users in a manner that will facilitate rather than obstruct a growing economy within the state in the years ahead? Third, how may these development, allocation and use processes be managed through decision making and decision implementation?

My remarks in formulating possible answers to those questions are organized under the following headings: (1) Projecting demands and supplies of waters, (2) Allocating water among competing uses, and (3) Organizing water use and development management entities.

Throughout this paper, planning is considered an intermediate but conjoint step between research and action. Research is necessary to yield data and ideas for planning. And planning in using these data and ideas is basic to action in ameliorating the state's water problems.

Projecting Demands and Supplies of Water

In the planning process, efforts will necessarily be directed to approximating demands and supplies of water in the years ahead. Such approximations are necessary in providing essential elements of a normative and predictive framework of analysis. However, these approximations are not to be considered as aggregates but as segmented differentiated supply and demand approximations derived from relevant estimators. Included in the differentiations are: (1) qualities linked with demands by amounts and qualities linked with supplies by amounts, (2) spatial occurrences of quality-linked supplies and of quality-linked demands and (3) temporal occurrences of quality-linked supplies and quality-linked demands.[1]

Both the quality of available water supplies and quality of water demanded by particular uses are extremely varied. As the state and nation move toward quality control legislation and administration, quality-oriented research is sorely needed to help guide these actions. It appears that control legislation is moving further and faster than is supported by available facts. But this is part of the cost of the research establishment not performing timely and relevant studies.

There are two fundamental characteristics of the supply of the demand for water insofar as quality is concerned. These are 1) quality heterogeneity of water supplies, and 2) quality differentiation of demand according to uses.

There remains a tendency to consider water a homogeneous commodity or factor as the case may be. However, it is becoming increasingly obvious that water is extremely heterogeneous and it (in its supply and in its demand) is highly differentiated in quality as well as spatially and temporarily. In fact, it may be useful to think of numerous water commodities and many water factors. Besides quality determinants, there are both spatial and temporal differentiating determinants in addition to structure rigidities mentioned earlier.

In referring to demand, further differentiation is required in terms of direct and derived components of demands. This differentiation becomes important in systems analysis involving regional accounts as well as in those allocations which must be made through ordinal rather than cardinal oriented criteria. Thus, not only must we solve the complex problem of determining the technical coefficients for water used as an input, but also the even more difficult one of specifying the demand for water as a "final product," with all of the difficulties inherent in specifying the ordinally ordered and non-economic parameters.

Quality Heterogeneity of Water Supplies

A particular supply unit of water may be hard or soft, warm or cool, colored or clear, or it may vary in many other ways. The common chemical formula for water, H_2O has tended to impute a homogeneity to water which actually does not exist. During recent decades the structure of water has been

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1/ For further discussion of these differentiations see Ackerman and Lot, 1959.

complicated by the discovery of three isotopes for both hydrogen and oxygen which results in mixtures of thirty-three different substances. Thus, water is not a simple single compound but is extremely complicated.

Water has many unusual properties which vary among existing supplies and condition its use. Water occurs in three distinct forms, solid, liquid, and gas. While most substances contract when frozen, water expands. In addition, water has a very high heat capacity and surface tension. It easily dissolves many compounds which thereafter remain in solution, thus earning for water the title, "universal solvent." Water quality varies tremendously through impurities which are introduced by natural as well as man-made forces. Thus, various water sources possess different qualitites that must be appraised in terms of the use to which a particular source of water is to be put.

Quality Differention of Demand for Water2/

A supply of water with a particular quality may serve a number of purposes unequally well. Different uses demand different properties in water or at least vary in their toleration of particular properties. For example, living cells may require the presence of certain minerals in water, whereas battery cells will not tolerate minerals. Quality of water must necessarily be associated with a particular use. Different qualities are required (or tolerated) for human consumption, navigation, power, irrigation, food processing, manufacturing, air conditioning, recreation, and fish and wildlife propagation. Even within each of these major categories specialized demands require different water qualities. Within the recreational use, swimming, fishing, and boating possess quality differentiations. Within manufacturing, beer, aluminum, paper, and synthetic fiber production possess important quality differentiations.

Thus, the "quality mix" of a particular water supply must be appraised in terms of the uses to which it is put. Water quality suited for one use may be absolutely unsuited for another use. For instance, navigation purportedly can tolerate the lowest quality mix, requiring basically only a little water surface and adequate depth. It appears that there is little, if any, relevancy for an universal quality standard. On the other hand, quality standards must be

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2/ For discussion of a theoretical framework for handling conflicts between demands for water of different qualities, see Timmons and Dougal, 1967.

developed in relation to the specific uses to be made of particular water supplies in the process of satisfying human wants.[3]

Recent water use projections for Iowa suggest that the gross use of water may be expected to increase 4.1 percent.

Allocation and/or Development

Recent concern with water has emphasized development of additional supplies rather than reallocation of present supplies. As stated in the Rand Corporation Research Study: "Essentially all the limited analytical attention devoted in the past by other authors to the technology and economics of water supply has been directed to the question of when and how to develop additional water supplies and not to the question of whether existing supplies are being well utilized. Perhaps this has been due to the romantic appeal of solutions to water problems through construction of great dams and aqueducts as compared with the undramatic nature of solutions through better utilization on reallocation of existing supplies." (Hirshleifer, DeHaven, Milliman, 1960, p. 4).

The North American Water and Power Alliance (NAWAPA), and Missouri River Diversion Canal Proposals, aside from the proliferous smaller projects such as the Central Arizona Project (CAP), carrying price tags running into hundreds of billions of dollars and time lags running between one-third and one-half centuries, are illustrative of the water development insanities visited upon the nation.

The rapidity of technological change including potential desalinization, cloud seeding, and chemical synthesis, provides sufficient uncertainties and perhaps probabilities of these long term projects being rendered obsolete and useless before they even reach completion.

It appears that the major problems rest with allocation of existing regional supplies rather than in development of additional supplies. For example, one recent study in Arizona reveals that seven sectors of the state's economy, which rank from first to seventh, inclusive, in amount of personal income generated per acre-foot of water, were allocated only ten percent of the state's water supply. On the other hand, sectors ranking eighth to tenth, inclusive, were allocated 90 percent of the state's water. (Young and Martin, 1967, p. 12).

3/ See Timmons, 1967.

Unless and until means are found and developed for a more efficient allocation of existing supplies, we cannot determine the needs or requirements for additional supplies. Furthermore, unless remedied, current built-in allocation inefficiencies most likely will be extended and perhaps frozen into additional supplies as they are developed.

Allocating Water Among Competing Uses

Current allocative devices such as permits and the appropriation and riparian doctrines if taken as "givens" severely restrict analysis of water allocation within the framework of supply and demand. Efforts must be made in research and planning, to use these allocative devices as dependent variables in the allocation process. In fact, current allocative devices, as determined through water rights, tend to make water a free resource within the limits of supply with resulting diseconomies of use 1) between uses, 2) in intensity of a particular use, and 3) through externalities. For example, under the Iowa Water Allocation Law, the payment of a $15.00 fee provides an individual (firm, municipality) with as much water as is needed for a "beneficial" use. (Code of Iowa, 1966). It seems reasonable to interpret the statute as meaning any use is beneficial as long as the marginal productivity of the water is non-negative. The resulting "uneconomic" uses are not difficult to imagine.

In bringing together the demands and supplies as differentiated by quality, time and space in the approximations, we are confronted with the problem of allocation if there is not in prospect sufficient supply of water of a specific differentiation to satisfy the demand of such a differentiation.

In this case, planning is concerned with the problem common to economics of allocating a scarce resource among competing ends. Such planning may pursue two major alternatives or combinations thereof. These two alternatives are: (1) expanding and creating market mechanisms for water pricing; and (2) institutional pricing through synthesizing market prices and costs as weights assignable to the several competing uses.

Expanding and Creating Market Mechanisms for Pricing

One alternative of allocation is to create market mechanisms wherein water is priced as a product or as a factor. Subject to restraints of spatial and temporal occurrence, water could be metered and sold by private, government, or quasi government entities on a F.O.D. or F.O.B. basis. In this manner, when a particular differentiated supply became scarce, price would ration the supply among the highest valued uses, or call forth an increased supply as motivated by price or a combination of the two.

This alternative would necessarily invalidate current existing claims to water, established through the various rights systems. This alternative has been discussed widely in the literature but very little research has been devoted to its elaboration and implementation. Professor Gaffney's ideas on this matter are certainly relevant and helpful. (Gaffney, 1962).

Institutional Rationing

Another alternative for allocating a scarce water supply component among competing uses would be through institutional rationing. However, such rationing must be based upon criteria other than mere rights of use as is presently the case, if we are interested in getting water into uses with the highest value product. Here again, there are means whereby this object may be accomplished. As reasoned by Professors Young and Martin: "...It is presumed that signals offered by the price system should have relevance in allocation of water in Arizona." (Young and Martin, 1967, p. 9).

As an economic basis for institutional rationing of water whereby water is not put through market mechanisms and priced, there are two major approaches for assigning relative values to water in consideration of differentiated supplies and demands. These are value productivities and opportunity costing.

Value Productivity

In the value productivity approach, water would be priced through a synthetic market of shadow prices (defined by opportunity costs used in lieu of money prices) indicative of imputed values of water in alternative uses through input-output analysis. Alternatively, water could be allocated on the basis of relative contributions by uses to state, products or incomes through sector accounting processes. Table 2, taken from the Young and Martin Arizona study, reveals that the manufacturing sector ranked first in terms of personal income generated per acre-foot of water with a $82,301 payoff.

However, over 90 percent of the water was allocated to the agricultural sector with payoffs only in the $14 to $80 range which was less than one thousandth the payoff of water used in the manufacturing sector.

Table 2. Personal Income Per Acre-Foot of Water Intake in Arizona Sectors and Rank of Each, 1958.[a]

Percent of Arizona Water Consumed	Sector	Dollars of Personal Income Per Acre-Foot[b]	Sector Rank[c]
90%	Food and Feed Grains	14 ($3)[d]	10
	Forage Crops	18 ($1)[d]	9
	High Value Intensive Crops	80 ($13)[d]	8
10%	Primary Metals	1,685	7
	Livestock and Poultry	1,953	6
	Utilities	2,886	5
	Mining	3,248	4
	Agricultural Processing Industries	15,332	3
	Trade Transportation and Series	60,761	2
	Manufacturing	82,301	1

[a] Source: Young & Martin, 1967.

[b] Personal income is defined to include wages and salaries, rents, profits, and interest.

[c] Ranked from highest (1) to lowest (10) value added.

[d] Additional personal income generated indirectly from inputs purchased from other sectors.

Interpreting the results of this analysis, the authors conclude that, "...if, the problem is to obtain maximum economic growth for the state, this water must generate benefits in excess of costs of transporting and distributing it. Since this is not the case reallocation of available water becomes the preferred solution." (Young and Martin, 1967, p. 18).

Opportunity Costs Estimated from Shadow Pricing

Another approach which is complementary to the value productivity and income generated ideas briefed above, is based upon opportunity costing analysis wherein the cost is suggested in the form of shadow prices estimated from relinquished or diminished options.

Four components of opportunity costing analysis are considered here. They are a) relinquished use options, b) diminished use options, c) relinquished supply-source options, and d) relinquished supply treatment options. The first two components are very similar to the case cited by Professor Gaffney wherein each wild duck taken in Ventura County California used $560 worth of water valued in terms of lima bean production sacrificed by water used in the duck club. (Gaffney, 1962, p.200-02).

Relinquished use options. The price of a particular use may be imputed from the cost of the use option(s) relinquished in the achievement of the particular use. For example, the denial or forced cessation of use of water from a stream by an industrial plant results in an annual loss of $100,000 worth of product as the plant goes out of business in order to protect the annual production of 25,000 trout annually. In this example the production of trout becomes the use allocated. Even though the price of trout may be difficult to determine in the market, the price may be estimated from the cost of the relinquished use forced out in the allocation process. In this instance, the trout would have an imputed price of $4 each.

Diminished use options. Continuing with the same example, let us assume that the 25,000 trout could be produced annually with a reduction in product by the industrial plant of $50,000 annually. In this case the use diminished amounting to $50,000 would impute a price to the trout of $2 each.

Relinquished supply source options. Continuing with the same example, let us assume that the industrial plant could either obtain its water from another source or could release its effluent in another manner. Let us further assume that this alternative source of water or effluent disposal would cost the plant $50,000 more than the cost of the use of the trout stream. In this case, the relinquishment of the stream by the plant in order for the 25,000 trout to be produced would yield an imputed price to the trout of $2 each.

Relinquished supply treatment options. Let us assume further that the industrial plant could treat its effluent in a manner that would not affect adversely trout production in the stream for a cost of $25,000 but the plant would remain in business with a net product value of $75,000 rather than $100,000. In this instance the price imputed to the trout would be $1 each.

Through these suggestions, it would appear there are numerous criteria and tools whereby the allocation of water may be evaluated. Also, it is obvious that present legal systems of water allocation do not discern between use values and within use levels of application. Consequently, water becomes a free resource to the extent of its availability as determined by existing water rights with no incentive to economize.

Organizing Water Use and Development Management Entities

In bringing together within a planning unit the several differentiated supply and demand components, in the interest of optimizing all uses from a scarce water supply, we become concerned with decision making units which we shall term "management entities." River Basins or Water Resource Regions have been delimited in an effort to approximate such water use entities. The North Central Region of the United States is made up of all or parts of seven Water Resource Regions for purposes of comprehensive planning by the Water Resources Council which was established by Congress in 1965. (Water Resources Planning Act: U. S. Statutes at large 79, chapter 244, 1965). These regions are much too large and heterogeneous to provide the supply-demand use entities required for allocative purposes even though useful at a particular level of aggregation.

Proposals were presented to the Sixty-third Iowa General Assembly which would form six Conservancy Districts within Iowa.

Several determinants appear important in identifying water use entities for purposes of economic analyses. Included among these determinants are space, time, quality, technology, source, benefits, costs and incidence.

Spatial determinants are important wherein water problems are modified, intensified, or relaxed, depending upon the movement and congregation of people and industry. California is a classical example, as well as the Pacific Southwest.

Temporal determinants appear to be important insofar as flow probabilities, frequencies, and risk are concerned.

Quality determinants need to be considered in regards to actual industrial sensitivity and response to quality mix of water. Food and beverage processing industries for packaged products may be the most sensitive, as well as drinking water, but many large users of water may be quite insensitive to the quality mix. So what percent of water use is in the latter category? Certainly recreation, fish and wildlife uses are affected, but what about the high income producers?

Technological determinants offer the most hope for continuing to be able to solve water problems. Pricing systems will affect the amount of emphasis to be placed on technology and water saving research. Consequently a feed-back exists from political process in regard to this determinant.

Source determinants are also reflected to some extent in spatial determinants. However, in the case of ground water versus surface water and use and re-use (versus new supplies), we have unique source variables.

Costs, benefits, and incidences are determinants, and as outlined by Boulding, there is a strong social case for making water expensive to accomplish improvement in technology, and to make water "dear," even by taxing it if necessary. (Boulding, 1964, p.91).

Following the identification of supply-demand management entities based upon the criteria of determinants as outlined above, we become concerned with optimizing water use including internalizing the externalities.

In the use of water by private or by public firms external diseconomies frequently arise among competing uses whereby part of the costs of use are shifted to other firms (independent economic units) in a spatial or temporal incidence. Through this process dissociation problems arise whereby certain water costs of one use are transferred to other water uses. Therein subsequent water uses are made more expensive or thereby other uses are foreclosed entirely. For example, the effluent discharged by a private or public firm, such as a municipality or a dairy product processing plant respectively, would change the quality of the water to the extent that fishing or swimming downstream would be prohibited or decreased.

Dr. Allen Kneese has concluded that "a society that allows waste dischargers to neglect the offsite costs of waste disposal will not only devote too few resources to the treatment of waste but will also produce too much waste in view of the damage it causes." (Kneese, 1964, p.43).

This type of dissociation may be interspatial or intertemporal in the sense that the costs are transferred either to other geographical areas or to future points in time.

On the other hand, benefits may be shifted or externalized from costs incurred by water users in making investments which yield a water quality also required by other uses. If the investor in water quality cannot capture the benefits required to provide the incentive to make the investment, he may be compensated by users who receive the benefit. Presumably, a surplus of benefits would be created which would constitute a base for compensation. Or users could be organized into investment groups who would share the costs in relation to benefits received from the water quality investments. The formation of a water quality district would be an application of this concept.

Consider another example of this type of dissociation as it relates to quantities of water. A large municipality constructs a reservoir for water supply. Its use is largely nonconsumptive. Assume that an efficient waste treatment plant in the city discharges a high quality effluent into the downstream channel. If irrigators or other water users make subsequent beneficial use of that water in the downstream channel, without compensation, the municipality has failed to capture all of the benefits of its investment. This situation has occurred in Iowa below the Coralville Reservoir in the case of irrigation and potentially could occur in other situations in the State. It points out inadequacies of the present Iowa water allocation system.

The level or size of the multidimensional objective function must be determined as well as the division of welfare and the means for dividing the welfare. Thus, the size of the income pie, the size of the pieces distributed and nature of the instrument for cutting the pieces are all important facets of the process. As stated by Professors Young and Martin: "We advocate choices which would maximize the aggregate income of the state's population. In addition, we require that no one segment of the population should gain an unfair advantage over any other segment in the distribution of income gains. We are concerned with the size of the "income pie" attributed to each alternative water policy and the division of this pie. (Young and Martin, 1967, p.9).

Various levels of firms could be formed within or from management entities corresponding to the incidences of allocation decisions to be made. Decisions made at lower or smaller aggregations must necessarily be consistent with decisions (but not necessarily the same kind of decisions) made at higher or larger aggregations of determinants discussed earlier.[4/]

[4/] For a more extensive discussion of the types of local or regional public districts, and the needs for consolidation of activities and functions in one water resource management firm, see Smith, 1964.

These types of firms, from an analytical viewpoint, are not unlike the multiple firm aggregations dealt with in watershed analyses using linear programming tools.[5] Also, the research approach from an analytical viewpoint may use systems analysis as applied conceptually at least to river basins.[6]

In summary, we have posed three major questions relating to the planning for Iowa's future water needs. In pursuing the means for answering these questions we have suggested the need for a multidisciplinary approach with the kinds of issues with which economics is concerned. These include estimating water demands and supplies and differentiated by quality, time and space. Also, the allocation of water among competing uses is discussed in terms of using market and institutional criteria. Procedures are suggested for placing relative values on water in competing uses in terms of productivity and opportunity costing. Finally, the need for and nature of management entities are outlined as a decision making basis for planning and carrying out specified uses and developments of water resources. In the presentation, the conjoint interrelationships between planning, research and action (or implementation) have been suggested.

Journal Paper No. J-6471 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa. Project No. 1445

5/ See Pavelis, Johnson, Schroder & Timmons, 1961.

6/ See Maas, Hufschmidt, Dorfman, Thomas, Marglin & Fair, 1966.

REFERENCES CITED

Ackerman, Edward A. and George O. G. Lof. Technology in American water development: The John Hopkins Press, Baltimore, Md. 1959.

Boulding, Kenneth. The economist and the engineer: economic dynamics of water resources development. In Smith, S. C. and E. N. Castle, eds. Economic and public policy in water resource development: pp. 82-92. Iowa State University Press, Ames, Iowa. 1964.

Gaffney, M. Mason. Comparison of market pricing and other means of allocating water resources. In Water law and policy in the Southeast (Papers prepared for presentation at the Southeastern Water Law Conference, University of Georgia, November, 1961): pp. 195-227. Institute of Law and Government, School of Law, University of Georgia. 1962.

Hirshleifer, Jack, J. C. DeHaven J. W. Milliman. Water supply: economics, technology, and policy: University of Chicago Press, Chicago, Illinois. 1960.

Iowa, Code of, 1966. Title 17, chapter 455 A. 19. 1966. (See also chapter 455 A.1 and 455 A.22).

Kneese, Allen V. The economics of regional Water Management: The John Hopkins Press, Baltimore, Md. 1964.

Maass, Arthur, M. M. Hufschmidt, Robert Dorfman, H. A. Thomas, Jr., S. A. Marglin, and G. M. Fair. Design of water-resource systems: Harvard University Press, Cambridge, Mass. 1966.

Pavelis, G. A., H. P. Johnson, W. D. Shrader, and J. F. Timmons. Methodology of programming small watershed development: Iowa Agri. and Home Economics Expt. Sta. Res. Bull. 493. 1961.

Smith, Stephen C. The role of the public district in the integrated management of ground and surface water. In Smith, S. C. and E. N. Castle, eds. Economics and public policy in water resource development. pp. 341-352: Iowa State University Press, Ames, Iowa. 1964.

Timmons, John F. Economics of water quality. In Willrich, T. L. and N. W. Hines, eds. Water pollution control and abatement. pp. 33-50: Iowa State University Press, Ames, Iowa. 1967.

Timmons, John F. and M. D. Dougal. Economics of water quality management. In Proceeding of international conference on water for peace; Vol 6, Planning and developing water programs. pp.667-678. U. S. Government Print Off., Washington, D. C. 1967.

Water Resources Planning Act: U. S. Statutes at large 79, chapter 244 1965.

Young, Robert A. and William E. Martin. The economics of Arizona's water problem: The Arizona Review 16(3): 9-18. March 1967.

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THE IMPORTANCE OF WATER RESOURCES RESEARCH[1]

Don Kirkham
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Director Iowa State Water Resources Research Institute

Water resources research is, I believe, except for research in the science of peace, the most important research area of modern times. I shall talk about some important areas of water research needed in Iowa but a few preliminary remarks seem pertinent.

Food, water, clothing and shelter are considered essential for man's life. But food and water are more important than clothing and shelter. Man has lived without clothing. In the winter of 1834, when Charles Darwin sailed around the end of the South American continent in the Beagle, he saw Indians at Tierra del Fuego going naked in the snow.

Water is more important than food. A person can go many days without food, but not without water. In Arab countries, the people fast during their month of Ramadan. If Ramadan falls in the summertime, it is a severe hardship because no water or food can be taken from sunup to sundown. The more devout Muslim while working during Ramadan in the hot summer fields does not even swallow his saliva. In the Sahara Desert, the most vicious act of an enemy is the poisoning of a well.

To come closer to home, I might say that I grew up in Utah, a grandson of Mormon pioneers who came to that then desert, unproductive land to be left unmolested in their religion. There the Mormon pioneers learned to irrigate. I early learned the importance of water because my father had farms on which my brothers and I worked during the summers. One farm was under the lower canal, and the other under the upper canal. The upper canal only had water when the snow in the mountains was normal. In years when the snowfall was less than normal, there was no water in the upper canal, and the fields of the upper farm did not produce. The farms under the lower canal had water from Utah Lake, and this water could be depended on. Among my father's farm hands, we had a full-time irrigator. One of my first surprises in the area of water science was to learn that our irrigator went out to irrigate when it was raining. Our irrigator knew from his experience, or that of others, that a Utah summer rain did not provide the water of a good irrigation.

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[1] Journal Paper No. J-6240 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa, Project 998. Work supported in part by the Department of the Interior, Office of Water Resources Res. P.L. 88-379.

An important water problem I learned about when I was in Utah was salting of soil through improperly applied irrigation water. There was a whole community in Utah that had abandoned its settlement because improperly applied irrigation water had, by evaporation, brought excess salts to the soil surface and poisoned their farm land. I learned of other problems. One of my uncles had to put in tile drains 12 feet deep to keep salt from rising to the surface of a soil. Also some waters were suitable for irrigation, some not. Water was the very essence of these people's physical lives. My mother's father was an early leader in arid Millard County, Utah. One of the towns in Millard County was and still is called Oasis. I shall never forget my mother telling me that my grandfather, when she was only 3 years old, died from illness contracted while repairing a break in an important irrigation canal.

In those days, much of the water knowledge came through experience. We are more sophisticated now, but our problems have multiplied. There are, not only those of getting enough water for domestic purposes and for our crops, but also the whole problem of water pollution has arisen. Our streams and lakes that used to provide recreation have become fouled by improper use. Water pollution is now a distinct area of research. Nevertheless, some of the water problems I met as a boy are still with us, and research is still needed on those problems. We still ask: How much water is required to produce a crop of corn? How much for soybeans? Potatoes? Plants use more water than they need. This is called luxury consumption. How can this be stopped? What is the best way to prevent soils from salinizing in reclaimed land areas where the sun brings salts to the surface when irrigation water is supplied? In Iowa, when should supplementary irrigation be applied to increase our crop yields?

The Iowa State Water Resources Research Institute

Our nation's water problems have become so acute in recent years that Congress has called on the land grant universities of the nation to set up water resources institutes for university-level research on water problems. The land grant universities were selected for the establishment of these water-resource research institutes because the land grant universities had made such an outstanding record in research in agriculture and related areas. America, through land grant universities research, had attained the highest standards of agriculture production in the world. By the 1964 Water Resources Research Act, Congress has now helped to establish water resources research institutes in the 50 states and the Territory of Puerto Rico. The institute in Iowa is called the Iowa State Water Resources Research Institute, and in keeping with the times we abbreviate it ISWRRI (mnemonic: is worry!).

I believe it is important for those attending this symposium and those others who will read the published report of the sumposium to know about the organization of ISWRRI. The state institutes, although they are all funded from Washington, D.C., in the same way, are not all set up the same way. In Iowa, there is the Director, who happens now to be me, and a council of eight members. The council members are appointed by the Vice President of Research of Iowa State University and presently are: Dr. E. R. Baumann, Professor of Sanitary Engineering; Dr. Robert Bachmann, Associate Professor of Zoology and Entomology; Dr. Keith M. Hussey, Head of the Department of Earth Science; Dr. Howard P. Johnson, Professor of Agricultural Engineering; and Dr. John F. Timmons, Professor of Economics, all from Iowa State University, Ames. From the State University of Iowa, we have Professor J. W. Howe, Department of Mechanics and Hydraulics; Professor N. William Hines, School of Law and Agricultural Law Center, and Dr. John F. Kennedy, Director of the Institute of Hydraulic Research. An important function of the Council is to evaluate and recommend which research projects should be funded by Washington for the "annual allotment grant" made to each water resources research institute. Presently this amount is $100,000 a year. Another function of the Council is to evaluate and recommend the funding of so-called matching grant projects submitted to the Institute. Suitable projects are rated and sent to Washington, and, if the university or other sponsor of the applicant puts up half of the amount, the federal government will put up the other half. We now have 7 matching grant projects in operation, and we have had 32 allotment grants, 18 completed, 14 in progress. Besides the selecting of the allotment and matching grant projects, our council members advise our legislature, other public groups and the public, when called upon for special water knowledge. I must say that ISWRRI cooperates very closely with established research units, both on the university campuses and elsewhere. The Water Resources Research Act of 1964, under which we operate, states that we are not to interfere with other water resources research projects, and we are advised to keep in touch with the research projects going on in these other agencies. This is the reason we meet annually with all the agencies we know of who have strong interest in water resource research. These agencies advise us on important areas of research. Presently (April 1969), the "allotment" and matching grant" projects that have been or are being supported by ISWRRI, some of them suggested by the agencies we meet with, are as follows:

ISWRRI Allotment Grant Projects

1. Economic factors in the establishment of water quality stream standards (1966-1968) (dates are inclusive)
2. Evaluation of flood damage to corn from controlled depth and frequency of flooding (1966-1968)

3. Moisture movement to vertical sinks in water-unsaturated soil (1965-1968)
4. Recession characteristics of Iowa streams (1966-1968)
5. Competitive recreational uses of selected Iowa lakes (1966-1968)
6. Discharge--valley form relationships of selected Iowa streams (1966-1968)
7. To collect, characterize and study the biodegradability and the chemical oxidation of carbon-adsorbed materials from effluents from sewage plants (1966-1968)
8. Pollen and diatoms in sediments of a post-Pleistocene lake (1965)
9. Preimpoundment survey of vegetation of Saylorville Dam impoundment area (1965)
10. Legal aspects of small watershed program in Iowa (1965)
11. The movement of radionuclides through soil formations (1966-1967)
12. Geology of the regolith aquifers of the Nishnabotna Basin (1966-1968)
13. Properties of tile drainage water (1966-1968)
14. Influence of geohydrology on landscape and soil formation (1966-1969)
15. Laboratory investigation of flow in river bends (1966-1967)
16. Reoxygenation of Iowa streams (1966-1968)
17. Feasibility of fish production in tertiary waste treatment ponds (1968-1969)
18. Economic analysis of alternative water pollution control measures (1968-1969)
19. Model flood-plain zoning ordinance (1968)
20. Energy loss of flow around alluvial channel beds (1968)
21. Using soil filtration to reduce pollution potential of lagoon effluent entering ground water system (1969)
22. Management of cattle feedlot wastes (1969)
23. Waterfowl populations and recreational use patterns in the proposed Saylorville Reservoir area as related to preimpoundment conditions (1969)
24. Development of a mathematical model for the simulation of flat-land watershed hydraulics (1969)
25. Development of pulsating adsorption filter for tertiary treatment of waste waters (1969)
26. Simultaneous flow of water and heat in water-unsaturated Iowa soils during evaporation (1969)
27. Limnological factors affecting pesticide residues in surface waters (1969)
28. Effects of limnological factors on water treatment (1969)
29. Effects of river curvature on resistance to flow (1969)
30. Interrelationship of surface and subsurface flow in the Nishnabotna drainage basin (1969)
31. Use of infrared and other radiation techniques to evaluate drought in Iowa and adjacent areas (1969)
32. Treatment of aqueous agricultural wastes for clean water and for microbial protein production (1969)

ISWRRI Matching Grant Projects

1. Study of operation of the Iowa water permit system (1966)
2. Ground-water seepage patterns to wells for unconfined flow (1967)
3. Physical, legal and economic aspects for assessment of costs among drainage districts (1968)
4. Structure of forest bordering the Saylorville Impoundment (1967)
5. Analysis of the economic implications of the permit system of water allocation (1968)
6. Economic analysis of organization of water users (1968)
7. Flow of water into tile drains in stratified soils (1969)

THE ISWRRI ADVISORY COUNCIL

I have said that the ISWRRI council meets annually with an advisory group of representatives of state and federal agencies concerned with water problems. Agencies presently represented, with identification letters for later reference, include:

STATE AGENCIES

1. Iowa Conservation Commission (ICC)
2. Division of Fish and Game, Iowa Conservation Commission (IFG)
3. Iowa Highway Commission Materials Office (IHM)
4. Iowa Highway Research Board (IHR)
5. Iowa Natural Resources Council (INR)
6. Iowa State Department of Health (IDH)
7. Environmental Engineering Services, Iowa State Department of Health (IES)
8. Iowa Water Pollution Control Commission (IPC)
9. Iowa State Soil Conservation Committee (ISC)
10. Drake University (IDU)
11. Iowa State University Veterinary Diagnostic Laboratory (IVL)
12. Iowa Development Commission (IDC)

FEDERAL AGENCIES

1. U. S. Geological Survey (USGS)
2. Soil Conservation Service (US-SCS)
3. Soil and Water Conservation Research Division, Agricultural Research Service (US-ARS-SCS)
4. U. S. Bureau of Public Roads, Division of Bridge Engineering (USBPR)
5. U. S. Fish and Wildlife Service Bureau of Sport Fisheries and Wildlife (USFWL)
6. U. S. Weather Bureau (USWB)
7. Federal Water Pollution Control Administration (FWPCA)
8. U. S. Bureau of Outdoor Recreation (USODR)

9. U. S. Army Engineers (Rock Island, St. Paul, Kansas City and Omaha districts) (USCE)
10. North Central Forest Experiment Station of the U.S.D.A. (USFS)

Water Research Needs as Suggested by the ISWRRI Advisory Council

This list includes 12 state agencies and 10 federal agencies. The representatives of these agencies have suggested important areas of research that I shall list, needed for Iowa. The list emphasizes the importance of water resources research. This list should stimulate and help research workers in their selection of problems, some of which we hope our Institute can support financially. Some of the items in the list, especially from 1966 and 1967 are being, or have been, worked on to a limited extent. The list is not in order of priorities, and there is some overlap from year to year. Some of the items are given almost verbatim as they were presented at our Advisor's Meeting. For conformity of presentation, quotation marks have been omitted. An agency seeming to have a major interest in the item, generally the agency that suggested the item, has its initials given.

For the Year 1966

1. There is a need for basic information on which to base water quality standards applicative to industry, farmers, and municipalities. There is a need for basic stream data such as temperature, oxygen content, and pH. There are problems with taste and odor of fish, such as the gassy flavor of channel catfish from the lower Des Moines River. (ICC)

2. There is an anticipated great increase in concentration of large farm feedlots. There is a need for guidelines to be set up for disposing of wastes from such feedlots before they are established in great numbers. (IDC)

3. There is need for a deeper channel in the Missouri River for providing a means of exporting farm commodities. What is the best way to deepen the river and maintain it? (IDC)

(The next 7 items are from the U. S. Geological Survey.)

4. Elimination or control of iron bacteria in wells. (USGS)

5. Development of an inexpensive method of sulfate removal from ground-water supplies. (USGS)

6. Determination of nitrate buildup in streams and ground-water systems. (USGS)

7. Impact of pesticides and insecticides on water supply systems. (USGS)

8. Laboratory studies to develop effective and inexpensive structures to control channel meandering in loess soils. (USGS)

9. Development of inexpensive instrumentation for measuring low-velocity flows. (USGS)

10. Effects of urbanization on peak flows and water quality. (USGS)

11. Some of the water-related problems involved with highway construction and maintenance are: erosion from bare soil (need work on both methods of checking erosion and costs of the methods), effects of using weed and brush killer, salt problems from highway deicing (a commonly used additive is chromium), and risks due to storage of salt, asphalt, or chemicals in large depots. (IHM)

12. Legal research for regulation of the transportation and storage of fertilizers, asphalt, etc., from the standpoint of possible contamination of ground or surface water. (IHM)

13. Research on drainage structure design, on back water, and on periods of inundation, for highway engineering design. (IHR)

(The next 18 projects are from the Iowa Natural Resources Council)

14. Economic evaluation of water resources developments with regard to benefits and losses attributable to flood control, recreation, fish and wildlife, water supply, water quality control, and irrigation. (INR)

15. Hydrology and planning with emphasis given to the smaller (150 sq. mi. or less) drainage areas. (INR)

16. Research on the origin and movement of sediment from the uplands to the mouths of the state rivers including the effect of sediment load on fish and wildlife, water treatment requirements and problems, reservoir life, and river behavior. (INR)

17. Scour and sediment relationships with regard to engineering works. (INR)

18. Behavior of bridges and road embankments during flood flows, both in the laboratory and in the field. (INR)

19. Adaptability of recreational use of flood control reservoirs or other type reservoirs with large pool fluctuations. (INR)

20. Channel stabilization methods taking into account effects on fish, wildlife, and recreation, first cost, maintenance costs, and benefits to agriculture and flood-plain improvements. (INR)

21. Evapotranspiration rates of common Iowa crops and total water use for specific yields. (INR)

22. Economic feasibility of irrigation of various Iowa crops. (INR)

23. Value of capillary fringe moisture and relationship between depth of water table and value of capillary fringe moisture. (INR)

24. Quality of farm drain tile discharge and filters needed to remove any contaminates. (INR)

25. Prediction of low flows from soil moisture, climatological, and other readily available data. (INR)

26. Evaporation from open water versus evapotranspiration from an equal area of marsh vegetation. (INR)

27. Correlation between rainfall, ground-water levels, and sustained low stream flows. (INR)

28 Artificial recharge possibilities of ground-water reservoirs in Iowa. (INR)

29. Industrial use of water by unit of product. (INR)

30. Effect of generation plant on stream with and without cooling towers (consumptive use versus temperature rise of water in stream). (INR)

31. Model county and municipal flood-plain ordinances under existing statutes and judicial decisions. (INR)

(The next six projects are from the Iowa Environmental Services, Dept. of Health.)

32. Information is needed to help establish public health regulation standards. (IES)

33. The fate of nitrates in soil. (IES)

34. How to minimize salt as a water pollutant. (IES)

35. A better measure of pollution than the number of coli bacteria present. (IES)

36. Better ways to remove tastes and odors from water. (IES)

37. Find the safety factors needed in case of a breakdown of a sewage treatment process, such as might be caused by a power failure. (IES)

38. Since silt is probably our greatest pollutant, there exists a real need for methods and ways to minimize erosion. Larger farm machinery is making it very difficult to utilize some present-day conservation practices meaning that new easier-to-use practices are needed. The problem of erosion is even more important because there will be more acres of row crops in the future to meet expanding national and world food needs. In addition to problems arising from soil losses from agricultural lands, there is also a problem of silt losses from real estate developments. (ISC)

39. Research on educational programs to get the public to accept Soil Conservation Service recommendations. (US-ARS-SCS)

(The next four projects are from the U. S. Soil Conservation Service.)

40. Problems associated with the sulfates in the ground waters of southern Iowa. (US-SCS)

41. Waste disposal methods for large feedlots. (US-SCS)

42. Influence of pesticides, etc., on the soil by the year 2000 or 2020. (US-SCS)

43. Turbidity of lakes in relation to adjacent soil type. (US-SCS)

(The next six projects are from the U. S. Bureau of Outdoor Recreation.)

44. Demand for water-oriented recreation (this is an area of little known but often needed information). (USODR)
45. Development of design and use standards and of estimates for costs of land and facilities for outdoor recreation. (USODR)
46. Economic impact of outdoor recreation developments in regard to recreation expenditures, seasonality of economic benefits, and techniques to stimulate complementary developments. (USODR)
47. Effect of water quality upon the recreational uses of waterways and impoundments. (USODR)
48. Evaluation of effect of low flow releases from impounded water on downstream recreation and natural beauty. (USODR)
49. Determination of ways and means to assure compatible uses of available water and in particular with regard to recreation. (USODR)
50. The stability of structures for training rivers, in particular, dikes. (USBPR)
51. Influence of engineering projects on recessions of rivers, such as effects of dumps on a river plain. (USBPR)
52. Preimpoundment studies of the Saylorville Reservoir area. (USCE)
53. Water-quality standard for reservoirs and data on the recreational use of reservoirs. (USCE)

(Projects 54 through 63 are from the U. S. Bureau of Sport Fisheries and Wildlife.)

54. Recreational use patterns on the Des Moines River and Big Creek areas scheduled for inundation by the Saylorville Impoundment. (USFWL)
55. Furbearer and waterfowl use patterns and ecology on the Des Moines River and Big Creek areas scheduled for inundation by the Saylorville Impoundment. (USFWL)
56. Chemical, biological and siltation effects of feedlots on farm ponds, lakes and streams. (USFWL)
57. Occurrences of water-borne diseases in ponds, lakes or streams, receiving runoff from feedlots for cattle and hogs. (USFWL)
58. Management of water areas and land for waterfowl spectacle for general outdoor recreational use. (USFWL)
59. Movement of fertilizers and insecticides from farm lands to ponds, lakes, and streams, and underground water supplies. (USFWL)
60. Soil erosion, silting, and pollution as affected by recreation area site development and area overuse. (USFWL)

61. Design criteria for use in construction of lagoons, holding tanks, digestion tanks, and leaching fields for disposal of wastes from farms, roadside rest areas, recreation areas, and rural industries. (USFWL)

62. Hydrology and ecology of farm ponds, lakes, and potholes. (USFWL)

63. Ecological effect of chloride contamination from salt application to highways and city streets. (USFWL)

64. Bog and swamp hydrology. (USFS)

65. Technical effectiveness of trees planted along stream banks to check erosion. (USFS)

66. Research in the U.S. Weather Bureau Office of Hydrology is directed largely toward the responsibility of the Weather Bureau for issuing forecasts of floods and river conditions to the general public. Continuous flow forecasts are increasingly important for water supply, flood control, pollution abatement, navigation, and many other purposes. For small water management structures, such as urban storm sewers and culverts, it is necessary to have flow data as to frequency and volume of maximum flow. (USWB)

67. A water-related problem in Veterinary Science is high nitrate content in water. Nitrate contents from farm wells as high as 100 ppm (one was 2,800) have been measured. Ordinarily nitrate problems first show up as effects on reproductivity or weight gains of livestock, but there is also an influence on human health (such as night blindness). They estimate that 15 to 20 percent of the Iowa farm water supplies have nitrate levels above 44 ppm. Commercial fertilizers are not believed to be the cause of these high nitrate concentrations. Research is needed on night blindness and wells. (IVL)

Research Needs Suggested at the 1967 ISWRRI Advisors' Meeting

Besides projects suggested in 1966 for which the research has not been started or completed, the Advisors suggested or reiterated the following:

(The next two rather extensive items are from the Iowa Conservation Commission.)

68. There is a need for intensified research on control of blooms of blue-green algae in lakes and streams. The State Conservation Commission is devoting much time and futile efforts to controlling these monstrous growths in the natural lakes, primarily in Dickinson County. Last summer, for example, 68,900 pounds of copper sulfate were used, most in East Okoboji. In spite of intensive efforts to maintain some control, the treatments are of little value, and of course, are very expensive. Copper sulfate is a poisonous substance and may have harmful affects on the biota even though presently they are difficult to appraise. Many of the lakes though, have been treated for 40 years with copper sulfate. (ICC)

69. Research is needed to discover a new, more effective, and less expensive algacide, but preferably research should be directed toward natural controls. This could involve some species of animal that would consume these growths at a sufficient rate and still not upset the predator-prey relationships of fish which is required for good angling. Efforts have been made to decrease the available phosphorus content from known sources of pollution. But this would be of little value except where treated sewage might enter a lake. The vast sources of watershed contamination virtually eliminates this approach. Some research has indicated that a reduction in the phosphorus content of lakes subject to heavy blooms might effectively control the growth. In view of the great amount of research that has been done over the past 30 or 40 years on this problem, it appears that a crash program is needed with virtually unlimited financial support such as the lamprey control study on the Great Lakes. A satisfactory chemical or biological control can be developed if sufficient emphasis is placed upon this increasingly vexing problem. Aside from the unsightliness of these offensive primitive plant growths, occasionally certain species become extremely toxic to all warm-blooded animals that drink from the infested waters. Several catastrophic losses to wildlife and livestock have occurred in Iowa and elsewhere. Consequently, it is hoped that sufficient interest might be generated by this Institute to initiate a research program directed toward a solution of this problem.* (ICC)

70. In Iowa, 80 percent of domestic water use is derived from ground water, yet roughly 1/3 of Iowa's ground-water supplies have high sulfate and nitrate concentrations. Sulfates may run as high as 2,500 parts per million (ppm) and nitrates 300 ppm. USGS gives high priority to the following research areas for 1967: (i) development of inexpensive methods of sulfate removal from ground-water supplies; (ii) determination of nitrate buildup in streams and ground-water systems; and (iii) elimination or control of iron bacteria in water wells. (USGS)

71. Economic and social aspects of water resources research should be emphasized. The new research should be directed toward new codes to advise the public. (IHM)

72. Water pollution caused by highway operations, road salting, road bank erosion, etc. (IHR)

(Projects 73 through 89 were suggested by the Iowa Natural Resources Council who believe items 73, 79, 83, 87 and 89 should have high priority.)

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* In regard to item 69, ISWRRI is cosponsoring, with the Water Institutes of other Mid-Continent States, a research symposium at Iowa State University, Nov. 18, 19, 20, 1969, entitled "The role of agriculture in clean water." The Iowa Agricultural Experiment Station, the Iowa State Extension Service, and other agencies are cooperating.

73. Economic evaluation of water resources developments with regard to benefits and losses attributable to flood control, recreation, fish and wildlife, water supply, water quality control, and irrigation. Such methods would aid in the determination of desirable water resources developments and the allotment of resources between uses where demand exceeds supply. The foregoing would consist of a number of coordinated research projects. (INR)

74. Hydrology and planning with emphasis given to the small (150 sq. mi. or less) drainage areas. The studies might include the effects on runoff and flood frequency, effects of flood-plain encroachment on hydrograph shape and flood routing, economic factors affecting intensive flood-plain uses, and effects of general urbanization of small watersheds. (INR)

75. Research on the origin and movement of sediment from the uplands to the mouths of the state rivers including the effect of sediment load on fish and wildlife, water treatment requirements and problems, reservoir life, and river behavior. (INR)

76. Scour and sediment relationships with regard to engineering works. Of particular interest is a study of the time dimension of scour at constructions during flood occurrences. (INR)

77. Behavior of bridges and road embankments during flood flows, both in the laboratory and in the field. Methods presently used should be examined for theoretical soundness and hydraulic coefficients should be tested by comparison to both laboratory and prototype experience. (INR)

78. Adaptability of recreational use of flood control or other reservoirs with large pool fluctuations. (INR)

79. Channel stabilization methods taking into account effects on fish, wildlife, and recreation, first cost, maintenance costs, and benefits to agriculture and flood-plain improvements. In addition, structural stability analyses of riprap and other measures used in channel works. (INR)

80. Evapotranspiration rates of common Iowa crops and total water use for specific yields. (INR)

81. Economic feasibility of irrigation of various Iowa crops. (INR)

82. Value of capillary fringe moisture and relationship between depth of water table and value of capillary fringe moisture. (INR)

83. Quality of farm drain tile discharge and filters needed to remove any contaminates. (INR)

84. Prediction of low flows from soil moisture, climatological, and other readily available data. (INR)

85. Evaporation from open water versus evapotranspiration from an equal area of marsh vegetation. (INR)

86. Correlation between rainfall, ground-water levels, and sustained low stream flows. (INR)

87. Artificial recharge possibilities of ground-water reservoirs in Iowa. (INR)

88. Industrial use of water by unit of product. (INR)
89. Effect of generation plant on stream with and without cooling towers (consumptive use versus temperature rise of water in stream). (INR)

(The next item with 5 subitems is from the Iowa Water Pollution Control Commission.)

90. Major water pollution factors in Iowa are: (i) anaerobic lagoons, (ii) eutrophication of lakes, (iii) salt accumulation in ground-water supplies due to salts and corrosion inhibitors used in highway operations, (iv) fertilizers (use of anhydrous ammonia is increasing by leaps and bounds), and (v) pollution of surface waters by animals wastes. (IPC)
91. Research on water capture on the land to reduce overland flow; also research on properties of tile drainage water should be continued. (ISC)
92. The role of land treatment and use upon the availability and the quality of surface runoff needs further exploration. None of the agricultural chemicals can do what they are intended to do if they are allowed to wash off in excessive amounts. We need facts relative to the economics of keeping agricultural chemical (i.e., fertilizers, insecticides and herbicides) as near to their point of application as possible. We need facts on the effect of land treatment measures (contouring, terracing, conservation cropping systems, etc.) on the quality and the rate of direct surface runoff. We need to anticipate future land use and agricultural chemical use so that we might avoid some of the water-related problems involved in their misuse. (US-SCS)
93. Quantative and reliable data should be obtained regarding the level of nitrates coming out of tile drains. In northeast Iowa, the problem of surface drainage into sink holes is an important one. Furthermore, the pollution caused by feedlots located in watersheds and the question "Who will determine the water quality controls" should be studied. (US-SCS)
94. Flow in river bends as related to highway structures. (USBPR)

(The next five projects are from the Corps of Engineers.)

95. Channel straightening and stabilization. (USCE)
96. Flood-plain classification. (USCE)
97. Effects of reservoir operation on the growth of aquatic plants. (USCE)
98. Tolerance of native shrubs and trees to flooding. (USCE)
99. Saturation point of recreational use of reservoirs. (USCE)

(Projects 100 through 115 are from the U. S. Bureau of Sport Fisheries and Wildlife.)

100. Recreational use patterns on the Des Moines River and Big Creek areas scheduled for inundation by the Saylorville Impoundment. (USFWL)

101. Furbearer and waterfowl use patterns and ecology on the Des Moines River and Big Creek areas scheduled for inundation by the Saylorville Impoundment. (USFWL)

102. Chemical, biological and siltation effects of feedlots on farm ponds, lakes, and streams. (USFWL)

103. Occurrence of water-borne diseases in ponds, lakes, or streams receiving runoff from feedlots for cattle and hogs. (USFWL)

104. Management of water areas and land for waterfowl spectacle for general outdoor recreational use. (USFWL)

105. Movement of fertilizers and insecticides from farm lands to ponds, lakes, streams, and underground water supplies. (USFWL)

106. Soil erosion, silting, and pollution as affected by recreation area site development and area overuse. (USFWL)

107. Design criteria for use in construction of lagoons, holding tanks, digestion tanks, and leaching fields for disposal of wastes from farms, roadside rest areas, recreation areas, and rural industries. (USFWL)

108. Hydrology and ecology of farm ponds, lakes, and potholes. (USFWL)

109. Ecological effect of chloride contamination from salt application to highways and city streets. (USFWL)

110. Effect of thermal pollution and resultant open waters in winter on the seasonal occurrence of waterfowl, with special reference to "wintering" of waterfowl. (USFWL)

111. Effects of thermal pollution on reproductive cycles of fish and other aquatic organisms on disease and parasite organisms that might otherwise be periodically reduced by low temperatures. (USFWL)

112. Use of thermal pollution in securing year-round production of fish and perhaps maintain populations of species not capable of withstanding normal winter temperatures. (USFWL)

113. Use of water circulators to destroy thermal and chemical stratification thereby increasing the cycling of nutrients and perhaps controlling bluegreen algae through the stimulation of more desirable algal species. (USFWL)

114. Evaluate effects of power plants (fossil fuel and atomic) in relation to fish and wildlife, especially their relationship to intake of cooling waters, the effluent, and resultant thermal pollution on fish and wildlife and ecology of streams. (USFWL)

115. Evaluate effect of siltation on general aquatic organisms used in the food chain of fish and wildlife in general. (USFWL)

116. Behavior of ground water under different types of vegetation. (USFS)

117. Agricultural pollution will increase because the price of nitrogen fertilizer is now about 10 cents a pound, but in 10 years, it will probably drop to 5 cents per pound, resulting in larger applications. ISWRRI should attempt to prepare "a standard problem analysis procedure." (USFS)*
118. Evaluation of pollution as related to the whole ecosystem. (IDU)

Research Needs Suggested at the 1968 ISWRRI Advisors' Meeting

In addition to projects suggested in 1966 and 1967 for which the research has not been started or completed the advisors suggested for or reiterated research as follows:

(The next nine projects (119 through 127) are from the U. S. Corps of Engineers.)

119. Effects of flood-plain encroachment on hydrograph shape and flood routing. (USCE)
120. Economic factors affecting intensive flood-plain uses. (USCE)
121. Effects of general urbanization on small watersheds. (USCE)
122. Adaptability of recreational use to fluctuations of pool levels in flood control reservoirs. (USCE)
123. Research into channel stabilization methods to minimize losses of fish, wildlife and recreation. (USCE)
124. Economic impact of water resources projects as concern secondary benefits. (USCE)
125. Rationale or analysis and conversion of secondary benefits to national or regional benefits. (USCE)
126. A study to determine the "saturation point" of recreational use as related to a given surface area of water and project lands. (USCE)
127. A study to develop a procedure for evaluation of natural beauty. (USCE)

(The next four projects (128 through 131) are from the Iowa Conservation Commission.)

128. Lake eutrophication is probably the foremost problem facing the State Conservation Commission. Although we realize that eutrophication, or the aging process whereby lakes evolve into marshes and eventually dry land areas cannot be stopped, it most assuredly can be slowed down. Researchers working with ISWRRI can discover how to arrest and control the inflows of nutrients and silt into our natural

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* ISWRRI has not prepared "a standard problem analysis procedure", other than general outline forms for submitting a research project. ISWRRI thinks one investigator may be more successful with his approach than that which might be suggested by ISWRRI.

and artificial lakes. There are at least four approaches to the problem, which are at best only remedial controls. These include: chemical, biological, mechanical and ecological controls. For conservation purposes the ecological approach seems to hold the most promise. With regard to ecological control, research by ISWRRI might tell us how to slow down the nutrient input, how to make nutrients in the form of plant and fish crops and evaluate these techniques as a tool to retard eutrophication, how to interfere with sediment-water interchange of nutrients, or perhaps create specific plant diseases to control water weeds and algae. (ICC)

129. We need comprehensive studies by disinterested individuals of the total effects of straightening streams. These investigations should involve indepth pre- and post-straightening studies and should evaluate changes either anticipated or brought about in the physical, chemical, and biological features of the streams. (ICC)

130. Fish kill resulting from various kinds of waste disposal occur in Iowa periodically. Although we usually know or can determine the source of these kills, we need research directed toward indentifying specific pollutants and methods for correcting them. (ICC)

131. Thermal loading of our flowing waters is increasing at an accelerated rate. In connection with this there are many things that need evaluation. Among the more important, we want to know are: To what degree is thermal loading beneficial? Conversely, to what degree and at what point does thermal loading become harmful? What effect does different levels of thermal loading have on the biomass of the receiving water? (ICC)

132. Effects of stream straightening on various highway structures. (USBPR)

133. Use of chemical to maintain stability of soil structure to keep the plowed soil surface "open" and prevent erosion. (US-ARS-SCS)

134. Research on some fish species that are slowly becoming extinct in Iowa. (USFWL)

135. Benefits and damages to fish and wildlife resulting from large storage reservoirs and channel straightening works. (USFWL)

136. Economics of stream straightening, channel scour, low-cost bank protection facilities, crop losses due to inundation caused by highways, and stream pollution resulting from erosion of highway slopes. (IHR)

137. In connection with highway rest stops, the problems seem concentrated on the following areas: provision of an adequate water supply, construction of sanitary facilities, and disposal of wastes. (IHR)

138. Flood-plain zoning ordinances; assessments of costs among drainage districts. (INR)

139. Conventional sanitary land fills are being used for solid waste disposal purposes. However, the ground water may be polluted by recharge and seepage through the landfill.

Therefore, the effectiveness of the sanitary landfill depends on the characteristics of the soil at the bottom of the fill. Research is needed to specify more clearly what types of soils or lining material would be suitable to prevent seepage through sanitary landfills. (IDH)

140. How to put a value on water resources research data. (USGS)

141. Ground-water recharge on a massive scale. (USGS)

Item number 141 concludes the list of items. The list is imposing and brings out the importance of research. The list is by no means inclusive. For example, there have been listed research projects planned or currently underway in the Iowa Agricultural and Home Economics Experiment Station, or the Iowa State University Engineering Experiment Station, both at Ames; or the Institute of Hydraulic Research at Iowa City. Members of the ISWRRI Council, being staff members of the two universities are involved in water problems research in divisions of their universities.

CONCLUSION

At the beginning of this talk I said that, in my opinion, except for research in the science of peace, water resources research was the most important research area. Water research is also important in peace. Our federal government has initiated a program entitled "Water for Peace." A world-wide Water for Peace meeting was held in Washington, D.C., in June 1967. Two of our ISWRRI members participated in this meeting with research papers.

The many projects listed here prove the importance of water resources research. Such research, and its application, should help bring peace to the world and make better living for ourselves and our children.